

**Red Dog Mine  
Closure and Reclamation Plan**

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**SD C3: Dam History Report, Red Dog Tailings  
Main Dam, Future Raises to Closure  
(URS, 2007)**

**DAM HISTORY REPORT  
RED DOG TAILINGS MAIN DAM  
FUTURE RAISES TO CLOSURE  
RED DOG MINE, ALASKA**

For

**TECK COMINCO ALASKA, INC.  
URS JOB NO. 33757098  
September 14, 2007**

September 14, 2007

Mr. Gary Coulter  
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**Dam History Report  
Red Dog Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska  
PO # 1257477, Contract # RD-02-06  
URS Job No. 33757098**

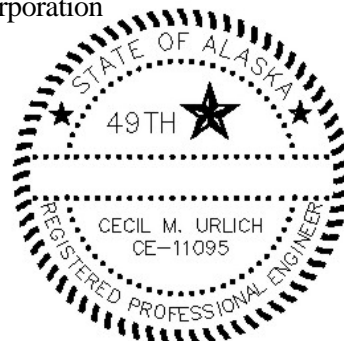
Dear Mr. Coulter:

URS Corporation is pleased to submit one copy of our report to Teck Cominco Alaska, Inc. (TCAK) on the history of the Red Dog Tailings Main Dam. The report was completed under TCAK Purchase Order No. 1257477 of Contract No. RD-02-06 dated July 25, 2004, and Change Order Nos. 002, 003, 004 and 005.

This report was prepared to provide backup information on the dam in support of the seepage, stability and conceptual design of the future raises to closure. A brief history was provided in the geotechnical report, and was intended to be an appendix to the seepage, stability, and conceptual design reports. However, it was later determined to be more effective as a stand alone report that the other reports could refer to.

We thank you for the opportunity to provide engineering support for the tailings main dam future raises to closure. Please call if you have any questions or need additional information.

Sincerely,  
URS Corporation



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## **1.0 INTRODUCTION**

The tailings main dam at the Red Dog Mine is a 182-foot high rock fill embankment with a primary seepage control system in the dam and a secondary seepage control system downstream of the dam. The mine operator, Teck Cominco Alaska, Inc. (TCAK), and SRK Consulting (Canada) Inc., are developing a mine closure plan that is based on operations to around year 2030. This will require raising the dam by 26 feet from the Stage VII-B crest elevation of 960 feet (El. 960) to a final crest at El. 986 and height of 208 feet.

In order to provide technical input to the closure plan for the tailings facility part of the mine, TCAK retained URS Corporation to complete a conceptual design of the tailings main dam at closure. In order to develop the conceptual design, URS completed a geotechnical investigation of the dam foundation for the Stage VII-B and closure configuration, a review of the construction history of the dam, and seepage and stability analyses of the dam from the Stage VII-B configuration through the future raises to closure.

This URS report describes the history of the tailings main dam in order to provide backup information in support of the seepage, stability, and conceptual design reports. A brief history was provided in the geotechnical report, and was intended to be an appendix to the seepage, stability, and conceptual design reports. However, it was later determined to be more effective as a stand alone report that to which the other reports could be referred. The work was completed under TCAK Purchase Order No. 1257477 of Contract No. RD-02-06, dated July 25, 2004, and Change Orders Nos. 002, 003, 004 and 005.

## **2.0 GENERAL SITE CONDITIONS**

### **2.1 Location and Climate**

Red Dog Mine is a zinc-lead mine in Alaska that is operated by Teck Cominco Alaska Inc. (TCAK) and owned by Northwest Alaska Native Association (NANA) Regional Corporation. NANA acquired surface and subsurface title to the resources as part of a settlement under the Alaska Native Claims Settlement Act (ANCSA) of 1971, and entered into a lease agreement with Cominco Ltd. (now TCAK) in 1982.

The mine is located in the Northwest Arctic Borough (NWAB) within northwestern Alaska near the southwestern end of the DeLong Mountains of the western Brooks Range. It is situated approximately 90 miles north of the Arctic Circle, 90 air miles northwest of Kotzebue, and about 50 miles inland from the Chukchi Sea. The mine site is located on a ridge between the Middle and South Forks of Red Dog Creek.

The tailings main dam (formerly known as the tailings dam) consists of two parts: an embankment located in an approximately west-to-east alignment across the South Fork of Red Dog Creek; and a wing wall to the southeast that extends out from the east end of the embankment. The tailings dam impounds tailings and water up the valley of the South Fork to near the saddle of the divide between the watersheds of the South Fork and Bons Creek. The dam location is shown in Figure 1.

Just below and north of the tailings main dam, the South Fork flows northwest to Red Dog Creek. Almost three miles northwest of the dam, Red Dog Creek flows into Ikalukrok Creek, which flows south and west

for 32 miles to the Wulik River. The Wulik River flows for 32 miles and discharges into the Chukchi Sea at Kivalina. A fish weir is situated across Red Dog Creek, 1.2 miles downstream of the tailings main dam.

The mine is in the Kotzebue Sound climatic subregion of the northwest part of the Alaska continental zone, an area characterized by long, severe winters and moderately warm, windy and wet summers. An average of 20 to 30 inches of precipitation falls annually at the mine, of which 7 to 10 inches is winter snow. Annual temperatures average about 15 degrees Fahrenheit (°F) and range from -60 to +85 °F.

## **2.2 Surface Conditions**

The mine is located in an area characterized by moderately sloping hills and broad stream valleys. Elevations in the mine area range from about El. 800 downstream of the tailings dam to over El. 2,900 a few miles to the east.

Bedrock outcrops and talus deposits occur on creek side slopes and surrounding hills. The area is underlain by continuous permafrost except under creek channels, including the South Fork of Red Dog Creek where the tailings main dam is located. The active layer ranges in thickness from inches in vegetated areas up to 20 feet on exposed rocky hillsides.

Vegetation in the mine area was identified in baseline studies as shrub tundra, open low shrub, dwarf shrub, cushion tundra and sedge grass tundra. The dominant vegetation in the South Fork valley of Red Dog Creek is tussock tundra consisting mainly of cotton-grass and sedges. Mat and cushion tundra communities dominated the upper slopes adjacent to the stream drainage.

The permafrost influences the watershed characteristics, including runoff, infiltration, and groundwater recharge and discharge characteristics, groundwater discharge and base flow to streams is low. However, springs have been identified that may discharge in the winter to create flow in parts of Red Dog Creek. These springs may be recharged in upland areas but could also be replenished at the spring location.

Summer low flows are sustained by near-surface storage in tundra and in the active layer above the permafrost. This is the zone where most of the hydrologic cycle and water exchange commonly occurs in small arctic tundra watersheds.

## **2.3 Drainage Conditions**

Historical topographic maps, air photos and construction records show that five pre-mine drainages flowed from the areas that are now occupied by the waste piles and mill facilities east of the tailings main dam. The drainages flowed through the area that is now occupied by the dam and into the South Fork of Red Dog Creek as shown on Figures 2 and 3. These drainages were altered by the mill site grading work during the first few years of the dam construction. The five drainages were as follows from south to north:

- Three streams drained the original mine waste pile and south mill areas, converged into the original tailings impoundment area upstream of the dam footprint, and discharged to the creek within the dam footprint.
- One inferred drainage was identified from topographic maps and air photos as a topographic low that passed through the original mill area from northeast to southwest and discharged just upstream of the dam's east abutment where the curtain wall is under construction.

- A mill site diversion berm was constructed north of the east abutment during the mill site grading to divert water from the mill site into the tailings impoundment.

The three natural surface streams had their water conveyances contained within culverts that were installed during the starter dam construction. The culverts were later replaced and relocated as a result of a mill facility expansion and development which led to a reduced capacity because of sediment accumulation in culverts and trenches, increased tailings, water surface and dam crest levels, and excavation and installation of the curtain wall for the Stage VII-B raise.

In reviewing the original site topography, an inferred drainage was identified. The drainage flowed from northeast of the tailings main dam to the east abutment. This drainage is documented in the Stage II and III construction daily reports (Dames & Moore 1989d and 1990b) by means of comments about large quantities of water being encountered during the east abutment excavation.

The mill site diversion berm is shown in the original design drawings. It was built around 1992 to divert water from the mill site into the tailings impoundment (Zigarlick 2007). It diverted surface drainage that would have flowed to a point downstream of the dam, and might now direct water to the east abutment area. The berm is now buried but may still act as a subsurface diversion to near-surface flow out of the mill area.

The five flow features were either modified or buried during the mill site development and in the present-day mill site likely serve as diverters and conveyors of surface water that is now evident along the eastern part of the dam toe. It is possible that surface runoff and near surface groundwater is being contained by the mill site diversion berm. The culverts may now be plugged with sediment or damaged from road use.

## **2.4 Tailings Operations**

The main components of the mine are an open pit for ore extraction, a mill and concentrate facility, and a tailings impoundment. Ore is mined from the open pit and transported to the mill where it is crushed to silt and fine sand-sized particles. Flotation methods are used to separate out a lead and zinc concentrate. The waste (tailings) is pumped as a solids and water mixture to the tailings impoundment.

The tailings impoundment provides storage for tailings, surface water runoff from the mill site and nearby developed areas, and surface water runoff from around the open pit that is collected at the mine water diversion dam and pumped to the impoundment. The impoundment is contained at its north end by the tailings main dam and around the rest of its perimeter by natural topography.

A tailings back dam is under construction along the north side of an overburden waste pile that is located on the saddle at the south end of the impoundment. The back dam will contain an impervious liner system that will extend from the dam crest to bedrock. The purpose of the back dam will be to contain the rising tailings and water levels and prevent tailings water from entering the Bons Creek watershed to the south.

Water is removed from the tailings impoundment by a barge-mounted reclaim pump system located on the east side of the impoundment. This water passes through a treatment plant and sand filter before being either discharged to Red Dog Creek or returned to the impoundment if discharge criteria are not met.

### 3.0 TAILINGS MAIN DAM COMPONENTS

The tailings main dam is at the north end of the tailings impoundment. It is under the jurisdiction of the Alaska Dam Safety Program, is in the National Inventory of Dams as ID# AK 00201, and is classified as a Class II (significant) hazard dam in accordance with Title 11 of Alaska Administrative Code 93.157. The dam was designed and is operated as a “zero” discharge facility with three major components:

- Tailings main dam;
- Seepage collection dam,
- Seepage pumpback system.

The major components of the dam are described in the following sections. Figure 1 is a site plan and layout of the dam. Plan views are shown of the current dam configuration (Stage VII-B) on Figures 2 and 3. The major components of the tailings main dam are shown on Figure 4.

#### 3.1 Tailings Main Dam

The tailings main dam was built in seven stages (I to VII) as shown on Figure 5. Stage VII was constructed in two stages (VII-A and VII-B). Stages I to VII-B comprise the embankment across the South Fork of Red Dog Creek. Stage VII-B also includes the curtain wall portion of the wing wall. The dam has the following major components:

- A rockfill embankment across the South Fork of Red Dog Creek.
- A rock under-drain from the Stage II downstream toe to the seepage collection pond.
- A liner system containing a high-density polyethylene (HDPE) geomembrane in the dam.
- A HDPE-lined cutoff trench along the side and below the upstream toe of the dam.
- A HDPE-lined cutoff wall filled with concrete below the cutoff trench for Stages II to VII-B.
- A rockfill buttress and stability berm on the upstream face to protect the HDPE liner.
- A coffer dam of rockfill and tailings approximately 300 feet south of and parallel to the main dam.
- A 300-foot wide tailings beach between the main dam and coffer dam.
- A coffer dam of rockfill and tailings approximately 225 feet from and parallel to the wing wall.
- A 225-ft wide tailings beach between the wing wall and coffer dam.
- A pipeline utilidor that crosses the east abutment for tailings discharge, seepage return and mine water.
- A pipe bench on the upstream dam face that supports the tailings discharge pipeline.
- A HDPE-lined curtain wall with its bottom embedded in control density fill.
- Piezometer and thermistor instrumentation in and around the dam and the wing wall.

The east end of a former tailings beach near the east abutment of the main dam was occupied by a sand filter facility. In preparation for the Stage VII-B raise and future raises, this facility was moved in 2005 to northeast of the dam, and the pipeline utilidor was moved in 2006 to east of its former position.

