Appendix A Summary of Highland Modeling and Containment Transport Assessments

This Appendix presents a summary of groundwater flow and contaminant transport assessments previously prepared for the Highland Mine and Millsite. This summary was prepared in response to the Nuclear Regulatory Commission (NRC) request in its letter dated January 14, 2010 (Response to Notice of Intent to Submit a License Amendment for the ExxonMobil Highland Reclamation Project, License SUA-1139). In the letter, the NRC requests that certain elements accompany the license amendment application, including *"a description of all models used to predict contaminant concentrations seeping from the mill tailings, and any issues that could bear on the validity of those models"*. The following summary provides details related to models and assessments that were used to estimate both tailings seepage rates and concentrations of chemical constituents in seepage from the Highland Tailings Impoundment. It also provides a discussion of the evolution of the hydrogeologic and geochemical conceptual site models (CSM) based on available data as they relate to the predictions of previous modeling.

Various seepage rate and chemical transport assessments were developed between 1972 and 2007, covering the entire period prior to mine development to approximately 20 years after mining and milling had ceased. A description of the primary seepage rate and transport assessments follows.

1973 – Final Detailed Statement on the Environmental Considerations, prepared by the United States Atomic Energy Agency (ADAMS ML 102730143)

Prior to mining, initial estimates of potential seepage and transport of chemical constituents were made based on limited data and assumptions of how the tailings basin would be operated. Seepage estimates were developed based on a one-dimensional analytical approach (e.g. Darcy's Law). At that time no quantitative estimates of chemical transport rates and/or concentrations within groundwater were available. Key findings as quoted from the study include:

- "Seepage from the tailing reservoir is expected to be confined principally to the tailing dam sand unit (TDSS) immediately above the tailing dam shale (TDSH) member".
- "The tailing dam sand unit is only partially saturated with water".
- "...drill holes through the shale (TDSH) in the tailing pond area disclose dry sandstone immediately beneath the shale whether or not water is present above the shale"
- "No natural water flow pattern in the tailing dam sand unit can be determined..."
- "Groundwater present beneath the tailings pond area is not part of the normal water table as vertical communication is prevented by the tailing dam shale."
- "Initially, 80 gallons per minute (gpm) is expected to seep from the tailing basin walls and 20 gpm through the face of the dam".

- "...seepage will eventually diminish to about 1 to 10 gpm over a period of 2 ¼ years because of the sealing effect" (from tailings).

- "Seepage that will occur through the dam is expected to evaporate as soon as it reaches the surface". "Exxon has stated that a seepage collection basin would be installed below the dam if seepage occurs in such an amount that it can be effectively measured, collected, and pumped."

- "No appreciable migration of waste chemicals or radioactive materials from the seepage from the retention system is expected because of the ability of most soils to remove contaminants from liquids through ion-exchange, adsorption, and chemical reactions."

- "...groundwater monitoring wells have been drilled at 4 locations around the tailings storage basin to detect subsurface seepage of tailings solution."

- "During reclamation, since water pumping will have ceased, the water table will return to its normal level producing two lakes with groundwater and rainfall"

- "The quality of these lakes is expected to be the same quality as groundwater in the area".

- "A buildup of radioactivity is not expected to occur in these lakes for the following reasons: (1) The ore-grade material is to be completely mined and removed from the pit, (2) no water accumulation will be in the pits at the time the upper part of the pit walls will be blasted, and (3) exposed uranium minerals will be covered by several feet of rock and soil blasted down from the pit walls. Consequently, no large areas of uranium minerals in the pit walls will be exposed to the atmosphere for oxidation or weathering."

Discussion

This document presents a summary of pre-mining observations and data related to groundwater conditions in the area for the proposed Highland Mine and Millsite. At that time, the groundwater in the TDSS was considered isolated from the regional flow system based on observations of unsaturated conditions beneath the TDSH. The observation of unsaturated to partially saturated conditions in the TDSS and underlying Ore Body Sandstones (OBSS) prior to mining is important, because these observations are fundamental to the current hydrogeologic CSM. Later studies were based on a conceptual model that assumed significant discharge from TDSS and OBSS outcrops in the vicinity of the tailing dam. This assumption is not supported by pre-mining observations, it is doubtful that the regional groundwater system actually consisted of significant discharge in the outcrop areas prior to active mining.

Early estimates of potential seepage from the tailing impoundment were based on a limited, pre-mining data set and a one-dimensional analytical estimate of potential maximum flows. A sensitivity analyses and/or range of flow estimations was not provided. Estimates of potential migration of constituents at that time were based on a theoretical assessment of the assimilative capacity of the soil and estimates of the cation exchange capacity of Highland soils. A significant body of scientific literature on the environmental chemistry of uranium and selenium available since 1973 indicates that the estimates made regarding the attenuation of these constituents are not justified under the conditions present at Highland during active milling.

1978 – Identification of Future Water Problem, Highland Uranium Mine and Mill, prepared by Dames & Moore

The study described in this report was conducted to estimate groundwater and surface water availability for mine operations covering the period 1978 to 1985, based on mine plans in place in 1977. The study included development of an analytical groundwater model to estimate yield from dewatering wells, along with an analytical surface water flow model for nearby drainages to estimate potential surface water supplies. While modeling was not specifically focused on assessing tailing pond seepage rates and constituent transport, the study does include descriptions and estimates of tailing pond seepage. The study explicitly includes "tailings seepage to the open pits" as a source of water for process water at the mine and includes it as a source in predicted water supply management scenarios. Based on the assessment of various water sources, it is implied that tailings seepage was observed entering the mining area and was being used in 1977 as a source of water for the mill and tailings process.

Key findings from the study are summarized as follows:

- In 1978, approximately 1,000 gpm was produced from dewatering wells and water pumped from both the underground and surface mines.
- Dewatering well production supplied plant needs for uses "where high quality water is needed".
- Process water was obtained principally by pumping from the open pits, and was stored in the mill ponds and process water tank.
- Process water was defined as "1) well water in excess of that required for mill uses, 2) water produced from water-bearing strata being exposed by both underground and open pit mining, and 3) tailings pond water seepage into the open pits".
- Seepage from the tailings area to the open pits was noted to be occurring, and was estimated at 100 gpm in 1977. The seepage rate was estimated "*based on information obtained during previous studies and under the assumption of steady-state seepage conditions*".
- Tailings seepage to the open pits was predicted to decline to 30 gpm by 1982.
- Tailings seepage not reporting to the open pits was categorized as "lost", which was defined to be equal to "gross seepage minus seepage to the pits minus dam seepage reclaim."

- "Lost" seepage was estimated at 200 gpm in 1977, and was predicted to increase to 320 gpm in 1985 based on the expectation that the tailings dam would be raised in 1982.
- Total tailing pond seepage was estimated at 300 gpm in 1977, and was estimated to increase to 350 gpm in 1985.
- No discussion of seepage water quality is provided. However, it is clearly stated that only water from dewatering wells was available for use as potable water supply.
- The study concluded that insufficient sources of water were available to support the proposed mill expansion.

Discussion

This study recognized that, during active mining, tailings seepage was migrating to the surface mine and was a component of sump flows being pumped and used for various mine processes. The study identifies tailings seepage entering the open pits as a source of process water being used at the time, and an important component of the water balance for future expansion. Tailings seepage flow rates were estimated to comprise approximately 26% of the water being pumped from the open pits in 1977. In addition, the study notes that up to 350 gpm may have been seeping from the tailing impoundment into the TDSS. Results of this investigation show that the volume of tailings seepage was greater than pre-mining estimates. The recognition that tailing seepage was flowing into the active mining area is an important component of current CSM, as discussed in Section 1.2.2.7 of the main text.

1980 – Hydrologic Evaluation – Pit 5 Lake Reclamation, Highland Uranium Mine, Converse County, Wyoming prepared by Dames & Moore

This study was developed to evaluate hydrologic conditions around the proposed Pit 5, including an assessment of the nature and timing of pit lake development and a general prediction of long-term pit lake water quality. Mining at Highland was terminated before Pit 5 was mined and therefore this pit was not developed. However, the study does introduce an updated assessment of regional groundwater flow and discusses elements important to long-term lake development. The study included an assessment of 1) the source of water filling the lake, including expected quantities and quality, 2) the quality of lake water after equilibrium is reached, 3) expected water outflow and the effects on groundwater quality near the lake, 4) the expected shoreline elevation, and 5) potential end uses of the lake.

Results of the study can be summarized as follows:

- Regional groundwater flow conditions based on a study by Hagmaier (1971) are introduced, including the conclusion by Hagmaier that regional groundwater levels are at a maximum near Highland Flats, located west-northwest of the Highland Mine and Millsite.

- An estimated pre-mining groundwater potentiometric map is produced. Water levels in the region of planned Pit 5 are estimated at approximately 5,200 feet above mean sea level (ft amsl).

- Based on the conceptual model presented by Hagmaier (1971), regional groundwater was assumed to discharge east of the mine in outcrops near North Fork Box Creek.

- A two-dimensional steady-state finite-difference groundwater flow model was developed based on the regional conceptual model. The model was designed to "identify regions from which flow enters the pit, quantity of seepage entering the pit, expected areas of influence and an estimate of time required after mining operations cease to reach an equilibrium condition."

- The final elevation of the pit lake was estimated based on modeling at 5,175 ft amsl. This estimate was produced by iteratively running the model at different assumed lake elevations and reviewing the resulting groundwater inflows. These inflows were then compared to estimates of precipitation and evaporation to assess the Pit Lake water balance. The final elevation was chosen as a point where predicted groundwater inflows roughly match estimated evaporation conditions.

- The model predicted it would take approximately 40 years for the lake to reach equilibrium. The lake was predicted to rise 190 feet during the first 10 years after mining, with another 80 feet of rise predicted for the next 30 years.

- Identified sources of water to the lake included groundwater inflows, direct precipitation, runoff from both disturbed (mine impacted) and undisturbed (natural) areas. Discharge was calculated to be primarily from evaporation. Dames and Moore did not make an assessment of the potential for tailing seepage to flow toward the lake during mining or when the lake started filling with water.

- The lake is predicted to generally act as a regional groundwater sink, with groundwater inflows balanced by evaporation from the lake. As such, only groundwater influent chemistry is used in the pit lake chemical evaluation.

- Predicted surface and groundwater flow rates were used to develop a chemical mass balance based on measured and estimated water chemistry of the principal water sources to the Pit Lake. Dames & Moore estimated that groundwater derived from flow through backfilled pits was negligible, based on predictions that fill materials would have much lower permeability than the undisturbed aquifer.

- Because the lake was predicted to be a hydraulic sink, the study concluded that the lake would "*assume a character similar to other internally drained lakes in the region, such as Soda Lake, Pratts Soda Lake, and Nine-Mile Lake.*"

- Concentrations of various constituents were predicted to increase over time due to evapoconcentration. The lake was predicted to be "moderately saline (TDS 3,000 to

10,000 ppm) after 300 years." Natural uranium concentrations were predicted to rise to 287 pCi/L (0.42 mg/l) after 500 years.

- Stock watering and wildlife usage were noted as the main potential use for the lake.

Discussion

This study introduces a numerical groundwater flow model that has inputs related to pre-mining groundwater flow conditions that were based on a conceptual model introduced by Hagmaier in a 1971 PhD thesis. A key component of this conceptualization is that all the sandstones, including the TDSS and OBSS, act as a single flow system between recharge areas interpreted to the west-northwest of the site and discharge areas predicted to be at outcrop areas east of the Highland site. The regional conceptual groundwater model developed by Hagmaier (1971) was based on a limited number of regional deep wells, only five of which were located within five miles of the Highland site. Discussion related to vertical separation between individual sandstones observed at the Highland site and subsequently observed at in-situ uranium recovery (ISR) facilities located near Highland was not provided. Relatively elevated groundwater levels were used as inputs to the model for the Highland site to represent local pre-mining groundwater conditions. The estimated pre-mining gradients used to develop the model were based primarily on information from the Hagmaier thesis and a very limited data set. Pre-mining observations of unsaturated conditions at the outcrop areas also are not accounted for in this conceptualization.

The use of the Hagmaier regional conceptual model has important implications, because the hydrologic inputs developed provided the primary basis for predictions of long-term pit lake levels in this and subsequent models. The potential uncertainties in this conceptual model, along with discrepancies with observed pre-mining conditions at Highland, are not discussed or accounted for. This study focuses on the flow of regional groundwater to pit lake as understood at the time. The study did not directly assess the potential for tailings seepage or other mine-impacted groundwater to affect long-term pit lake chemistry.

1982 – Highland Uranium Tailings Impoundment Seepage Study, prepared by Exxon Production Research Company (ADAMS ML102730142)

This study was prepared toward the end of active mining and milling to "address questions posed by NRC regarding the amount and direction of seepage from the Highland Uranium tailings impoundment, and seepage into North Fork Box Creek." The study included three components; 1) a laboratory program to quantify the chemical interactions between pond liquor and geologic strata underlying the impoundment, 2) a geologic model to describe the structure and lithology of the principal sandstone and shale units, and 3) a model to predict the seepage from the pond and the migration of solutes in the seepage . Both the geologic model developed based on boring logs from drilling at the site, and the laboratory tests of chemical interactions of seepage with the rock from the site were used as inputs into the modeling.

The groundwater flow and chemical transport model was developed using a finite difference approach, and consisted of developing three detailed cross-sectional models simulating both horizontal and vertical flow and transport through geologic strata underlying the tailings pond. A two-dimensional areal model was also developed to assess horizontal flow and transport over a larger area of the site. The models were developed based on data from approximately 30 monitoring wells, most of which were installed during 1980 and 1981. Exxon developed model transport parameters based on the laboratory batch tests. The models were used to simulate seepage rates and solute transport from 1972 through the end of the mine life, which was anticipated to be December, 1983, and after closure out to year 2000.

Results of flow and transport modeling can be summarized as follows:

- Seepage from the tailing impoundment into underlying TDSS, which outcrops directly beneath the pond, is predicted to rapidly increase early in the mine life to approximately 100 gpm before significant buildup of tailings in pond begins to restrict vertical movement.

- Seepage from the tailings impoundment is predicted to decrease between 1974 and 1975 to 50 gpm, and then increase at a rate of approximately 19 gpm per year until the maximum pond elevation is reached in 1983. The maximum seepage rate is predicted to reach approximately 200 gpm in 1983 at the end of the mine life.

- Seepage from the tailings impoundment is then predicted to decrease at a rate of approximately 38 gpm per year after the mill is shut down and the pond dries out. Seepage is predicted to cease in 1991 after all the water in the pond has evaporated or drained from the tailings into the TDSS.

- The maximum lateral movement of the unattenuated seepage front is predicted to occur to the west of the pond, reaching the northern edge of Pit 2 in 1992. The seepage front is predicted to move a maximum of 1,300 feet to the southwest and 300 feet to the northwest of the pond by 2000.

- Migration of the acidic front (low pH) was predicted to be highly attenuated, moving a maximum of 500 feet from the pond.

- Vertical movement of seepage was predicted to move through the TDSH into the upper ore body sand (50SS). The acidic front is not predicted to migrate vertically through the TDSH.

- Transport assessments were made primarily by using "relative" velocities developed by multiplying the simulated flow velocities by factors ranging from 1.0 (unattenuated) to 0.05 (highly attenuated). Various attenuation factors were used for various chemicals within tailings seepage. All radionuclides were predicted to be highly attenuated and the maximum predicted migration was less than 100 feet from the impoundment. Most other metals were also assumed to be attenuated and to migrate at rates slower than the simulated groundwater velocities.

- Results from simulations for 1972 through 1982 were compared with site chemical data to assess the overall calibration of the transport model. The model was noted as being in "good agreement" with monitoring well data north and south of the pond. Solute migration east of the pond (toward North Fork Box Creek) was noted as being underestimated by the model. It was also noted that the model under-predicted solute migration to the west of the pond by up to 1,300 feet (i.e. chemicals were already 1,300 farther to the west in 1982 than predicted by the model). It was noted that this was likely due to "high permeability streaks or vertical leakage near the tailings discharge spigot".

- Groundwater flow into North Fork Box Creek was predicted to increase from a pre-mining rate of approximately 20 gpm to a maximum of 40 gpm during pond operation. Seepage was then predicted to decrease to approximately 7 gpm as the pond dried up and the tailings drained over time.

- Groundwater flow is predicted to return to "regional flow" conditions by 1995, and solutes are predicted to be "swept to the east" at a velocity of about 35 feet per year.

Discussion

This study provides the first detailed assessment of potential tailings seepage rates and constituent transport using numerical modeling. The model was based on data available in 1982, which was limited to a number of newly installed monitoring wells. Predicted tailings seepage rates from the model are generally reasonable, and are within the range of estimates produced in 1978 from observations during active mining.

It was noted in the report that the model under-predicted seepage migration to the east and west, which generally coincide with the primary migration pathways identified in Section 1.2.2.7 of the main document. Comments received at the time from WDEQ noted the following in relation to the modeling study and model predictions:

- "Dewatering operations at the mine cause groundwater to flow toward the surface mines from the area under the tailing impoundment."

- "If attenuation of solute movement has been overestimated, discharge of these solutes to the proposed permanent impoundments west of the tailings pond and North Fork Box Creek east of tailings pond could be a very serious concern."

- "...it appears that there is a good chance that solutes will be discharged into the pit."

The results of the batch tests conducted as part of this study and the attenuation factors (e.g. relative velocities) had a profound impact on transport predictions of this and all subsequent models with the exception of the most recent Pit Lake model (Attachment 2). While batch tests are an accepted method for approximating partition coefficients (EPA, 1999), batch tests can be problematic when the elements that are being evaluated are redox sensitive, as are selenium and uranium. As discussed in Section 2.2.3.1, the mobility of both uranium and selenium is highly dependent on redox conditions, both being highly mobile under oxidizing conditions and significantly less mobile under reducing conditions. In theory, the batch tests are designed to measure constituent attenuation by adsorption and ion exchange reactions. However, removing samples from the environment and placing them in air-tight jars, can also change the redox conditions. Under reducing conditions, selenium and uranium would likely be reduced and removed by precipitation reactions rather than adsorption or ion exchange reactions, and thus caution must be used, with redox sensitive elements, when interpreting batch test data. This would likely not have been completely appreciated in the early 1980's when these tests were performed. It was not until the mid to late 1990's that the scientific community began to realized the importance of redox conditions and the direct role of microorganisms in controlling the mobility of these elements (Lovley, 1993; Lovley, 1995; Oremland, 1994).

As discussed in the main document (Sections 1.3.3 and 2.2.3), the current understanding of the migration of redox sensitive constituents indicates that there was likely much less attenuation of uranium and selenium than predicted by the batch tests owing to differences in redox conditions. Our current understanding of the biogeochemistry of these constituents supports the concept that these constituents likely would be mobile and transported readily under the oxidizing conditions that are expected to exist during active mining, and prior to installation of monitoring wells near the tailing impoundment. Water quality data collected from monitoring wells near the tailings impoundment, within the backfill, and within the Highland Pit Lake clearly show that tailings seepage flowed into the mined areas in the past.

1983 – Surface Mine Reclamation Lake Study for Highland Uranium Operations, prepared by Exxon Production Research Company

This study presents an evaluation of the hydrologic characteristics of the lake formed by "allowing the surface mine to fill naturally with water." The Exxon study differs from the Dames & Moore 1980 Pit Lake assessment, as this study focused on mine Pits 3 and 4. The study assessed the quantity and quality of water flowing to the pit during the time lake was filling with water, which included groundwater inflows, direct precipitation, and surface water runoff (including routing Antelope Creek into the pit). Groundwater inflows to the lake during development were estimated based on an analytical method and the expectation of radial flow out from the tailings impoundment toward the pit. Pit Lake water quality was estimated based on measured and estimated inflow water quality. The study used a "Lake Simulation Program (LSP)" that makes the simplifying assumption of a well mixed system to achieve generally instantaneous equilibrium concentrations during Pit Lake development.

Results of the study can be summarized as follows:

- Precipitation, surface water runoff, and groundwater inflows will fill the pit slowly over a period of approximately 100 years to a maximum elevation of 5,118 ft amsl.
- During lake filling, flows from tailing seepage and backfilled pits were not explicitly simulated or accounted for.

- At the lake's maximum elevation, water will discharge from the lake primarily by evaporation (~ 88%) and groundwater outflow toward the east (~12%).
- Given that groundwater inflow is estimated to be greater than groundwater outflow, and that significant evaporation is predicted to occur, concentrations of chemical constituents are predicted to increase over time.
- The LSP model was used to predict long-term concentrations of TDS and dissolved radium-226 only. Concentration data from a variety of surface water and groundwater sources were used in the study.
- The LSP model predicted that TDS and radium levels in the lake would rise to approximately 4,100 ppm and 16 piC/l, respectively, over 2000 years of lake life.

After several thousand years, sediment was predicted to accumulate to a depth covering all aquifers once intercepted by the lake. At that time, the lake is predicted to be hydrologically and geochemically similar to many stock water ponds in the area.

Discussion

This study represents the first detailed study of potential hydrologic and water quality conditions within the Highland Pit Lake as currently configured. Predicted flows to the lake were strongly influenced by the regional conceptual model of groundwater flow from Hagmaier (1971), as previously discussed. Incorporating the Hagmaier conceptual model that regional groundwater gradients force flow from the west toward discharge at outcrop locations east of the Highland tailings impoundment constrains the predicted long-term lake level to an elevation within a limited range set by the regional gradient. The study does not account for the fact that if the Hagmaier regional conceptual model was not representative of long-term groundwater flow conditions, then the long-term lake levels predicted could be in error.

As noted, pre-mining observations indicate that the TDSS was locally isolated from deeper groundwater, and that the deeper sandstones were partially saturated to unsaturated near the outcrops. Recent water level data have confirmed that the system has generally returned to this condition, with numerous TDSS wells at the outcrop drying out as the system has de-saturated. Given these observations, it is doubtful that the regional groundwater gradients contemplated in the Hagmaier work representing all sandstone units were reflective of actual conditions prior to mining. As such, the pit lake assessment likely over-predicts the long term level of the pit lake.

1984 – Reclamation Lake Water Quality for Highland Uranium Operations, prepared by Exxon Technical Services Division, Development and Operations Department (ADAMS ML102860099)

This study updates the 1983 study and presents an updated assessment of predicted hydrologic and geochemical characteristics of the long-term Pit Lake at Highland from the EPRCO 1983 study. The update was desired based on the fact that additional mining in 1983 changed the size and shape of the planned lake. The study included predictions related to the potential effect of pit wall sloping that were not included in the 1983 study. Specifically, this study evaluated the potential affect that sloping and covering all or a portion of the TDSS outcrop in the pit walls would have on Pit Lake water quality, where this was not evaluated in previous study.

Results of the study are summarized as follows:

- The study notes potential issues with the 1983 study, as follows:
    - The previous study did not evaluate the potential affect of backfill cover over any of the TDSS aquifer inflow or outflow zones outcropping in the final open pit.
    - The previous study used a TDSS permeability of 2 darcys, which was lower than indicated by field tests at the mine.
    - At the time of the previous modeling, Exxon planned to route flow from Antelope Draw to the Pit Lake, and.
- The 1984 modeling used the same modeling program as used in 1983 modeling thus providing directly comparable results.
- Exxon predicted that covering the TDSS outcrop in the pit wall would significantly restrict the rate of both inflows to and outflows from the pit. Because the previous study predicted that most of the flow was derived from the TDSS, restricting flow rates have a significant impact on simulated results in this model. The LSP model was run with a scenario assuming that both 50% of outcrop would be covered with backfill, and another scenario assuming 100% of the outcrop would be covered.
- Various TDSS permeabilities were simulated by Exxon, ranging from 4.0 to 5.0 darcys.
- Simulations were run both with and without inflows from Antelope Draw.
- The model was used with all combinations of scenarios to simulate variations in the long-term Pit Lake level and in concentrations of radium and TDS.
- Results of LSP model are summarized as follows:
    - If 50% of the outcrop was covered and flow from Antelope Draw was diverted to the Pit Lake, over the range of TDSS permeabilities, the Pit Lake elevation ranged from 5126 to 5132 ft amsl, radium concentrations ranged from 9.37 to 11.50 piC/l, and TDS ranged from 3122 to 3645 ppm.
    - If 50% of the outcrop was covered and flow from Antelope Draw was not diverted to the Pit Lake, over the range of TDSS permeabilities, the pit lake elevation

ranged from 5114 to 5123 ft amsl, radium concentrations ranged from 11.91 to 16.91 piC/l, and TDS ranged from 4376 to 5843 ppm.

  - If 100% of the outcrop was covered and flow from Antelope Draw was diverted to the Pit Lake, over the range of TDSS permeabilities, the pit lake elevation ranged from 5110 to 5114 ft amsl, radium concentrations ranged from 42.00 to 63.65 piC/l, and TDS ranged from 11,164 to 16,020 ppm.
  - If 100% of the outcrop was covered and flow from Antelope Draw was not diverted to the Pit Lake, over the range of TDSS permeabilities, the pit lake elevation ranged from 5096 to 5101ft amsl, radium concentrations ranged from 149.00 to 162.56 piC/l, and TDS ranged from 37,920 to 39,120 ppm.

- The results show that if TDSS flow rates are lowered due to backfill covering the pit wall, the lake is predicted not to fill to the point where groundwater would discharge, and thus water quality in the lake in subject to evapoconcentration over the long term.
- The study concludes that the option with 50% backfill cover of the TDSS outcrop would produce reasonable water quality, independent of flows from Antelope Draw.

Discussion

As with the 1983 pit lake study, a principal issue with this study is the use of regional groundwater flow conceptual model developed by Hagmaier (1971), which constrains the range of potential long-term lake levels based on the regional gradient. The study does not discuss in detail estimates of reduced inflows based on pit wall backfill cover. It is unclear how backfill used to slope the surface would significantly reduce flows over the long term, but this evaluation points to the sensitivity of the method to TDSS flow rates. This study does point out that lower inflow rates to the lake over the long-term will result in lower stable lake levels.

1988 – Phase 2 Final Report, Exxon Highland Tailings Seepage Analyses, prepared by Water, Waste, and Land, Inc.

This study focused on using data from monitoring wells installed after 1980 to assess the suitability of the flow and transport model developed by EPRCO in 1982. The study focused on understanding whether the groundwater level and chemical transport conditions predicted by the seepage model developed in 1982 adequately predicted conditions observed between 1982 and 1988, and whether the model's longer-term predictions could be considered reasonable. The study included a comparison of model predictions to current (1987) water level and water quality data, development of predictions of steady-state chemical concentrations in backfilled mine pits, and an evaluation of alternatives "suitable for mitigating the groundwater situation at the Highland Site."

Results of the study are summarized as follows:

- Data from numerous wells installed after 1980 were available and used in the assessment to develop piezometric surface and chemical isoconcentration maps representing observed conditions in 1982, 1985, and 1987.

- The study notes that steep gradients existed in the TDSS between the tailing impoundment and mined areas in 1982, which was observed to decline between 1982 and 1987.

- Comparison of model predictions in the TDSS to observed heads for the time periods all indicated "large head differences", with the maximum head difference occurring west of the tailing impoundment (between the tailing impoundment and the mined area). In most instances, observed water levels were significantly higher than those predicted by the 1982 model.

- The under-prediction of water levels west of impoundment was attributed to "predicted early establishment of the regional flow, which is not yet evident in the actual data".

- Water levels collected in the TDSS in newly installed wells west of the mine pit were noted as being "much lower than predicted", and that "regional flow back into the mine area has not occurred to the extent predicted."

- A summary of the model comparison in the TDSS was provided as follows:

    - "The regional gradient was less than initially estimated and subsequently used in the ERPCO flow model."

    - "The dewatering program affected the surrounding aquifers to a greater extent than initially estimated."

    - "The constant head boundaries imposed along the western boundary of the modeled area were too close to the mine area causing the model to under-predict the amount of drawdown which occurred due to dewatering and mining operations."

    - "The permeability of the TDSS was simulated as higher than actually exists."

- Significant downward gradients between the TDSS and 50SS were evident in the 1987 data as presented in the report; with water levels in the 50SS as much as 71 feet lower than the overlying TDSS.

- The study uses chloride as the conservative tracer and a concentration of approximately 200 mg/l (equal to that measured in the tailings solution) to represent the location of seepage movement away from the tailing impoundment. Concentrations of chloride in the TDSS were greater than 200 mg/l in monitoring wells between the impoundment and the backfilled pits and Pit Lake. It was noted that the "extent of seepage beyond these wells cannot be accurately determined."

- The ERPCO model predictions of chloride movement in the TDSS, as compared to 1987 observed conditions, "appear to be accurate to the north of the tailing basin but appear to overestimate seepage front migration to the south and underestimate seepage migration front migration to the east and west of the tailing basin."

- For the 50SS, ERPRCO model predictions were noted as being reasonably accurate to the east of the tailing dam, but that the "estimated location of the seepage front is substantially further to the west than predicted by the model."

- The data collected indicates that "steep gradients exist between the tailing basin and the backfilled pits, indicating a large portion of the tailings fluid will flow into the backfilled pits."

- Steady-state concentrations of constituents in the backfill were predicted based on the assumption that "all of the groundwater mound beneath the tailings basin will flow into the backfilled pits where it will be well mixed with existing pit groundwater". The maximum TDS concentration in the backfill was predicted at 2,760 mg/l, occurring in approximately 100 years.

- A study of potential mitigation alternatives to control groundwater flow included a grout curtain, a slurry wall, a pump-back system, and a no-action alternative. The objective of the alternatives was to "reduce the migration of contaminants in the TDSS away from the tailings basin."

- The study recommends the no-action alternative, based on the evaluation that the "low pH front will not move a substantial distance from the impoundment...and the relatively large costs associated with any of the active mitigation alternatives."

Discussion

This study provides an assessment of how previous estimates of seepage migration from the tailings impoundment match data collected through 1987. The majority of groundwater monitoring wells were installed in the early 1980s, and therefore data related to groundwater levels and quality are representative of the period late in the mine life, after tailings seepage had been occurring for some time. The results of this study point out again that the original model under-predicted seepage migration to the east and west of the tailings impoundment. Water levels were under-predicted near the impoundment. Newly installed wells west of the surface mine showed that the EPRCO model results, based on the regional model of Hagmaier, over predicted groundwater levels, and that water levels west of the mine are lower than those assumed by the regional conceptual model.

The findings that data indicated the tailing seepage had moved farther west than predicted in 1987 is consistent with previous studies that recognized that tailing seepage had moved into the surface mine area during active mining. This is also consistent with the current conceptual site model (CSM) described in the main document.

1989 – Supporting Information to License Amendment Response, Highland Reclamation Project, prepared by Water, Waste, and Land, Inc. (ADAMS ML103060256)

This study was provided in support of Exxon's response to the License Amendment issued by NRC on February 8, 1989 requiring Exxon to submit a corrective action program (CAP) to address groundwater exceedances of NRC protection standards. While the report does not present detailed groundwater flow or transport modeling, it does address the general fate and transport of tailings seepage in groundwater at Highland. The document describes environmental components affected by tailings seepage, potential hazards associated with tailings seepage, and an assessment of potential corrective actions to mitigate hazardous constituents at the site. This information is then used to develop proposed Alternative Concentration Limit (ACLs) for the site.

Pertinent information from the report is summarized as follows:

- The report notes that past studies "theorized" that regional groundwater flow in the TDSS discharged in outcrop areas east of the tailing impoundment. An updated conceptualization is provided postulating that these outcrop areas served as local recharge zones, with some discharge during wetter periods. Based on this updated conceptualization, groundwater beneath the tailings basin prior to mining was assumed to be "relatively flat with most of the groundwater...being relatively stagnant."
- During operations, seepage from the tailings basin resulted in a large groundwater mound. As the mound grew, it resulted in seepage into alluvial deposits downstream of the dam. It notes a seepage collection and pumpback system was installed in 1975.
- The study notes that during mining, dewatering caused a large "groundwater sink" to be developed in the area of active mining. The combined effects of the groundwater mound under the tailing impoundment and the groundwater sink in the mine area resulted in "most of the seepage flow from the tailings basin flowed toward the pit during active operations".
- The seepage from the pumpback system downstream of the tailings dam "ceased in 1987". On this basis, the study concludes that "inflow to the backfill is responsible for dissipation" of the groundwater mound beneath the tailings basin.
- The study notes that "the groundwater flow regime in the vicinity of the tailings basin is very transient in nature and these conditions are expected to remain for a significant time into the future."
- Over the long-term, after the pit lake has filled, it is "anticipated that conditions similar to those that existed prior to initiation of operations will be re-established." As such groundwater in the TDSS beneath the tailing impound is expected to return to a "relatively stagnant" condition.

- Long-term groundwater discharge from the TDSS is not expected to occur through outcrops along the abutments of the tailing dam. This is supported by the fact that the observed seeps dried out in 1987, when groundwater levels in the TDSS were well above the long-term predicted steady lake levels (approximately 5120 feet, ERPRCO, 1983). Discharge of groundwater from the TDSS is expected to occur south of the mine area in outcrops along North Fork Box Creek.

- A two-dimensional finite difference flow model was developed to assess the time required for dissipation of the groundwater mound beneath the tailing impoundment and to assess the performance of injection wells as part of corrective action. The model predicted that the mound would require between 20 to 60 years to dissipate fully, and that between 22.5 and 35.4 gpm of groundwater within the TDSS, derived primarily from tailing seepage, would flow into the backfill over a 50 year period.

- The study notes the "possibility for contamination of the lake (with tailings seepage) exists", but concludes that "most, if not all, contaminated water which currently exists in the TDSS must flow through the backfilled mine pits to reach the lake", and that the backfill materials have "excellent attenuating capabilities, particularly for hazardous constituents".

- The report highlights wells within the tailings basin footprint where tailings seepage is evident. The most recent groundwater quality data indicate that the majority of the wells in the TDSS in the tailings basin footprint were impacted, and the report states that "a considerable portion of the TDSS aquifer has been contaminated with tailings seepage."

- The volume of impacted water in the TDSS was estimated at approximately 1.9 billion gallons.

- Although no explicit predictions of long-term groundwater quality are provided, the report notes that poor quality groundwater is likely to persist within the TDSS in the vicinity of tailing impoundment for more than 100 years. This was based on predicted time required for the groundwater mound to dissipate, the Pit Lake to develop, and regional groundwater flow conditions to re-establish.

- A variety of short-term and longer term closure options are assessed, including limiting infiltration, various groundwater pumping and injection scenarios, installation of a slurry wall, and water purging. The study concluded that "the Highland Reservoir POE water quality will not be affected by whatever mitigation plan is implemented because of site specific hydrological and geochemical conditions".

Discussion

The assessments provided in this report are based on the recognition that tailings seepage flowed into the active surface mine area during mine operations, and that seepage into the backfilled pits and the Pit Lake would continue to occur in the future. The report also notes that the regional conceptual model as used in previous studies may not be reflective of actual conditions, and re-introduces a conceptualization that groundwater within the TDSS was mostly stagnant prior to mining, and will likely return to this condition over the long term. However, the study also suggests that the assimilative capacity of mine backfill materials will serve to restrict constituent migration toward the Pit Lake.

The results outlined in this previous ACL Application are generally consistent with the current understanding of tailings seepage conditions as presented in the main text. The expectation that migration of uranium and other hazardous constituents are likely highly attenuated in the backfill is a key difference between this and the current CSM presented in the main text. As previously noted, the current understanding of the biogeochemistry of selenium, and uranium does not support the conceptual model that predicts significant attenuation of these constituents in the backfill. In addition, considerable experience at other sites has shown that these constituents are not attenuated to the degree previously thought.

1998 – Hydrologic and Chemical Evolution of Highland Reservoir, Converse County, Wyoming, prepared by Shepherd Miller, Inc.

This study was designed to revisit and update the Pit Lake study developed by EPRCO in 1983 to assess long-term concentration of key constituents in the Highland Pit Lake. The study was based on 14 years of water quality data collection from the lake between 1984 and 1998. The study used a systems modeling approach using STELLA® to assess long-term concentrations of uranium, selenium, radium, and TDS in the pit lake. The model was calibrated to observed chemical conditions in the lake during the initial 14 years of lake development.

Key model inputs, assumptions and results from the study include:

- Sources of water flowing to the pit during lake development include groundwater inflows from the ore body sandstones (OBSS) and the TDSS, flow from a local perched groundwater flow system, surface runoff flows, and direct precipitation to the Pit Lake.
- Estimates of hydrologic inflows were developed based on methodology and results provided in the EPRCO 1983 study.
- Estimated inflow rates from precipitation, runoff, and flow from the perched aquifer were kept constant through the pit lake modeling. Precipitation and runoff volumes were scaled based on the predicted size of the lake surface and the changing area providing runoff as the lake level rises.
- Inflow from the TDSS was predicted to be zero until the lake level rose above the top of the TDSH, establishing hydraulic contact. As such, no TDSS inflow was simulated to occur until 18 years into Pit Lake development, and thus no inflow from the TDSS was assumed to occur during the calibration period.

- Outflows from the lake were assumed to be from evaporation and groundwater outflow once the lake was predicted to rise above the regional discharge point, predicted to be 5100 ft amsl. Groundwater outflows were predicted to begin 65 years into lake development.

- Chemical concentrations of the various groundwater sources were developed based on water quality sampling at the site.

- Hydrologic steady state for the lake was predicted to occur "within the first 200 years", with a stable surface elevation of approximately 5,119 feet, consistent with the 1983 EPRCO model.

- Groundwater inflow concentrations were initially assumed to represent background conditions. However, the model did not match observed conditions, as there was a greater mass of constituents observed in the lake than accounted for by using background concentrations.

- During calibration, chemical mass was added to groundwater inflows from the OBSS based on a predicted percentage of mixing with tailings pond seepage. The percentage of seepage mixed with the OBSS inflows was predicted to increase from near zero to approximately 10% of flows for the 14 year calibration period. The percentage of seepage flow in groundwater flowing to the pit was predicted to increase to a maximum of 16% of groundwater inflows at 40 years into lake development. The percentage of tailings seepage was then predicted to decline to near zero after 100 years.

