PLAINTIFF'S FEASIBLE PLAN

State of Louisiana and Vermilion Parish School Board vs. Louisiana Land and Exploration, et al
Docket No. 82162, Div "D"; 15th JDC
East White Lake Field, Vermilion Parish, LA

Prepared For:

The Vermilion Parish School Board
and
TALBOT CARMOUCHE & MARCELLO LAW FIRM
17405 Perkins Road
Baton Rouge, LA 70810

Prepared By:

ICON
ENVIRONMENTAL SERVICES

2049 COMMERCIAL DRIVE
PORT ALLEN, LA 70802
(225) 344-8490

January 2016

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

TABLE OF CONTENTS (continued)

TABLES

Table

APPENDICES

Appendix

SECTION 1.0 PROJECT OVERVIEW AND SITE HISTORY

1.1 PROJECT OVERVIEW AND COMPLIANCE WITH REQUIREMENTS OF PLANS

ICON Environmental Services, Inc. (ICON) was retained by Talbot, Carmouche, and Marcello Law firm in 2004 to perform a contamination assessment at the Vermilion Parish School Board (VPSB) property at the East White Lake field, Vermilion Parish, LA. The property is located in Section 16, T15S R01E, approximately 5 miles southwest of the town of Forked Island. This Feasible Plan was prepared for the owners of the property, the State of Louisiana and the Vermilion Parish School Board pursuant to LA R.S. 30:29. UNOCAL admitted that it was a responsible party for environmental damage.

The site is currently used for hunting and fishing, with anticipated future uses including a year-round hunting and fishing lodge with housing accommodations, cafeteria, and a marina. An ecological risk assessment that is attached in Appendix C has found that constituent concentrations in subaqueous sedimbent exceed risk criteria. Sediment in and along the banks of canals is contaminated with petroleum hydrocarbons, including a former pit location that UNOCAL attempted to close in 2014. Verification samples show that soils in that area continue to exceed 29B limits for HEM Oil & Grease. Simply beaching a boat in that area, and launching back into the canal results is significant sheen and oil on the surface of the water in the canal.

The VPSB has indicated that a likely future use of the property will include commercial recreational facilities (hunting and fishing lodge), with will require the use of groundwater that is currently contaminated for future potable public water supply. Data show that the Chicot Aquifer Shallow Sand Unit (CHCTS) that is extensively used for potable and public supply in the region exhibits gross contamination by historical oil and gas activities. Soils comprising the confining unit of the Chicot Aquifer, and permeable zones above the confining unit exhibit salt contamination and other constituents that are leaching into the underlying Chicot Aquifer.

This plan presents the results of environmental testing of soils, subaqueous sediment, and groundwater, and presents a plan to remediate the environmental damage in accordance with the requirements of the applicable rules and regulations of the Office of Conservation (609.A.4), with the following exceptions and clarifications:

- Site soils are grossly contaminated with produced salt water. Saturated Paste EC in soil samples grossly exceeds the Statewide Order 29B limit of 8 mmhos/cm for elevated wetlands and for site development over broad areas, with some samples exceeding 200 mmhos/cm. These soils are leaching contaminants to underlying groundwater. Removal of these soils would be technically infeasible and would destroy a large portion of the freshwater marsh. A plan to isolate these soils that are grossly contaminated with produced saltwater is included herein. The Office of Conservation may require an exception to salt standards listed in

LAC43.XIX.313, but this remedial technique is intended to comply with requirements of LAC43.XIX.303.C (to prevent contamination of a groundwater aquifer or a USDW) and 303.E (prevent discharge of produced water or other E&P waste into manmade or natural drainage or directly into state waters without a discharge permit).

- Subaqueous sediment is contaminated at concentrations that exceed limits established in an ecological risk assessment (attached in Appendix C). Remedial standards listed resulting from this risk assessment support the Threshold Effects Level (TEL) screening concentrations listed in the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables for Inorganics in Solids (SQuiRT), that were used for contaminated sediment at the base of canals. These standards are employed in addition to requirements of the Office of Conservation.
- Groundwater in a shallow groundwater-bearing zone (herein referred to as the Peat Zone) exists between ground surface and an average depth of 15 feet below land surface, and is contaminated with petroleum hydrocarbons, heavy metals and produced salt water. Standards applicable to a $GW3_{ndw}$ groundwater classification listed in the Louisiana Risk Evaluation and Corrective Action Program (RECAP) were used to evaluate contamination in this aquifer in lieu of the 29B background remedial standard. The modeled yield of the Peat Zone indicates that groundwater extraction is not feasible. Salt concentrations present in this aquifer will be isolated along with salt-contaminated soils present in this zone.
- A plan to remediate contaminated groundwater in the Chicot Aquifer Shallow Sand Unit (CHCTS) to background constituent concentrations is included herein. The CHCTS is comprised of a finer-grained fluvial deposit with discontinuous clay beds from approximately 33 to 60 feet below land surface, overlying a massive coarser-grained sand deposit to a depth of 275 feet. Delineation of contamination to background concentrations has not been achieved in this portion of the aquifer because contamination extends offsite. A plan to remediate this upper zone of the CHCTS to background constituent concentrations is included herein, but the lack of delineation induces a degree of uncertainty in cost estimates. Delineation of contamination to background concentrations has been generally been achieved for the CHCTS below a depth of 60 feet below land surface with the exception to the north and east, and efforts to achieve delineation onsite are ongoing. A plan to remediate to background concentrations based on a concentration gradient where control is available is included herein. This portion of the CHCTS is where most water supply wells are screened.
- Plans for remediation of contaminated groundwater consider offsite disposal of recovered wastewater and an option for onsite injection. The VPSB has made it clear that the use of an onsite SWD for purposes of injecting contaminated groundwater will not be allowed absent their

approval, which has not been obtained at this time. In addition, the use of a SWD for such purposes would only be recommended if the operation of the well was under the control of the VPSB contractor. Because the wastestream to be injected is wastewater resulting from remediation operations, any SWD would likely have to be permitted as a Class I nonhazardous industrial injection well, and would necessarily need to be highly protective of all subsurface horizons; Class II wells are permitted to inject produced salt water by a production company in possession of a valid operator code.

1.1.1 Qualifications and Methods

Sampling and testing was performed in accordance with Statewide Order 29B (as per 611.F). Sampling was performed by employees of ICON Environmental Services, Inc. under the direction of Gregory W. Miller, P.G. and Wayne Prejean, P.E. A summary of qualifications as per 611.C.1 follows:

- Gregory Miller obtained a bachelor of science in geology from the University of Southwestern Louisiana in 1982, and has been employed as a professional geologist since 1983. He worked in the oil and gas industry as a core and log analyst from 1983 to 1986. Since that time, he has worked in the environmental industry in the northeast United States from 1986 to 1990, and in the Gulf Coast since 1990. Mr. Miller has performed hundreds of assessments of oil and gas production facilities and fields. Mr. Miller has been recognized in State and Federal courts as an expert in the fields of geology, hydrogeology, site assessment, implementation of the Louisiana RECAP protocol, and remediation. Mr. Miller holds license #939 from the State of Louisiana Board of Professional Geoscientists. Mr. Miller is the president and an owner of ICON Environmental Services, Inc. (ICON), and holds the State License Board of Contractor’s License #35504 for ICON with specialization in hazardous materials site remediation. ICON holds License #4001 from the Louisiana Professional Engineering and Land Surveying Board to provide professional engineering services in the State of Louisiana. A copy of Mr. Miller’s resume and list of testimony experience is included in Appendix E.
- Mr. Wayne Prejean, P.E. obtained a bachelor of science in environmental engineering from Louisiana State University in 1999, and has worked as an environmental consultant since 1999. Mr. Prejean has been recognized in State courts as an expert in the fields of environmental engineering, environmental site assessment and remediation. Mr. Prejean is currently senior engineer at ICON Environmental Services, Inc. (ICON), and holds license #32502 to provide professional engineering services in Louisiana. A copy of Mr. Prejean’s resume and list of testimony experience is included in Appendix E.

Samples were analyzed by contract laboratories holding LELAP certification for applicable constituents of concern at the time of sampling (as per 611.D), and all 29B sample analyses were in accordance with the “Laboratory Procedures for Analysis of Exploration and Production Waste” (as per 611.D); copies of lab reports are included in

Appendix D, and these reports include certification by the laboratory of the testing methods and quality assurance/quality control data (as per 611.D.1). Copies of LELAP certification and/or a list of LELAP certified labs is included in Appendix E (as per 611.D).

Results of sampling were evaluated by comparing to applicable Statewide Order 29B criteria (as per 611.E), including:

- A tabular summary of soil and sediment data with comparison to 29B standards (Table 4-1).
- A tabular summary of groundwater data with comparison to 29B standards (Tables 4-3, 4-4 and 4-5).
- Maps showing sampling locations (as per 609.A.3) and exceedances of 29B regulatory standards in soil and sediment (Figures 4-1 through 4-7; Figure 4-10 through 4-14; and Figure 4-16).
- Maps showing sampling locations (as per 609.A.3) and exceedances of the 29B background regulatory standards for groundwater as per requirements of 609.A.3 (Figures 4-19 through 4-35).

These maps show that the vertical and horizontal extent of the environmental damage has been delineated in soil and groundwater (as per 611.B) with the following exceptions:

- Contaminated sediment at the base of canals extends offsite.
- Soil contaminated at concentrations exceeding 29B limits for salt constituents extends offsite to the east, as depicted in Figures 4-3 through 4-7; delineation has been largely achieved elsewhere.
- Chloride contamination in groundwater in the upper portion (33 to 60 feet bls) of the CHCTS has not been delineated because contamination above background constituent concentrations appears to extend offsite. This plan includes a plan to remediate this portion of the CHCTS to background constituent concentrations. Additionally, a water supply well at the northeast corner of the property owned by Mr. Crouch exhibits contamination from a source located offsite to the east (UNOCAL shore based scrubber facility), and has not been delineated. This contamination associated with the Crouch water supply is not addressed in the remediation plan at this time until delineation is achieved. However, the cost to remediate this contamination would likely be similar to a unit cost developed from the plan herein.

Cost estimates presented in this Feasible Plan differ somewhat from that presented at trial due to the following:

- The collection of additional soil and groundwater data from onsite locations since trial resulted in a change in the extent of groundwater and soil contamination.
- Salt constituents in soil were mapped in much greater detail in preparation of this plan as compared to previous reports. This allowed refinement of areas targeted for remediation.
- Additional sampling and remapping of heavy metals and petroleum hydrocarbons in soil and canal sediment resulted in slightly different contamination distribution,

with a one-foot thick reduction (from four feet to three feet) in the estimated average thickness of contaminated sediment at the base of canals.

- The collection of samples from numerous water wells in the Little Prairie area facilitated calculation of background constituent concentrations in the CHCTS. Remedial design of groundwater contamination in this plan is based on restoration to background constituent concentrations.

1.1.2 <u>Plan Distribution</u>

Three hard copies of this plan are herewith hand-delivered to the Department of Natural Resources, Office of Conservation by the time limit established by the court of January 5, 2016 (as per 609.A). A reasonable effort has been made to obtain a complete list of parties (as per 609.A.1). A Commissioner's Conference has not been held at this time (as per 609.A.2). As per 615.A, a copy of this plan has been sent to:

Vermilion Parish School Board c/o
Mr. William Coenen
Talbot, Carmouche and Marcello Law Firm
17405 Perkins Road
Baton Rouge, LA 70810

UNOCAL
Chevron
Chevron Midcontinent
Carrollton
All c/o
Victor Gregoire
Partner
Kean Miller LLP
II City Plaza
400 Convention Street, Suite 700
Baton Rouge, Louisiana 70802
Post Office Box 3513 (70821-3513)

1.2 SITE HISTORY

The earliest record of oil and gas development on the subject property is provided by the Louisiana Department of Natural Resources (LDNR) SONRIS database. The earliest well listed on the property is the Union Oil of California VPSB #1 (sn24764) spudded on October 1940, produced oil from Miocene Sands at a depth of 10500 feet, and was plugged and abandoned in 1999.

The SONRIS database indicates that over 50 wells were completed by 1960 (many dual completions), and over 65 were completed by 1973. The SONRIS database indicates that the first salt water disposal (SWD) well was permitted in 1973 (SWD#37 sn40010, drilled in 1950 and converted to SWD in 1973, and plugged and abandoned in 1980).

Reviews of historical aerial photographs identify the following pertinent features:

- **1935, Figure 1-1**: This image shows the VPSB property is undeveloped with the exception of the Schooner Bayou Canal.
- **1940, Figure 1-2**: The north-south oilfield canal is evident on this image. Two canal arms are also evident, one extending west to the location of an offsite well on the Heirs of Walter White property (sn23537), and one extending to the east on VPSB property. No wells on the VPSB property had been drilled as of the date of this image.
- **1951, Figure 1-3**: Two additional canals extending east of the north-south oilfield canal are evident. The central facility (“A” Battery) is evident, and numerous wells had been drilled as of this date. Also visible is the former “B” tank Battery and a heater-treater located just east of the VPSB #3 well (sn29537) located in the western portion of the property. Scarring of the land surface is evident south of the A-Battery. Additional scarring evident in the southeast corner of the property may be reflective of a marsh burn.
- **1964, Figure 1-4**: Features are similar to the 1951 image, the area south of the “A” Battery appears to be relatively more submerged as compared to surrounding areas, possibly indicating a higher rate of marsh damage and/or subsidence in that area.
- **1968, Figure 1-5**: Features are similar to the 1964 image, both the “A”Battery and “B” Battery are visible. Pits are visible on the west and east edges of the north-south canal that is located adjacent and west of the “A” Battery. A pit is visible west of the “B” Battery and the marsh appears damaged south of the B Battery. Scarring consistent with salt crusting is visible north of Schooner Bayou. Possible pits are visible west of VPSB#6 (sn52979), south of VPSB SWD38 (sn970681), and northwest across the canal from VPSB #17 (sn40019).
- **1979, Figure 1-6**: The marsh surrounded by canals located southwest of the A-Battery appears bermed and flooded. A large triangular pit with small skimmer pit at the apex of the triangle is visible south of the B-Battery.

- **1998, Figure 1**-7: The triangular pit south of the B-Battery appears overgrown with vegetation. An anomaly that could be a pit or crater feature is visible southeast of VPSB SWD#6 (sn28381).
- **2004, Figure 1-8**: This is a color infrared (IR) image. In these types of images, clear water appears dark because water absorbs near infrared (NIR) wavelength energy. Water with suspended particles appears as shades of blue, because the particles reflect a small amount more of green light than does clear water. Healthy vegetation appears bright red because growing plants exhibit high NIR reflectance. Stressed vegetation shows up darker red. Different types of plants vary in their NIR reflectance. An isolated area of dark water (presumably clearer than surrounding turbid water) appears south of the B-Battery, and is entering the canals and flowing in an easterly direction. This area coincides with very high chlorides measured in groundwater at the top of the Chicot Shallow Sand Aquifer.
- **2014 Figure 1-9**: This image depicts conditions similar to current conditions. The former "B" Battery was removed in 1985 and is no longer visible in this image. Active oil and gas wells are depicted on this image.

The area south of the central facility and "A" Battery is the main corridor for field flowlines. A map included in the SWD application file for VPSB A SWD #43 depicts flowlines, reproduced in **Figure 1-10** with the 1998 aerial image. The highest concentrations of salt contaminated groundwater occur in the Peat Zone near this network of flowlines.

Figure 1-10 also depicts former pits visible on historical imagery. The unregistered pit located nearest and west to the B-Battery was partially closed for Oil & Grease by Mike Pisani & Associates, but numerous exceedances of Oil & Grease remain today. Simply beaching the bow of a boat onto the shore adjacent to the pit remediation area, and then backing into the canal results in a heavy sheen on the surface of the water that covered the entire canal on December 1, 2015. A heavier sheen was observed on surface water in the canal at the B-Battery Skimmer Pit located southeast of the B-Battery, after similar disturbance of the shore.
Sampling indicates that The A-Battery Pit (#57p235) also exhibits HEM Oil & Grease in exceedances of Statewide Order 29B limits.

Figure 1-10 also depicts the locations of three documented cases of surface breaches of salt water disposal (SWD) wells, as follows:

- **SWD A#39**. Documents show that on November 15, 1994, gas was detected in the freshwater system. Gas monitoring was performed to determine if concentrations were hazardous in the living quarters, and the conclusion was no explosive conditions. Another document stated that SWD A39 had pressure on the casing on November 11, 1994, and that the casing had surface seepage for the previous 7 days. Documents show that on December 3, 1994, SWD #A39 had tubing to casing communication, and casing was leaking at the surface. The well was shut in and tubing and casing pressures dropped to zero. The next day, pressures were still zero, but the casing was again leaking. Injection resumed from 7am to noon, and casing did not pressure up nor leak. After the pump disengaged, tubing and casing pressure were zero, but casing was again leaking. Casing intermittently leaked until the injection well was shut in on December 5. On December 3, the freshwater well (located 1000 feet north of SWD #A39) was making gas, and sand was observed in the kitchen sink and sewage trap. WW1 is the source of freshwater for the living quarters, and is installed at the top of the Chicot Upper Sand Aquifer, with total depth of 460 feet (as per SWD permitting information).
- **SWD A#12.** An authorization for expenditure dated March 27, 1981 states that "*the 10-3/4" and 5-1/2" casing both have holes, and at high injection rates water is communicated to the surface*".
- **SWD A#16.** An authorization for expenditure dated October 2, 1980 states that "*The VPSB "A"Well No. 16 SWD is the only disposal well that has been available in the East White Lake Field. It was recently discovered that salt water is apparently escaping through a hole in the casing and channeling to the surface outside of the conductor pipe, contaminating the fresh water canal".*

All three of these surface breaches represents a source of contamination to the fresh water aquifers at the site, and have possibly contributed to salt water contamination to shallow soils on the property (see letter to DNR-OC from John Carmouche dated January 29, 2015).

SECTION 2.0 GEOLOGY, GROUNDWATER CLASSIFICATION, AND APPLICABLE REMEDIAL STANDARDS

2.1 GEOLOGY / HYDROGEOLOGY

2.1.1 TOPOGRAPHY AND REGIONAL SETTING

The site is located 5 miles southwest of Forked Island, Vermilion Parish, Louisiana. The entire property is mapped on the Geological Map of Louisiana as ***Qcf*** (Chenier Plain, Fresh Marsh, clay and silt of high organic content), located near the east bank of White Lake (**Figure 2-1**). The elevation at the site ranges from ~2 feet MSL to 0 ft MSL.

