

THE UNIVERSITY OF TEXAS AT AUSTIN
Department of Civil Architectural and Environmental Engineering

Evaluation of Settlements at the Conquista Tailings Impoundment

by

Todd M. Sheridan, E.I.T.
Jorge G. Zornberg, Ph.D., P.E.
Robert B. Gilbert, Ph.D., P.E.

A report presented to TCEQ

on the history, subsurface characterization and a settlement analysis of the
Conquista Tailings Impoundment located in Karnes City, TX.

August 29, 2012

SUMMARY

This report presents the history, subsurface characterization and settlement analysis of the Conquista Tailings Impoundment located in Karnes City, TX. This research draws information from sources available to the Texas Commission on Environmental Quality (TCEQ) in Austin, Texas. Documents included in this report date back to the mid-1980s and can be as recent as 2011.

This report focuses on the eastern section of the Conquista Tailings Impoundment, documenting the monitoring results collected so far, comparing past settlements with calculated values, and predicting future settlements expected to be experienced in this portion of the site. The site was analyzed using one-dimensional consolidation analysis, based on a series of loading conditions (cover loading, lowering of water table). In addition, simulations were also conducted using finite element analysis aided by the software PLAXIS.

The magnitude of settlement that has occurred in the area of concern was found to match closely the settlements predicted using consolidation analyses. The analyses should follow closely the multiple sources of loading at the site. Further investigations into the subsurface conditions in the eastern portion of the Conquista Tailings Impoundment are recommended, including refinement of material properties adopted in the consolidation analyses.

TABLE OF CONTENTS

| | |
|---|-----|
| Summary | i |
| Table of Contents..... | ii |
| List of figures | iii |
| Glossary..... | v |
| Introduction | 1 |
| Scope | 3 |
| Chapter 1: Background Information..... | 4 |
| Uranium Mining Processes | 4 |
| Containment of Uranium Tailings..... | 6 |
| History of Uranium Mining | 8 |
| Uranium Mining in Texas..... | 10 |
| Site History..... | 11 |
| Embankment Construction and Tailings Deposition..... | 13 |
| Mill Site Decommissioning..... | 14 |
| Cover System..... | 17 |
| Chapter 2: Collected Observations and Data | 20 |
| Settlement Data | 20 |
| Groundwater Conditions | 22 |
| Laboratory Data | 25 |
| May 29th, 2012 Site Visit..... | 26 |
| Chapter 3: One-Dimensional Consolidation Analysis | 27 |
| Approach 1: Immediate Settlement due to Loading with Cover Soils | 28 |
| Approach 2: Time-dependent Settlements due to Loading with Cover Soils..... | 32 |
| Approach 3: Total settlement with the effect of continued lowering water table | 35 |
| Chapter 4: Finite Element Analysis | 39 |
| Phase descriptions..... | 40 |
| Settlement Analysis..... | 52 |
| Chapter 5: Conclusions and Recommendations | 53 |
| Conclusions..... | 53 |
| Recommendations | 55 |
| References | 56 |

LIST OF FIGURES

| | |
|---|----|
| FIGURE 1 - Location of Conquista Tailings Impoundment (Maps.Google.com) | 1 |
| FIGURE 2 - Location of Conquista Tailings Impoundment (Maps.Google.com) | 2 |
| FIGURE 3 - Location of Conquista Tailings Impoundment (Maps.Google.com), Coordinates: (28.888, -98.099)..... | 2 |
| FIGURE 4 - In-situ Leaching Process (Uraniuminfo.org) | 5 |
| FIGURE 5 - Potential Hazards (AntiNuclear.net)..... | 7 |
| FIGURE 6 - Price of Uranium through History (SeekingAlphas.com)..... | 9 |
| FIGURE 7 – Cross Section of Conquista Tailings Impoundment..... | 12 |
| FIGURE 8 – Plan View of Conquista Tailings Impoundment (Conoco Phillips, 2011)..... | 15 |
| FIGURE 9 – Progression of Impoundment Decommissioning (News Article - unreferenced)..... | 15 |
| FIGURE 10 – Cross Section of Final Cover..... | 18 |
| FIGURE 11 – Area of Concern (Conoco Phillips, 2011)..... | 20 |
| FIGURE 12 – Ground Surface Elevations..... | 21 |
| FIGURE 13 – Top of Tailings Elevations..... | 21 |
| FIGURE 14 – Perched Water Table Elevations Within Tailings..... | 24 |
| FIGURE 15 – Picture of Soil Cracks in Eastern Portion (Picture From Site Visit)..... | 26 |
| FIGURE 16 - Settlements Using Approach 1 | 29 |
| FIGURE 17A - Approach 1 ($C_c=0.5$) with N4E7 Settlement Monument Data..... | 29 |
| FIGURE 17B - Approach 1 ($C_c=0.5$) with additional lift of fill and N4E7 Settlement Monument Data..... | 30 |
| FIGURE 18 - Approach 1 Settlement due to Change in Water Table Elevation..... | 31 |
| FIGURE 19A - Settlements Using Approach 2 | 33 |
| FIGURE 19B - Settlements Using Approach 2 with a third lift of fill..... | 33 |
| FIGURE 20 - Approach 2 ($C_v=120 \text{ ft}^2/\text{day}$) with N4E7 Settlement Monument Data | 34 |
| FIGURE 21 - Approach 2 and Approach 3..... | 36 |
| FIGURE 22 - Approach 3 with N4E7 Settlement Monument Data | 36 |
| FIGURE 23A - Ultimate Settlements (Through 2051) | 37 |
| FIGURE 23B - Ultimate Settlements with additional fill in 2014 (Through 2051)..... | 38 |
| FIGURE 24 - PLAXIS Cross Section with Material Labels | 41 |
| FIGURE 25 - PLAXIS Material Properties..... | 42 |
| FIGURE 26 - Generated Mesh from PLAXIS..... | 43 |
| FIGURE 27 - PLAXIS Phase Descriptions | 44 |
| FIGURE 28 - Initial Phase..... | 45 |
| FIGURE 29 – Phase 1 | 46 |
| FIGURE 30 – Phase 2..... | 47 |
| FIGURE 31 – Phase 3..... | 48 |

| | |
|---|----|
| FIGURE 32 – Phase 4..... | 49 |
| FIGURE 33 – Phase 5..... | 50 |
| FIGURE 34 – Phase 6..... | 51 |
| FIGURE 35 – PLAXIS Settlement Data..... | 52 |

GLOSSARY

Coefficient of Consolidation (C_v) - The parameter used to describe the rate at which saturated clay or other soil undergoes consolidation when subjected to an increase in pressure.

Compression Index (C_c) – The parameter used to describe the rate at which the soil will compress due to loading.

Consolidation – "Consolidation is any process which involves decrease in water content of a saturated soil without replacement of water by air." – Karl Terzaghi

Evapotransperative - A term used to describe the sum of evaporation and plant transpiration from the Earth's surface to atmosphere.

Hydraulic Conductivity - The property that describes the ease with which water can move through pore spaces or fractures.

Ore - A type of rock that contains minerals with important elements including metals. The ores are extracted through mining; these are then refined to extract the valuable element(s).

Perched Water Table - A perched water table (or perched aquifer) is an aquifer that occurs above the regional water table.

Piezometer - A device used to measure static liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure (more precisely, the piezometric head) of groundwater at a specific point.

Spigotted – A method of spraying sludge, or waste, to induce sedimentation of materials. Coarser material will settle first while finer particles will travel further.

Decommission - A general term for a formal process to remove something from active status.

Tailings - The materials left over after the process of separating the valuable fraction from the uneconomic fraction (gangue) of an ore. Also called mine dumps, slimes, tails, refuse, leach residue, or slickens.

Tailing Ponds - Areas of refused mining tailings where the water borne refuse material is pumped into a pond to allow the sedimentation (meaning separation) of solid particles from the water. The pond is generally impounded with a dam, and known as tailings impoundments or tailings dams.

Introduction

This report presents an analysis of the settlements in the eastern section of the Conquista tailings impoundment located in Karnes County, TX (FIGURES 1 through 3). The site has historically experienced continued settlements in the eastern area of the site. These continued settlements represent a concern for the final closure of the site as they may create “ponding” zones, which in turn, may lead to continued maintenance. Unattended, continued settlements could compromise the ability of the cover system to function as an infiltration barrier. This report investigates the tailing material and subsurface conditions in order to identify the mechanisms leading to settlements and subsequently predict the future settlements. After an evaluation of historical documents, a series of multiple loadings were identified that lead to settlements in the concerned area. Current and future settlements are thought to be induced by consolidation of the tailings material located beneath the clay cover system. That is, as water is squeezed out of the soil pores due to added weight, the material compresses causing settlement. Sources of loading include the placement of the original cover system, placement of additional cover soils for regrading of the cover, and continued lowering of the perched water table. Loads to be added in the future may include an engineered cover and/or additional fill for grading purposes.

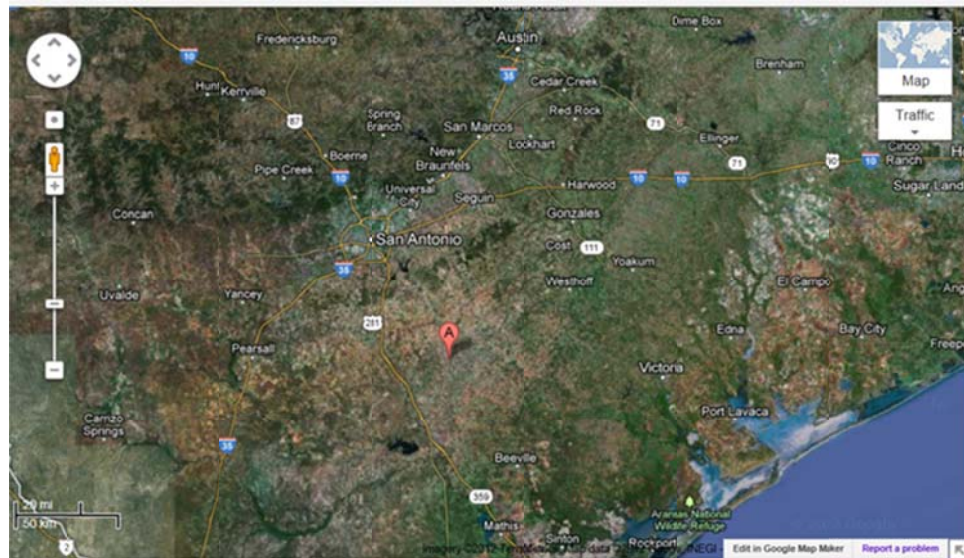


FIGURE 1 - Location of Conquista Tailings Impoundment (Maps.Google.com)



FIGURE 2 - Location of Conquista Tailings Impoundment (Maps.Google.com)

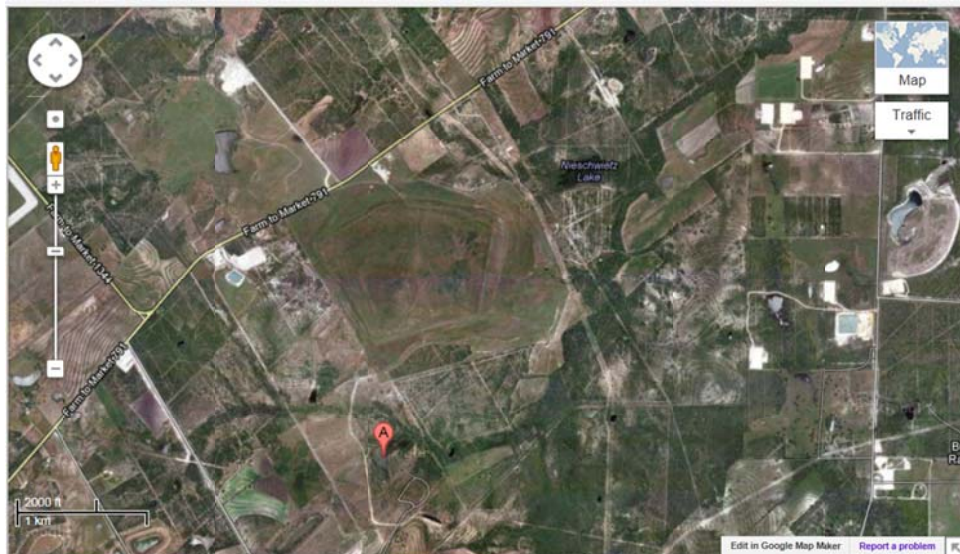


FIGURE 3 - Location of Conquista Tailings Impoundment (Maps.Google.com), Coordinates: (28.888, -98.099)

Scope

The main focus of this project is the analysis of the time-dependent settlements at the uranium tailings impoundment. The impoundment was initially closed with a cap in the 1980s. The closure cap was then upgraded in the 1990s due to problems caused by differential settlement of the tailings. Since that time, the tailings have continued to settle, resulting in continued maintenance operations.

The original set of activities to be accomplished as part of this project includes the following:

- i. Review available reports and data concerning the properties of the tailings, the method of placement, the initial closure cap, the upgraded closure cap, and the settlement.
- ii. Participation in site meetings with personnel from TCEQ.
- iii. Review of previously submitted SIGMA/W, SEEP/W and FLAC Models
- iv. Conduct a numerical simulation using a code agreed upon after discussion with TCEQ (e.g. PLAXIS) to predict the settlement and calibrate it with the available data.
- v. Use numerical simulation results to predict future settlement and cap performance.
- vi. Produce a report summarizing the findings.

As will be discussed in this report, items iv and v of the original scope were expanded to incorporate one-dimensional settlement analyses. These analyses allow use of more adequate material properties and loading sequences than those used in finite element simulations. They can also be used to assess the hypothetical placement of additional fill as part of the final future closure of the site.

Chapter 1: Background Information

URANIUM MINING PROCESSES

Uranium mines can be found at the surface (open pit mining) or underground. The ore extracted from the mines is often at very low concentrations, ranging from 0.1% to 0.2% uranium content. Therefore, a large amount of ore needs to be mined to obtain an adequate amount of uranium (Wise-uranium.org).

Open pit mines are excavated from the surface to reach the uranium below grade. These mines were popular in the mid-1900s due to the ease of construction. Later, underground mines became more attractive. Two common mining techniques include heap leaching and in-situ leaching (Wise-uranium.org).

Heap leaching is a mining technique that can be used on excavated material when the uranium content is too low for the ore to be economically processed in a uranium mill. The leaching liquid, often sulfuric acid, is infused on top of an ore pile and infiltrates until reaching a liquid collection system, placed over a liner. After collected, the liquid is pumped to a processing plant. The risk of this technique includes the possible release of dust particles, radon gas, and leaching liquid into the environment (Wise-uranium.org).

In-situ leaching (FIGURE 4) pumps leaching liquid, often ammonium-carbonate or sulfuric acid, through drill holes into underground uranium deposits. The leaching fluid, which binds to the uranium, is then extracted and pumped out from below. This technique can only be used for uranium deposits located in an aquifer in permeable rock, confined by comparatively impermeable formations. However, it is popular because it reduces the risk of injury and radon exposure to employees, is relatively inexpensive, and mitigates the need for large tailing piles. In-situ leaching presents risks associated with the leaching of contaminated liquids beyond the uranium deposit, thus contaminating surrounding groundwater while also creating a condition that results in the impossibility of restoring natural conditions in the leaching zone when completed (Wise-uranium.org).