### **3.2 Seepage Collection Dam**

The seepage collection dam was constructed approximately 150 feet downgradient from the downstream toe of the Stage VI tailings main dam. The seepage collection dam was built in one stage of construction when the starter dam for the tailings main dam was built in 1988. It has the following major components:

- A rockfill embankment across the South Fork of Red Dog Creek.
- A 100-mil high-density polyethylene (HDPE) liner on the upstream face of the dam.
- A HDPE-lined cutoff trench extending up the east abutment.
- A HDPE-lined cutoff wall filled with concrete below the cutoff trench.
- A partly lined spillway on the east abutment between the dam and cutoff trench.
- A rock-filled drain filling the remaining seepage collection pond area.
- Piezometer instrumentation in and around the dam.

The seepage collection pond is confined at its downstream end by the seepage collection dam and at its upstream end by the termination of the rock under-drain from the Stage II of the tailings main dam.

### **3.3 Seepage Pumpback System**

A seepage pumpback system was installed at the upstream end of the seepage collection pond and within the impoundment area of the seepage collection dam. It consists of the following major components:

- Three precast concrete pumpback chambers in the seepage collection pond.
- Three vertical turbine pumps, one in each pumpback chamber.
- A manifold from the pumps to a 14-inch diameter HDPE return pipeline.
- A well and pump at the toe of the seepage collection dam to capture seepage from the pond.
- An 8-inch diameter HDPE pipeline from the well pump to the seepage collection pond.
- A 14-inch diameter HDPE return pipeline from the manifold to the tailings impoundment.
- A return pipe discharge at the upstream face of the tailings main dam near its east abutment.
- A single Doppler flow meter on the return pipeline that measures the pumpback flow.

The pumpback system regulates the water levels in the collection pond for summer and winter conditions. The seepage collection pond levels are kept low during the summer to minimize the potential for seepage through the seepage collection dam, and are kept higher in the winter to reduce the potential for freezing.

## **4.0 TAILINGS MAIN DAM CONFIGURATION**

The tailings main dam was built in seven stages of raise by the method of downstream construction (Stage I to Stage VII-B) as shown on Table 1. Stage I was the starter dam. Stage VII is the current configuration that was built in sequences of VII-A and VII-B.

The maximum dam heights on Table 1 are the differences between the crest elevation and the elevation of the natural creek bed at the downstream toe. The difference between the maximum dam height or increase

in height for two successive raises is typically larger than the raise height because the dam toe extends downstream to a lower elevation.

The design of the tailings main dam included primary and secondary seepage control systems to support a “zero” seepage loss criteria (Dames & Moore 1986). The primary controls were built either into, or directly connected to, the main dam embankment. The secondary controls were the seepage collection dam and pumpback systems.

**Table 1 - Tailings Main Dam Configuration and Construction History**

Dam Stage	Year of Construction	Raise Height (ft)	Dam Crest El (ft)	Toe El <sup>1</sup> (ft)	Max. Dam Height <sup>2</sup> (ft)	Crest Width (ft)	Crest Length (ft)
Stage I (Starter Dam)	1988	-	865	790	75	42	1088
Stage II	1989	25	890	788	102	42	1352
Stage III	1990	20	910	786	124	42	1776
Stage IV	1991	15	925	784	141	42	1917
Stage V	1993	15	940	782	158	42	2175
Stage VI	1993	10	950	778	172	52	2427
Stage VII-A	2003/2004	5	955	778	177	52	2550
Stage VII-B	2005 to 2007	5	960	778	182	52	3457

Note: <sup>1</sup> Lowest elevation of the natural creek bed on the upstream or downstream toe of the dam

<sup>2</sup> Dam height is the maximum vertical distance from the natural bed of the creek at the downstream toe.

<sup>3</sup> References: (Dames & Moore, 1990a&b, 1991a&b, 1992, 1993a&b).

<sup>4</sup> Stage VII-B crest length includes the 2640 feet along the original, main dam alignment plus the wing wall crest length from its intersection at the east abutment to its termination point (817 ft).

## 5.0 DESIGN AND CONSTRUCTION HISTORY

The design and construction history of the tailings main dam is described in two phases: the originally designed and constructed Stages I to VI, and the recently designed and constructed Stages VII-A and B. The discussion below is illustrated by a series of photos that are presented after the figures, and by samples of the geomembrane and geotextile materials in plastic envelopes after the photos.

### 5.1 Stages I to VI

Stages I to VI of the tailings main dam were designed by Dames and Moore (now URS) for Cominco Alaska (now TCAK) in the mid to late 1980s and constructed in phases by Green Alaska, Alaska Interstate Construction (AIC) and Cominco Alaska between 1988 and 1993. The design included a cutoff trench to bedrock, a cutoff wall into bedrock, a liner system in the dam and tailings beach for seepage control. Investigation, design and construction reports and other relevant correspondence are referenced.

The starter dam construction included a temporary 36-inch pipe along the deepest part of the original creek channel to divert runoff past the dam area. Ice-rich soils were removed from the dam footprint. A 12-inch perforated HDPE pipe was placed as a toe drain along the line of deepest excavation in the cutoff trench and aligned perpendicular to the creek.



At the intersection of the toe drain and the original creek channel, two 10-inch HDPE riser pipes were teed off the toe drain five feet apart and extended up the dam to the crest. The purpose of the riser pipes was to provide a means of removing any water that might collect in the toe drain by inserting a submersible pump into one of the pipes.

The starter dam was constructed of rock fill with a liner system over the upstream face of the dam. The liner was keyed into a cutoff trench about 15 feet deep, extended below ice-rich soils and highly weathered shale. The cutoff trench was filled with rock fill. A hole was cut in the liner system for the 36-inch diversion pipe and a boot was fabricated to provide a seal between the pipe and geomembrane. A rock buttress was placed over the liner system to protect it from ice and weathering.

For the starter dam construction, the ice-rich soils in the starter dam footprint were removed and the starter dam was built on moderately weathered bedrock. Improved foundation conditions were encountered in the Stage II to VI footprints. Therefore, the Stage II to VI raises, except the cutoff system, was built directly on the native ground encountered.

The starter dam was completed in July 1988. The diversion pipe was plugged with grout in September 1988. As the tailings impoundment started to fill with water, more seepage was observed flowing into the seepage collection pond than was estimated during the design. Milling was not scheduled to start in time for tailings to be placed ahead of the rising water to help reduce the seepage. Methods to reduce seepage were developed in the winter of 1988 and 1989 for implementation in 1989.

Cominco Alaska and Dames & Moore developed two methods of reducing seepage. These consisted of placing a blanket of shale in the water over the cutoff trench upstream of the starter dam; and installing a grouted HDPE geomembrane cutoff wall below the cutoff trench for the future Stage II to IV raises. The same cutoff wall system was designed for the seepage collection dam. It was decided that the Stage V to VI design would rely on a tailings beach to control seepage with no cutoff wall.

The Kivalina shale blanket was installed in late 1988 over the seepage cutoff trench behind the starter dam in accordance with Dames & Moore (1988b) recommendations. It was not considered feasible at the time to remove the impounded water and construct a deeper cutoff trench or wall in dry conditions. The blanket was placed underwater by end-dumping to a thickness of 31 feet and for a distance of about 50 feet back from the upstream crest of the cutoff trench.

During the winter of 1988/1989, a seepage cutoff wall was designed for the Stage II to IV raises and the seepage collection dam. The wall was built by excavating a one-foot wide vertical cut from the bottom of the cutoff trench to at least four feet deep to penetrate all ice lenses and blast-damaged rock that could be excavated. HDPE geomembrane was installed vertically along the centerline of the cut, embedded in grout, and connected to the HDPE geomembrane in the cutoff trench.

Up to 12 feet of fill that was mostly Kivalina shale was placed in the east part of the Stage II to VI area between May and August 1988 while the starter dam was being built. In October 1988, most of the fill in the Stage II area was removed to improve dam stability. A test pit exploration and subsequent analyses showed that the Stage III to VI raises would be stable if the fill was left in place, but could consolidate. Some fill was removed from the Stage III to VI area to lower the consolidation potential and increase stability.

During the starter dam construction in 1988, a road was pioneered down the east side of the Stage II to VI footprint area to provide an access road to the seepage collection pond, as shown on Figure 2. Daily field reports for the starter dam construction (Dames & Moore 1988c) indicate that the access road was



constructed of several materials including highly weathered Kivalina shale. This material was compacted by the heavy equipment and vehicle traffic, and would have developed into a low permeability zone.

The Stage II raise and the cutoff walls for this raise and for the seepage collection dam were constructed in 1989. The schedule for constructing Stage II and all subsequent raises was driven by water management requirements and not by tailings production. In general all raises were constructed two to six years ahead of the original schedule. All raises were constructed in the following sequence:

- Excavation of ice-rich soil along the abutments of the dam.
- Extension of toe drain along the cutoff trench excavation in the abutments.
- Placement of random rock fill to construct the embankment.
- Extension of the instrumentation piping along with the rockfill placement.
- Extension of the two up-slope riser pipes through the upstream face of the dam.
- Installation of the bedding and geotextile components of the liner system.
- Excavation of the cutoff trench and cutoff wall along the upstream toe.
- Anchoring of the geomembrane into the cutoff wall with concrete.
- Placement and welding of geomembrane to the previously installed geomembrane.
- Placement of the rock buttress to protect the liner system.

The Stage III and IV cutoff walls were built at the same time as the raises. An additional seepage control measure was installed in 1991 for the Stage IV raise; it consisted of a beach of Kivalina shale beach in the area of the east abutment. The beach extended several hundred feet back into the impoundment.

Pneumatic piezometers and thermistors were installed in the tailings main dam and seepage collection dam after their initial construction in 1989. The location of the original instruments and conduits are shown on Figure 6. The piezometers were replaced during the mid 1990s by vibrating wire piezometers in the main dam and open well screens in the seepage collection dam. The vibrating wire piezometers were used because they were more reliable in arctic conditions, could be set up for automated downloading using a data logger, and contained built-in thermistor points.

Dames & Moore (1990a&b, 1991a&b and 1993a&b) provided full-time resident engineering during construction of the Stage I to IV raises and the seepage collection dam, and part-time resident engineering for the Stage V and VI construction.

## **5.2 Stage VII-A and VII-B**

A ten-foot Stage VII raise of the tailings main dam was planned in the mid-1990s to increase the dam height to 182 feet at crest El. 960 (Dames & Moore 1995a). URS (2002a and 2002b) completed stability analyses using geotechnical data from earlier dam (Dames & Moore 1986) and mill (EBA 2000) site investigations, and concluded that Stage VII could have a steeper slope than Stage VI. Therefore, the Stage VII design concept was to widen the downstream slope starting part way up the Stage VI slope.

The ten-foot Stage VII concept was changed in 2003 to two five-foot raises (VII-A and VII-B) because of construction window time constraints. Stage VII-A would raise the dam to 177 feet high at crest El. 955. Stage VII-B would raise the dam to 182 feet high at crest El. 960. The design included extending the seepage cutoff wall from its Stage IV west and east terminations as an added seepage control because a tailings beach could not be continually maintained while tailings were discharged away from the dam.

The embankment part of Stage VII-A was designed in 2003 using geotechnical data from the earlier tailings dam and mill site investigations. The raise was constructed by AIC and TCAK from September 2003 to February 2004 (URS 2004). Because of time constraints, the cutoff wall part of Stage VII-A was deferred to the Stage VII-B construction.

The Stage VII-B design was completed in 2004, and revised in 2005 and 2006. The 2004 design used geotechnical data from the earlier tailings dam and mill site investigations. The revised 2005 and 2006 design used geotechnical data from a geotechnical investigation that was completed in 2005 for finalizing the Stage VII-B design and developing conceptual designs of future raises to closure (URS 2007a, 2007b, 2007c).

The Stage VII-B design consisted of a 5-foot raise to El. 960, cutoff wall extensions from the Stage IV west and east ends to the Stage VII-B cutoff trench, and a wing wall to the southeast from the east abutment to protect the mill facility from the rising tailings water (URS 2006a). The key component of the Stage VII-B wing wall is a deep curtain wall tied into the east end of the cutoff wall to provide a continuous sub-surface barrier for seepage control.