The site is located in the Mermentau hydrologic basin, in the Lakes sub-basin ("*Hydrologic Investigation of the Louisiana Chenier Plain, Prepared for the Louisiana Coastal Wetlands Conservation and Restoration Task Force, LDNR, October 2002*"). The current hydrology of the area is controlled by control structures built and managed by the US Army Corps of Engineers (USACE) (**Figure 2-2**). The closest of these control structures to the VPSB property is the Schooner Bayou Control Structure, located several miles east of the property.

This environmental assessment includes an evaluation of contamination caused by discharge of produced water. Contamination by produced water can pose a direct threat to the ecosystem, can enhance land erosion, and can pose a threat to underlying groundwater aquifers. The natural salinity of the surrounding ecosystem is therefore of concern in this evaluation. A review of published resources indicates that the natural salinity of the region has historically changed due to the following main factors:

- Man-induced hydrologic alterations. Before navigation channels were constructed in the early 1900s, the natural drainage in this area was easterly through Belle Isle and Schooner bayous. Human activities including navigation improvement, flood control, agriculture and petrochemical exploitation have altered the hydrology of the area. Navigation and oilfield canals have allowed saltwater intrusion into the basin. The construction of the Warren Canal was used for rice irrigation and induced saltwater intrusion. The USACE constructed three locks and two sector-gated control structures to mitigate this saltwater intrusion. For the last 60 years, these locks and structures have had the greatest effect on hydrology in the region.
- Relative Sea Level Rise. A 1989 USGS report of Sea Level Rise and Subsidence in Louisiana included data at the Schooner Bayou Control Structure that showed a relative sea level rise of 0.47 cm/yr [0.185 in/yr] from 1942-62, and a rise of 0.93 cm/yr [0.367 in/yr] from 1962-83. This relative rise is a function of land subsidence and rising sea level.

The VPSB property is currently mapped by the DNR as fresh marsh wetland habitat type (**Figure 2-3**, October 2002). In 1949 the vegetative map for this area shows sawgrass marsh, and was mapped as fresh marsh in 1978 and 1988 (*Mermentau Cooperative River Basin Study Report, USDA, NRCS, April 1997*). Historical development of canals and hydrologic controls in the area include:

- 1912 – Construction of the Old Intracoastal Waterway (Schooner Bayou Canal)
- 1913 – Installation of Schooner Bayou Lock (later replaced by the control structure)
- 1944 – Completion of the Gulf Intracoastal Waterway
- 1951 – Installation of the Schooner Bayou Control Structure, which replaced the former lock.
- 1958 – Construction of Louisiana Hwy 82.

Each of these features would have affected hydrology in this area.

The United States Fish and Wildlife Service publishes a National Wetlands Inventory, and includes maps accessible via a web-based geographical information system (GIS) available at www.fws.gov/wetlands/data/mapper.html. The map for the subject property is included in Figure 2-4, which shows the following mapped units:

- PEM1F: Palustrine System including nontidal freshwater wetlands dominated by trees, shrubs, and emergents that occur in tidal areas where salinity due to ocean derived salts is below 0.5 ppt; Emergent Class (EM), characterized by erect, rooted, herbaceous hydrophytes that is present for most of the growing season most years, and dominated by perennial plants; Subclass Persistent (1) dominated by species that normally remain standing until the beginning of the next growing season; and Water Regime (F) semipermanently flooded, where surface water persists throughout the growing season most years. This unit is found in the interior of the marsh located in between the canals and spoil banks at the site.
- PSS1C: Nontidal freshwater Palustrine System with Scrub-Shrub (SS) Class, dominated by woody vegetation less than 20 feet tall, and trees or shrubs that are small or stunted because of environmental conditions; Subclass (1) Broad leaved deciduous trees and shrubs; and Water Regime (C) seasonally flooded, where surface water is present for extended periods especially early in the growing season in most years. This unit is found along the spoil banks adjacent to canals.
- PSS1As: Nontidal freshwater Palustrine System with Scrub-shrub (SS) Class; Subclass (1) Broad leaved deciduous trees and shrubs; Water Regime (A) Temporary Flooded, where surface water is present for brief periods during the growing season; and Special Modifier (s) Spoil where deposition of spoil materials that has been excavated by man forms the primary substrate type.
- PUBH: Nontidal freshwater Palustrine System with Subsystem (UB) Unconsolidated Bottom, includes all wetlands and deepwater habitats with at least 25% cover of particles smaller than stones, and vegetative cover less than 30%; and Water Regime (H) Permanently Flooded where water covers the land surface throughout the year in all years.
- PAB4Hx: Nontidal freshwater Palustrine System, Aquatic Bed (AB) Class dominated by plants that grow principally on or below the surface of the water for

most of the growing season in most years; Subclass (4) Floating Vascular comprised of beds of floating vascular plants that occur in lacustrine, Palustrine and riverine systems and in the fresher waters of the estuarine system, and plants are moved about by wind or water currents; Water Regime (H) permanently flooded. This unit is found in small areas at the ends of canals at the site.

- R2UBHx: Riverine System including wetlands contained in natural or artificial channels periodically or continuously containing flowing water or which forms a connecting link between two bodies of standing water; Subsystem (2) Lower perennial, characterized by a low gradient and slow water velocity with no tidal influence, and a substrate of sand and mud; (UB) Class of unconsolidated bottom; Water Regime (H) permanently flooded and Special Modifier (x) excavated within a channel that has been dug through artificial means by man.

Topographic elevations based on LIDAR data are depicted on Figure 2-5, and shows that surface elevations for most of the site range from +1 to +2 feet NVGD, with higher elevations in spoil piles along canals and Schooner Bayou, and regionally the lowest elevations (+0.5 feet NVGD) located just southeast of the property. Thus, it is inferred that overall site drainage is to the southeast other than currents induced by operations of the Schooner Bayou Lock.

Soil samples of the surrounding marsh were collected by LSU and were analyzed for organic content and major cations and anions, and mapped marsh types based on this data as reported in "The Coastal Marshlands of Louisiana, Chemical Properties of the Soil Materials, Brupbacher, Sedberry, Willis, LSU Department of Agronomy and Agricultural Experiment Station, March 1973". Data points, marsh classification and chloride content for sample points near the VPSB property at East White Lake are depicted on Figure 2-6. Marsh is classified as brackish at sample points near Vermilion Bay (14-028 and 14-038), and at one other location near Freshwater Bayou Canal where it intersects Vermilion Bay (13-069). All other locations in the vicinity of the subject property are classified as fresh water. Chlorides at sample location 12-048 were 1500 ppm, at a similar distance from White Lake as the subject property.

Periodic storm surges associated with Hurricanes have occurred in this area for centuries. The relatively recent USACE control structures in the region have altered the drainage of storm surges. Salinity has been monitored at the Schooner Bayou Control Structure since it was built. A plot of salinity from 2003 to the current time period is presented as **Figure 2-7**, and includes two significant hurricane events (Katrina-Rita in September 2005 and Gustave in 2008), as well as some tasks performed with this assessment. The plot shows a period of approximately one year for salinity to return to low baseline levels. This is likely a function of climate (rainfall and wind speed and direction) in addition to operation of the control structures.

2.1.2 SUBSURFACE GEOLOGY

Subsurface geology and groundwater resources were evaluated using data from published resources including driller's logs and geophysical logs of water wells, USGS/LGS Water Resources Publications, shallow geophysical logs of oil/gas wells, and published data from the USGS; and onsite field characterization sampling and measurement including core samples from soil borings, direct-push conductivity logs, and geophysical logs of numerous recent borings (Appendix A).

In general, the shallow subsurface geology at the site within the top 800 feet is comprised of fluvial sands and gravels of the Pleistocene Chicot Aquifer, including an upper sand that occurs at ~30 to ~300 feet below land surface [bls] classified by the DNR water well registration database as the Chicot Shallow Sand Unit (CHCTS) and a lower sand that occurs at ~420 to ~800 bls classified as the Chicot Upper Sand Unit (CHCTU). These Pleistocene aquifers are capped by stiff confining clay and silty clay of Pleistocene age that functions as a confining stratum to the CHCTS, and has been historically subaerially exposed and eroded. Recent Holocene age near shore marsh and bay sediments have been deposited on top of the Pleistocene confining clay layer. Dr. Harold Fisk mapped the surface of this Pleistocene confining clay in the late 1940's as part of the design study for the Schooner Bayou Control Structure, and is presented herein in Figure 2-14. A cross section diagram from this same study was drawn along a transect through Schooner Bayou on the subject property (Figure 2-15) and shows a buried 15-foot deep eroded channel on the surface of the Pleistocene confining clay that slopes to the south-southwest. This sloping channel could affect the migration of discharged produced salt water that would tend to flow down slope, with the high density of the produced water driving the migration.

The generalized subsurface geology at the site can be characterized as:

- 0 to ~ 15 ft – **Holocene Very Soft Silty CLAY and PEAT**, some organic clay layers. This unit is groundwater-bearing, and is herein referred to as the ***"PEAT Zone".*** Soil in this stratum commonly contains greater than 50% moisture content.
- 15 to 35 ft **– Pleistocene Silty CLAY and CLAY,** some layers of Peat and rare lenses of SILT and Silty SAND. Some cracks in clay were observed to be filled with silt. This unit comprises the Chicot Aquifer Confining Unit.
- 35 to ~300 ft – **CHICOT SHALLOW SAND AQUIFER**, also referred to herein as the CHCTS consistent with DNR water well classification data, and is comprised of sand with some gravel zones. At the top of this aquifer from ~35 to 90 feet bls, a series of discontinuous clay beds occur. It is likely that this upper portion of the aquifer was deposited as fluvial meander channels of the ancestral Mississippi River, and a series of such channels have been mapped to occur through the White Lake area as included in LGS Water Resources Series No. 4 (Riley, Fisher 2009), reproduced herein in Figure 2-8.

- 300 to ~400 ft – **CLAY with numerous SAND Beds**. This clay is approximately 200 feet thick four miles south of VPSB property, and is approximately 30 feet thick 1 mile north of the VPSB property.
- ~400 to ~900 ft thick – **CHICOT UPPER SAND AQUIFER (CHCTU).** The USGS maps the base of fresh water (defined by 250 mg/L chlorides) at a depth of approximately 600 feet at the site (**Figure 2-9**). The base of the USDW (10,000 mg/L TDS) occurs at a depth of 800 feet bls. Thus, the fresh-water / saltwater interface occurs within the Lower Chicot at this site.

Cross section diagrams were prepared from onsite boring data and geophysical logs along transects depicted in Figure 2-11. A north-south cross section depicted in Figure 2-12 includes lithological control to a depth of 500 feet bls. Two east-west cross sections were prepared as shown in Figure 2-23.

Numerous water supply wells used for domestic, public and irrigation supply have been installed in the Chicot Shallow Sand (CHCTS) in Vermilion Parish, and numerous such wells continue to be used near this site at the community of Little Prairie near the Hwy 82 bridge over Schooner Bayou Canal **(Figure 2-10**). ICON evaluated logs of water supply wells in this area, and mapped the depth to the top of the CHCTS. In the community of Little Prairie, the depth to the top of the CHCTS is less than 30 feet below land surface, and by the Schooner Bayou Canal Bridge at Hwy 82 is as shallow as 12 feet below land surface, likely associated with an abandoned Mississippi River Channel deposit.

Water quality data were available from the USGS for a group of wells installed in 1961 near the Warren Canal (**Figure 2-16**). It is believed that these wells were installed to evaluate salt water intrusion associated with irrigation pumping of the Warren Canal and the possible deleterious effect to water quality of the CHCTS in this very vulnerable area. Geological Survey Water Supply Paper 1364 (*Water Resources of Southwestern Louisiana, Jones, Hendricks, Irelan, USGS, 1956*) describes historical irrigation withdrawals before the Mermentau Basin control structures were installed, and subsequent salt-water encroachment problems in the Chicot Aquifer at the Vermilion River where abandoned Mississippi River Channel deposits place surface waters in contact with groundwaters. The publication states that:

> "*In the summer of 1951 the river was filled with salty water for a total of about 13 weeks through a channel distance of 38 miles. This encroachment occurred during the period of heavy withdrawals from irrigation wells and maximum decline of groundwater levels. Because the Prairie formation of the Chicot reservoir is interconnected hydraulically with the Vermilion River throughout most of this distance, water recharged to the groundwater reservoir beneath this reach was salty during that period*".

Groundwater sampling of wells in Little Prairie near the Warren Canal defined a plume of groundwater chlorides in the CHCTS with concentrations as high as 980 mg/L in 1961 (Figure 2-16). This area of chloride contamination coincides with the shallowest occurrence of the top of the aquifer. Most of these test wells and potable water supply wells were shallower than 100 feet deep.

Recent sampling of water supply wells in this area (Figure 2-17) shows that this plume of chlorides had declined to a concentration of 530 mg/L (at the Donald Stelly camp well, TD of 90 feet). Chlorides near the bridge at Hebert's Landing were less than 250 mg/L in two water supply wells. Chloride concentrations at two wells screened at the top of the CHCTS further north of Little Prairie ranged from 374 to 417 mg/L. This data shows that water quality of the CHCTS in the area of the subject property is acceptable for potable use, (although high in hardness, iron and manganese, all of which is commonly treated using water softeners), and is currently utilized for potable supply. Two water supply wells are screened at the top of the CHCTS on VPSB property north of Schooner Bayou:

- An abandoned supply well (Crouch water supply) with total depth of 34 feet bls. This well exhibits elevated chloride concentrations that are believed to result from produced water discharges associated with the former UNOCAL shore based scrubber facility located 2000 feet east of the well on the north shore of Schooner Bayou. Shallow soil contaminated with produced water was confirmed at that location.
- A water supply owned by Pervis Hebert that is 41 feet deep and is reportedly still in use. Chlorides were measured at 824 to 851 mg/L in that well, and those concentrations are believed to reflect some degree of contamination by produced saltwater discharges.

2.1.3 GROUNDWATER FLOW

Groundwater flow direction within the Peat zone (top 15 feet bls) has not been determined, but is expected to be highly variable and influenced by surface features such as canals.

Top of casing surveying was performed by measuring the height of the well casing above surface water level, using a tape and/or surveyor's level. The surface water level relative to a static temporary benchmark was verified at the beginning and end of the survey. Potentiometric surface elevations were determined by subtracting the depth to water measurements (obtained on March 5, 2010, March 31, 2010, and on December 30, 2015) from the top of casing elevation. The data are summarized on Table 2-1.

Because of the presence of high concentrations of contamination by produced water in some wells, potentiometric data were corrected for density effects to properly evaluate groundwater flow. Hydraulic head is the measured depth to water in a well, and is a function of elevation head and pressure head. The pressure head of the water level in a well is a function of the density of the water and the gravitational constant. In lay terms, in an instance of two wells with the same potentiometric surface, the measured depth to water in a well with highly saline water will be greater as compared to the depth to fresh water in the other well. In order to properly evaluate groundwater flow potential, a groundwater flow regimen of variable density can be normalized using a reference density typically called the fresh water head (the imaginary equivalent column of water of equal density for all wells). All measurement data were corrected using methods included in the publication "*Using Hydraulic Head Measurements in Variable-Density Ground Water Flow Analyses, Post, Kooi and Simmons, GROUND WATER, Vol 45, No.6, Nov-Dec 2007, Pp 664-671".* Equivalent fresh water head was calculated as follows:

$$\boxed{h_f = \frac{\rho}{\rho_f} h - \frac{\rho - \rho_f}{\rho_f} Z}$$

Where hf = Equivalent Freshwater Head
h = measured head
ρ_f = density of freshwater
ρ = density of saline groundwater
Z = Elevation of middle of screen

$$\boxed{\rho = \left(6.87 \times 10^{-4} \bullet C_{TDS}\right) + 998.4575}$$

Density in Terms of TDS (*de Marsily 1986*) is:
ρ = density of saline groundwater
C_{TDS} = TDS concentration (mg/L)

The equivalent freshwater head at the top and intermediate depths of the CHCTS on all measurement dates is summarized on Table 2-1. Potentiometric maps constructed using this data are presented as Figure 2-18 (for the March 5, 2010 event), Figure 2-19 (for the March 31, 2010 event), and Figures 2-20 and 2-21 (for top and intermediate depths of CHCTS on December 30, 2015).

The horizontal component of groundwater flow direction at the top of the CHCTS in March 2010 was to the west or west-southwest at a hydraulic gradient of 0.00033 and 0.0055. Only three control points were available on these dates, so the potentiometric contours are drawn as a planar surface. Groundwater flow at the top of the CHCTS on December 30, 2015 was converging to a trough centered near the center of the property. The long-term groundwater flow direction in this region at the top of the CHCTS is not known, but is expected to be somewhat variable due to variable surficial recharge in this area where the confining unit is relatively thin.

The horizontal component of groundwater flow direction at intermediate depths in the CHCTS from approximately 60 to 100 feet below land surface in December 2015 was to the west or west-southwest at a hydraulic gradient of 0.0014. This relatively steep gradient is influenced by anomalously low head at TBB1D; the source of this is not known. There was a strong downward gradient of 0.034 in the top 100 feet of the CHCTS at nested wells TBB1S/TBB1D on the December 2015 measurement date. The head in the shallower Peat zone was very similar (1.43 at TBB3S) as the top of the CHCTS (1.45 at TBB2M). The head in the CHCTU (as measured in BC1 screened at 469-489') was five feet lower as compared to the top of the CHCTS. The downward gradient at the nested wells TBB1 might possibly be influenced by an abandoned well that was found just off of the property near these nested wells (Figure 2-21). This well is believed to be an abandoned rig supply well associated with Heirs of Walter White #2 Well (sn23537).

The abandoned well has open casing that is just below the surface water, and is deeper than 427 feet deep (as measured by ICON personnel, who did not have equipment capable of deeper measurement on that date). The condition of the casing is not known, but if the well is screened in the CHCTU and casing is compromised within the CHCTS, then a hydraulic connection between the two aquifers would result in a localized area of lower hydraulic head, and is seen at the TBB1 well nest. More potentiometric monitoring is recommended, and the abandoned well needs to be rehabilitated or plugged and abandoned.