- Calibration of the model also required that a source term be included for uranium, radium, and selenium to account for the difference in the mass of these constituents calculated for the Pit Lake and that which was predicted to enter through all water sources. To account for the mass difference during model calibration, it was assumed that leaching of constituents from the exposed and oxidized portions of the remaining mineralized zone provided the addition mass loading.

- The source terms for uranium and radium were held constant for the duration of modeling time, while the source term for selenium was assumed to represent a short term flux of selenium.

- The concentration of TDS in the lake at year 2000 was predicted to be approximately 3,500 mg/l. Concentrations of uranium and radium at year 2000 were predicted to be approximately 2,800 and 10 piC/L, respectively. The concentration if selenium was predicted to decline to less than 0.05 mg/L by year 60.

Discussion

This study presents an update of the 1983 EPRCO Pit Lake assessment. While the geochemical considerations were updated based on observed water quality in the Pit Lake, the hydrologic model was not specifically updated and groundwater flow rates and predictions were derived primarily from the 1983 study. As such, the final pit lake elevation was again constrained by the Hagmaier regional groundwater conceptual model with assumed high groundwater levels for the Highland site. As previously noted, earlier studies and recent data support the concept that the groundwater level and gradients derived from Hagmaier (1971) used in this model is not reflective of actual regional conditions, and thus using these water levels likely overestimates the long-term Pit Lake level.

This study does introduce to the Pit Lake assessment the need for tailing seepage to have flowed to the lake to account for observed geochemical conditions within the lake. This is consistent with past studies and site observations, and is consistent with the interpretations provided in the current ACL License Amendment Application. However, the migration of hazardous 11e.(2) tailings constituents radium, selenium, and uranium were still predicted to be attenuated and therefore the tailings solution was not factored into the chemical mass balance for these constituents.

1998 – Highland Tailings Basin Groundwater Study – Final Report, prepared by Rebecca Carovillano

This study was performed in support the 1998 ACL application to NRC, and included 1) developing a piezometric surface map for the TDSS using "the most recent" data (1996) and estimating groundwater flow rates and flow paths, 2) verifying the 1988 location of the chloride seepage front and estimating the location of the 1996 chloride seepage front, 3) calculating the 1988 and 1996 liquid volumes in the TDSS within the chloride seepage front, and 4) modeling the piezometric surface at a time in the future when water levels are stable, and estimating groundwater flow rates and flow paths at that time. The study included development of three-dimensional groundwater flow model using the USGS model MODFLOW.

Results from the study are summarized as follows:

- The groundwater level map representing 1996 conditions indicated the mound beneath the tailing impoundment "has dissipated to a point where it is significantly reduced."
- Based on this map, groundwater "beneath the tailings basin migrates west to the Highland Reservoir", and "there is no significant flow from the tailings basin to the south". As such, "the North Fork of Box Creek does not lie in the path of groundwater migration from the basin."
- Groundwater velocities immediately around the Highland Reservoir were estimated at 0.46 ft/day.
- The study re-interprets the tailings seepage front based on chloride that was developed by WWL (1988), based on a review of both chloride and TDS concentrations over time. The reinterpretation of the seepage front showed less migration to the north of the tailing

impoundment, and greater migration to the southwest of the impoundment toward the backfilled pits. Migration to the west and east of the impoundment was kept the same as the original interpretation.

- An estimation of the tailings seepage front representing 1996 was developed. Results showed that the northern portion of the front was essentially the same as in 1988, as were conditions southwest of the tailing basin. Very little movement of the front was interpreted between 1988 and 1996.

- Liquid volume within the revised 1988 tailings seepage front was estimated at approximately 1.7 billion gallons, 0.5 billion gallons within an area of highest chemical concentrations directly west of the impoundment (referred to as the "finger area"). Liquid volumes were estimated to have decreased in 1996 to 1 billion gallons (within the seepage front) and 132 million gallons (within the finger area). The decline was due primarily to a decline in water levels within the TDSS over that period.

- A three-dimensional groundwater flow model was developed using MODFLOW to assess the long-term steady state level of the Pit Lake, along with the piezometric surface of the site. Model development and results are summarized as follows:

    - The model simulated a square area of 30,000 feet by 30,000 feet with the pit lake roughly in the middle of the model domain. As such the lake was located roughly 2.8 miles from the model boundaries.

    - The model had 9 vertical layers representing the principal sandstone and shale units at the site.

    - The model used constant head boundaries on the western and eastern edges of the model. The constant water level along the western model boundary was assumed at 5200 ft amsl in the TDSS and 5175 ft amsl in the TDSH. Constant head values in the OBSS units were varied from 5025 ft amsl in 1988 increasing to 5125 in 1996 and afterward. The time varying constant heads were used as model inputs for the OBSS units based on predicted impacts from local and regional dewatering activities.

    - Constant head boundaries for the TDSS along the eastern edge of the model were set corresponding to predicted top of the TDSS outcrop. Constant head values for the OBSS were set farther to the east at the assumed elevation of the top of the 50SS (i.e. the top of the OBSS units).

    - Different rates of recharge were added to the model representing background conditions, seepage from the tailing impoundment, and recharge at the Pit Lake surface. Tailings seepage rates were varied as a function of the size of the evaporation pond at the impoundment surface that contained water pumped from wells as part of the ongoing corrective action. Seepage ranged from approximately 5 inches per year to a negative 24 inches per year to simulate net evaporation.

- The model was calibrated to water level fluctuations observed at the site between 1988 and 1996. Calibration was deemed reasonable based on a visual match between the predicted and contoured piezometric surface for 1996.
- A long-term simulation resulted in a steady-state pit lake elevation of 5125 ft amsl. The model was not used to predict the timing of lake development.
- At steady-state, the Pit Lake was simulated as a flow-through lake, with some discharge occurring toward the east. It is noted that the predicted water table is within the TDSH in the eastern portion of the tailing basin, suggesting the TDSS will be dry near the outcrop.

Discussion

The groundwater model developed during this study represents a more modern assessment using MODFLOW to simulate groundwater flow. However, the model boundaries were developed based on the regional conceptual model (Hagmaier, 1971) of high hydraulic gradients to the west of the site and discharge along outcrop areas that are currently observed to have de-saturated since tailing seepage has declined after mining. As such, the Pit Lake elevation and water levels predicted from the model are constrained to reach a level driven by model boundary inputs. The model as presented generally is not consistent with very early studies and data that indicated this conceptualization was not reflective of actual conditions (AEA, 1973; Dames & Moore, 1973), and as such likely over-predicts the long-term stable elevation of the pit lake.

2007 – Long Term Pit Lake and Groundwater Hydrology at the Highland Mine Site, Final Report, prepared by Tetra Tech.

This study includes development of a three-dimensional groundwater flow model using the USGS code MODFLOW to estimate the transient groundwater component in filling the Pit Lake. The model was used to support a broader assessment of Pit Lake geochemistry. It was noted that the "groundwater flow into the lake from surrounding hydrologic units is a primary control in: 1) the rate of Pit Lake filling; 2) the long-term steady-state water level; 3) the ability of the lake to become a flow-through system; and 4) long-term mass balance concentrations of constituents in the pit lake." A key objective of the model was to assess the long-term equilibrium of the lake related to whether the lake would act as a groundwater sink or as a flow-through system, as either condition would result in differing estimates of lake water quality over the long term. This report is provided as Attachment 1 of the main document.

Results of the study are summarized as follows:

- The model was developed to simulate the mining and post closure period (1972 through 2003) as the calibration period, and then simulates potential future conditions through the year 2100.

- The model simulates a 20 square mile area surrounding the site. The model has 5 vertical layers representing the principal sandstone units at the site (i.e. the near surface undifferentiated sands, TDSS, 50SS, 40SS, and 30SS). The intervening shales are not explicitly modeled, but are included as low permeability restrictions to vertical flow between the layers (i.e. the effect of the shales is included in the vertical conductance values used in the model).

- The model uses general head boundaries (GHBs) along the western, northern, and southern boundaries. These boundaries represent groundwater flux into the model domain from regional groundwater flow.

- All discharge from the model domain is simulated using drain cells located along either North Fork Box Creek or within the tailing basin drainage downstream of the tailing dam. Sandstone outcrops were assumed dry and simulated as no-flow boundaries.

- Pit Lake filling was simulated using very high hydraulic conductivity values for model cells representing the lake. Non-groundwater flow components of the Pit Lake water balance were estimated based on the lake area and added to the model as specified flux.

- Tailings seepage was added to the model as recharge to the groundwater system at rates ranging from 220 gpm in 1984 to 5.1 gpm in 1992 and thereafter.

- Dewatering from mine operations at the Buffalo shaft were simulated for the period 1979 through 1984 as pumping from model layer 5.

- The model was calibrated to observed water level conditions at the site. The calibration was considered reasonable.

- The model was then used to predict the timing of Pit Lake filling and ultimate level of the pit lake. The model predicted the lake level to stabilize at approximately 5060 ft amsl in the year 2054, 70 years after filling began.

- The model predicts that the lake is a net sink to groundwater, and that no long-term groundwater outflow will occur.

- The study notes that this result varies from previous studies and provides a discussion as to the differences.

Discussion

This study represents the most recent evaluation of regional and site groundwater flow conditions, and is generally consistent with current observations, data, and conceptualization of groundwater flow conditions. Recharge to the mine backfill and the Pit Lake from tailing seepage is accounted for in the assessment. The observation of limited to no recharge along outcrop areas is reflected in the model. Groundwater gradients within the regional system to the west as represented in the model are based on additional data and are reflective of lower water levels observed in this area at regional ISR sites. Thus this model is more reflective of actual flow conditions than several previous models that were based on the Hagmaier (1971) regional conceptual model. As such, there is an increased confidence in the predictions that the long-term predicted lake level and hydraulic conditions (i.e. that the lake will remain a hydraulic sink) are reasonably accurate. The findings from this model have been included in the overall hydrogeologic discussion provided as part of the main text in this document, and this report is provided as Attachment 1 of the main document.

2007 – Long Term Geochemical Evolution of the Highland Pit Lake, Final Report, prepared by Tetra Tech

This study was initiated in response to the latest hydrological modeling which indicated that the Highland Pit Lake would fill to a level lower than previous studies had predicted and therefore remain a groundwater sink. The modeling was done to evaluate the potential changes in Pit Lake water chemistry with the predicted hydrological change from a flow-through system to a groundwater sink.

The Tetra Tech model, like the 1998 SMI modeling, used a Dynamic Systems Modeling (DSM) approach using STELLA® (version 7.02) to assess long-term concentrations of uranium, selenium, radium, major ions, and TDS in the pit lake. However, in this model output from the DSM were coupled to the geochemical equilibrium model PHREEQC (version 2.12; Parkhurst and Appelo, 1999) to evaluate the affect of chemical equilibrium reactions. The model was calibrated to observed chemical conditions in the lake during the initial 19 years of lake development, using available data up to 2003. The model used a mass balance approach to estimate the amount of 11e.(2) byproduct in the tailings seepage that was entrained in the Pit Lake. This report is provided in Attachment 2 of the main document.

Results of the study are summarized as follows:

- Water-quality measurements from the Pit Lake during the first 19 years of filling indicate that leaching of constituents to the OBSS groundwater system from exposed uranium roll-front deposits, and seepage from the Tailings Basin have resulted in elevated levels of radium, selenium, uranium, sulfate, and TDS in the Pit Lake.
- Calibrations of the computer model for uranium, radium and selenium required that a source term be included to account for leaching of constituents from the exposed and

oxidized portions of the remaining mineralized zone. The major source terms incorporated into the DSM were input as an early flushing of constituents from the remaining oxidized ore body and seepage from the Tailings Basin. This approach provided a good fit of modeled to existing water-quality data. The potential contribution of the Tailings Basin was also evaluated.

- The disposal of tailings to the east of the Pit Lake, structurally elevated by as much as 200 to 400 feet, affected the level of TDS during the early history of the Pit Lake. For example, in the first 20 years of the filling of the Pit Lake, mass balance calculations indicated that 53% of the chloride and a maximum of 30% of the sulfate came from the tailings impoundment.

- Under current conditions, the primary source of chemical mass entering the Pit Lake is from the OBSS. Specifically, uranium, radium, and selenium are leached from the remaining mineralized zone exposed in the pit walls. However, seepage from the Tailings Basin has also contributed a significant mass of constituents to the Pit Lake. Model simulations indicate that as much as 24% of the uranium and 11% of the selenium in the Pit Lake could come from the tailings impoundment.

- Evaporation of water from the Pit Lake constitutes the sole hydrologic outflow and, therefore, affects the long-term evolution of chemistry in the Pit Lake due to evapoconcentration.

- The predicted concentration of TDS at year 1,000 is approximately 10,310 mg/L. The primary control on TDS is the concentration of sulfate, which increases to a maximum modeled concentration of 7,208 mg/L at 1,000 years.

- The precipitation of calcite imposes limits on the concentrations of calcium and bicarbonate in the lake.

- The predicted activity/concentrations of uranium and radium after 1,000 years are 4.54 mg/L (3,034 pCi/L) and 3.7 pCi/L, respectively.

- The concentration of selenium was predicted to increase from the 2003 level of 0.09 mg/L to 0.14 mg/L after 1,000 years

Discussion

This study represents the most recent evaluation of the geochemical evolution of the Pit Lake that incorporates predictions from the updated hydrological model, and is generally consistent with current observations, data, and geochemical conceptual site model. A major difference in this modeling of Pit Lake chemical evolution was the assumption that both hazardous (uranium, radium, and selenium) and non-hazardous (chloride and sulfate) constituents in the tailing seepage would migrate to the Pit Lake. Earlier models acknowledged that the 11e.(2) byproduct constituents chloride and sulfate were transported to the Pit Lake, but restricted the migration of radium, selenium, and uranium. This deviation from previous assumptions is based primarily on two factors.

First, as discussed above, in previous models the migration of hazardous constituents was severely restricted because large retardation factors were applied in the models. These retardation or attenuation factors were developed from some simple batch equilibration tests conducted by EPRCO in the early 1980's. However, an extensive body of scientific literature produced over the past 3 decades, our current understanding of uranium, radium, and selenium geochemistry, and experience at numerous other U.S. Department of Energy (DOE) and UMTRCA sites (Anderson et al., 2003; Fendorf et al., 2002; Hsi and Langmuir, 1985) sites does not support the application of these very high attenuation factors under the oxidizing conditions associated with the tailings impoundment at Highland during active mining. This is especially true for the redox active constituents, such as uranium and selenium, for which transport properties are significantly affected by oxidation state. Under oxidizing conditions both constituents are expected to be highly mobile, whereas under reducing conditions both are expected to be immobile. The transport dependency of uranium and selenium on redox conditions was not well established in the early 1980's and therefore it is unlikely that there was any attempt to control for redox conditions in the batch testing. A thorough discussion of the geochemical behaviour of uranium and selenium under changing redox conditions is provided in the main document in Sections 1.3.2, 2.1.2, and 2.2.3

The second factor that contradicted the use of large attenuation factors was the available site data collected over 20 years. Several wells including Wells 112, 117, 125, 177, 178, and 180 showed elevated levels of tailings derived constituents chloride, sulfate, and uranium. Of special importance were Wells 117, 177, and 178 located along one of the identified primary flow pathways and between the tailings and Backfilled Pit 1, and Well 180, also along a primary flow pathway and completed within the backfill. The early models of radionuclide transport predicted that these constituents would not migrate more than about 100 ft from the impoundment (EPRCO, 1982). Elevated uranium was observed at wells 178 and 180 as early as 1986 and these wells are approximately 1,860 ft and 3,300 ft from the TDSS outcrop under the tailings impoundment, respectively. Thus the groundwater monitoring data collected at the Site indicate that transport of chloride, sulfate, and uranium from the tailings impoundment to the Pit Lake occurred. The transport of selenium is harder to demonstrate with site data, and this is likely due to the biogeochemistry of this element. The selenate and selenite ions are reduced by a great variety of bacteria and fungi (Lovley, 1995; Oremland, 1994), and are reduced at much higher redox potentials than uranium. Therefore, it is expected that much of the selenium would be reduced and removed from the groundwater soon after the Mill shutdown and before groundwater monitoring wells were installed.

Summary

Numerous predictive models have been developed over the past 30 years to evaluate the development of the Highland Pit Lake and the fate and transport of 11e.(2) byproduct material from the Highland Tailings Impoundment to the groundwater system and Pit Lake. As such, the models and predictions have evolved with time. Key factors that have contributed to the evolution of the models and predictions include:

- The amount of data available for use in calibrating the models;
- The availability of increasingly sophisticated tools and modeling software; and
- An increasing understanding of geochemistry and the behavior of radionuclides, metals and metalloids under varying environmental conditions.

Thus, the models have evolved from the early purely predictive models which were based on limited or no data to calibrate against to the most recent models that benefit from an extensive data set for groundwater and surface water quality to provide representative calibrations. The current hydrogeologic and geochemical CSM presented in the main text of this document builds on the previous work and benefits from the most extensive data set available for model validation. In addition, the current CSM and predictions of 11e.(2) byproduct constituent migration is consistent with the current scientific understanding of the biogeochemistry of the key elements of concern.

REFERENCES

Anderson, R.T. et al., 2003. Stimulating the In Situ Activity of Geobacter Species To Remove Uranium from the Groundwater of a Uranium-Contaminated Aquifer. Appl. Environ. Microbiol., 69(10): 5884-5891.

EPA, U.S., 1999. Understanding Variation In Partition Coefficient, Kd, Values Volume I: The Kd Model of Measurement, and Application of Chemical Reaction Codes. EPA402-R-99-004A, U.S. Environmental Protection Agency and U.S. Department of Energy, Washington, DC.

Fendorf, S., Wielinga, B., Hansel, C.M., 2002. Operative pathways of chromate and uranyl reduction within soils and sediments. In: Zhang, P., Brady, P.V. (Eds.), Geochemistry of Soil Radionuclides. SSSA Special Publication. Soil Science Society of America, Madison, Wisconsin, pp. 111-129.

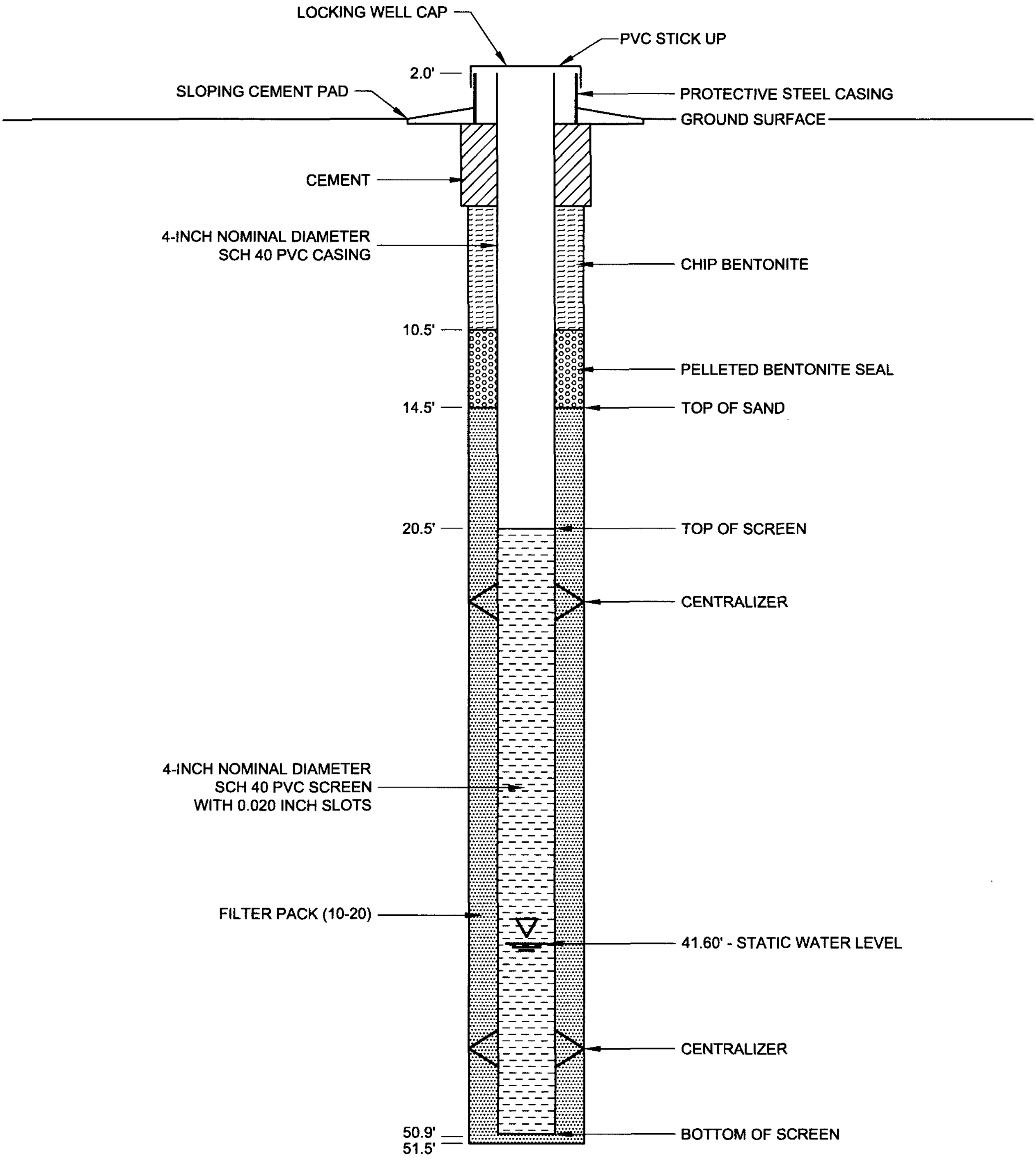
Hsi, C.-K.D., Langmuir, D., 1985. Adsorption of uranyl onto ferric oxyhydroxides: Application of the surface complexation site-binding model. Geochimica et Cosmochimica Acta, 49: 1931-1941.

Lovley, D.R., 1993. Dissimilatory metal reduction. Annu. Rev. Microbiol., 47: 263-290.

Lovley, D.R., 1995. Microbial Reduction of Iron ; Manganese ; and Other Metals. Advances in Agronomy, 54: 175-231.

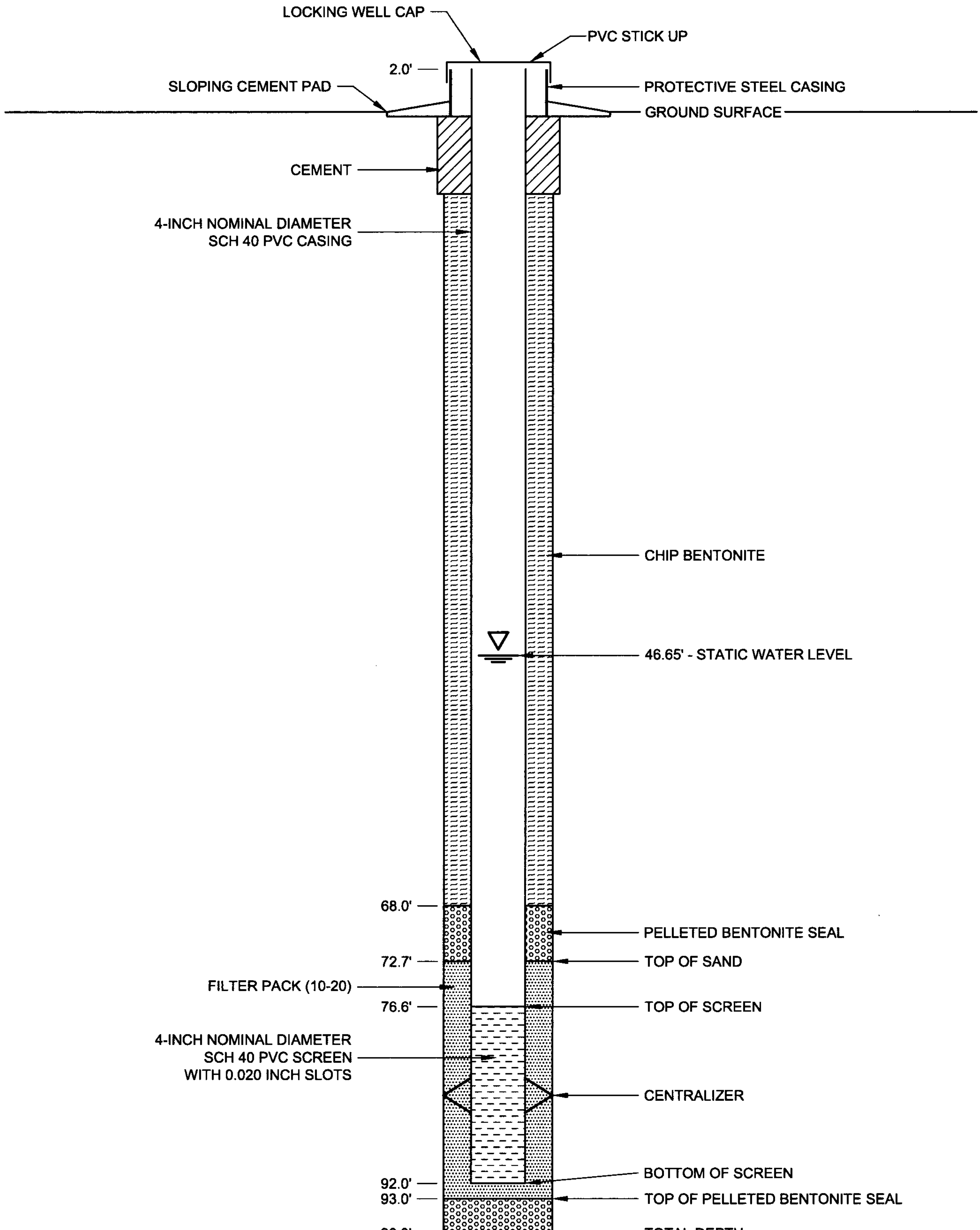
Oremland, R.S., 1994. Biogeochemical transformations of selenium in anoxic environments. In: Frankenberger, W.T.J., Benson, S. (Eds.), Selenium in the Environment. Marcel Dekker, Inc., New York, pp. 389-419.

Appendix B Well Logs for Wells Installed in the Southeast Drainage



WELL PERMIT #162572

MFG, Inc. *consulting scientists and engineers*	**FIGURE 5** **WELL MFG-1 COMPLETION DETAIL**	Date: NOVEMBER 2004 Project: 180548 File: WC-SUM.DWG

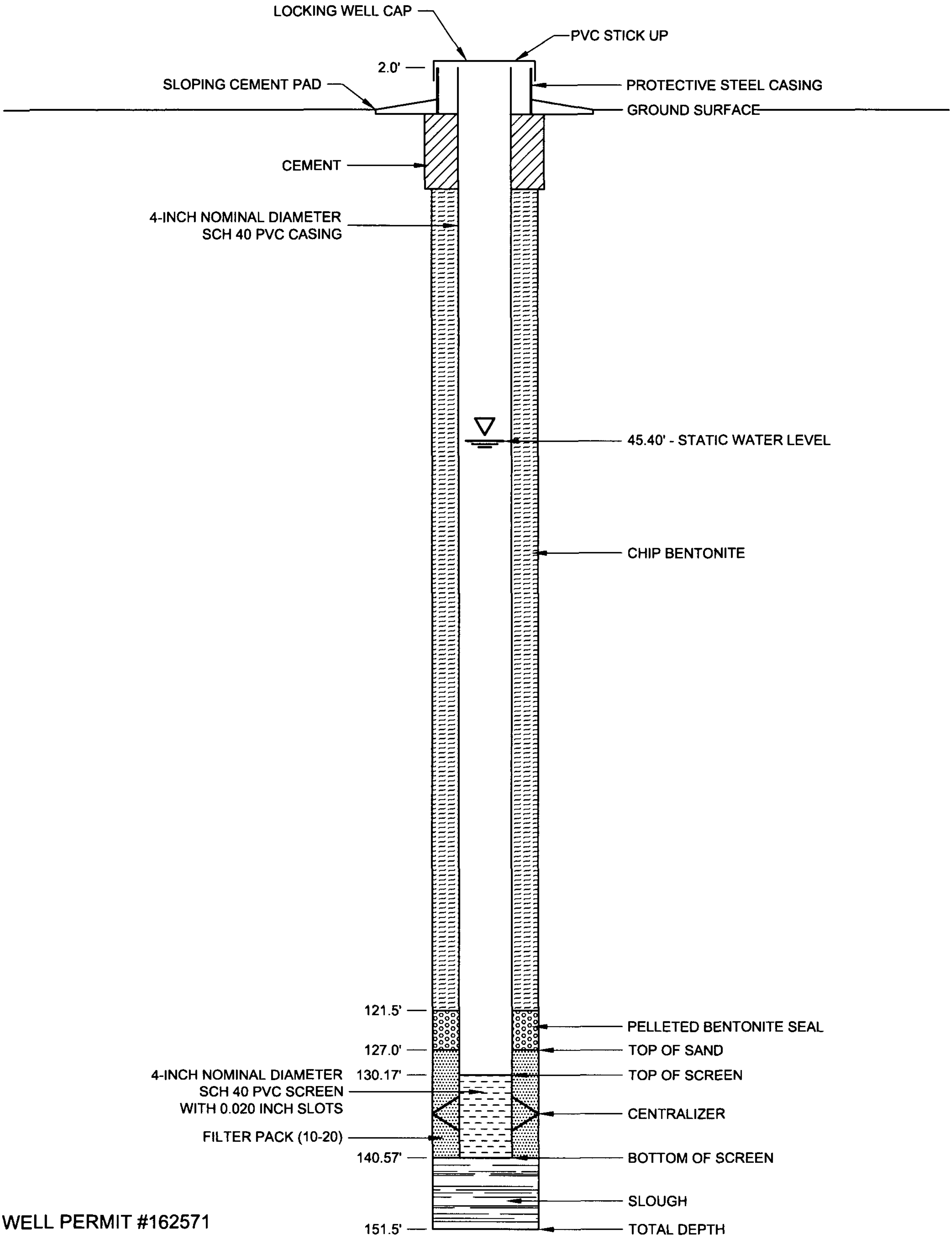


WELL PERMIT #162573

MFG, Inc.
consulting scientists and engineers

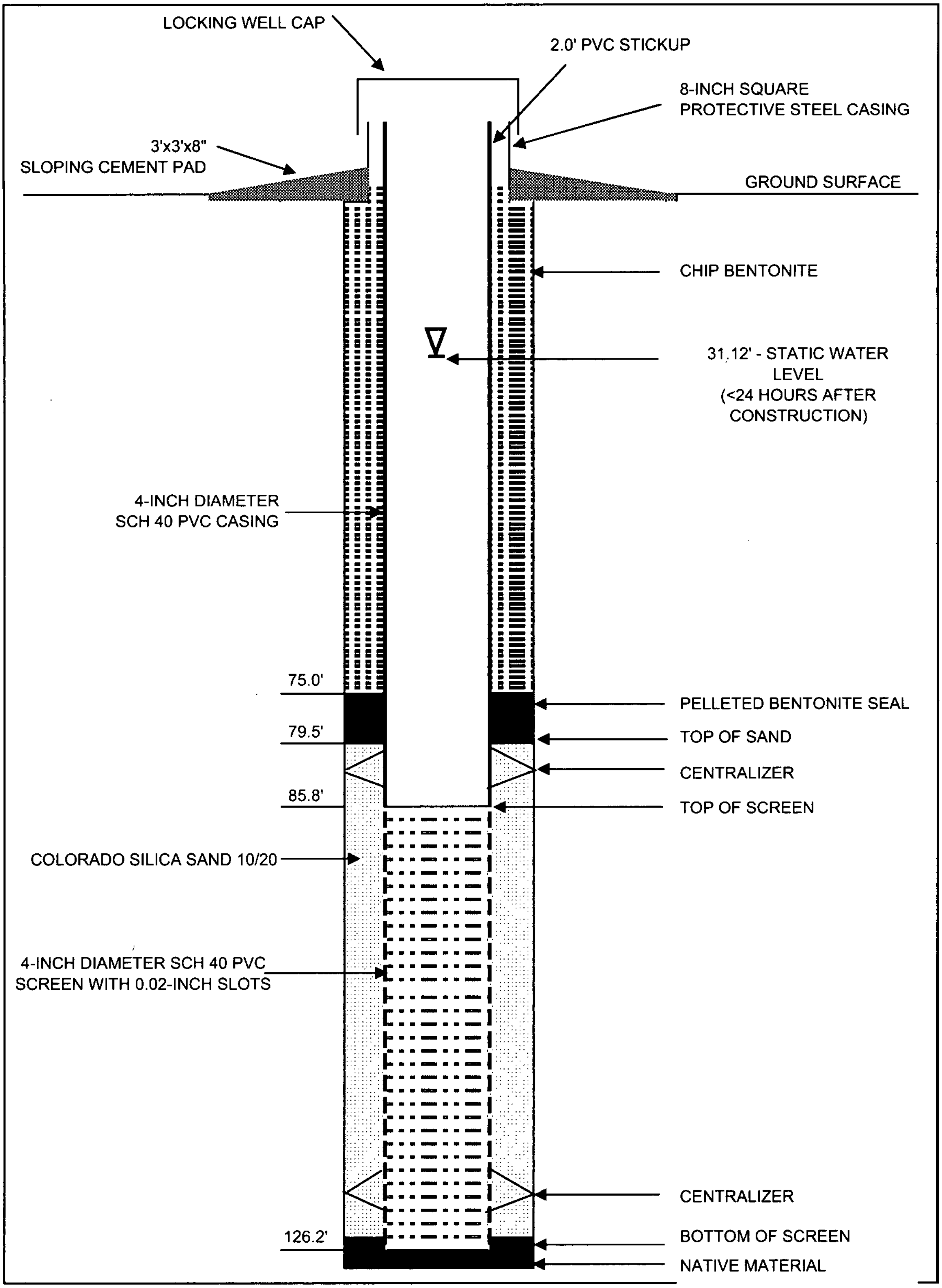
FIGURE 6
WELL MFG-2 COMPLETION DETAIL

Date:	NOVEMBER 2004
Project:	180548
File:	WC-SUM.DWG



WELL PERMIT #162571

MFG, Inc. *consulting scientists and engineers*	FIGURE 7 WELL MFG-3 COMPLETION DETAIL	Date: NOVEMBER 2004
		Project: 180548
		File: WC-SUM.DWG