Stage VII-B construction was conducted from July to November 2005, June to October 2006, and April to August 2007. The construction was performed by TCAK and Kobuk River/AIC, LLC (KR/AIC). TCAK constructed coffer dams around the west and east cutoff wall work areas so that the excavation to the Stage IV cutoff wall terminations could be kept dry during construction.

The 2005 construction included a 5-foot raise along the western-most 2,200 feet of the dam, a western extension of the cutoff wall from the west end of the Stage IV cutoff wall termination to the Stage VII-B cutoff trench, and relocation of the sand filter facility as well as some pipelines from the east abutment area. The raise was not completed to the east abutment because the pipeline utilidor relocation was delayed until the Culvert Raise/Pipe Bench Lining Project was implemented in 2006.

The 2006 construction included a temporary relocation of the pipeline utilidor to the west to allow the raise to continue to the east, a 5-foot raise of the eastern-most 440 feet of the dam, an eastern extension of the cutoff wall from the east end of the Stage IV cutoff wall termination to the Stage VII-B cutoff trench, a tie-in of the east end of the cutoff wall to the start of the curtain wall part of the wing wall, the first 80 feet of the curtain wall towards the southeast, and the relocation of the pipeline utilidor to the east.

In 2006, new piezometers and thermistors were installed at the downstream toe of the tailings main dam and on both abutments along the planned future alignment of the future raises to closure, including a wing wall extending from the right abutment. URS reviewed the historical instrumentation data collected and the locations of existing and functioning instrumentation to select the types and locations of new instrumentation. Locations of the instrumentation are shown on Figures 2 and 3.

In 2006, TCAK constructed the Culvert Raise/Pipe Bench Lining Project. The pipeline utilidor was moved to the east by raising the road on the east abutment 5 feet for a distance of about 200 feet north of the Stage VII-B crest, raising the culverts below the road 5 feet, and constructing a pipe bench from about 800 feet north of the Stage VII-B crest to the crest. The utilidor has eight pipelines from east to west: three for mine water diversion, one for water treatment plant overflow, one for seepage pumpback, two for non-compliance reclaim water from the new sand filter, and one for gravity tailings overflow.

The relocated pipelines were placed along this new corridor over a secondary containment system consisting of HDPE geomembrane. South of the Stage VII-B crest, the pipelines continue to their

discharge points in the tailings impoundment. The secondary containment extends for a distance of 15 feet south of the centerline of the Stage VII-B crest.

In 2007, the Stage VII-B curtain wall component of the wing wall was extended 637 feet out towards the southeast from its 2006 termination for a total curtain wall length of 717 feet. Construction of the curtain wall included excavating soft and loose soils to a stable work bench, trenching through ice-rich soils to competent bedrock, installing curtain panels, extending the geomembrane to El. 960 and backfill to El. 960. On August 25, 2007, construction of Stage VII-B was completed.

For the Stage VII-B raise, each construction season was terminated when it was determined that efficiency and quality would be compromised because of deteriorating weather conditions. The terminations were winterized at the end of each season by covering them with soil, and then opened up at the start of the following season.

URS provided full-time construction quality assurance (CQA) field management for Stages VII-A and B. NANA/Dowl completed the CQA field monitoring and soils laboratory testing under the direction of URS for Stage VII-A in 2003 and for Stage VII-B in 2005 and 2006. URS provided the CQA field monitoring, geomembrane and soils laboratory testing for Stage VII-B in 2007.

## **6.0 CONSTRUCTION MATERIAL TYPES**

The dam embankment, liner system and drainage system are constructed of eight types of rock and soil materials (Soil Types 1 to 8) as specified by Dames & Moore (1988a). Soil Type 9 was specified by URS for use as backfill upstream of the curtain wall in 2007. The soil types are described below.

### **6.1 Soil Type 1 – Random Rockfill (24-inch)**

Soil Type 1 was used as rockfill in Stages II to VII-B, and the protective buttress in Stages I to VII-B. It consists of moderately weathered to fresher select chert, shale and sandstone, or mine waste. It is well-graded and consists primarily of gravels and cobbles with a maximum diameter of 24 inches, less than 25 percent by weight passing the No. 200 sieve, and less than 5 percent ice by volume.

Ice content variations were allowed in Soil Type 1. For Stages I to VI, an average ice content of 12 percent by volume with less than 5 percent by weight passing the No. 200 sieve was allowed in this material. For the Stage I to VI buttress, the average ice content was allowed to be 15 percent by volume in material with less than 20 percent by weight passing the No. 200 sieve. For Stage VII, the average ice content was allowed to be 10 percent if there was less than 5 percent passing the No. 200 sieve.

### **6.2 Soil Type 2 – Rockfill (24-inch)**

Soil Type 2 was used as rockfill in the Stage I starter dam, but was not used in the raises. It consists of slightly weathered to fresh select chert carbonate and sandstone from the mill site area. Unlike Soil Type 1, Soil Type 2 does not contain mine waste. Soil Type 2 is well-graded and consists primarily of gravels, cobbles or blasted rock with a maximum diameter of 24 inches, less than 15 percent by weight passing the No. 200 sieve, and less than 5 percent ice by volume.

An ice content variation was allowed for Soil Type 2. The average ice content was allowed to be 12 percent by volume in material with less than 5 percent passing the No. 200 sieve.

### **6.3 Soil Type 3 – Processed Select (3-inch)**

Soil Type 3 was used as the filter drain material between the two geotextiles. For Stages I to VI, it consists of crushed and screened slightly weathered to fresh chert carbonate and sandstone from the mill area, and alluvium and colluvium from the creek bed. For Stage VII-A and B, Soil Type 3 consists of blasted and screened fresh barite, chert and shale from the Siksikpuk formation in the DD2 Quarry.

Soil Type 3 is a well-graded aggregate with a maximum particle size of 3 inches and less than 5 percent ice by volume. In Stages I to VI, Soil Type 3 contains less than 5 percent by weight passing the No. 200 sieve. For the Stage VII raises, Soil Type 3 contains less than 10 percent passing the No. 200 sieve.

Ice content variations were allowed for Soil Type 3. For Stages I to VI, the average ice content was allowed to be 12 percent by volume if there was less than 5 percent passing the No. 200 sieve. For the Stage VII raises, the average ice content was allowed to be 10 percent by volume if there was less than 5 percent passing the No. 200 sieve.

### **6.4 Soil Type 4 – Processed Select (1-inch)**

Soil Type 4 was used as the bedding and cover material for the HDPE geomembrane. For Stages I to VI, it consists of crushed and screened slightly weathered to fresh chert carbonate and sandstone from the mill area, and alluvium and colluvium from the creek bed. For Stage VII-A and B, Soil Type 4 consists of blasted and screened fresh barite, chert and shale from the Siksikpuk formation in the DD2 Quarry.

Soil Type 4 is a well-graded aggregate with a maximum particle size of 1-inch and less than 5 percent ice by volume. In Stages I to VI, Soil Type 4 contains less than 5 percent by weight passing the No. 200 sieve. For the Stage VII raises, Soil Type 4 contains less than 20 percent passing the No. 200 sieve.

Ice content variations were allowed for Soil Type 4. For Stages I to VI, the average ice content was allowed to be 12 percent by volume if there was less than 5 percent passing the No. 200 sieve. For the Stage VII raises, the average ice content was allowed to be 10 percent by volume if there was less than 5 percent passing the No. 200 sieve.

### **6.5 Soil Type 5 – Rock Drain and Riprap**

Soil Type 5 was used in the rock drain component of the drainage system and the seepage collection pond. It has not been used in the dam raises. Soil Type 5 consists of fresh processed chert-carbonate with at least 85 percent of the material between 6 and 18 inches in size, less than 15 percent of the material smaller than 6 inches in size, and less than 10 percent ice by volume. Up to 12 percent ice by volume was allowed at the discretion of the geotechnical engineer.

### **6.6 Soil Type 6 – Random Rockfill (12-inch)**

Soil Type 6 was used as rockfill over the rock drain and pumpback chambers in the seepage collection system. It has not been used in the dam raises. Soil Type 6 consists of moderately weathered to fresher chert, shale and mudstone from the mill area and mine waste. It is well-graded material consisting primarily of gravels and cobbles with a maximum particle size of 12 inches, less than 25 percent by weight passing the No. 200 sieve, and less than 5 percent ice content by volume.

An ice content variation was allowed for Soil Type 6. The average ice content was allowed to be 12 percent by volume in material with less than 5 percent passing the No. 200 sieve.

#### **6.7 Soil Type 7 – Transition Rockfill (12-inch)**

Soil Type 7 was used in Stages I to VII as the transition rock fill material in the liner system to protect the lower geotextile from soil Types 1 and 2, rockfill. Soil Type 7 is either a slightly weathered to fresh select chert-carbonate material, sandstone, or non-mineralized mine waste. The material is well-graded consisting primarily of gravels and cobbles with a maximum particle size of 12 inches, less than 15 percent passing the No. 200 sieve, and less than 15 percent ice by volume.

An ice content variation was allowed for soil Type 6. The average ice content was allowed to be 10 percent by volume in this material with less than 5 percent passing the No. 200 sieve.

#### **6.8 Soil Type 8 – Kivalina Shale (Select Finer Fraction)**

Soil Type 8 was used as the seepage control blanket behind the Stage I starter dam and Stage IV east abutment area. Soil Type 8 was proposed for use as backfill upstream of the Stage VII-B curtain wall but was later replaced for this purpose with soil Type 9. It is a fine-grained moderately to highly weathered shale from mine waste or the overburden stockpile south of the tailings impoundment. Soil Type 8 consists of well-graded aggregate with a predominant particle size of 1 inch, more than 15 percent passing the No. 200 sieve, less than 15 percent water content by weight, and no visually detectable ice.

A maximum particle size variation was allowed for Soil Type 8 for the Stage VII-B backfill behind the curtain wall in 2006. The variation was a maximum particle size of 3 inches with less than 10% of the particles greater than 1 inch in size, and material in direct contact with the curtain wall to have a maximum particle size of 1 inch.

#### **6.9 Soil Type 9 – Random Mine Waste Fill**

Soil Type 9 was specified during the Stage VII-B construction in 2006 as mine waste that can be used as fill upstream of the curtain wall. The use of this material was restricted to the area upstream of the curtain wall because it is mine waste with higher metals content than is allowed in the dam downstream of the liner. The source of Soil Type 9 was mine waste that was broken down into Types 9A, 9B and 9C during the 2006 Stage VII-B construction season.

Soil Type 9A is silty gravel and sand with a maximum dry density of about 160 pounds per cubic foot (pcf), about 10 percent of its particles greater than 3 inches in size, and less than 17 percent passing the No. 200 sieve. It was used upstream of the curtain wall but not in contact with the panels.

Soil Type 9B consists of a silty gravel with sand and has a maximum dry density of over 200 pcf, and maximum particle size of about one inch. It was used upstream and adjacent to the panels to protect them from the risk of being punctured by the larger Type 9A material.

Soil Type 9C consists of silty gravel with sand with a particle diameter less than one inch. It is a 50/50 blend of Soil Types 4 and 9B, and has a maximum dry density of about 168 pcf. Although it is a 50/50 blended material it was used exclusively upstream of the curtain wall.

During the 2007 construction of Stage VII-B, the random mine waste fill upstream of the curtain wall was collectively referred to as Type 9. According to the field sieve analysis, the Type 9 fill used was representative of Type 9A.

## **7.0 PRIMARY SEEPAGE CONTROL SYSTEM**

### **7.1 Primary Seepage Control Components**

The primary seepage controls in the tailings main dam include the following components:

- Liner system over the entire upstream face of the dam, protected by a rock buttress, and continuing down to a cutoff trench to prevent seepage through the dam.
- Cutoff system consisting of a cutoff trench and a cutoff wall along the upstream toe of the dam to reduce seepage under and around the dam to Red Dog Creek.
- Curtain wall system consisting of a curtain wall embedded in a trench along the wing wall alignment to reduce the potential for seepage under the wing wall toward the mill facility.
- Drainage system consisting of a perforated pipe toe drain and a main pipe and rock drain under the dam in the original creek channel to collect seepage from within and under the dam.
- Tailings management by beaching tailings along the upstream face of the dam and thereby keeping the impounded water away from the dam.
- Riser pipe extending up the dam from the toe drain that can be used to lower the water level in the dam if piezometers indicate high water levels.