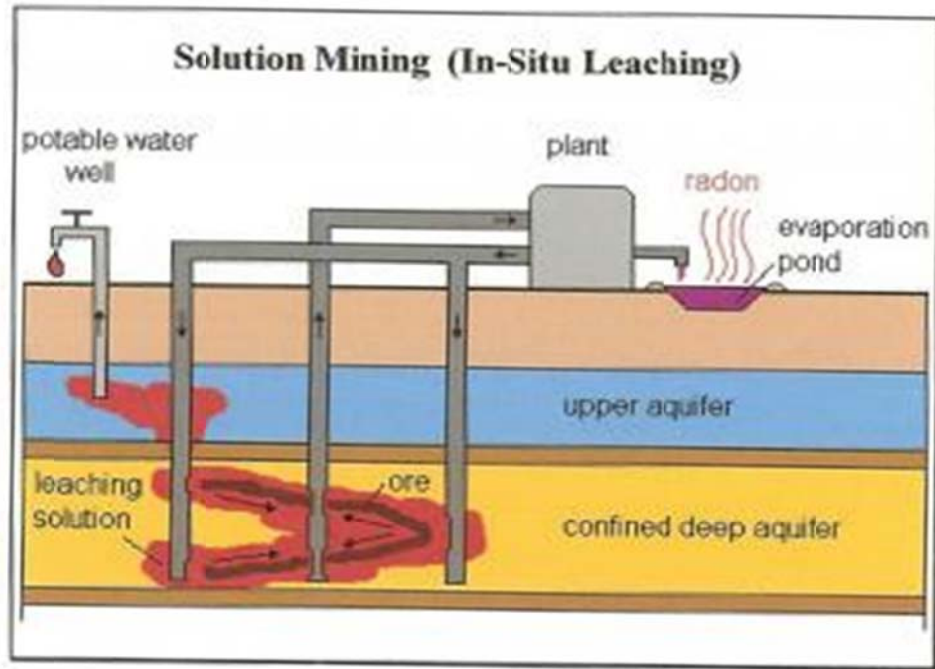


FIGURE 4 - In-situ Leaching Process (Uraniuminfo.org)

CONTAINMENT OF URANIUM TAILINGS

The uranium-bearing material from open pits or underground mines is leached in a uranium mill processing plant in order to extract the uranium. These mills are usually located on, or near, the site to reduce transportation costs and typically use sulfuric acid to extract minerals. Along with uranium, the leaching agent extracts various constituents from the ore such as vanadium, selenium, iron, lead and arsenic. The final product, often referred to as “yellow cake,” contains U_3O_8 and some impurities. After the completion of a mining site, the mill and equipment used may contain large amounts of radioactively contaminated material. This material must be disposed of in a secure manner. Commonly, tailing impoundments are constructed to contain the waste produced (Wise-uranium.org).

Uranium mill tailings are commonly disposed as sludge in special ponds or piles. The amount of sludge produced is about the same as the ore milled (e.g. for a uranium content of 0.5%, 99.5% of the material is waste). The concerns associated with the sludge lie in the radioactivity of the material. Approximately 85% of the initial radioactivity remains in the sludge after processing. In addition, heavy metals and other contaminants are used during the milling process exist in the sludge. The produced waste is impounded at specific sites to meet pre-determined standards set by the Environmental Protection Agency (EPA) and the Nuclear Regulatory Commission (NRC) (Wise-uranium.org).

The requirements defined by the EPA and the NRC establish the maximum contaminant concentrations for soils, admissible radon release (20 pCi/m²-sec) and life expectancy for the impoundment (200 to 1,000 years). This demand of life expectancy must assure a safe disposal without active maintenance. If these conditions are not met, the tailings must be relocated (Wise-uranium.org). FIGURE 5 illustrates some of the potential hazards that may result from uranium mill tailings.

Uranium Mill Tailings Hazards

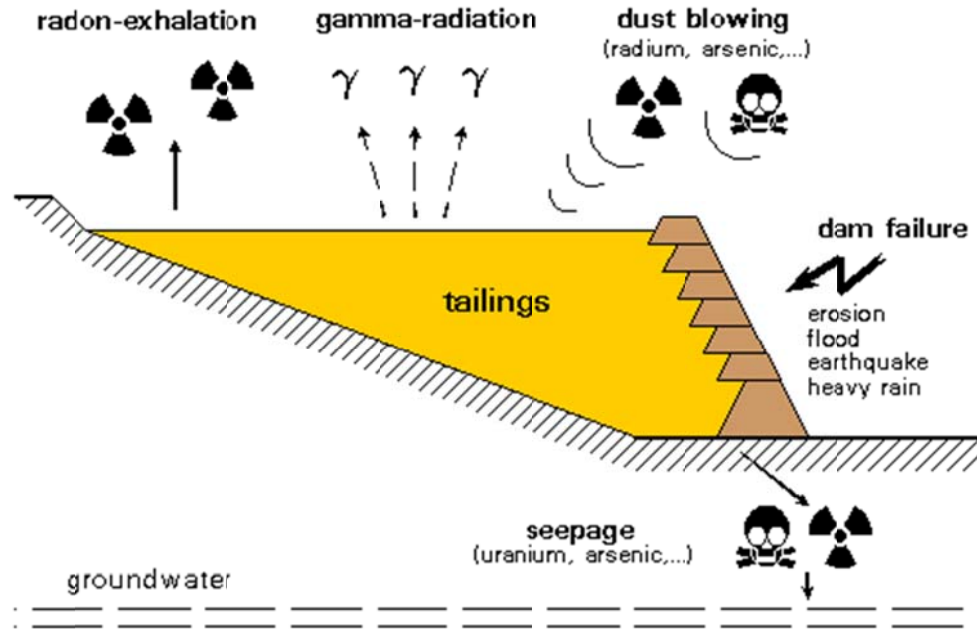


FIGURE 5 - Potential Hazards (AntiNuclear.net)

HISTORY OF URANIUM MINING

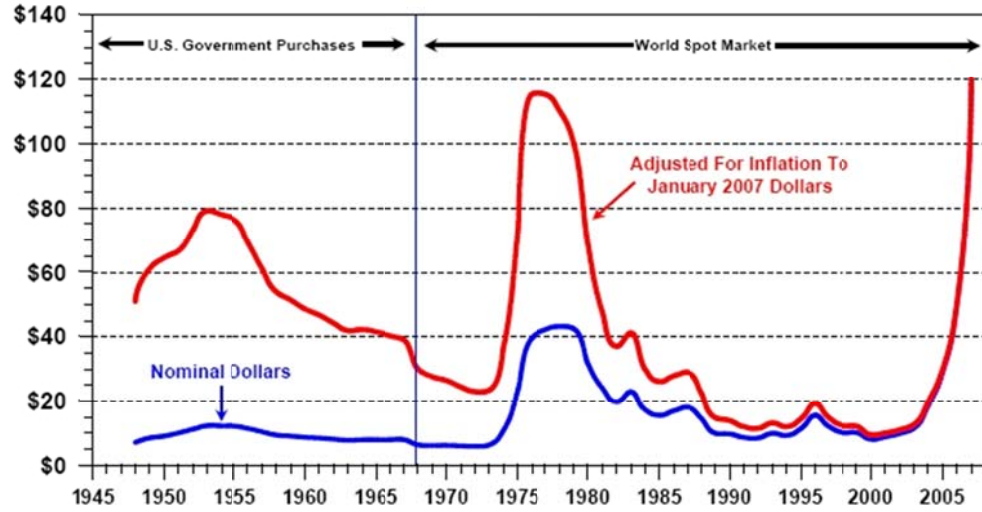
Although the properties of uranium were unknown at the time, some uranium-rich minerals (e.g. pitchblende) were discovered as early as 1565. Pitchblende was extracted from the ground in a yellowish powder form; however, this powder was originally misidentified as sulfur. The first deliberate mining process of uranium ore took place in the 19th century, in the present day Czech Republic. The first process was intended to extract the ore for use as radium, which is the decay product of uranium. Because of the lack of understanding of uranium properties at the time, many deaths came about from radiation poisoning. The early use of uranium ore was primarily luminous paint for watch dials and other instruments, as well as some health-related applications. As we now know, the health-related applications may have produced harmful rather than beneficial outcomes (Cna.ca).

Uranium ore deposits were discovered in the United States in 1871 in gold mines located in Colorado. Pre-World War II, the majority of our uranium ore deposits were mined in the vanadium deposits of the Colorado Plateau, between Utah and Colorado. During the war and the construction of the Atomic Bomb, the mining process moved to the American Southwest. Specifically, Arizona and New Mexico provided much of the uranium supply for the Manhattan Project. Government agencies needed to effectively conceal the purchase of uranium for obvious reasons; therefore, they instead purchased vanadium, which was known to have traces of uranium that could be extracted (Cna.ca; World-nuclear.org).

Currently, Kazakhstan, Canada, and Australia are the leading producers of Uranium. Uranium is traded in the commodities market as U_3O_8 at a price of \$52/lb (February 2012), but this has not always been the case. In the 1980s, the price dropped down to \$7/lb., which caused many mining operations to declare bankruptcy and shut down, leaving their tailings and radioactive deposits behind (World-nuclear.org). Figure 6 shows the price history of uranium.

Uranium Price History

(Dollars Per Pound U₃O₈)



Source: 1948-1967 from U.S. Department of Energy Publication GJO-100(82); 1968-2007 from TradeTech (Denver, Colorado)

FIGURE 6 - Price of Uranium through History (SeekingAlphas.com)

URANIUM MINING IN TEXAS

Mining for uranium in Texas began in the mid-1950s. The deposits were found using aerial detection for radioactive material. Surprisingly, the ore grade uranium was found in surficial layers and was relatively easy to access. The material was located in a farmland in Karnes County, TX, creating a “gold rush” effect for farmers and oil tycoons. Most notably, Susquehanna Western, Inc. was at the forefront of this exploratory expedition (Uraniuminfo.org).

The process of mining began as an unregulated open-pit mining operation that resulted in companies dumping large volumes of hazardous, radioactive metals in the south-central Texas area, outside San Antonio. The most notable projects in this area were at the Conoco/Conquista site in Karnes County, at the Chevron site in Panna Maria, also in Karnes County, and at Exxon's Ray Point site in Live Oak County. Uranium tailings resulted from the disposal of waste material from a conventional uranium mill, which contained radioactive byproducts and heavy metals. Tailings were reported to include discrete surface waste resulting from the uranium solution extraction processes. These processes included use of techniques such as in-situ recovery, heap leach, and ion-exchange. Byproduct material did not include underground ore bodies depleted by solution extraction. The waste from these solution extraction facilities was transported to a mill tailings impoundment for disposal (Uraniuminfo.org).

By the mid-2000s, there were uranium operations in eighteen (18) counties in southwest Texas with forty (40) strip-mines permitting coverings (over 31,000 acres), which included four (4) uranium tailings ponds. Eighty (80) in-situ mining sites, with over 20,000 surface wells, were licensed. These sites used surface wells to extract uranium through the use of solvents. Thirty-two (32) deep well injection sites were permitted for use of disposal of radioactive waste into deep aquifers (Uraniuminfo.org).

SITE HISTORY

The uranium-rich sites in south-central Texas are located in Eocene sandstone deposits. Continental Oil Company operated a mill site in one of these deposits near Falls City, TX since September 1971. In January 1982 the site was transferred to Conoco. The operations were conducted to recover uranium from the sandstone using several open-pit mines in the surrounding area. The Conquista site is located approximately eight miles southwest of Falls City, TX in Karnes County. This is a 614-acre tract of land in which a pentagon-shaped tailings impoundment covers 243 acres (Waste, Water & Land, 1994).

The mill produced approximately 8.75 million tons of uranium ore at an average concentration of 0.10 % and produced over 2,000 tons of uranium oxide (U_3O_8) for the U.S. Atomic Energy Commission. The mill used a conventional sulfuric acid leach and solvent extraction process to recover the U_3O_8 from the ore from milled sandstone. The tailings produced from this operation amounted to more than 3.1 million tons of waste, which came in forms of sand and slime fractions, as well as liquid waste generated from the process. The waste disposed in the ponds also included milling materials and equipment, treated sanitary waste, laboratory waste, and runoff from the ore pad and mill area. The waste was disposed across the site and impounded in unlined settling ponds. These “tailings ponds” reached depths of forty (40) feet and were located over a naturally occurring clay aquitard. The ponds were subjected to evaporation and the remaining land was enclosed with a vegetated cover system. Due to differential settlement, the initial closure cap was upgraded in the 1990s (Waste, Water & Land, 1994).

The original ground surface elevations ranged from 360 feet above mean sea level in the eastern side, to 420 feet above mean sea level in the southwestern corner. When initially constructed in 1971, the impoundment made use of the natural drainage path of Conquista Creek, which was confined by embankments only on the eastern and northern sides and high grounds of the western and southwestern locations. The embankments were constructed using the locally available Dubose Member clay, which is found within the impoundment and at select borrow areas. The tailings were spigotted from the outer edges of the embankments to create “tailing beaches” on the perimeter and “slime ponds” in the central areas. Ponded water was then pumped out for re-use in the milling process (Waste, Water & Land, 1994).

The embankments rose to a maximum height of forty-five (45) feet, on the eastern side, although most of the site rose to less than ten (10) to fifteen (15) feet. In 1979 and 1981, the embankments were then raised to an elevation of 416

and 436 feet above mean sea level, respectively. The final embankment heights ranged from sixteen (16) to seventy (70) feet with a 3:1 downstream slope (outside) to the natural ground and a 2:1 upstream slope (inside). FIGURE 7 shows a sketch depicting the subsurface conditions at the site (Waste, Water & Land, 1994).