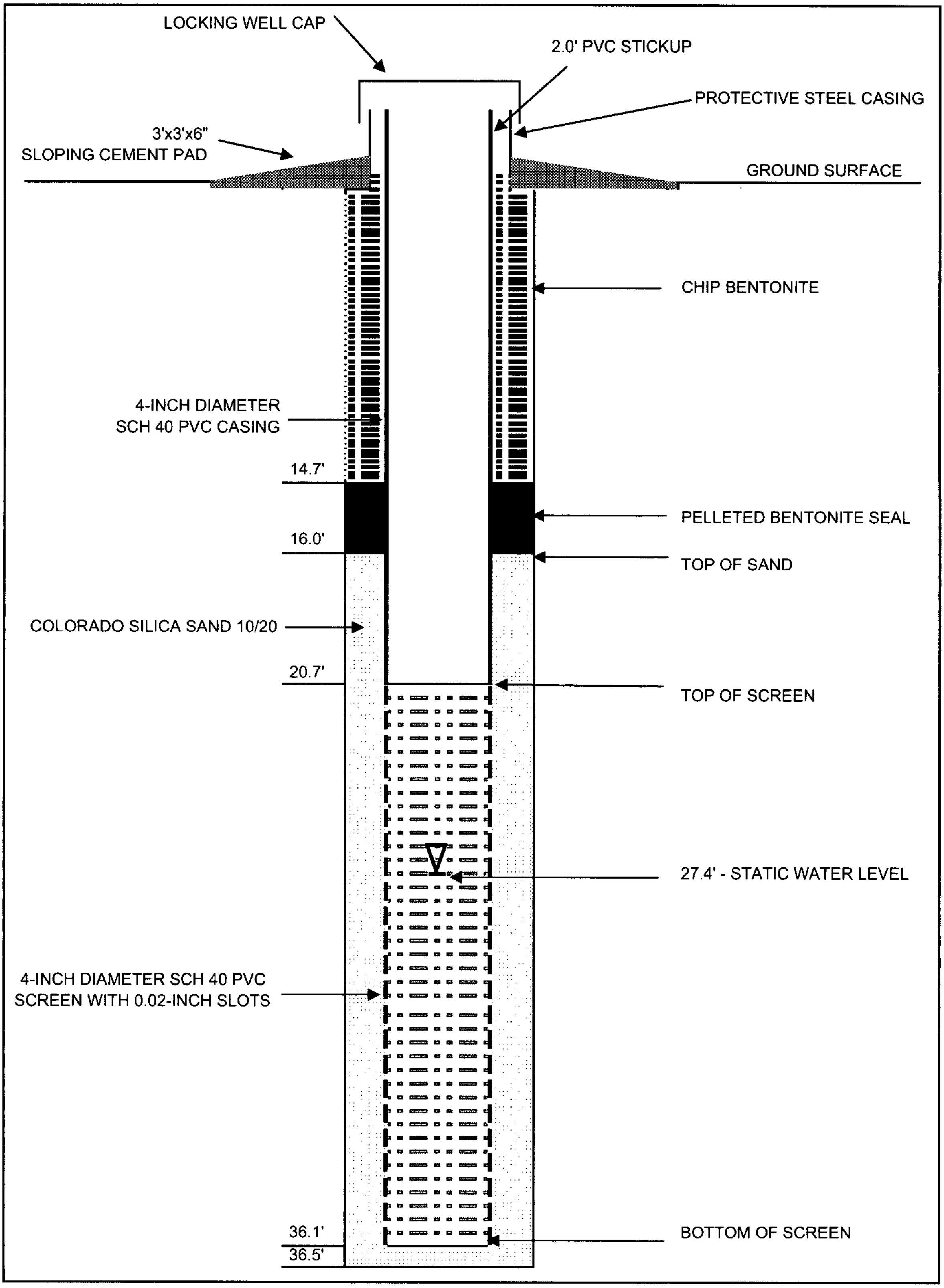


BBL an ARCADIS company

MONITORING WELL BBL - 1 COMPLETION DETAIL

DATE: AUGUST 2006
PROJECT: 85598
NOT TO SCALE

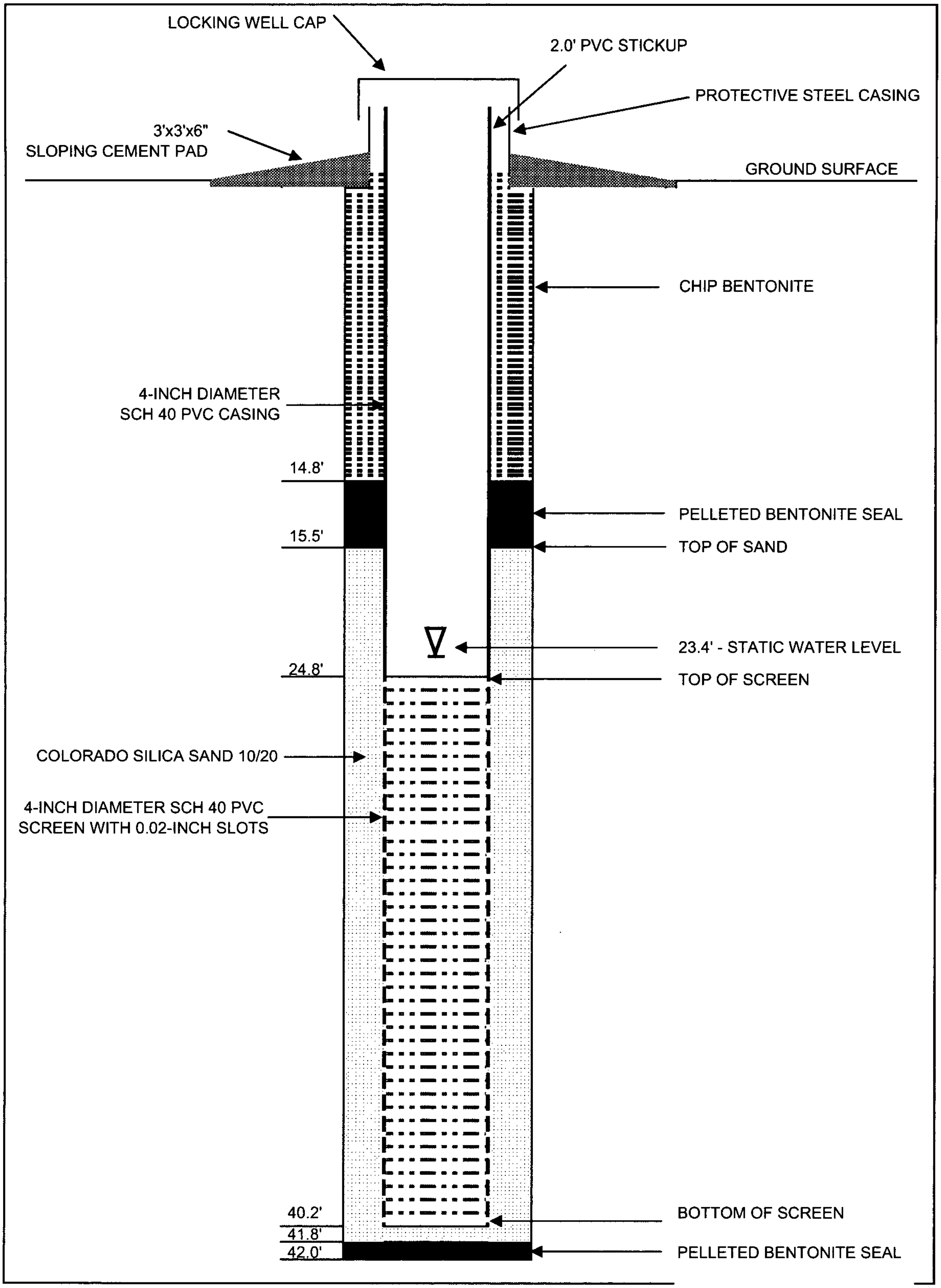
G:\PROJECTS\ExxonMobil\85598 Highland\Groundwater\MW Installation 2006\BBL-1 Well Completion Detail.xls



BBL® an ARCADIS company

MONITORING WELL BBL - 2 COMPLETION DETAIL

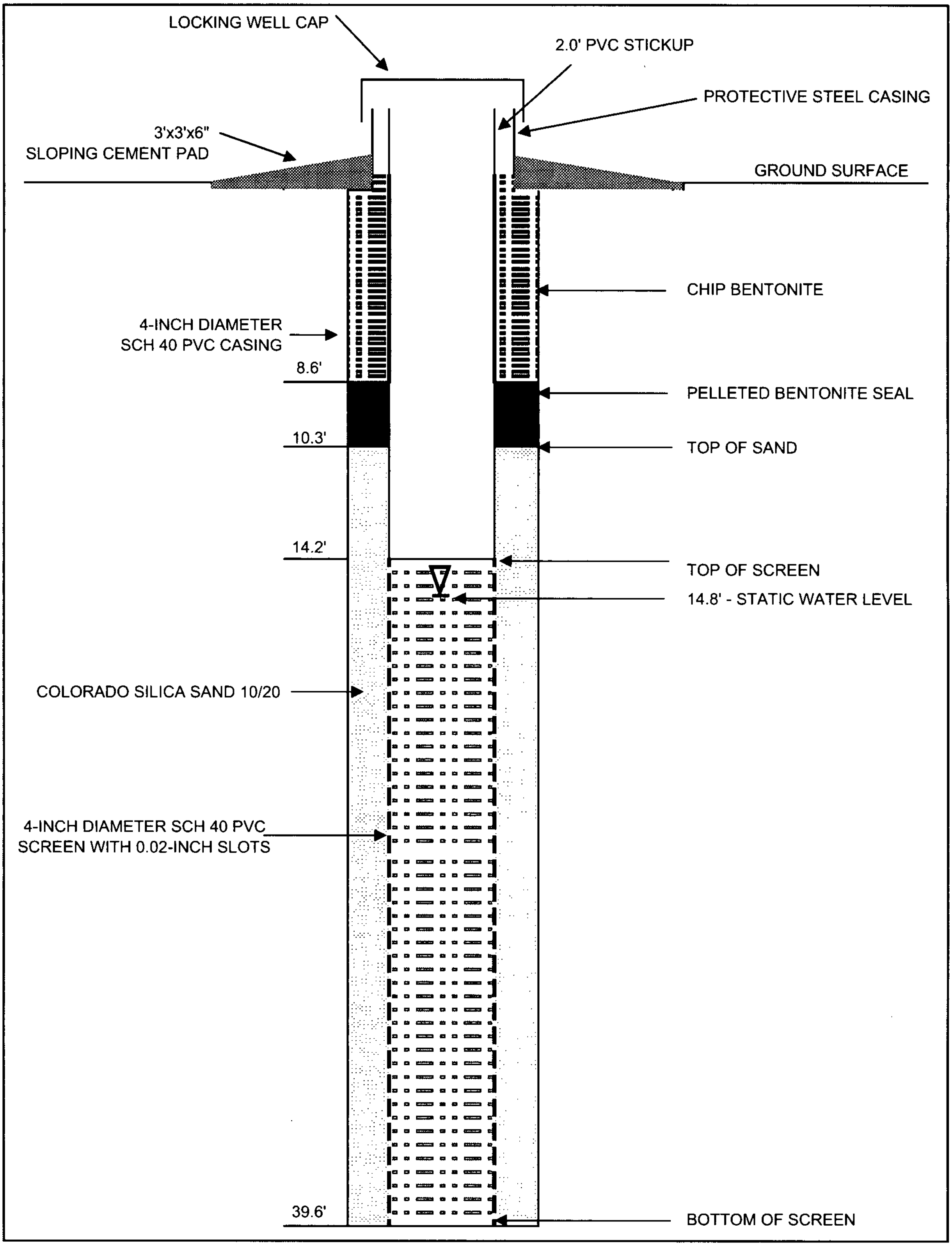
DATE: AUGUST 2006
PROJECT: 85598
NOT TO SCALE



BBL® an ARCADIS company

MONITORING WELL BBL - 3 COMPLETION DETAIL

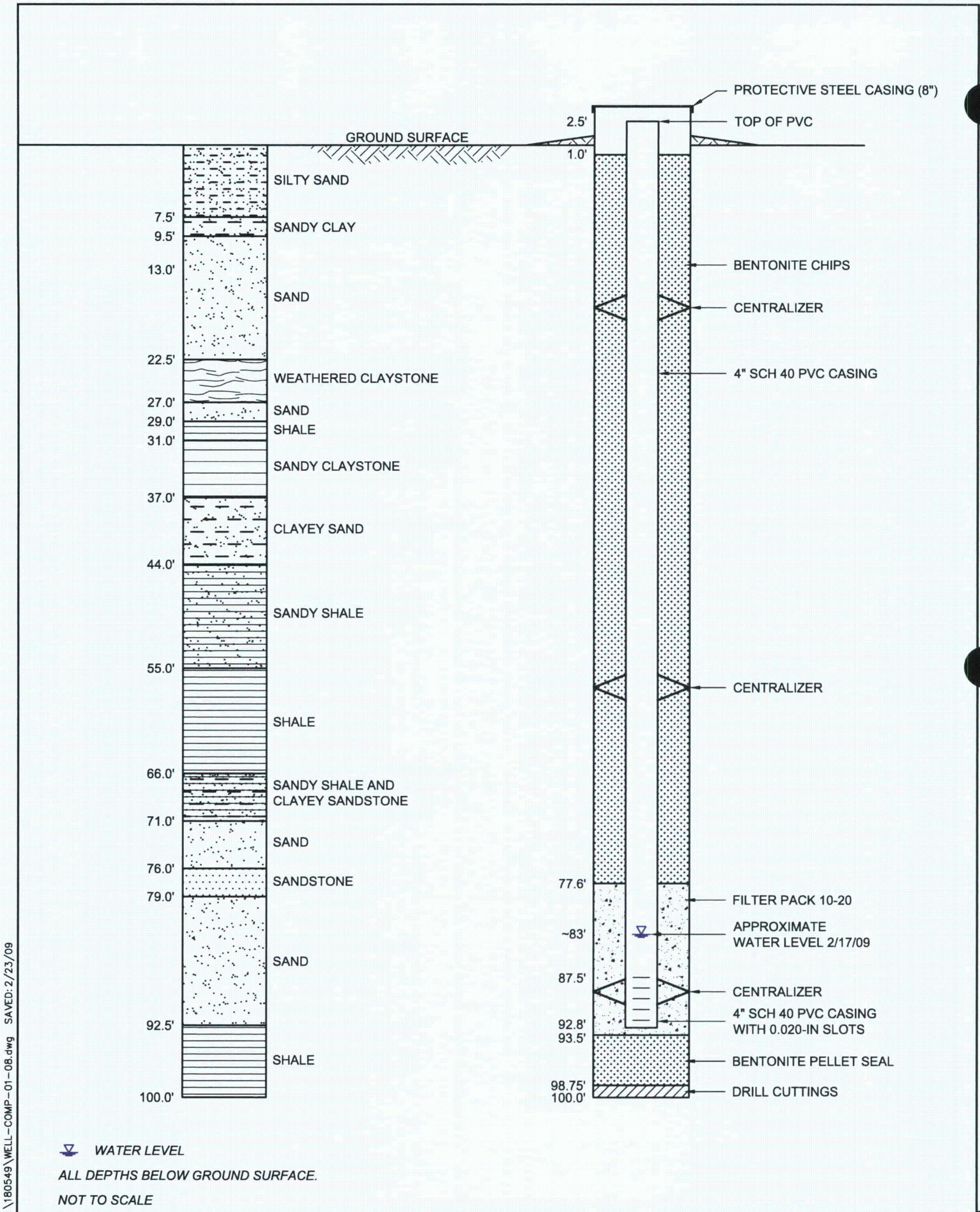
DATE: AUGUST 2006
PROJECT: 85598
NOT TO SCALE



BBL® an ARCADIS company

MONITORING WELL BBL - 4 COMPLETION DETAIL

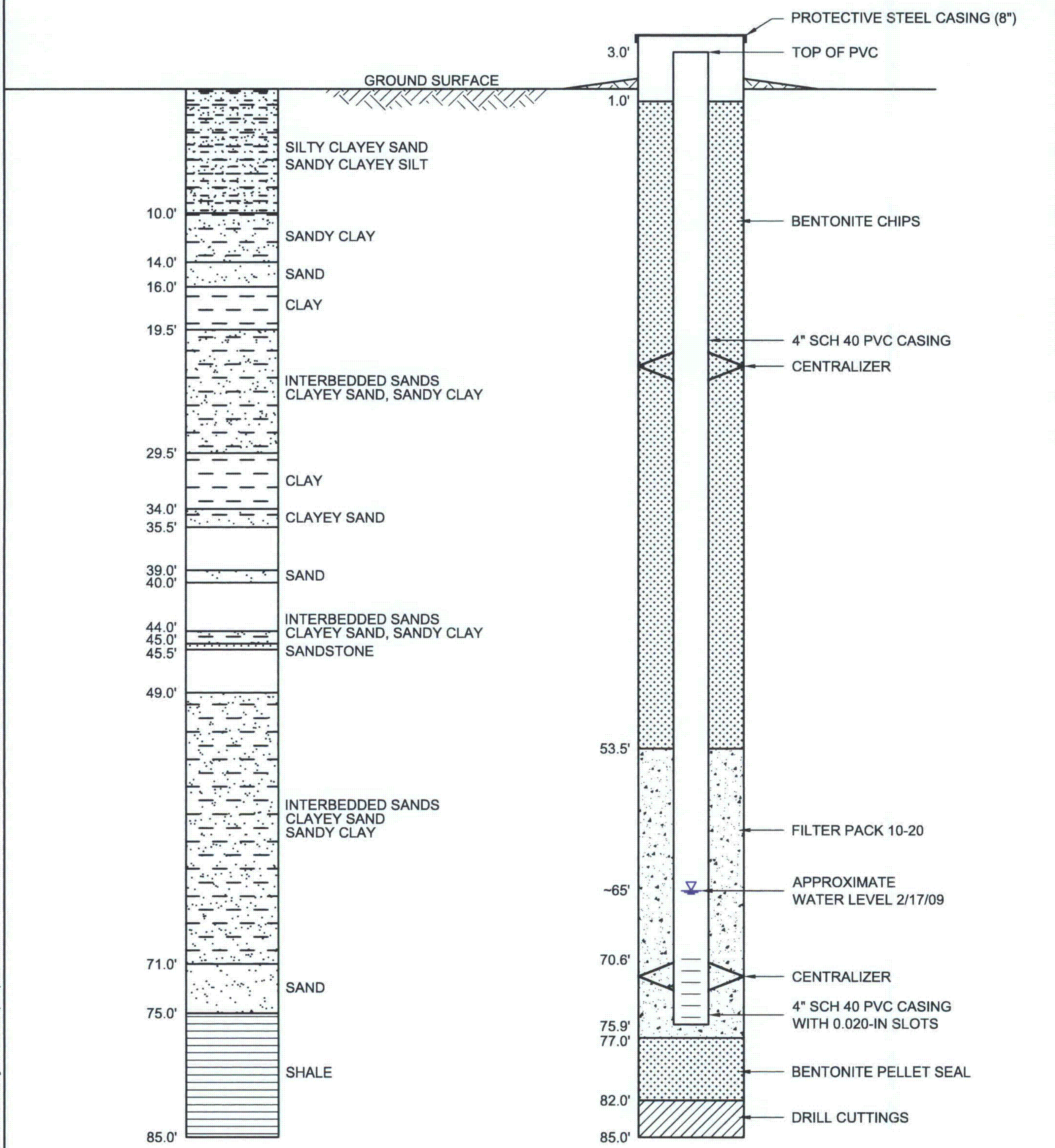
DATE: AUGUST 2006	
PROJECT: 85598	
NOT TO SCALE	



Project No. 180549.2009

February 20

COMPLETION DIAGRAM
BOREHOLE Tt-1



WATER LEVEL

ALL DEPTHS BELOW GROUND SURFACE.

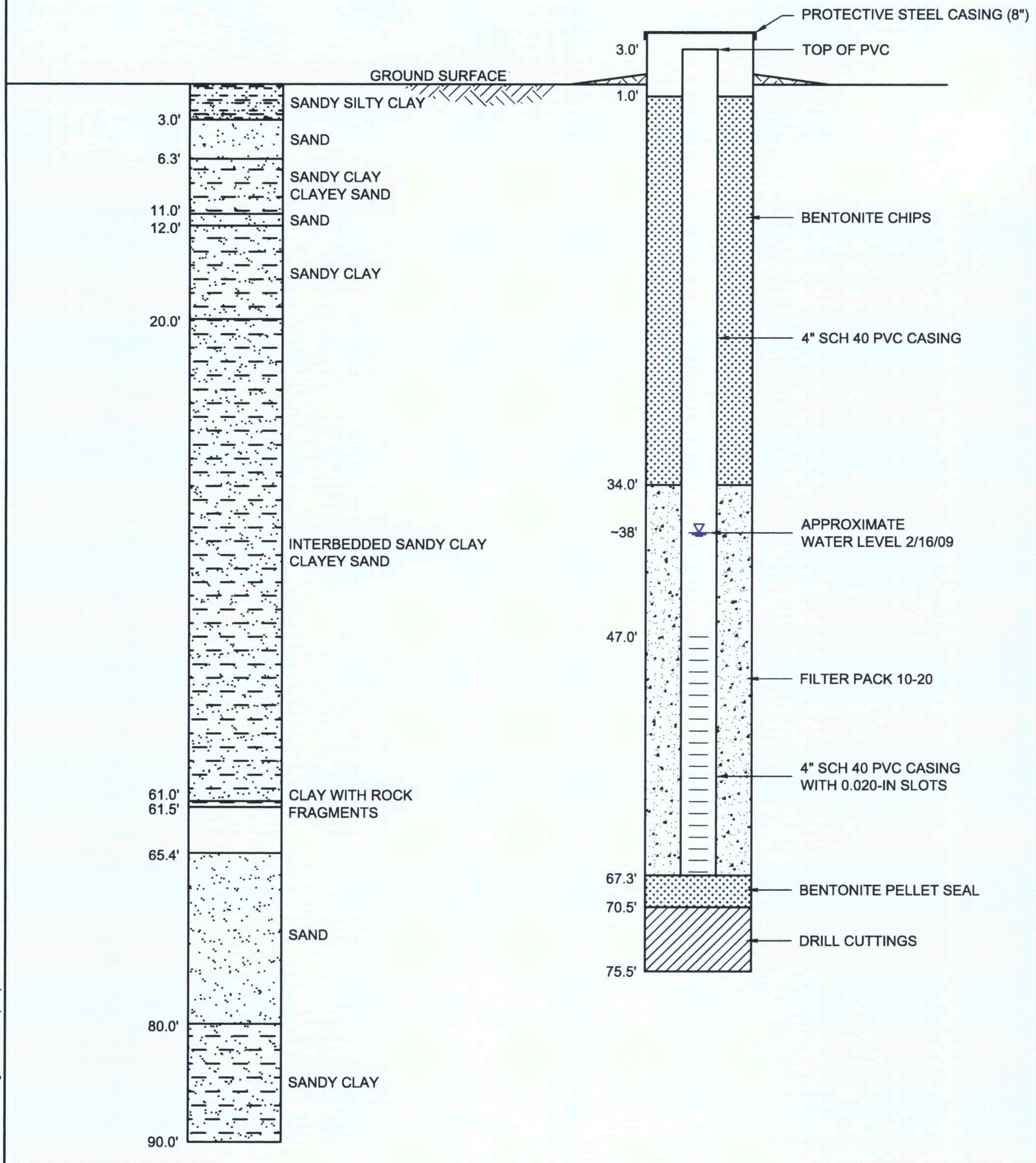
NOT TO SCALE

E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 2009

COMPLETION DIAGRAM
BOREHOLE Tt-2



WATER LEVEL

ALL DEPTHS BELOW GROUND SURFACE.

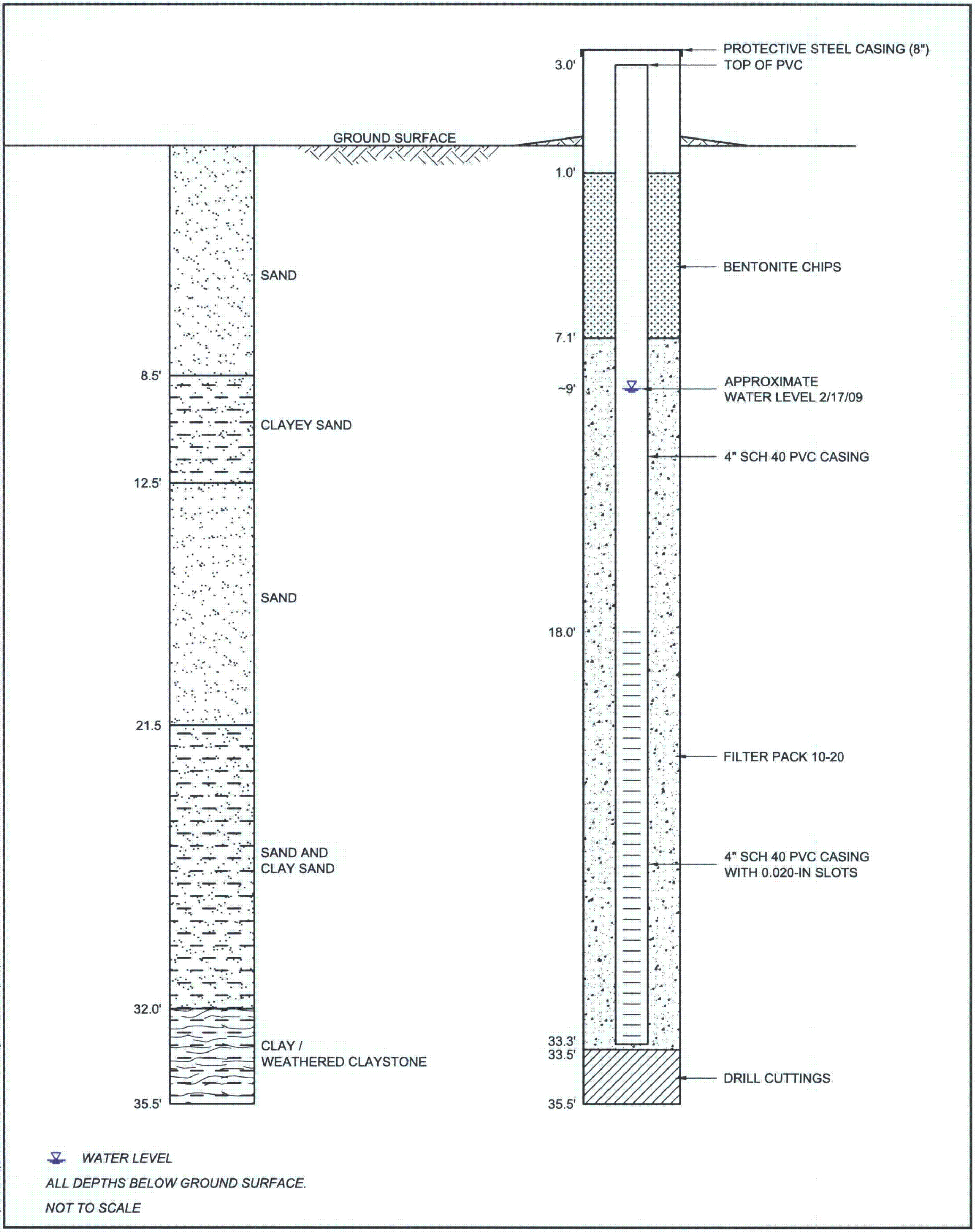
NOT TO SCALE

E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 20

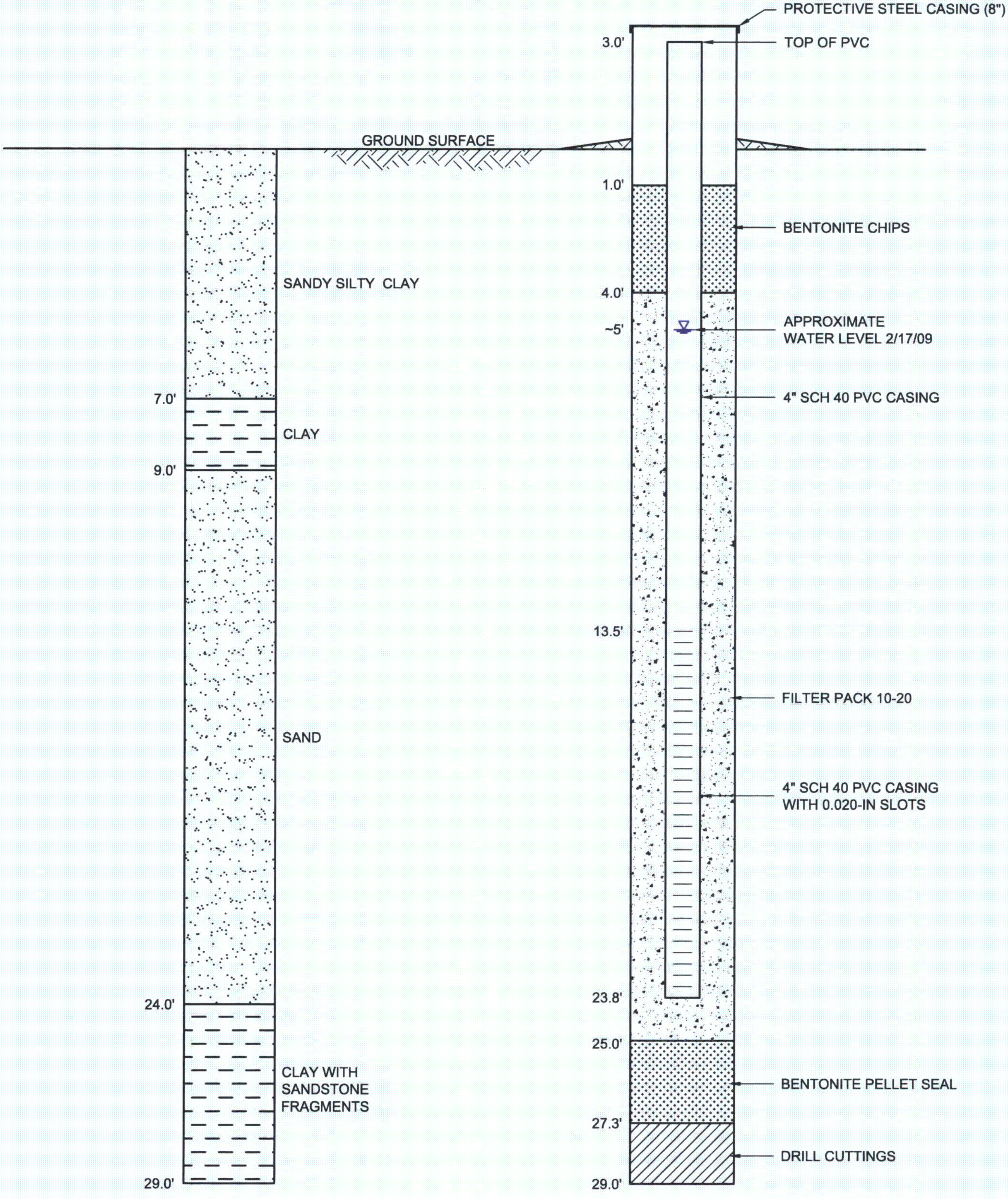
COMPLETION DIAGRAM
BOREHOLE Tt-3



Project No. 180549.2009

February 2009

COMPLETION DIAGRAM
BOREHOLE Tt-4



WATER LEVEL

ALL DEPTHS BELOW GROUND SURFACE.

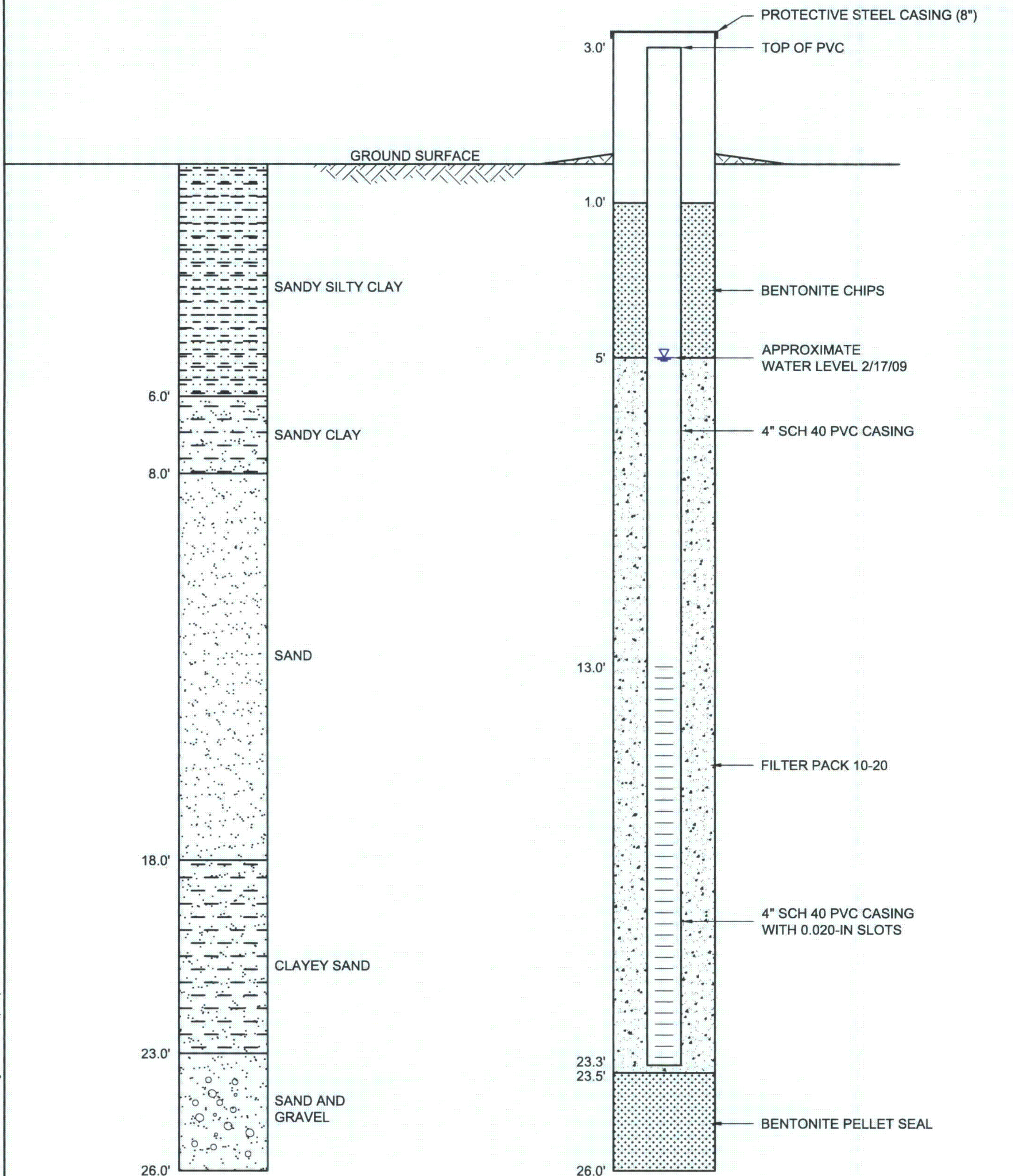
NOT TO SCALE

E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 20

COMPLETION DIAGRAM
BOREHOLE Tt-5



WATER LEVEL

ALL DEPTHS BELOW GROUND SURFACE.

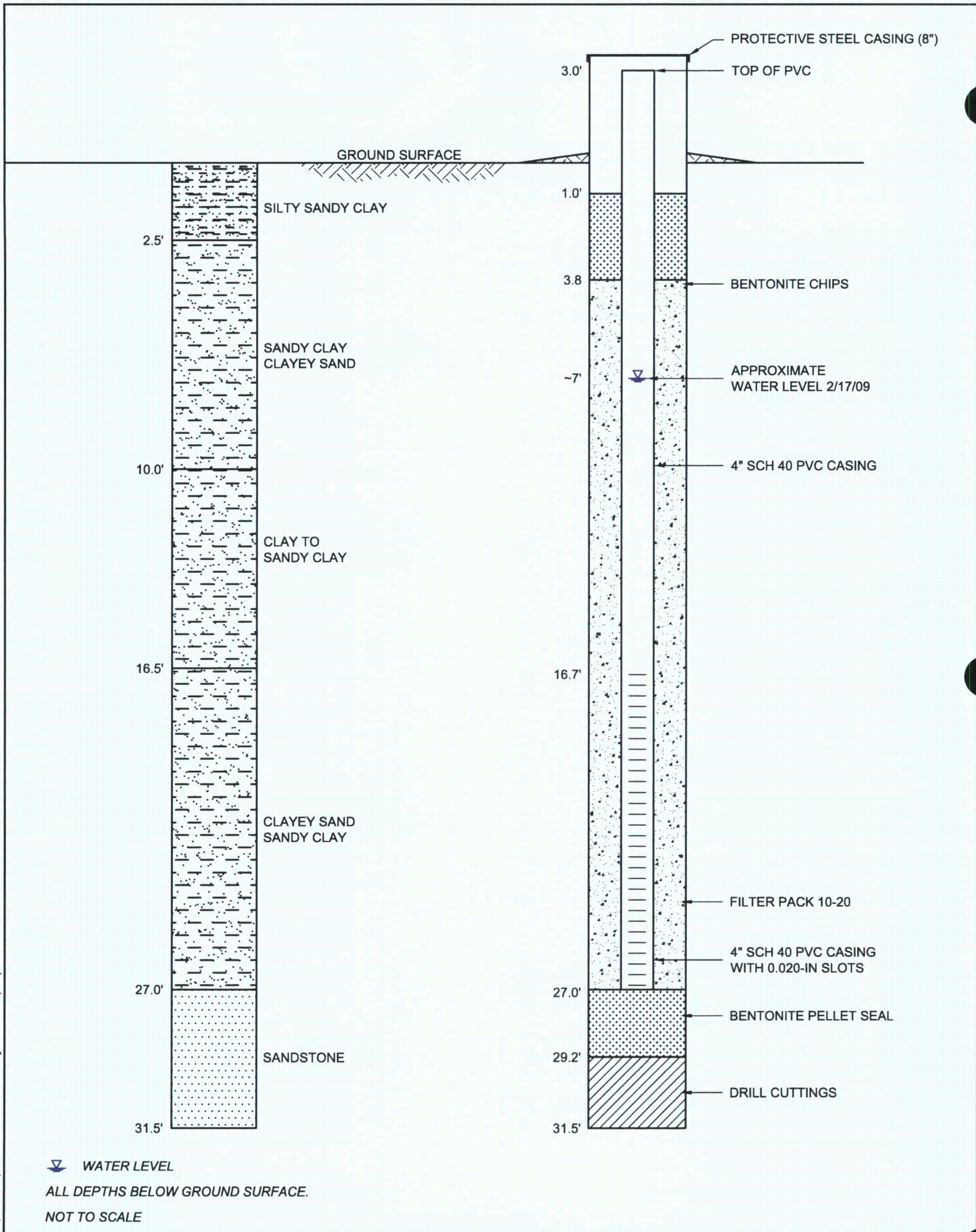
NOT TO SCALE

E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 2009

COMPLETION DIAGRAM
BOREHOLE Tt-6

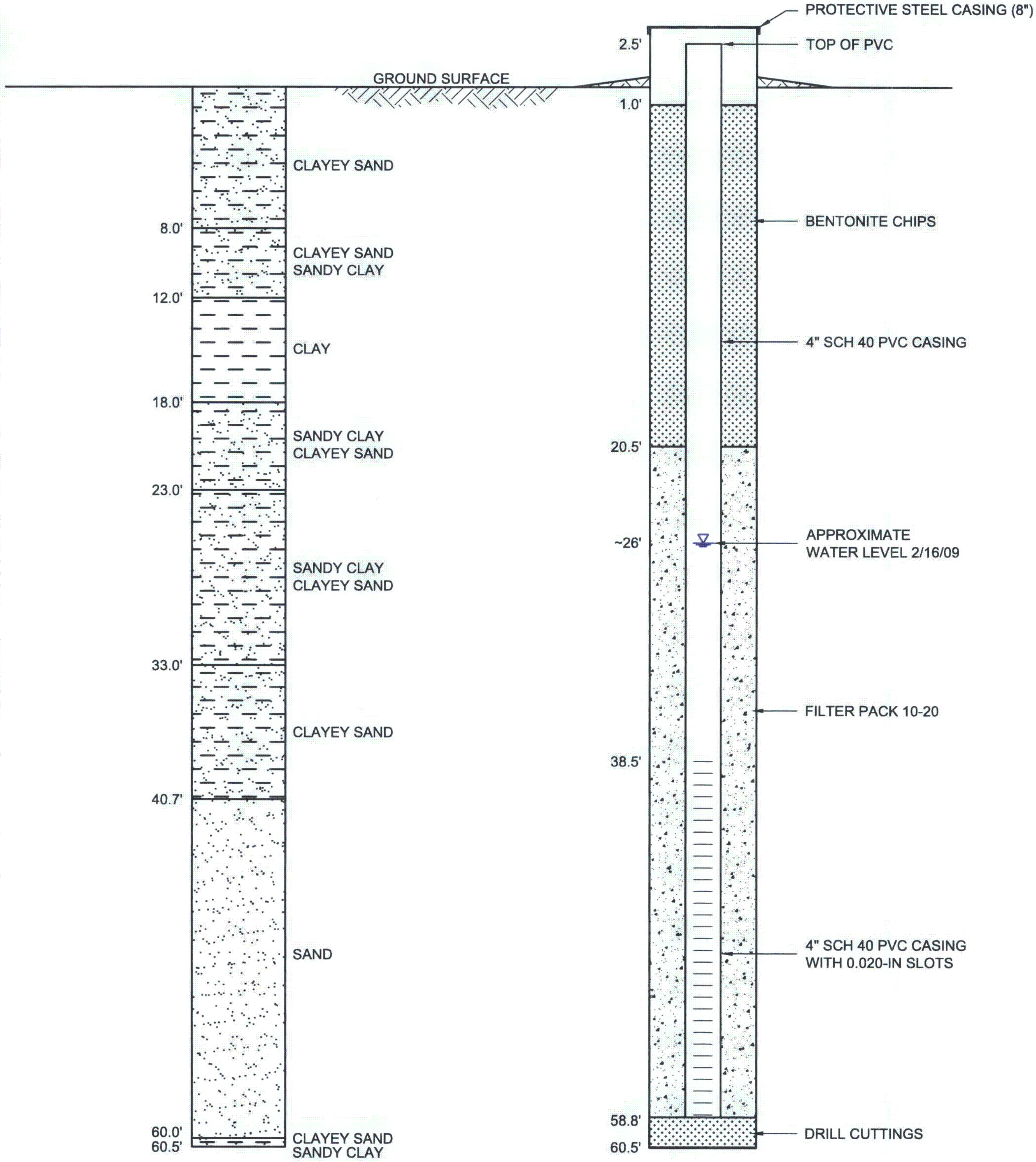


E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 20

COMPLETION DIAGRAM
BOREHOLE Tt-7



WATER LEVEL

ALL DEPTHS BELOW GROUND SURFACE.