Falling head slug tests were performed by pouring an instantaneous slug of water into the well, and recording the rate of water level equilibration using a data logger. Slug tests were evaluated using the Bouwer and Rice and Hvorslev methods with the aid of a computer program (Superslug). A summary of hydraulic conductivity data is presented in Table 2-2, and computer printouts of calculations and plots can be found in Appendix B. The top of the CHCTS at 33 to 60 feet below land surface exhibited a geometric mean hydraulic conductivity of 6.03 feet/day. No aquifer tests were performed in wells screened at deeper depths of the CHCTS.

2.2 GROUNDWATER CLASSIFICATION

2.2.1 PEAT ZONE

Aquifer testing of wells installed in the Peat Zone has not been performed at this time. It is anticipated that the yield of wells installed in this zone will likely be less than 800 gallons per day. Thus, the Peat Zone would likely be classified as per the Louisiana Department of Environmental Quality Risk Evaluation and Corrective Action Program (RECAP), as a Groundwater 3, **"groundwater within an aquifer that is sufficiently permeable to transmit water to a well at a maximum sustainable yield of less than 800 gpd"**.

2.2.2 CHICOT SHALLOW SAND AQUIFER (CHCTS)

The Chicot Aquifer is the principal aquifer utilized in this area, as well as throughout southwest Louisiana. Seven public water supply wells are screened in the Shallow Sand Aquifer (CHCTS), and all are approximately 7 miles from the site and include:

- St Anne Daycare, Ve10528z, 3-inch diameter, 80 feet TD, installed July 2000.
- Forked Island Shipyard, Ve870, 2-inch diameter, 86 feet TD, installed October 1984.
- Roland Campbell, Ve8353z, 4x2-inch diameter, 120 feet TD, installed October 1993.
- Amoco Production Co., Ve1072, 2-inch diameter, 190 feet TD, installed September 1991.
- Ma & Pa Bait Shop, Ve10891z, 3-inch diameter, 100 feet TD, installed Nov 2001.
- La DOTD, Bridge #1, Ve763, 4x2-inch diameter, 278 feet TD, installed Feb 1982.
- Hanks Flying, Ve1053, 2-inch diameter, 120 feet TD, installed January 1991.

Additionally, I have been informed by VPSB personnel that future plans for the property include potential recreational facilities (hunting and fishing lodge) that would likely utilize a public supply well.

Measured water quality from domestic and irrigation wells screened at the upper portion of the CHCTS in the Little Prairie area near the property show TDS concentrations ranging from 485 to 1360 mg/L (chlorides ranging from 118 to 530 mg/L). Some wells in this area likely exhibit residual elevated salts related to historical irrigation and intrusion from pre-control structure times. Because the VPSB property is located further west (2.3 miles) than documented areas of salt water intrusion associated with irrigation in the Vermilion River and Warren Canal, it is more probable than not that natural groundwater quality in the CHCTS at the VPSB property likely exhibited TDS less than 1000 mg/L before oil and gas operations began.

The CHCTS would be classified as:

- GW1B assuming pre-contamination TDS concentrations of less than 1000 mg/L: Groundwater within an aquifer that could potentially supply drinking water to a public water supply (yield greater than or equal to 4800 gallons per day) and TDS less than or equal to 1000 mg/L.
- GW2A assuming pre-contamination TDS concentrations greater than 1000 mg/L: Groundwater within an aquifer that currently supplies water to a domestic supply, agricultural supply or any other supply. (RECAP notes that if a public water supply well is located within one mile of the site property boundaries and is screened in the same stratum as the aquifer of concern or has a direct hydraulic connection, then the aquifer shall be classified as GW1. Thus a future public supply installed in the CHCTS at the site would result in GW1 classification).

2.2.3 CHICOT UPPER SAND AQUIFER (CHCTU)

Two onsite wells are screened in the CHCTU: James Guidry camp well located north of Schooner Bayou, and the facility water well. The CHCTU would be classified as GW1B: groundwater within an aquifer that could potentially supply drinking water to a public water supply (yield greater than or equal to 4800 gallons per day) and TDS less than or equal to 1000 mg/L.

2.3 APPLICABLE REMEDIAL STANDARDS

2.3.1 SOIL EXPOSURE

Standards for the evaluation of soil contamination are found in Statewide Order 29B in LAC 43.XIX.313, and are listed by method of pit closure as follows:

- LAC43.XIX.313.C lists standards for **all pit closure techniques (except solidification)**:
    - pH (6-9 for land treatment, burial and trenching, 6-12 for onsite land development).
    - Total Metals as ppm (arsenic [10], barium [20000 for wetlands and 40000 for uplands], cadmium [10], chromium [500], lead [500], mercury [10], selenium [10], silver [200], zinc [500]).
- LAC43.XIX.313.D lists standards for **Land Treatment** and include standards for salt constituents as follows:
    - Upland areas (EC [<4 mmhos/cm], SAR [<12] and ESP [<15%])
    - Elevated freshwater wetland areas (EC [8 mmhos/cm], SAR [<14], ESP [<25%]).

  As per the USFWS Wetlands Map (Figure 2-4), much of this site is a submerged wetland where mapped as PEM1F; and portions are either non-wetland or mapped as PSS1As (temporarily flooded) or PSS1C (seasonally flooded) that would likely be considered an elevated wetland. The standards listed in this method are applicable to portions of this site.
- LAC43.XIX.313.E lists standards for **Burial or Trenching**, and includes additional criteria for moisture content (<50% by weight), EC (<12 mmhos/cm), and HEM Oil & Grease (<3%). Additionally, the bottom of the burial cell must be at least 5 feet above the seasonal high water table and the top of the buried mixture must be 5 feet below land surface and covered with native soil. This site does not meet the water table isolation criteria and thus this method is not applicable for this site.
- LAC43.XIX.313.F lists standards for **Solidification**, and includes:
    - pH (6 – 12),
    - Leachate testing for HEM Oil & Grease (<10mg/L) and for chlorides (<500 mg/L),
    - Leachate Testing for Heavy Metals (arsenic[<0.5 mg/L], barium [<10 mg/L], cadmium [<0.1 mg/L], chromium [<0.5 mg/L], lead [<0.5 mg/L], mercury [<0.02 mg/L], selenium [<0.1 mg/L], silver [<0.5 mg/L] and zinc [<5 mg/L]),
    - Unconfined compressive strength (>20 lbs/in2), permeability (<1x10-6 cm/sec), and wet/dry durability (>10 cycles to failure).
    - Additionally, the bottom of the burial cell must be at least 5 feet above the seasonal high water table and the top of the buried mixture must be 5 feet below land surface and covered with native soil.

This site does not meet the water table isolation criteria and thus this method is not applicable for this site.

- LAC43.XIX.313.G lists standards for **Onsite Land Development**, and includes:
  - pH (6-12) and metals as per LAC43.XIX.313.C
  - EC (<8 mmhos/cm)
  - HEM Oil & Grease (<1%)
  - Leachate Testing for chlorides (<500 mg/L)
  - Waste processing shall not be processed in an unlined pit with bottom that is deeper than 5 feet above the seasonal high water table
  - NORM concentrations shall not exceed DEQ criteria
  - Must process material with DEQ approved stabilizing additives, and material can be used to develop lease roads, drilling and production locations, etc.

  This method could be utilized at the subject property to construct pads for future camps, etc; and thus the standards appropriate to this technique are applicable to this site.
- LAC43.XIX.313.H lists criteria for **Passive Closure**, but contains no standards.
- LAC43.XIX.313.I lists criteria for **Offsite Disposal of E&P Waste**, and includes:
  - Provisions that waste can only be sent offsite for storage, treatment or disposal if sent to an approved commercial facility or transfer station.
  - "The criteria for land treatment, burial, solidification, or onsite generation of reuse material listed above will apply, as appropriate, to the onsite disposal of any E&P waste remaining onsite". "Any E&P waste that fails to meet the criteria of this paragraph for onsite disposal shall be moved offsite by the operator to a permitted commercial facility or transfer station".

  Offsite disposal represents a feasible method for disposition of some E&P Waste at this site, particularly at former pit locations and south of the A-Battery. This site does not meet the water table isolation criteria for burial or solidification, and thus the criteria for those two techniques are not applicable. This site does meet the criteria for land treatment in some areas (LAC43.XIX.313.C) and Onsite Land Development (LAC43.XIX.313.G) and thus the criteria for those two techniques would be applicable.

Soil and pit sludge data were therefore compared to pit closure criteria applicable to E&P sites located in elevated wetland environments as listed in LAC: 43.XIX.313.C and onsite land development as listed in LAC.43.XIX.313.G:

Arsenic	10 ppm
True Total Barium	20,000 ppm
Cadmium	10 ppm
Chromium	500 ppm
Lead	400 ppm
Mercury	10 ppm
Selenium	10 ppm

Silver	200 ppm
Zinc	500 ppm
Oil & Grease	< 1% dry wt
EC	<8 mmhos/cm
SAR	<14
ESP	<25%
Leachate Chlorides	<500 mg/L

Because the Statewide Order standard for petroleum hydrocarbons (HEM Oil & Grease) is generally not considered to be a risk-based standard, the Screening Option standards for non-industrial exposure to petroleum hydrocarbons in the Louisiana Department of Environmental Quality's Risk Evaluation and Corrective Action Program (RECAP) were also used as a comparative standard for soils, sludges and subaqueous sediment as follows:

TPH-D	325 mg/kg (adjusted for additivity due to concurrent presence of TPH-O)
TPH-O	900 mg/kg (adjusted for additivity due to concurrent presence of TPH-D)

The LDEQ RECAP document states that petroleum hydrocarbon data analyzed using the fractionation method provides more specific data to evaluate toxicity. ICON evaluated all data at this site where both hydrocarbon mixture data (ie, TPH-DRO [C_{10}-C_{28}] and TPH-ORO [C_{28}-C_{35}] by Method 8015-B) and fractionation data (using Tx 1006 method [C_6-C_{35}]) were available for 48 individual samples. This evaluation showed that:

- The sum of the fractionation data (Tx1006) was always less than the sum of Method 8015B data, even considering Tx1006 included C_6 to C_{10} fractions and Method 8015B did not.
- The sum of the Tx1006 data was as much as 50 times less (for samples where some TPH was detected using each method) to 180 times less (where Tx1006 was nondetect and 8015B had detects).
- Overall, the sum of Tx1006 data was 16 times lower as compared to the sum of 8015B data for the same sample.

This shows that the fractionation method, which requires silica gel filtering to separate aliphatic from aromatic hydrocarbons resulted in (on average) a significant loss of sample concentration. The TX1006 method includes a statement in "(4.0) Interferences" that "*the method depends on correctly integrating a mass of unresolved peaks, usually found in the approximate nC10-nC35 range, using a forced baseline. The resulting baseline, if drawn incorrectly, will have a significant effect on the concentration reported. It is imperative that the chromatograms be checked (using a realistic scale relative to the chromatogram) for correct baseline extension*". Thus, although the hydrocarbon mixture (Method 8015B) data are less precise for evaluating toxicity, they provide more accurate concentration data to evaluate toxicity, and were relied on for this site.

2.3.2 SOIL SOURCE (LEACHABILITY)

Produced saltwater contamination has resulted in very high soil conductivities (>50 mmhos/cm) that exist in clays and peats within the Peat Zone and extends vertically downward through the silty clay and clay Pleistocene confining zone. Groundwater in the Chicot Shallow Sand Aquifer is contaminated with chlorides at concentrations exceeding 10,000 mg/L in areas where the confining zone exhibits these high EC concentrations, suggesting that source soils remain in place and are actively leaching salts to underlying groundwater. The leaching potential of salts in soil is assessed using the 7-day Leachate Chloride method included in the 29B Laboratory Procedures for the Analysis of E&P Waste, revised 11/2011. I have personally been involved in monitoring a commercial facility closure that demonstrated that the 29B Leachate Chloride test is amazingly accurate. The LDEQ proposes (in "frequently asked questions to RECAP) a method based on SPLP extraction testing to evaluate chloride leachability from soils, but in my opinion misapplies the SPLP test in a manner that is inconsistent with EPA and other states. I have tested the SPLP method as suggested by LDEQ at an actively leaking solution-mined brine contaminated site and found that the test (as applied by LDEQ) can NEVER result in a 'failure", and the test ALWAYS results in a conclusion of no leaching threat, no matter the concentration. Thus, it is my opinion that the SPLP test as suggested in the LDEQ Frequently Asked Questions should never be implemented at any site.

METHOD DESCRIPTION

A brief description of each method is as follows:

- The Synthetic Precipitation Leaching Procedure (SPLP) utilizes extraction procedure Method 1312 in which a **20:1 ratio (by weight)** of extraction fluid to solid sample is employed, and is allowed to extract for 18 hours in a rotary extraction device. For samples east of the Mississippi River, the extraction fluid is made using reagent grade water and sulfuric/nitric acid to a pH of 4.2 +/-0.05. For samples west of the Mississippi, the pH is 5 +/- 0.05. The extraction mixture is filtered of solids and the extract is analyzed using SW846 Method 9253, which is a silver nitrate titration method for chloride content. Interferences with Method 9253 include bromide, iodide and sulfide (all of which are titrated along with chlorides). I have no problem with this analytical method. As per RECAP FAQs dated 07/03/2012, for protection of groundwater meeting the definition of Groundwater Classification 1: Compare the SPLP test results to the product of GW1 x 20 (default value for DF_{Summers}). The comparative standard for SPLP Chlorides using the US EPA secondary drinking water maximum contaminant limit of 250 mg/L x 20 = 5000 mg/L. Thus, the SPLP result is compared to a standard of 5000 mg/L; this reflects a 400:1 dilution of the actual salt concentration leaching from the sample. This methodology is not consistent with procedures at EPA or at other states, and is scientifically invalid. It is this misapplication of SPLP data that I take issue with.
- For sites under jurisdiction of Statewide Order 29B and the Louisiana Department of Natural Resources, the leachability of salts from soils is determined using the 29B

Leachate Chloride test (Laboratory Procedures for Analysis of E&P Waste, Revised Nov 2011). This method was designed to simulate water leach effects on treated Exploration and Production Wastes addressed specifically under LAC 43:XIX.Subpart 1. Chapter 3 (Onsite Storage, Treatment and Disposal of E&P Waste) and LAC 43:XIX.565.F (Testing Criteria for Reusable Material). A representative sample of the waste solid is extracted by continuous contact with reagent water (ASTM Type II water) at a **1:4 solid:solution ratio** for 7 days "with flask contents swirled on a daily basis to effect gentle, intermittent agitation". After this time period, solids are separated from the mixture by filtration, and chlorides are analyzed using EPA Method SW-846 9056 or 9253. Method 9253 was previously summarized. Method 9056 is an ion chromatography method for determination of inorganic ions including chlorides. The measured concentrations of chlorides in the extract are compared to the regulatory standard of 500 mg/L.

LITERATURE REVIEW OF REGULATORY METHODS

Contaminant mobility is evaluated in terms of how tightly bound the contaminant is to soil particles, and is described by the contaminant-specific desorption coefficient, or Kd value. Increasing Kd values reflect decreasing mobility in soil. Contaminants with a Kd value less than 1.0 are considered to be highly mobile in soil, and contaminants with a Kd value greater than 20 in soil are considered to be essentially immobile (*Technical Memorandum, State of Hawaii, Use of laboratory batch tests to evaluate potential leaching of contaminants from soil, April 2007*). It is generally known that chloride ions are conservative tracers of groundwater movement, and there is little if any potential interaction ionically or otherwise with surfaces of soil particles. The Kd for chloride is often assumed to be zero mL/g. Some United States regulatory agencies have recommended use of a chloride ion Kd of 0.1 mL/g (*Derivation of Matrix Soil Standards for Salt under the British Columbia Contaminated Sites Regulation, Addendum B: Protocol for Estimation of Site-Specific Adsorption Coefficients (Kd), February 2002*). Thus, as expected, chloride is a highly mobile and therefore easily leached contaminant. Batch tests such as the SPLP test were not designed to directly estimate the concentration of a contaminant in soil leachate, but were instead designed to calculate Kd sorption or desorption coefficients. The Kd coefficient is then used in a leaching model to predict contaminant concentration in groundwater beneath a soil source. The solution volume of two liters (per 100 grams of soil), or 20:1, was selected for the SPLP test primarily to help ensure that laboratory detection limits could be met, not to mimic the supposed concentration of the contaminant in actual soil leachate (*Technical Memorandum, State of Hawaii, April 2007).* This fact is reiterated by the recent New Jersey regulation "*Guidance for the use of the Synthetic Precipitation to Develop New Jersey Site-Specific Impact to Ground Water Remediation Standards, Version 2.1, April 24, 2013*". This document states that "Leachate concentrations measured in the SPLP test are not equivalent to those what would be observed under field conditions because the relative amounts of soil and water used in the SPLP test are completely different from those in a natural soil system".

Other states utilize various other methods to determine the soil to groundwater pathway (leachability) using batch test data, all of which are much more scientifically valid than the method suggested by RECAP FAQs:

- Florida utilizes a regression method to correlate SPLP data to total constituent concentrations in soil in the same sample. Data are plotted on a scatter plot with total sample concentrations on the x-axis and SPLP data for the same sample on the y-axis. A minimum of 10 discrete samples per soil investigation interval of interest are recommended. A linear regression best fit line is drawn, and if the correlation coefficient (r2) is 0.8 or higher, a horizontal line is drawn from the site-specific risk-based groundwater standard for that COC to the linear regression best fit line, and the total soil concentration that is protective of the groundwater standard is read from the x-axis. If the correlation coefficient is less than 0.8, then the highest total sample concentration having a corresponding SPLP value that is below the groundwater standard is designated as the soil standard that is protective of groundwater. (*Guidance for Determining Leachability by Analysis of SPLP Results, Florida DEP, Bureau of Waste Cleanup, Program & Technical Support Section, Tallahassee, Florida, June 2009*).
- Nevada requires that a minimum of three soil samples per AOI be collected for SPLP and total constituent concentration analysis. It is required that two SPLP extractions be employed: one using a solution with pH of 5 +/10.05 (as per the method) and one using a solution of neutral pH. The guidance states that the SPLP test inherently has a 20:1 dilution, and that this dilution factor is the only dilution that should be used (a DAF factor should not be applied to the SPLP results). The soil leachability standard is calculated assuming a linear relationship by multiplying the groundwater protection standard by the ratio of the total soil concentration to the SPLP leached concentration (SoilGW = Total Soil Concentration / SPLP Concentration). (*Nevada Guidance 2010, Attachment A, Further Evaluation of Soil Leaching to Groundwater*).
- Wisconsin guidance emphasizes that the SPLP test inherently has a 20:1 dilution factor, and that this dilution factor is the only dilution that should be used, unless a much more extensive scientific analysis of the controlling mechanisms of leachability phenomena is conducted at the specific contaminated site. Wisconsin uses two methods to apply SPLP data (*Guidance on the Use of Leaching Tests for Unsaturated Contaminated Soils to Determine Groundwater Contamination Potential, Wisconsin Department of Natural Resources, Bureau for Remediation and Redevelopment, Oct 2003*):
  - The first is a comparison of the SPLP results to the site-specific groundwater standard using the 95% confidence interval of three or more samples. The total soil concentration is compared to the leached concentration.
  - The soil leachability standard is calculated assuming a linear relationship by multiplying the groundwater protection standard by the ratio of the total soil concentration to the SPLP leached concentration (SoilGW = Total Soil Concentration / SPLP Concentration). The mean of the total

and leached values for each sample are statistically evaluated, and the value at the lower 95% confidence limit is used as inputs to the equation.