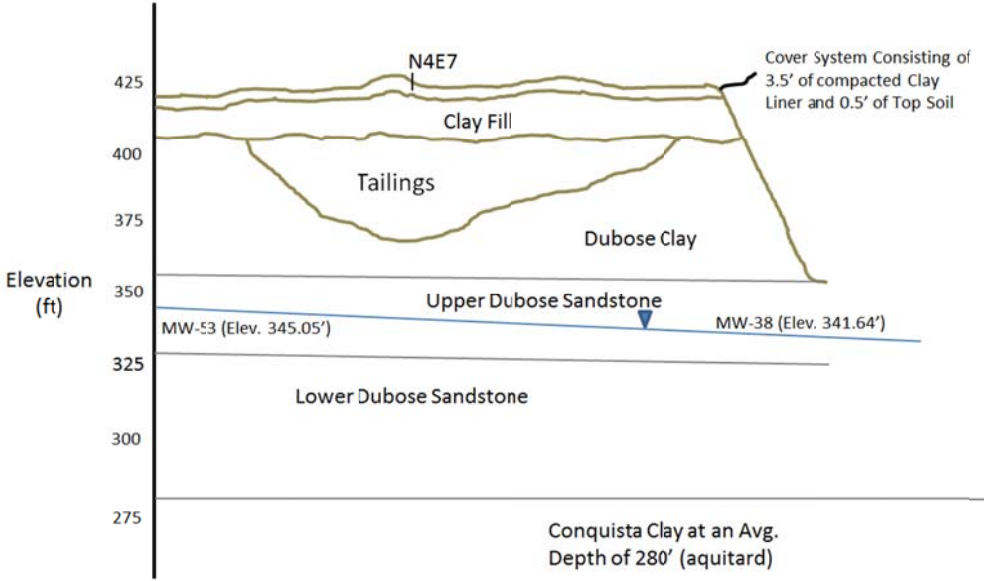


FIGURE 7 – Cross Section of Conquista Tailings Impoundment

EMBANKMENT CONSTRUCTION AND TAILINGS DEPOSITION

The pentagon-shaped impoundment covers an area of roughly 250 acres, which is enclosed by surrounding embankments. The initial ground surface elevation in 1979 ranged from 360 feet at the eastern confinement to over 420 feet at the southwestern corner. The embankments were constructed on a naturally dry area of Conquista Creek with a 2.5:1 upstream slope and a 3:1 downstream slope. Crest widths ranged from fifteen (15) to twenty (20) feet. The embankments were constructed using borrow material from the southwestern area of the site. Up to twenty (20) feet of clay were excavated. The eastern embankment rose to a maximum height of forty-five (45) feet with the majority of the section being less than ten (10) to fifteen (15) feet (Tetra Tech, Inc., 2011).

In 1981, the embankments were raised almost twenty (20) feet to a final elevation of 436 feet amsl. The embankments were heightened using a centerline method with a clay core and a shell composed of random fill. The downstream side of the embankment remained at a constant 3:1 slope, while the upstream face was constructed with a 2:1 slope and a crest width of approximately twenty (20) feet (Waste, Water & Land, 1994).

The embankments were constructed with seepage collection systems built into the downstream toe of the embankments. This system drained to sumps located at the low points across the embankments. An interceptor ditch was constructed to collect runoff from the small upstream drainage area. The ditches allowed diversion of the liquids around the pond and into the natural downstream drainage. The collection system discharges through solid pipes into sumps located outside the embankment perimeter. The discharge is then pumped back into the tailings pond (Tetra Tech, Inc., 2011).

The tailings were discharged along the northern and eastern sides of the impoundment using a sub-aerial method of spigotting around the entire perimeter. This discharge method kept the free water surfaces away from the embankments and resulted in the formation of sand beaches along the embankments. The tailings beaches reached a maximum elevation of 424 feet on the upstream face of the embankment. The downstream slopes were seeded with Coastal Bermuda grass to create a vegetative cover to reduce erosion (Waste, Water & Land, 1994).

MILL SITE DECOMMISSIONING

The initial mill site decommissioning began at the end of the secondary recovery in October of 1982 and was completed by the end of 1984. In 1983, the mill site equipment was dismantled and reusable equipment was sold. Materials and equipment that could not be sold were disposed of into the tailing ponds. Before decontamination took place, a gamma survey was conducted and the contaminated areas were marked. Excavation of these areas was conducted using a backhoe and scrapper, this excess material was then buried in the impoundment. After the decontamination process was complete, the western two-thirds (2/3) of the impoundment were covered with approximately five (5) feet of clean fill. After a second gamma survey confirmed that the area was decontaminated, a layer of topsoil was placed on top and seeded with native grasses. FIGURE 8 shows a plan view of the Conquista Impoundment (Tetra Tech, Inc., 2011).

Tailings pond water was managed by pumping the residual pond water to the eastern section of the impoundment prior to covering this section. At this time, the eastern section of the impoundment was still open as pond water and runoff were contained in these tailings. At the closing of the reclamation work in 1985, approximately 160 gallons of pond water covered the eastern portion of the impoundment. This water was evaporated initially by spraying along the “tailing beaches” to provide evaporation from the wetted surfaces. Later stages of the project led to the construction of smaller evaporation cells to facilitate the process prior to fill placement (Tetra Tech, Inc., 2011).

Due to anticipated differential settlements, the reclamation plan was revised in 1991. The revised plan consisted of a domed surface sloping to the west at a 0.5 percent slope and sloping to the east at a 1.0 percent slope. The slopes of the downstream embankment faces were reduced to a 5:1 inclination. This configuration was adopted to minimize the volume of earthwork needed while meeting the required regulation standards set by Texas Regulation for Control of Radon (TRCR). The final surface of the impoundment was constructed by regrading the tailings, as well as by random fill placement. FIGURE 9 shows the progress of the decommissioning at the Conquista Tailings Impoundment (Tetra Tech, Inc., 2011).

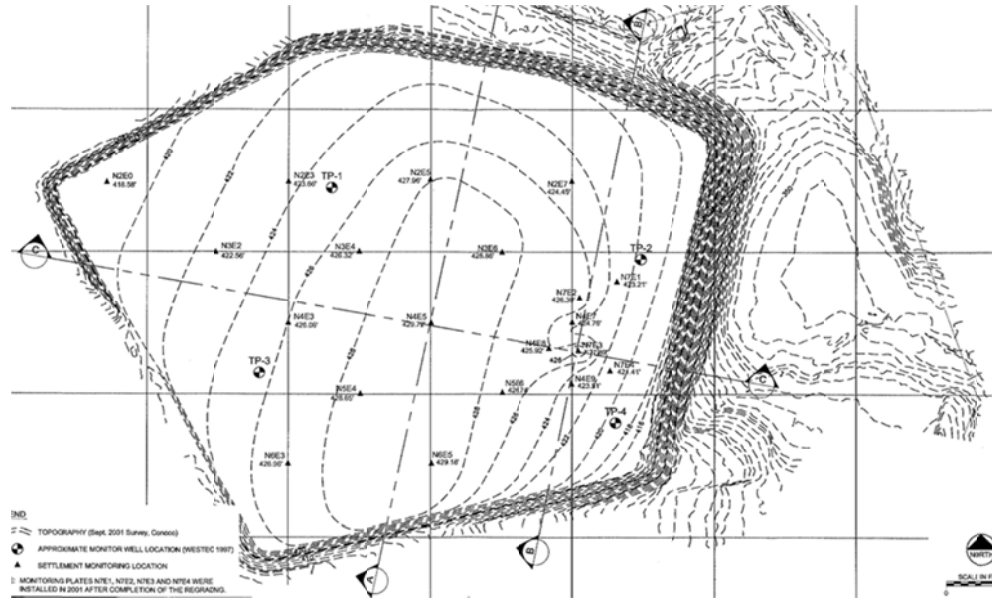


FIGURE 8 – Plan View of Conquista Tailings Impoundment (Conoco Phillips, 2011)

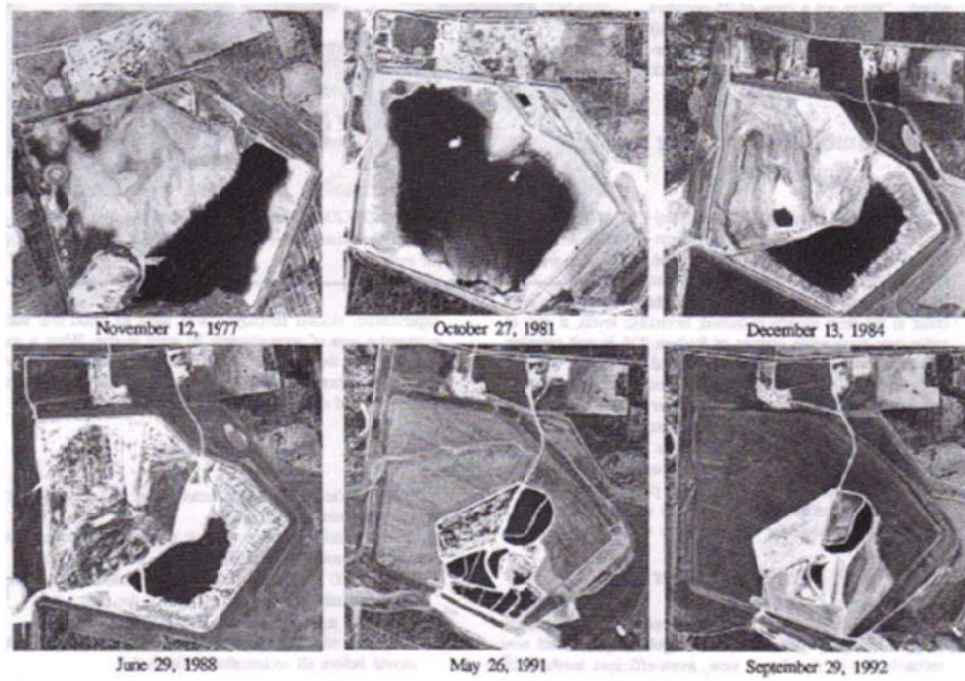


FIGURE 9 – Progression of Impoundment Decommissioning (News Article - unreferenced)

Since the tailings beneath the western section of the impoundment had been pre-loaded with a minimum of five (5) feet of random fill, it undertook consolidation during four (4) years prior to the closure of the eastern portion. This allowed conventional earthmoving equipment to be used in this area. The tailings along the perimeter of the eastern portion of the impoundment did not have the same pre-loading and consolidation history, therefore specialty equipment, such as small dozers and high-flotation pull scrapers, was used. This allowed the regrading work to take place within one (1) foot of the saturated zone of the tailings. Following the regrading of the tailings, a geogrid was placed in order to facilitate machine operations during placement of the random fill. The random fill placed above the tailings varied from five (5) to fifteen (15) feet with an average depth of ten (10) feet (Tetra Tech, Inc., 2011).

Subsequently, an engineered cover was constructed. The cover consisted of a 3.5-foot thick compacted clay cover and 0.5 feet of topsoil. The compacted clay layer aimed at reducing the average rate of radon emanation to the regulated value of 20 pCi/m²-sec and to achieve a hydraulic conductivity of less than 10⁻⁷ cm/sec. The low hydraulic conductivity aims at providing infiltration control. The final closure plan included a vegetative cover, which required gentle slopes and uniform surfaces, to meet the TRCR regulations for erosion stability control (Waste, Water & Land, 1994).

The soils used for the cover system were obtained from three locations at the site: borrow areas from the southwest, southeast, and north side of the impoundment. The Dubose clay found in these areas was selected based on results from hydraulic conductivity tests, radon attenuation testing and modeling, and dispersivity testing. The material from the southwest borrow area was also used in the initial reclamation plan in 1984. Materials that did not meet the specifications were used as random fill underneath the engineered cover in order to meet the desired slopes (Tetra Tech, Inc., 2011).

COVER SYSTEM

Initial Cover System (1984):

The initial reclamation plan of 1984 consisted of covering the western part of the impoundment with borrow material from the southwestern corner of the site. The thickness of the fill material was approximately five to ten feet in depth. It was constructed by pushing fill from jetties built across the impoundment. The equipment and materials from the mill that could not be decontaminated or salvaged were buried in the tailings impoundment. (Waste, Water & Land, Inc., 1987).

Final Cover System (1992):

The final cover system was placed to mitigate differential settlement of the previously designed system and meet EPA and NRC standards. This final cover consisted of three and a half (3.5) feet of compacted clay to create a radon and water barrier between the surface air and the contaminated material. A final six (6) inches of topsoil was placed on top to create a vegetative surface (Steffen Robertson and Kirsten, 2000).

NRC guidelines for uranium tailings impoundments are documented in 10 CFR 40, Appendix A (1987). The guidelines state that surface water run-off should not be allowed to “pond”. The site was designed with a domed configuration to control surface water run-off channels, but differential settlement throughout the eastern portion created great concern regarding the need of extended maintenance of the existing cover.

The NRC stipulates that the site must have isolations, or control, of radiologic hazards. The containment should be effective for 1,000 years or, in any case, for at least 200 years. The cover should limit the release of radon-222 to the atmosphere to values that do not exceed 20 pCi/m²-sec. These standards were reported to have been met by the installed cover system. Since the deposition of the waste below grade was not possible due to comparatively high groundwater level, the impoundment was located above grade.

Finally, the configuration of the confinement and domed surface creates an adequate assessment for minimizing upstream catchment. The vegetative cover aimed at satisfying the NRC requirement for wind erosion protection and an established vegetative cover. The impoundment is located in an inactive fault

zone, but has still been designed for site seismicity. An additional requirement relates to the need of promoting the deposition of sediments. The spigotting the slimes to create tailing beaches was implemented with the objective of fulfilling this requirement. FIGURE 10 illustrates the cross section of the designed final cover system.



FIGURE 10 – Cross Section of Final Cover

An additional assessment was conducted, which consider the potential loading with a future cover system. The hypothetical load was considered to be conducted in 2014 and to correspond to the amount of fill needed to bring the surface elevation back to the original grade of 422 feet above mean sea level. This evaluation is conducted to have a sense of the impact of additional fill placement, but should not be construed as a design recommendation for final closure of the site. Accordingly, the consolidation analysis involved four (4) loading sources have been identified to affect the tailing material and will be evaluated in the following order:

1. The installation of the cover system in 1993
2. The additional fill added to surface in 2001

3. A hypothetical additional fill to be conducted in 2014

As discussed in Chapter 2, additional settlements are triggered by the continued decrease in perched water table that has occurred at the site. Accordingly, an additional loading-inducing process at the site is:

4. The continued lowering of the water table

Chapter 2: Collected Observations and Data

SETTLEMENT MONITORING DATA

Settlement data has been collected since 1993 after installation of the final cover system. FIGURE 11 shows ground surface elevations (AMSL) versus time at the locations of interest.