NOT TO SCALE

E:\180549\WELL-COMP-01-08.dwg SAVED: 2/23/09

Project No. 180549.2009

February 2009

COMPLETION DIAGRAM
BOREHOLE Tt-8

Appendix C Highland Groundwater and Surface Data CD

Appendix D PHREEQC Input Files

Tailings Neutralization by Calcite with Surface Adsorption

```
PHASES
Fix_pe
e- = e-
log_k 0.0

SOLUTION 1 Background Major Ion Chemistry (182)
units mg/l
pe    4.0
Alkalinity  148 as HCO3
Ca    24
Mg    4.17
Na    100
Cl    8.35
S(6)  177
pH    8.2
END

SOLUTION 2 Highland Tailings (average)
units mg/l
pH    2.17
Ca    434.7
Mg    1052
Na    262
S(6)  11510
Cl    486.5
K     42
N(-3) 230 as NH3
N(5)  2.65 as NO3
B     0.700
Al    566
As    0.161
Ba    0.100
Cd    0.083
Cr    3.383
Cu    1.650
Fe    775
Pb    0.320
Mn    45
Ni    1.400
Se    0.118
Ag    0.025
Zn    11.500
Mo    0.115
V     8.535
U     13.97

EQUILIBRIUM_PHASES 1
Al(OH)3(a)         0.0    0.0
Al4(OH)10SO4       0.0    0.0
Barite             0.0    0.0
Ba3(AsO4)2         0.0    0.0
Calcite            0.0    10
Cr(OH)3(a)         0.0    0.0
```

```
Gypsum              0.0    0.0
CO2(g)              -1.8
Ferrihydrite        0.0    0.0
Otavite             0.0    0.0
Fix_pe              -8     O2(g)

SURFACE 1
    -equilibrate with solution 1
    Hfo_s       0.0001    600       1.5
    Hfo_w       0.0028

END
```

Desorption of adsorbed constituents by clean groundwater

```
PHASES
Fix_pe
e- = e-
log_k 0.0

SOLUTION 0 Background Major Ion Chemistry (182)
units mg/l
pe     4.0
Alkalinity  148 as HCO3
Ca     24
Mg     4.17
Na     100
Cl     8.35
S(6)   177
pH     8.2
END

SOLUTION 1 Highland Neutralized Tailings
units mg/l
pH     7.03
Alkalinity  190 as HCO3
Al                0.032
As                0.00004
Ba                0.005
Ca                540
Cd                0.015
Cl                490
Cr                0.0023
Cu                0.0013
Fe                0.0013
K                 42
Mg                1070
Mn                45
Mo                0.10
Na                260
Ni                0.55
S(6)              5000
Se                0.021
```

```
U                  2.7
Zn                 0.89


EQUILIBRIUM_PHASES 1
Al(OH)3(a)          0.0    0.0
Al4(OH)10SO4        0.0    0.0
Calcite             0.0    10
Gypsum              0.0    0.0
CO2(g)              -1.9
Ferrihydrite        0.0    0.0
Fix_pe              -8     O2(g)

SURFACE 1
  -equilibrate with solution 1
      Hfo_s 0.0001      600   115
      Hfo_w 0.0028

EXCHANGE 1
  -equilibrate with solution 1
            X     0.6

ADVECTION
      -cells      1
      -shifts     30

SELECTED_OUTPUT
      -file c:\Highland_Transport.dat
      -reset      false
      -simulation false
      -solution   false
      -state      false
      -step       true


USER_PUNCH
      -headings PV Cl SO4 U Se pH
10    PUNCH (STEP_NO + 0.5/50)
20    PUNCH TOT("Cl")*35.453*1000
30    PUNCH TOT("S(6)")*96.0616*1000
40    PUNCH TOT("U")*238.029*1000
50    PUNCH TOT("Se")*78.96*1000
60    PUNCH -LA("H+")
END
```

Appendix E Detailed Corrective Action Assessment

APPENDIX E

DETAILED ASSESSMENT OF CORRECTIVE ACTION ALTERNATIVES

TABLE OF CONTENTS

TABLES

FIGURES

EXHIBITS

1.0 INTRODUCTION

ExxonMobil is in the process of applying for an amendment to its U.S. Nuclear Regulatory (NRC) Radioactive Materials License (SUA-1139) for the Highland Uranium Project located in Sections 20, 21, 28 and 29, Township 36 N, Range 72W in Converse County, Wyoming. The focus of the amendment application is to update the groundwater compliance monitoring program in License Condition 33 to address recently identified groundwater impacts not previously encompassed by earlier licensing actions.

This report assesses groundwater corrective action alternatives as per 10 CFR Part 40 Appendix A, Criterion 5B(5) and 5B(6). The alternative groundwater corrective actions are assessed for practicability, cost and benefit in protecting human health and the environment from the hazardous constituents uranium, selenium and radium-226+228 recently identified in the groundwater of the ephemeral drainage southeast of the tailings embankment, and for the hazardous constituents uranium and selenium identified in the Pit Lake. Based on the assessment presented in the sections below, the proposed corrective action alternative is the implementation of institutional controls over an expanded long-term care boundary which encompasses the Southeast Drainage and the Highland Pit Lake and adoption of new ACLs for uranium.

Alternative corrective actions developed, including an assessment of the practicability and costs of each alternative, are discussed in Section 2.2. Following the analysis of the practicability and costs of the alternatives, alternative corrective actions are selected and an analysis of benefits derived from successful implementation of the selected corrective actions is presented in Section 2.3. Finally, Section 2.6 analyzes if the proposed alternative reduces concentrations to as low as reasonably achievable (ALARA). Detailed cost sheets documenting the bases for the cost estimates and sources of the cost values are presented in Exhibit 1.

2.0 Alternative Corrective Actions

Radiological and non-radiological hazardous constituents from the reclaimed tailings impoundment have been transported down the shallow regolith of the Southeast Drainage and into the Highland Pit Lake. The long-term seepage from the tailings impoundment is estimated to be approximately three to five gallons per minute into the Tailings Dam Sandstone and this seepage will persist fpr the indefinite future due to infiltration through the tailings cover (ECMC, 1998). The portion of seepage flux from the tailings contributing flow to the Southeast Drainage ranges from below 0.1 gpm to as much as three gpm. This alternative corrective actions assessment focuses on mitigating this long-term tailings seepage down the limited Southeast Drainage groundwater system, the legacy of historical seepage down the Southeast Drainage, and the hazardous constituents in the Highland Pit Lake.

Criterion 5B(6) of 10 CFR 40 Appendix A states that:

"The licensee must provide the basis for any proposed limits including consideration of practicable corrective actions, that limits are as low as reasonably achievable, and information on the factors the commission must consider."

A range of practicable alternative corrective actions have been assessed to comply with the requirements of 10 CFR Part 40, Appendix A, Criterion 5B(5) and 5B(6) and as per NRC guidance in NUREG-1620 (NRC, 2000) and NRC guidance (NRC, 1996). The corrective action alternatives evaluated in this assessment address contaminant source control by removing ground-water hazardous constituents at the point of compliance or treating them in place. The alternatives also address removing and treating any hazardous constituents that exceed MCLs in the Highland Pit Lake and in the groundwater between the point of compliance and the down-gradient property boundary of the Southeast Drainage. Corrective action alternatives considered assess both active and passive methods as well as in-situ and ex-situ treatment technologies.

2.1 Alternative Corrective Action Assessment Criteria

Each of the corrective action alternatives has been evaluated for practicability and costs. The evaluation of practicability for each alternative was performed using the following criteria.

Engineering Feasibility:

This criterion assesses the degree of engineering or technical practicability by considering whether the technologies are proven or experimental and whether it is possible to apply the technology to the site-specific conditions.

Effectiveness

This criterion assesses to what degree the alternative can reduce impacts to groundwater or Pit Lake water quality.

Durability:

This criterion assesses how long the remedy will maintain protective conditions that are ALARA and the capital life of the equipment.

Degree of Active Maintenance

This criterion assesses the number of times the capital life of the equipment will be exceeded within the design performance period and the amount of maintenance the alternative would require to maintain the efficacy of the alternative.

Each practicability criterion is given a relative ranking of excellent, moderate or poor, for each alternative, with excellent being the most desirable ranking.

Further, the costs for each alternative were also evaluated:

Capital Costs:

These costs comprise the cost of designing, purchasing and installing all capital equipment and infrastructure for each alternative.

Operating Costs:

These costs comprise the labor, utilities and supplies necessary for operating each alternative.

All costs are developed using established current cost bases and are presented as net present values using a 1% discount rate as per Criterion 10 of 10 CFR Part 40 Appendix A. As per 10 CFR 40, Appendix A, Criterion 6(1), the minimum performance period for maintaining protective conditions is assumed to be 200 years. Therefore, those alternatives requiring perpetual maintenance and capital equipment replacement are assumed to operate for 200 years.

Regardless of the alternative(s) selected, it is assumed that some degree of compliance monitoring, including compliance sampling, analysis, POC well maintenance, and reporting, will be required annually. The cost of compliance monitoring has not been included in the costs developed for each of the alternatives. It has been estimated that annual compliance monitoring will cost approximately $19,300 annually (Exhibit 1). This cost includes collection and analysis of up to five samples (four wells and one Pit Lake sample), as well as maintenance of up to four wells. This cost also includes a 10% contingency. The annual well maintenance cost was estimated assuming 1% of the capital cost to install four new wells, estimated at $51,000.

Criterion 10 of 10 CFR 40 Appendix A requires a minimum one-time charge to cover the costs of long-term surveillance contemplated in Criterion 12. The one-time payment for surveillance is stipulated in the ACL Guidance (NRC, 1996) to be in the amount of $250,000 in 1978 dollars, to be converted to current dollars, or $872,224 based on the U.S. Bureau of Labor Statistics Consumer Price Index, all Urban Consumers, U.S. City Average, All Items (CPI-U) for January 1978 (62.5) and December 2010 (218.056). Because Criterion 12 indicates that final disposition of the 11e.(2) byproduct material should be such that no ongoing maintenance is required and annual inspections are the minimum required surveillance activity, the estimated baseline annual monitoring and well maintenance costs are conservatively assumed to be in addition to the required $250,000 in 1978 dollars, though this required amount was intended to cover some monitoring costs. This one-time cost has not been included in the costs of the alternatives as it is common to all alternatives.

2.2 Description and Assessment of Alternative Corrective Actions

The following sections describe the developed alternatives and assess the practicability and costs. Both active and passive, ex-situ and in-situ methods are considered. Multiple options for several of the alternatives are presented in an effort to optimize their effectiveness, as per *Section 3.3.3.2* of the NRC ACL guidance (NRC, 1996). Table 1 summarizes the results of these assessments.

Specifically, the following alternative corrective actions are assessed for practicability and costs:

- No-Action
- Southeast Drainage Alternative Corrective Actions
    - Source Control
        - Interception Cut-Off Wall
        - Interception with Pumping Wells
        - Permeable Reactive Barrier
    - Down-gradient Corrective Action
        - Groundwater Extraction with Pumping Wells
        - In-Situ Redox Manipulation with Injection Wells
    - Management of Collected Water
        - Direct Disposal in the Highland Pit Lake
        - Evaporative Treatment in Lined Ponds
        - Ion Exchange and Discharge
        - Reverse Osmosis
- Highland Pit Lake Alternative Corrective Actions
    - In-Situ Redox Manipulation
        - Land Mixing (reductant mixing on the Pit Lake margins)
        - Floating Platform (reductant mixing on the Pit Lake surface)
    - Ex-Situ Treatment using Ion Exchange
    - Backfill of Pit Lake
        - Surface Drainage to North Fork Box Creek
        - Closed Surface Drainage
- Institutional Controls with Alternate Concentration Limits

2.2.1 No-Action Alternative

The No-Action alternative does not mitigate any of the hazardous constituents in the Southeast Drainage or in the Highland Pit Lake. With no further action, these conditions would not provide for the future protection of human health or the environment and would not provide sufficient control over the lands necessary for the long-term stabilization and control of the hazardous constituents. These conditions would not reduce exposure concentrations to as low as reasonably achievable (ALARA). Therefore, this alternative is not considered further.

2.2.2 Southeast Drainage Corrective Actions

The following sections describe the corrective actions developed for protecting human health and the environment in the Southeast Drainage.

2.2.2.1. Source Control

Seepage from the unlined tailings impoundment has entered the uppermost aquifer of the Tailings Dam Sandstone. Tailings seepage migrates under the tailings embankment and into the limited groundwater system associated with the Southeast Drainage. The source control corrective actions identified for analysis are based on interception of this seepage near its source, at the base of the tailings embankment. Figure 1 shows the proposed location of potential source control corrective actions.

Several potential methods for source control have been identified. These include engineered barriers for hydraulic capture, using an interceptor trench or pumping wells, to intercept contaminated groundwater in the uppermost aquifer from leaving the area of the tailings impoundment. Also included is a permeable reactive barrier to prevent the migration of hazardous constituents into the Southeast Drainage. Each of these is discussed in more detail in the sections below.

Interception Cut-Off Wall

Methods for constructing engineered barriers for groundwater interception include the use of slurry walls, sheet-pile walls and geomembrane cut-off walls (i.e., high density polyethylene or HDPE). Each method has specific benefits and limitations. For example, slurry walls are constructed of natural materials (i.e., bentonitic clays) which may have a longer capital life than sheet-pile walls or geomembranes, while sheet-pile walls may be installed to greater depths than geomembrane cut-off walls. Geomembrane cut-off walls can be easier to install and more cost effective than sheet-pile walls, depending on the site-specific geologic conditions and depth. None of the identified barrier methods are capable of absolute effectiveness and all permit a certain amount of hydraulic leakage. Consequently, complete containment of the contamination is not feasible; however, the seepage rate is anticipated to be very low.

Only interception using a geomembrane cut-off wall is evaluated in detail. This method does not rely on the availability of specialty contractors or materials, though it may have a shorter capital life than a slurry cut-off wall. Due to the depth of the required barrier, this method is anticipated to be in the middle of expected installation costs, and therefore assessment of this specific method is assumed to be adequate to determine if this general approach would sufficiently reduce the groundwater contaminant concentrations to protective levels that are ALARA and to assess if this approach is practicable.

Interception Cut-Off Wall: Conceptual Design

The depth to the first aquitard (Tailings Dam Shale) at the proposed POC well MFG-1 is less than 55 feet below the ground surface as shown in Figure 2. The interception cut-off wall consists of an engineered barrier using 80-mil HDPE installed in an open trench constructed using traditional excavation methods. The trench would be approximately 150 feet in length (perpendicular to groundwater flow) and four feet in width and extend into the aquitard approximately 5 feet (total depth of 55 feet). The trench would be slightly sloped to drain towards the middle of the trench.

An 80-mil high density polyethylene (HDPE) geomembrane would be placed along the trench's down-gradient wall to the surface. The trench floor (sump) would be lined with bentonitic clay pellets, placed approximately 1 ft thick over the bottom of the trench to create an impermeable bottom. A non-woven geotextile could be placed along the bottom of the trench prior to placement of the bentonite to prevent loss of bentonite into the formation below the trench. A groundwater collection drain consisting of well screen or perforated piping along the base of the trench for the entire length would be installed to collect accumulated groundwater and direct it to the extraction points.

Extraction wells would be installed near the middle and on either end of the trench to extract accumulated groundwater and prevent groundwater from circumventing the edge of the interceptor trench. Extraction wells would be constructed using 6-inch inside diameter (ID) Schedule 40 PVC well screen and extend to the ground surface. The trench would be backfilled with pea gravel or other appropriately sized gravel pack to provide a porous media to collect the groundwater. Small submersible pumps with level controls would be placed in the extraction wells to pump the intercepted water as it accumulated. The well head, controls and equipment would be located in a precast concrete pump vault for protection. The recovered water would be handled ex-situ using one of the water management alternatives discussed in Section 2.2.2.3.

Subsurface power and communication lines would be extended from the current Smith Ranch\Highland In-Situ Recovery (ISR) facility to the interceptor trench location. Two separate trenches would be required for these lines. Figures 1 through 3 present schematic illustrations of the cut-off system design.

Interception Cut-Off Wall: Operations

The pumping system would operate year-round using grid-based power with a buried electrical line from the existing Smith-Ranch\Highland ISR facility approximately two miles to the west. In addition, there would be a data logger and control system to turn the pumps on and off at pre-set water levels. All pumping equipment would be installed in below-ground vaults and all water lines to the treatment systems would be buried below frost level to ensure uninterrupted winter operation. A phone-based communications system using a buried phone line would also extend from the Smith Ranch-Highland facility to allow the system to be audited remotely and to notify the operator of equipment failure for prompt repair.

Interception Cut-Off Wall: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent

This alternative relies on proven technologies and installation methods and the equipment and materials are readily available. The monitoring and communications equipment is similarly proven, commonly used and appropriate for the site-specific conditions.

Effectiveness: Moderate

This alternative could reasonably be expected to limit the mass flux of hazardous constituents to the Southeast Drainage by at least one and possibly two orders of magnitude. However, it could not reasonably be relied upon to completely eliminate seepage due to the limitations in construction quality control and natural variability in the geologic conditions into which the barrier is installed.

Durability: Poor

The capital life of the pumping equipment, sensors, control and communication instrumentation is estimated to be approximately 15 years and 100 years for the geomembrane barrier material. This alternative remains effective only for the duration of the capital life of the equipment and materials. Seepage through the tailings is expected to continue at the steady state rate of approximately 5 gpm with approximately 0.13 gpm discharging down the Southeast Drainage in perpetuity (Section 2.2.1.2 in main document). Consequently, this corrective action will be required in perpetuity.

Degree of Active Maintenance: Poor

The interception alternative requires that the equipment, monitoring, and maintenance be conducted in perpetuity. This includes regular remote monitoring of the system and due to the limited capital life of the equipment, regular maintenance and periodic capital equipment replacement. In addition, the intercepted water cannot be allowed to build up behind the barrier and create higher driving heads and must be removed, requiring perpetual water treatment or discharge.

Interception Cut-Off Wall: Capital Costs

The initial capital construction costs of this alternative are approximately $1,335,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for the alternative's equipment, utilities and the barrier. It was estimated that the pumping equipment (pump, breakers and controls) would need to be replaced every 15 years at a cost of approximately $33,000, the utilities and wells would need to be replaced every 50 years at a cost of approximately $335,000, and the barrier would need to be replaced every 100 years at a cost of approximately $553,000. Replacement costs do not include contingencies. All capital and replacement costs have been rounded to the nearest $1,000.

Interception Cut-Off Wall: Operating Costs

The annual cost of operating this alternative is approximately $33,000. The annual operating cost includes an annual system inspection, reporting, groundwater sampling and analysis, electrical usage, and maintenance of the pumping equipment. Maintenance of the alternative is estimated at 1% of equipment costs. A 10% contingency has been included in the annual operating costs. An annual inspection of the alternative's components has been included in the costs, and is assumed to be separate from the annual inspection included in the base surveillance fund ($250,000 in 1978 dollars). However, annual compliance monitoring of POC wells has not been included in these costs. All operating costs have been rounded to the nearest $1,000.

Interception Cut-Off Wall: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $5,110,000. All NPV values have been rounded to the nearest $10,000.

Interception With Pumping Wells

A second approach developed for intercepting long-term seepage to prevent impact to the Southeast Drainage is the placement of pumping wells in a closely spaced line transverse to the axis of the Southeast Drainage. These wells could be used to capture the water entering the Southeast Drainage. However, as shown on Figure 2, there is very little saturated thickness (approximately 6 feet) at this point. Using wells to create a capture zone without a down-gradient barrier would be inefficient and would not likely be able to capture all of the seepage. It is expected that wells would run dry and seepage would bypass the wells as pumps cycled on and off. As approved by the NRC in allowing the groundwater CAP to be discontinued, once the aquifer water levels have significantly decreased, pumping as a recovery or mitigation measure becomes impracticable. Therefore, use of pumping wells for source control interception is considered impracticable and is not addressed further in this assessment.

Permeable Reactive Barrier (PRB)

In this alternative, groundwater treatment using In-situ Redox Manipulation (ISRM) technology would be accomplished by installation of a continuous permeable reactive barrier (PRB). The treatment or reactive zone would be constructed of zero-valent iron (ZVI). A continuous PRB was selected over a funnel and gate PRB to reduce fouling impacts and to handle a wide variation in flow. A schematic of a typical continuous PRB is shown in Figure 3.

PRB: Conceptual Design

The barrier wall would consist of a treatment zone extending 150 feet across the drainage, perpendicular to groundwater flow, to contain residual tailings seepage. The treatment zone would be approximately 5 feet thick and would be keyed approximately 5 feet into the bedrock aquitard layer located approximately 50 feet below ground surface (total depth of 55 feet bgs). The treatment zone would extend to within 20 feet of the surface to capture groundwater flow. The area above the treatment zone, from the surface down to a 20-foot depth, would be backfilled with native aquifer material from the treatment zone excavation to reduce costs. The PRB would be constructed using an extended-arm track hoe. During construction, the trench would be held open with a biopolymer slurry that is degraded by an enzyme added during treatment zone construction. Excavation spoils would be disposed of on-site.

Three groundwater monitoring wells would be installed surrounding the wall to monitor groundwater quality as it flows through the treatment zone. One well would be installed immediately up-gradient of the treatment zone, one well would be installed immediately down-gradient of the treatment zone, and one well would be installed within the treatment zone. These wells would be used to determine the treatment effectiveness and degree of fouling within the ZVI. Wells would be installed to match the depth of the PRB.

The treatment or reactive zone would be constructed of ZVI. ZVI removes uranium from groundwater by two processes – reduction of uranium to less soluble species, and adsorption and co-precipitation of soluble uranium onto iron hydroxide corrosion products. The application of ZVI PRBs to reduce metal and metalloid concentrations has been the subject of study at many sites, including at the Department of Energy's facility in Oak Ridge, Tennessee (ITRC, 2005). It is assumed that a sand-ZVI mixture would be installed in the PRB at a 4:1 ratio.

Depending on site-specific conditions, PRBs are expected to last 10 to 30 years before requiring maintenance. Typical ZVI barriers are designed to provide adequate treatment for the longer end of this range; however, fouling often shortens the lifespan of a PRB due to plugging of the treatment zone by the formation of precipitates. For the purposes of this assessment, it is assumed that the PRB lifespan is 15 years. In many cases the spent ZVI is excavated, disposed of, and replaced. In this application it is assumed that the ZVI would be removed and a new barrier wall would be installed in the same location. In this application, it is conservatively assumed (lower cost) that the ZVI removed from the PRB would be disposed of on-site away from the PRB with costs only for moving the spent ZVI. Practically, the ZVI would also be 11e.(2) byproduct material and would have to managed according to NRC requirements, which would likely involve re-opening the existing tailings impoundment or constructing a new cell on site, both of which would add costs.

PRB: Operations

PRBs are passive treatment systems that require no ongoing operations except for performance monitoring. However, the reactive material would be consumed or fouled over time and would therefore require periodic re-installation of ZVI. It is anticipated that installation of a new zone of reactive material would be required every 15 years. In addition, monitoring of the three installed wells would periodically be required to assess the performance of the PRB. For the purposes of this assessment, quarterly sampling has been assumed in addition to an annual inspection.

PRB: Practicability

The following presents the assessment of this alternative's feasibility based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent

PRB have been successfully installed in numerous sites. The site-specific conditions such as the depth of the underlying shale and the hosting geologic media are consistent with the range of conditions suitable for application of this technology.

Effectiveness: Excellent

Though site-specific characterization and testing would be required prior to detailed design and installation, it is anticipated that lowering the redox potential of the groundwater through installation of ZVI would result in precipitation/sorption and immobilization of uranium to the point that the MCL of 0.03 mg/L could be met.

Durability: Poor

Because it cannot be assumed that long-term seepage down the Southeast Drainage groundwater system decreases to insignificant levels over time, the PRB would be required in perpetuity to maintain protective conditions in the drainage below. There are little data regarding the durability of ZVI in this application. However, it is assumed that the capital life of the PRB would be approximately 15 years and that at the end of the PRB capital life it would have to be destroyed and replaced. The capital life of the wells is assumed to be 50 years, the same as for most conventional wells. Consequently, the PRB is assumed to require replacement more than 13 times over the next 200 years. Therefore, the durability of this alternative is deemed to be poor.

Degree of Active Maintenance: Poor

As described under the durability criterion, this system would be required in perpetuity and would require regular capital replacement. In addition, regular monitoring of the installed wells would be required to assess the performance of the PRB. Therefore, this alternative is deemed poor for degree of active maintenance.

PRB: Capital Costs

The initial capital construction costs of this alternative are approximately $1,730,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for replacement of the PRB, including the ZVI and the monitoring wells. It was estimated that the PRB would need to be replaced every 15 years at a cost of approximately $1,169,000 without contingency costs, and the two up-gradient and down-gradient monitoring wells would need to be replaced every 50 years at a cost of approximately $23,000, without contingency.

PRB: Operating Costs

The annual cost of operating this alternative is approximately $45,000. This estimate includes quarterly groundwater monitoring of the three monitoring wells and an annual inspection of the alternative's components has been included in the costs over the duration of the corrective action, and is assumed to be above the base surveillance fund. No other operating costs or utilities are required for operation of this alternative. In addition, annual compliance monitoring of POC wells has not been included in these costs. A 10% contingency has been included in the annual operating costs.

PRB: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $12,140,000.

2.2.2.2. Down-gradient Corrective Action

Groundwater characterization has identified the hazardous constituents uranium, selenium, and radium-226+228 as exceeding Site GPLs in the Southeast Drainage. Selenium exceeds the Site GPL and MCL of 0.05 mg/L only in well BBL-2 (0.01 mg/L to 0.078 mg/L, Exhibit 2) and radium-226+228 exceeds the Site GPL and MCL of 5 pCi/L only in well BBL-3 (2.8 pCi/L to 8.9 pCi/L, Exhibit 2), but their mean and maximum concentrations at the head of the Southeast Drainage as represented by Well MFG-1 are currently below Site GPLs (see Figure 1 for well locations).

Uranium concentrations, however, have been consistently above the MCL of 0.03 mg/L in both MFG-1 (0.13 mg/L to 0.39 mg/L) and the other Southeast Drainage wells (average of 0.04 mg/L in BBL-4 to an average of 0.12 mg/L in TT-8), with the exception of Wells TT-4, -5 and -6 located in the vicinity of North Fork Box Creek which are all below the MCL (Exhibit 2). Therefore, down-gradient corrective actions identified for analysis are based on mitigating the uranium, selenium and Ra-226+228 concentrations between the toe of the tailings embankment and the confluence of the Southeast Drainage with North Fork Box Creek and are assessed in the following sections. The down-gradient corrective actions assessed include groundwater extraction through pumping wells and in-situ treatment through bioremediation using in-situ redox manipulation (ISRM).

Each of these alternatives must be considered in conjunction with a source control alternative in order for the down-gradient corrective action to have a finite operational timeframe. If a source control alternative is not implemented in conjunction with a corrective action of the down-gradient groundwater between the POC and POE, the remedy may be required in perpetuity due to the potential for long-term seepage from the tailings impacting the limited groundwater system of the Southeast Drainage.

Based on information developed from earlier drilling programs, it has been determined that the aquifer thickness ranges from approximately 5 to 30 feet (Figure 2) in depth and has a hydraulic conductivity value of approximately 7 feet per day, based on a slug test at well TT-8 (Section

1.2.2.7 in the main document). In addition, the average hydraulic gradient is approximately 0.005 ft/ft down the Southeast Drainage and the porosity is estimated to be approximately 30%, typical of fine sand (Section 2.2.1.2 in the main document).

Using these aquifer properties, the average linear velocity of groundwater down the drainage can be estimated using the following formula:

$$Vx = -\frac{Kdh}{n_e dl}$$

Where; *Vx = average linear velocity*
K = hydraulic conductivity
n_e = effective porosity
dh/dl = groundwater gradient

This results in an average linear velocity of 0.12 ft/day for the Southeast Drainage. In addition, it has been assumed that approximately five pore volumes would be necessary to completely flush out all absorbed hazardous constituents. This assumption may need to be further evaluated in the future to determine its appropriateness. This velocity and pore volume assumptions would be used in subsequent sections to determine the duration each corrective action would need to be implemented in order to completely flush the Southeast Drainage of hazardous constituents.

Groundwater Extraction With Pumping Wells.

This alternative was developed to mitigate the hazardous constituents in the Southeast Drainage down-gradient from the proposed source control locations. The alternative includes the placement of sets of extraction wells along the length of the Southeast Drainage to capture the water in the Southeast Drainage. As shown on Figure 2, there is greater saturated thickness down-gradient in the Southeast Drainage (as much as 30-40 feet) than at the area considered for source control, and therefore this alternative is considered more viable than the use of extraction wells for source control. Using wells to create capture zones down-gradient in the Southeast Drainage, in conjunction with a source control alternative, would prevent the hazardous constituents from reaching the POE at concentrations above their respective MCLs.

Groundwater Extraction with Pumping Wells: Conceptual Design

Groundwater extraction would be performed by installing a series of 4-inch ID Schedule 40 PVC extraction wells with slotted screens that penetrate the entire saturated thickness of the aquifer. Approximately nine fully penetrating wells would be installed in the Southeast Drainage. The wells would be installed in clusters of three at three locations within the drainage to collect seepage as it flows down the drainage. Environmental-grade submersible pumps with variable speed controllers would be installed near the bottom of the wells to maximize the available drawdown for each well. Each well would be sized in order to allow pumping of extracted water to a treatment system or the Pit Lake. In addition, water level sensors would be placed in each well that would allow the well pump to be automatically turned off as the water levels were drawn down to the maximum appropriate level and then turned on as the water levels recovered sufficiently to resume pumping. Figure 4 illustrates the conceptual extraction well locations. The recovered water would be handled ex-situ using one of the water management alternatives discussed in Section 2.2.2.3.

Subsurface power and communication lines would be extended from the current Smith Ranch\Highland In-Situ Recovery (ISR) facility to the interceptor trench location. Two separate trenches would be required for these lines.

Groundwater Extraction with Pumping Wells: Operations

The pumping system would operate year-round using grid-based power with a buried electrical line from the existing Smith-Ranch\Highland ISR facility approximately two miles to the west. In addition, there would be a data logger and control system to control the pump speeds and turn the pumps on and off at pre-set water levels. All pumping equipment would be installed in below-ground vaults and all water lines to the treatment systems would be buried below frost level to ensure uninterrupted winter operation. A phone-based communications system using a buried phone line would also extend from the Smith Ranch-Highland facility to allow the system to be audited remotely and to notify the operator of equipment failure for prompt repair.

If treatment of the extracted water was selected to handle the extracted water, in order to accelerate the corrective action, the treated water would be discharged to the top of the Southeast Drainage to provide a flushing or rinsing of the aquifer solids to strip any hazardous constituents adsorbed onto the aquifer matrix. The only identified treatment actions that would allow flushing of the aquifer with treated water are the Chemical Precipitation, Ion Exchange or Reverse Osmosis alternatives discussed below in Section 2.2.2.3. The discharged water would meet all applicable National Pollutant Discharge Elimination System (NPDES) water quality requirements prior to discharge.

Based on the average linear velocity of 0.12 ft/day calculated above, an assumption of five pore volumes, and a maximum distance between wells of 1,400 feet, it is estimated that this alternative, in conjunction with a source control alternative, would take approximately 160 years to effectively reduce the hazardous constituent concentrations to their respective MCLs. After the extraction system is shut down, a two-year monitoring period would be implemented to ensure that concentrations do not rebound and that hazardous groundwater constituent concentrations remain at levels protective of public health, safety and the environment.

Groundwater Extraction with Pumping Wells: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent

This alternative relies on proven technologies and installation methods. The pumping, control and monitoring equipment is similarly proven, commonly used and appropriate for the site-specific conditions.

Effectiveness: Moderate

Groundwater extraction and freshwater flushing of the impacted aquifer associated with the Southeast Drainage is considered likely to decrease the hazardous constituent concentrations to levels protective of public health and the environment. However, due to the low hydraulic conductivity and relatively high degree of heterogeneity of the materials (alluvium and regolith) in the Southeast Drainage limited aquifer, complete evacuation of all the impacted groundwater may not be achievable. In addition, it is expected that aquifer water levels will significantly decrease with prolonged pumping and recovery or mitigation measures will eventually become impracticable. Therefore, the effectiveness of this alternative is considered to be only moderate, based on the uncertainty of the hydrogeologic and baseline conditions.

Durability: Poor

The capital life of the pumping equipment, sensors, and control instrumentation is estimated to be approximately 15 years, while the capital life of the extraction wells and utilities are expected to be approximately 50 years each, and therefore all would need to be replaced several times during the estimated duration of the corrective action. After the groundwater has been extracted and the aquifer solids rinsed with fresh water, rebound of hazardous constituent concentrations is considered unlikely. This assumes that a source control measure is implemented with this corrective action. If source control measures are not implemented with this alternative, this alternative would be required in perpetuity. Due to the short equipment life anticipated and the relatively long time required to flush all hazardous contaminants from the Southeast Drainage, the durability of this alternative is considered poor.

Degree of Active Maintenance: Poor

Extraction through pumping requires that the equipment be maintained and monitoring be conducted over the relatively long expected duration of the alternative. This includes regular monitoring of the system and regular maintenance; thus, this alternative requires a relatively high degree of active maintenance. Furthermore, implementation of the source control component and associated water treatment system would require perpetual care and maintenance. The degree of active maintenance for those alternative components is described in their respective sections.

Groundwater Extraction with Pumping Wells: Capital Costs

The initial capital construction costs of this alternative are approximately $943,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1 Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for the alternative's equipment, utilities and the wells. It was estimated that the equipment would need to be replaced every 15 years at a cost of approximately $142,000, the utilities and wells would need to be replaced every 50 years at a cost of approximately $376,000 and $132,000, respectively.

Groundwater Extraction with Pumping Wells: Operating Costs

The annual cost of operating this alternative is approximately $93,000. The annual operating cost includes an annual site inspection, reporting, groundwater sampling and analysis, electrical usage, and maintenance of the pumping equipment. Maintenance of the alternative is estimated at 1% of equipment costs. Annual monitoring of the nine extraction wells has been included in the annual operating costs. An annual inspection of the alternative's components, to be performed in conjunction with the annual sampling, has been included in the costs over the duration of the corrective action, and is assumed to be above the base surveillance fund. In addition, annual compliance monitoring of POC wells has not been included in these costs. A 10% contingency has been included in the annual operating costs.

Groundwater Extraction with Pumping Wells: Net Present Value

Applying a 1% discount rate, the Net Present Value to operate this alternative for the requisite 160 years is estimated to be approximately $9,670,000.

In-Situ Redox Manipulation (ISRM) with Injection Wells

This alternative was developed to mitigate the hazardous constituents in the Southeast Drainage down-gradient from the proposed source control locations using in-situ redox manipulation. The alternative includes the placement of injection wells near the end of the Southeast Drainage to inject a slow release electron donor in the Southeast Drainage in order to create reducing conditions and precipitate out hazardous constituents. As long as reducing conditions are present in the Southeast Drainage, this alternative would prevent the hazardous constituents from reaching the POE.

ISRM with Injection Wells: Conceptual Design

In this alternative, groundwater would be treated using ISRM technology by injecting a slow-release electron donor in the form of an emulsified vegetable oil (EVO) into the aquifer. Adding an electron donor such as EVO to an aquifer creates reducing conditions where the precipitation of uranium (as uraninite) is favorable. Injections would be performed by installing a series of 2- to 4-inch ID Schedule 40, PVC injection wells with slotted screens that penetrate the entire saturated thickness of the aquifer. One row of approximately 14 wells would be installed perpendicular to groundwater flow as shown in Figure 5. The average depth of the wells is assumed to be 50 feet. The wells would be installed approximately 10 feet on center, creating a treatment zone approximately 150 feet wide across the drainage. This width would ensure that all seepage is treated. The goal of the injections is to disperse the electron donor so that uranium is precipitated as groundwater flows through the treatment zone. Based on the information developed from earlier drilling programs, the aquifer thickness in the area of proposed injection well placement is approximately 30 feet in depth. Impacted groundwater down-gradient of the row of injection wells would be allowed to flush out of the Southeast Drainage. Initially, 54,000 pounds of EVO would be pumped into the aquifer with an assumed radius of influence of 6 feet. Based on the estimated radius of influence, the treatment zone would be 150 feet wide, 30 feet thick (top to bottom) and 12 feet long (in the direction of groundwater flow).