- Hawaii uses that same methodology as New Jersey, but utilizes a spreadsheet to facilitate calculating the site-specific contaminant Kd using each sample’s total and SPLP concentration, and using the resulting Kd value in the USEPA equilibrium partitioning equation to calculate the concentration of the contaminant in the source-area leachate. The spreadsheet then applies a groundwater:leachate dilution factor consistent with USEPA Soil Screening Guidance, July 1996. The spreadsheet uses a default DF of 20 for sites less than or equal to 0.5 acres. If the source soils occupy more than 0.5 acres, the dilution factor is calculated as: 1 + (K*i*d/I*L), where K is aquifer hydraulic conductivity (m/yr), “i” is regional hydraulic gradient, d is mixing zone depth (default is 2 meters), I is surface water infiltration rate(m/yr) and L is length of contaminated soil area parallel to groundwater flow (m). (*Technical Memorandum, State of Hawaii, Use of laboratory batch tests to evaluate potential leaching of contaminants from soil, April 2007).*
- Indiana recommends simply comparing SPLP results to the groundwater protection standard. (*Indiana Department of Environmental Management, Remediation Closure Guide, July 2012*).
- Alabama also recommends simply comparing SPLP results to the groundwater protection standard. (*ADEM Alabama Risk-based Corrective Action Guidance Manual, April 2012*).

FIELD TEST OF SPLP CHLORIDES AS PER LDEQ (FIGURE 2-22)

I have personally applied the LDEQ SPLP methodology as specified in FAQs at a worst case site: an actively leaking solution brine mining pit at the Napoleonville Salt Dome, with documented leakage of a brittle fiberglass liner for a period of at least 26 years (Figure 2-22). Water in an underdrain system beneath the liner had chloride concentrations of 213,000 mg/L. Soil beneath and surrounding the pit had extremely high salinity of 150 mmhos/cm with a few samples exceeding 200 mmhos/cm. Soil that exceeded an EC of 8 mmhos/cm comprised a surface area of 6.65 acres. Groundwater in the shallow aquifer surrounding the pit had high chloride concentrations of 149,000 mg/L, but no monitoring wells were installed directly beneath the pit. I also ran split soil samples using the LDNR-OC leachate chlorides procedure. The maximum result of the SPLP testing of five samples was 1850 mg/L (thus “passing” the comparative 5000 mg/L limit), and the maximum Leachate Chloride result was 14,200 mg/L (thus “failing” the 500 mg/L LDNR limit). The results of this study prove that it is scientifically impossible to “fail” the SPLP test when administered as LDEQ FAQs suggests because it results in a 1:400 dilution of leachable salts, and is scientifically invalid to predict the leaching potential of chlorides, one of the most soluble constituents known. This test was performed using salts at saturation concentrations, with 98% saturated brine. Produced water by comparison typically exhibits chloride concentrations of 70,000 mg/L.

FIELD TEST OF LEACHATE CHLORIDES PER 29B (FIGURE 2-23)

I have personally been involved in the closure of a commercial E&P waste treatment facility in Livonia, Louisiana. The closure involved onsite mixing of approximately 175,000 yd^3 of E&P waste by onsite mixing with clean soils to achieve closure criteria. The mixed material was placed into three stockpiles (4.8 acres, 7.4 acres and 10 acres). ICON had performed site-wide quarterly groundwater monitoring for five years before closure, and continued for over 10 years after closure. Chloride concentrations in shallow groundwater adjacent to one of the stockpiles (Unit 6 – 7.4 acres in size and approximately 15 feet tall) had averaged 25 mg/L in a clayey silt shallow aquifer located approximately 15 feet below land surface. Surficial clays and silty clays overlying the shallow aquifer and underlying the closed stockpile had laboratory measured permeability of $6.8\text{x}10^{-8}$ cm/sec (horizontal) and $2.5\text{x}10^{-8}$ cm/sec (vertical). Laboratory-measured permeability of the shallow aquifer was $2\text{x}10^{-4}$ cm/sec (horizontal) and $5\text{x}10^{-5}$ cm/sec (vertical). The closed E&P stockpile had maximum EC of 7.5 mmhos/cm, and 29B Leachate Chlorides of 311 mg/L. Groundwater monitoring data from Monitoring Well W18 adjacent to the stockpile exhibited an increase in chloride concentration over a nine to ten year period that peaked in concentration at 500 mg/L. Thereafter, chloride concentrations decreased to average concentrations of 300 mg/L that allowed closure of the facility using a LDEQ RECAP MO2 evaluation. This actual field demonstration shows that the 29B Leachate Chloride test that predicted a potential leaching concentration of 311 mg/L was extremely accurate, confirmed by actual field monitoring.

This study also demonstrated the ability of dissolved salts in groundwater to migrate through 15 feet of clay that had a laboratory-measured permeability of $6.8\text{x}10^{-8}$ cm/sec (horizontal) and $2.5\text{x}10^{-8}$ cm/sec (vertical). Geotechnical laboratory testing for permeability is performed using distilled or deionized water. It has been known for decades that the hydraulic conductivity (permeability) of clays is affected by the salt concentration of the solution, and the chemical composition of the liquid moving through a liner must be taken into account ("*Design Considerations for Earth Linings for Seepage Control, Herman Bouwer, Groundwater, Vol 20, No.5, Sep-Oct 1982*"). The United States Corps of Engineers Field Manual (*EM 1110-2-1901, 30Sep86*) states that "*cohesive soils may be two to three orders of magnitude more permeable to seepage water containing moderate amounts of dissolved salts (less than 300 ppm by weight) than the distilled water*". Therefore, any suggestion that the low permeability of clays prevents migration of produced water contamination is not valid unless the salinity of the contaminated water is considered.

LEACHING STANDARD USED FOR THIS PLAN

My extensive personal experience and literature reviews support the use of the 29B Leachate Chloride test as the most appropriate test to accurately predict the leaching potential of salt constituents. The 29B Leachate Chlorides test results were compared to the regulatory standard of 500 mg/L. Data from 2006 (pre-Act 312) utilized testing for soluble chlorides (Method M4500 using a 1:1 soil:wtr extraction) instead of saturated paste EC. Data collected after 2006 utilized saturated paste EC, and in some instances also included testing for soluble chlorides. Crossplots of soil EC, soluble chlorides and 29B Leachate Chloride data were prepared. All crossplots demonstrated a positive linear correlation. Figure 2-24 (Soil EC vs. 29B Leachate Chloride) included 49 datasets and showed the strongest correlation with r2 of 0.781, and indicates that a saturated paste EC of 6.2 is equivalent to a 29B Leachate Chloride value of 500 mg/L. The crossplots indicate the following relationships:

- EC 6.2 mmhos/cm (Soluble CL of 2577 mg/kg) = 29B Leachate CL of 500 mg/L
- EC 8 mmhos/cm (Soluble CL of 3325 mg/kg) = 29B Leachate CL of 642 mg/L

2.3.3 SEDIMENT

Contaminated subaqueous sediment exists at the base of canals where the public has access for fishing; thus ecological considerations would include bioaccumulation in organisms that represent a human food source (fish, alligators, turtles, ducks, etc). Because of these considerations, subaqueous sediment data were compared to the National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables for Inorganics in Solids (SQuiRT), using the value for the Threshold Effects Level (TEL). An ecological risk assessment and toxicological evaluation for this site was performed by Dr. William Rogers of Omega Envirosolutions, Inc. in March 2014. This ecological assessment resulted in Tier III Ecological Risk Assessment (ERA) Wildlife Protective Levels that were similar to the NOAA SQuiRT values (included herein in Appendix C). The NOAA SQuiRT tables do not have standards for total petroleum hydrocarbons; thus the RECAP Screening Standards were used for subaqueous sediment samples. This evaluation resulted in the following comparative standards that were used for subaqueous sediment:

	NOAA SQuiRT TEL (mg/kg)	ERA Tier III WPL
Arsenic	5.9	6
Barium	n/a	81
Cadmium	0.596	na
Chromium	37.3	35
Lead	35.0	34
Mercury	0.174	0.94
Zinc	98	na
TPH-DRO	65	293

2.3.4 GROUNDWATER

2.3.4.1 Chicot Shallow Sand Aquifer

Groundwater at E&P sites is specifically regulated by Statewide Order 29B which states that "*Contamination of a groundwater aquifer or a USDW with NOW is strictly prohibited*" *(LAC 43:XIX.303.C).* Contamination is defined in LAC43.XIX.301 as "*The introduction of substances or contaminants into a groundwater aquifer, a USDW or soil in such quantities as to render them unusable for their intended purposes*". The LDNR-OC has historically applied the groundwater standards listed in Chapter 5 of 29B (LAC43:XIX.Chapter 5) to groundwater contamination at E&P "pit" sites; thus, the default standard has been essentially the same as LAC43.XIX.549.C.4: "*The concentration of measured constituents in any groundwater aquifer shall at no time significantly exceed background water quality data*". This interpretation is supported by language in #2) of the First Amended MOU between the LDNR-OC and LDEQ Regarding Approval of RECAP Groundwater Evaluation and Remediation Plans at Oil Field Sites dated February 2011, wherein it is stated that RECAP can be used *"as an exception to Statewide Order 29B groundwater background concentration requirements set forth in LAC 43:XIX.303.C for parameters listed under LAC 43.XIX.311.C; or as required by and set forth in LAC 43:XIX.541 or 539.E.2 for parameters listed under LAC 43:XIX.549.E.2; or as required and set forth in LAC 43:XIX.421.A for parameters listed under LAC 43:XIX.311.C.*"

Groundwater data were available from five water supply wells screened at similar depths in the Chicot Shallow Sand Aquifer to the monitoring wells at the VPSB property, and are located in the community of Little Prairie by Hebert's Landing. These wells were sampled in October 2015, and data are summarized on Table 4-5. The wells used to represent background constituent concentrations include:

- Greg Raspberry well, TD 85 ft.
- Ve12018 well, screened at 90 ft.
- Donald Stelly Camp Well, screened at 90 feet.
- Stelly Well (Ve 5361z), screened at 86 feet.
- Sidney Meche Well, screened at 50 feet.

The locations of these wells can be found on Figure 2-17. Background was calculated as the arithmetic mean concentration plus one standard deviation (Table 4-5). This evaluation resulted in the following groundwater comparative background standards for oilfield indicator constituents:

Arsenic	<0.01 mg/L
Barium	1.03 mg/L
Cadmium	<0.005 mg/L
Chromium	<0.01 mg/L
Lead	<0.01 mg/L

Mercury	<0.0002 mg/L
Strontium	0.88 mg/L
Zinc	0.16 mg/L
Chlorides	487 mg/L
TDS	1304 mg/L
Radium 226-228	2.42 mg/L

These constituent concentrations are within US EPA Primary Maximum Contaminant Levels (MCLs). Salt constituents slightly exceed the US EPA Secondary MCLs of 250 mg/L for chlorides and 500 mg/L for TDS. The calculated background chloride concentration of 487 mg/L is supported by site-specific data, because MW4D screened at 75-77 feet bls exhibited chlorides of 426-447 mg/L. Because the future intended use of the Chicot Shallow Sand Aquifer includes potable use as possible public supply, a variance from the Statewide Order 29B background groundwater standards was not employed for these aquifers.

2.3.4.2 Chicot Upper Sand Aquifer

Groundwater in the CHCTU is available from two onsite water wells (James Guidry and the facility water well), and data from a groundwater sample from Monitoring Well BC1 is pending on this date.

Constituent concentrations were compared to:

- USEPA Drinking Water Standards and/or the LDEQ RECAP MO1 remedial standards.
- Historical trends for data available for the facility water well, beginning in 1983.

2.3.4.3 Peat Zone

The Peat Zone is in hydraulic communication with surface water via canals. The gross contamination by salt constituents within the Peat Zone groundwater represents a source for continued leaching to the Chicot Aquifer. Groundwater within the Chicot Aquifer is grossly contaminated by salts, at concentrations exceeding 10,000 mg/L. A downward vertical hydraulic gradient from the PEAT Zone to the Chicot Aquifer was measured during the sampling event. As such, the potential for contaminants to continue leaching to the Chicot Aquifer is of concern.

The RECAP Table 3 remedial standards and appropriate ARARs for a GW3ndw result in the following groundwater remedial standards for the **PEAT Zone**:

Arsenic	**0.05 mg/L**	**GW3ndw, Table 3**
Barium	**45 mg/L**	**GW3ndw, Table 3**
Lead	**0.05 mg/L**	**GW3ndw, Table 3**
Mercury	**0.003 mg/L**	**GW3ndw, Table 3**
TPH-D	**24 mg/L**	**RECAP, GW3ndw Table 3**

TPH-O	**24 mg/L**	**RECAP, GW3ndw Table 3**
Radium 226-228	**5 pCi/L**	**MCL**
Chlorides	**Potential for Leaching is based on the 29B Leachate Chloride Limit of 500 mg/L.**	

SECTION 3.0 ASSESSMENT CHRONOLOGY AND DESCRIPTION

3.1 CHRONOLOGY

Field assessment at the VPSB East White Lake property was performed from April 2006 to December 2015, and is still ongoing. In general, assessment activities occurred as follows:

- **April 2006**: ICON performed a Geonics EM-31 Terrain Conductivity Survey.
- **April 2006**: ICON collected of subaqueous sediment (sludge) samples from locations SS01 through SS15 using a 2-inch diameter PVC pipe sampling tube.
- **August 2006**: ICON ran conductivity logs at locations B1 through B19 using a Geoprobe conductivity logging system advanced using a hydraulic direct push rig on a barge.
- **August 2006**: ICON collected core samples at B2 through B19 at the same locations of conductivity log borings using a vibracore sampling system with the assistance of QRI, Inc. Two additional locations (B20 and B21) were also sampled.
- **October and November 2006**: ICON collected soil samples at locations AB1 through AB22 using a mud rotary wash rig on an air boat. Monitoring wells were installed in eight of the AB borings, one installed in the Chicot Aquifer (AB1) and all others in the Peat Zone.
- **November 2006** – ICON developed, purged and sampled the eight AB monitoring wells.
- **November 2006 –** ICON collected shallow subaqueous sediment at the locations of several of the AB borings (AB1-4, 13,14,15).
- **November 14, 2006**: ICON sampled two water supply wells, the well at the Peak Operating office in the field (WW1), and an unregistered water well located at a house in Little Prairie near the Hwy 82 bridge (labeled WW2). A complete set of depth to water measurements was performed on August 14th.
- **February and March 2010 –** ICON collected subaqueous sediment samples at locations Sed1 through Sed33 using a Russian Peat Borer sampler.
- **March 2010 –** ICON installed three monitoring wells (MW1 through MW3) installed in the Chicot Aquifer.
- **March 2010 –** ICON developed, purged and sampled the three Chicot Aquifer monitoring wells.
- **May 2010 –** ICON collected split groundwater samples from monitoring wells installed by MPA.
- **September and October 2010 –** ICON collected split groundwater samples from direct-push water sampling drive points that were installed by MPA.
- **November and December 2014 –** ICON collected split soil samples associated with the partial closure of an unregistered pit located west of the B-Battery.

- **January 2015** – ICON collected sludge and soil samples from hand-augered borings at pits located at the former B-Battery and at the backfilled pit located near the A-Battery. A groundwater sample was collected from a temporary well installed in one of the borings at the B-Battery.
- **November and December 2015** – ICON drilled borings (subcontracted to Guichard Drilling) using mud rotary wash method, performed borehole geophysical logs at each boring location, and installed monitoring wells TBA-1D, TBB-1s and 1D, TBB-2m and 2d, TBB-3s and 3d, MC1 and BC1. Groundwater from the wells was sampled in December 2015.

3.2 METHODOLOGY

3.2.1 Screening Technology – Terrain Conductivity Surveys

The EM-31 surveys were performed using a Geonics EM-31 terrain conductivity meter. The instrument induces an electrical current and measures the conductivity of the shallow subsurface. The instrument utilizes a single transmitter frequency and a fixed coil spacing that results in an effective depth of investigation of approximately 18 feet in the normal mode of operation. The EM-31 induces a current flow within the earth that consists of concentric circles, assuming the conductivity is laterally uniform. Therefore, the rotation of the instrument in a horizontal plane about the transmitter coil as a pivot will produce no change in the meter reading (for example, along a north-south transect, the instrument is pointed east-west). Any change in readings as such is an indication of lateral inhomogeneities in conductivity (slight changes in readings) or interference from surface or shallow buried conductors (large changes in readings). Potential sources of interference (pipelines, metal objects, etc.) were noted in the field notes. Areas with chloride impact show up as positive anomalies when the data are displayed as a grid or contours on a site map. Surveys were performed on land by surveying with the instrument at hip level. Readings were observed while walking, and were logged at specific locations determined using hand-held global positioning system (GPS) receivers. The site was surveyed in March 2006 using this technology.

The EM-31 data and contours are depicted on **Figure 3-1**. The data were used to aid in locating subsequent boring locations. The EM data clearly show high anomalies in areas that were later found to exhibit high salt concentrations (elevated EC, soluble chlorides and Leachate chlorides in soil samples).