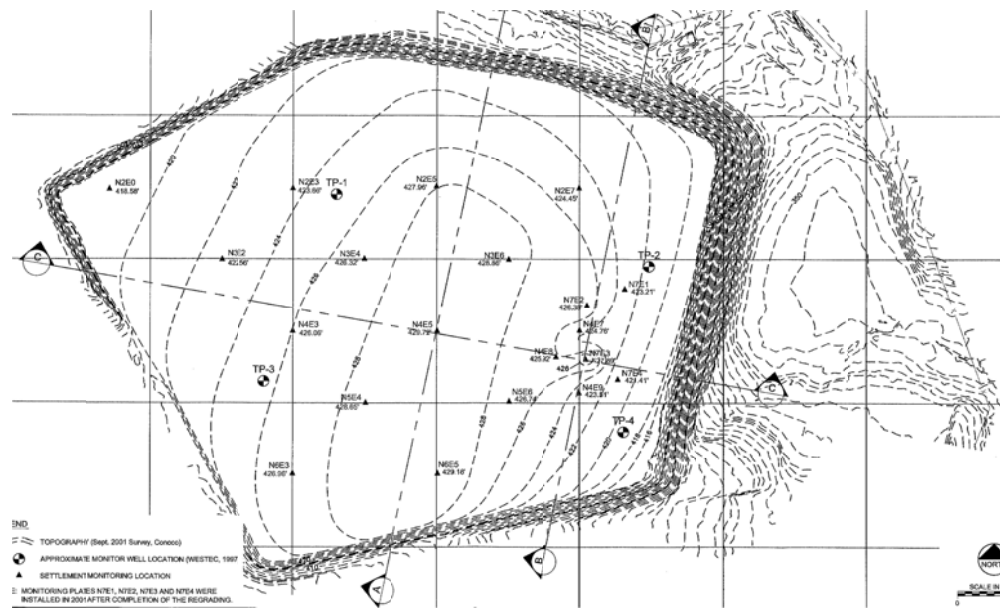


FIGURE 11 – Area of Concern (Conoco Phillips, 2011)

FIGURE 12 shows the elevation of the ground-surface as a function of time. The figure indicates the development of time-dependent settlements as well as the placement of soil lifts to bring the ground elevation back to the original grade. It can be seen that in 2001 a lift of five (5) to ten (10) feet was placed in the locations being monitored by settlement monuments. The lift was added to fill in the areas that amassed the most settlement over the previous ten (10) years. The added load created by the weight of the soil triggered additional settlements and continuation of the consolidation process (Tetra Tech, Inc., 2004).

This additional lift of fill material added to the eastern portion will be considered the second loading factor. By removing the depth of the cover system and the second lift of additional fill, the settlement data can be reconstructed to

determine the elevation of the tailings surface. FIGURE 13 shows the elevation of the tailings surface (Tetra Tech, Inc., 2004).

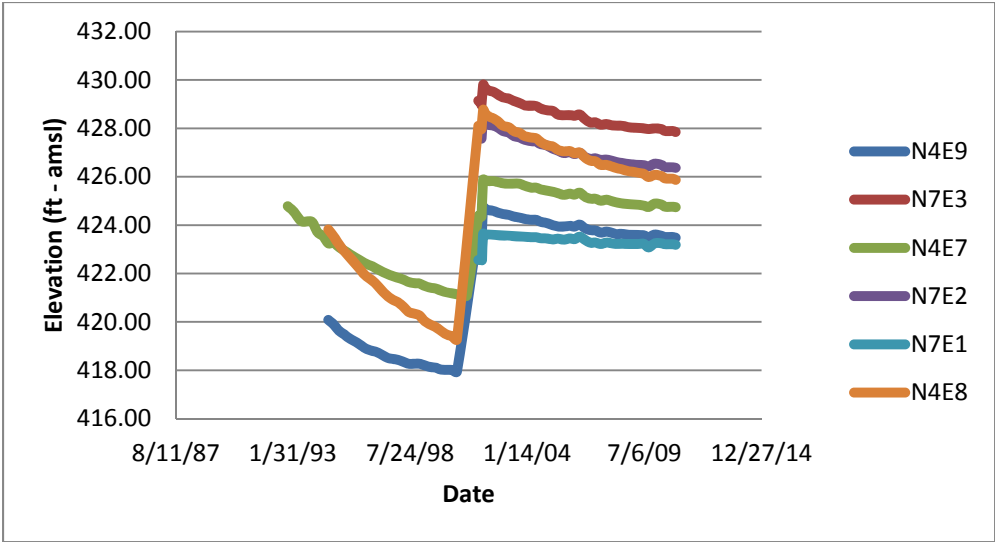


FIGURE 12 – Ground Surface Elevations of multiple surface monuments

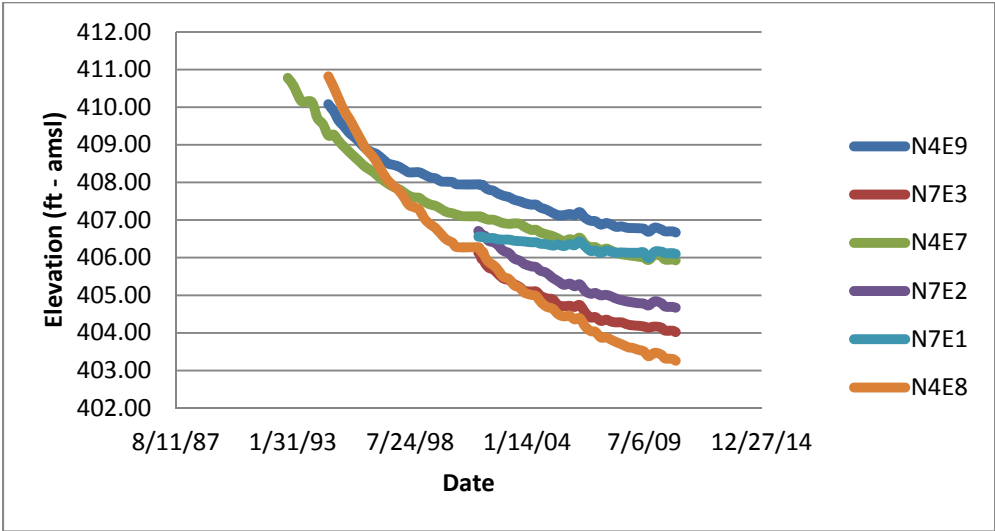


FIGURE 13 – Top of Tailings Elevations at the locations of settlement monuments

Settlement data collected by settlement monument N4E7 are used in this report for comparison with predicted settlements using one-dimensional theory of consolidation. Settlement monument N4E7 is located directly above the thickest section of tailings. Tailings below N4E7 reach a thickness ranging from 35 to 40 feet and are consequently expected to lead to the largest settlements (Tetra Tech, Inc., 2004).

PERCHED WATER TABLE MONITORING DATA

Sixteen (16) piezometers were installed throughout the site along with twenty-six (26) monitoring wells to observe the water level around the site perimeter. The piezometers and monitoring wells were installed to monitor the water levels within the Dubose Sands and Deweesville Sands. In addition to these piezometers and monitoring wells, four (4) test pit wells were installed with monitoring well to monitor the height of the water table in the tailing material. Two (2) test pits, TP-1 and TP-3, were installed in the western portion of the impoundment, while two (2) test pits, TP-2 and TP-4, were installed in the eastern portion of the site (Tetra Tech, Inc., 2011).

The elevation of the perched water table in the eastern portion of tailings is monitored by TP-2 and TP-4, with screen intervals of 24.2 to 34.2 feet and 24.9 to 34.9 feet below the ground surface, respectively. These wells have shown a steady decreased of water table since installation. TP-2, which is located in the northern area of the eastern tailings, showed a decrease in water level from a maximum of 404 feet above mean sea level to 394.25 feet above mean sea level. TP-4, located in the southern area of the eastern tailings, showed a decrease in water level from a maximum of 403.5 feet above mean sea level to 394.25 feet above mean sea level. FIGURE 14 shows the ground water elevation within the eastern tailings, TP-2 and TP-4 (Tetra Tech, Inc., 2011).

As the elevation of the perched water table decreased within the tailings, the pore water pressures within the tailings material decrease, leading to an increase in effective stresses. This loading effect is an additional load that contributes to the time-dependent settlement of the tailing material. As the water table lowers, the weight and pressure acting vertically on the soil increases, which induces additional consolidation settlements (Tetra Tech, Inc., 2011).

An additional assessment was conducted, which consider the potential loading with a future cover system. The hypothetical load was considered to be conducted in 2014 and to correspond to the amount of fill needed to bring the surface elevation back to the original grade of 422 feet above mean sea level. This evaluation is conducted to have a sense of the impact of additional fill placement, but should not be construed as a design recommendation for final closure of the site. Accordingly, the consolidation analysis involved four (4) loading sources have been identified to affect the tailing material and will be evaluated in the following order:

5. The continued lowering of the water table
6. The installation of the cover system in 1993

7. The additional fill added to surface in 2001
8. A hypothetical additional fill to be conducted in 2014

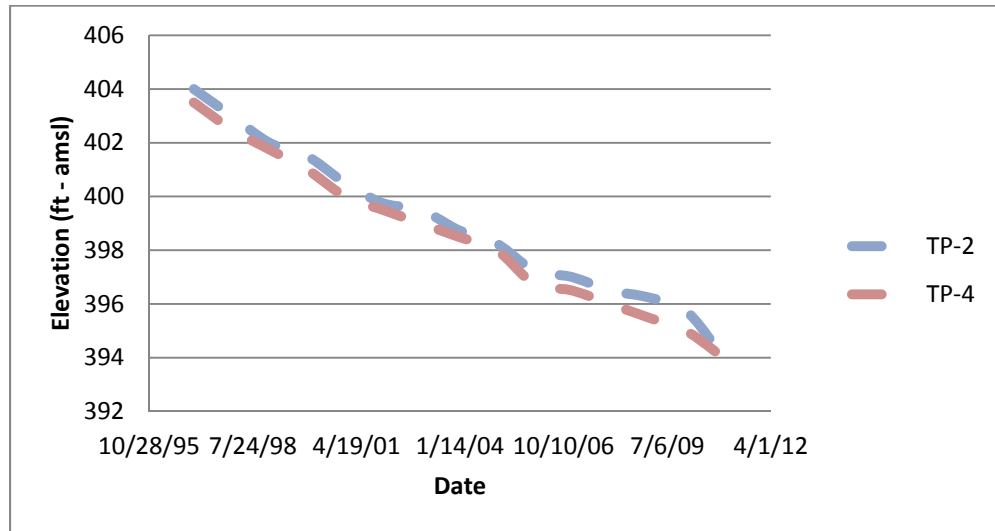


FIGURE 14 – Perched Water Table Elevations Within Tailings

LABORATORY DATA

Testing has been conducted to characterize the various materials at the Conquista Tailings Impoundment. A relevant laboratory report was compiled by Waste, Water & Land, Inc.(WW&L) in 1986. A number of tests were reported on the relevant soils in the area of the tailings. Samples of tailings materials were also collected for testing. The problem with the data presented in the aforementioned report is that the tests were conducted using samples from the western portion of the impoundment, over two and a half decades ago. The tailings contained in the western portion are expected to have significantly different properties than those in the eastern portion of the site.

Although only data from the western portion of the site were reported, the initial void ratio ($e_0 = 2.5$) and unit weight of the tailings ($\gamma = 83$ pcf) were used when defining the characteristics of the materials in the eastern portion. Use of these properties was reported as adequate because the tailings were removed using the same method of extraction from the same location, and were initially deposited using similar methods (Waste, Water & Land, Inc., 1986).

Relevant information for determination of a number of parameters needed for the analyses could not be found for tests conducted in the eastern portion of the tailings. The selection of parameters such as the consolidation coefficient or the compressibility coefficient can impact significantly the predicted settlements. An additional experimental testing program using tailings from the eastern portion of the site would be expected to lead to more accurate analyses.

MAY 29TH, 2012 SITE VISIT

On May 29th, 2012, Todd Sheridan, Dr. Zornberg (University of Texas – Austin), and Michael Pimentel (TCEQ) visited with Ernest King, the site manager, at the impoundment in Karnes County, TX. During the site visit the settlement monuments were located and the local conditions of the site were observed. Comparatively large cracks were observed to develop in the eastern portion of the site, as shown in FIGURE 15. The cracks ranged from 5 to 14 inches in length and from 2 to 4 inches in thickness. One crack was seen to extend over twelve (12) inches below the ground surface. Cracks of this magnitude were not identified during the field inspection of the western area of the impoundment. These cracks could lead to infiltration rates through the cover that are higher than those anticipated if the integrity of the cover is not compromised, as anticipated in the guidelines used for cover design.



FIGURE 15 – Picture of Soil Cracks in Eastern Portion (Picture From Site Visit)

Chapter 3: One-Dimensional Consolidation Analysis

The placement of fill over the tailings as well as the continued lowering of the perched water table was anticipated to have triggered the time-dependent settlements observed at the site. Accordingly, a one-dimensional consolidation analysis was conducted of at the location in the western portion of the tailings impoundment with the highest depth of tailings material.

Considering that consolidation could explain the observed settlements, analyses were conducted considering the conventional assumptions of having a linear e - $\log p$ curve (i.e. a constant compression index C_c value) as well as an initial void ratio under normally consolidated conditions. The void ratio varies with time as the subsurface compresses and is a function of the compressibility of the material. The initial void ratio used in the analyses is 2.5. Normally consolidated conditions are assumed because the only initial load that the tailings have experienced is their self-weight. The assumptions were used to simplify the analysis based on the lack of initial parameters presented in the eastern portion. The limited initial parameters used, e_0 and $\gamma_{tailings}$, were taken from the Waste, Water & Land report conducted using samples collected from the western section of the site.

The consolidation analyses were conducted considering three approaches, which account for the multiple loadings applied to the tailings materials.

APPROACH 1: IMMEDIATE SETTLEMENT DUE TO LOADING WITH COVER SOILS

Approach 1 aims at back-calculating the compression index (C_c) in the eastern portion of the tailings impoundment. This analysis explicitly ignores the time-dependent nature of the settlements, as the objective is on defining the magnitude of the ultimate settlement induced by the placement of fill over the tailings material.

The compression index (C_c) was back-calculated considering the settlements induced due to immediate loading of the cover system and the lowering of the water table. Specifically, the compression index was varied until finding an adequate match with data from the settlement monuments. The value of C_c was assumed to remain constant with time. It was also assumed that any excess pore pressures generated by the lowering of the water table dissipate immediately, so the time-dependent settlements are controlled by the rate of level change in the perched water table. FIGURE 16 shows the settlements induced by the multiple sources of loading as a function of time, considering varying values of C_c . FIGURE 17A compares the selected value of $C_c = 0.5$ with the actual settlement monument data from N4E7. The sudden settlement increases shown in the previous figures correspond to the immediate loading of the cover system, which took place in 1994 and the additional lift added in 2001.

FIGURE 17B provides the same information as FIGURE 17A, but considering an additional load induced by additional six (6) feet of fill to be hypothetically placed in 2014.