It should be noted that the original Stage I to VI designs included all of the above components except that the seepage cutoff system included only the cutoff trench and not the cutoff wall.

### **7.2 Evolution of Seepage Control Components**

During the starter dam construction and Stage III tailings dam operations, considerably more seepage was observed at the downstream toe of the tailings main dam than was expected. In order to reduce this seepage, additional primary seepage controls were designed and constructed as follows:

- A blanket of Kivalina shale over the Stage I part of the cutoff trench in 1989 to further reduce seepage from occurring under and around the starter dam.
- A cutoff wall under the Stage II to IV part of the cutoff trench from 1989 to 1993 to further reduce seepage during the first years of mining and tailings operations.
- A blanket of Kivalina shale in the east abutment area as part of the Stage IV construction in 1991 that extended several hundred feet into the impoundment from the abutment.
- Full reliance of the tailings beach along the upstream face of the dam for seepage control at the Stage V level of the dam and all subsequent stages of dam construction.

After the starter dam was constructed, Dames & Moore (1989a,b,c) and EBA Consultants (1989 and 1990) completed seepage and thermal analyses and concluded that the primary means of seepage control would be a cutoff wall for Stages II to IV, and a tailings beach for Stage V and later stages (Cominco Alaska, 1989). A cutoff wall was not installed in the starter dam because the impounded area had filled



with water and tailings production was starting. Therefore, the Kivalina shale blanket was placed to reduce seepage.

During Stage V operations, a tailings beach was developed and the seepage rate decreased, but the beach became a source of dust. A dust control system was constructed consisting of eight rockfill berms on the beach extending out from the dam; each berm was 500 to 700 feet long and 200 to 250 feet apart. This system was difficult to manage along with tailings discharge operations, and became inundated as the tailings water level rose.

The Stage VII-A and B raise designs recognized the need for more primary seepage controls. These consisted of a tailings beach developed by building a coffer dam on tailings and filling the space between it and the main dam with tailings, and extensions of the cutoff wall from its Stage IV terminations through all future raises. As a result, the following additional seepage controls were constructed in 2005 and 2006:

- A 300-foot wide tailings beach parallel to the dam crest and confined by a rockfill coffer dam.
- A cutoff wall extension to the west from the previous Stage IV cutoff wall west termination.
- A cutoff wall extension to the east from the previous Stage IV cutoff wall east termination.

The secondary seepage controls consisted of the seepage collection dam and seepage pumpback system located immediately downstream of the toe of the tailings main dam as described in Section 8.0.

### 7.3 Liner System

The main method of seepage control through the tailings main dam is a liner system that was placed on the upstream face of the dam and protected with a rockfill buttress. The liner system was built into the starter dam and extended up all raises through to Stage VII-B. The same method of liner installation was used for all raises with a continuity of installation personnel from the starter dam to Stage VII-B.

The key component of the liner system is a HDPE geomembrane seepage barrier. Other components of the liner system include geotextiles and graded soil and rockfill zones that protect the geomembrane and provide drainage for any water that may leak through the geomembrane. The components of the liner system from bottom to top are as follows, with the purpose of each shown in parentheses (see Figure 5):

- Soil Type 1 - Random Rockfill (24-inch minus rock to protect the liner system)
- Soil Type 7 - Transition Rock (12-inch minus rock to protect the geotextile from Soil Type 1)
- Type 1 Geotextile - 10 oz/yd<sup>2</sup> non-woven strengthening geotextile between Soil Types 7 and 3
- Soil Type 3 - Filter Drain (3-inch minus rock and soil)
- Type 2 Geotextile – 16 oz/yd<sup>2</sup> non-woven separation geotextile between Soil Types 3 and 4
- Soil Type 4 – Liner Bedding (1-inch minus rock to protect the geomembrane)
- 100 mil thick HDPE Geomembrane (provides the seepage barrier part of the liner system)
- Soil Type 4 - Liner Cover (1-inch minus rock to protect the geomembrane from Soil Type 1)
- Soil Type 1 - Protective Buttress (24-inch minus rock to protect the liner system).

The bottom of the new geomembrane for each raise was welded to the top of the geomembrane in the previous raise and to the top of the geomembrane part of the cutoff wall outside the previous liner system. The top of the geomembrane in each raise was buried in an anchor trench along the crest of the raise so it could be recovered for the next raise. The east end of the geomembrane was connected to the curtain wall.

The geomembrane was placed in panels from top to bottom so that most seams were vertical. This minimized the amount of horizontal welding, except for connection welds to the previous panels. During the construction of each new raise, the top of the geomembrane of the previous raise was exposed by excavation, and the geomembrane and the seam welds were observed to be in excellent condition.

The geomembrane installation activities included cutting, rolling, deploying, placing, seaming, testing, repairing and documenting. Geomembrane rolls were lifted by backhoe, placed near a geotextile mat, rolled onto the geotextile, and cut to the required panel length. The panels were re-rolled and taped, moved to the crest above their planned location, unrolled down the slope, placed alongside the adjacent new panel and lower previous panel, held down with sandbags, and welded to adjacent panels.

The geomembrane panels were seamed by fusion and extrusion welding. All welds were tested for leaks by either air pressure or vacuum test methods. CQA and CQC personnel inspected the testing and watched for pressure losses or bubbles that would indicate leaks in the seam. Any leaks that were found were repaired.

In a limited number of instances, such as the vertical installation of the curtain wall, a seam location was inaccessible for proper testing or multiple wrinkles in the geomembrane made it difficult to use the air pressure test. In this case, a double extrusion weld bead was placed as a redundancy.

## **7.4 Cutoff System**

The original Stage I to VI design of the tailings main dam included a seepage cutoff system along the upstream toe of the dam that was designed as a trench through ice-rich soils and highly weathered shale, and into more competent and less weathered shale (Dames & Moore 1986, 1987a). The downstream slope of the trench was to be lined with the bottom extension of the geomembrane on the upstream face of the dam.

The Stage I cutoff trench excavation and site preparation work in 1988 showed that competent and less weathered shale was deeper than expected. The cutoff trench was built deeper than designed, and more material had to be removed to reach competent rock and maintain design side slopes. After the starter dam and cutoff trench were constructed, the tailings impoundment started to fill with water and more seepage occurred than what was originally estimated. To mitigate this without having to drain the impoundment, the Kivalina shale blanket was placed over the cutoff trench, which resulted in an immediate reduction of seepage.

Dames & Moore (1986) assumed that the maximum seepage from the impoundment would occur when water filled behind the starter dam with no tailings. Rock up to 50 feet deep was assumed to be non-frozen with average hydraulic conductivity of  $1 \times 10^{-5}$  cm/s, although higher conductivities of about  $1 \times 10^{-4}$  cm/s were recorded. Assuming 30 feet of water behind the dam, a seepage flow rate of 1 to 10 gallons per minute (gpm) was estimated and increased by 10 to 20 gpm to account for holes in the geomembrane.

Seepage was first observed in the downstream area of the starter dam two weeks after construction was completed when there was about 29 feet of water behind the dam. The seepage rate was measured to be about 450 gpm. Dames & Moore considered several possible seepage paths that included the bedrock to geomembrane interface, bedrock fractures and thaw zones, geomembrane holes or seam breaks, and the zone around the diversion pipe. Measures to reduce seepage considered all possible paths.

It was decided that a Kivalina shale blanket would be placed over the seepage cutoff trench in the creek bed for added seepage control, as it was not feasible to drain the impoundment and construct a



geomembrane/grout type of wall. The blanket was placed underwater in late 1988 by end-dumping to a thickness of 31 feet and about 50 feet back from the upstream crest of the cutoff trench. Measurements showed that the blanket reduced the seepage to approximately 100 gpm with 25 feet of water stored.

Designs of future raises to the tailings main dam were improved by adding a geomembrane/grout cutoff wall in Stages II to IV and developing a tailings beach for Stages V and VI. For Stages II to IV, the cutoff system design was changed to limit the trench depth, reduce the amount of excavation, and extend a cutoff wall from the bottom of the trench to more competent and less weathered shale. The reason for this was to minimize the size of trench excavation to reach the more competent and less weathered rock.

The change of design involving the Kivalina shale blanket for Stage I, the cutoff wall design for Stages II to IV, and the reliance on a tailings beach with no cutoff wall for Stages V and VI, were developed following inspections of the Stage I excavations by senior Dames & Moore geotechnical design engineers in August 1988, meetings with staff from Cominco, Parsons, and Green Construction, and design review meetings and correspondence with senior review engineers from EBA and Klohn Leonoff.

The modified Stage II to IV cutoff system included two components: a cutoff trench about 30 feet below the original ground surface; and a cutoff wall below the trench. The cutoff wall consisted of a vertical geomembrane in a slot cut along the middle of the trench, encased in grout. The cutoff wall extended to a depth of either 4 feet, or competent bedrock with less than 10 percent ice content, whichever was greater (Dames & Moore 1989a, b, and c). The Stage II to IV cutoff system was installed from bottom to top as follows:

- 100 mil thick HDPE Geomembrane to provide the seepage barrier part of the cutoff wall.
- Grout encasement in vertical wall to secure the bottom of the geomembrane to the bedrock.
- Soil Type 4 -Liner Cover (1-inch minus) soil to protect the geomembrane from Soil Type 1.
- Soil Type 1 - Random Rockfill (24-inch minus) rock of which the dam is constructed.

During Stage IV construction, the proximity of the mill facilities to the east abutment resulted in an evaluation of alternate cutoff concepts because of potential shoring needs for cutoff wall construction. An EBA (1990) thermal analysis concluded that a tailings beach would prevent thaw from penetrating into the abutment at the top of the dam, and would preserve permafrost in the abutment. Therefore, a cutoff wall was not included in the Stage V and VI raises, but a cutoff trench was maintained for redundancy.

The Stage V and VI raises subsequently had cutoff walls added to them as part of the Stage VII raise construction. As a result, a continuous cutoff wall now extends from Stage II through VII-B, and the east end of the Stage VII-B cutoff wall is tied into the northwest end of the curtain wall.

## **7.5 Curtain Wall System**

The future raises to closure of the tailings main dam includes a wing wall that extends out from the east abutment of the embankment towards the southeast. The wing wall is required to protect the mill facilities from the rising tailings and water in the tailings impoundment. The seepage barrier part of the wing wall includes a curtain wall that was constructed as part of the Stage VII-B raise.

The curtain wall was connected to the cutoff wall at the right abutment of the embankment where the future raises of the embankment will transition to the wing wall and the dam will turn from a west-east alignment along the embankment crest to a northwest-southeast alignment along the wing wall crest. In August 2007, the curtain wall construction was completed for a length of 717 feet out from the right abutment of the embankment.

The main components of the curtain wall are a “GSE Curtain Wall Interlock” system of vertically-placed 20-foot wide interlocking HDPE geomembrane panels with the bottom parts of the panels embedded into bedrock by means of controlled density fill (CDF). The construction sequence was as follows:

- Excavate less competent soils to form a work bench of more competent soils
- Trench from the work bench down to competent bedrock
- Dewater the excavated work bench and open trench as needed
- Deploy 20-foot wide HDPE geomembrane panel with interlocking edges and install the hydrophilic seal within the interlocking channel
- Connect geomembrane panel onto support frame and suspend with a crane
- Insert interlocking geomembrane panel vertically into the trench
- Pour low-slump, CDF bulkheads in trench at the leading edge on both sides of panel
- Pour CDF backfill concurrently in the bottom of the trench to top of bulkhead
- Place Soil Type 4 backfill in trench concurrently on both sides of panels
- Weld regular HDPE geomembrane sheets along the top of the panels allowing for a minimum of 3 ft of additional length above EL. 960 for anchoring and future retrieval
- Cut the HDPE geomembrane extensions allowing for a minimum of 3 ft excess for liner anchoring at the Stage VII-B crest at El. 960
- Place Soil Type 7 downstream of Soil Type 4 to the Stage VII-B crest at El. 960
- Place Soil Type 9 fill upstream of Soil Type 4 to El. 960
- Anchor and protect the geomembrane with a layer of geotextile above and below the geomembrane at El. 960 in preparation for Stage VIII.