3.2.2 Screening Technology – Soil Conductivity Logging

Soil conductivity logs were obtained using a Geoprobe® Soil Conductivity probe. A SC5000 Wenner Array conductivity probe was advanced using a Power Probe hydraulic direct push rig with Geoprobe tooling operated from a barge, and conductivity readings at each boring were logged into a field computer. The log that is generated depicts bulk conductivity in units of mS/m. The probe is calibrated at the factory to several concentrations of fluid conductivity. The probe has a vertical resolution of 0.05 ft, and a sampling rate of 20 samples per second. Prior to use, and several times each day, the probe calibration and continuity/isolation of the contact array was checked using a calibration block. The field computer completes the calibration check automatically, and will not allow use of a contact that does not meet minimum criteria for calibration, continuity or isolation.

In native materials, clays have a relatively high electrical conductivity (generally 200 to 450 mS/m), silts have an intermediate conductivity, and sand/gravel and/or peat and wood zones have a low conductivity (less than 50 mS/m). In soils impacted by brine, the conductivity exceeds values obtained in unimpacted sediments. Thus, the conductivity log is an excellent indicator of brine impact. The conductivity data are obtained at a frequency of one reading per 0.05 foot, and the depth is concurrently measured using a potentiometer (string pot) and concurrently logged onto a field computer. Conductivity logs are plotted and imported onto a soil boring log where log response can be evaluated along with lithological descriptions and laboratory data. Conductivity logs can be viewed on Boring Log Diagrams included in Appendix A, and are depicted on Figure 3-2. As can be seen in **Figure 3-2**, conductivity logs at B15 and B17 exhibited the highest readings at the base of the Peat Zone and within the underlying clay zone (confining layer to the Chicot Aquifer). Conductivity logs at B3, B5 and B18 were also elevated at this depth.

3.2.3 Borehole Geophysical Logging

Any monitor well installation requires knowledge of subsurface lithology and groundwater occurrence to optimize utility of the well. ICON used a Century Logging System mounted in an all-terrain van to log borings drilled using the mud rotary wash method. ICON's logging system is capable of slower logging speeds than are available with most commercial logging services which allows natural gamma logging at variable time constants to optimize detail and to minimize statistical error. Two tools were run (8044A and 9512C) which allowed collection of the following suite of logs:

> ***Natural Gamma*** - The gamma curve responds to radioactivity, and typically will read higher adjacent to clays because of the relatively more abundant Potassium-40 (K-40) radioisotope, particularly in potassium silicate clays. The gamma curve increases counts (deflects to the right) adjacent to clays, and decreases counts (deflects to the left) in clean sands. Thus, the tool is capable of delineating clay lenses as thin as ½ foot. A gamma curve was recorded with each of the tools, one calibrated to an API standard and the other calibrated to a counts-per-second (cps) standard. The gamma curve is able to log in an air-filled boring and can be used through casing. Both gamma curves are displayed in the left track of the log (black and green curves).
>
> ***Single Point Resistance*** - Measures relative resistance of aquifer bulk matrix and groundwater directly at the borehole wall. Resistance generally reads higher (increasing ohms) adjacent to fresh-water bearing permeable zones, and low

(decreasing ohms) adjacent to clay and brackish-water filled permeable zones. This tool provides high resolution, delineating clay lenses as thin as one inch. Single point resistance curves are typically used for lithological correlation. The single point resistance curve is displayed in the right track of the log (blue curve).

Normal Resistivity - Measures resistivity of aquifer bulk matrix and groundwater at a fixed distance beyond the borehole wall, based on electrode spacing. Fresh water sands are highly resistive, and clays and brackish water exhibit low resistivity. Two curves were recorded: a 16-inch short normal (16-inch spacing between a sending and a measuring node), and a 64-inch long normal (64-inch spacing between a sending and a measuring node). The long normal measures resistivity in a zone that extends approximately five feet beyond the borehole wall. This curve provides quantitative measurements. Normal resistivity curves are displayed in the center track of the log (blue curve for 16-inch normal and green curve for the 64-inch normal).

Lateral Resistivity - Measures resistivity of aquifer bulk matrix and groundwater in an asymmetrical geometry around the borehole using three electrodes, a sending electrode and two recording electrodes. The tool is used to read formation resistivity beyond the zone of borehole fluid invasion. The tool has a spacing of 48 inches (between the transmitting and midpoint of the two receiving electrodes). The tool typically reads to a distance in the formation that is similar to the electrode spacing (48 inches), but will only read true resistivity when the formation is more than twice the electrode spacing (bed thickness of 8 feet). For beds thinner than this, the curve response needs to be corrected to use in a quantitative manner. The lateral curve is displayed in the middle track of the log (magenta curve).

Spontaneous Potential - Indicative of clay/sand boundaries and can show grain size fining and coarsening, and can be used to indicate highly permeable zones where borehole fluid is invading the aquifer. The tool measures small electrical potentials, measured in millivolts (mV) that occur when fluids of different salinities are in contact. An electrical potential is produced when permeable formations containing groundwater is invaded by borehole fluid of a different salinity. Impervious formations like clay layers have very little or no borehole fluid invasion, so no SP currents are generated and the SP curve is flat (baseline) adjacent to clay beds. If the borehole fluid has the same salinity as groundwater in permeable formations, no SP current is generated. The magnitude of the SP curve deflection is determined by the ratio of the resistivity of the drilling mud filtrate (Rmf) and the resistivity of the formation water (Rw). SP curves are typically used for lithological correlation and can be used to measure salinity of groundwater. If formation water is more saline than the drilling fluid filtrate, a negative SP curve deflection will result (deflection to the left of the clay baseline); and if formation groundwater is less saline than drilling fluid filtrate, a positive deflection to the right of the clay baseline will result. The SP curve is displayed in the left track of the log (blue curve).

Induction Conductivity - Measures the conductivity of aquifer matrix and groundwater within a zone at 10 to 50 inches away from the borehole walls. The tool uses three coils, one sending coil and two receiving coils with a primary spacing of 20” and an offset of 60 inches. The transmitter coil induces a ground current that moves through the formation as ring shaped loops perpendicular to the borehole. The currents generate a secondary magnetic field that is measured at receiver coils as signals proportional to the conductivity of the formation. The tool is not sensitive to borehole fluid, casing or grouting materials and can be run in air-filled borings or monitoring wells, and can read through PVC well pipe. Apparent resistivity (inverse of conductivity) is commonly displayed in logs through PVC-cased wells. The curve is displayed in the right track of the log (red curve).

3.2.4 Soil and Groundwater Sampling

Subaqueous Sediment and Sludge Sampling

Samples of sediment at the base of canals and in areas of the marsh that were inundated and were obtained in 2006 (SS1 through SS15; and shallow intervals at AB1-4, and AB13-15) were collected using a 2-inch diameter PVC pipe that was pushed to refusal into the basal sediment. Upon reaching total depth, the top of the PVC pipe was capped to create suction to aid in retaining the sample, and the pipe was withdrawn. The pipe with the core sample was located to the bank and the sample was extruded onto clean plastic sheeting where a geologist or engineer described the core, and prepared samples for laboratory analysis. A portion of the core was also placed in a clean ziplock bag and the headspace of the bag was measured using an organic vapor meter (OVM) with a photoionization detector (PID). The pipe was then decontaminated and was prepared to collect samples at the next boring. Multiple sample tubes were used concurrently to aid in sample collection.

Samples of sediment at the base of canals in areas of the marsh that were inundated and were obtained in 2010 (Sed1 through Sed33) were collected using a Russian Peat Borer sampling tool. The tool obtains a two-foot long discrete core sample. The tool was advanced to the desired depth (0-2, 2-4 and 4-6 ft below land surface) in the closed position and was rotated to collect a half-cylinder core sample at multiple spots around a single location (to allow adequate sample volume for laboratory analysis). The core samples were described by a geologist, and were placed in a 5-gallon bucket with dedicated clean trash can liner, where the multiple core samples from a given interval were homogenized and split with a representative from Mike Pisani & Associates, Inc. (MPA).

Soil Sampling

Soil samples from Borings B2-19 in August 2006 were collected using a vibracore sampler with thin-walled aluminum barrels. These samples were collected at the same locations where conductivity probes were previously acquired; locations were referenced using the bank scar created by the conductivity logging barge. Vibracore services were provided by Quaternary Resources, Inc. (QRI). Core samples were located to the bank where a geologist or engineer described the cores and prepared samples for laboratory analysis.

Soil samples from Borings AB1-22 were collected by pushing a split-spoon core barrel ahead of a mud-rotary wash boring. The mud-rotary wash borings used surface water for drilling. The split spoon barrel was pushed to two-feet deeper than the base of the mud rotary boring to collect a representative sample. Core samples were removed from the barrel and were described by an engineer, and were prepared for laboratory analysis.

Laboratory Analysis of Soil Samples

Soil and sediment samples selected for laboratory analysis were placed in appropriate laboratory-supplied containers. Samples for analysis of petroleum constituents were chilled and maintained in an ice chest during shipment to the laboratory.

Soil was analyzed by Sherry Laboratories, Inc, Lafayette, LA (LELAP accredited for all constituents) for one or more of the following constituents:

- Saturated Paste EC (29B)
- Exchangeable Sodium Percentage (29B)
- Sodium Adsorption Ratio (29B)
- Leachate Chlorides (29B)
- Soluble Chorides (SW846 MethodM4500-CL at 1:1 extract)
- Heavy Metals (SW846 Method 6010B)
- TPH-Diesel and TPH-Oil (SW8015B)
- BTEX-TPH-Gasoline (SW8015B)
- Semivolatile Organic Compounds (SW8270C)
- Polychlorinated Biphenyls (PCBs)

Additionally, selected soil samples were analyzed for Radium 226-226 by Eberline Services, Inc.

Because of the high moisture content of sediment and soil samples, all soil sample results were reported on a dry weight basis with the exception of TPH data.

Monitoring Well Installation

Monitoring wells AB1 through AB19 were installed in 2006, wells MW1-3 were installed in March 2010. These monitoring wells were installed in boreholes drilled using a mud-rotary wash rig with surface water drilling fluid. Wells were installed in the boreholes, filter sand was placed around the well screens to a minimum of one foot above the top of the screen, and a bentonite seal was placed above the filter sand (bentonite pellets or crumbles).

Monitoring wells TBA-1D, TBB-1s and 1D, TBB-2m and 2d, TBB-3s and 3d, MC1 and BC1 were installed in 2015 using the mud rotary wash method (contracted to Guichard Drilling) and potable water for drilling fluid (obtained from Broussard Brothers dock). These boreholes were logged using a Century Logging System before wells were installed. Filter sand was placed around the well screens to one to two feet above the top of screen, and a bentonite seal was placed above the filter sand. The wells were grouted to surface using neat cement or a mix of bentonite with Portland cement. The wells were installed through steel surface casings that were pushed to refusal.

Monitoring Well Sampling

Because the wells installed in 2006 and 2010 were installed using surface water drilling fluid, care was taken during well development and sampling to ensure that samples were representative of the formation. Well AB-1 and AB-2 were 2-inch diameter wells; all other wells installed in 2006 and 2010 were ¾-inch diameter wells. Wells installed in 2015 were 2-inch diameter. Field parameters (specific conductance, temperature and pH) were measured during purging. When field parameters stabilized, discharge water was interpreted to be representative of formation conditions.

Purge information by well is as follows:

- AB1 (Chicot Aquifer); purged with Grundfos downhole submersible pump with dedicated tubing; purged 350 gallons prior to sampling. Static head was 0.22 feet below surface water.
- AB2 (Peat Zone): purged 9 gallons with Grundfos downhole pump with dedicated tubing until well purged dry.
- AB3 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; sampled after purging the well dry at 8 gallons.
- AB5 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; sampled after purging 6 gallons.
- AB6 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; total volume pumped not logged.
- AB7 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; sampled after purging 7 gallons.
- AB15 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; sampled after purging 6 gallons.
- AB19 (Peat Zone): purged using peristaltic pump with dedicated downhole tubing; sampled after purging 5 gallons.
- MW1 (Chicot Aquifer); purged with peristaltic pump with dedicated tubing; purged 75 gallons prior to sampling. Static head was 1.19 feet below surface water. Specific conductance of the groundwater discharge was 21,280 uS/cm, specific conductance of the surface water near the well at the time of sampling was 1489 uS/cm.
- MW2 (Chicot Aquifer); purged with peristaltic pump with dedicated tubing; purged 75 gallons prior to sampling. Static head was 1.23 feet below surface water. Specific conductance of the groundwater discharge was 3061 uS/cm, specific conductance of the surface water near the well at the time of sampling was 1391 uS/cm.
- MW3 (Chicot Aquifer); purged with peristaltic pump with dedicated tubing; purged 74 gallons prior to sampling. Static head was 0.1 feet

below surface water. Specific conductance of the groundwater discharge was 22,720 uS/cm, specific conductance of the surface water near the well at the time of sampling was 1709 uS/cm.

Groundwater was analyzed by Sherry Laboratories, Inc. (LELAP accredited for all constituents), Lafayette, LA for one or more of the following:

- Chlorides
- Heavy Metals
- TPH-Diesel and TPH-Oil
- Total Dissolved Solids
- BTEX
- TPH-Gasoline

Groundwater was analyzed by Pace Laboratories, Inc. (LELAP accredited for both tests), for:

- Radium 226
- Radium 228

3.2.5 Quality Assurance / Quality Control

ICON utilized methods to ensure representativeness of soil samples, including:

- The use of split spoon barrels that were pushed to two-feet deeper than the base of the mud rotary boring to collect a representative sample and eliminate the potential for cross contamination.
- Removal of the smear layer on the outside of the core sample in preparing the laboratory soil sample.
- The use of a new pair of disposable gloves to handle each sample increment.

ICON used low-flow micropurge techniques to sample groundwater to minimize the effects of turbidity on groundwater constituents. ICON measured turbidity of groundwater during purging and during sampling activities. A target turbidity goal of 40 NTU was achieved in most cases. Other field parameters measured during the purging and sampling process of the monitoring wells included pH, specific conductance, temperature, dissolved oxygen (DO), and oxygen reduction potential (ORP).

The following Quality Assurance/Quality Control (QA/QC) samples generally included the following:

- One trip blank was included per ice chest containing VOC samples.
- Containers were provided by the contract laboratories and included preservative appropriate for the constituent of concern (HCl for volatile organic compounds and TPH-G; nitric acid for metals and radionuclides).
- One field duplicate groundwater sample per 20 samples and sent to the primary laboratory.

- All samples containers were properly labeled with permanent ink, and maintained on ice in a cooler during transport to the laboratory. All samples were accompanied with a completed chain of custody record.
- Most soil and groundwater samples were split with defendant's consultants and independently sent to a contract laboratory for analysis. The results of the defendant's split data were considered in this report.

All laboratory analyses were performed by certified laboratories holding valid LELAP certification for the tests performed. One blind duplicate groundwater sample (AB6 duplicate labeled as BD-01) was collected during the November 2006 sampling event and one blind duplicate groundwater sample (MW1 duplicate labeled as BD-01) was collected during the March 2010 sampling event. The blind duplicate sample provides an indication of overall precision for field and laboratory methods, and typically exhibits more variability than laboratory duplicates. There are no guidelines regarding data qualification based on poor field duplicate precision, and a target of 70% RPD is often used by data validators. Professional judgment is typically used to qualify results. The relative percent difference (RPD) for the detected constituents are as follows:

- Arsenic: 8.7% (AB6), (ND in both MW1 samples)
- Barium: 0.5% (AB6), 0% (MW1)
- Selenium: 9.5% (MW1), (NA in AB6)
- Strontium: 5.2% (AB6), 0% (MW1)
- Zinc: 94.3% (MW1), (NA in AB6)
- TDS: 14.4% (AB6), 1.6% (MW1)
- Chlorides: 0% (AB6), 0% (MW1)
- TPH-D: 7.9% (AB6), (ND in both MW1 samples)
- TPH-O: 0.6% (AB6), (ND in both MW1 samples)
- Benzene: (ND in both AB6 samples), 3.4% (MW1)

In general the duplicate samples indicated good precision of field and laboratory methods.

SECTION 4.0 ASSESSMENT RESULTS AND COMPARISON TO REMEDIAL STANDARDS

Constituents detected in soil and groundwater samples are summarized on Tables 4-1 through 4-4. Those concentrations that exceed the referenced standard are shaded on the tables.

4.1 SOIL AND SEDIMENT CONTAMINATION

4.1.1 Salt Contamination

Statewide Order 29B has an EC limit of 8 mmhos/cm for pit closure in elevated wetland environments and for onsite development (both methods could be applicable to this property), and an EC of 8 mmhos/cm soil corresponds to a leachate concentration of 642 mg/L, slightly above the 29B regulatory standard of 500 mg/L. An EC of 8 mmhos/cm corresponds to a soluble chloride concentration of approximately 3000 mg/L.

Results of this assessment have identified gross soil contamination in the Peat Zone and the underlying Chicot Aquifer Confining Unit. Groundwater within the Chicot Aquifer is grossly contaminated by salts, at concentrations exceeding 10,000 mg/L. A downward vertical hydraulic gradient from the Peat Zone to the Chicot Aquifer was measured during the 2010 sampling event. As such, the potential for contaminants to continue leaching to the Chicot Aquifer is of concern.

Figures 4-1 and 4-2 depict soil EC concentration on the cross section diagrams, and show:

- The highest soil EC was found in the Peat Zone where concentrations exceeded 50 mmhos/cm south of the A-Battery, and concentrations exceeded 200 mmhos/cm south of the B-Battery. Another pocket of contaminated soil within the Peat Zone was found near the east property line where concentrations exceeded 50 mmhos/cm.
- Soils of the Chicot Aquifer confining unit were contaminated at concentrations exceeding 8 mmhos/cm (indicative of an exceedance of the 29B Leachate Chloride limit) throughout the profile at locations underlying grossly-contaminated soils in the Peat Zone. Groundwater at the top of the CHCTS was contaminated at the highest chloride concentrations (exceeding 10,000 mg/L) at locations corresponding to contaminated soil within the confining unit. These conditions indicate past leaching to underlying groundwater, and likely continued leaching to underlying groundwater.
- Soil EC concentrations in the Peat Zone and in the underlying Chicot Aquifer confining unit at locations distal to this salt contamination are generally below 4 mmhos/cm, supporting the numerous sources cited previously that this area is a fresh water wetland.