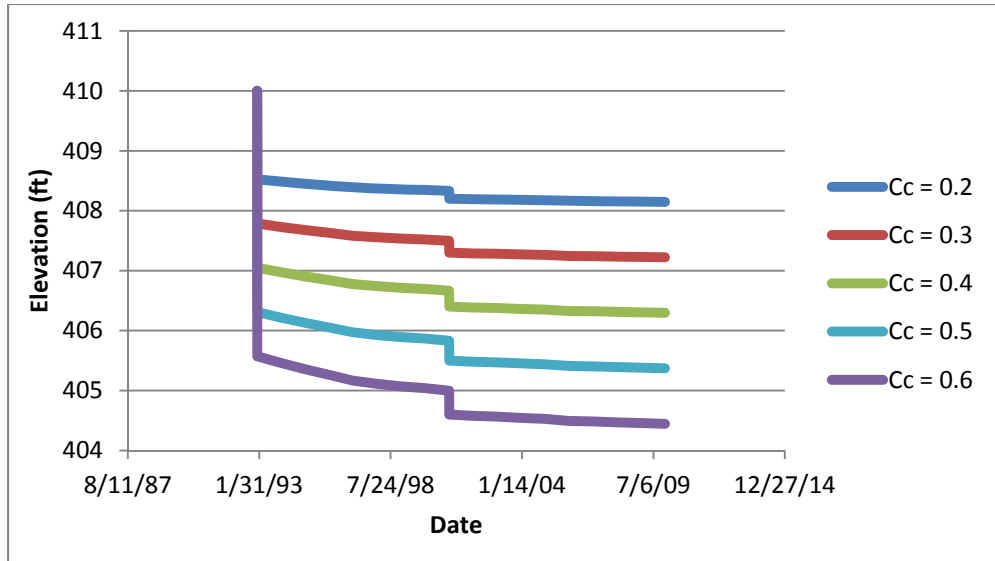


FIGURE 16 - Settlements Using Approach 1

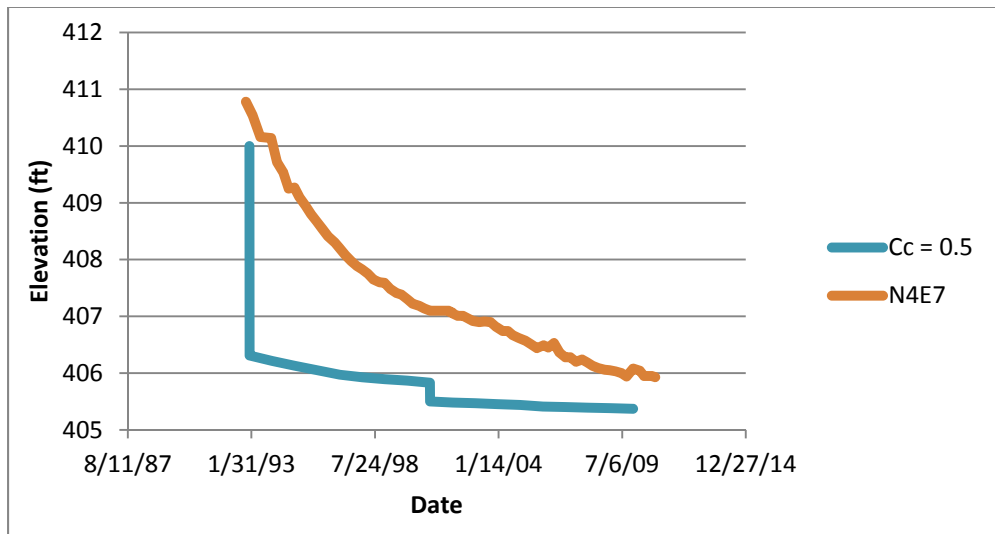


FIGURE 17A - Approach 1 ($C_c=0.5$) with N4E7 Settlement Monument Data

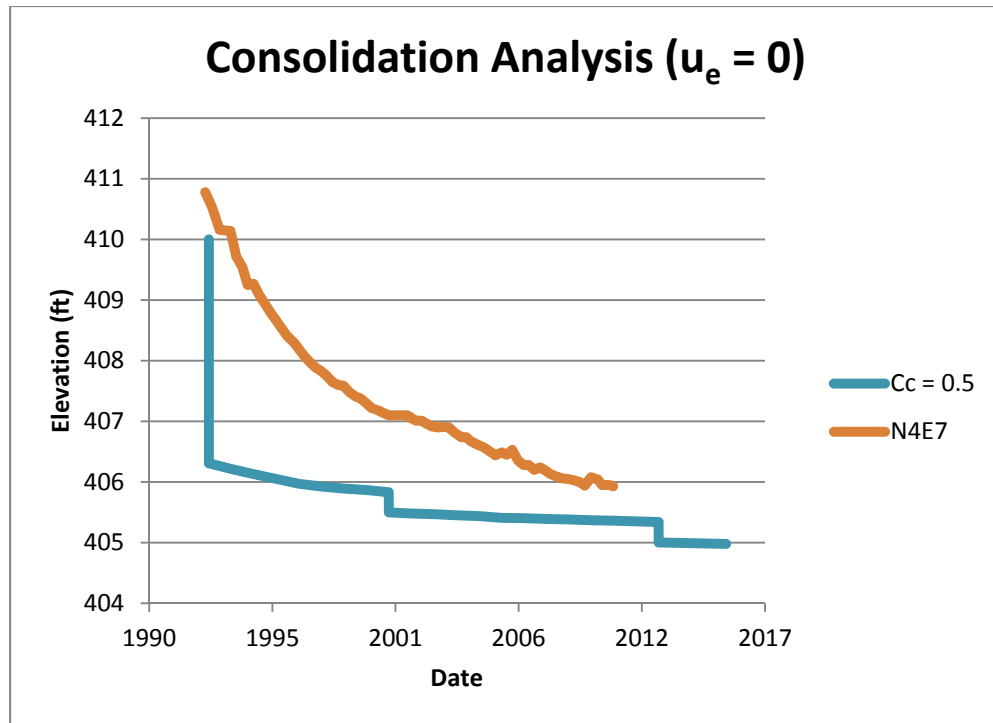


FIGURE 17B - Approach 1 ($C_c=0.5$) with additional lift of fill and N4E7 Settlement Monument Data

As expected, the settlements predicted with Approach 1 exceed the actual monitored settlements at any given time. This can be attributed to the assumption that the excess water pressures will dissipate at the same rate at the reduction in ground water elevation.

FIGURE 18 illustrates the magnitude of the time dependent settlements induced solely by the lowering of the water table.

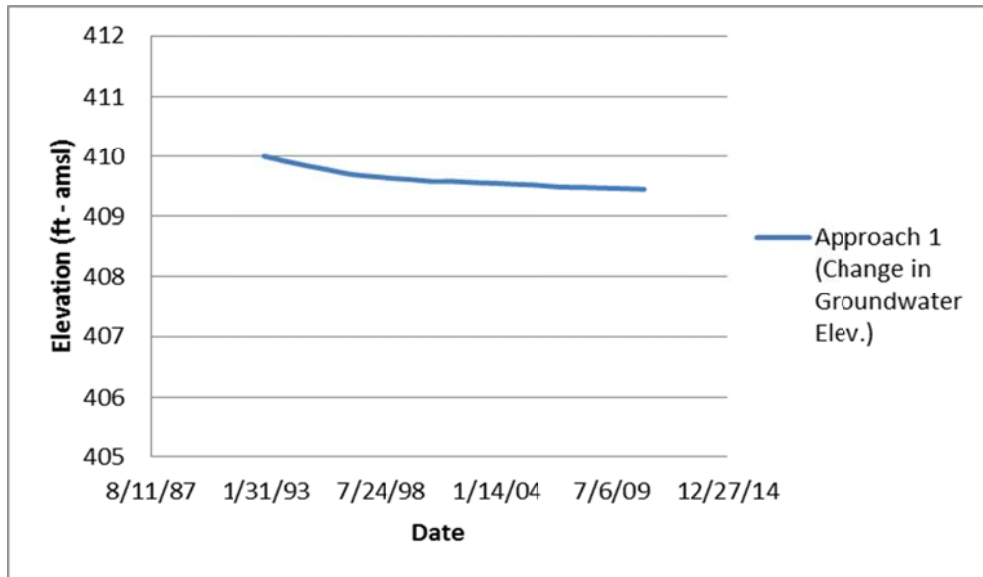


FIGURE 18 - Approach 1 Settlement due to Change in Water Table Elevation

APPROACH 2: TIME-DEPENDENT SETTLEMENTS DUE TO LOADING WITH COVER SOILS

A second analysis was conducted, Approach 2, which takes into account the time history of the settlements by accounting for a consolidation coefficient (c_v). The ultimate settlement under the load applied was initially defined using C_c . The analyses were conducted by assuming that the water table level remains constant and, accordingly, that settlements are solely induced by having placed fill over the tailings material. The percent of consolidation is subsequently estimated, allowing quantification of the amount of consolidation that has occurred at a given time. FIGURE 19A shows the effect of settlement due to placement of cover system in 1993 (First Cover) and the additional lift in 2001 (Second Cover). By the time the addition of the second cover was placed, the settlement caused by the first cover is assumed to have reached a maximum (i.e. the consolidation process due to the initial cover is assumed to have been completed). The placement of additional fill in 2001 induced further settlements, also illustrated in FIGURE 19A. FIGURE 19B illustrates the case of an additional (third and final) soil lift, with a thickness of six (6) feet. This additional lift is hypothetical and was adopted as it would bring the elevation of the surface approximately back to original grade. The ultimate predicted settlement induced by this additional soil lift equals 0.33 ft.

FIGURE 20 compares the monitored settlement data collected by 2010 against the settlements predicted using Approach 2. This approach is able to capture the trend in the settlement data. However, as it does not account for the additional settlement induced by lowering of the water table, the predicted settlements are somewhat smaller than the field monitored data.

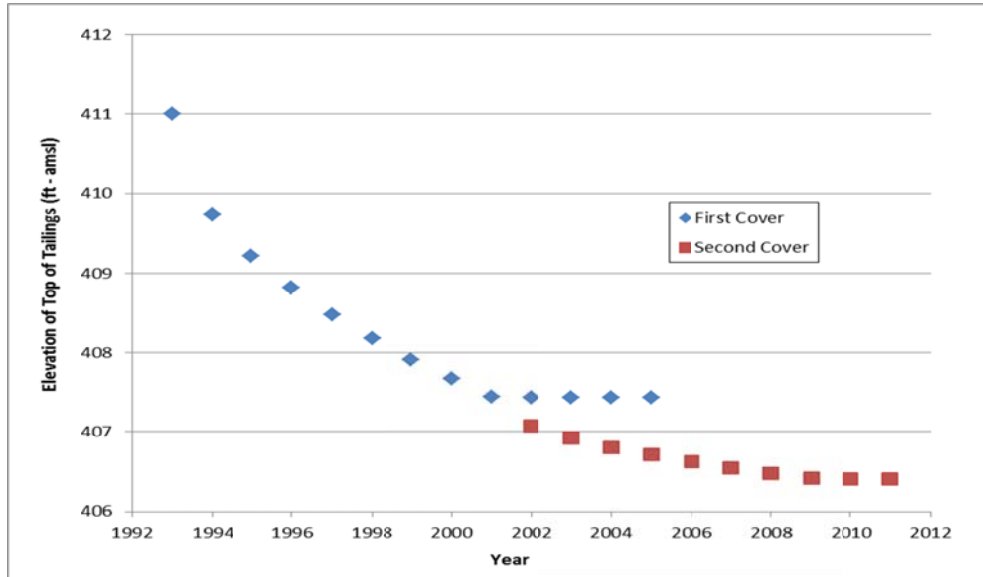


FIGURE 19A - Settlements Using Approach 2

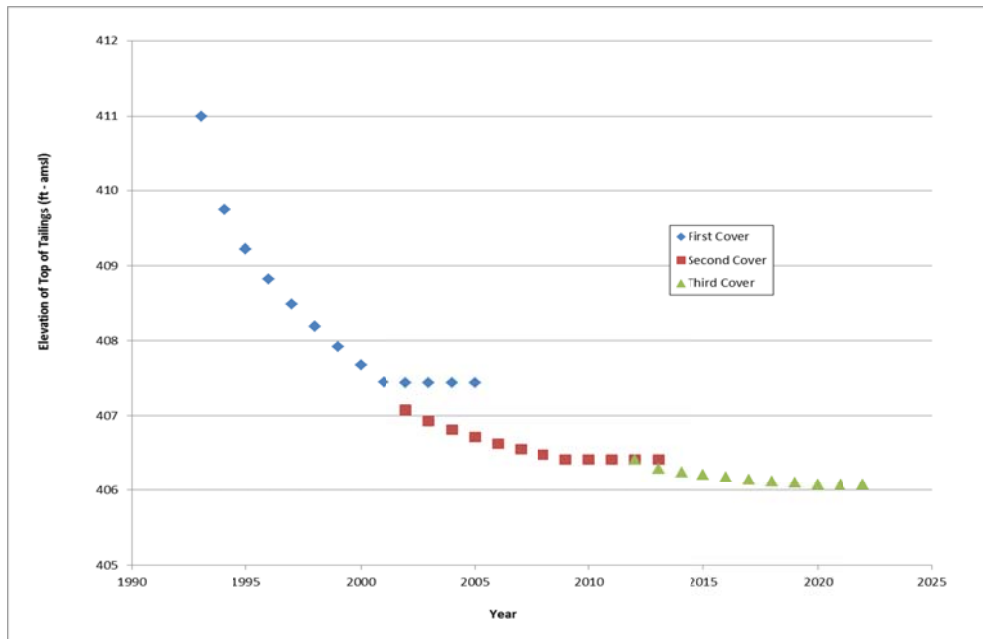


FIGURE 19B - Settlements Using Approach 2 with a third lift of fill

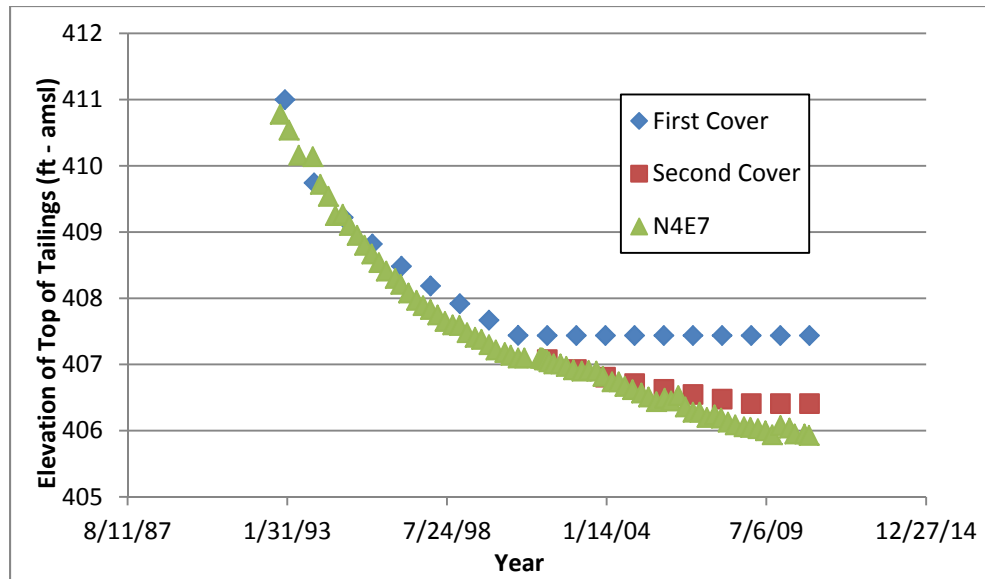


FIGURE 20 - Approach 2 ($C_v=120$ ft²/day) with N4E7 Settlement Monument Data

APPROACH 3: TOTAL SETTLEMENT WITH THE EFFECT OF CONTINUED LOWERING WATER TABLE

Approach 3 takes into account not only the loadings induced by placement of cover soils (in 1993 and 2001), but also the increase in effective stresses induced by the lowering of the water table.