Critical aspects of the curtain wall construction that required CQA scrutiny, judgment and decision were the depth of trench excavation through ice-rich soil and rock and fractured rock to competent ice-free rock, dewatering of the trench required to maintain stable side slopes and prevent sloughing of the slopes, and embedment of the interlocking geomembrane panels and CDF into bedrock along the trench bottom.

## **7.6 Drainage System**

The tailings main dam includes an internal drainage system at the base of the dam downstream of the liner and seepage cutoff systems. The purpose of the drainage system is to collect any seepage from within and under the dam and convey it to the seepage collection pond in order to maintain a low phreatic surface in the dam. The drainage system consists of four components from upstream to downstream as follows:

- A toe drain along the deepest part of the cutoff trench
- A rockfill layer under the Stage I starter dam
- A blanket underdrain in the creek channel from the starter dam to the seepage pond
- A rock bench that covers the blanket drain downstream of the existing dam footprint.

The toe drain consists of perforated HDPE pipe along the line of deepest excavation in the cutoff trench and is seated in the bottom of the liner bedding. It extends along the toe of the upstream slope of the dam and downstream of the HDPE geomembrane. The pipe is 12-inch diameter in Stages I to III and 10-inch diameter in Stages IV to VI. It manifolds to the riser pipes and discharges to the rockfill layer.

The rockfill layer is Soil Type 2 that has the same maximum size as Soil Type 1, but fewer fines. The rockfill was placed over bedrock under the footprint of the starter dam to replace ice-rich soils that were excavated for the starter dam foundation. It is basically part of the starter dam that was also built of Soil Type 2, and connects to the blanket drain. It extends approximately 320 feet along the original creek channel and 1,200 feet across the valley.

The blanket underdrain is Soil Type 7 and extends along the original creek channel from the downstream toe of the starter dam, and discharges to the rock drain of the seepage collection pond. It is approximately 750 feet long, 50 feet wide and 6 feet deep. From 25 feet to 50 feet upstream of the pumpback chambers, the blanket drain width narrows from 50 feet to about 12 feet and continues around the west side of the pumpback chamber building.

The rock bench is Soil Type 5. It covers the blanket drain from the downstream toe of the tailings main dam to the seepage pumpback chambers, and forms a flat area across the valley. Several small flows exit the slope and toe of the bench and discharge into the seepage collection pond by drainages behind and around the pumpback structures and to the west beyond the structures. These flows are believed to be the combined surface runoff from the abutments and main dam, and seepage from the tailings impoundment.

The largest flow out of the rock bench is from a cavity at the toe of the bench, upstream of the pumpback structures, and downstream of the start of the width transition of the blanket drain. It appears as if this flow breaks out of the blanket drain at the start of the width transition, and flows through the rock drain to the cavity discharge. The cavity was measured to be about 15 inches in diameter and 12 inches back into the bench. Inspections and probes show that cavity walls are firm with no soft spots or holes.

The flow out of the cavity and all other smaller flows are regularly inspected as part of the TCAK monitoring program, and have continuously been observed to be clear and free of sediment. Bucket tests were performed over several hours by URS during the 2005 and 2006 dam safety inspections, and confirmed these observations. Therefore, the cavity and surrounding areas appear to be stable and show no signs of piping while the seepage and runoff are being discharged through them.

## **7.7 Tailings Management**

The initial design of the tailings main dam called for depositing tailings along the upstream face of the dam and thereby to better develop a seal between the dam and original ground. The first tailings were deposited behind the dam in November 1989 when it was in the Stage II configuration. Tailings were deposited along the upstream face of the dam.

During the first eight years of operations, there was too much water in the tailings impoundment to allow for development of a tailings beach, and water was impounded against the dam. An additional seepage control was added in 1991 to the Stage IV raise by placing a beach of fine grained Kivalina shale material in the area of the east abutment. The beach extended several hundred feet back into the impoundment.

Beaching of tailings along the upstream slope of the tailings main dam was started in 1997 from the east abutment. A full beach was developed along the dam by 2000 (TCAK, 2002). Figure 7 shows the plan view of the Stage VI dam before a complete beach was developed. A dust control system was constructed on the beach during the winter of 2001 (Figure 8). The full beach resulted in a decrease of the pumpback rate, reflecting a decrease in the seepage rate.

After the beach was developed, TCAK started discharging tailings from the east side of the impoundment, and eventually the rising water inundated the beach. By late 2004, the beach was almost submerged and

water reached the face of the dam (Figure 9). The loss of the tailings beach was followed by an increase in the pumpback rate, reflecting an increase in seepage. The underdrain piezometer readings correlate positively to the pumpback rate, while the other piezometers do not reflect the same pattern.

From January to May 2005, a partial tailings beach was constructed to protect the sand filter facility from flooding (Swendseid 2005). A coffer dam was built to Stage VII-A at crest El. 955, about 320 feet away from, and parallel to, the crest of the main dam. The space between the coffer dam and main dam was filled with tailings, except between the west ends of the main dam and coffer dam where a small area was left for the Stage VII-B cutoff wall excavation (Figure 10).

This small area between the west end of the coffer dam and main dam was in direct hydraulic contact with the tailings impoundment and remained full of water. Therefore the tailings backfill did not serve as a full beach because it did not extend along the entire main dam. There was no apparent decrease in pumpback rates, and therefore no apparent decrease of seepage rates, during the time of hydraulic contact.

A secondary coffer dam and tailings backfill were placed at the west end of the coffer dam in July 2005 to isolate an area for the Stage VII-B cutoff wall excavation. This removed the hydraulic contact between the impoundment and main dam. The water level in the isolated area dropped in August 2005 without pumping because of seepage and evaporation. Subsequent pumpback data showed a significant drop in pumpback rate, and therefore of seepage rate, that is attributed to the presence of the full tailings beach.

The historical effectiveness of the tailings beach due to varying tailings management practices are indicated in Figures 11 through 14 as background shading for reference in the following discussion. The presence of effective tailings beach conditions may be summarized as follows:

- No effective beach condition was present:
  - Before May 1998.
  - From May 2003 to July 2005.
- Fully effective 600-foot wide beach condition was present:
  - From August 1999 to September 2002.
- Fully effective 300-foot wide beach condition was present:
  - From August 2005 to date.

To prepare for a rise of tailings water between the 2005 and 2006 construction seasons, TCAK placed a coffer dam and tailings backfill over the tailings in the east abutment area to protect the east end of the main dam and the nearby sand filter, pipeline and mill facilities. The coffer dam was built to the Stage VII-B crest level at El. 960, and located about 250 feet away from, and parallel to, the planned curtain wall alignment. The space between the coffer dam and curtain wall alignment was filled with tailings.

## 7.8 Riser Pipe System

Two riser pipes extend up the highest part of the dam from the intersection of the toe drain and the original creek bed. The two pipes are constructed of HDPE, are separated by five feet horizontally along the crest, and are referred to as the east and west risers. They extend approximately 484.5 feet up the upstream face of the dam at three slopes with bends and approximate dimensions from bottom to top as follows:

- **Starter Dam:** 10-inch diameter, 216.9 feet long, slope 2 horizontal to 1 vertical (2:1) from the creek bed to the starter dam crest at El. 865 (based on design drawing)

- **Stage II to VI:** 10-inch diameter, 212.7 feet long, slope 2.5:1 from the starter dam crest to El. 944 six feet below the Stage VI crest (based on design drawing)
- **Stage VII-A:** 5.75-inch diameter, 22.6 feet long, slope 2:1 from El. 944 six feet below the Stage VI crest to El. 954 one foot below the Stage VIIA crest (Stage VIIA as-built drawing)
- **Stage VII-B:** 5.75-inch diameter, 32.6 feet long, slope 3.75:1 measured outside the dam (It is assumed that the pipe from El. 944 to El. 962.5 on the outer slope of Stage VII-B is at 3.75:1).

The purpose of the riser pipes was to allow submersible pumps to be inserted in them to lower the water level in the dam if the piezometers were to indicate higher water levels than allowed by the Operations and Maintenance (O&M) Manual. Such high water levels have never been indicated, so TCAK has never had to activate the riser pipes. The two riser pipes were installed for redundancy.

For the Stage I to VI raises, the riser pipes were extended to the next stage crest. Up to Stage VII-B, the riser pipes were terminated in a pre-cast concrete box. A Dames & Moore daily report during Stage VI construction notes that the riser pipe connection box was installed 14 feet north of the design location because “the wrong slope was used”. However, the impact of this on the Stage IV pipe slope is not known. The Stage VII-B riser pipe termination is an open pipe extending out of the downstream slope.

In August 2000, TCAK tried to measure the depth to water in the riser pipes by using a wire spool and water level indicator. The distance to water along the west pipe was found to be 250.2 feet from the Stage VI crest, which is at El. 854.2 or 11 feet below the starter dam crest. The depth to water in the east pipe was not determined because a blockage was encountered 89 feet down the pipe from the Stage VI crest, which is at El. 915.9 or half way up the Stage IV raise. The nature of the blockage was not determined.

In October 2006, Kleinfelder Inc. and URS completed a riser pipe survey by using a push-type submersible color video camera. Unfortunately, the camera that could fit into a 5.75-inch pipe had a 297-foot long cable. Therefore, the full length of the riser pipes was not surveyed. The west pipe was surveyed for the full cable length without seeing any blockages, water, or damage. The east pipe was surveyed a distance of 133 feet (+/- 1 foot) where a blockage was encountered.

The obstruction in the east riser pipe appeared to consist of angular rock fragments of size estimated to be about one half of the pipe diameter, or five inches. The material appears to be similar to that on the present dam crest. The camera view was partially obstructed by the rocks, but the pipe did not appear to be damaged; nor did it have visible cracks or deformations that would otherwise indicate a pipe failure.

The 2006 survey showed the blockage in the east riser to be at approximately El. 915.1, which compares favorably with the 2000 blockage measurement estimate of El. 915.9, which is about half way up the Stage IV raise.

As a result of the measurements and video survey, URS concludes that the blockage in the east riser is caused by rock fragments from the construction fill that somehow got into the pipe, and is not caused by stress to the pipe induced by dam movement.

## 8.0 SECONDARY SEEPAGE CONTROL SYSTEM

The secondary seepage control system for the tailings main dam are the seepage collection dam and pumpback system downstream of the tailings main dam as described in Section 3.2 and 3.3. The

collection dam and pumpback system were designed by Dames & Moore in the mid to late 1980s when the main dam was designed. The seepage collection dam design was modified during the winter of 1988 and 1989 to include the same type of cutoff wall that was being designed for the tailings main dam.

The originally-designed seepage collection dam was built by Green Construction in 1988 and completed in April 1988. The tailings starter dam was still being built and the seepage collection pond started to fill with water from snow melt and starter dam diversion pipe flow. The HDPE geomembrane in the seepage collection dam was keyed into a cutoff trench about 15 feet deep, where it was assumed to be below ice-rich soils and highly weathered shale. The geomembrane was placed in freezing conditions and the contact between the bottom of the geomembrane and top of bedrock was believed to be frozen.

A design seepage rate of 10 to 20 gpm was estimated for a full seepage collection pond. When the pond filled, seepage up to 2250 gpm was observed, which is 112 to 225 times higher than estimated. When the water level had dropped by one foot, the seepage decreased to about 700 gpm, or 35 to 70 times the estimate for a full pond. The seepage path was believed to be the geomembrane to rock contact. It was concluded that this contact had thawed, and water flowed through the rock joints under the contact and into the rock fill. The geomembrane was believed to be sound because of the construction controls.

The seepage control system in the seepage collection dam was improved in 1989 by adding a vertical HDPE geomembrane and grout cutoff wall below the cutoff trench in the same way as was completed for the tailings main dam described in Section 7.3. The wall was built by draining the pond, excavating vertically below the cutoff trench to better quality bedrock, extending the HDPE geomembrane vertically down the centerline of the excavation to the bottom, and backfilling the excavation with grout.