Figures 4-3 through 4-7 depict soil EC concentrations in layers, to depict the lateral distribution of salt contamination. Figures 4-3 through 4-6 (0-3 foot, 3-6 foot, 6-10 foot and 10-16 foot depth increments) depict soil EC that generally occurs within the Holocene Peat Zone. General observations show:

- Three significant areas of contamination at land surface (0-3 foot depth increment as depicted on Figure 4-3) with EC greater than 16 mmhos/cm:
    - Area A) south of the A-Battery,
    - Area B) south of the B-battery, and
    - Area C) near the east property line.
- These same three contaminated areas extend to the base of the peat zone as seen in Figures 4-4 (3-6 foot increment), Figure 4-5 (6-10 foot increment) and Figure 4-6 (10-16 foot increment). At these deeper depths, contamination south of the A-Battery segregates into three commingled pockets of elevated EC contamination:
    - The north pocket is likely associated with surface discharges from the A-Battery tanks and possibly discharges from a former pit by the flare.
    - The south pocket is located near SWD #A39, where documentation indicates a surface breach had occurred in 1994.
    - The east pocket is located near SWD #A16, where documentation indicated a leak in surface casing in 1980 and channeling outside the conductor casing into the canal.
- As seen in Figure 4-7 (16-24 foot increment), these same three contaminated areas extend downward into the Pleistocene Chicot Aquifer confining clay. Contamination in Figure 4-7 at concentrations exceeding 8 mmhos/cm represents sources for continued leaching into the underlying aquifer.
- In Figures 4-3 through 4-7, soil EC less than 4 mmhos/cm is seen at locations distal to the center of the East White Lake oilfield.

4.1.2 Petroleum Hydrocarbon Contamination in Sediment and Soils

Figure 4-8 depicts the lateral extent of soil and sediment contaminated with petroleum hydrocarbons in the diesel range. Much of the canal sediment surrounding the “A” Battery area exhibited TPH-D within the 100-500 mg/kg concentration range. The highest concentrations of TPH-D were detected in soils/sediment in areas between the canals located southeast and behind the “A” Battery, behind the “B” Battery, and at Area C near the east property line. The very high TPH concentrations at Sed15 were associated with the former pit in that area, and some of the TPH-D contamination was removed by UNOCAL in 2014, but much remains around the excavation area. A substantial sheen is created on the canal surface by simply beaching a boat in this area. For the most part, soil contaminated with TPH-D was limited to the upper 6 feet bls of the soil profile. Six feet of oily sludge was encountered at Sed7 at the base of the canal near the compressors located east of the office. The deepest TPH-D contamination was observed at Sed21 by SWD#A16, and may be associated with the 1980 surface breach.

Figure 4-9 depicts the lateral extent of soil and sediment contaminated with petroleum hydrocarbons in the oil range. The distribution of TPH-O is very similar to the distribution of TPH-D. Table 4-2 provides results of laboratory analysis of specific semivolatile organic compounds - PAH list analyzed using EPA Method 8270. PAH compounds were detected above the NOAA SQRT comparative standard and/or the RECAP Soil$_{ni}$ standard for the soil sample that exceeded 1770 mg/kg as TPH-D. Those PAHs were not detected in 10 samples that exhibited TPH-D of less than 412 mg/kg. The data are insufficient to predict the TPH-D concentration that would result in an exceedance of the PAH standards, but a conservative assumption would use a TPH-D concentration of 500 mg/kg for the possible exceedance of a PAH standard listed in the NOAA SQRT tables.

Figure 4-10 depicts exceedances of the 29B Oil & Grease limit in soil and sediment. Much of the samples collected before 2014 were analyzed for TPH-D and TPH-O by method SW8015B, but were not analyzed for 29B Oil & Grease. Many of these earlier samples exhibited high levels of TPH-D and/or TPH-O. Thus, Figure 4-10 likely underestimates 29B Oil & Grease exceedances. Exceedances were found:

- In canal sediment near the compressors
- In a former pit area east of the compressors
- Behind the A-Battery
- Southwest of the A-Battery at a former pit located west of the canal, and at a former pit near the flare east of the canal. Documentation shows that there were two pits associated with the A Battery. One pit was registered (UIC pit ID 57p235) and was located southwest of the A Battery on the west bank of the canal. I have not seen any pit closure documentation associated with this pit; only a single page from a laboratory report described a post-closure sample collected from a depth of 0-4 feet deep, with very low constituent concentrations reported. One of the pits was documented to have been condemned in 1987 due to seepage at the base of the levee [C4074021_0068662]. Historical aerial photography suggests this pit was closed in the late 1980's. The post-closure sample data is not likely representative of closed pit conditions because the sample depth is likely inadequate to be representative of site conditions. No registration information could be found for the pit on the east side of the canal. A Newpark closure document indicated pit sludges with Oil & Grease of 15% and EC of 150 mmhos/cm; pit levees with Oil & Grease of 4.7% and EC of 11 mmhos/cm; and natural soil (collected in canal bottom and west bank of canal west of the pit) with Oil & Grease of 0.58% and EC of 12 mmhos/cm [C4074021_0031641 - 31675]. This data indicates that pit levees were contaminated and surrounding soils were impacted with petroleum hydrocarbons and salts. Pit sludges from one of these two pits were pumped into the VPSB A#3 well during abandonment. It is likely that pit levees remained because of difficulty forming a pumpable slurry.
- Exceedances of 29B Oil & Grease remain in soils around the pit UNOCAL excavated in 2014.

- A 13-foot thickness of soil exceeding the 29B Oil & Grease limit was found and is likely associated with an unregistered former pit located south of the B-Battery.

4.1.3 Heavy Metals Contamination in Sediment and Soils

Figures 4-11 and 4-12 depict the lateral extent of soil and sediment exceeding the arsenic comparative standard. Much of the sediment and intermediate depth soils exceeded the NOAA SQRT standard of 5.9 mg/kg. Figure 4-11 depicts data for the 0-6 foot depth increment, and shows seven distinct pockets of soil that exceeded the 29B standard of 10 mg/kg and/or the RECAP screening standard of 12 mg/kg. It is noted that the NOAA SQRT standard for arsenic was also exceeded just south of the former production area at AB1 through AB4; these borings also exhibited elevated salt constituents in soil in the upper six feet that could be related to produced water discharge that are thus not believed to represent background conditions. Figure 4-12 depicts data for the 6-12 foot depth increment, and shows and additional three distinct pockets of soil that exceeded the 29B standard of 10 mg/kg and/or the RECAP screening standard of 12 mg/kg at depth, but not in shallower intervals. The source of elevated arsenic in these deeper intervals is not known. It is noted that this deeper arsenic contamination is not addressed in the remediation plan, but could be addressed using excavation at a unit cost based on the remediation plan contained herein. For the most part, the lateral extent of arsenic has been delineated onsite.

Figure 4-13 depicts the lateral extent of soil and sediment exceeding the barium comparative standard. Barium appears to be less associated with the production facilities and appears to be prevalent in certain canals and is likely related to discharge of drilling fluid associated with wells in those canals.

Figure 4-14 depicts the lateral extent of soil and sediment exceeding the comparative standard for mercury. The distribution of mercury in sediment and soil clearly indicates a source associated with the meter at the LACT unit located north of the canal from the A-Battery, where concentrations in canal sediment exceeded the 29B limit of 10 mg/kg. Elevated concentrations also indicate a source at the “A” Battery and “B” Battery facilities. Subsequent sampling at the same general locations resulted in considerable variability in sample concentrations, suggesting that the source of mercury likely exists in elemental forms in dispersed globules. Figure 4-15 shows the results of mercury detected in surface water samples and shows that elevated mercury concentrations in soil coincides with areas where mercury was detected in surface water. This correlation suggests that mercury-contaminated soil represents a source for dissolution into surface waters, and is of ecological concern for food-chain species.

4.1.4 PCB Contamination in Sediment and Soils

Six soil and/or sediment samples were analyzed for PCBs, and one sample (Sed7 at 4-6 ft) exhibited Araclor 1254 at a concentration of 204 ug/kg (0.204 mg/kg). This result exceeds the RECAP Soilni screening standard of 0.11 mg/kg. Sed7 was collected in the canal slip behind the compressor building.

4.2 GROUNDWATER CONTAMINATION

4.2.1 Groundwater Contamination in the Peat Zone

Groundwater within the Peat Zone exceeded RECAP screening standards for arsenic, barium, TDS, chlorides, TPH-D, TPH-O and Radium 226-228. Because the zone is likely a GW3 ndw classification, constituent concentrations were compared to the RECAP Table 3 MO-1 RS for a GW3ndw. **Figure 4-18** depicts groundwater chloride concentrations in the Peat Zone and **Figure 4-24** depicts groundwater barium in the Peat Zone. Both figures show the highest concentrations south of the "A" Battery.

Constituents of concern considering the Peat Zone to be classified as a $GW3_{ndw}$ include chlorides and Radium 226-228. Chloride concentrations as high as 14,400 mg/L were detected in groundwater in the Peat Zone. Generally, groundwater concentrations correlated to the same geographic locations of gross soil salt contamination.

4.2.2 Groundwater Contamination in the Chicot Aquifer Shallow Sand Unit (CHCTS)

Constituents detected in groundwater samples from the CHCTS monitoring wells at concentrations that exceed calculated background concentrations include arsenic, barium, chromium, lead, strontium, zinc, TDS, chlorides, benzene, toluene, TPH-Diesel, TPH-Oil, and Radium 226-228.

Constituents detected in groundwater samples from the Chicot Aquifer monitoring wells at concentrations that exceed appropriate USEPA maximum contaminant levels (MCLs) and/or RECAP remedial standards include arsenic, barium, lead, selenium, strontium, TDS, chlorides, benzene, TPH-Diesel, and Radium 226-228.

Chlorides

Figure 4-19 depicts groundwater chloride concentrations at the top of the CHCTS, for wells screened at depths between 33 and 60 feet bls. This zone is characterized by finer grain size and discontinuous clay beds, and was likely deposited as a fluvial meander of the ancestral Mississippi River. Figure 4-20 depicts groundwater chloride concentrations for wells screened between depths of 33 to 60 feet in the CHCTS, where the aquifer is comprised of massive fine to medium grained sand. These two figures show:

- The highest concentrations at the top of the aquifer (10,700 mg/L by the SWD#A39 breach in 1994, and 13,400 mg/L at the former pit west of the B-Battery) occur in very close proximity to the area of highest soil EC contamination in the clay confining unit (Figure 4-7). Groundwater exceeding 1000 mg/L of chloride at the top of the aquifer comprises a surface area of 261.6 acres. The lateral extent to the calculated background chloride concentration of 487 mg/L has not been delineated, and appears to extend offsite. A second plume of chlorides exceeding 1000 mg/L was detected at the abandoned Crouch water supply at the northeast corner of the property, and is believed associated with contamination at the offsite UNOCAL shore based scrubber facility, where two pits were located. This facility is considered the source of contamination at the Crouch well because:
    - The facility released 1700 bbls of distillate in 1964;
    - The 1979 historical aerial image shows salt scarring on the north bank of Schooner Bayou extending from the scrubber facility to the Crouch camp;
    - And recent soil sampling in this area confirms salt contamination to soils near the scrubber facility.

  This second chloride plume is not considered in the remedial plan at this time. However, the cost to remediate this contamination would likely be similar to a unit cost developed from the plan herein.
- Groundwater chlorides in the massive sand at depths of 60-95 feet exhibits the highest concentrations at the same locations, but concentrations are an order of magnitude lower. Groundwater exceeding 1000 mg/L of chloride at a depth of 60-95 feet in the aquifer comprises a surface area of 49.3 acres. The lateral extent to the calculated background chloride concentration of 487 mg/L has been delineated to the south, and was closely approached at MW6i to the northwest (where chlorides were 550 mg/L), but has not been delineated to the east or north. Additional delineation testing is ongoing.
- A dilution model was applied to the measured concentration of chlorides in the CHCTS between 33 and 95 feet, assuming a produced water chloride concentration of 70,000 mg/L (average as determined from onsite produced water analyses), and the measured size of the concentration contours on Figures 4-19 and 4-20. As shown on Table 4-7, just considering contamination to 1000 mg/L, the chloride concentrations indicate that 827,172 bbls of produced water have reached the CHCTS, and this volume would increase considering the additional volume present between background concentrations of 487 mg/L and 1000 mg/L.

Figures 4-22 and 4-23 depict groundwater chloride concentrations on the cross section diagrams. Figure 4-22 shows the CHCTS to the base of the aquifer at 275 feet bls. Groundwater chlorides at MC1, screened at a depth of 181 feet bls in this aquifer, exhibits chlorides of 769 mg/L, higher than the calculated background concentration of 487 mg/L. The induction log response is shaded red on this figure, and an increase in induction log generally occurs adjacent to the presence of salt water. An increase in induction response is seen for BC1 at the base of the CHCTS at 275 to 300 feet; a well needed to confirm the presence of elevated chlorides has not yet been installed at this horizon at this location.

Barium

Figures 4-25 (33-60 feet bls), 4-26 (60-95 feet bls), and 4-27 (95-200 feet bls) depicts groundwater barium concentrations in the CHCTS. Groundwater barium concentrations exceed the calculated background concentration of 1.03 mg/L over a broad area that corresponds to the area of elevated chlorides. Three pockets within the background exceedance area have concentrations in excess of the drinking water standard (2 mg/L). Barium in groundwater was 1.55 mg/L at well MC1, screened at 161-181 feet bls, exceeding the calculated background limit.

Benzene

Figures 4-28 (33-60 feet bls) and 4-29 (60-95 feet bls) depict groundwater benzene concentrations in the CHCTS. Groundwater benzene concentrations exceed the calculated background concentration and the MCL of 5 ug/L at two areas:

- Near the location of SWD#A16, where a surface breach was documented in 1980;
- At the former pit located west of the B-Battery

The maximum detected concentration of benzene was 30 ug/L at MW1. As shown in Figure 4-29, benzene was not detected in the massive sand of the CHCTS between 60 and 275 feet bls.

TPH-Diesel

Figures 4-30 (33-60 feet bls) and 4-31 (60-95 feet bls) depict groundwater TPH-D concentrations in the CHCTS. The distribution of TPH-D at the top of the aquifer at 33-60 feet bls is very different as compared to the massive sand at 60-95 feet bls. Groundwater TPH-D concentrations exceed the calculated background concentration of 0.14 ug/L at two areas at the top of the aquifer between 33 and 60 feet bls, at:

- At SB1 near the location of SWD#A16, where a surface breach was documented in 1980;
- At MPA03T near SWD#A39 where a surface breach was documented in 1994.

The concentrations did not exceed the RECAP MO1 remedial standard at either of these two locations at the top of the CHCTS. Groundwater TPH-D concentrations exceed the calculated background concentration of 0.14 ug/L at one area at the 60 to 95 foot depth of the CHCTS, at TBB3D located at the former B-Battery. The TPH-D concentrations are considerably higher at this depth as compared to the top of the aquifer, suggesting that the source of contamination is a subsurface source, such as a leaking well casing. The concentrations at the 60 to 95 foot depth exceed the RECAP MO1 remedial standard of 0.34 mg/L over a broad area.

Strontium

Figures 4-32 (33-60 feet bls) and 4-33 (60-95 feet bls) depict groundwater strontium concentrations in the CHCTS. Groundwater strontium concentrations exceed the calculated background concentration of 0.88 mg/L over a broad area that corresponds to the area of elevated barium and chlorides. Two pockets within the background exceedance area exceed the USEPA Lifetime Health Advisory Level of 4 mg/L. Strontium in groundwater was 1.27 mg/L at well MC1, screened at 161-181 feet bls, exceeding the calculated background limit.

Radium

Figures 4-34 (33-60 feet bls) and 4-35 (60-95 feet bls) depict groundwater Radium 226-228 concentrations in the CHCTS. Groundwater strontium concentrations exceed the calculated background concentration of 2.42 pCi/L over a broad area that corresponds to the area of elevated barium and chlorides. A large area at the top of the CHCTS at 33 to 60 feet bls exceeds the USEPA MCL of 5 pCi/L, with the highest detected concentration of 23.5 pCi/L. It is reported that the solubility of radium increases with salt content of the water. A large area of groundwater at the 60-95 foot depth of the CHCTS exceeds background concentrations, and two areas within the background exceedance area had Radium 226-228 above the USEPA MCL of 5 pCi/L. Data for wells at the B-Battery and at deeper portions of the CHCTS were pending at the date of this report.

4.2.3 Groundwater Contamination in the Chicot Aquifer Upper Sand Unit (CHCTU)

ICON sampled the water supply well for the field in 2006 and 2010. Laboratory results of sampling of this well were available in historical permit applications for SWD wells. The applications indicated that the water supply well is completed to a depth of 460 feet bls. Historical chloride concentrations indicate increasing concentrations through time as follows:

- 1983: 12 mg/L (SWD permit application, UNOCAL exhibit 122.005)
- 1995: 84 mg/L (SWD permit application, Resource Acquisition)
- 2006: 170 mg/L (ICON sample)
- 2010: 192 mg/L and 195 mg/L (ICON and MPA samples)

The apparent increase in chloride concentration in the water well may be indicative of a release to the CHCTU from three potential sources:

- Faulty well construction at SWD #30 that was located near the water supply well. The DNR review of the permit application for SWD #43 Area of Review flagged a well near this water supply to have insufficient casing to protect the USDW (well sn89035). This problem well was a former producer that was converted to SWD in April 1974 and was plugged in 1981. The well file for sn89035 shows that the 5-1/2" casing was perforated at 1041-43 feet for a block squeeze as part of the conversion to SWD status. A potential leak in the 5-1/2" casing above this squeeze zone could enter the CHCTU at a depth of 820 feet to 650 feet bls at the base of the 10-3/4" casing. This is the same portion of the CHCTU where the water well is screened.
- SWD A#38 was drilled in 1982 at a location approximately 400 feet from this water supply well. During drilling through surface pipe set at a depth of 228 feet,

the rig stuck drill pipe at a depth of 1867 feet. UNOCAL attempted to fish the stuck pipe for twelve days with no success. The well was abandoned with stuck pipe by placing a cement plug from 221 feet to 20 feet below land surface; thus the borehole remains open (un-cemented) in the interval from 221 feet to 1867 feet below land surface. This condition could result in hydraulic communication between deeper saline and brackish reservoirs and shallower fresh water aquifers (the top of the CHCTU occurs at 425 feet bls, and the base of the CHCTS occurs at 275 feet bls).