Rigorously, the time-dependent settlements induced by a given load can be estimated using conventional one-dimensional consolidation theory only if the excess pore water pressures from a previous loading have already dissipated. Consequently, the analyses presented in Approach 2 assume that any remaining excess pore water pressures (from the first loading) has become negligible at the time of the subsequent loading. This assumption is deemed accurate for the one-dimensional analyses conducted in this study.

Also, the time-dependent settlements calculated using Approach 1 to predict the settlements induced by the lowering of the water table are considered to be accurate if the rate of lowering the water table is slow enough that excess pore water pressures remain reasonably low. This is considered a reasonable assumption. Consequently, a combined approach is considered in Approach 3. Specifically, the settlement caused by the surface loading (Approach 2 – Figure 19A) will be added to the settlement cause solely by the drop in elevation of the water table (Approach 1 – FIGURE 16). FIGURE 21 presents the settlements predicted using Approach 3 (settlements previously calculated using Approach 2 are also shown as reference). FIGURE 22 presents a comparison of the settlements predicted using Approach 3 against the field monitoring data from monument N4E7.

The settlements predicted using Approach 3 are shown to match well the monitoring data. Further testing of the tailings will refine the parameters used in the calculations and will allow for more accurate calculations.

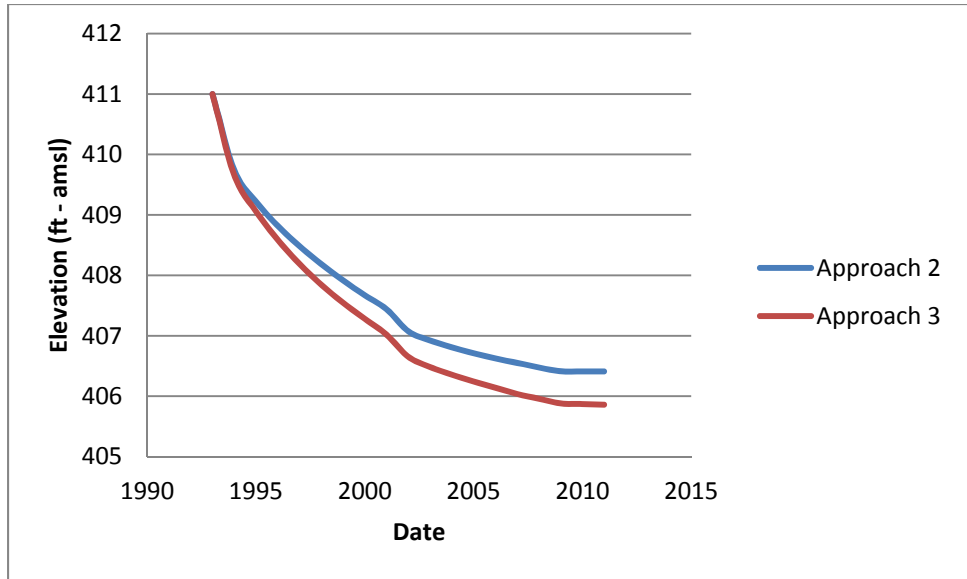


FIGURE 21 - Approach 2 and Approach 3

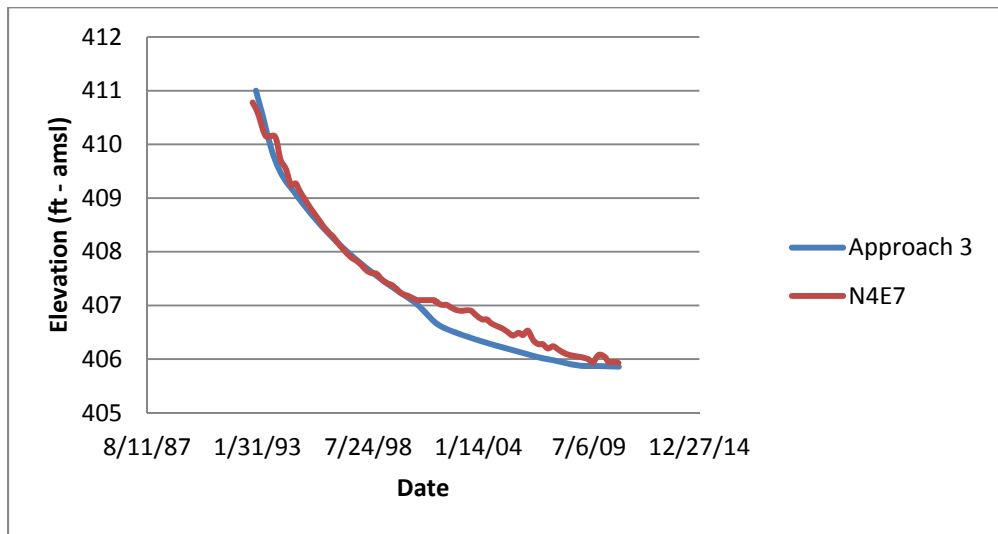


FIGURE 22 - Approach 3 with N4E7 Settlement Monument Data

Approach 2 indicates that the settlement caused by the second cover has completed and the remaining settlement will be caused by the lowering of the water table. Assuming the parameters of consolidation and rate of water table reduction (0.5 ft/yr) remain the same, settlements can be projected assuming

continued lowering of the water table. At the present rate of drop of the water table, the perched water table will continue to drop until 2051, inducing an additional settlement of 0.24 feet to a final tailings surface elevation of 405.62 feet. FIGURE 23A shows the monitoring data from surface monument N4E7 settlement data along with the predicted settlements through 2051. This prediction is based solely on the fact that there will be no additional loading sequences placed at the surface and that the water table will continue to drop to the base of the tailings. The remaining settlement will then be due to the final consolidation of the tailings, due in part to the drop in the water table.

If an additional lift of soil placed over the current cover soils, the settlements induced by this additional load can be predicted. FIGURE 23B presents the results considering additional 6 feet of soil placed in 2014. As shown in the figure, the total settlements increase by 0.33 feet, bringing the final tailings surface elevation to 405.29 feet above mean sea level. The fill itself is assumed to be incompressible (i.e. all settlements are due to compression of the tailings material). Accordingly, the predicted settlements correspond to a total of 20 feet of fill above the tailings surface (10-foot thick fill and cover system, 5-foot thick fill in 2001, 6-foot thick additional fill in 2014). The final surface elevation will be approximately 426.29 feet amsl for these loading conditions.

This has been calculated by breaking the consolidation of the tailings into individual years and the predicted height of the perched water table at that time. This aspect is particularly significant because it shows the effect of the water table within the tailings and how it will affect the site in the future.

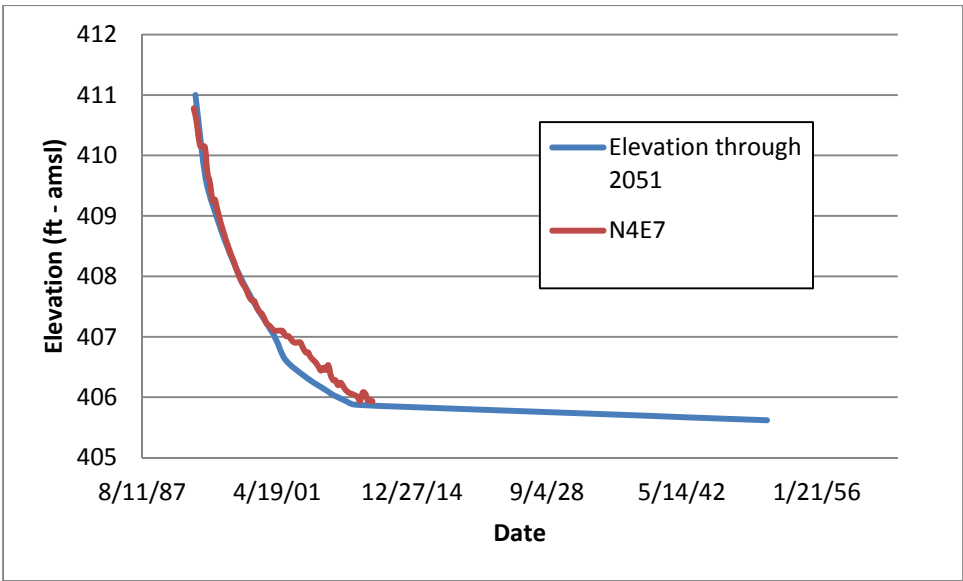


FIGURE 23A - Ultimate Settlements (Through 2051)

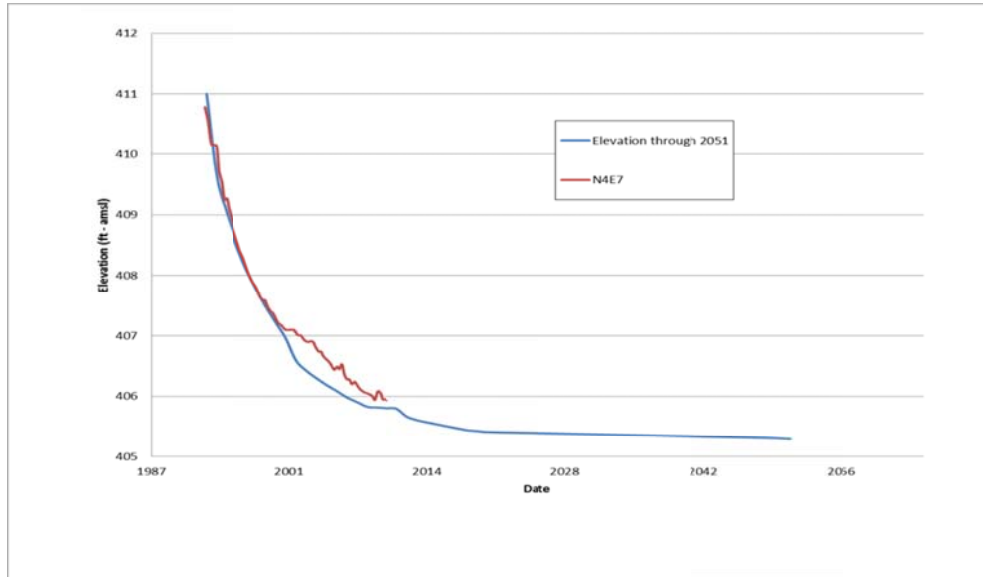


FIGURE 23B - Ultimate Settlements with additional fill in 2014 (Through 2051)

Chapter 4: Finite Element Analysis

An additional evaluation to assess the settlements at the site was conducted using a finite element simulation. The simulation was conducted using the code PLAXIS. This simulation will allow for a multi-dimensional assessment of the site. The site materials will be classified as linear-elastic materials and will be based on Young's Modulus (E). Young's Modulus, in the multi-dimensional analysis, is comparable to the coefficient of compressibility, in the one-dimensional analysis. Young's Modulus measures the elastic response and the ability to deform under a load. Increasing the amount of dimensions in the analysis can lead to an over-prediction of settlements. The initial layout and material properties were constructed from reports based on past subsurface investigations. Specifically, analyses conducted by Tetra Tech (Conoco Philips 2011) were evaluated as part of this investigation. The analyses were conducted using the codes SEEP-W, SIGMA-W, and FLAC. The input data used in those analyses was considered adequate and consistent with the information available from the site. Consequently, the analyses conducted in this study were conducted using a different finite element code in order to validate the results reported by Conoco Philips 2011.

FIGURE 24 shows the layout of the subsurface generated design with labels for each soil type. FIGURE 25 shows the material properties used for the PLAXIS design for each given soil type. FIGURE 26 depicts the generated mesh from the PLAXIS output. The PLAXIS figures in the following section show elevations from 280 feet to 425 feet (the thickness of subgrade being observed) and a length of 3600 feet (the width of impoundment).

PHASE DESCRIPTIONS

After the materials were defined and the mesh was generated, the next step was to define the loading history. The history was broken into seven (7) stages, which can be seen in PLAXIS format on FIGURE 27. The seven (7) stages were as follows:

1. Initial Phase (1991-1992): Two (2) years of consolidation of the tailings under its own weight (FIGURE 28)
2. Phase 1 (1993): Construction of fourteen (14) feet of fill in one (1) year (FIGURE 29)
3. Phase 2 (1994): Construction of five (5) feet of fill in one (1) year (FIGURE 30)
4. Phase 3 (1995-1997): Consolidation of tailings under weight of fill for three (3) years (FIGURE 31)
5. Phase 4 (1998-2002): Consolidation of tailings under weight of fill for five (5) years (FIGURE 32)
6. Phase 5 (2003-2007): Consolidation of tailings under weight of fill for five (5) years after additional five (5) feet of fill placed in 2001 (FIGURE 33)
7. Phase 6 (2008-2010): Consolidation of tailings under weight of fill for three (3) years (FIGURE 34)

It should be noted that the elevation of the perched water table was reduced at a rate of 0.5 ft/year. Also, the objective of the finite element simulation was to reproduce the settlements that have occurred so far. For prediction purposes, the results of the one-dimensional analysis are considered more appropriate. As indicated in Chapter 3, one-dimensional analyses indicate that the ultimate predicted settlement induced by an additional soil lift of 6 ft equals 0.33 ft.