ISRM with Injection Wells: Operations

The initial ISRM treatment would be conducted as a one-time event. This treatment would be capable of creating localized reducing conditions to precipitate and immobilize uranium for up to one year. During this time, the electron donor would be diluted and consumed by uranium, dissolved oxygen, nitrate, sulfate, and other groundwater constituents. Eventually, oxidizing conditions would return to the aquifer and uranium could be remobilized. As a result of the relatively high sulfate concentrations present, reinjection of the electron donor is assumed to be required each year to ensure that uranium is not remobilized.

Based on the average linear velocity of 0.12 ft/day calculated above, an assumption of five pore volumes, and a distance of approximately 3,500 feet from the location of a source control to the treatment well location, it is estimated that this alternative, in conjunction with a source control alternative, would take approximately 400 years to effectively reduce the hazardous constituent concentrations to their respective MCLs. Annual electron donor injections would be required even beyond this timeframe to maintain reducing conditions in the drainage throughout the requisite 1,000 years of management.

In addition, periodic monitoring of the injections wells would be required to assess the efficacy of the injections and to identify when additional injections may be necessary. For the purposes of this assessment, quarterly sampling has been assumed in addition to an annual inspection.

ISRM with Treatment Wells: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Moderate

This alternative relies on a relatively innovative technology with a few successful applications at similar sites. The mechanical equipment and materials are commonly available and commonly used and appropriate for the site-specific conditions.

Effectiveness: Moderate

This alternative is considered likely to decrease the hazardous constituent concentrations to levels protective of public health and the environment. The hazardous constituents would be immobilized, but would remain in place and could be subject to remobilization if oxidizing conditions return to that localized portion of the aquifer. Because the hazardous constituents could be remobilized, the effectiveness of this alternative is considered moderate.

Durability: Poor

Because hazardous constituents would be present but immobilized, the treatment zone must be maintained in perpetuity. It is assumed that reinjection of the electron donor would occur every year to maintain localized reducing conditions in the aquifer. As a result, up to 200 injections of electron donor would be required over the next 200 years. The capital life of the wells is assumed to be 50 years, the same as for most conventional wells, and would require complete replacement four times over the same period. Therefore, the durability of this alternative is deemed to be poor.

Degree of Active Maintenance: Poor

Quarterly monitoring would be required to ensure the efficacy of the treatment. The injection wells would have to be regularly inspected and maintained. Re-injection of electron donor would be required every year to maintain treatment efficacy. Therefore, this alternative is deemed to score poor for degree of active maintenance.

ISRM with Treatment Wells: Capital Costs

The initial capital construction costs of this alternative are approximately $426,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for replacement of the injection wells. It is estimated that the injection wells would need to be replaced every 50 years at a cost of approximately $203,000.

ISRM with Treatment Wells: Operating Costs

The annual cost of operating this alternative is approximately $158,000. This estimate includes annual re-injections of the electron donor, quarterly groundwater monitoring of select wells for assessment of the ISRM effectiveness, and an annual inspection of the alternative's components. These have been included in the costs over the duration of the corrective action, and the costs are assumed to be above the base surveillance fund. No other operating costs or utilities are required for operation of this alternative. In addition, annual compliance monitoring of POC wells has not been included in these costs. A 10% contingency has been included in the annual operating costs.

ISRM with Treatment Wells: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative for the estimated 200 years of operation is estimated to be approximately $14,370,000.

2.2.2.3. *Management of Collected Water*

Several options exist for the management of water extracted from the Source Control or Down-gradient Corrective Actions. Each of these options remove hazardous constituents from the Southeast Drainage and prevent them from re-entering the groundwater. The treatment methods evaluated include:

- Direct disposal in the Highland Pit Lake
- Evaporative treatment in lined ponds
- Chemical precipitation and discharge
- Ion exchange and discharge
- Reverse osmosis and discharge

Other methods exist but the methods identified above are the simplest and present low cost alternatives sufficient to determine if these or similar approaches are practicable and provide acceptable cost-benefit ratios.

<u>Direct Disposal in Highland Pit Lake</u>

This alternative considers pumping all recovered groundwater from the Southeast Drainage directly to the Highland Pit Lake. The amount of water to be intercepted as a source control action is estimated to range from approximately 0.1 to 3 gpm. The amount of groundwater that could be recovered from the Southeast Drainage between the proposed POC and North Fork Box Creek is estimated to range from approximately 3 to 5 gpm (Section 2.2.1.2 in the main document).

The Highland Pit Lake already has significant amounts of the 11e.(2) byproduct constituents uranium and selenium. Specifically, the Highland Pit Lake contains an estimated 3.9 billion gallons of water and approximately 104,145 lbs (47,240 kg, assuming an average concentration of 3.2 mg/L) of dissolved uranium and 2,380 lbs (1,080 kg, assuming an average concentration of 0.073 mg/L) of dissolved selenium. The quantities of water, uranium and selenium that would be added to the Pit Lake on an annual basis under this alternative represent a miniscule volume and constituent mass addition to the Highland Pit Lake and would have no significant or practical impact on the Pit Lake water levels or water quality. Specifically, assuming current uranium concentrations in well MFG-1 (0.37 mg/L maximum for 2010, Exhibit 2), current selenium concentrations in BBL-2 (0.072 mg/L, maximum for 2010, Exhibit 2) and a pumping rate of 3 gpm (1.58 Mgal/yr or 0.040 % of the Pit Lake Volume), the mass loading would be 4.9 lbs of uranium/year (0.005% of the total Pit Lake uranium mass) and 0.9 lbs of selenium/year (0.04% of the total Pit Lake selenium mass). This alternative represents the lowest capital and operating cost treatment alternative for managing recovered groundwater.

<u>Direct Disposal in Highland Pit Lake: Conceptual Design</u>

The groundwater recovered from the extraction point, whether from a source control action or from a down-gradient corrective action in the Southeast Drainage, would be pumped in a buried (ensuring year-round operation) 2-inch ID Schedule 80 PVC pipe, to the Highland Pit Lake. The discharge point would be installed sufficiently below the Pit Lake water surface to ensure winter freezing would not block the pipe discharge.

A data logger and digital flow meter would be installed near the discharge point to monitor the discharge flow rate. A phone-based communications system using a buried phone line extended from the Smith Ranch-Highland facility would allow remote assessment of the discharge rate for comparison to the pumping rates, ensuring prompt detection of potential line losses.

Figure 6 illustrates the conceptual layout of the system design.

Direct Disposal in Highland Pit Lake: Operations

This alternative would operate year-round as necessary to handle the flow extracted from the Southeast Drainage. The alternative would not require on-site personnel on a daily basis. Annual inspection of the system components would be performed at the same time as the extraction system. Periodic repairs of the system, data metering, recording and telecommunications equipment would be required. The capital life of the data metering, recording and telecommunications equipment is estimated to be 15 years and the pipe is estimated to have a capital life of 50 years. Because the submersible pumps used in the Southeast Drainage alternatives are sized to pump water to the Highland Pit Lake, no additional pumping is required in this alternative.

All piping from the Southeast Drainage would be buried below frost level to ensure uninterrupted winter operation.

Direct Storage in Highland Pit Lake: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent.

This alternative relies on proven technologies and installation methods. The monitoring and communications equipment is similarly proven, commonly used and appropriate for the site-specific conditions.

Effectiveness: Excellent

This alternative would be highly effective in managing the recovered waters.

Durability: Moderate

The capital life of the monitoring equipment and communication instrumentation is estimated to be approximately 15 years, significantly less than the 200 to 1,000 year operational time frame. If groundwater extraction was the preferred corrective action for mitigation of the Southeast Drainage impacts, this component would be required in perpetuity and the components would be replaced numerous times over the next 200 to 1,000 years.

Degree of Active Maintenance: Poor

Though the placement of extracted groundwater in the Highland Pit Lake is a relatively passive mechanism, the necessity for regular remote monitoring of the system and the limited capital life of the equipment, regular maintenance and periodic capital equipment replacement require a significant amount of active maintenance on the part of the long term custodian.

Direct Storage in Highland Pit Lake: Capital Costs

The initial capital construction costs of this alternative are approximately $185,000; this capital cost needs to be added to one of the source control or down-gradient corrective actions for the Southeast Drainage as well. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for the alternative's equipment, the water lines, and the electrical and control extensions required. It was estimated that the equipment would need to be replaced every 15 years at a cost of approximately $30,000, the water, electrical and controls lines would need to be replaced every 50 years at a cost of approximately $103,000.

Direct Storage in Highland Pit Lake: Operating Costs

The annual cost of operating this alternative is approximately $3,000; this operating cost needs to be added to one of the source control or down-gradient corrective actions for the Southeast Drainage as well since pumping has not been included in this estimate. The annual operating cost includes electrical usage and maintenance of the piping, valves and equipment. Maintenance of the alternative is estimated at 1% of equipment costs. It is assumed that the annual inspection cost would be incurred within the extraction component of this alternative. Routine monthly inspection of the system has not been included in these costs. In addition, annual compliance monitoring of POC wells has not been included in these costs. A 10% contingency has been included in the annual operating costs.

Direct Storage in Highland Pit Lake: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $750,000.

Evaporative Treatment In Lined Ponds

When a solution evaporates, the water vaporizes and a concentrated residual solution or a solid residue is left behind which can then be disposed of, recovered, or recycled. Evaporation was the method approved for the original Highland Project CAP. The evaporation ponds and associated systems were considered operationally effective with low operating costs until groundwater recovery rates diminished to the point of impracticability. Evaporation may be enhanced by spray misting the liquids with irrigation-type sprinklers, which can increase the overall amount of water evaporation by up to 40 percent.

Construction of evaporation ponds on the reclaimed tailings cover surface has the advantage of co-locating a potential source of contamination, should the ponds leak, over the existing source of contamination.

Evaporative Treatment in Lined Ponds: Conceptual Design

Evaporation ponds would be constructed in two or more cells using a multi-liner system comprised of gecomposite clay underliner (i.e., Bentomat), a 40-mil high density polyethylene (HDPE) leak detection liner overlain by a geosynthetic drainage layer (geogrid) which in turn would be overlain by a 60-mil HDPE primary liner. The drainage layer would be graded to gravity drain to a sump where water levels and collected waters could be measured and recovered. The ponds would be constructed entirely above grade with the liners anchored in a perimeter anchor trench. The ponds would be sized to accommodate 6 months pumping volume (at 5 gpm), as well as the volume of direct precipitation from the 100 year storm event and allow for at least 2 feet of freeboard. It has been assumed that all material required for constructing the pond embankments could be obtained on-site and that no imported material would be required.

The water recovered from the extraction systems would be pumped through buried 2 inch Schedule 80 PVC pipes to the ponds. All water lines to the treatment systems would be buried below frost level to ensure uninterrupted winter operation. Submersible pumps with level monitoring controls, digital flow gages and data loggers would be installed in the leak detection sump to record sump water levels and pumping rates. Waters from the leak detection sump would be returned to the pond.

A data logger, level control system and digital flow meter would be installed to monitor the water levels in the pond and in the leak detection sump with automated controls to turn the pump on and off at a pre-set water levels. A phone based communications system using a buried phone line extended from the Smith Ranch-Highland facility would allow automated alarms to be sent to a designated off-site monitoring location should pond levels, leak detection sump water levels or leak detection pumping rates exceed pre-set limits.

Figures 7 and 8 present schematic illustrations of the system design.

Evaporative Treatment in Lined Ponds: Operations

The ponds would receive water year round but would not require on site personnel on a daily basis. It is assumed that monthly remote inspections of the system would be performed, as well as an annual site inspection, and that periodic maintenance of the pumping, data recording and telecommunications equipment would be required. It is also assumed that, at the end of the ponds' capital life, new ponds would be constructed sequentially, directly on the existing pond cells, maintaining the same foot print. The contents of one pond would be pumped into another cell and the new cell constructed. The water would then be transferred to the new cell while the other cells were constructed.

Evaporative Treatment in Lined Ponds: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent

This alternative relies on proven technologies and installation methods. The monitoring and communications equipment is similarly proven, commonly used and appropriate for the site-specific conditions.

Effectiveness: Excellent

This alternative would be highly effective in managing the recovered waters. This technology and approach has been previously approved by the NRC and its demonstrated effectiveness at several Title II uranium facilities is evidenced by the fact that it has been the most common corrective action treatment technology used at these facilities over the past 30 years.

Durability: Poor

The capital life of the pumping equipment, sensors, control and communication instrumentation is estimated to be approximately 15 years. The capital life of the pond synthetic liner materials is estimated at 50 years. If groundwater extraction and evaporation is the required corrective for mitigation of the Southeast Drainage impacts, this component would be required in perpetuity and the ponds would be replaced several times over the next 200 to 1,000 years.

Degree of Active Maintenance: Poor

Though the ponds are a relative passive treatment mechanism, the necessity for regular remote monitoring of the system and the limited capital life of the equipment, regular maintenance and periodic capital equipment replacement require a significant amount of active maintenance on the part of the long term custodian.

Evaporative Treatment in Lined Ponds: Capital Costs

The initial capital construction costs of this alternative are approximately $2,553,000; this capital cost needs to be added to one of the source control and/or down-gradient corrective actions for the Southeast Drainage. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. Replacement costs were also estimated for the alternative's monitoring equipment, the utilities and the pond liner system. It was estimated that the monitoring and instrumentation equipment would need to be replaced every 15 years at a cost of approximately $75,000. The water, electrical and controls lines would need to be replaced every 50 years at a cost of approximately $52,000. The ponds would need to be reconstructed every 50 years at a cost of approximately $1,644,000.

Evaporative Treatment in Lined Ponds: Operating Costs

The annual cost of operating this alternative is approximately $76,000; this operating cost needs to be added to one of the source control or down-gradient corrective actions for the Southeast Drainage as well since pumping has not been included in this estimate. The annual operating cost includes estimated electrical usage and maintenance of the piping, valves and equipment. Maintenance of the alternative is estimated at 1% of equipment costs. An annual inspection of the alternative's components has been included in the costs over the duration of the corrective action, and is assumed to be above the base surveillance fund. Routine monthly inspection of the system has not been included in these costs. In addition, annual compliance monitoring of POC wells has not been included in these costs. A 10% contingency has been included in the annual operating costs.

Evaporative Treatment in Lined Ponds: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $11,790,000.

Ion Exchange Treatment and Discharge

Another approach for treating the water extracted from the Southeast Drainage involves performing ex-situ treatment of the water in a water treatment plant and discharging the treated water back to the Southeast Drainage. A combination treatment approach consisting of ion exchange (IX) and coagulation/filtration has been evaluated. This approach is same as the approach discussed in more detail in Section 2.2.3.2, though the costs have been scaled back to be more consistent with the much smaller flow expected from the Southeast Drainage (Section 2.2.1.2 in the main document).

Ion Exchange Treatment and Discharge: Conceptual Design

The treatment process was originally developed in the ACL for treatment of the Pit Lake water and has been adapted for treatment of the Southeast Drainage. Figure 9 provides a conceptual process flow diagram for treatment of the Southeast Drainage water.

The water recovered from the extraction systems would be pumped from the extraction system through buried 2-inch Schedule 80 PVC pipes to the treatment system using the pumps installed in the extraction system. All water lines to the treatment systems would be buried below frost level to ensure uninterrupted winter operation. A small, skid-mounted chemical treatment system would be installed at the Site. Water would be pumped from the extraction point into a 5,000 gallon double-walled equalization tank. The water would then be metered into the treatment system.

As shown on the process flow diagram, the treatment system would consist of two interacting treatment technologies. The front end of the system would consist of filtration to remove suspended solids followed by ion exchange for removal of uranium. It is anticipated that an anionic IX resin would be most suited to this application. Some interference and competition from other ions, such as sulfate, is likely to occur which would decrease the expected IX efficiency for uranium removal. IX resin would be regenerated off-site. Though there are currently no facilities known to be licensed to accept uranium loaded third-party resin for stripping and regeneration, it is understood that more than one ISR licensee is currently in the process of applying for license amendments to accept such resins. This alternative is predicated on the assumption that there would be a facility licensed to accept these resins at the time of implementation should this alternative be selected.

The effluent from the IX would feed a chemical treatment process that consists of a metal salt addition, potential pH adjustment, coagulant addition, and filtration. Due to the relatively high pH of the Southeast Drainage water, the species of selenium is most likely selenate. Coagulation is more effective in removal of the selenite species, than in removal of the selenate species, and therefore pH adjustment may be required to improve the coagulation and flocculation process (Sobolewski, 2005). The multi-media filters would periodically be backwashed to remove solids retained in the filtration bed. This backwash water would be collected in a tank and pumped through a solid separation system consisting of a clarifier, sludge thickener tank, and a filter press. Water from the solids handling system would be returned to the head of the plant for retreatment. Treated water from the system would be sampled regularly and discharged back to the Southeast Drainage under a (NPDES permit. It has been assumed that all solids generated would be disposed of on-site.

The proposed treatment process should be tested at the bench-scale level prior to design and construction of the treatment system.

A phone-based communications system using a buried phone line extended from the Smith Ranch-Highland facility would allow automated control of the system.

Ion Exchange Treatment and Discharge: Operations

This alternative would operate year-round for the duration of the selected corrective action alternative. The effluent from the treatment system could be discharged back to the Southeast Drainage to provide additional flushing. This alternative would likely require at least one full-time plant operator on a daily basis. Regular sampling and inspection of the system would likely be required for proper chemical dosing and for NPDES permit requirements. Periodic repairs of the system, data metering, recording and telecommunications equipment would be required. It has been assumed that storage of one vessel worth of ion exchange resin would be provided with the system to minimize treatment system downtime. Regular deliveries of IX resin and chemicals would be required to supply the treatment system. It is assumed that all sludge generated would be able to be disposed of on-site.

Ion Exchange Treatment and Discharge: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Moderate

This alternative relies on proven technologies and installation methods. The treatment, monitoring and communications equipment is similarly proven and commonly used and appropriate for the site-specific conditions. However, it is unclear if the combined treatment approach would sufficiently reduce hazardous constituents until bench-scale testing on the specific water in the Southeast Drainage is performed. Therefore, the feasibility of this alternative is considered moderate.

Effectiveness: Moderate

Because the presence of competing ions in the water, there is significant uncertainty regarding the efficiency of the proposed treatment system and therefore the effectiveness of this alternative is considered to be moderate.

Durability: Poor

The capital life of the treatment equipment is estimated to be approximately 25 years, significantly less than the 200 to 1,000 year operational time frame. The treatment system would be required in perpetuity and the treatment system would need to be replaced numerous times over the next 200 to 1,000 years. Regeneration of the ion exchange resins off-site would result in selenium and uranium wastes being generated at another facility.

Degree of Active Maintenance: Poor

Significant operations and maintenance labor is required for the treatment system. Regular maintenance, sampling, and periodic capital equipment replacement requires a significant amount of active maintenance on the part of the long-term custodian.

Ion Exchange Treatment and Discharge: Capital Costs

The initial capital construction cost of this alternative is approximately $1,755,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. The capital costs were largely based on a scaled-down version of the system developed by AES as described in Exhibit 3. Design and construction management of the alternative have been included in the capital costs, at 10% of the construction costs. A 25% contingency on construction costs has also been included in the capital costs. A bench-scale study has also been included in the capital costs. Replacement costs were estimated for the alternative's equipment, as well as the piping and utilities. It was estimated that the equipment would need to be replaced every 25 years at a cost of approximately $1,103,000 the piping and utilities would need to be replaced every 50 years at a cost of approximately $58,000.

Ion Exchange Treatment and Discharge: Operating Costs

The annual cost of operating this alternative is approximately $245,000. The annual operating cost includes electrical usage, IX resin, chemical usage and maintenance of the piping, valves and equipment. Maintenance of the alternative is estimated at 3% of equipment costs. It is assumed that one full-time employee would be required for regular operations, monitoring, maintenance, sampling and inspections. Monthly NPDES compliance monitoring has been assumed. An annual inspection of the treatment system components has been included in the costs over the duration of the corrective action, and is assumed to be above the base surveillance fund. A 10% contingency has been included in the annual operating costs. Annual compliance monitoring of POC wells has not been included in these costs. IX resin regeneration costs are predicated on a facility within 1,000 miles of the site being able to amend their license to accept and regenerate the material. These costs do not account for the value of the recovered materials. In addition, it is assumed that resin would be replaced after being regenerated four times.

Because the amount of sludge generation cannot be accurately defined prior to bench-scale testing, no costs for handling, transportation or disposal of sludge have been included. Preliminary calculations of sludge generation estimate that the volume of sludge generated would be less than 1 cubic yard annually. It is assumed that this sludge would be able to be disposed of on-site. Due to the small expected quantity of sludge this cost is expected to be nominal.

Ion Exchange Treatment and Discharge: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $26,320,000.

Reverse Osmosis and Discharge

Reverse osmosis (RO) physically separates various dissolved inorganic contaminants from an aqueous stream, regardless of its electrical charge, by selective permeation of water through a semi-permeable membrane, leaving a partially purified stream and a residual concentrated stream. RO involves developing a pressure gradient large enough to overcome the osmotic pressure of the ions within the waste stream. Pressures in the range of 400 to 1,800 pounds per square inch are applied to more concentrated wastewater solutions, forcing the purified water to diffuse through the semi-permeable membrane. The relatively clean water can then be recycled or disposed of, and the concentrated solution can be treated further or routed to evaporation ponds for disposal.

RO can be successfully used to remove a high percentage of dissolved ionic species, including heavy metals and radionuclides. RO becomes more feasible for use as the water becomes less concentrated with TDS and is less acidic. The type of membrane must be carefully selected to be compatible with the characteristics of the wastewater and the different ionic species. RO systems are extremely sensitive to the presence of particulate matter.

Although RO may be slightly more effective than chemical precipitation for metals removal, it has high capital costs, requires sophisticated equipment, is expensive to maintain, is energy intensive, and requires significant pretreatment of the liquids to minimize fouling and scaling of the membrane. Careful management of the RO system sophisticated equipment under the narrow design conditions is required for the system to be effective. Furthermore, the system requires further treatment or disposal of the concentrated waste stream. Operating costs associated with an RO system include maintenance, labor, power, chemical feeds and membrane replacement. Maintenance and power costs are relatively high due to the high-pressure feed pumps.

RO is used extensively in uranium in-situ leach (ISL) operations to restore collected water prior to re-injecting it into the groundwater system. However, TDS levels of ISL waters are carefully controlled and are kept within specific tolerance limits. Membrane life is related to the amount and effectiveness of liquid pretreatment, pH control, and operations of the unit under design conditions. Generally, the higher the TDS concentrations and the lower the pH of the treatment solution, the more pretreatment and membrane replacement are required. The water currently recovered by the CAP would require substantial pre-treatment before it could be treated by RO. Approximately 20% of the RO-treated water would be returned as reject that would require some form of treatment prior to disposal (solidification or evaporation).

For the reasons stated above, primarily unsuitability of the method and high cost, RO was rejected as a possible alternate groundwater corrective action at the Highland site and is not considered further.

2.2.3 Highland Pit Lake Corrective Action Alternatives

Several alternatives were assessed for treating the Highland Pit Lake. The alternatives considered two primary approaches, including treating the Pit Lake using in-situ redox manipulation (ISRM) techniques and ex-situ conventional water treatment methods. In addition, the alternative of backfilling of the Pit Lake is also assessed. However, it is assumed that the pit waters would have to be treated and discharged from the pit prior to backfilling to avoid raising water levels into areas needed for borrow materials and from driving the pit waters away from the pit due to the increased water levels created by the backfill displacing the pit water. The following sections describe the corrective actions developed for treatment of the Highland Pit Lake.

2.2.3.1. Pit Lake Treatment Using In-situ Redox Manipulation (ISRM)

The goal of this treatment technology is to add sufficient organic carbon and macronutrients (typically nitrogen and/or phosphorous) to the Pit Lake to enhance microbial growth and facilitate a change from aerobic, oxygen-dependent respiration to anaerobic respiration, which would induce the reduction of selenium, uranium and/or sulfate. The reduction of these compounds would result in their precipitation, and thus, removal from the Pit Lake water column.

The coupling of carbon oxidation with the various potential electron acceptors follows a predictable order, which is based on the energetics of the reaction (i.e., how much energy is available from the oxidation-reduction reaction). Molecular oxygen is a much stronger oxidant than is sulfate and there is considerably greater energy available from carbon oxidation coupled to the reduction of O_2 than there is when sulfate is used as the terminal electron acceptor. The biogeochemical reactions for the oxidation of organic carbon coupled to the reduction of oxygen and sulfate are summarized below, where CH_2O is the empirical formula for a carbohydrate (sugar).

$$CH_2O + O_{2\,(g)} \rightarrow HCO_3^- + H^+$$

$$2CH_2O + SO_4^{2-} \rightarrow HS^-_{(aq)} + 2HCO_3^- + H^+$$

When organic carbon is added to a system, the bacteria that use oxygen in respiration will generally out-compete those that use less energetically favorable terminal electron acceptors and therefore dominate the system. After oxygen has been consumed, if nitrate is available, denitrification would be the dominant process and so on down the chain of potential terminal electron acceptors.

In-situ redox manipulation (ISRM) as a remediation technology takes advantage of these respiratory pathways to promote direct and/or indirect metal reduction and precipitation, and the removal of nitrate and sulfate.

Several metals/metalloids are potential terminal electron acceptors and are reduced directly by bacteria in anaerobic respiration including iron, manganese, chromium, arsenic, selenium, and uranium (Nealson and Myers, 1992; Lovley, 1993; Newman et al., 1998; Tebo and Obraztsova, 1998; Oremland et al., 1999; Wielinga et al., 2001; Fendorf et al., 2002). Direct reduction of selenium and uranium can be exploited for Pit Lake remediation as the reduction of these elements can result in formation and precipitation of solid phases as described by the reactions below.

$$2CH_2O + 2HSeO_3^- + 2H^+ \rightarrow 2Se^0_{(s)} + 2CO_2 + 4H_2O$$
$$2CH_2O + 2UO_2(CO_3)_2^{2-} + 2H_2O \rightarrow 2UO_{2\,(s)} + 5HCO_3^- + H^+$$

After precipitation out of the water column and deposition to the lake sediments, the solid phase species can potentially be protected from reoxidation by the accumulation of organic material and burial in the sediments or by establishment of a permanently stratified lake with an anoxic hypolimnion (bottom layer).

Implementation of this technology for the treatment of the Highland Pit Lake was evaluated with two substrate delivery scenarios, which are described below. The treatment consists of mixing methanol and a de-sugared molasses product (DSM) to create reducing conditions in the lake, whereby naturally occurring bacteria would reduce selenium and uranium, causing them to precipitate. In addition, macronutrients (nitrogen and phosphorus; i.e. fertilizer) would be added to the organic mixture to stimulate primary productivity in the lake and increase sedimentation to more rapidly bury the precipitates in the lake sediments.

The alternatives differ in the methodology used to deliver and mix the methanol and DSM into the Pit Lake. Therefore, because the two alternatives are similar and differ only in the manner in which they deliver reactive materials, they are assessed as a single alternative but are distinguished by the approach and differences in costs.

ISRM Alternative A: Anaerobic Treatment With Land Mixing Conceptual Design

Under ISRM Alternative A, it is assumed that methanol and DSM would be delivered to Douglas, Wyoming via rail and would then be trucked to the site and transferred to on-site storage tanks. In order for large trucks to gain access to the site, the existing roadway would be improved. Mixing and storage tanks would be located near the buildings on the west side of the lake (Figure 10). One 5,000 gallon mixing tank and seven 5,000 gallon storage tanks would be required. Pumping stations consisting of two diesel-engine powered 1,000 gpm pumps would be located at the north and east side of the lake. Access roads would be improved or created to gain access to these locations. Water would be pumped from the lake up to the mixing tank. The methanol, DSM, and fertilizer would be pumped into the mixing tank simultaneously to allow adequate mixing with lake water. Mixing samples would be collected from the tank outlet to confirm the mixing is adequate. After mixing, the water would be gravity drained to a discharge point on the south side of the lake.

A total of 2,500,000 gallons of DSM and 1,000,000 gallons of methanol would be added to the lake over the course of the implementation of this alternative. These quantities are based on Pit Lake water quality measurements and assumptions regarding potential electron sinks. The estimated loading rates for DSM and methanol are 100 gpm and 50 gpm, to the 1,000 gpm net pumping rate from the Pit Lake. This is a relatively low volume of additives in comparison to quantity of water pumped and should allow adequate mixing prior to discharge within the lake. Six truckloads of additives would be delivered daily to meet additive demand. The project duration is estimated to be 28 days, if mixing is performed 10 hours per day. Two laborers would be available at the site to oversee operations. A security guard and spill prevention measures would be present at the rail spur in Douglas, Wyoming to oversee the loading and unloading of methanol and DSM. Confirmation samples would be collected from the lake once mixing is complete.

ISRM Alternative B: Anaerobic Treatment With Floating Platform Conceptual Design

Alternative B is similar to Alternative A, but uses a different method of additive delivery. In Alternative B, one mixing tank and 6 storage tanks would be placed on the west side of the lake and the existing access road would be improved for deliveries (Figure 11). Instead of creating pumping stations, a floating platform would be constructed that would house a single 1,000 gpm pump. Additives would be pumped into the mixing tank and supplied to the platform via a floating pipe. The additives would be delivered to the inlet of the pump at the water's surface and would be discharged below the surface at a depth of approximately 10 feet. In this alternative, the rate of DSM and methanol delivery is 60 gpm and 40 gpm, respectively. This is small compared to the total capacity of the pump, so that the additives would be thoroughly mixed with lake water by the pump prior to discharge. Mixing and confirmation samples would be collected as in Alternative A.

The floating platform has the additional benefit of mobility. The platform would be towed to several locations by a small boat to more evenly disperse the additives throughout the lake. Given the slightly lower additive loading rates, this alternative would require 45 days of mixing 10 hours per day. A total of 2,500,000 gallons of DSM and 1,000,000 gallons of methanol would be added to the lake over the course of the project. Five truckloads of additives would be delivered daily to meet additive demand. One boat captain and two laborers would oversee pumping operations. Two additional laborers would oversee mixing and deliveries. A security guard and spill control measures would be located at the rail spur.

Pit Lake Treatment Using ISRM: Operations

This is a one-time treatment and there would be no ongoing operations. This is based on an assumption of no re-oxidation of the uranium and selenium precipitates.

Pit Lake Treatment Using ISRM: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Moderate

This alternative relies on a relatively innovative technology with limited successful applications in this environment. The mechanical equipment and materials are commonly available and commonly used and appropriate for the site-specific conditions.

Effectiveness: Moderate

The likely efficacy of this alternative is considered moderate due to uncertainty regarding whether the hazardous constituent concentrations can be reduced to MCLs or the license condition standards, which would be protective of public health and safety. Only full-scale testing would be sufficient to determine the actual efficacy of this alternative, which is neither practical nor warranted. Additional uncertainty with regard to effectiveness comes from the potential reoxidation of both selenium and uranium in a Pit Lake that is not yet at steady state.

Durability: Moderate

The evaporative nature of the Pit Lake indicates that, like many closed lake systems in Wyoming, it will eventually become saline with increasing dissolved solids concentrations. Therefore, though this one-time treatment may temporarily remove hazardous constituents from the Pit Lake, the water body would not remain protective of human health and the environment over the requisite 200 years to 1,000 years, though these increase would not be due to increases in 11e.(2) byproduct material but rather from naturally occurring radiological and non-radiological constituents.

Degree of Active Maintenance: Excellent

After implementation, there would be no additional maintenance required for this alternative and therefore the degree of active maintenance associated with this alternative is considered excellent. However, the 11e.(2) byproduct material precipitated by this alternative would remain at the bottom of the lake and presumably isolated from future re-oxidation and mobilization. Therefore, institutional controls and long-term custodial control of the Pit Lake may be required, regardless of the temporary improvement of the Pit Lake water quality.

Pit Lake Treatment Using ISRM: Capital Costs

The initial capital construction costs of Alternative A are approximately $6,206,000; Alternative B is estimated to cost $6,119,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, each at 10% of the construction costs. Given the relative complexity of this project a 30% contingency on construction costs has also been included in the capital costs. No replacement costs have been assumed to be necessary for these alternatives.

Pit Lake Treatment Using ISRM: Operating Costs

All the costs associated with implementing this one time application are included in the capital costs. Therefore there are no operating costs. Should additional treatment be required in the future, the same capital costs would be incurred. It is assumed that no periodic or annual monitoring would be required for this alternative. In addition, annual compliance monitoring of POC wells has not been included in these costs.

Pit Lake Treatment Using ISRM: Net Present Value

Because there are no annual operating costs or replacement costs, the NPV is the same as the initial capital costs of $6,206,000 for Alternative A and $6,119,000 for Alternative B.

2.2.3.2. Pit Lake Treatment Using Ex-Situ Treatment

A second approach for treating the water in the Highland Pit Lake involves performing ex-situ treatment of the water in a water treatment plant. In 2010, uranium concentrations were measured at approximately 3.2 mg/L and selenium concentrations were measured at approximately 0.07 mg/L (Exhibit 2). The EPA primary drinking water standards are 0.03 mg/L for uranium and 0.05 mg/L for selenium. If the Highland Pit Lake were to require active treatment, the estimated stored volume requiring treatment is approximately 3.9 billion gallons. Groundwater, precipitation, and surface inflows are not expected to have appreciable uranium or selenium concentrations; therefore continued treatment beyond the initial 3.9 billion gallons would not be required. A combination treatment approach consisting of ion exchange (IX) and coagulation/filtration has been selected as the most cost-effective approach.

Pit Lake Treatment Using Ex-Situ Treatment: Conceptual Design

There are several types of water treatment technologies which have been determined by EPA as best available technologies (BAT) for selenium and uranium removal. For selenium, the BATs are activated alumina, coagulation/filtration, lime softening, and reverse osmosis. For uranium, the BATs are lime softening, ion exchange, and reverse osmosis. EPA lists other non-BAT technologies for removal or uranium and selenium; however, these technologies are either cost prohibitive or have not been extensively tested at the full scale. For the EPA BATs, activated alumina, lime softening, and reverse osmosis treatment technologies have been rejected as viable alternatives for reasons discussed in Exhibit 3. A combination of ion exchange (IX) and coagulation/filtration is anticipated to be the most effective treatment option, from both a cost and efficiency standpoint. A conceptual process flow diagram for treatment of the Pit Lake water and resultant reduction of selenium and uranium concentrations in the treatment effluent is presented in Figure 9.

As shown in the process flow diagram, the treatment system would consist of two interacting treatment technologies. The front end of the system would consist of filtration to remove suspended solids followed by ion exchange for removal of uranium. It is anticipated that an anionic IX resin would be most suited to this application. Some interference and competition from other ions, such as sulfate, contained in the Pit Lake is likely to occur which would decrease the expected IX efficiency for uranium removal. IX resin would be regenerated off-site. It is assumed that the IX resin would need to be replaced after four regenerations. As previously discussed, this alternative and associated costs is predicated on the assumption that there would be a facility licensed to accept these resins at the time of implementation should this alternative be selected.

The effluent from the IX would feed a chemical treatment process to remove selenium that consists of a metal salt addition, potential pH adjustment, coagulant addition, and filtration. Due to the relatively high pH of the Pit Lake water, the species of selenium in the Pit Lake is most likely selenate. Coagulation is more effective in removal of the selenite species, than in removal of the selenate species, and therefore pH adjustment may be required to improve the coagulation and flocculation process (Sobolewski, 2005). The multi-media filters for removal of the solids would periodically be backwashed to remove solids retained in the filtration bed. This backwash water would be collected in a tank and pumped through a solid separation system consisting of a clarifier, sludge thickener tank, and a filter press. Water from the solids handling system would be returned to the head of the plant for retreatment. Treated water from the system would be sampled regularly and discharged back to the Pit Lake. It has been assumed that all solids generated would be disposed of on-site.

Major treatment equipment would be located inside a treatment building. A full-scale SCADA system and instrumentation typical of a full-scale treatment plant would be installed at the treatment plant. A detailed description of the process and required equipment is included in Exhibit 3.

The proposed treatment process should be tested at the bench- and pilot-scale levels prior to design and construction of a treatment plant.

Pit Lake Treatment Using Ex-Situ Treatment: Operations

This alternative would operate year-round until the entire volume of the Highland Pit Lake had been treated. A system flow rate of 1,000 gpm has been assumed for treatment of the Pit Lake. Due to the high flow rate expected and to prevent exposure of the Pit Lake walls, the effluent from the treatment system would be discharged back to the Highland Pit Lake. It is estimated that treating the 3.9 billion gallons of water existing in the Pit Lake would take approximately 8 years, based on operating the plant at a plant flow rate of 1,000 gpm for 24 hour per day, 365 days per year and an assumed plant uptime of 90-95%. After this time, the plant could be decommissioned or used as necessary to treat any other water requiring treatment such as the Southeast Drainage.

The alternative would require three full-time plant operators on a daily basis for the expected 8 years of operation. Regular sampling and inspection of the system would be required; monthly sampling of the effluent has been assumed. Periodic repairs of the system, data metering, recording and telecommunications equipment would also be required. It has been assumed that storage for one full IX resin change-out would be constructed to minimize treatment system downtime. Regular deliveries of IX resin and chemicals would be required to supply the treatment system. It is assumed that all sludge generated would be able to be disposed of on-site. The capital life of the treatment equipment, including data metering, recording and telecommunications equipment is estimated to be 25 years. The piping is estimated to have a capital life of 50 years and the building and foundations are estimated to have a capital life of 100 years.

Pit Lake Treatment Using Ex-Situ Treatment: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Moderate

This alternative relies on proven technologies and installation methods. The treatment, monitoring and communications equipment is similarly proven and commonly used and appropriate for the site-specific conditions. However, it is unclear if a treatment system of this magnitude and complexity has been constructed at a similar site. Further, the efficacy of the treatment methods together would not be fully understood until bench and pilot scale testing on the specific water in the Highland Pit Lake is performed. Therefore, the feasibility of this alternative is considered moderate.