TCAK later added a shallow pumping system downstream of the seepage collection dam to capture any seepage that may escape from the seepage collection pond. A return pipeline conveys water from this pumping system over the seepage collection dam to the seepage collection pond.

## **9.0 INSTRUMENTATION**

Instrumentation has been installed throughout the tailings main dam to monitor pore pressures for dam stability and hydrologic characterization. The instrumentation locations are shown on Figures 2 and 3 and tabulated below. The piezometers consist of 21 vibrating wire type transducers. The thermistors consist of eight thermistor strings.

Pneumatic piezometers and thermistors were installed in the tailings main dam in 1989. The piezometers were replaced in the mid 1990s by vibrating wire piezometers because they were easier to install and monitor, could be automated for data collection with a data logger, and had built-in thermistor points.

Buttress piezometers were installed in 1997 for a hydrologic characterization (Water Management 1999). Other instruments that were installed during the original dam construction have been abandoned. Piezometer properties including tip depth, material properties, and tip thermal conditions are summarized in Table 2.

Properties for each of piezometer were obtained by consolidating data from several sources including the geotechnical investigation (URS 2006b), as-built drawings (Dames & Moore 1995b), stability analysis (URS 2002 a and b), and piezometer data from TCAK. The tip soil formation was estimated from boring



logs if there was a log for the piezometer, or by using data from nearby borings and design and construction reports.

The piezometer tip thermal condition was determined by utilizing the transducer temperature and checking it against the data notes included with the data set that URS has on file. In some cases there was a pressure reading for a piezometer when the transducer indicated that it was frozen. The piezometers can be grouped as follows:

- Underdrain piezometers (P-10A, P-10B, P-09A, P-09B, P-08A and P-08B).
- Crest piezometers (P-11, P-12A, P-12B, P-13 and P-14A).
- East buttress piezometers (P-97-028, P-97-029, P-97-030 and P-97-031).
- 2005 Piezometers (P-05-62, P-05-63, P-05-65, P-05-67, P-05-68 and P-05-69).

Section 5.3.1.2 of the O&M Manual requires that the significance of piezometer readings for dam stability should be checked if the following observations are made:

- Water level at piezometer P-10 exceeds El. 813.
- Water level at piezometer P-09 exceeds El. 817.
- Water level at piezometer P-08 exceeds El. 825.

Piezometric readings are plotted for the record period along with the recommended EALs for P-10, P-09 and P-08 as shown on Figure 11. None of the readings for these piezometers has exceeded the EAL levels.

**Table 2 - Piezometer Tip and Ground Surface Elevations**

Piezometer	Surface El. (ft)	Piezometer Tip El. (ft)	Soil/Rock Type at Tip	Tip Condition
P-08A	947.1	795.0	Type 7, 12" minus select fill (underdrain)	Always thawed
P-08B	947.1	770.0	Slightly to moderately weathered shale	Always thawed
P-09A	867.5	790.1	Type 7, 12" minus select fill (underdrain)	Always thawed
P-09B	867.3	766.1	Slightly to moderately weathered shale	Always thawed
P-10A	823.1	790.3	Type 7, 12" minus select fill (underdrain)	Always thawed
P-10B	823.6	765.3	Slightly to moderately weathered shale	Always thawed
P-11	949.4	900.2	Highly to severely weathered shale	Always thawed
P-12A	947.7	829.9	Type 1, 24" minus random rock fill	Frozen from Oct. to Dec. 2003
P-12B	947.6	808.2	Slightly weathered shale	Frozen since installed in Aug. 1997
P-13	948.8	830.9	Slightly weathered shale	Always thawed
P-14A	947.7	881.2	Highly weathered shale	Frozen since installed in Sept. 1997
P-97-028	809.4	760.9	Moderately to highly weathered shale	Always thawed
P-97-029	824.1	793.9	Highly weathered shale	Frozen since Jan. 2001
P-97-030	862.0	809.0	Slightly to moderately weathered shale	Always thawed
P-97-031	894.2	879.5	Slightly to moderately weathered shale	Periodically thawed from 2002 to 2006
P-05-62 (SS-05-05)	811.3	787.9	Type 7, 12" minus select fill (underdrain)	Always thawed
P-05-63 (SS-07-05)	970.3	929.6	Moderately weathered Shale	Always thawed
P-05-65 (SS-09-05)	956.8	929.0	Silty clay w/ gravel & boulders	Always thawed
P-05-67 (SS-15-05)	983.2	954.9	Highly weathered shale	Always thawed
P-05-68 (SS-16-05)	989.6	961.4	Completely weathered shale	Always thawed
P-05-69 (SS-17-05)	831.4	823.6	Silty fine to coarse sand with gravel	Always thawed

The underdrain piezometers were installed along the original creek bed alignment and they monitor the underdrain performance. The 'A' piezometers extend into the underdrain and the 'B' piezometers extend

into the foundation rock below the underdrain (TCAK 2007). Previously it was understood that the ‘B’ piezometer tips were located approximately 20 feet below the ‘A’ piezometer tips (URS 2002 a and b).

Four piezometers are located along the rockfill buttress as shown in Figure 13. Except for P-97-031 which terminates in dam fill, the buttress piezometers are located in the foundation beneath the dam. Buttress piezometers P-97-028, P-97-029, P-97-030 and P-97-031 were installed in the rock fill buttress in 1997 as part of a Phase II hydrologic characterization (Water Management Consultants, 1999).

As part of the 2005 geotechnical investigation (URS 2006b), new piezometers and thermistors were installed for monitoring the tailings main dam and future raises to closure. Polyvinyl chloride (PVC) pipes were installed in the borings following the drilling and sampling in 2005, and TCAK installed the piezometers in 2006 at SS-05-05, SS-07-05, SS-11-05, SS-15-05, SS-16-05 and SS-17-05.

## 10.0 REFERENCES

- Alaska Department of Natural Resources (ADNR), 2005 “Guidelines for Cooperation with the Alaska Dam Safety Program.” Alaska Department of Natural Resources, June 2005.
- Cominco Alaska, Inc., 1989, Letter to EBA Engineering Inc., December 14, 1989.
- Dames & Moore, 1986, Design Report, Proposed Tailings Dam, Red Dog Mine Development” for Cominco Alaska, Inc.", June 6, 1986.
- Dames & Moore, 1987a, Construction Drawings, Tailings Impoundment Dam, Red Dog Project, Alaska, Revision 1, for Cominco Alaska., Inc., January 27, 1987.
- Dames & Moore, 1987b, Waste Storage Areas Geotechnical Design Report, for Cominco Alaska, Inc., July 16, 1987.
- Dames & Moore, 1988a, Technical Specifications, Proposed Tailings Dam, Red Dog Mine Development, for Cominco Alaska, Inc., Revised April 11, 1988.
- Dames & Moore, 1988b, Evaluation of Seepage Losses and Potential Remedial Measures, Tailings Starter Dam, Red Dog Mine Project, letter to Cominco Alaska, Inc., October 17, 1988.
- Dames & Moore, 1988c, Tailings Main Dam, Stage I Construction Daily Reports by Howard Weston and Michael Foster, for Cominco Alaska, March to December 1989.
- Dames & Moore, 1989a, Proposed Remedial Measures, Stages III Through VI, Tailings Dam Embankment, Red Dog Mine Project, letter to Cominco Alaska, Inc. , May 12, 1989.
- Dames & Moore, 1989b, Construction Drawings, Tailings Impoundment Dam, Red Dog Project, Alaska, Revision 4, for Cominco Alaska., Inc., September 13, 1989.



Dames & Moore, 1989c, Design Rationale for Tailings Dam Abutments, Red Dog Mine Project, letter to Cominco Alaska, Inc., December 9, 1989.

Dames & Moore, 1989d, Tailings Main Dam, Stage II Construction Daily Reports by Frank Richards, for Cominco Alaska, August to February 1989.

Dames & Moore, 1990a, Red Dog Mine Tailings Dam Stage III Construction Completion Report, for Cominco Alaska, Inc., December 3, 1990.

Dames & Moore, 1990b, Tailings Main Dam, Stage III Construction Daily Reports by Frank Richards and Jeff Stanley, for Cominco Alaska, July to August 1990.

Dames & Moore, 1991a, Completion Report, Tailings Dam - Stage III, Red Dog Mine Development, for Cominco Alaska, Inc., October 11, 1991.

Dames & Moore, 1991b, Tailings Main Dam, Stage IV Construction Daily Reports by Douglas Washburn and Frank Richards, for Cominco Alaska, June to July 1991.

Dames & Moore, 1992, Tailings Main Dam, Stage V Construction Daily Reports by Jeff Stanley and Kenneth E. Yockey, for Cominco Alaska, August to December 1992.

Dames & Moore, 1993a, Tailings Dam – Stages V & VI Completion Report, for Cominco Alaska, Inc., October 13, 1993.

Dames & Moore, 1993b, Tailings Main Dam, Stage VI Construction Daily Reports, for Cominco Alaska, by Kenneth Yockey and Jeffrey Stanley for Cominco Alaska, January to August 1993.

Dames & Moore, 1995a, “Design Report: Proposed Tailings Dam Modifications Red Dog Mine”, for Cominco Alaska, February 1995.

Dames & Moore, 1995b, “Transducer P-10A, P-10B, P-9A and P-9B Installation Log”, November 6, 1995.

EBA Engineering Consultants Ltd., 1989, “Red Dog Project - Tailings Dam Review, Seepage Analysis” letter to Cominco Alaska, Inc., January 11, 1989.

EBA Engineering Consultants Ltd., 1990, “Red Dog Tailings Dam, Cutoff Trench Details”, letter to Cominco Alaska, Inc., April 19, 1990.

EBA Engineering Consultants Ltd., 2000, “Geotechnical Evaluation Report: Proposed VIP Project Millsite” Red Dog Mine, Alaska, for AGRA Simons Limited, Vancouver, BC, April 2000.

Koon, Bradley, 2001, “Construction and Operation of a Tailing Dam in Alaska’s Arctic”, Red Dog Mine, Cominco Alaska Inc., for the Association of State Dam Safety Officials Conference, Anchorage, AK, May 2001.

Swendseid, Jim. “Personal communications on tailings and pumpback operations”, Teck Cominco Alaska Inc., 2000 to 2006.

- Teck Cominco Alaska, Inc. (TCAK), 2002, Red Dog Mine Site Current Conditions, Waste Management Permitting Program Tasks B-14, C-02 and D-02, December 5, 2002
- Teck Cominco Alaska Inc. (TCAK) 2007, 2006 Annual Instrumentation Report, Red Dog Tailings Dam, Red Dog Mine, to Alaska Department of Natural Resources, January 10, 2007 (and previous annual reports).
- URS, 2002a, “Stability Analysis Report, Stage VII Widening, Red Dog Tailings Dam”, for Teck Cominco Alaska Inc., Red Dog Mine, Alaska, December 19, 2002.
- URS, 2002b, “Stability Analysis Report, Stage VII Raise, Red Dog Tailings Dam”, for Teck Cominco Alaska Inc., Red Dog Mine, Alaska, December 19, 2002.
- URS Corporation, 2004, Construction Completion Report, Red Dog Tailings Impoundment Stage VII-A Raise, for Teck Cominco Alaska, Inc., March 30, 2004 (includes record photos and drawings).
- URS Corporation, 2005a, Technical Specifications, Stage VII-B Raise, Red Dog Tailings Dam, Red Dog Mine, Alaska, for Teck Cominco Alaska, Inc., May 27, 2005
- URS Corporation, 2005b, Periodic Safety Inspection Report, Tailings Dam, Red Dog Mine Project, to Teck Cominco Alaska, Inc., August 5, 2005.
- URS Corporation, 2006a, Construction Drawings, Red Dog Mine Tailings Dam, Stage VII-B, Red Dog Mine, Alaska, Revision 3, April 5, 2007 and all previous revisions.
- URS Corporation, 2006b, “Geotechnical Investigation Report: Red Dog Tailings Main Dam, Future Raises to Closure, Red Dog Mine, Alaska”, for Teck Cominco Alaska Inc., July 28, 2006.
- URS, 2007a, “Seepage Analysis Report: Tailings Main Dam, Future Raises to Closure, Red Dog Mine, Alaska”, for Teck Cominco Alaska (TCAK), February 26, 2007.
- URS, 2007b, “Stability Analysis Report: Tailings Main Dam, Future Raises to Closure, Red Dog Mine, Alaska”, for Teck Cominco Alaska (TCAK), April 13, 2007.
- URS, 2007c, “Conceptual Design Report: Tailings Main Dam, Future Raises to Closure, Red Dog Mine, Alaska”, for Teck Cominco Alaska (TCAK), 2007 (under completion).
- United States Geological Survey (USGS), 1996, Distribution of Mineral Occurrences in the De Long Mountains, 1:250,000-scale Quadrangle, Northwestern Alaska, Alaska Resource Data File”, Open File Report 00-023, Anchorage, AK, 1996.
- Water Management Consultants, Inc. 1999, excerpts from “Results of the Phase II Hydrologic Characterization of the Tailing Impoundment,” for Hartig, Rhodes, Norman, Mahoney and Edwards March, 1999.
- Weaver, Jeff., 2007, “Personal communications regarding piezometer and thermistor instrumentation and ground thermal conditions”, Geomatrix Consultants.