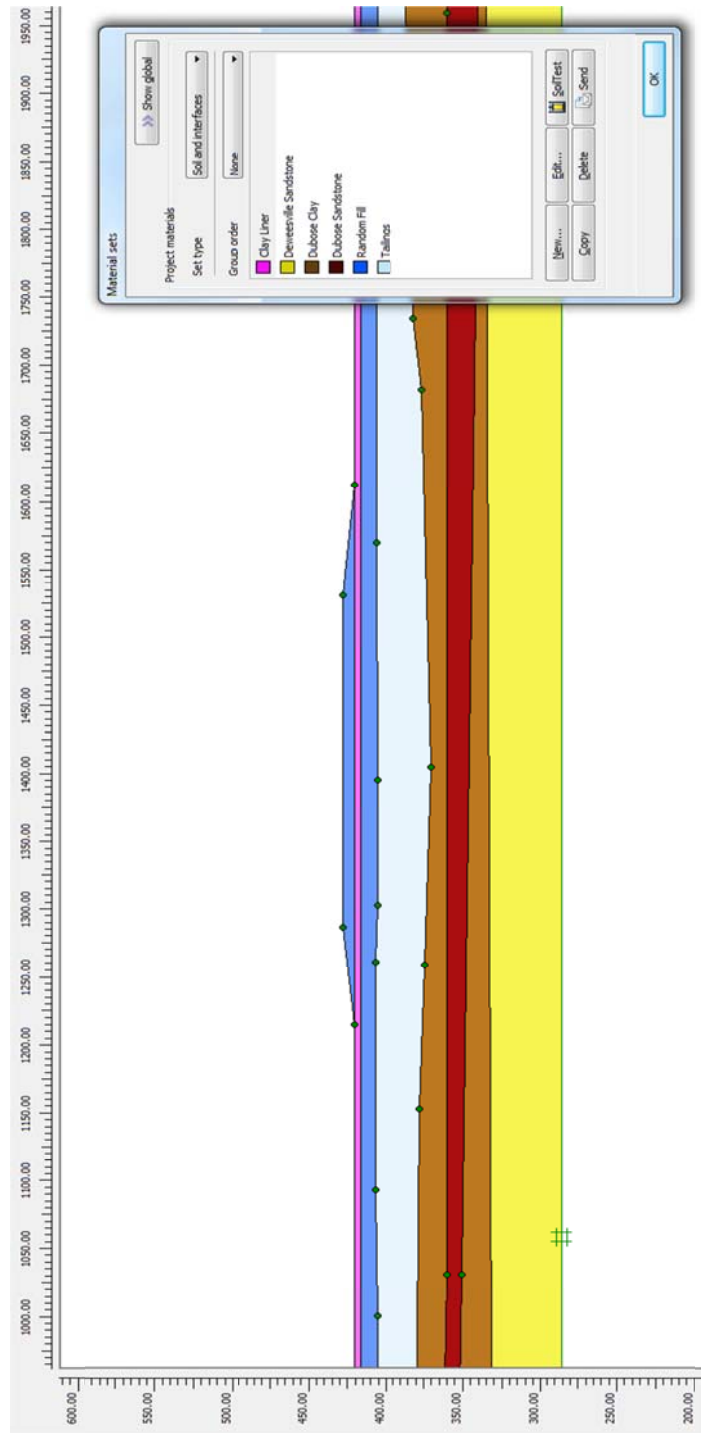


FIGURE 24 - PLAXIS Cross Section with Material Labels

| Property | Unit | Material | | | | | | | |
|------------------------|--------------------|------------------------------|------------------------|------------------------------|------------------------|------------------------------|------------------------|------------------------------|------------------------------|
| | | Clay Liner | Deweeseville Sandstone | Dubose Clay | Dubose Sandstone | Random Fill | Tailings | | |
| General | | | | | | | | | |
| Material Model | - | Linear Elastic Undrained (A) | Linear Elastic Drained | Linear Elastic Undrained (A) | Linear Elastic Drained | Linear Elastic Undrained (A) | Linear Elastic Drained | Linear Elastic Undrained (A) | Linear Elastic Undrained (A) |
| Drainage | - | | | | | | | | |
| γ_{unsat} | lb/ft ³ | 80 | 137 | 90 | 137 | 109 | 137 | 109 | 46 |
| γ_{sat} | lb/ft ³ | 100 | 137 | 114 | 137 | 124 | 137 | 124 | 83 |
| $e_{initial}$ | - | 0.6 | 0.35 | 0.6 | 0.4 | 0.7 | 0.4 | 0.7 | 2.5 |
| Parameters | | | | | | | | | |
| E' | lb/ft ² | 1.60E+06 | 6.00E+08 | 1.60E+06 | 1.25E+08 | 1.60E+06 | 1.25E+08 | 1.60E+06 | 4177 |
| ν' | - | 0.25 | 0.3 | 0.25 | 0.3 | 0.25 | 0.3 | 0.25 | 0.25 |
| Data Set | - | USDA | USDA | USDA | USDA | USDA | USDA | USDA | USDA |
| Model | - | Van Genuchten | Van Genuchten | Van Genuchten | Van Genuchten | Van Genuchten | Van Genuchten | Van Genuchten | Van Genuchten |
| Type | - | Clay | Sand | Clay | Sand | Clay | Sand | Clay | Clay |
| < 2 μ m | % | 65 | 4 | 65 | 4 | 65 | 4 | 65 | 85 |
| 2 μ m - 50 μ m | % | 20 | 4 | 20 | 4 | 20 | 4 | 20 | 12 |
| 50 μ m - 2 mm | % | 15 | 92 | 15 | 92 | 15 | 92 | 15 | 3 |
| k_x | ft/day | 5.67E-05 | 16.5 | 1.65E-04 | 53.4 | 5.67E-05 | 53.4 | 5.67E-05 | 2.83E-05 |
| k_y | ft/day | 5.67E-05 | 16.5 | 1.65E-04 | 53.4 | 5.67E-05 | 53.4 | 5.67E-05 | 2.83E-05 |
| Flow Parameters | | | | | | | | | |