Effectiveness: Moderate

Because of the relatively high pH of the Pit Lake water and the presence of competing ions in the Pit Lake water, there is significant uncertainty regarding the efficiency of the proposed treatment system and therefore the effectiveness of this alternative is considered to be moderate.

Durability: Moderate

The capital life of the treatment equipment is estimated to be approximately 25 years, more than the expected 8-year operational time frame. Regeneration of the ion-exchange resins off-site would result in selenium and uranium wastes being generated at another facility. As previously discussed, it is assumed that there would be a facility licensed to accept these resins at the time of implementation should this alternative be selected.

Degree of Active Maintenance: Good

Due to the relatively short time required for treatment and once completed there would be no additional maintenance required for this alternative and therefore the degree of active maintenance associated with this alternative is considered excellent.

Pit Lake Treatment Using Ex-Situ Treatment: Capital Costs

The initial capital construction cost of this alternative is approximately $9,035,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Design and construction management of the alternative have been included in the capital costs, at 12% and 10% of the construction costs, respectively. A 25% contingency on construction costs has also been included in the capital costs. Geotechnical, bench-scale, and pilot-scale studies have also been included in the capital costs. Replacement costs were estimated for the alternative's equipment, the piping, as well as for the treatment building. It was estimated that the equipment would need to be replaced every 25 years at a cost of approximately $4,713,000, the piping would need to be replaced every 50 years at a cost of approximately $802,000, and the building and foundation would need to be replaced every 100 years at a cost of approximately $410,000. However, it is not anticipated that any replacement would be required during the alternative's anticipated 8-year operational life.

Pit Lake Treatment Using Ex-Situ Treatment: Operating Costs

The annual cost of operating this alternative is approximately $1,478,000. The annual operating cost includes electrical usage, IX resin regeneration and replacement, chemical usage, sludge sampling, handling, transportation and disposal, and system maintenance. Maintenance of the alternative is estimated at 3% of equipment costs for spare parts. It is assumed that three full-time employees would be required for regular operations, monitoring, maintenance, sampling and inspections. Monthly effluent sampling has been assumed and included in the costs. A 10% contingency has been included in the annual operating costs. Annual compliance monitoring of POC wells has not been included in these costs. IX resin regeneration costs are predicated on a facility within 1,000 miles of the site being able to amend their license to accept and regenerate the material. Though there are currently no facilities known to be licensed to accept uranium loaded third-party resin for stripping and regeneration, it is understood that more than one ISR licensee is currently in the process of applying for license amendments to accept such resins. These costs do not account for the value of the recovered materials. In addition, it is assumed that resin would be replaced after being regenerated four times.

Because the amount of sludge generation cannot be accurately defined prior to bench-scale testing, no costs for handling, transportation or disposal of sludge have been included. Preliminary calculations of sludge generation estimate that the volume of sludge generated would be less than 100 cubic yards annually. It is assumed that this sludge would be able to be disposed of on-site.

Pit Lake Treatment Using Ex-Situ Treatment: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $20,340,000.

2.2.3.3. Backfill Pit Lake

Another mechanism to mitigate exposure to hazardous constituents in the Highland Pit Lake is backfilling the Pit Lake with the reclaimed mine waste rock at the Highland uranium mine and mill site. However, it is considered necessary that to implement a backfill alternative, the Pit Lake water would have to be treated and the waters discharged from the pit prior to backfilling rather than simply pushing the backfill into the water-filled pit. This would be necessary to avoid the rise of water levels into the backfill borrow areas and high heads driving the Pit Lake waters and associated 11e.(2) byproduct derived hazardous constituents away from the pit.

The backfill approach has been assessed with two alternative designs in an attempt to optimize the reduction in hazardous constituent concentrations and preserve the long-term stabilization of the 11e.(2) byproduct material. A more detailed presentation of these alternatives and detailed calculations for each alternative is presented in the MWH (2010) report presented in Exhibit 4. The first backfilling alternative involves using Site mine spoils to fill the pit to a level above the predicted long-term water level. This alternative develops a final surface grading plan that allows surface drainage across the backfilled pit to flow out to North Fork Box Creek to the south, rather than creating a closed basin that could allow seasonal ponding at the bottom of the backfilled pit (Figure 1 of Exhibit 4). The second alternative backfills the pit to an elevation of 5,100 feet above mean sea level with a flat bottom and no path for surface run on to exit the depression (Figure 4 of Exhibit 4). Therefore, because the two alternatives are similar and differ only in the manner in which they configure the pit backfill and final topography, they are assessed as a single alternative but are distinguished by the approach and differences in costs.

Pit Backfill Alternative 1: Pit Backfill with Surface Drainage to North Fork Box Creek Conceptual Design

The Pit Backfill Alternative 1 design was divided into three cut and three corresponding fill areas to further break down the amount of fill required and help determine the limits of borrow areas to provide fill (Figure 2 of Exhibit 4). The goal of the grading plan was to determine the extent and slopes of the cuts needed to provide the required fill amounts for the backfill design. The individual cut and fill areas can be seen in Figure 1 of Exhibit 4. Quantities for each backfilled section are provided below.

Fill Area A: 18,323,014 cy

Fill Area B:	17,963,131 cy
Fill Area C:	4,711,314 cy
TOTAL:	**40,997,459 cy**

For this alternative, it was assumed that the material for Fill Area A would be obtained by regrading the pit slopes of Cut Area A back at a 4:1 (horizontal : vertical) slope then pushing the material cut into the pit. The remainder (and majority) of the fill required would be provided by borrowing stockpiled material from the northeast borrow (North Dump). Fill Area B material would be obtained from the excavation of the proposed channel at the south end of the pit leading to the North Fork Box Creek drainage, as well as regrading slopes to a 4:1 pitch. Finally, Fill Area C material would be obtained from regrading the pit walls in Cut Area C to a 4:1 slope along the western edge of the section and 10:1 slope along the southern edge of the section. A cut-fill isopach for this alternative is given in Figure 3 of Exhibit 4.

Assuming two eleven-hour shifts per day and a nine month construction season, it has been estimated that Alternative 1 would take approximately four years to complete, including initial seeding of vegetation cover. This duration assumes all three sections are worked on concurrently.

Pit Backfill Alternative 2: Pit Backfill with Closed Surface Drainage Conceptual Design

The second alternative for the pit backfill is to fill the pit to an elevation of 5,100 feet. This would create a closed basin containing any surface water on the flat backfill surface within the pit. Fill Area D material would be obtained partially from a 4:1 dozer pushdown in Cut Area D, with the remainder borrowed from the North Dump adjacent to the pit (as was planned for Fill Area A in Alternative 1). The two remaining fill areas (Fill Areas E and F) would be completed with dozer pushdowns at a 4:1 slope in Cut Areas E and F. The individual cut and fill areas can be seen in Figure 5 of Exhibit 4. An isopach, showing cut and fill contours for the regrading of this alternative is given in Figure 6 of Exhibit 4. Approximate volumes of backfill material required for this alternative are given below.

Fill Area D:	14,497,886 cy
Fill Area E:	14,224,875 cy
Fill Area F:	2,631,440 cy
TOTAL:	**31,354,201 cy**

Assuming two eleven-hour shifts per day and a nine month construction season, it has been estimated that Alternative 1 would take approximately three years to complete, including initial seeding of vegetation cover. This duration assumes all three sections are worked on concurrently.

Pit Backfill: Operations

This is a one-time action; there would be no additional costs or ongoing operations.

Pit Backfill: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1

Engineering Feasibility: Moderate

This alternative relies on conventional earth-moving technology commonly used in mining and mine reclamation. However, because removing and treating the Pit Lake water is required, and therefore the engineering feasibility must tied to the overall feasibility, which for treatment is moderate.

Effectiveness: Moderate

The efficacy of this alternative is considered moderate in that it is predicated on treatment and removal of the impacted pit water prior to backfilling. The effect of this alternative would be to keep the Pit Lake from becoming saline and a potential future source of elevated metals and radionuclide concentrations to ecological or human exposures. However, due to the fact that the resulting groundwater in the pit backfill, though diminished of 11e.(2) byproduct material hazardous constituents, would have long-term water quality with high metals and uranium concentrations (e.g., comparable to wells 170, 171, 173). The water would still be unsuitable for domestic consumption due to interactions with the low-level mineral grade of the backfill waste-rock material, and therefore this alternative's effectiveness is considered moderate.

Durability: Excellent.

The backfilling of the Pit Lake, combined with the treatment and discharge of the Pit Lake waters, would be highly effective in reducing human access to the byproduct material hazardous constituents. However, as mentioned above, little net benefit for restoration of the groundwater resource would be achieved because the overall long-term water quality would not improve sufficiently to be usable for a domestic drinking water supply due to interactions with the low-level mineral grade of the backfill waste rock material.

Degree of Active Maintenance: Excellent

Once implemented, there would be no additional maintenance required for this alternative. However, the overall long-term groundwater quality would not improve sufficiently to be usable for a domestic drinking water supply due to groundwater interaction with the mineralized backfill.

Pit Backfill: Capital Costs

The initial capital construction costs of Alternative 1 are approximately $80,030,000; Alternative 2 is estimated to cost $68,980,000. The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1. Permitting, dewatering and construction management of the alternative has not been included in the capital costs. A 10% contingency has also been included in the capital costs. The selected in-situ or ex-situ water treatment alternative for treating the pit water prior to backfilling should be added to these costs to assess the total cost of this alternative. No replacement costs have been assumed to be necessary for these alternatives.

Pit Backfill: Operating Costs

All the costs associated with implementing this one-time application are included in the capital costs. Therefore there are no operating costs. Should additional treatment be required in the future, the same capital costs would be incurred. It is assumed that no periodic or annual monitoring would be required for this alternative. In addition, annual compliance monitoring of POC wells has not been included in these costs.

Pit Backfill: Net Present Value

Because there are no annual operating costs or replacement costs, the NPV is the same as the initial capital costs of $80,030,000 for Alternative 1 and $68,980,000 for Alternative 2.

2.2.4 Institutional Controls and Alternative Concentration Limits

This alternative proposes a POC well for the Southeast Drainage with an ACL for uranium, as well as modification to the long-term surveillance boundary to include the Southeast Drainage and the Highland Pit Lake.

The proposed long-term surveillance boundary encompasses the Pit Lake to remove potential human access to the 11e.(2) byproduct hazardous constituents in the Pit Lake. The proposed boundary also encompasses the Southeast Drainage to remove potential human access to the 11e.(2) byproduct hazardous constituents in the Southeast Drainage's limited groundwater system. The implementation of institutional controls for the lands within the proposed boundary through transfer of land title for the surface and subsurface estates to the long-term custodian provides the requisite reasonable assurance of controlled access to the groundwater, and surface water in the Highland Pit Lake containing hazardous constituents. Use of the Pit Lake water and Southeast Drainage groundwater for all other receptors are protective. The proposed POC well and ACL for uranium establish a monitoring system that ensure conditions at the POEs remain protective of public health, safety and the environment.

Institutional Controls with ACLs: Conceptual Design

Figure 12 presents the proposed long-term care boundary and illustrates the location of the existing POC wells as well as an additional proposed POC well. Well MFG-1 is proposed as a new POC well for the limited groundwater system of the Southeast Drainage. This well appropriately monitors the groundwater conditions at the head of the Southeast Drainage and at the toe of the tailings embankment.

An ACL for uranium of 0.7 mg/L is proposed for well MFG-1. This is half the protective exposure concentration at the POE (1.4 mg/L) where the Southeast Drainage joins North Fork Box Creek based on the existing water quality and class of use for the waters in and under North Fork Box Creek and twice the highest historical measurement. Given that the current concentration in MFG-1 is approximately 0.3 mg/L, the highest mean concentration in the rest of the Southeast Drainage groundwater is 0.119 mg/L, and dilution and/or attenuation of uranium transport in the Southeast Drainage has been neglected in developing the ACL, this proposed value is highly conservative and provides the requisite reasonable assurance of long-term protection at the point of exposure.

The existing POC well 175 located on the western side of the tailings impoundment between the tailings and the Pit Lake has recently exhibited confirmed concentrations of uranium above the MCL of 0.03 mg/L. NRC was notified of this confirmed exceedance via a conference call on November 29, 2010, which was followed by a letter dated January 1, 2011 describing more completely the nature of conditions in well 175. In approving the 1998 ACL, NRC concurred that continued pumping of the TDSS sandstone is no longer productive, there are no remaining reasonable corrective actions, and the implementation of ACLs is appropriate and can reduce exposure concentrations to the public and the environment to levels that are ALARA. This conclusion remains valid. Consequently, an ACL of 3 mg/L for uranium in Well 175 is also proposed. This concentration is roughly the modeled equilibrium concentration of uranium in the neutralized tailings seepage within the TDSS (see Section 2.1.2.6 and Table 2-7 in the main document) and represents a maximum potential future concentration at this location.

Water levels in the TDSS have dropped significantly since the cessation of mining and the completion of surface reclamation (Section 1.2.2.7 in the main document). The eastern portion of the TDSS is becoming drained (i.e., well 177). As tailings seepage rates have drastically diminished, the seepage rate is predicted to decrease to a steady state condition between 3 gpm and 5 gpm (Section 2.2.2 in the main document). A portion of this minimal seepage may migrate into the Pit Lake while other portions flow north and down the Southeast Drainage.

Given that the Pit Lake currently has 3.9 billion gallons of water with a uranium concentration of approximately 3.2 mg/L, the flow contribution from all the long-term tailings seepage to the Pit Lake would constitute only 0.07 percent of the total volume on an annual basis. The corresponding annual mass contribution from this flow at a uranium concentration of 3 mg/L would comprise less than 0.06% of the existing uranium mass in the Pit Lake and would not cause any increases in the current or future Pit Lake uranium concentration. Further, institutional control over access to groundwater between the tailings and the Pit Lake are proposed. Consequently, an ACL for uranium at well 175 could be significantly higher than proposed and still maintain protective conditions between the tailings and the Pit Lake and within the Pit Lake. Therefore, this ACL would maintain protective conditions in the Pit Lake and would have essentially no potential for future exceedance due to the geochemical controls on uranium concentrations within the TDSS.

After this license amendment for ACLs is approved, Exxon would request license termination. NRC would consult the Department of Energy (DOE), Office of Legacy Management, which would develop a Long-Term Surveillance and Monitoring Plan. At license termination, the approved long-term surveillance and monitoring funds would be transferred to the NRC and title to the surface and subsurface estates of the lands encompassed by the proposed long-term surveillance boundary would be transferred to the long-term custodian, who would possess and monitor the site under a general license with the NRC.

Access controls would consist of fencing around the proposed boundary, a distance of approximately 10 linear miles. The fencing would be 6-feet tall with strands of barbed at the top. Two 12-foot wide traditional livestock access gates would be placed at key points around the perimeter to provide access. This fencing is not necessary for maintaining protective conditions but is included as an additional measure for restricting site access. Ownership of the land and the subsurface estate, coupled with annual monitoring and inspections would ensure that the site groundwater was not inappropriately used and no inappropriate chronic exposures occur.

The ACL guidance states that ".....the identified corrective action is followed by a suitable monitoring period, to verify that the remediated water quality is stable" (NRC, 1996). MFG-1 has had five years of groundwater monitoring data collected and other Southeast Drainage wells have several years of data that demonstrate stable water levels and water quality. Similarly, the Pit Lake has been monitored for many years and has shown predictable and relatively stable water quality. Therefore, Exxon proposes to continue groundwater monitoring as per License Condition 33 and include MFG-1 and a single location in the Pit Lake at a single depth in this monitoring program through the license termination process.

Institutional Controls with ACLs: Operations

The DOE would perform annual inspections, monitoring, and reporting and any other activities identified by the approved Long-Term Surveillance and Monitoring Plan. It is assumed that the monitoring program would include annual sampling of the three existing POC wells as well as the proposed POC well MFG-1 (Figure 12), the proposed POE well TT-7 and sampling of the Pit Lake at one location and at one depth. An annual report would be prepared transmitting and discussing this data.

Periodic maintenance of the access control fencing would also be required. No maintenance of the earthen berms and rock barriers placed around the pit highwall margins is anticipated or required to maintain protective site conditions.

Institutional Controls with ACLs: Practicability

The following presents the assessment of this alternative's practicability based on the criteria identified in Section 2.1.

Engineering Feasibility: Excellent

This alternative relies on institutional controls to ensure long-term protection of public health, safety and the environment, through permanent Federal custody as identified in Section 202 of the Uranium Mill Tailings Radiation Control Act of 1978. By controlling title to the surface and subsurface estates, performing annual inspections and implementing engineered access controls (fencing), a reasonable assurance of public protection from exposure to hazardous constituents is achieved. These controls have been successfully implemented for the more than 40 Title I and Title II sites currently under Federal custody.

Effectiveness: Excellent

This alternative would be highly effective in maintaining protection of public health, safety and the environment. By controlling title to the surface and subsurface estates, performing annual inspections, and implementing engineered access controls (fencing), a reasonable assurance of public protection from exposure to hazardous constituents is achieved. These controls have been successfully implemented for the more than 40 Title I and Title II sites currently under Federal Custody.

Durability: Excellent

This alternative does not rely on any active mechanisms to maintain protective conditions. Federal custody of the site is a sufficiently durable mechanism for protection of public health safety and the environment and provides a reasonable assurance of protection for the requisite 200 years and, to the extent practicable, up to 1,000 years. Though maintenance of the fencing would be required periodically, it is not essential to maintain protective conditions.

Degree of Active Maintenance: Excellent

This alternative does not rely on active mechanisms. The proposed long-term surveillance fund would cover annual inspections. This fund would also cover any periodic repairs to fencing for access control, a minor maintenance cost common to many Title I and Title II site already accepted by the NRC and the DOE. However, the fencing maintenance is not a significant effort, does not expose DOE to significant financial or legal liability, and is not required to maintain protective conditions.

Institutional Controls with ACLs: Capital Costs

The initial capital costs for this alternative are approximately $1,370,000. The capital costs consist of the construction of access control fencing around the proposed long-term care boundary and are estimated to be approximately $1,368,000. Design and construction management for the fencing have been included in the capital costs, each at 3% of the construction costs. A 1% contingency on construction costs has also been included in the capital cost of the fencing. Replacement costs were also estimated for the fencing at a cost of approximately $1,232,000 every 50 years.

The detailed basis for this estimate was developed from the conceptual design described above and is provided in Exhibit 1.

Institutional Controls with ACLs: Operating Costs

The annual cost of operating this alternative for the requisite 200 years is approximately $25,000. This estimate assumes the sole annual cost for this alternative is periodic maintenance of the fencing. The cost of performing an annual inspection and report is covered with the initial $250,000 (1978 dollars) capital expenditure to the long-term custodian. Fence maintenance is assumed to cost approximately 2% of the fence capital cost annually, or $25,000. No contingency has been included in the annual fence maintenance or compliance monitoring cost. Annual compliance monitoring of POC wells, estimated to be approximately $19,000 (Exhibit 1), has not been included in these costs.

Pit Lake Treatment Using Ex-Situ Treatment: Net Present Value

Applying a 1% discount rate, the Net Present Value of this alternative is estimated to be approximately $5,140,000.

2.3 Benefits of Corrective Action

As per Section 3.3.3.2 of the NRC ACL Guidance (NRC, 1996), the benefits of implementing the identified corrective actions are weighted against the costs of performing (or not performing) such measures. The benefits of implementing the identified corrective action alternatives are evaluated considering:

> *"...the avoidance of adverse health effects, value of pre-contaminated ground-water resources, prevention of land-value depreciation, and benefits accrued from performing the corrective action."*

In general, successful implementation of a corrective action for the Southeast Drainage groundwater system would have the primary benefit of allowing that groundwater in the limited channel of the Southeast Drainage to be used as a potential future domestic drinking water supply. However, due to the limited nature of the Southeast Drainage groundwater system, remote nature of the site, the lack of current and likely future use of this or similar groundwater systems for drinking water in the region, the widespread biological contamination of surface waters (e.g., giardia), this exposure scenario is extremely unlikely.

Successful implementation of a corrective action for the Highland Pit Lake would differ depending on the selected alternative. Backfilling the pit would have the primary benefit of removing any exposure pathway due to treatment of the pit water and removal of any surface water expression by pit backfilling to an elevation above the long-term groundwater levels. This would remove any potential for a human exposure pathway but would also remove a water resource for ecological receptors for which it is currently protective. Alternatively, treating the Pit Lake without pit backfilling would have the primary benefit of temporarily improving the water quality such that it would be protective as a potential human drinking water source for approximately 200 years until evapoconcentration once again degraded the water quality to the point where high TDS concentrations (>10,000 mg/L) would render the water unsuitable for drinking water. The Pit Lake TDS is currently approximately 1,000 mg/L and is anticipated to increase 10-fold over the next 1,000 years.

The following sections addresses the specific benefits associated with restoring the water quality in the Southeast Drainage and the Highland Pit Lake.

2.3.1 Potential Reduction of Adverse Health Effects

This section evaluates potential reduction of adverse health effects from potential exposure to the hazardous constituents in the Southeast Drainage groundwater and Highland Pit Lake. The primary potential exposure route associated with these water resources is ingestion of drinking water. In the Highland Pit Lake the hazardous constituents above the maximum contaminant limit (MCL) are uranium and selenium, while in the Southeast Drainage uranium is above the MCL throughout the drainage while selenium and radium-226+228 are each only slightly above their respective MCLs, each in only one well.

For this evaluation, it has been assumed that hazardous constituents could be reduced to below the MCL solely for the purposes of assessing avoidance of potential dose and associated adverse health effects. For chemicals with radiological health effects (uranium and radium), the potential reduction of adverse health effects is evaluated in terms of avoided dose. For chemicals with other potential non-cancer health hazards (uranium and selenium), the potential reduction of adverse health effects is evaluated in terms of a comparison to regional screening levels (RSLs) for tap water that are protective of human health and developed by U.S. EPA for the Superfund program (EPA, 2010).

Potentially Exposed Population

It was conservatively assumed that the potentially exposed population for this small and remote area was a resident family of four. As the entire Southeast Drainage area is less than ¼ of a square mile, this constitutes a hypothetical population density of 16 persons per square mile, which is more than four times the current population density for Converse County, Wyoming, as a whole and many times the current population density in the project area. In reality, it is highly unlikely that a family of four would settle in the Southeast Drainage area or the vicinity of the Highland Pit Lake and use these resources as a drinking water supply.

Southeast Drainage Evaluation

There are no pre-impact groundwater quality data for the aquifer associated with the Southeast Drainage. The Southeast Drainage is a Class 3B surface-water body, which is not known to support fish populations or drinking water supplies and where those uses are not attainable (WDEQ, 2001). It is remote (25 miles) from towns and residential developments. The two residential ranch houses that are located more than two miles from the site do not use shallow groundwater as a drinking water source. All local domestic and industrial wells within 10 miles of the tailings are screened at least 180 feet below the ground surface and do not access alluvial groundwater (Exhibit 5). Access to these limited water resources is solely through the floodplain and channel materials, which are relatively shallow with thin saturated thicknesses, typically less than 30 feet. In addition, the regolith/alluvial floodplain and channel deposits do not extend under the terraces formed by un-weathered bedrock. This alluvial floodplain is regularly inundated by seasonal rains and the resulting overbank flow from the primary flow channels. Further, the alluvial floodplains and primary flow channels of North Fork Box Creek have poor access due to the steep topography resulting from the channel incision into the native formations. The use of such a limited and shallow groundwater system as a drinking water supply is not practiced in this area and is not a common practice in the region. In addition, biological fouling (giardia and fecal coliform bacteria) of the ephemeral surface water pools by wildlife and livestock that use these pools as drinking water sources is ubiquitous in the west.

Therefore, based on the remote nature of the site and the factors listed above, establishment of a domestic drinking water supply from the limited groundwater system in the Southeast Drainage POE is considered highly unlikely. In addition, infrequent acute human exposure to drainage surface waters through the ingestion pathway is also considered highly improbable.

Radiological Hazard Evaluation

The mean of the 2010 uranium concentration measurements in well MFG-1 is 0.37 mg/L (Exhibit 2). If the groundwater could be remediated to the current MCL (0.03 mg/L), then the maximum groundwater concentration reduction would be 0.34 mg/L or 0.00050 µCi/L (assuming an activity concentration of 677 pCi/L for each mg/L of uranium). Similarly, the mean of the 2010 radium-226+228 activity concentrations in well BBL-3 is 5.4 pCi/L, just 0.4 pCi/L above the MCL (5 pCi/L). If the groundwater could be remediated to the current MCL, then the maximum groundwater concentrations reduction by implementing a corrective action would be 0.4 pCi/L.

Based on the analysis presented in Exhibit 6 the avoided individual lifetime (30 years) intake from groundwater would be 4.83 µCi for uranium and 0.0084 µCi for radium-226+228. The annual averted dose equivalent for uranium would be 43.3 mrem/year and 0.4 mrem/year for radium-226+228, for a total annual averted dose of 43.7 mrem/year. This is comparable to the increase dose one would receive by living in Denver compared to living in the coastal states due to terrestrial radiation (DOE, 2008). Assuming four people were exposed at these levels the total lifetime averted dose would be 5.25 person-rem.

This estimate represents the maximum averted dose for uranium and radium-226+228 assuming the mean concentration from the wells in the Southeast Drainage with the highest concentrations. However, it should be noted that recent uranium concentrations in all other Southeast Drainage monitoring wells (March 2010 through October 2010) are less than or equal to 0.12 mg/L. Similarly, radium-226+228 is below the MCL of 5 pCi/L in all wells other than BBL-3. Therefore, a more realistic annual averted dose could be calculated assuming a reduction in uranium concentrations of 0.09 mg/L (0.12 mg/L minus the 0.03 mg/L MCL for uranium) and assuming no action was required for radium-226+228. In this case, the annual averted dose would be 11.5 mrem/year and the total lifetime avoided dose for four people would be 1.38 person-rem. This is comparable to the annual increased dose that an individual would receive by living at 3,000 feet above sea level compared to living at sea level (DOE, 2008).

Quantification or even identification of any adverse health effects resulting from such low doses cannot be reliably made. Therefore, there are no identifiable avoided adverse health effects from reduction of uranium and radium that would result from implementing a successful corrective action in the Southeast Drainage. Details of these calculations are included in Exhibit 6.

Chemical Hazard Evaluation

Selenium occurs above the MCL in only one well (BBL-2), which indicates that elevated selenium in groundwater is discrete and not widespread. The maximum measured selenium concentration of 0.0777 mg/L in the Southeast Drainage wells (BBL-2, Exhibit 2) exceeds the MCL (0.05 mg/L) by about 50 percent.

To evaluate potential non-cancer health effects for chemicals exceeding MCLs, the upper bound representative concentrations in the Southeast Drainage were compared to RSLs for tap water developed by EPA to evaluate potential exposure to these chemicals in a drinking water source (EPA, 2010). The RSLs were developed to evaluate potential lifetime exposure to the chemical in the media of concern. EPA is working on developing toxicity criteria for uranium specifically, but that process has not been completed so that an RSL is not available for uranium. The RSL for selenium is 0.180 mg/L, which is also comparable to the Drinking Water Equivalent Level (DWEL) for selenium of 0.200 mg/L. Both the RSL and DWEL represent a lifetime exposure concentration protective of adverse, non-cancer health effects, which assume that all of the exposure to a contaminant is from drinking water. The upper-bound concentration of selenium (0.0777 mg/L) is below the RSL and DWEL for selenium. As such, reduction of the selenium concentrations to the MCL may not result in a significant benefit to human health.

Pit Lake

There was no open water body prior to mining of the Highland pits and, consequently, no pre-mining surface water quality in the pit area. The sole water resource was groundwater associated with the ore zones, which was unsuitable for domestic use due to the natural mineralization. The water quality in the current Pit Lake represents the combination of groundwater from the ore zones of the OBSS, tailings seepage from the impoundment through the TDSS and backfilled pits, meteoric waters from direct precipitation, and mine surface runoff. There is no documentation or records to indicate that any mill effluent was discharged into the pit prior to or during its filling with water.

Radiological Hazard Evaluation

Uranium is the only radiologic constituent in the Pit Lake thatexceeds an MCL. The 2010 average uranium concentration of 3.24 mg/L (Exhibit 2) exceeds the MCL by approximately two orders of magnitude. Based on the assessment included in Exhibit 6, the avoided individual lifetime (30 years) intake of uranium from drinking the Pit Lake water would be 45.6 µCi. The annual averted effective dose equivalent for uranium for a 30-year period for an individual would be 409 mrem/year per person (Table 2). This is roughly the annual radiation dose for typical commercial airline flight crew member (DOE, 2005).

Chemical Hazard Evaluation

The selenium levels in the Highland Pit Lake (2010 average is 0.071 mg/L, Exhibit 2) slightly exceed the MCL (0.05 mg/L) but are well below the EPA RSL and DWEL for selenium of 0.2 mg/L and 0.18 mg/L, respectively (EPA, 2010; EPA, 2009). Adverse health effects would not be expected from even long-term chronic consumption of selenium at these concentrations.

Therefore, there is no significant specific human benefit of avoiding adverse health effects by reducing the selenium concentration in the Pit Lake.

Ecological Evaluation

The primary benefit of reducing selenium concentrations would be to reduce the potential exposure of avian populations (shorebirds, waterfowl and red-tailed hawks) herbivores and predators to elevated selenium concentrations through direct ingestion and through the food web. However, the assessment of ecological risk for the Pit Lake area (Attachment 3, in the main document) indicates that the risks to waterfowl, shorebirds, predators and herbivores from selenium, is insignificant. Consequently, there is minimal incremental benefit to human or ecological receptors in the form of avoidance of adverse health effects from remediating the selenium concentrations in the Highland Pit Lake.

2.3.2 Value of Pre-Contaminated Groundwater

Section 3.3 of the NRC ACL guidance (NRC, 1996) states that the value of the pre-contaminated groundwater is considered to be:

> *".....equal to the cost of domestic or municipal drinking-water supplies, or the cost of supplied water to replace the contaminated resources."*

Valuation of the pre-contaminated groundwater resources in this report considers:

1. projected future water use demands;
2. the availability of alternate water supplies;
3. the estimated costs for providing domestic or municipal water supplies; and
4. the estimated cost of supplied water to replace the contaminated resources.

Projected Future Water Use Demand

Projection of future water use demand for the area is speculative. In the case of the Southeast Drainage, the groundwater resources are not irrevocably removed from the hydrologic cycle and all future use. Rather, only access to the limited groundwater resource over a shallow depth and discrete area for domestic consumption would be impacted. All other uses would continue to be protective of public health, safety and the environment and the water, once it enters the North Fork Box Creek drainage the groundwater system remains available for all appropriate uses. Therefore, projection of future water use demand for the Southeast Drainage groundwater system is focused solely on that specific drainage and not regionally as the availability of the resource to the region is in no way impaired.

There is currently no demand on the groundwater resource in the North Fork Box Creek drainage adjacent to the Site. Based on the remoteness of the area, the low population density in the county and project area, and the low projected population growth, it is unlikely that the demand for these resources will change significantly in the future.

The assessment of future demand for the Highland Pit Lake as a drinking water source is similar to that of the Southeast Drainage groundwater. The Highland Pit Lake is also remote from existing population centers, and is subject to the ubiquitous bacteriological contamination of surface waters and shallow alluvial waters in the western states (i.e., giardia). In addition, the water is not highly visible from surrounding areas nor is it easily accessed. As a result, the projected change in future water use demand on this resource as a domestic drinking water supply is considered to be very low.

Availability of Alternate Water Supplies

Due to the remote nature of the site, there is no access to a municipal water supply. However, alternative water supply may be made available through development of a similar resource on adjacent lands. Alternate water supplies would be available through purchase of similar or adjacent lands with associated water rights. The value of the land in this area and associated water rights was determined with a survey of comparable land sales in the region performed in 2009 by Petroleum Land Services, LLC (Exhibit 7). The appraised unit price per acre ranged from approximately $650 to $1,625 per acre for comparable parcels recently sold within 12 miles of the Highland Site.

Based on the 2009 survey of comparable land prices, the value of not only the groundwater but the land as well is conservatively estimated to be $2,000 per acre or roughly $14,000 for the 7 acres that comprises the narrow and limited extent of the Southeast Drainage aquifer. This area is estimated by assuming that the affected portion of the groundwater is 200 feet wide and the entire length of the Southeast Drainage, approximately 4,000 feet long. If the area were considered to be the entire 160 acres comprising the area surrounding the Southeast Drainage included in the proposed long-term care boundary, the total value would be approximately $320,000.

As another method for assessing the value of the local water resources, the Wyoming branch of the US Bureau of Reclamation was queried regarding the price of water sold in 2010 for private use. In a letter dated June 2, 2010 (Exhibit 8) the USBR indicated that short-term surface-water storage in Glendo Reservoir used to supplement natural surface flows was sold for $5/ac ft ($0.015/1,000 gallons) with a 50 ac-ft minimum. Alternatively, the cost for purchasing stored water for municipal and or industrial purposes was $75/ac ft ($0.23/1,000 gallons).

Based on the Pit Lake volume of 3.9 billion gallons, the range of value of this water at $0.015/1,000 gallons to $0.23/1,000 gallons is $58,500 to $897,000. However, it should be noted that the majority of the value of the Pit Lake water is currently retained in that it is of sufficient quality to be used for agricultural and livestock watering. Therefore, the above values over estimate the incremental value of the Pit Lake as a drinking water supply.

Estimated Costs for Domestic or Municipal Water Supplies

As mentioned above, there is no access to a municipal water supply due to the remote nature of the site. Domestic water supplies for ranches and water wells in the region use individual deep groundwater wells for potable water sources. The cost for establishing a domestic water supply well is estimated as the cost of installing a relatively deep groundwater well. It is assumed that a new well would be installed to a depth of 500 feet and a 3 HP submersible pump installed. This cost is conservatively estimated to be $38,800 (Table 3).

Estimated Cost of Supplied Water

The estimated cost for providing supplied water to replace the drinking water resource of this limited system for a single family of four is based on the assumption that potable water for individual consumptions is purchased commercially. Uses of local groundwater for all other domestic purposes, including laundry, watering of crops, livestock watering are acceptable based on the current water quality of both the Pit Lake and the Southeast Drainage groundwater system.

Based on a verbal quote from Culligan Soft Water, 639 North 4th Street, Douglas, Wyoming, five gallon bottles of softened water, delivered to the site (25 miles each way) would be $7.50 per bottle with a $9.00 per bottle security charge. This would equate to an initial monthly cost of $2,025 and subsequent monthly costs of $225. Assuming a conservative future population of 16 persons/square miles, a family of four consumption of a little under 5 gallons per day, and an interest rate of 3%, the present value cost of providing bottled water for a 200-year period would be approximately $91,800.

There is currently no demand on the limited groundwater in the Southeast Drainage and for the water in the Pit Lake as a drinking water source and projections indicate that this is unlikely to change in the future. In addition, the availability of alternate water supplies, the estimated costs for domestic water supplies and the estimated costs for supplied water, the projected value of the site-specific pre-contaminated water resource is not anticipated to increase from the current value of the water resource by more than the rate of inflation.

2.3.3 Prevention of Land Depreciation

The prevention of land depreciation values in this sparsely populated and rural area familiar with uranium mining is a highly subjective factor to quantify. The surrounding lands are very sparsely populated and the primary land use is by the livestock industry in the form of cattle and sheep grazing and livestock feed crops (hay) by smaller private landholders (family ranches) as well as for natural resource development (i.e., in-situ uranium recovery, oil and gas recovery). These types of land use in the surrounding lands have been ongoing for over 100 years and would not be expected to change significantly nor would there be any substantial adverse impact to those land uses due to the expansion of the project long-term surveillance boundary.

The natural resource development industries have been a significant long-term economic driver for the local Wyoming communities around the project site. As such, the communities in the region have lived with the natural resource development and mining for decades, with many local families having worked on these natural resource development projects as an important part of their income. In contrast with other regions less familiar or invested in natural resource development projects, the local perception regarding potential risk associated with natural resource development in general and uranium mining in particular is not uniformly positive or negative and is often neutral. Consequently, the incremental potential for depreciation of land value due to the incremental difference in the long-term control area from its current size would likely be minimal and is not considered significant in this assessment.

2.3.4 Summary of Corrective Action Benefits

The benefits of performing corrective action for the Highland Pit Lake and the limited groundwater system of the Southeast Drainage have been addressed as per the Guidance (NRC, 1996; 2000). Specifically, the avoidance of adverse health effects, value of pre-contaminated groundwater resources, prevention of land-value depreciation, and benefits accrued from performing the corrective action have been assessed. The value of the pre-contaminated water resources was estimated considering projected future water use demands, the availability of alternate water supplies, the estimated costs for providing domestic or municipal water supplies, and the estimated cost of supplied water to replace the contaminated resources.

Table 2 summarizes the estimated avoided radiological dose and avoided adverse health effects from selenium exposure for the Southeast Drainage and Highland Pit Lake corrective action alternatives. Table 3 summarizes the benefits of the corrective action alternatives with respect to valuing pre-contaminated groundwater and the potential for land depreciation from the alternatives. Table 4 compares the Net Present Value costs of the corrective action alternatives to the estimated value of the pre-contaminated water resources and presents an estimate of the cost per person-rem of avoided dose per person for each alternative.

There are essentially no significant avoided adverse health effects achieved from reducing the selenium concentration in either the Pit Lake or the limited Southeast Drainage groundwater system because the selenium concentrations are below US EPA DWEL values (Exhibit 6). The reduction in lifetime radiological dose that might be achieved through successful implementation of both source control and groundwater corrective action beyond the proposed POC in the Southeast Drainage ranges from 1.38 person-rem to 5.25 person-rem (11.5 mrem/yr/person to 43.7 mrem/yr/person). These dose reductions are comparable to the difference in doses received by individuals living in Florida and Denver due to cosmic radiation alone (DOE, 2008), which are sufficiently small that no specific avoided adverse health effects can reasonably be attributed to the reduced dose.