Zigarlick, Ted. “Personal communications on mill site development and diversion berm”, Teck Cominco Alaska Inc., 2007.

## **FIGURES**





Source:  
Teck Cominco Alaska, Inc. (TCAK) "Aerial Photograph", Sept 2004.  
(Note: Prior to the Construction of Cofferdam and Infilled Tailings Beach)

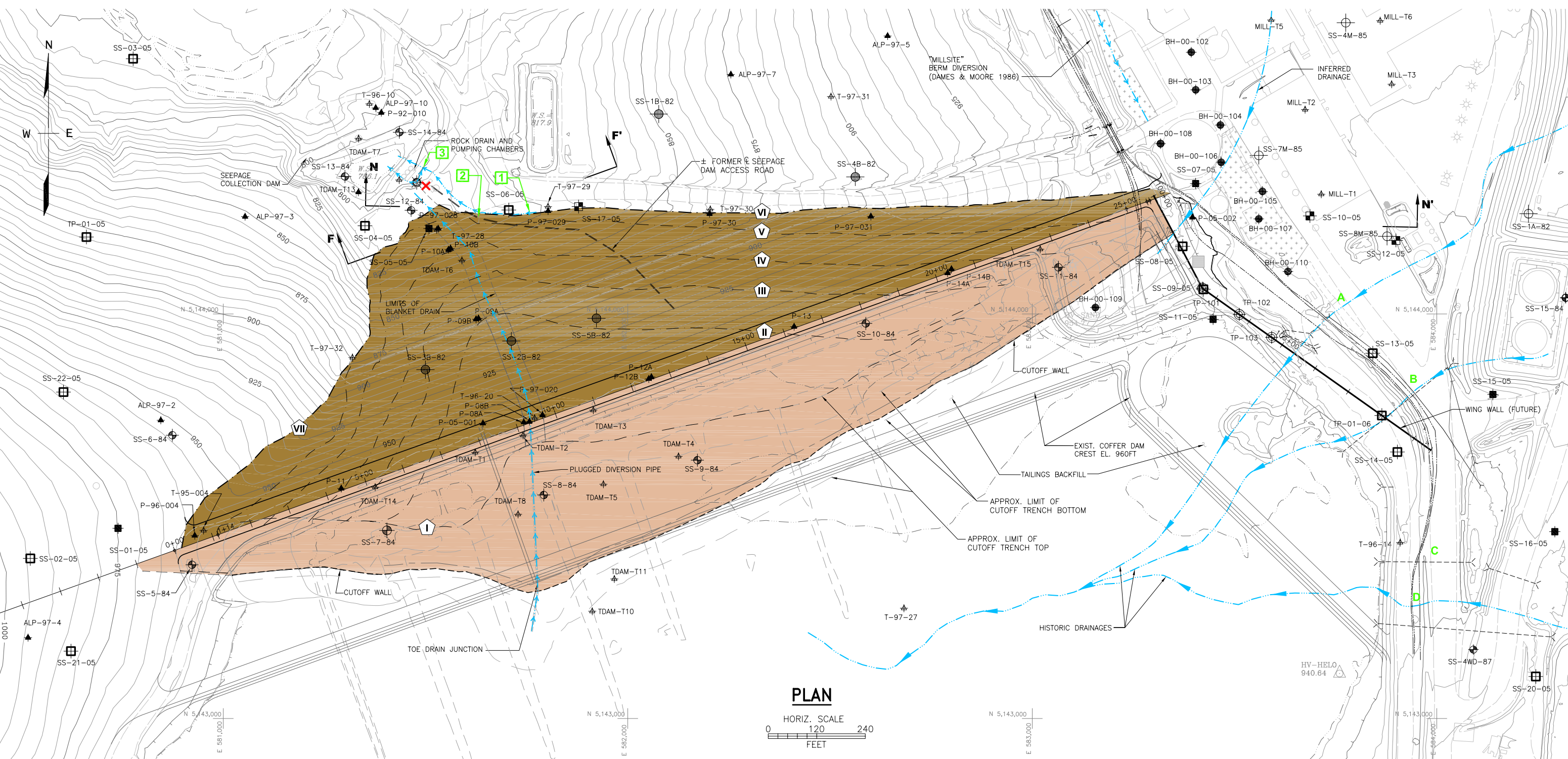
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Figure 1  
Site Plan (Aerial View, Sept 2004)

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska



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LEGEND

- |  |   |  |   |
|--|---|--|---|
|  | DAMES & MOORE FOR TAILINGS DAM (1982)           |  | URS WITH EITHER PIEZOMETERS OR THERMISTERS (2005-2006)                        |
|  | DAMES & MOORE FOR TAILINGS DAM (1984)           |  | URS WITH NO INSTRUMENTATION (2005-2006)                                       |
|  | DAMES AND MOORE FOR WASTE STORAGE (1984 & 1987) |  | SEEP DISCHARGE FROM UNDERDRAIN  |
|  | EBA ENGINEERING FOR MILL FACILITIES (2000)      |  | START OF OBSERVED SURFACE FLOW  |
|  | PND FOR RIGHT ABUTMENT WING WALL (2004)         |  | WET AREA AT TURNING POINT OF OBSERVED SURFACE FLOW AND SHALLOW DRAINAGE DITCH |
|  | PIEZOMETERS (PRE-2005)                          |  | DISCHARGE OF SURFACE FLOW TO SEEPAGE COLLECTION POND                          |
|  | THERMISTORS (PRE-2005)                          |  | LOCATION OF ELECTRICAL CABINET ON SIDE OF CONNEX                              |
|  | URS WITH PIEZOMETERS & THERMISTERS (2005-2006)  |  |   |

PLAN

HORIZ. SCALE  
0 120 240  
FEET

- |  |  |
|--|--|
|  | FLOW PATH                                      |
|  | NEW CULVERT LOCATION (APPROXIMATE, TCAK 2006)  |
|  | CULVERT (OLD LOCATION)                         |
|  | DOWNSTREAM TOES OF STAGE I TO STAGE VII RAISES |
|  | CURRENT DAM EXTENT (2006)                      |
|  | SATURATED SURFACE AREA                         |
|  | DRAINAGE REFERENCE POINTS                      |

Figure 2  
**Surface Conditions**

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska





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### LEGEND

- |  |  |  |   |
|--|--|--|---|
|  | DAMES & MOORE FOR TAILINGS DAM (1982)                  |  | URS WITH NO INSTRUMENTATION (2005-2006)                                       |
|  | DAMES & MOORE FOR TAILINGS DAM (1984)                  |  | SEEP DISCHARGE FROM UNDERDRAIN  |
|  | DAMES AND MOORE FOR WASTE STORAGE (1984 & 1987)        |  | START OF OBSERVED SURFACE FLOW  |
|  | EBA ENGINEERING FOR MILL FACILITIES (2000)             |  | WET AREA AT TURNING POINT OF OBSERVED SURFACE FLOW AND SHALLOW DRAINAGE DITCH |
|  | PND FOR RIGHT ABUTMENT WING WALL (2004)                |  | DISCHARGE OF SURFACE FLOW TO SEEPAGE COLLECTION POND                          |
|  | PIEZOMETERS (PRE-2005)                                 |  | LOCATION OF SUBSURFACE FLOWS OBSERVED DURING WINGWALL EXCAVATION (SEPT. 2006) |
|  | THERMISTORS (PRE-2005)                                 |  | LOCATION OF ELECTRICAL CABINET ON SIDE OF CONNEX                              |
|  | URS WITH PIEZOMETERS & THERMISTERS (2005-2006)         |  |   |
|  | URS WITH EITHER PIEZOMETERS OR THERMISTERS (2005-2006) |  |   |

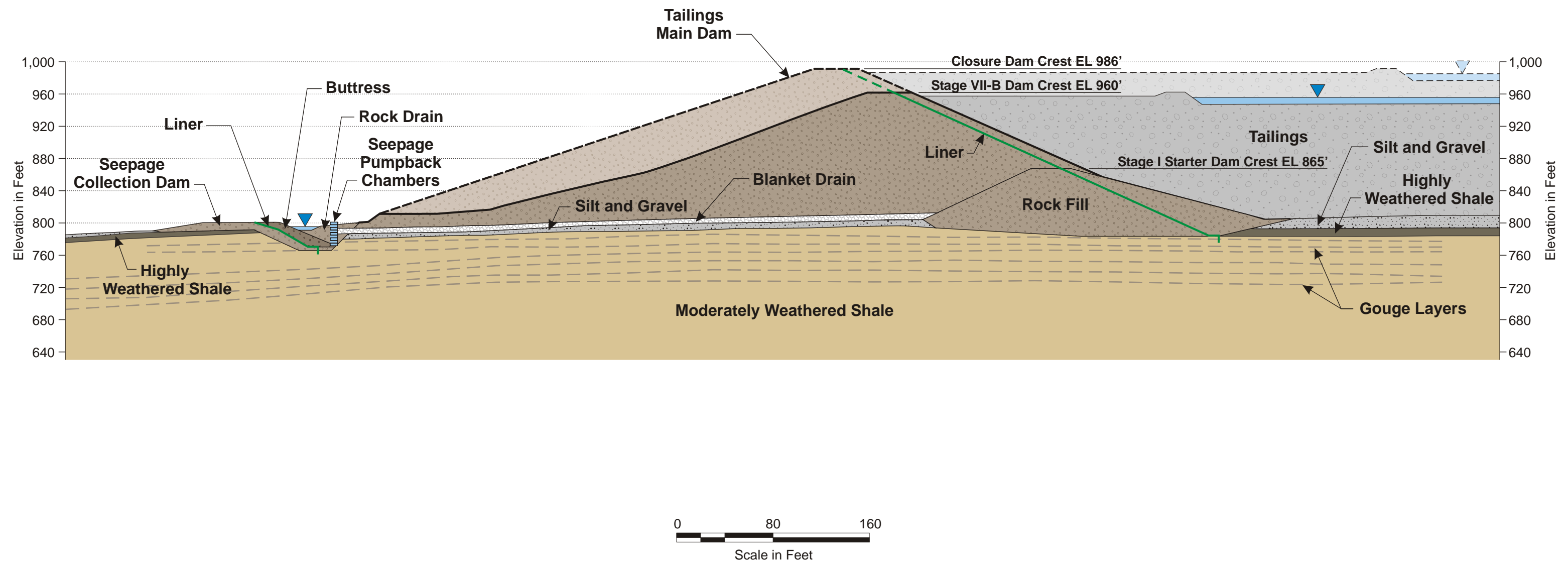
### PLAN

HORIZ. SCALE  
0 120 240  
FEET

- |  |   |  |                           |
|--|---|--|---------------------------|
|  | PERMAFROST PRESENT                            |  | SATURATED SURFACE AREA    |
|  | NO PERMAFROST, ACTIVE LAYER ONLY              |  | DRAINAGE REFERENCE POINTS |
|  | FLOW PATH                                     |  |                           |
|  | NEW CULVERT LOCATION (APPROXIMATE, TCAK 2006) |  |                           |
|  | CULVERT (OLD LOCATION)                        |  |                           |
|  | DOWNSIDE TOES OF STAGE I TO STAGE VII RAISES  |  |                           |
|  | CURRENT DAM EXTENT (2006)                     |  |                           |
|  | POSSIBLE KIVALINA SHALE                       |  |                           |