FIGURE 25 - PLAXIS Material Properties

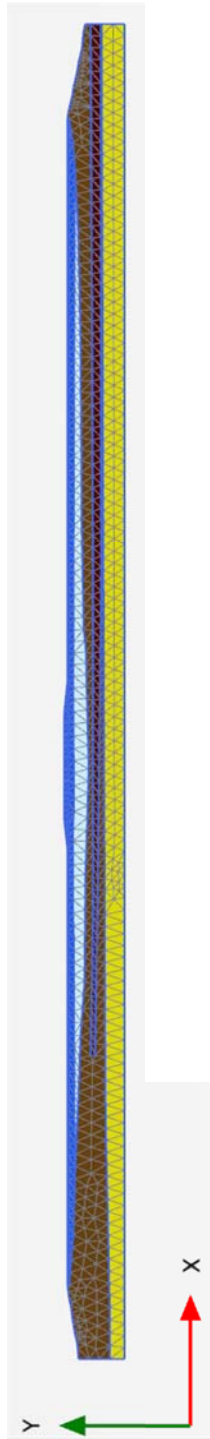


FIGURE 26 - Generated Mesh from PLAXIS

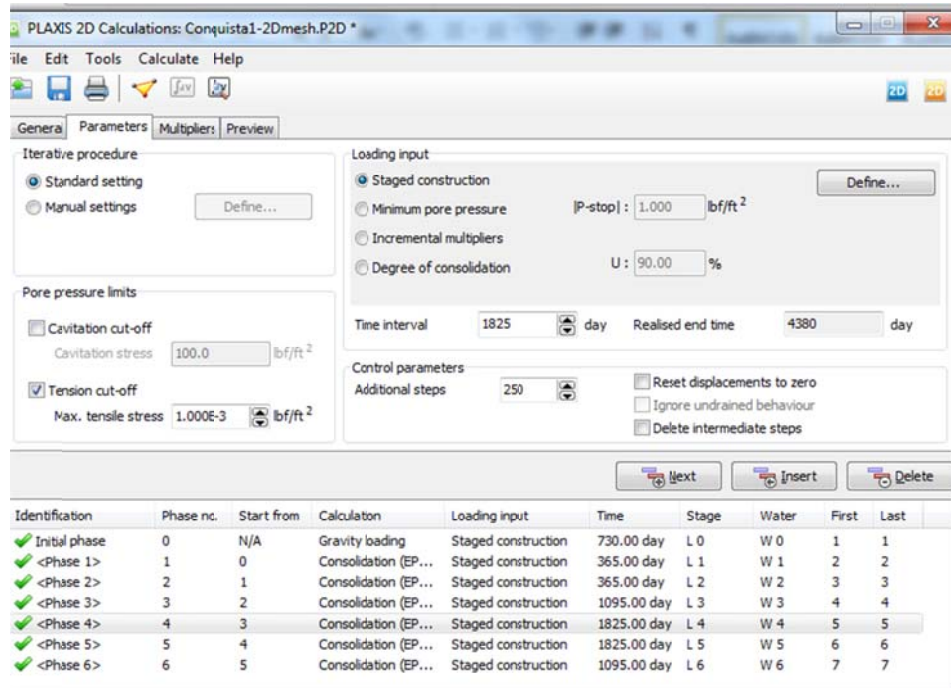


FIGURE 27 - PLAXIS Phase Descriptions

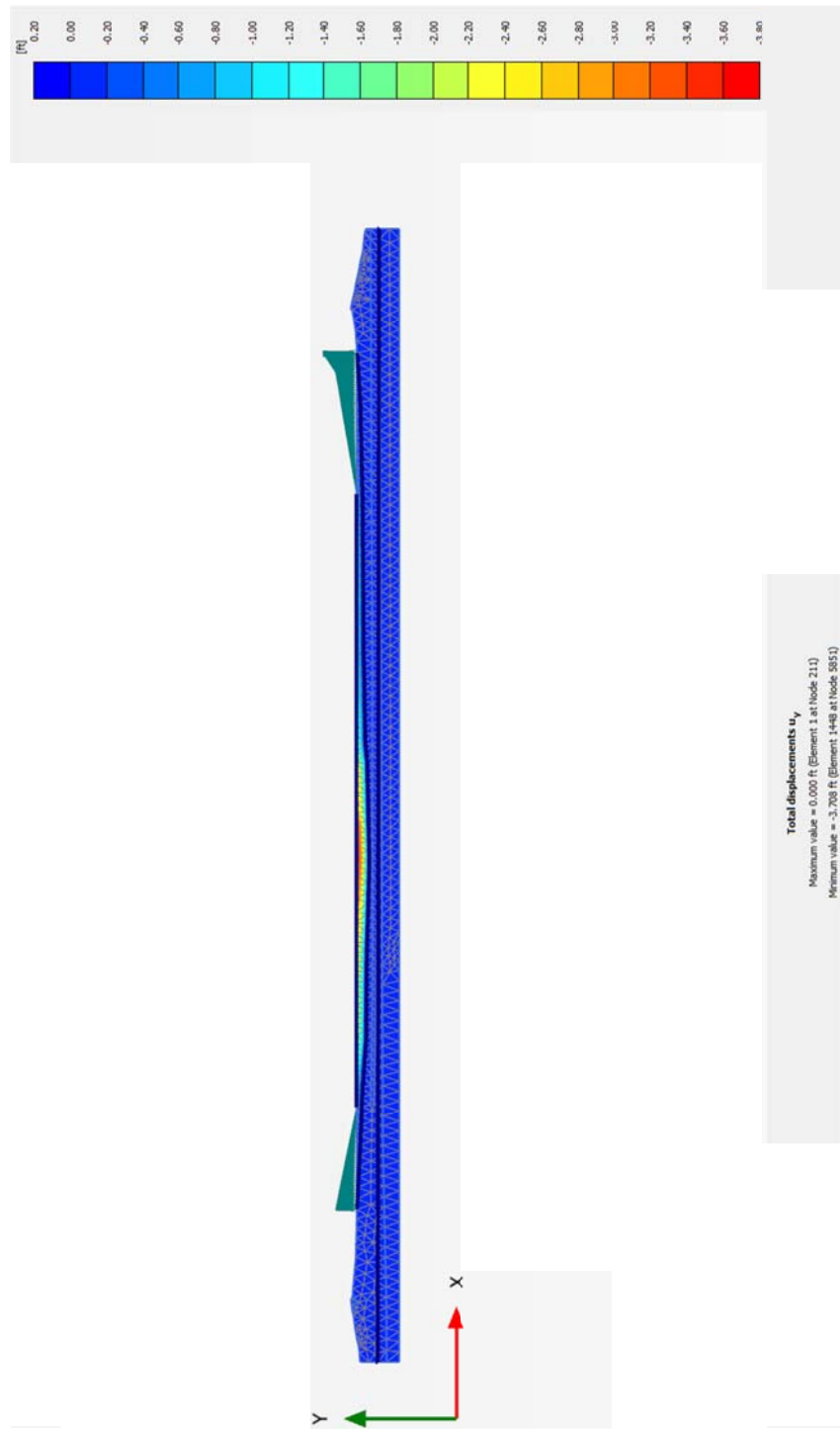


FIGURE 28 - Initial Phase

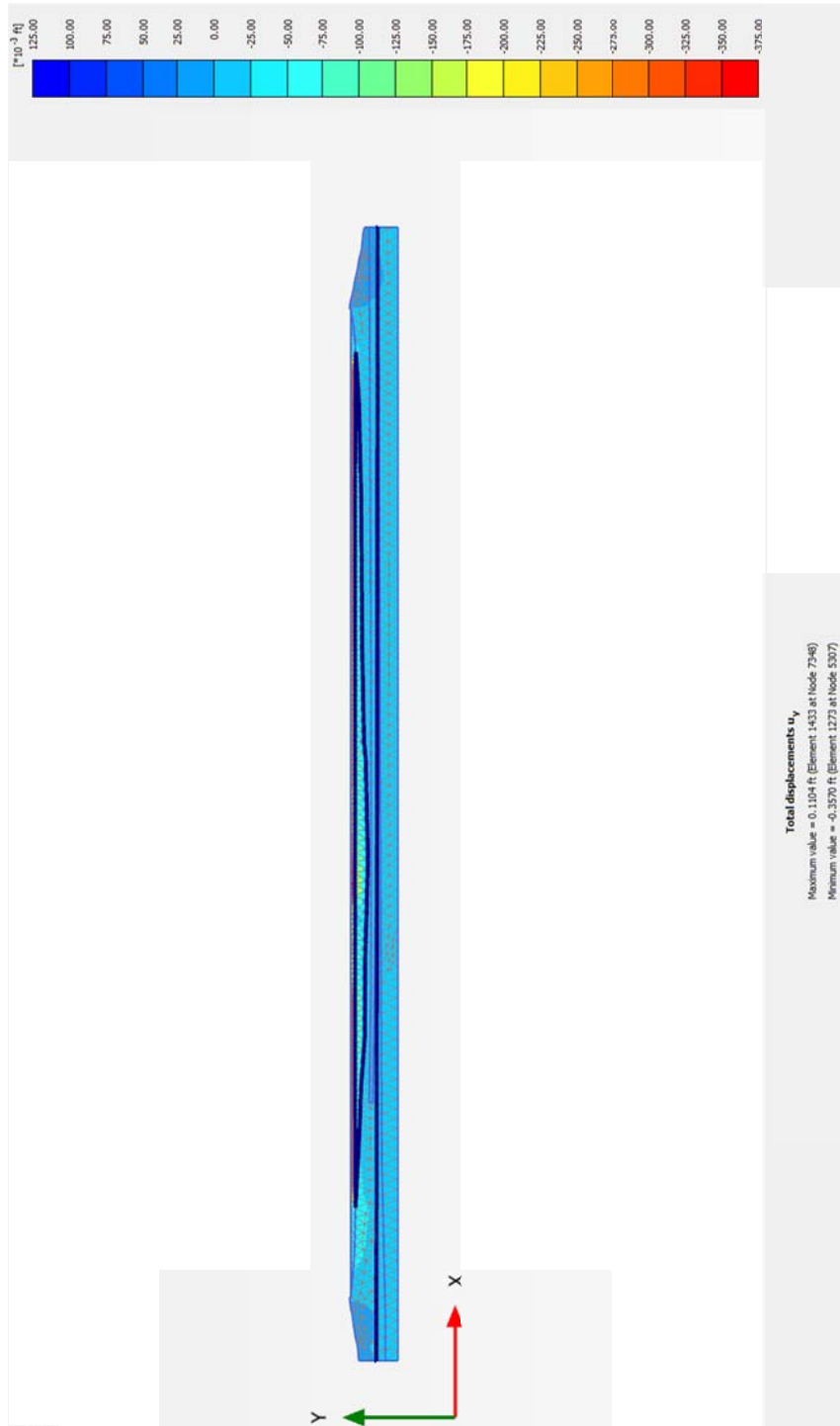


FIGURE 29 – Phase 1

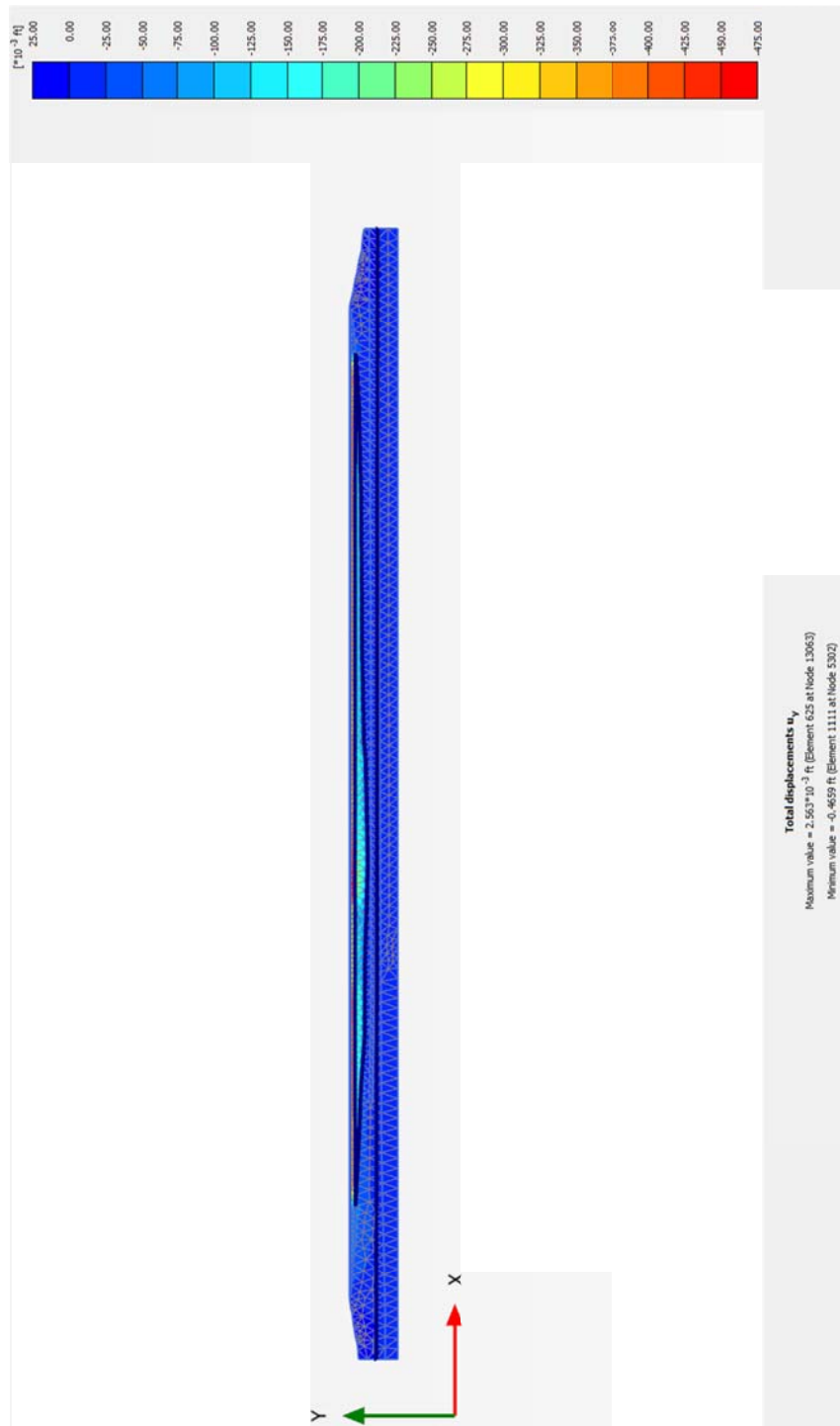


FIGURE 30 – Phase 2



FIGURE 31 – Phase 3



FIGURE 32 – Phase 4

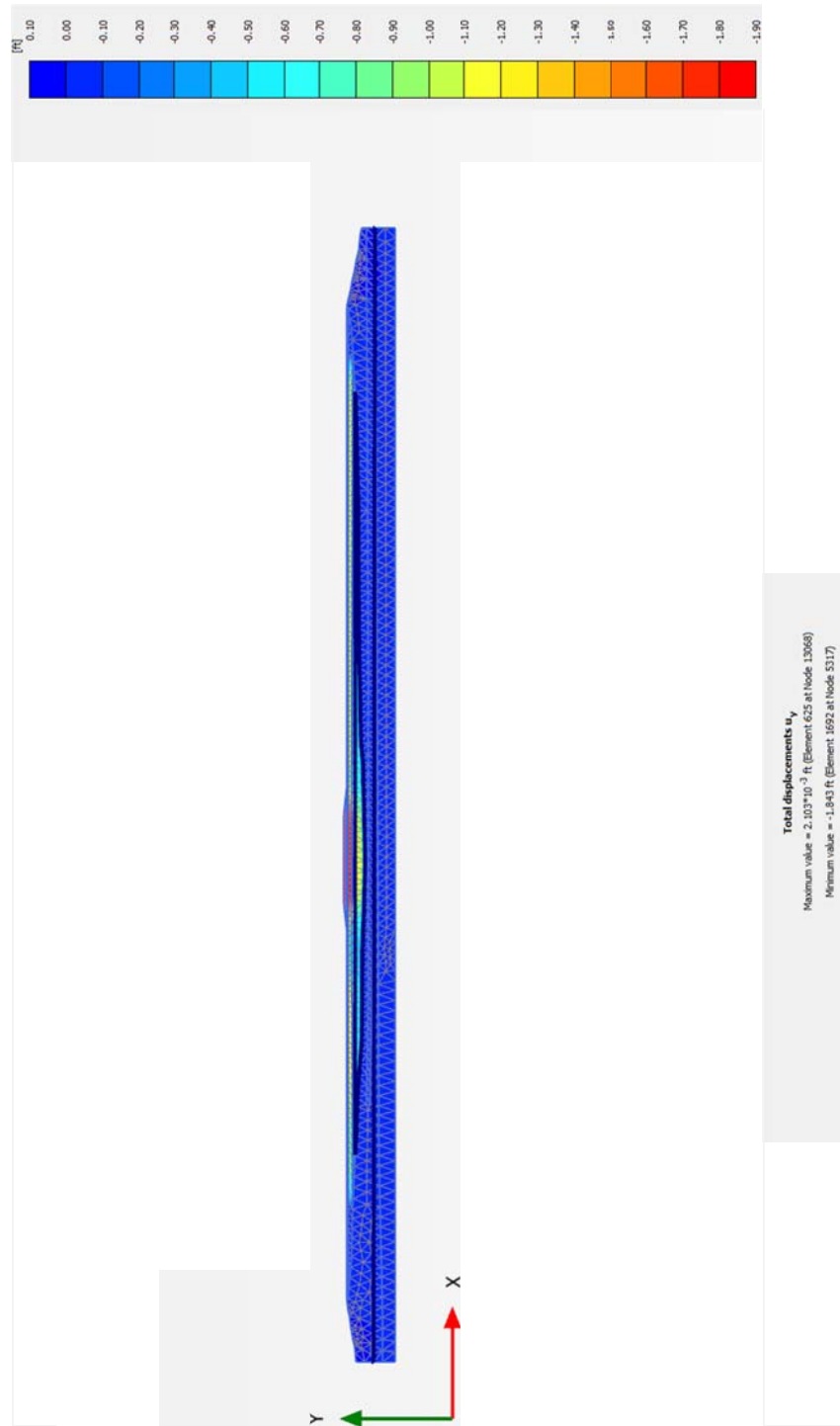


FIGURE 33 – Phase 5



FIGURE 34 – Phase 6

SETTLEMENT ANALYSIS

Previous finite element analysis has been completed by others on the Conquista Tailings Impoundment (Conoco Phillips, 2011). The analyses were conducted using the finite element codes SEEP-W, SIGMA-W, and FLAC. While it is difficult to compare all results from the analyses obtained by Conoco Phillips (2011) and those obtained in this study, focus was placed on the comparison of the highest predicted settlements. Specifically, the maximum settlement predicted in the study presented in this report (using PLAXIS) equals 10.5 feet. This value compares well with the maximum settlement of approximately 10 feet predicted by Conoco Phillips (2011). The area of greatest settlement and concern has been consistent throughout the other reports and is located above the area of thickest tailings. The settlements output by PLAXIS are shown to occur in stages (FIGURE 35). The phases break down the loading history of the impoundment. Each phase has been designed to account for the lowering of the perched water table as well as the two loading sequences from the cover and additional fill.

The initial phase creates the largest settlement due to the virgin tailings that exist below when the cover system is placed. The next three (3) phase settlements are controlled by the lowering of the water table and continued settlement of the material. In phase 4 the additional lift is placed which creates another jump in settlement felt by the tailings. The reason the settlements increase through stages 5 and 6 is due to the time duration that is being analyzed.

| Settlement By Phases | |
|------------------------------|-----------------|
| Phase | Settlement (ft) |
| Initial | -3.708 |
| 1 | -0.357 |
| 2 | -0.4659 |
| 3 | -0.6845 |
| 4 | -1.385 |
| 5 | -1.843 |
| 6 | -2.094 |
| Total Settlement (ft) | |
| | -10.5374 |

FIGURE 35 – Maximum settlements predicted using finite element code PLAXIS

Chapter 5: Conclusions and Recommendations

CONCLUSIONS

This report presents a compilation of historical documents provided by TCEQ and reviewed for the purpose of understanding the characteristics and loadings at the Conquista Tailings Impoundment. Of particular relevance was the evaluation of settlement and water level data obtained from monitoring at the site. Unfortunately, the property of tailings obtained so far was obtained from samples collected in the western portion of the site, while the largest settlements (and the focus of this report) are on the performance of the eastern portion of the site. The collected information was complemented with data generated using one-dimensional consolidation analyses and finite element analysis.

One-dimensional analyses were conducted using superposition of settlements induced by a series of loads applied to the tailings material. These analyses were able to reproduce well the magnitude and trends trend observed using field data collected so far. This has aided in identifying the significant role that the lowering of the perched water table plays in the time-dependent settlements observed in the field. The continued lowering of the water table (at a rate of 0.5/yr) has led to seemingly continued settlements at the surface, even after settlements induced by the cover placement could have reached a plateau. The total settlement that is expected from the lowering of the water table is 2.1 feet and is expected to stop in 2051.

At the end of the consolidation process, the settlements induced by the loading of the tailings materials with fill placed in 1993 and 2001 is predicted to be 5.5 feet. By 2051 the final elevation of the ground surface at the location of surface monument N4E7 will be 419.62 feet amsl without any additional work to the grading of the area. If another layer of fill material is placed in the future (e.g. in 2014), additional settlements will be triggered. Specifically, If 6 feet of additional fill are placed as part of an engineered final cover system or for grading purposes; the final elevation of the ground surface at the location of surface monument N4E7 will be 425.29 feet amsl.

The finite element simulations conducted using the code PLAXIS led to results that are consistent with those obtained in previous studies using codes SEEP-W, SIGMA-W and FLAC. The results obtained in the finite element simulation difer from those obtained using one-dimensional analyses. This is due, in part, to the fact that the input parameters and time history are less refined and more difficult to control in the finite element simulation than in the one-dimensional analysis.

Both methods do show that the overall trend of monitored settlements can be explained by conventional consolidation theory, provided that the loading history is properly simulated.

RECOMMENDATIONS

Further characterization of the tailings material collected from the eastern portion of the tailings impoundment is recommended. It appears that significant assumptions have been made regarding the compressibility parameter and the time history of settlements. These parameters and results can be significantly refined with the availability of additional experimental and monitoring data. To date, the data that was available for consolidation analysis dates back to 1987 and is from the western portion of the site. The values reported in those reports sets the compression index at 0.2, while back-calculation of this parameter using monitoring results of settlement collected at the eastern portion of the site yields a value of approximately 0.5. Additional experimental results from samples of tailings material could lead to relevant refinement of the results predicted in this investigation.

In addition, no site historical documents were identified with infiltration analyses that predict the long term hydraulic performance of the cover system. Accordingly, characterization of the cover soils is recommended. It is unclear if the cover soils are expected to act strictly as a barrier or as an evapotranspirative component. Large cracks have been noticed in the eastern portion, while minimal to no cracking was observed on the western portion. The cracks that were observed ranged from 5-14 inches in length and between 2-4 inches in thickness. It appears that little emphasis has been placed on the predicted infiltration of water through the engineered cover. Prediction of cover performance should be conducted based on the results of the soil cover characterization.

REFERENCES

- Antinuclear.net/2010/01/11/dangers-of-radioactive-uranium-mill-tailings*. August 2, 2012.
- Cna.ca/curriculum/cna_can_nuc_hist/uranium_hist-eng.asp?bc=History%20of%20Uranium&pid=History%20of%20Uranium*. March 2012.
- Conoco Phillips. *Consolidation and Settlement Analysis for Conquista Tailings Impoundment*. June 14, 2011.
- Dames & Moore. *Proposed Expansion of Tailings Disposal Facility, Conquista Project*. February 13, 1987.
- Maxim Technologies. *Site Characterization/ Groundwater Conceptual Model Report*. May 2006.
- Seekingalpha.com/ article/ 34858-miners-lobbied-us-doe-to-revive-uranium-price*. August 2, 2012.
- Steffen Robertson and Kirsten. *Conoco Conquista Project – Tailings Impoundment Cover Repair Plan*. June 2000.
- Tetra Tech, Inc. *First Quarter 2011 – Tailings Inspection Report and Settlement Monument Survey Results*. April 26, 2011.
- Tetra Tech, Inc. *Groundwater Site Characterization Revision*. March 31, 2011.
- Tetra Tech, Inc. *Second Quarter 2004 – Tailings Impoundment Inspection Report and Settlement Monument Survey Results*. August 3, 2004.
- Tetra Tech, Inc. *Second Semi-Annual Groundwater Monitoring Report for 2010, Conquista Project Site*. March 2011.
- Texas Commission on Environmental Quality (TCEQ). *Site Visit and Report to Support Cone Penetration Testing and Inspection Work at Conoco Conquista (License R01634) Tailings Impoundment, Visit of September 14-19, 2010*. September 29, 2010.
- Texas Commission on Environmental Quality (TCEQ). *Site Visit to Conoco Conquista (License R01634) Tailings Impoundment and Site Trip Report, Visit of February 16, 2010*. February 24, 2010.
- Uraniuminfo.org/files/Sibley's%20Uranium%20Mining%20in%20Texas.pdf*. March 2012.
- Waste, Water & Land, Inc. *Description of Closure Plan In Application of Termination of Radioactive Material License 9-1634*. November 24, 1987.
- Waste, Water & Land, Inc. *Description of Closure of The Conquista Project Tailings Impoundment*. July 1994.
- Waste, Water & Land, Inc. *Summary of Field and Laboratory Testing, Conquista Tailings Basin*. August 1986.
- Wise-uranium.org/uvai.html*. July 2012.
- World-nuclear.org/ education/ mining.htm*. March 2012.