The reduction in lifetime radiological dose that might be achieved through successful implementation of corrective action in the Pit Lake is estimated to be 49.1 person-rem (401 mrem/yr/person, Exhibit 6). These doses are comparable to the doses received by commercial airline crews (DOE, 2008). No specific avoided adverse health effects can reasonably be identified or attributed to the reduced this dose.

The projected increase in water use demand on these specific water resources is considered very low. There is no availability of alternate water supply from a municipality, though alternate water supplies can be readily acquired via the installation of a groundwater well outside the area of contamination or the acquisition of adjacent land with water rights.

The estimated pre-contamination value of the limited groundwater in the Southeast Drainage ranges from $14,000 (comparable sale of 7 acres of land with water rights) to $320,000 (comparable sale of 160 acres of land with water rights) while the value of the Pit Lake water is estimated to range from $58,500 to $897,000.

The estimated cost of an alternative water supply via a domestic well is approximately $38,800. The cost of supplying a family of four with drinking water for 200 years was estimated to be approximately $91,800.

The incremental potential for land value depreciation of this proposed licensing action, relative to the existing potential that exists due to the reclaimed mine and approved stabilized tailings at the site, is considered low to negligible.

2.4 Corrective Action Assessment Summary and Conclusions

This application has assessed a robust range of corrective action alternatives to mitigate newly identified concentrations of hazardous constituents in groundwater and the Pit Lake above the MCLs. These corrective action alternatives included proven technologies that represent the state of practice for remediation of water quality impacts and considered active and passive as well as in-situ and ex-situ treatment technologies. Therefore, the types and ranges of technical alternatives considered are sufficient to establish if corrective actions for the site conditions are practicable.

Table 1 summarizes and compares the corrective action alternatives practicability (engineering feasibility, effectiveness, durability, degree of active maintenance) and costs.

Practicability

The engineering feasibility of all assessed corrective actions alternatives for both the limited Southeast Drainage groundwater system and the Highland Pit Lake were uniformly considered moderate to excellent as they relied on relatively proven and conventional technologies and methods. Similarly, the efficacy of the corrective action alternatives were ranked from moderate to excellent, with the moderate ratings only due to the uncertainty of applying the technologies on a site specific basis without additional detailed testing and design, uncertainty of the local hydrogeology, or the uncertainty of how the alternative would affect the groundwater concentrations.

The durability of the alternatives were generally poor to moderate due to the reliance on mechanical and electrical systems with limited capital lives, and due to the limited period over which some alternatives could maintain protective conditions without wholesale replacement of capital equipment and\or re-application of the corrective action. The exceptions to this were the backfilling of the Highland Pit, which included pre-treatment of the Pit Lake waters, essentially returning the groundwater to pre-mining conditions and removing any surface-water exposure pathways, and the alternative consisting of institutional controls and ACLs with the associated long-term care boundary. Both of these alternatives had high degrees of durability in maintaining protective conditions for the requisite compliance period of at least 200 years, and 1,000 years to the extent practicable.

The degree of active maintenance for all the Southeast Drainage source control and down-gradient corrective action alternatives were ranked poor while water management alternatives were ranked from moderate to poor. The ranking of poor for source control active maintenance for the limited Southeast Drainage groundwater system is due primarily to the fact that the long-term tailings water seepage down the Southeast Drainage cannot be presumed to nor will likely completely naturally cease or reduce to protective levels, thereby requiring perpetual active control and management. The degree of active maintenance for the Pit Lake treatment alternatives were ranked excellent, with the exception of the ex-situ treatment, reflecting their one time implementation with no perpetual obligation.

The general goal in design decisions for long-term isolation of the tailings and associated contaminants of 11e.(2) byproduct material is to do so with minimizing disturbance and without ongoing maintenance (10 CFR Part 40, Appendix A, Criterion 1, Criterion 12). In addition, the US Department of Energy, Office of Legacy Management guidance (DOE, 2009) states:

"Transition from a private licensee to LM invokes a process to ensure that LM concurs in regulatory findings that

- *The site was constructed in accordance with approved plans and specifications;*
- *The remedies are sound and are implemented to standards that ensure the site is and will remain protective of human health and the environment;*
- *LM obtains a defensible and protective real property position to control land uses that may result in unacceptable risk; and*
- ***Post-closure maintenance needs are of a routine nature, and no major interventions are forecast that transfer health or cost risk to LM.****[emphasis added]"*

Major active maintenance of long-term corrective actions that would become the obligation of the long-term custodian are open ended and are unacceptable to the US Department of Energy, Office of Legacy Management, the likely Long-term custodian. Therefore, all alternatives that require significant and perpetual (>200 years) active operation and maintenance and replacement of capital equipment during the initial 200 years of ownership by the long-term custodian are rejected from further consideration.

<u>Costs</u>

The costs of the alternatives varied widely (Table 4). The comprehensive alternatives for the Southeast Drainage had net present values (NPV) that ranged from $15,530,000 for source control, down-gradient groundwater corrective action and water treatment (cut off wall, pumping wells, in-pit disposal) to $26,510,000 for in-situ approaches for both source control and down-gradient groundwater corrective action (PRB with ISRM and injection wells with no ex-situ water management). Treatment alternatives for the Pit Lake had NPVs ranging from $6,119,000 for in-situ treatment with ISRM and floating platform based additive mixing to $20,340,000 for ex-situ treatment using IX. Pit backfill alternatives, which would also require treatment of the hazardous constituents in the Pit Lake prior to fill placement, had NPVs that range from almost $69,000,000 to over $80,000,000. The alternative implementing institutional controls with a new POC well and ACLs for the Southeast Drainage had a net present value of slightly less than $5,140,000.

2.5 Proposed Corrective Action Alternative

Table 4 compares the estimated cost range for corrective action in the Southeast Drainage and the Pit Lake, the estimated range of values for the pre-contaminated water resources, the ratio of the corrective action costs with respect to the estimated value of the water resource, and the cost range for avoided dose achieved by successful implementation of corrective actions. The data in Table 4, as supported by the assessment summarized in Tables 2 and 3, clearly indicate that the cost of the alternatives requiring active maintenance significantly exceed the value of the water resources and the benefits of the corrective actions. Specifically, the ratio of the alternatives net present value to the estimated value of the water resources range from 526 to 16 with costs ranging from 16 times to several hundred times greater than the resource values. Similarly, even Pit Lake alternatives that did not require active maintenance have ratios of the alternatives net present value to the estimated value of the water resources from 1,380 to 9, indicating the cost exceeds the resource value by at least nine times and as much as 1,000 times.

Therefore, based on the assessment provided above, the only practicable action that provides the requisite reasonable assurance of protection of public health, safety and the environment for at least 200 years and, to the extent practicable, 1,000 years with the most reasonable cost-benefit ratio is the implementation of institutional controls over the lands within the proposed long-term care boundary (**Figure 12**), adoption of the new Southeast Drainage POC well MFG-1 and performance monitoring well TT-7 in conjunction with the proposed uranium ACL for MFG-1 of 0.7 mg/L and the proposed ACL for uranium in well 175 of 3 mg/L. Section 2.6, below, presents the demonstration that this proposed alternative satisfies the ALARA requirement.

2.6 ALARA Demonstration

The proposed alternative ensures durable control of access to the contaminated water resources in the Pit Lake and the Southeast Drainage to prevent long-term consumption of the water as a drinking water source. Exposure to these water resources by all other receptors remains protective.

Per the NRC (NRC, 2000; 2003), if the cost per person-rem averted dose is greater than $2,000, then the proposed action, which provides the reasonable assurance of protection of public health, safety and the environment, is considered to be ALARA. As presented in Table

4, the proposed action has a cost per person-rem averted dose more than 200 times greater than this threshold. Though the cost per person-rem averted dose was not calculated in a manner entirely consistent with the methods presented in Appendix D of NUREG 1727 (NRC, 2000), the method used is a reasonable alternative allowed under the regulations and the results overwhelmingly demonstrate that the proposed action exceeds the threshold value. Therefore, the proposed action is ALARA.

Table 1 Alternative Corrective Action Comparison Summary

Alternative Corrective Actions	Engineering Feasibility	Effectiveness	Durability	Active Maintenance	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Net Present Value ($1,000)
NO-ACTION	**Not Carried Forward**						
SOUTHEAST DRAINAGE							
Source Control							
Interceptor Cut Off Wall	Excellent	Moderate	Poor	Poor	$1,335	$33	$5,110
Interception with Pumping Wells	**Not Carried Forward**						
Permeable Reaction Wall (PRB)	Excellent	Excellent	Poor	Poor	$1,728	$45	$12,140
Down-gradient Corrective Action							
Pumping Wells	Excellent	Moderate	Poor	Poor	$943	$93	$9,670
ISRM with Injection Wells	Moderate	Moderate	Poor	Poor	$426	$158	$14,370
Management of Collected Water							
Direct Disposal in Pit Lake	Excellent	Excellent	Moderate	Poor	$185	$3	$750
Evaporative Treatment in Lined Ponds	Excellent	Moderate	Poor	Poor	$2,553	$76	$11,790
Chemical Precipitation and Discharge	**Not Carried Forward**						
Ion Exchange and Discharge	Moderate	Moderate	Poor	Poor	$1,755	$245	$26,320
Reverse Osmosis and Discharge	**Not Carried Forward**						
HIGHLAND PIT LAKE							
ISRM with Land Mixing	Moderate	Moderate	Moderate	Excellent	$6,206	$0	$6,206
ISRM with Floating Platforms	Moderate	Moderate	Moderate	Excellent	$6,119	$0	$6,119
Ex-Situ Treatment with Ion Exchange	Moderate	Moderate	Moderate	Poor	$9,035	$1,478	$20,340
Pit Lake Backfill - Surface Drainage to South	Moderate	Moderate	Excellent	Excellent	$80,032	$0	$80,030
Pit Lake Backfill - Closed Surface Drainage	Moderate	Moderate	Excellent	Excellent	$68,983	$0	$68,980
INSTITUTIONAL CONTROLS & ACLs	Excellent	Excellent	Excellent	Excellent	$1,368	$25	$5,140

Table 2 Summary of Corrective Action Benefits – Avoided Radiological Dose and Non-Radiological Adverse Health Effects

	Lifetime Avoided Radiological Dose To an Individual (person-rem)	Avoided Radiological Dose To an Individual (mrem/yr)	Avoided Adverse Health Effects from Remediation of Selenium
Southeast Drainage			
Source Control & GW Corrective Action	0.34 – 1.31	11.5– 43.7	None
Highland Pit Lake	12.3	409	None

Table 3 Summary of Corrective Action Benefits – Value of Pre-Contaminated Groundwater & Land Depreciation

	Southeast Drainage	Pit Lake
VALUE OF PRE-CONTAMINATED GROUNDWATER (as a drinking water source)		
Projected Future Water Use Demand	Very Low	Very Low
Availability of Alternate Water Supply		
Municipal	None	None
Comparable Private Land w/ Water Rights	High	High
Private Well	High	High
Comparable Private Land w/ Water Rights (per acre) Southeast Drainage (7 acres - 160 acres) Pit Lake (116 Acres)	$2000/acre $14,000 - $320,000	$2000/acre $232,000
Value of Stored Water ($/1,000 gallons) Value of Projected Future Demand for Drinking Water (2,000 gallons/yr) (Value of Pit Lake 3.9Bgal @ $0.015 - $0.23/1,000 gal))	$0.015 - $0.23 $30 - $460	$0.015 - $0.23 $58,500 - $897,000
Cost of Alternative Water Supply		
Municipal	NA	NA
Private Well	$38,800	$38,800
Cost of Supplied Water (4 persons consuming 2 liters/day each)	$91,800	$91,800
PREVENTION OF LAND DEPRECIATION VALUES	Low to negligible incremental depreciation	Low to negligible incremental depreciation

Table 4 Comparison of Corrective Action Costs, Resource Value Estimates and Cost of Averted Dose

Alternative Corrective Actions	Corrective Action Net Present Value ($)	Value of Pre-Contaminated Resource ($)	NPV to Resource Value Ratio	Cost/person-rem (NPV$/person-rem)	
SOUTHEAST DRAINAGE CORRECTIVE ACTIONS **Lifetime Avoided Radiological Dose**				**Low: 0.34 person-rem**	**High: 1.31 person-rem**
Source Control & Corrective Action (Source Control\Corrective Action\Treatment)		**$14,000 - $320,000**			
Low: (Interceptor Cut Off Wall\Pumping wells\Pit Lake Disposal)	$15,530,000		1,109 – 49	$45,676,500	$11,855,000
High: (PRB\ISRM w/ Injection Wells\No Treatment)	$26,510,000		1,894 – 83	$77,970,600	$20,236,600
HIGHLAND PIT LAKE CORRECTIVE ACTION **Lifetime Avoided Radiological Dose**				**12.3 person-rem**	
ISRM with Land Mixing	$6,206,000		107 – 7	$504,553	
ISRM with Floating Platforms	$6,119,000		106 – 7	$497,480	
Ex-Situ Treatment with Ion Exchange	$20,340,000	**$58,000 - $897,000**	351 – 23	$1,653,659	
Backfill of Pit Lake - Surface Drainage to North Fork Box Creek	$80,030,000		1,380 – 89	$6,506,504	
Backfill of Pit Lake - Closed Surface Drainage	$68,980,000		1,189 – 77	$5,608,130	
INSTITUTIONAL CONTROLS WITH ACLs	$5,140,000		89 – 6	$417,886	

References:

AEC, 2010. Cost Estimate for Active Water Treatment, Highland Pit Lake, highland Mine and Mill Reclamation Project. Advanced Environmental Sciences, Inc., November. (Exhibit 3)

DOE, 2005. Chart compiled by NF Metting, Office of Science, August 2005 DOE/BER "Orders of Magnitude", http://www.nuclear.utah.edu/class_notes/shared/dose_ranges_aug05.pdf

DOE, 2008 Toward Cleanup at Santa Susana, Environmental Impact Statement for Remediation of Area IV of the Santa Susana Field Laboratory, Radiation Basics. Radiation Basics Fact Sheet. http://www.etec.energy.gov/EIS/Documents/Radiation_Basics_2008-07-22.pdf, January 2008.

DOE, 2009 Process for Transition of Uranium Mill Tailings Radiation Control Act Title II Disposal Sites to the U.S. Department of Energy Office of Legacy Management for Long-Term Surveillance and Maintenance, June 2009. Doc. No. S05096

ECMC, 1998. Supporting Information for Alternative Concentration Limit Application, Highland Reclamation Project, Exxon Coal and Minerals Company. Docket #40-8102. December.

EPA, 2009 US EPA 2009 Edition of the Drinking Water Standards and Health Advisories. EPA 822-R-09-011, Office of Water, U.S. Environmental Protection Agency Washington, DC. October, 2009.

EPA, 2010 US EPA Web site, Basic Information about Regulated Drinking Water Contaminants. http://water.epa.gov/drink/contaminants/basicinformation/selenium.cfm#three (last accessed December 24, 2010)

Fendorf, S., Hansel, C.M., Wielinga, B., 2002. Operative pathways of chromate and uranyl reduction within soils and sediments. In: Zhang, P-C., Brady, P. (Eds.), Geochemistry of Soil Radionuclides. Soil Science Society of America, Madison, pp. 111-129.

ITRC, 2005. Permeable Reactive Barriers: Lessons Learned/New Directions, Interstate Technology & Regulatory Council [ITRC], Permeable Reactive Barrier Team, February, 2005

Lovley, D.R., 1993. Dissimilatory metal reduction. Annu. Rev. Microbiol., 47: 263-290.

MWH Global, 2010. Cost Estimate for Partial Backfill of Highland Mine Pit. February. (Exhibit 4)

Nealson, K. H. and C. R. Myers (1992). "Microbial reduction of manganese and iron: New approaches to carbon cycling." Appl. Environ. Microbiol. 58(2): 439-443.

Newman, D. K., D. Ahmann, et al. (1998). "A brief review of microbial arsenate respiration." Geomicrobiology 15: 255-268.NRC 1996. Staff Technical Position Alternate Concentration Limits for Title II Uranium Mills. January.

NRC 2000. NMSS Decommissioning Standard Review Plan. NUREG 1727, Appendix D. September, 2000.

NRC 2003. Standard review plan for the review of a reclamation plan for mill tailings sites under Title II of the Uranium Mill Tailings Radiation Control Act. NUREG- 1620, Rev 1, June 2003.

Oremland, R. S., J. S. Blum, et al. (1999). "Simultaneous reduction of nitrate and selenate by cell suspensions of selenium-respiring bacteria." Applied and Environmental Microbiology 65(#10): 4385-4392.Sobolewski, A., 2005. Treatment options for selenium at northern mines. Northern Latitudes Mining Reclamation Workshop, Dawson City, AK.

Sobolewski, 2005. Treatment Options for Selenium at Northern Mines. *Northern Latitudes Mining Reclamation Workshop*. Dawson City, May 24-26, 2005.

Tebo, B. M. and A. Y. Obraztsova (1998). "Sulfate-reducing bacterium grows with Cr(VI), U(VI), Mn(IV), and Fe(III) as electron acceptors." FEMS Microbiol. Lett. 162: 193-198.

Tetra Tech, Inc. and Redente Ecological Consultants, LLC. 2011 (in progress). Final Highland Pit Lake-Specific Ecological Risk Assessment. Prepared for ExxonMobil (Fairfax, VA).

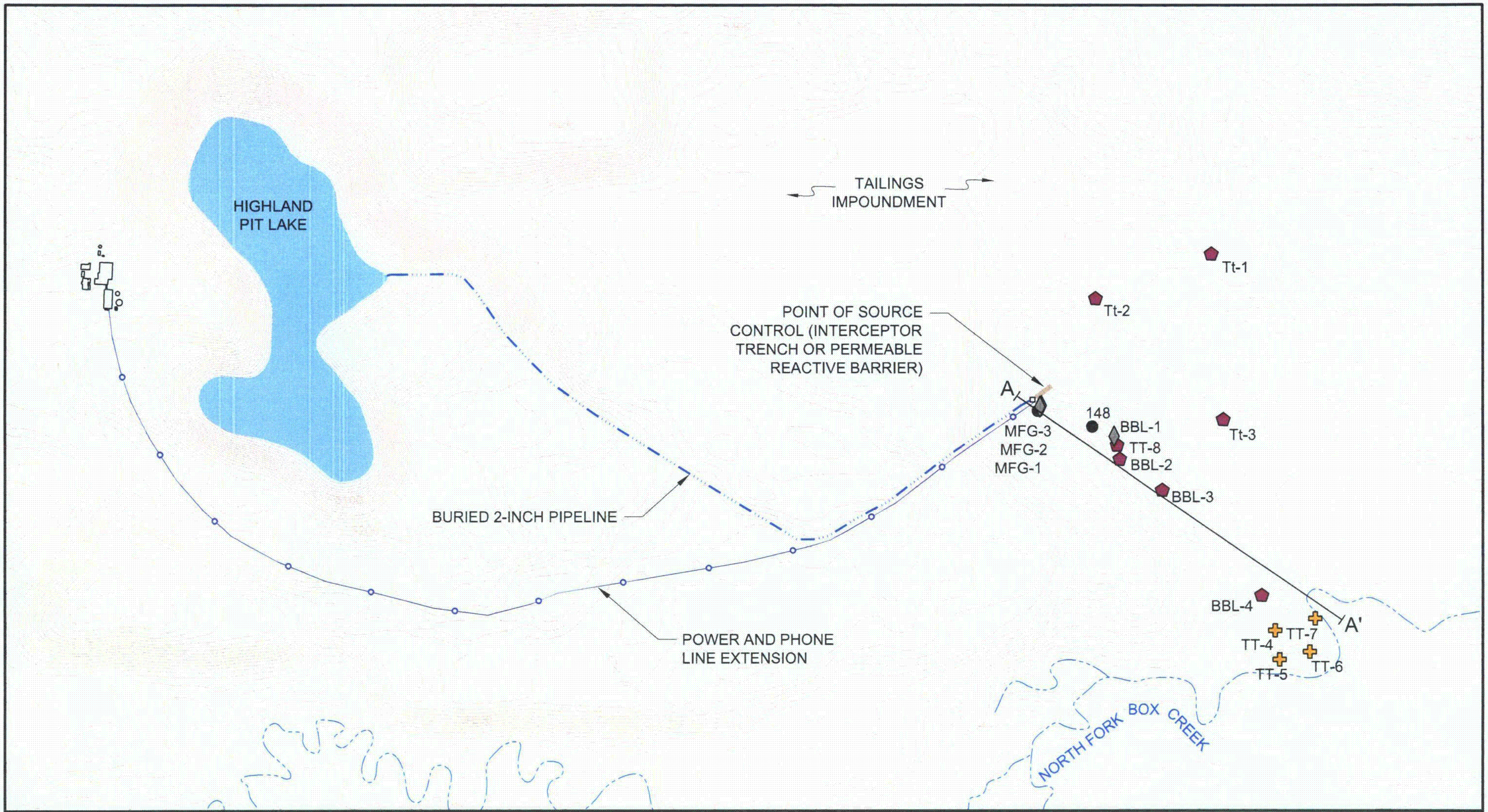
WDEQ 2001. Wyoming Water Quality Standards, Chapter 1. Wyoming Surface Water Classification List.

Wielinga, B., Mizuba, M.M., Hansel, C.M., Fendorf, S., 2001. Iron promoted reduction of chromate by dissimilatory iron-reducing bacteria. Envirn. Sci. Technol., 35(3): 522-527.

Wright Environmental Services, 2011 Assessment of Potential Health Effects From Exposure To Selected Contaminants In Groundwater And Surface Water At The ExxonMobil Highland Uranium Project. February. (Exhibit 6)

Appendix E

FIGURES



LEGEND

10-FOOT ELEVATION CONTOURS
PROPOSED 2-INCH PIPELINE
PROPOSED POWER AND PHONE LINE EXTENSION
WELLS SCREENED IN 50SS
WELLS SCREENED IN REGOLITH
WELLS SCREENED IN NORTH FORK BOX CREEK ALLUVIUM
WELLS SCREENED IN OTHER FORMATIONS

250 0 250 500 FEET

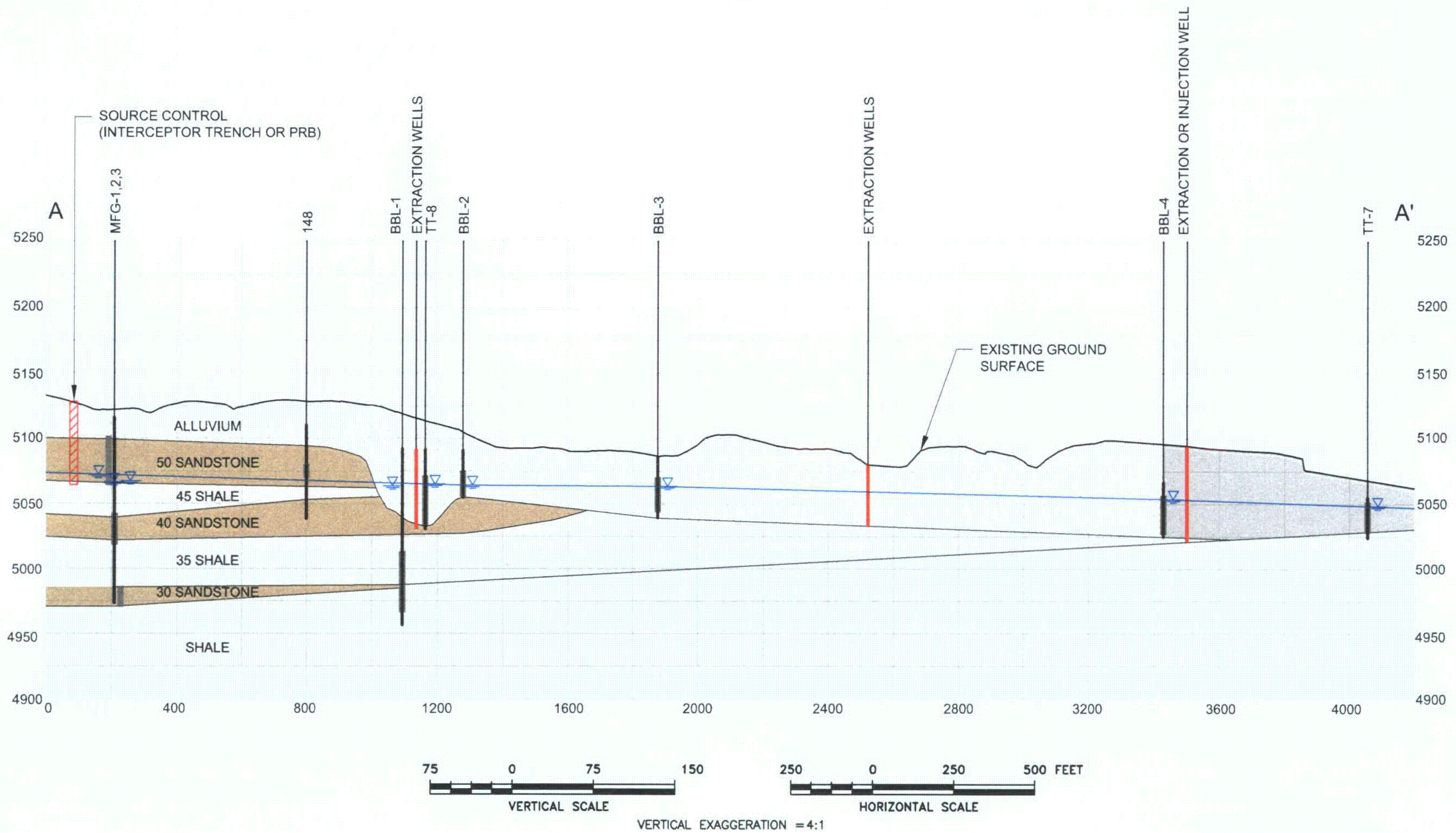
CLIENT: ExxonMobil

PROJECT: HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION

TITLE: CONCEPTUAL LAYOUT OF SOUTHEAST DRAINAGE SOURCE CONTROL ALTERNATIVES

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	1		

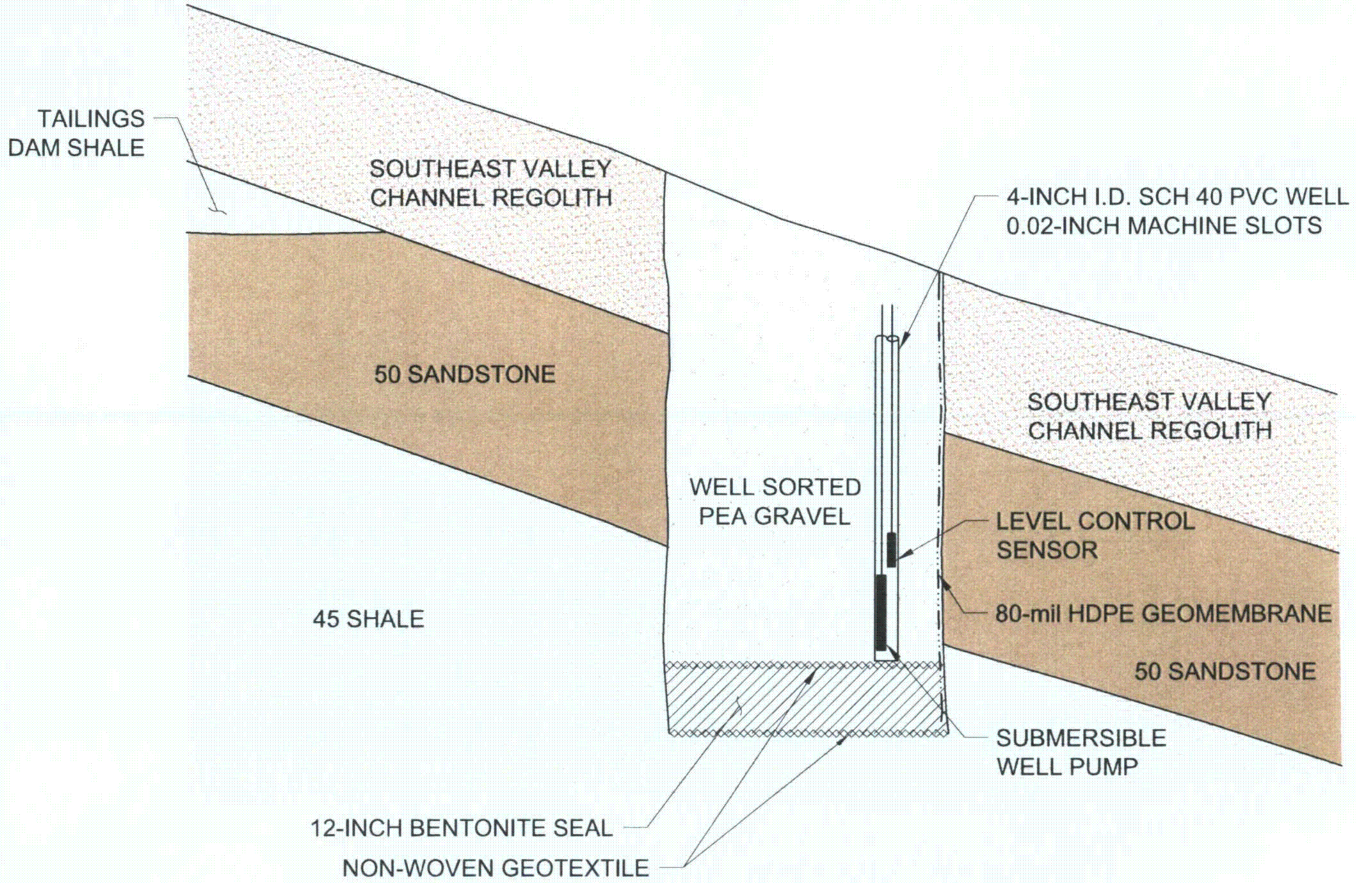


NOTE: CONCEPTUAL LOCATIONS OF SOURCE CONTROL AND DOWN-GRADIENT CORRECTIVE ACTIONS SHOWN FOR ILLUSTRATIVE PURPOSES. ALL OPTIONS WOULD NOT BE IMPLEMENTED TOGETHER.

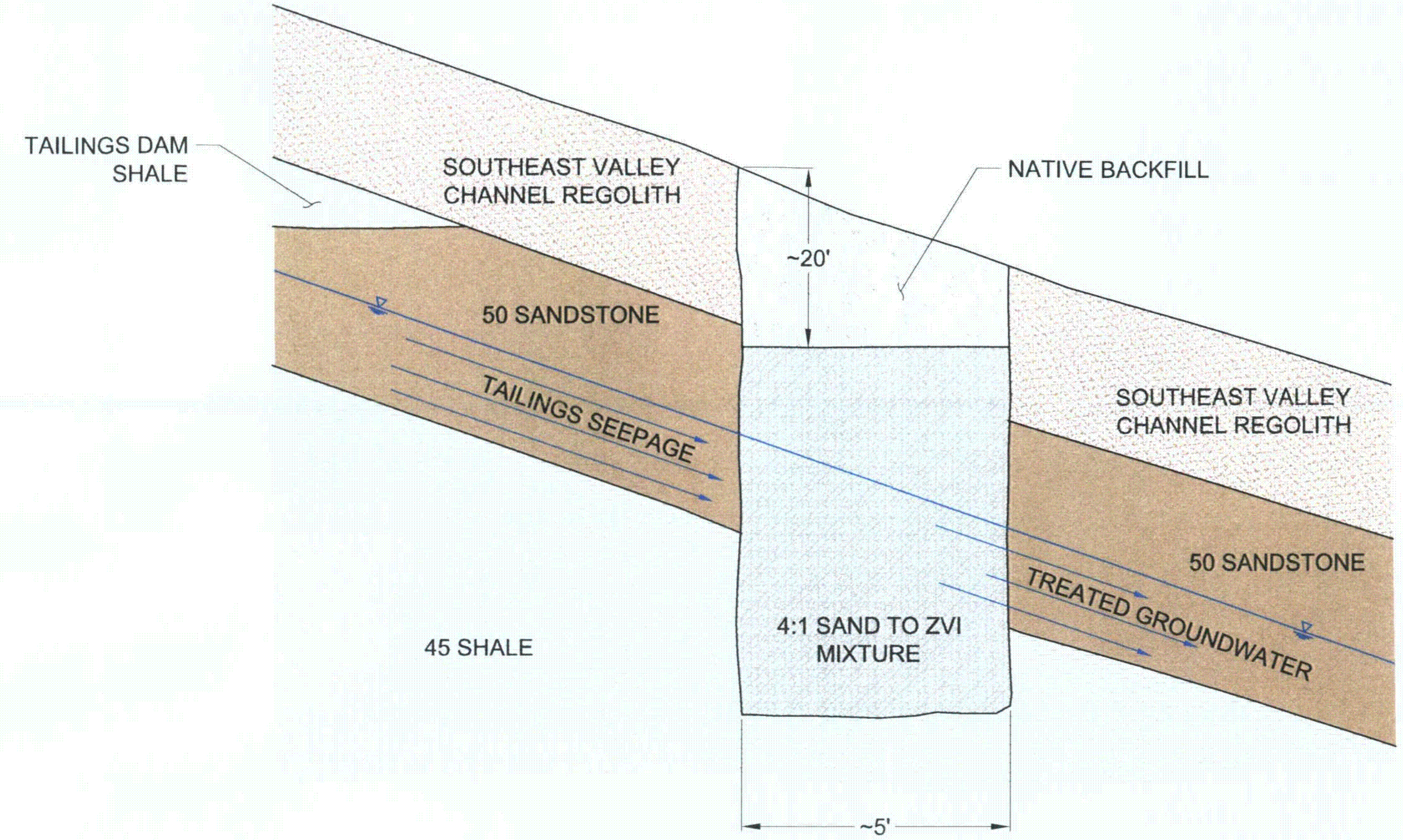
CLIENT	ExxonMobil
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	HYDROGEOLOGICAL CROSS-SECTION OF SOUTHEAST DRAINAGE

amec EARTH AND ENVIRONMENTAL

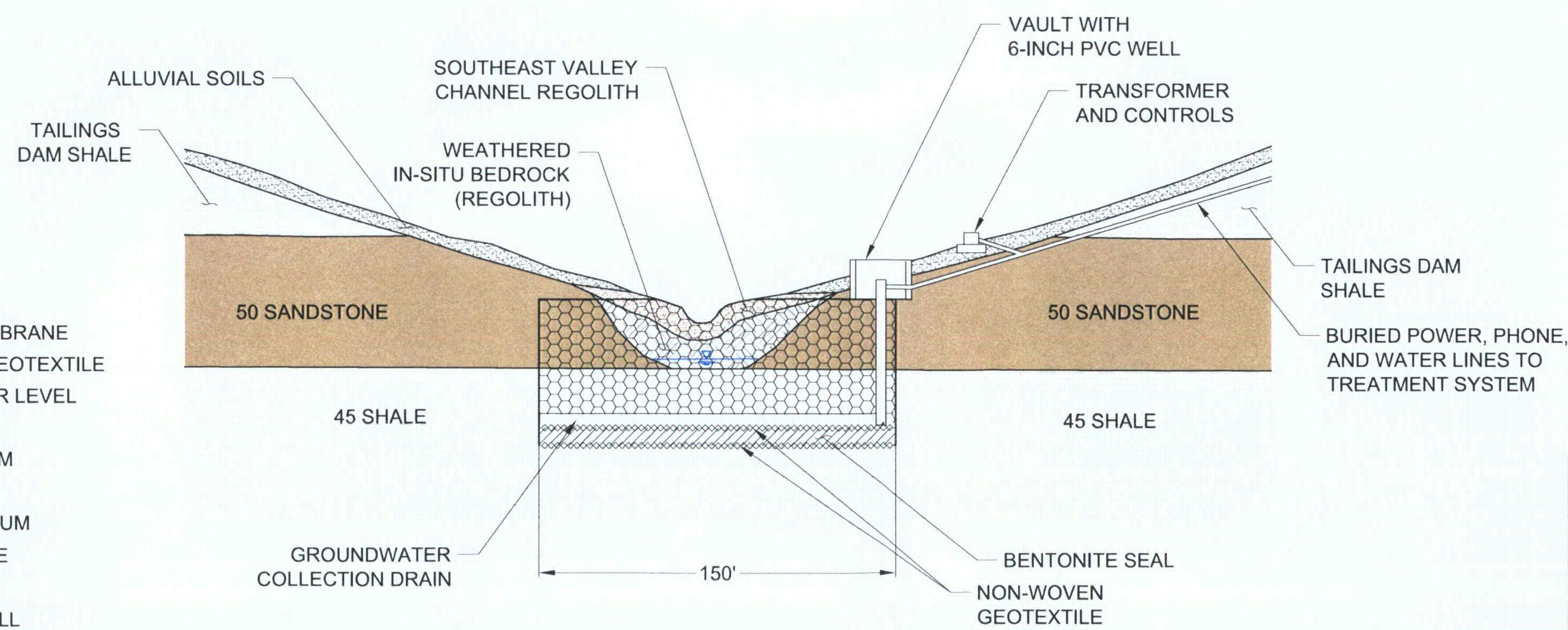
DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	2		