- A breach was documented at SWD A#39. Documents show that on November 15, 1994, gas was detected in the freshwater system. Gas monitoring was performed to determine if concentrations were hazardous in the living quarters, and the conclusion was no explosive conditions. Another document stated that SWD A39 had pressure on the casing on November 11, 1994, and that the casing had surface seepage for the previous 7 days. Documents show that on December 3, 1994, SWD #A39 had tubing to casing communication, and casing was leaking at the surface. The well was shut in and tubing and casing pressures dropped to zero. The next day, pressures were still zero, but the casing was again leaking. Injection resumed from 7am to noon, and casing did not pressure up nor leak. After the pump disengaged, tubing and casing pressure were zero, but casing was again leaking. Casing intermittently leaked until the injection well was shut in on December 5. On December 3, the freshwater well (located 1000 feet north of SWD #A39) was making gas, and sand was observed in the kitchen sink and sewage trap. WW1 is the source of freshwater for the living quarters.

SECTION 5 FEASIBLE PLAN

5.1 REMEDIATION FEASIBILITY STUDY

5.1.1 Remedial Goals

A feasibility study of remedial alternatives was performed within the framework of Title 43.XIX.Chapter 6. Criteria for a plan acceptable to the Office of Conservation are listed in LAC 43:XIX.603, wherein a Feasible Plan is defined as follows:

- (LAC 43.XIX.603.A.) Feasible Plan – the most reasonable plan which addresses environmental damage in conformity with the requirement of Louisiana Constitution Article IX, Section 1 to protect the environment, public health, safety and welfare, and is in compliance with the specific relevant and applicable standards and regulations promulgated by a state agency in accordance with the Administrative Procedure Act in effect at the time of cleanup to remediate contamination resulting from oilfield or E&P operations or waste.

Therefore a plan must meet 29B criteria or appropriate criteria of another Louisiana Agency, must be in compliance with specific relevant and applicable standards, and is reasonable. Title 43.XIX does not define “reasonable”. The EPA guidance for conducting remedial investigations and feasibility studies suggests a plan that meets remedial action objectives be evaluated for effectiveness (how proven and reliable the process is); implementability (ability to perform the option including permitting); and cost.

The assessment has identified two contaminated media that will be the focus of this evaluation:

- Contaminated subaqueous sediment and shallow soils that represent a potentially complete pathway for ecological and human exposure. The estimated lateral extent of such contaminated sediment and soil is depicted on Figures 4-16 (Statewide Order 29B exceedances) and 4-17 (Exceedance of Ecological Standards).
- Contaminated subsurface soils that represent a source for leaching of salts to the underlying Chicot Aquifer. The estimated lateral extent of such contaminated soil that exhibits salt contamination at concentrations above the 29B Chloride Leachate standard is depicted on Figure 4-7.
- Contaminated groundwater exists in the Peat Zone. The primary constituent of concern is chlorides, because of the leaching threat to surface waters and to the underlying CHCTS. A simple groundwater flow model (Hooghoudt-Donnan algorithm for flow to drains) was employed to evaluate the feasibility of removing contaminated water from the Peat Zone. Hydraulic conductivity was not measured, but publications suggest a hydraulic conductivity of $1x10^{-4}$ cm/sec/ 0.28 ft/day (*Hydraulic Properties of South Florida Wetland Peats, Thesis for University of Florida, Raleigh Myers, 1999*). The model showed that the most

efficient extraction would result in two trenches installed at the base of the peat zone, each approximately 875 feet long, and would result in a total flow capacity of 192 gallons per day. Because of this low yield, groundwater contamination in the Peat Zone will be addressed as soil contamination.

- Contaminated groundwater that exists within the CHCTS. The estimated lateral extent of contaminated Chicot groundwater is depicted on Figures 5-4, 5-5 and 5-6.

5.1.2 Considered Options

5.1.2.1 No Action

This option was rejected because it fails to meet the minimum standards of LAC 43.XIX, in that environmental standards are not met, and a USDW is currently contaminated. Additionally, potential exposure to contaminated subaqueous sediment in the canals and shallow soils is a concern.

5.1.2.2 Monitored Natural Attenuation

This option was rejected because it fails to meet the minimum standards of LAC 43.XIX, in that environmental standards are not met, and a USDW is currently contaminated. Current state regulations specific to Monitored Natural Attenuation (MNA) are listed in 2.16 of LDEQ Risk Evaluation and Corrective Action Program (RECAP). Criteria listed there include:

- MNA should be selected only where it can meet all of the remedial goals for the site, and where it can obtain those goals in an appropriate timeframe.
- It should be evaluated and compared to other remedial processes to determine which is most appropriate.
- To ensure timeframe estimates are comparable, the assumptions used in each treatment proposal are to be consistent with OSWER Directive Number 9200.4-17P.

Referring to the OSWER Directive, it is stated that:

- MNA will be an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a timeframe that is reasonable compared to other alternatives.
- At some sites, geochemical conditions and processes can chemically transform naturally occurring minerals (arsenic) in the aquifer matrix to forms that are more mobile and/or more toxic than the original materials. A comprehensive assessment should include evaluation of whether naturally occurring metals will become contaminants of concern.

It is clear that MNA cannot meet regulatory standards. Groundwater in the CHCTS is contaminated and the aquifer is used for water supply. It is too late to entertain this option because the source to be protected is already contaminated. Additionally, the Chicot Confining Unit is contaminated with salts at concentrations that exceed the leachability standard, indicating that a contaminant source available for continued leaching of contamination to the aquifer exists.

5.1.2.3 Source Removal

Excavation of contaminated sediment and soil represents an option that meets regulatory criteria, and is implementable within a reasonable timeframe. Excavation and offsite disposal is an effective option for contaminated shallow soil and subaqueous sediment at the base of canals. Excavation, followed by dewatering for volume reduction with offsite disposal represents the most viable alternative to eliminate the long-term exposure of humans and ecological receptors to this shallow contamination. Costs for implementing this scenario were evaluated and are addressed in Section 5.3 of this report.

Excavation of contaminated subsurface soils in the Peat Zone and in the Chicot Confining Unit that represent a leaching threat to underlying aquifers is not deemed to be feasible. Excavation of salt contamination to prevent future leaching to the Chicot Aquifer would have to be performed in a flooded excavation to counteract potential hydraulic basal heave that would cause a dry excavation to fail. Additionally, removal of such contamination by excavation would result in compromising the confining unit to the Chicot Aquifer and would create a potential hydraulic connection between surface water and the aquifer.

5.1.2.4 Groundwater Extraction, Treatment and Disposal

Groundwater in the CHCTS is contaminated above background constituent concentrations and above the EPA MCLs applicable to a drinking water aquifer. Source removal of the dissolved contaminant mass in groundwater via groundwater pumping is a viable and effective technique. Groundwater pumping accomplishes two tasks:

- Removal of contaminant mass to restore the aquifer to its intended use.
- Hydraulic control of migrating groundwater plumes to prevent further contamination of the groundwater resource.

This remedial option was selected based on the ability to meet remedial objectives, restore the aquifer to within regulatory standards, and the ability to accomplish the remedial objectives within a reasonable timeframe. Costs for implementing this scenario were evaluated and are addressed in Section 5.4 of this report.

5.1.2.5 Physical Containment

Containment via slurry walls or cutoff trenches, and capping are viable processes to prevent cross-media transfer of contamination, such as soil leaching contaminants to groundwater. The CHCTS is currently contaminated, indicating that leaching of COCs from overlying soils has, and likely will continue to occur. Although this option fails to meet the minimum standards of LAC 43.XIX, in that environmental standards are not met, and a USDW is currently contaminated, it was considered because it represents a viable alternative to mitigate future leaching to the aquifer. The 29B regulations allow an exception to meeting closure standards listed in Chapter 3 provided the responsible party can demonstrate that leaving the residual contamination will not pose a threat to the USDW. Barrier walls (grout curtain) and a grout floor beneath the contaminated soil in the confining unit would be required to mitigate a threat to future leaching of salts into the underlying USDW (the CHCTS). Costs for implementing this scenario were evaluated and are addressed in Section 5.3 of this report.

5.2 CONTAMINATED SEDIMENT AND SOIL EXCAVATION AND OFFSITE DISPOSAL

This remedial option was selected to remediate:

- All of the contaminated subaqueous sediment at the base of canals. Current potential exposure of this contamination to human and ecological receptors is occurring. Contamination includes 29B regulatory exceedances of the arsenic, mercury, and Oil & Grease standards; exceedances of the DEQ RECAP Soilni limiting standards for arsenic, barium, lead, mercury, TPH-D, TPH-O and/or PCBs; and exceedances of the NOAA SQRT TELs for arsenic, barium, cadmium, chromium, lead, and mercury. In many areas, the subaqueous sediment in the canals exhibited very high levels of salt.
- Areas of freshwater marshland that exist between the canals that are contaminated with arsenic, mercury, TPH-D, TPH-O and/or high levels of salts and Oil & Grease that exceed the 29B standards. This contaminated shallow soil represents a potential exposure threat to human and ecological receptors.

This option considers engineering and permitting issues associated with removal of basal sediment in canals, dewatering and volume reduction of recovered sediment, and offsite disposal of solids at a commercial E&P facility. This scenario is based on the assumption that after remediation, the canals and remediation areas between canals will be 2 to 4 feet lower than current elevation and will exist as open water; the costs do not include dams or weirs that may be needed to prevent tidal and boat wake erosion of shorelines. Current production facilities and activities were considered, and assumes new flowlines will be installed to the separator/tank battery facility from existing wells, if needed. This scope of work is very similar in scope to that proposed in a coastal use permit filed by UNOCAL in 1985 (CUP 19850116) for deepening all oilfield canals in East White Lake Field (45,600 linear feet and 456,000 yd^3), but this plan anticipates offsite disposal of contaminated sediments instead of stockpiling in spoil banks as proposed by UNOCAL. In the permit, UNOCAL stated that stockpiling in spoil banks would impact 91.7 acres of wetlands and 44.9 acres of non-wetlands. This permit application by UNOCAL further supports the landowner’s opinion that all areas of this field are not submerged wetlands.

The estimated lateral extent of such contaminated sediment and soil is depicted on Figures 4-16 (Statewide Order 29B exceedances) and 4-17 (Exceedances of Ecological Standards). All subaqueous sediment at the base of the canals designated for removal will excavated using a marsh excavator with clam bucket. This will require damming the canal at the downstream side to prevent turbid water from leaving the excavation area. The removed material will be dumped into a hopper where enough surface water will be added to slurry the material through a pipeline to a receiving barge that will be located on Schooner Bayou Canal. At this point, the material will be dewatered and the solid material will be transferred to a hopper barge for transport to the US Liquids Mermentau commercial E&P facility.

5.2.1 General Plan for Excavation of Canal Sediment and Soil

All subaqueous sediment at the base of the canals designated for removal will excavated using a marsh excavator with clam bucket. This will require damming the canal at the downstream side to prevent turbid water from leaving the excavation area. The removed material will be dumped into a hopper where enough surface water will be added to slurry the material through a pipeline to a receiving barge that will be located on Schooner Bayou Canal. At this point, the material will be dewatered and the solid material will be transferred to a hopper barge for transport to the US Liquids Mermentau commercial E&P facility

The general plan for excavation of contamination at the base of the canals and in the designated areas between canals is as follows:

- Prepare the final construction design and permitting. Permitting will include stormwater and wastewater discharge permitting with the LDEQ; and notification to the US Corps of Engineers for the remediation project. It is anticipated that the project will fall under jurisdiction of the Nationwide Permit process (Federal Register, Vol 72, No. 47, March 12, 2007). This activity appears to fall under Item 38 *"Cleanup of Hazardous and Toxic Waste" and includes "specific activities required to effect the containment, stabilization, or removal of hazardous or toxic waste materials that are performed, ordered, or sponsored by a government agency with established legal or regulatory authority. Court ordered remedial action plans or related settlements are also authorized by this NWP". The permittee must submit a pre-construction notification to the district engineer prior to commencing that activity, in accordance with general condition 27.* General Condition 27 is Pre-Construction Notification must include a project description, and be sufficiently detailed to determine that the adverse effects of the project will be minimal and to determine the need for compensatory mitigation, must include a wetlands delineation, a list of designated critical habitat. Cost estimates in this feasibility study do not include purchase of mitigation acreage.
- Sediment and shallow soil excavation will be performed using clamshell bucket excavator and will proceed by areas, such that a given area will be completed and isolated from the surrounding marsh (temporary silt curtain) before proceeding to the next designated excavation area.
- Excavated material will be temporarily stored in hoppers until transfer to hopper barge for dewatering. A project design excavation rate of 8 cubic yards per minute was used in estimating costs for this portion of the project.
- Mechanical dewatering of the excavated material will be accomplished using a barge mounted unit, having a design feed rate of approximately 1500 gallons per minute (gpm) of slurry. It is estimated that approximately 40-50% of the slurry feed volume will be discharged as dry solids. Discharge water from the process will be routed to holding barges for settling, and then routed through the water treatment train that is designed for the groundwater remediation portion of the

project; groundwater remediation will commence upon completion of the excavation.

- Dewatered solid material will be loaded into one or more 1500-bbl barges until at capacity, and then will be transported to US Liquids Mermentau, Louisiana facility for land treatment.
- Upon completion of excavation, approximately 250 confirmation samples of sediment will be collected.

The projected duration of this phase of the project is 60 days.

5.2.2 Estimated Cost for Excavation and Disposal of Contaminated Sediment and Soil

Excavation and dewatering unit costs and production rates were obtained from Javeler Construction in New Iberia, LA. Transportation and disposal costs were estimated based on the waste being classified as Exploration and Production Waste (E&P Waste). The cost estimate for soil remediation is based on transportation and disposal at a US Liquids Facility in Mermentau, LA. A disposal cost of $12.50 per barrel was provided by US Liquids for this remediation project. Barge transportation costs were obtained from Central Boat Rentals, based on a cost per barrel volume.

Estimated costs for completing excavation, dewatering, and disposal of all contaminated canal sediment and shallow soil that exceed Statewide Order 29B Standards total **$5,612,171**. Estimated costs for completing excavation, dewatering, and disposal of all additional contaminated canal sediment and shallow soil that exceed Ecological Standards are total **$32,228,191**. Estimated costs are itemized on tables in **Appendix F**.

Costs for management of discharge water from the mechanical dewatering process considers two options based on unit rates derived from groundwater remediation estimates for this project. A unit rate of $1.26 per barrel was derived for RO treatment with volume reduction and offsite disposal of concentrated wastewater (approximately 30% of the feed volume) at a commercial facility (R360 Mermentau). A unit rate of $0.42 per barrel was derived considering RO treatment and volume reduction with injection of concentrated wastewater into an onsite saltwater disposal well (SWD). The VPSB has made it clear that the use of an onsite SWD for purposes of injecting contaminated groundwater will not be allowed absent their approval, which has not been obtained at this time. In addition, the use of a SWD for such purposes would only be recommended if the operation of the well was under the control of the VPSB contractor. Comparative costs for offsite disposal and onsite injection of discharge water associated with dewatering of soil and sediment were developed and are itemized on tables in **Appendix F**.

The following table summarizes the costs associated with remediation of canal sediment and shallow soil by excavation and offsite disposal:

REMEDIATION OF CANAL SEDIMENT AND SHALLOW SOIL

	Remediate Soil that Exceeds 29B Limits	Remediate Additional Soil that Exceeds Ecological Risk Standards
Volume of Contamination (yd^3)	52,444	303,424
Excavation and Offsite Disposal	$5,612,171	$32,228,191
Volume Reduction and Offsite Disposal of Discharge From Dewatering	$253,010	$1,463,819
Volume Reduction and Onsite Injection into SWD of Discharge From Dewatering	$84,337	$487,940
TOTAL (with offsite disposal of discharge water)	**$5,865,181**	**$33,692,010**
TOTAL (with onsite injection of discharge water)	**$5,696,508**	**$32,716,131**

Additional cost calculations and the basis for assumptions in the cost estimate are included in **Appendix F**.

5.3 PHYSICAL CONTAINMENT OF SALT-CONTAMINATED SOILS

The estimated lateral extent of soil salt contamination at concentrations above the 29B Chloride Leachate standard within the Chicot Confining clay is depicted on **Figure 5-1**. These soils represent a source for leaching to the underlying CHCTS and will be contained using a combination of a slurry wall and grout floor. This will require jet grouting of the slurry wall around the perimeter of contamination shown on Figure 2-2 to prevent lateral migration, and subsurface injection of the grout floor throughout the areal extent of contamination to prevent vertical migration.

This option will involve installing a grout curtain slurry wall to an average depth of 15 feet below land surface around the perimeter of the two areas on Figure 5-1 that exhibit salt contamination at concentrations significantly higher than the 29B chloride leachate standard. The slurry wall will be installed using the jet grout method at closely spaced injection zones around the perimeter of contamination. Costs for jet grout slurry wall installation were obtained from Hayward Baker and it is anticipated that Hayward Baker will be contracted to complete this phase of the project. Hayward Baker is the largest geotechnical contractor in North America and has over 60 years of experience performing over 40,000 geotechnical projects involving jet grouting, such as foundation rehabilitation, soil stabilization, sinkhole remediation and groundwater control in various environmental settings.

A grout floor will be injected at the base of the Peat Zone to an average depth of 15 feet bls through 1-inch carbon steel pipes driven with a hydraulic probe and hammer rig mounted on an airboat. Injection points will occur at a 10-foot spacing with the objective of a 2-foot thick blanket at the base of soil contamination. At the center of these contaminated areas (as depicted on Figure 5-1), salt contamination was found to have penetrated well below the Peat Layer to the base of the Chicot Aquifer confining unit. At these three center areas, the grout floor will be injected to a depth of 35 feet bls, which is approximately 5 feet above the top of the Chicot Aquifer. ICON personnel have experience with jet grouting using these procedures to eliminate seepage into excavations and to seal zones of levee leakage.

5.3.1 General Plan for Containment of Salt-Contaminated Soil

- Slurry walls will be installed to an approximate depth of 15 feet along the perimeter of the plumes impacting the peat zone (Figure 2-2). Slurry construction will consist of a cement-bentonite grout, installed through closely spaced injection points using a rig mounted jet grout drill. It is anticipated that the injection rig will be mounted on an airboat, and a remote continuous feed cement mixing hopper will pump the grout to the injection rig.
- An approximate 2-foot thick cement/gel grout floor will be installed in the confining unit beneath each of the salt impacted soil plumes on Figure 2-2. The grout floors will be injected at the base of the Peat Zone (average depth of ~15

feet bls) through 1-inch carbon steel pipes driven with a hydraulic probe and hammer rig that is mounted on an airboat. Injection points will be installed at 10-foot spacing to the base of contamination. ICON personnel have experience with injecting grout into clay-rich subsurface soils, and this experience has determined that a 10-foot spacing will likely be sufficient to ensure overlap of the grout floor. In areas where salt contamination was found to have penetrated below the Peat Layer into the Chicot Aquifer confining unit (three center areas on Figure 2-2), the grout floor will be injected to a depth of 30 feet bls. The cement/gel grout will be mixed and pumped from spud barges located along the canals, at a design injection rate of 100 gallons/min. It is estimated that approximately twenty (20) injections points can be installed per day.

The projected duration of this phase of the project is approximately 9-11 months.

5.3.2 Estimated Costs for Containment of Salt-Contaminated Soils

Costs were estimated based on vendor provided production rates and unit costs. Slurry wall costs were obtained from Hayward Baker, and are based on a cost per square foot area. Grout floor installation costs were obtained from Reliable Production Services based on a cost per cubic foot volume.

Estimated costs for physical containment of salt impacted soils total estimated cost of **$41,821,858**. Itemize costs for physical containment and additional cost calculations and the basis for assumptions in the cost estimate are included in **Appendix F**.

5.4 GROUNDWATER EXTRACTION, TREATMENT, AND DISPOSAL

Groundwater in the CHCTS is contaminated above background constituent concentrations and above the EPA MCLs applicable to a drinking water aquifer. The most feasible option to remove this contamination is extraction of the contaminated groundwater. Costs were developed to remediate contaminated groundwater in the CHCTS at depth intervals of 33-60 feet bls and 60-95 feet bls. In order to predict recovery systems and duration of cleanup, a simple groundwater modeling study was performed to predict hydraulic drawdown at various pumping rates and recovery well geometries. Costs for a treatment train to treat multiple contaminants were utilized from estimates provided for a similar project. This treatment train utilizes physical filtration, chemical precipitation, and reverse osmosis; resulting in a volume reduction of approximately 70%. The remaining 30% is concentrated wastewater. Costs were calculated for onsite disposal of this concentrated wastewater into dedicated SWD wells, considering remediation of groundwater to background concentrations and the EPA drinking water MCL. For comparative purposes, costs for offsite disposal of the concentrated retentate were also calculated considering remediation of groundwater to background concentrations and to the EPA drinking water MCL, and are presented in the cost estimate.

5.4.1 Groundwater Extraction

Groundwater predictive modeling for the Chicot aquifer modeling was specifically used to evaluate the number of wells required to maximize removal of contaminant mass and attain hydraulic control of migrating plumes, while meeting the criteria of not dewatering the aquifer to an elevation below the base of the extraction system, and maintaining a water budget. The upper portion of the CHCTS at 33 to 60 feet bls is finer grained with discontinuous clay lenses. Hydraulic conductivity of this portion of the CHCTS was measured at three onsite wells for an average hydraulic conductivity of 6 feet/day. The lower massive sand of the CHCTS at 60 to 275 feet bls exhibits a prolific yield, and the limiting criteria for a project design yield was the capacity to inject concentrated wastewater (retentate) at the end of the treatment train.

To facilitate hydraulic analysis, the computer model Winflow was utilized. The computer program is an interactive analytical modeling tool that simulates two-dimensional steady-state and transient groundwater flow. The transient model was used for this project. The model uses the principle of superposition to evaluate the effects from multiple analytical functions (wells, trenches, sinks, etc) in a uniform regional flow field. Predicted drawdown at each recovery well was modeled using the Theis method applicable to confined aquifers. Predicted drawdown from multiple individual wells are added using the principle of superposition to compute the effective drawdown at any point. The cumulative drawdown is subtracted from a planar potentiometric surface. The surface can be horizontal or inclined at an angle in direction of regional gradient.

Assumptions in the model include:

- Aquifer has infinite aerial extent
- Aquifer is homogeneous, isotropic and of uniform thickness
- Pumping rate is constant
- Well fully penetrates the aquifer
- Wells and linesinks are in perfect hydraulic communication with the aquifer

Three scenarios were modeled:

- [FIGURE 5-7] Top of the CHCTS at 33 to 60 feet bls, considering remediation of all constituents to background concentrations, which will encompass chloride concentrations ranging from 750 to 1000 mg/L (Figure 5-4). It is assumed that pumping this portion of the CHCTS will result in achieving a background chloride concentration of 487 mg/L, but because of the lack of delineation, the pore volume flushing estimates will be doubled to account for unknown plume size and for the presence of salt-contaminated clay beds which will desorb chlorides and cause a tailing effect with time.
    - The model was built using the site-specific measured hydraulic conductivity of 6 ft/day as obtained from slug testing.
    - Aquifer thickness is 27 feet. Because Winflow is a 2-dimensional model, the aquifer thickness was increased to 35 feet to simulate substantial vertical flow that would likely result from high hydraulic communication with the highly permeable massive sand underlying the top of the CHCTU. This hydraulic connection would result in vertical flow that would decrease drawdown, in similar fashion to increasing the effective thickness of the aquifer.
    - The site model was built using a porosity of 0.35, storage coefficient of 0.15, transmissivity of 210 sq ft/day (35 ft * 6 ft/day) and a reference head (planar water table surface) at 3 ft MSL, sloping to the north at a gradient of 0.00012.
    - Extraction wells were added at locations that would result in hydraulic control of the commingled plume to background concentrations for all constituents, which encompassed chloride concentrations ranging from 750 to 1000 mg/L. Wells were placed in locations that would not interfere with current facility operations. The discharge of the wells was iteratively changed in conjunction with well spacing to result in a drawdown that leaves a 10 foot water column above the pumping level.
    - The model results in 15 extraction wells screened at 30 to 60 feet bls concurrently pumping at 10 gallons per minute (gpm). This configuration of well spacing and pumping rate is limited by the aquifer capacity.
- [FIGURE 5-8] Top of the CHCTS at 33 to 60 feet bls, considering remediation of all constituents to drinking water standards, and chloride concentrations to 1000 mg/L (Figure 5-6). This scenario was performed as a sensitivity analysis to evaluate the cost difference compared to the previous model, and to evaluate the resulting effect on remediation of the chloride plume.

  - The model was built using the same criteria as the previous model, including a site-specific measured hydraulic conductivity of 6 ft/day, aquifer thickness of 27 feet adjusted to 35 feet to simulate vertical flow from the underlying massive sand, a porosity of 0.35, storage coefficient of 0.15, transmissivity of 210 sq ft/day (35 ft * 6 ft/day) and a reference head (planar water table surface) at 3 ft MSL, sloping to the north at a gradient of 0.00012.
  - Extraction wells were added at locations that would result in hydraulic control of the commingled plume to drinking water concentrations for all constituents, and to 1000 mg/L for chlorides. This effectively resulted in a smaller plume size as compared to the previous model. The discharge of the wells was iteratively changed in conjunction with well spacing to result in a drawdown that leaves a 10 foot water column above the pumping level.
  - This model resulted in 12 extraction wells screened at 30 to 60 feet bls concurrently pumping at 10 gallons per minute (gpm), limited by the aquifer capacity. The smaller plume size resulted in 3 fewer wells.
  - As will be discussed in later sections, this model did not appreciably change the cost of remediation of this portion of the CHCTS, because:
    - The plume size was smaller.
    - The smaller plume size resulted in 3 fewer well to maintain target drawdown, so the overall rate of groundwater extraction decreased.
    - Beginning concentrations were higher because they are based on area averages.
    - Ending concentrations for heavy metals were higher because they are based on MCLs instead of background, but because the chloride limit of 1000 mg/L was limiting, there was little difference in the two scenarios.
- [FIGURE 5-9] Intermediate depth of the CHCTS at 60 to 90 feet bls, considering remediation of all constituents to background concentrations. The size of the chloride plume to background concentrations was estimated to the north and east, and was established by data to the west and south.
  - Because site-specific slug testing occurred in the shallower finer-grained portion of the aquifer, that value is not viewed as representative of the more permeable massive sand encountered below a depth of 60 feet bls. The model utilized a value of 100 ft/day, based on published values (Geological Bulletin #30, Table 7, page 147 lists pumping test data for Ve134 with a transmissivity of 260,000 gpd/ft with an aquifer thickness of 150 feet at that location; this converts to 34759 ft3/day/ft for a hydraulic conductivity of 230 ft/day). The value was decreased to 100 ft/day because Ve134 is screened in a deeper portion of the CHCTS.
  - Aquifer thickness is 215 feet (60 feet bls to 275 feet bls).
  - The site model was built using a porosity of 0.35, storage coefficient of 0.05, transmissivity of 21,500 sq ft/day (215 ft * 100 ft/day) and a

reference head (planar water table surface) at 3 ft MSL, sloping to the north at a gradient of 0.00012.

- Extraction wells were added at locations that would result in hydraulic control of the commingled plume to background concentrations for all constituents. The number of recovery wells was varied with various discharge rates to maximize hydraulic control of the plume. The cumulative discharge was limited by the disposal capacity of two SWDs, each of which was assumed to be able to dispose of 1700 bbls/day. The two wells would be able to handle 142,800 gpd (2*1700*42) of concentrated wastewater, resulting from approximately 66% concentration by volume in the reverse osmosis unit, allowing disposal of 428,400 gpd of pre-treatment contaminated groundwater (142,800*3). This cumulative daily volume of 428,400 gallons ie equivalent to just under 300 gpm cumulative recovery rate (428,000/24/60).
- The model (Figure 5-9) results in 6 extraction wells screened at 60 to 95 feet bls concurrently pumping at 50 gallons per minute (gpm).

5.4.2 Groundwater Treatment

The disposition of recovered contaminated groundwater is dictated by the characteristics of the wastestream. Recovered contaminated groundwater that has objectionable quantities of salt for potable use, is generally too fresh for direct disposal into a salt-water disposal well (SWD). This type of wastestream is not expected to be compatible with typical injection formations utilized by salt-water disposal wells (SWDs), because of the potential for swelling of interstitial clays within the typical injection zones, and incompatibility with formation water. Two options are available:

- Blending recovered contaminated groundwater that has objectionable concentrations of salts but is too fresh to inject directly into a formation with concentrated brine, to achieve chemical compatibility with formation water.
- Concentrating recovered contaminated groundwater that has objectionable concentrations of salts to a high concentration brine that is compatible with injection formation characteristics using reverse osmosis (RO) filtration.

The most feasible option to manage this wastestream at this site is to concentrate the recovered contaminated groundwater to facilitate volume reduction prior to injection of concentrate into a SWD well. Otherwise, blending would require drilling a salt water production well to generate sufficient volume for blending, and would result in a much larger wastestream to manage. Volume reduction and wastestream concentration can best be accomplished using pretreatment followed by filtration through a reverse osmosis (RO) unit.

Reverse Osmosis (RO) technology uses pressure to force a solution through a semi-permeable membrane which allows the solvent (groundwater) to flow through while the solute (contaminants) are captured on the inlet side of the membrane. The solvent flows from an area of high solute concentration to an area of extremely low solute concentration, which is the reverse of normal osmotic activity. RO technology has been implemented in similar processes and scenarios, and it has been proven to be highly effective for desalination of municipal water supplies. RO systems generally have efficiencies of 60-70% recovery of treated water, which can be re-injected into the aquifer. The amount of water passed through the membrane can be adjusted to control precipitation of super-saturated salts and osmotic pressure increase across the membrane. Super-concentrated wastewater, or rentenate (approximately 30-40% of the original feed volume), is created in this process and requires disposal or further treatment. Pre-treatment options were added to the RO system, to address contaminants detected in groundwater at the site that cause premature fouling of the RO membranes. The following generally describes the RO treatment process train for recovered groundwater:

- Recovered water entering the treatment system will flow into three 2,500-gallon process tanks for equalization prior to adsorption/filtration.

- Source water will be pumped to carbon adsorption/filtration units for removal of barium. Barium removal will be performed using two filter vessels containing a zeolite media. Barium precipitate sludge will be produced from the process and will require offsite disposal.

- Water leaving the adsorption/filtration units will then be pumped to the RO system, which can handle a recovery flow rate in excess of 25 gpm. The RO system will remove chlorides, salts, and any other dissolved solids remaining after pre-treatment. Approximately 70% of the source water is treated to the effluent standards within the RO unit. This clean effluent will be discharged via an LPDES discharge permit. The retentate (modeled as 30% of the source volume) will be pumped to holding tanks pending disposition.

The RO system is equipped with a remote sensing (telemetry) system that will allow offsite monitoring, via computer. System alarm conditions can be identified immediately, allowing the number of potential non-operational days to be reduced.

Capital costs for the treatment system include:

- purchase and installation of the RO treatment system
- groundwater recovery well installation
- treatment system enclosure
- treatment system distribution piping
- storage tanks for recovered groundwater

Projected costs for groundwater recovery and disposal under this option are based on the estimated time to achieve cleanup goals. The following general assumptions were made in estimating the cost to remediate the AOI under this option:

- The number of pore volume flushes required to achieve cleanup were calculated in accordance with US EPA Ground Water Issue paper EPA/504/S-97/504, September 1997, “Design Guidelines for Conventional Pump and Treat Systems”. Pore volume flushing calculations are included in **Appendix G**.
- The total volume of groundwater required to achieve cleanup is based on the greatest number of pore volume flushes required for a single constituent within the impacted area. A sensitivity analysis was performed to determine the contaminant requiring the largest number of pore volume flushes to achieve cleanup goals.
- The estimated cleanup time for an area is based on the total volume of groundwater required to achieve cleanup, the maximum required number of pore volumes to achieve the desired RS, and the well recovery rate projected from predictive modeling.
- Operation and maintenance costs include quarterly monitoring and reporting, personnel, equipment replacement, and energy requirements.

5.4.3 Concentrated Wastewater Retentate Disposal

For purposes of developing a comparative remediation estimate, this plan considers disposal of concentrated retentate (~1/3 of the total recovered contaminated groundwater volume) at either an offsite commercial SWD, or into an onsite SWD. A qualified engineer has not evaluated the suitability of formations at the site for permitting a SWD, considering the numerous historical problems with SWD wells. The VPSB has made it clear that the use of an onsite SWD for purposes of injecting contaminated groundwater will not be allowed absent their approval, which has not been obtained at this time. In addition, the use of a SWD for such purposes would only be recommended if the operation of the well was under the control of the VPSB contractor. Because the wastestream to be injected is wastewater resulting from remediation operations, any SWD would likely have to be permitted as a Class I nonhazardous industrial injection well, and would necessarily need to be highly protective of all subsurface horizons; Class II wells are permitted to inject produced salt water by a production company in possession of a valid operator code.

- Offsite disposal rates were obtained from US Liquids Mermentau.
- For onsite disposal of concentrated retentate, we relied on a cost estimate for a SWD provided by Guichard Drilling for a similar project. The depth of injection zones (~1500 to 2500 feet bls) is similar. We were advised by a professional petroleum engineer that a typical SWD could dispose of 1000 to 2000 barrels per day. This estimate assumes all SWDs will be new and properly installed wells. For this feasibility estimate, we assumed that two concurrently-operating SWDs will be required, and that reworking each well will be needed every two years (acid wash job) at an estimated cost of $100,000 per workover. An additional SWD is included in the budget to allow for continued operation while an SWD is down.

- Operation and maintenance costs include equipment replacement, well workover, and energy requirements.

5.4.4 Estimated Cost for Groundwater Remediation

The feasible plan for groundwater remediation of the 33-60 feet bls and 60-95 feet bls depths of the CHCTS considers two disposal options:

- Groundwater recovery and treatment with onsite injection of wastewater (retentate) into two onsite SWDs.
- Groundwater recovery and treatment with offsite injection of wastewater (retentate).

Costs considering the different remediation standards and disposal options are summarized in the following table. Estimated costs include pilot testing and optimization, groundwater extraction and treatment, equipment O&M and groundwater monitoring. Itemized costs calculations and the basis for assumptions in the cost estimate are included in **Appendix G.**

REMEDIATION OF GROUNDWATER IN THE CHCTS

	Remediate to Background Concentrations for all COCs	Remediate Metals To MCLs and Chlorides to 1000 mg/L
CHCTS 33-60 feet (offsite disposal of retentate)	$90,162,634	$78,861,076
CHCTS 33-60 feet (onsite injection of retentate into SWD)	$38,208,395	$38,460,434
CHCTS 60-95 feet (offsite disposal of retentate)	$63,301,455	
CHCTS 60-95 feet (onsite injection of retentate into SWD)	$18,824,859	

Thus, to remediate contaminated groundwater in both zones of the CHCTS (33 to 95 feet bls) using onsite injection would cost $57,033,254.

Additional cost calculations and the basis for assumptions in the cost estimate are included in **Appendix G**.

SECTION 6 SCHEDULE

The following activities will be completed in the estimated time and initiated in the following order, after LDNR approval of this plan.

- Soil Excavation of areas with exceedances and dewatering activities will take approximately 20-60 days and can be initiated 3 months after approval of plan.
- Installation of grout wall will take approximately 9-11 months and can be initiated 1-2 months after receipt of soil excavation sample lab reports.
- Installation of monitoring wells will take approximately 8-10 weeks and can be initiated 1-2 months after completion of the grout wall.
- Semi-Annual groundwater monitoring will take approximately 1-2 weeks and can be initiated immediately following completion of all monitoring wells. Groundwater sampling will be continued throughout the duration of the project until achieving the target cleanup standards for all constituents.
- Groundwater remediation system installation will take approximately 1-2 months and can be initiated 1-2 months following completion of all monitoring wells.
- Groundwater recovery pilot study will take approximately 6-12 months and can be initiated immediately following installation of the recovery system.
- Groundwater remediation will take approximately 18 years to reach remediation cleanup goals in the intermediate zone and 42-43 years to reach remediation cleanup goals in the top zone.
- Upon implementation of field activities quarterly updates and annual status reports will be submitted to the LDNR during duration of the project.
- A final report will be submitted to the LDNR within 2 months after achieving all remediation cleanup goals.