NORTHWEST-SOUTHEAST SECTION OF INTERCEPTOR TRENCH
NTS



NORTHWEST-SOUTHEAST SECTION OF PERMEABLE REACTIVE BARRIER
NTS



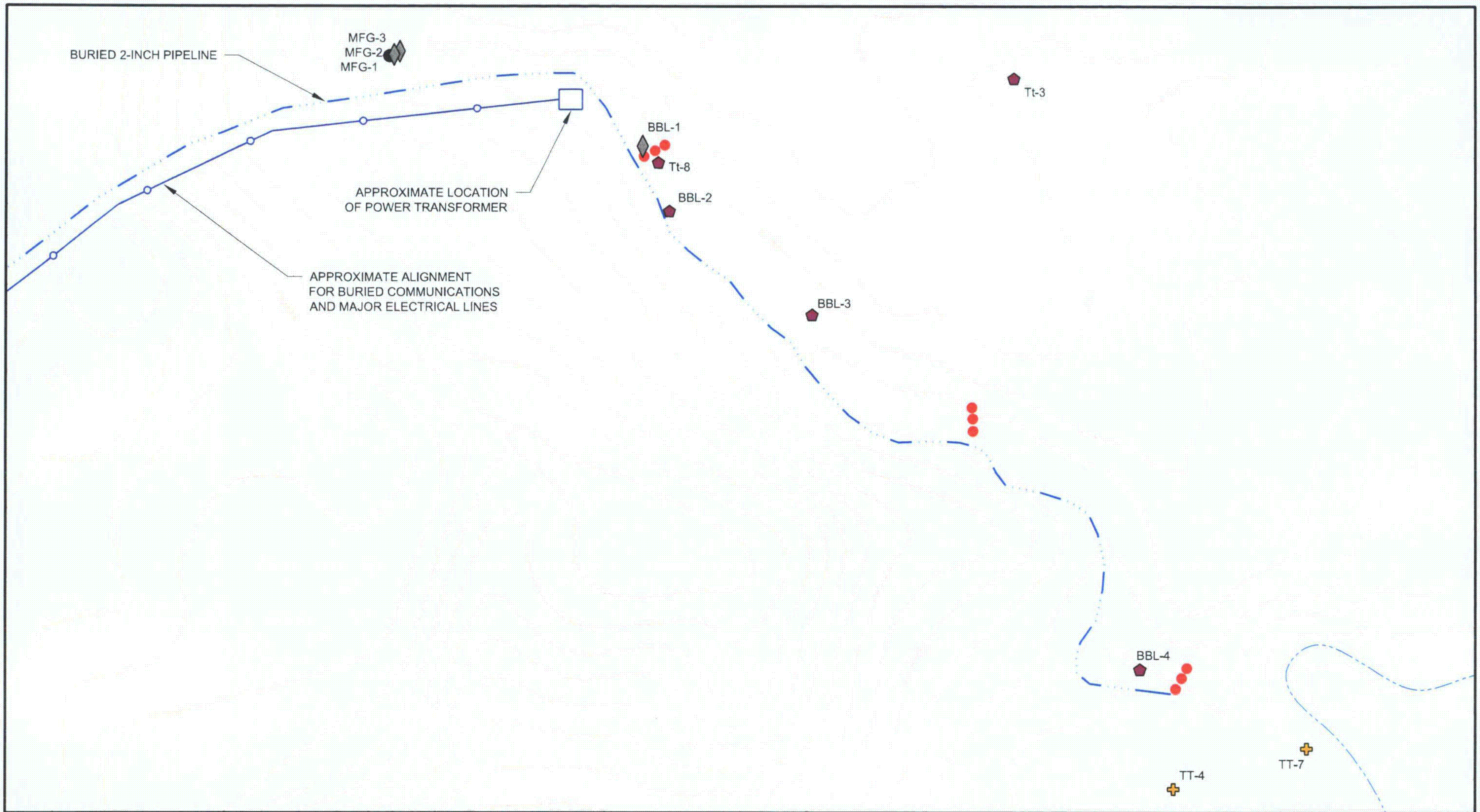
NORTHEAST-SOUTHWEST SECTION OF INTERCEPTOR TRENCH
NTS

LEGEND

CLIENT	ExxonMobil
PROJECT	HIGHLAND URANIUM PROJECT ACL APPLICATION
TITLE	CONCEPTUAL INTERCEPTOR TRENCH AND PERMEABLE REACTIVE BARRIER DETAILS

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	3		



LEGEND

- 10–FOOT ELEVATION CONTOURS
- PROPOSED 2–INCH PIPELINE
- PROPOSED POWER AND PHONE LINE EXTENSION
- WELLS SCREENED IN 50SS
- WELLS SCREEN IN REGOLITH
- WELLS SCREENED IN NORTH FORK BOX CREEK ALLUVIUM
- WELLS SCREENED IN OTHER FORMATIONS
- PROPOSED EXTRACTION WELL

75 0 75 150 FEET

CLIENT: ExxonMobil

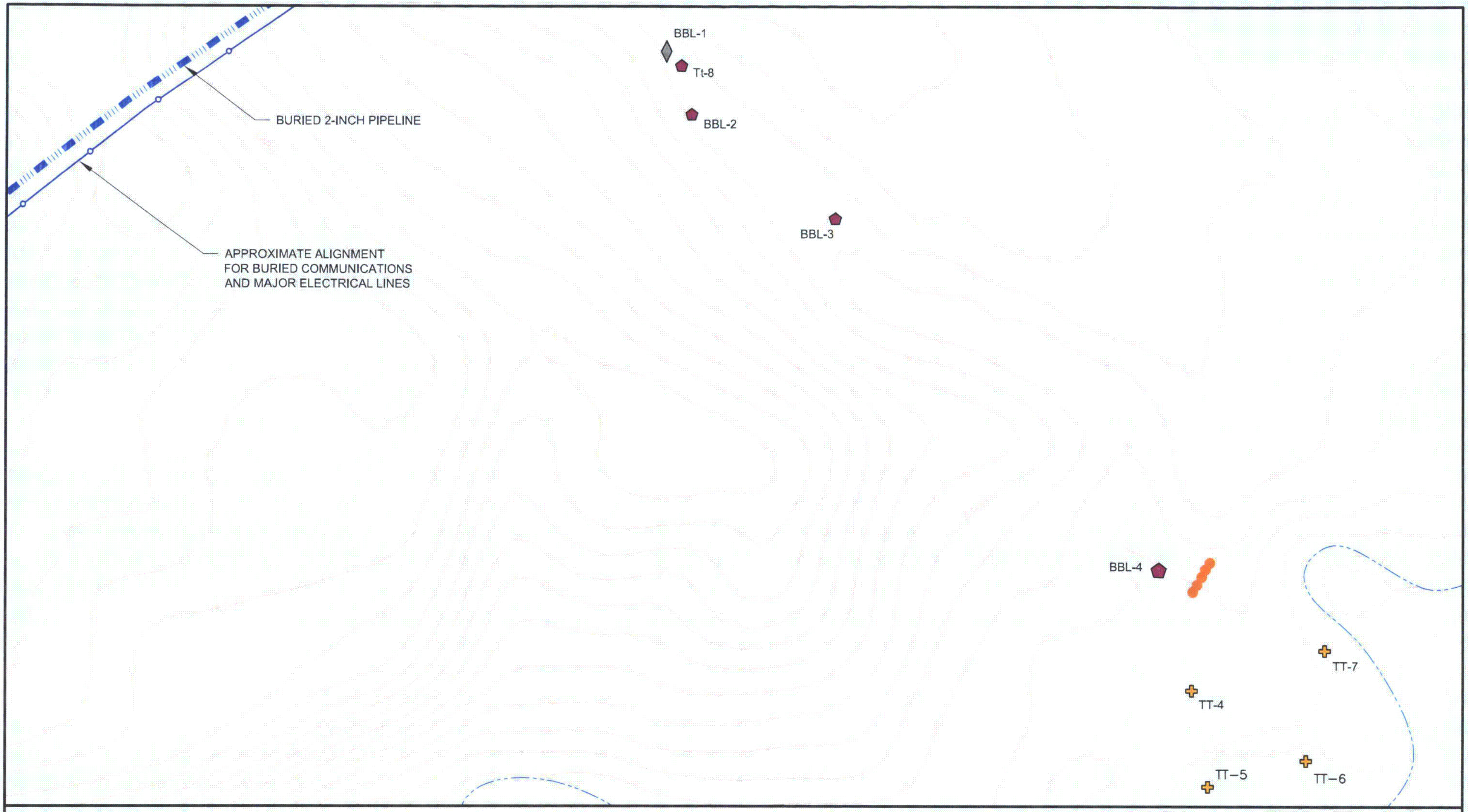
PROJECT: HIGHLAND URANIUM PROJECT
ACL AMENDMENT APPLICATION

TITLE: CONCEPTUAL LAYOUT OF SOUTHEAST DRAINAGE GROUNDWATER EXTRACTION WITH PUMPING WELLS

amec
EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11

FIGURE No. 4



LEGEND

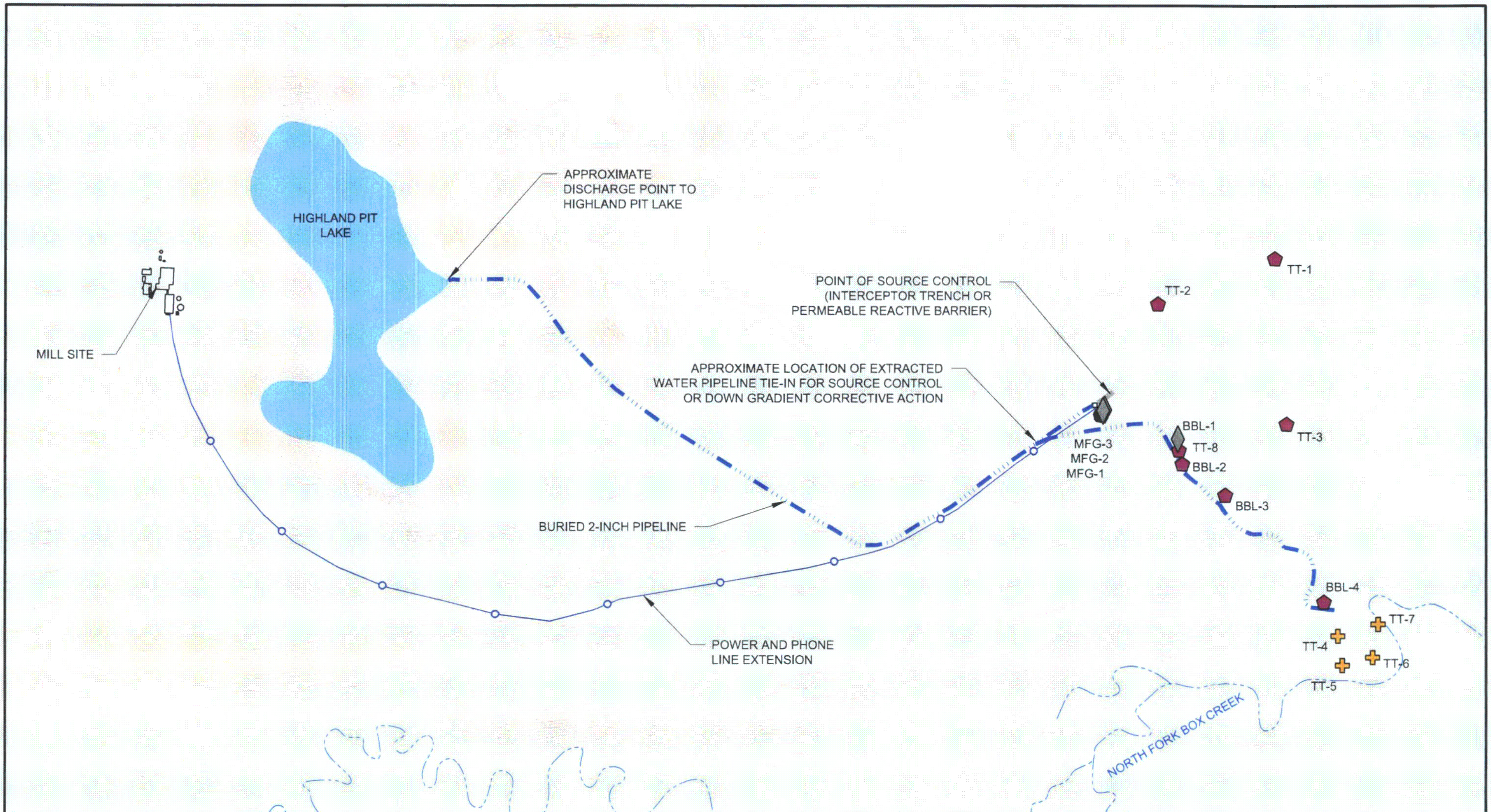
10–FOOT ELEVATION CONTOURS
PROPOSED 2–INCH PIPELINE
PROPOSED POWER AND PHONE LINE EXTENSION
WELLS SCREEN IN REGOLITH
WELLS SCREENED IN NORTH FORK BOX CREEK ALLUVIUM
WELLS SCREENED IN OTHER FORMATIONS
PROPOSED EXTRACTION WELL

75 0 75 150 FEET

CLIENT	ExxonMobil
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	CONCEPTUAL LAYOUT OF SOUTHEAST DRAINAGE INJECTION WELLS

amec
EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	5		



LEGEND

10-FOOT ELEVATION CONTOURS
PROPOSED 2-INCH PIPELINE
PROPOSED POWER AND PHONE LINE EXTENSION
WELLS SCREENED IN 50SS
WELLS SCREEN IN REGOLITH
WELLS SCREENED IN NORTH FORK BOX CREEK ALLUVIUM
WELLS SCREENED IN OTHER FORMATIONS

250 0 250 500 FEET

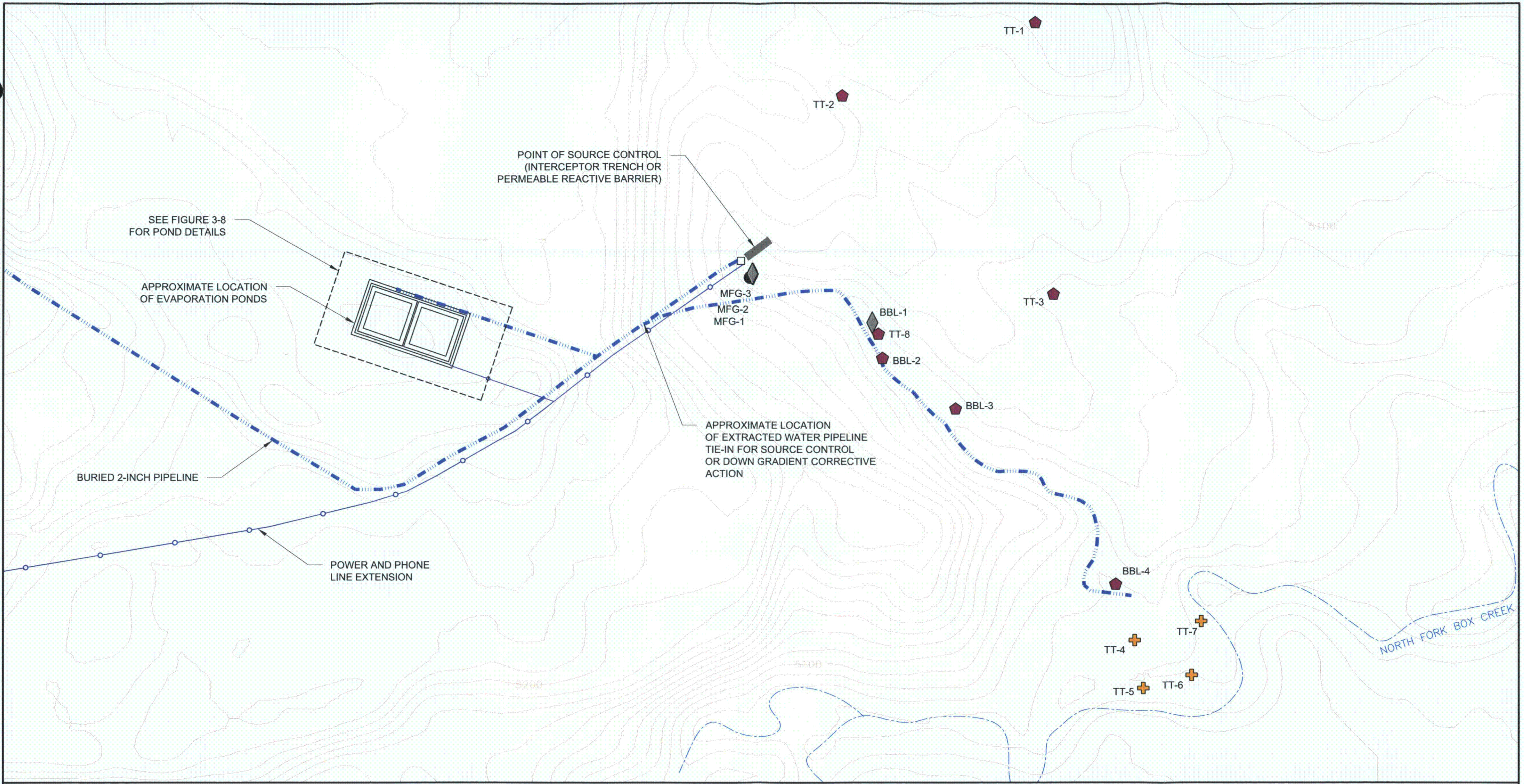
CLIENT: ExxonMobil

PROJECT: HIGHLAND URANIUM PROJECT
ACL AMENDMENT APPLICATION

TITLE: CONCEPTUAL LAYOUT OF SOUTHEAST
DRAINAGE DIRECT DISPOSAL ALTERNATIVE

amec
EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
		FIGURE No. 6	



LEGEND

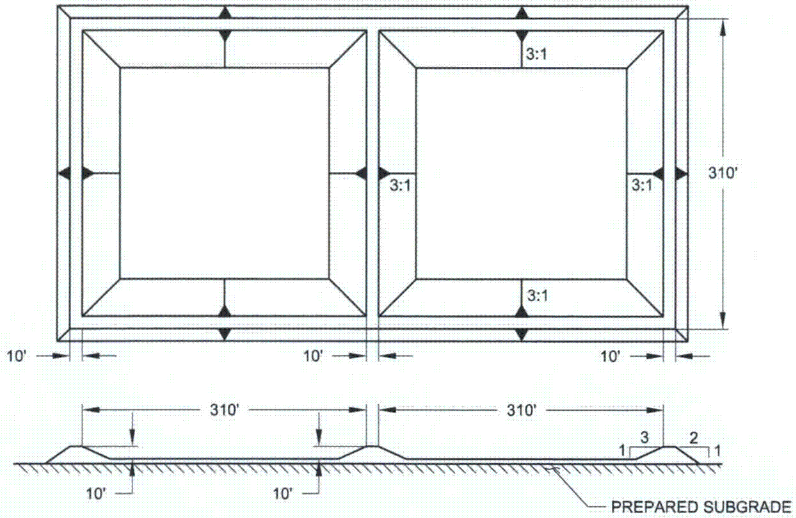
- 10-FOOT ELEVATION CONTOURS
- PROPOSED 2-INCH PIPELINE
- PROPOSED POWER AND PHONE LINE EXTENSION
- WELLS SCREENED IN 50SS
- WELLS SCREENED IN REGOLITH
- WELLS SCREENED IN NORTH FORK BOX CREEK ALLUVIUM
- WELLS SCREENED IN OTHER FORMATIONS

100 0 100 200 FEET

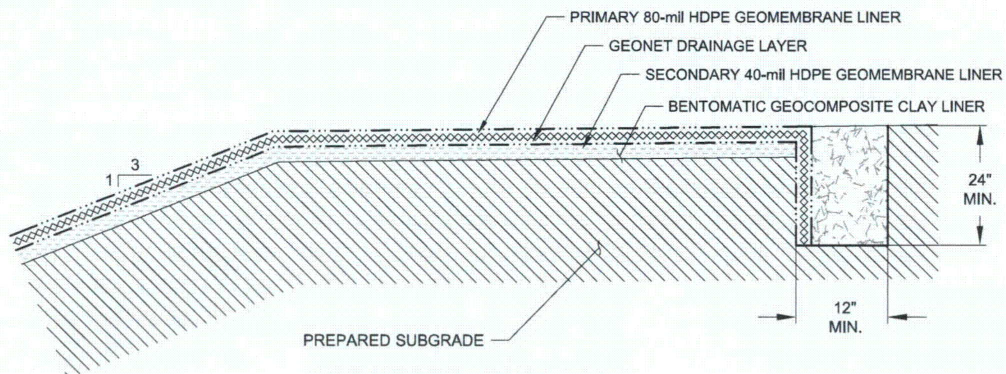
CLIENT	ExxonMobil Environmental Services
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	CONCEPTUAL LAYOUT OF EVAPORATION POND ALTERNATIVE

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	7		



EVAPORATION POND PLAN AND PROFILE



GEOMEMBRANE LINER DETAIL

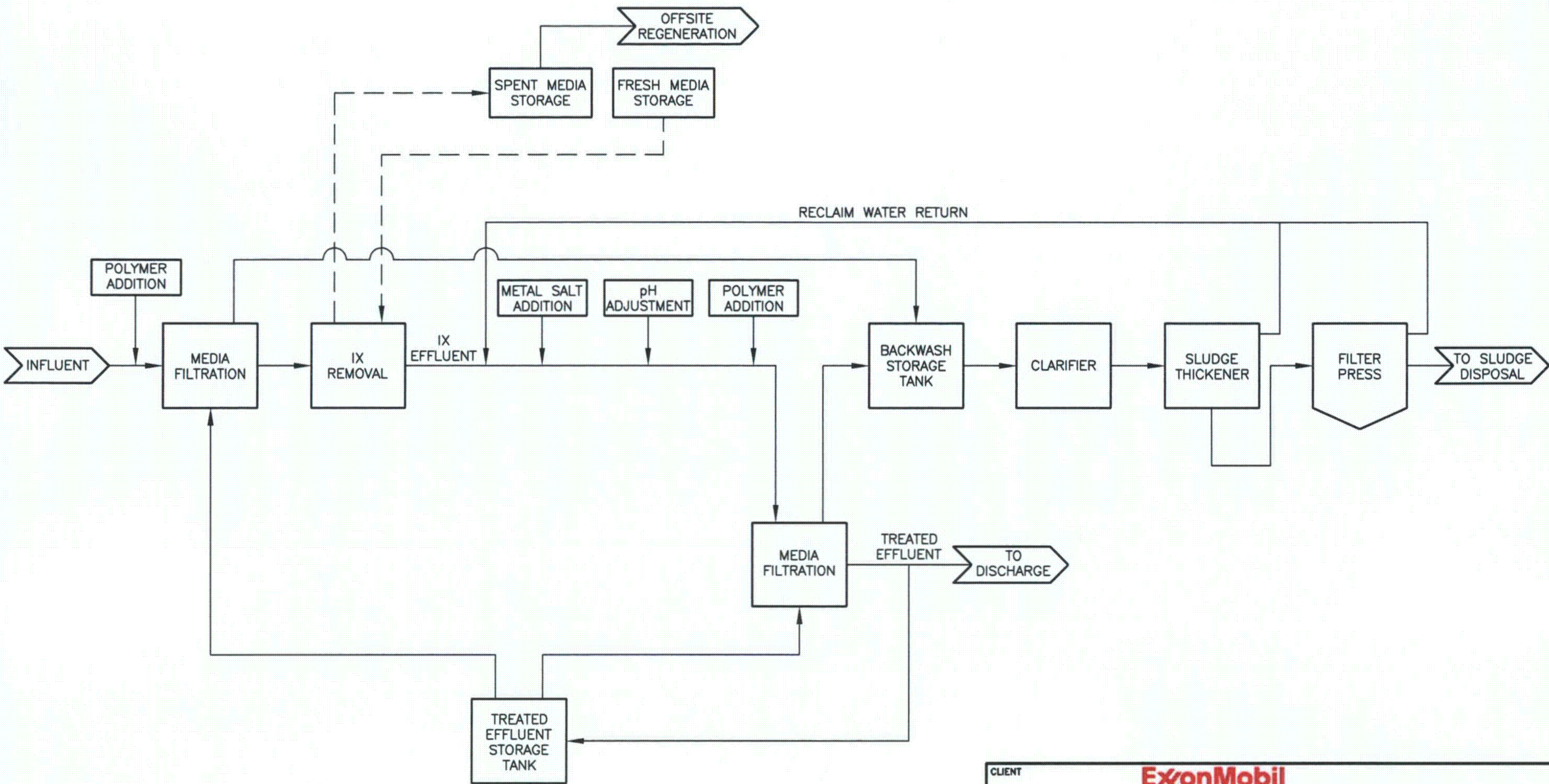
LEGEND

- GEONET
- HDPE GEOMEMBRANE LINER
- BENTOMATIC GEOCOMPOSITE CLAY LINER
- SUBGRADE
- RANDOM FILL

CLIENT	ExxonMobil Environmental Services
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	EVAPORATION POND CONCEPTUAL DESIGN

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	8		

amec
EARTH AND ENVIRONMENTAL



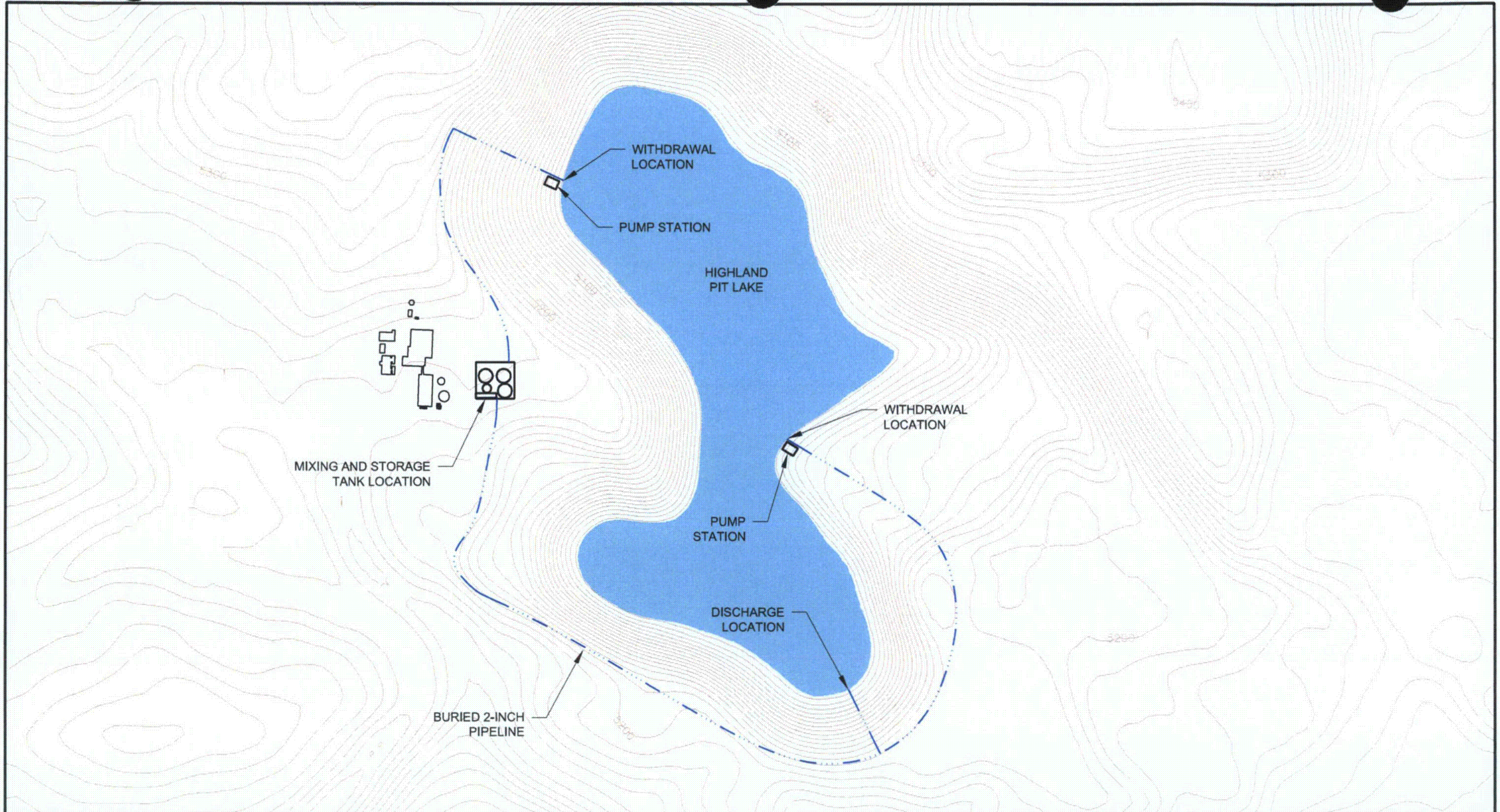
CLIENT: ExxonMobil Environmental Services

PROJECT: HIGHLAND URANIUM PROJECT
ACL AMENDMENT APPLICATION

TITLE: CONCEPTUAL PROCESS FLOW DIAGRAM FOR EX–SITU TREATMENT OF SOUTHEAST DRAINAGE WATER AND PIT LAKE

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	9		



LEGEND

10–FOOT ELEVATION CONTOURS

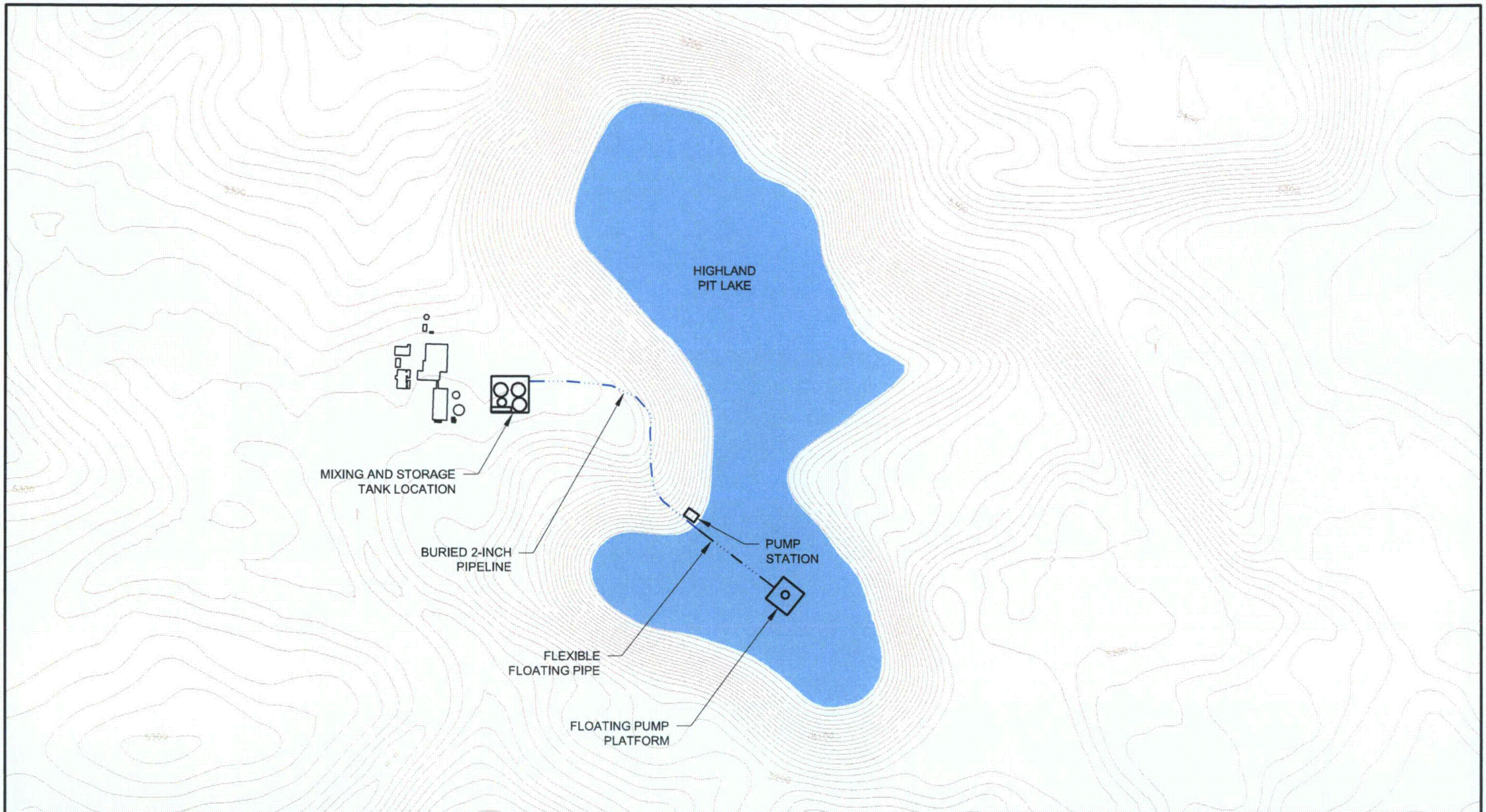
PROPOSED 2–INCH PIPELINE

150 0 150 300 FEET

CLIENT	ExxonMobil Environmental Services
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	CONCEPTUAL LAYOUT OF PIT LAKE IN–SITU REDOX MANIPULATION ALTERNATIVE A: LAND MIXING

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	10		



LEGEND

5300 10-FOOT ELEVATION CONTOURS

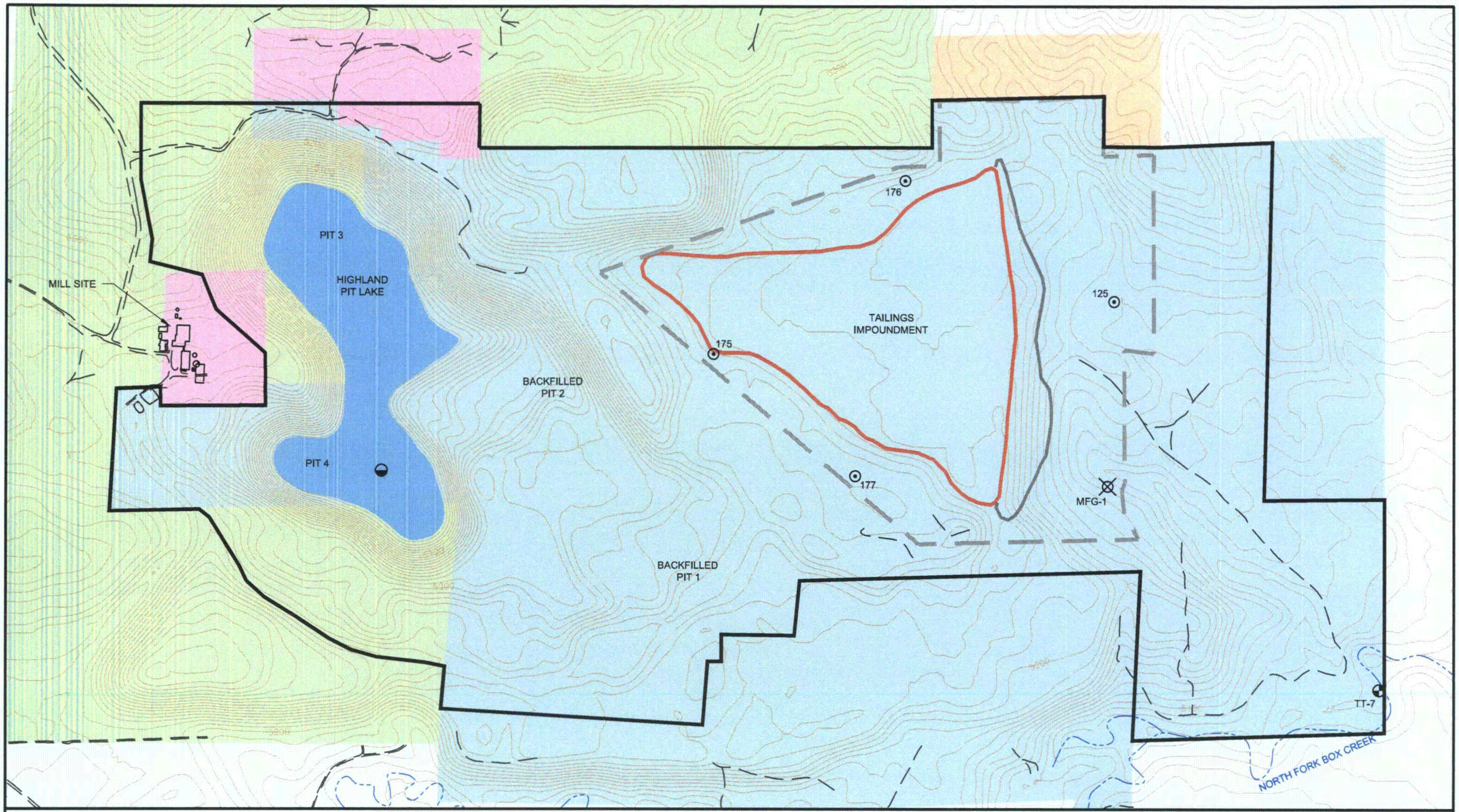
PROPOSED 2-INCH PIPELINE

150 0 150 300

CLIENT	ExxonMobil Environmental Services
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	CONCEPTUAL LAYOUT OF PIT LAKE IN-SITU REDOX MANIPULATION ALTERNATIVE B: FLOATING PLATFORM

amec
EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	11		



LEGEND

- 10-FOOT ELEVATION CONTOURS
- EXISTING ROADS AND TRAILS
- CURRENT LONG-TERM SURVEILLANCE BOUNDARY
- PROPOSED LONG-TERM SURVEILLANCE BOUNDARY
- EXTENT OF TAILINGS
- TAILINGS DAM
- CURRENT POINT OF COMPLIANCE WELL
- PROPOSED POINT OF COMPLIANCE WELL
- PROPOSED POINT OF EXPOSURE WELL
- PROPOSED POINT OF EXPOSURE SAMPLING LOCATION
- CAMECO RESOURCES OWNERSHIP AREA
- EXXON MOBIL OWNERSHIP AREA
- BONER OWNERSHIP AREA
- FOWLER OWNERSHIP AREA

250 0 250 500 FEET

CLIENT	ExxonMobil Environmental Services
PROJECT	HIGHLAND URANIUM PROJECT ACL AMENDMENT APPLICATION
TITLE	LOCATION OF POINT OF COMPLIANCE AND POINT OF EXPOSURE WELLS

amec EARTH AND ENVIRONMENTAL

DRAWN BY	JKM	CHECKED BY	BW
FILENAME	677520022	DATE	4/28/11
FIGURE No.	12		