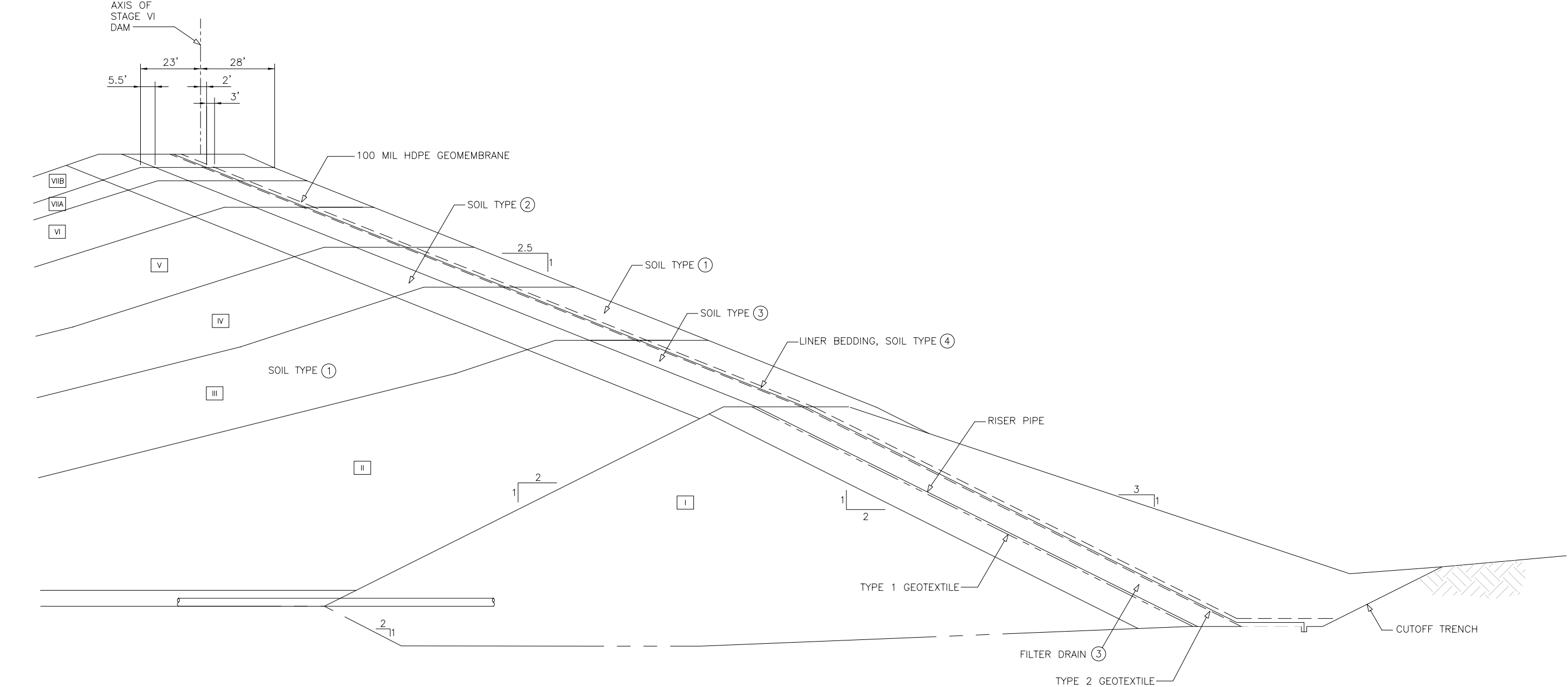
Figure 3  
**Subsurface Conditions**

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska



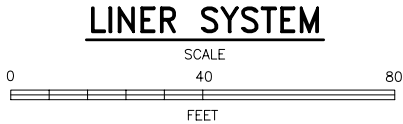


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SOIL TYPE	MATERIAL
①	RANDOM ROCKFILL (24 INCH)
②	SELECT (24 INCH)
③	PROCESSED SELECT (3 INCH)
④	PROCESSED SELECT (1 INCH)
⑦	SELECT (12 INCH)
GEOSYNTHETICS	
GEOMEMBRANE - 100 MIL HDPE	
GEOTEXTILE - 10 OZ AND 16 OZ NONWOVEN	

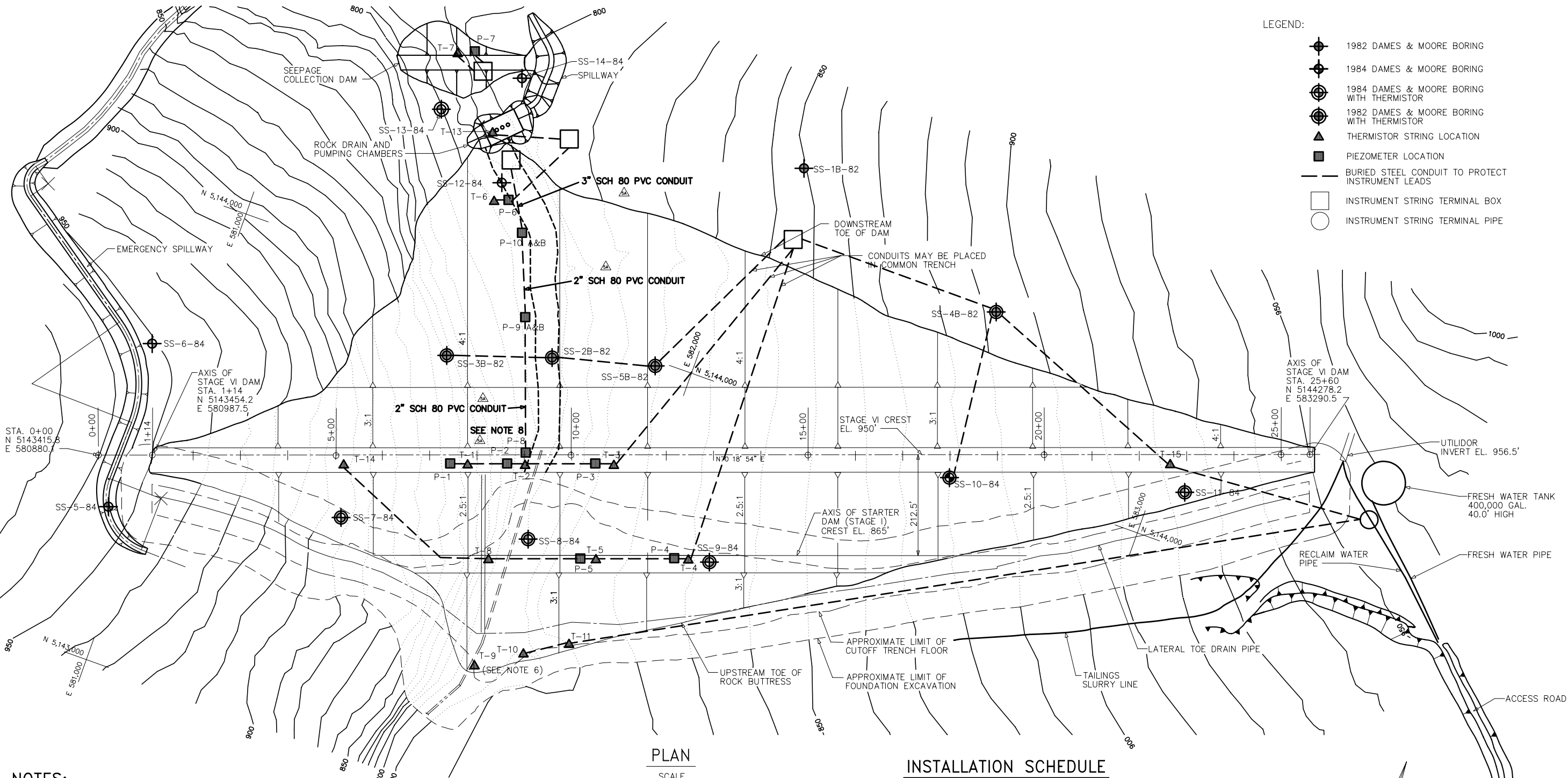
STAGE	CREST ELEVATION	COMMENTS
I	865'	EXISTING
II	890'	EXISTING
III	910'	EXISTING
IV	925'	EXISTING
V	940'	EXISTING
VI	950'	EXISTING
VII-A	955'	EXISTING
VII-B	960'	EXISTING



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AS-BUILT

Figure 6  
Tailing Dam  
Proposed Instrument Locations

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska



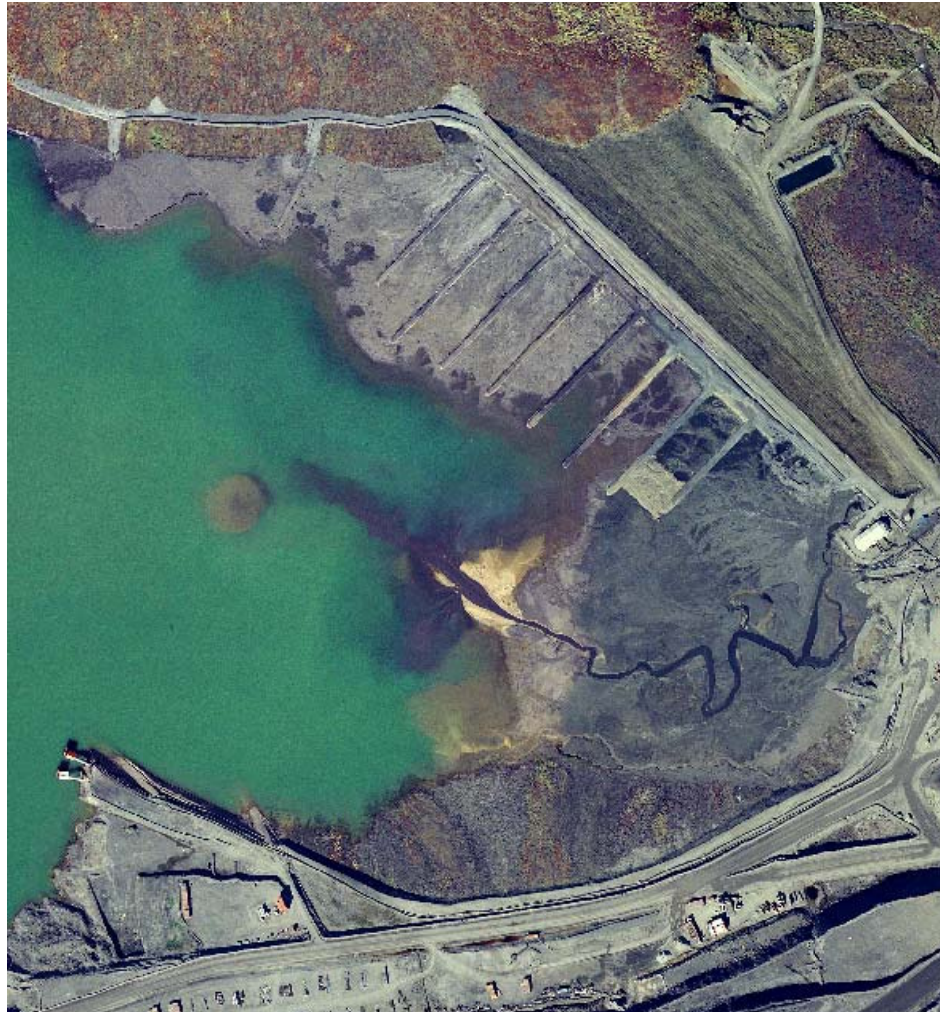
0 800 1600  
Approximate Scale in Feet

Figure 7  
**Stage VI Plan View**  
**Without Tailings Beach (September 2000)**

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**URS**

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska



0 800 1600  
Approximate Scale in Feet

Figure 8  
**Stage VI Plan View  
With Tailings Beach (August 2002)**





0 800 1600  
Approximate Scale in Feet

Figure 9  
**Stage VII-A Plan View  
With Tailings Beach (September 2004)**

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**URS**

Dam History of Tailings Main Dam  
Future Raises to Closure  
Red Dog Mine, Alaska





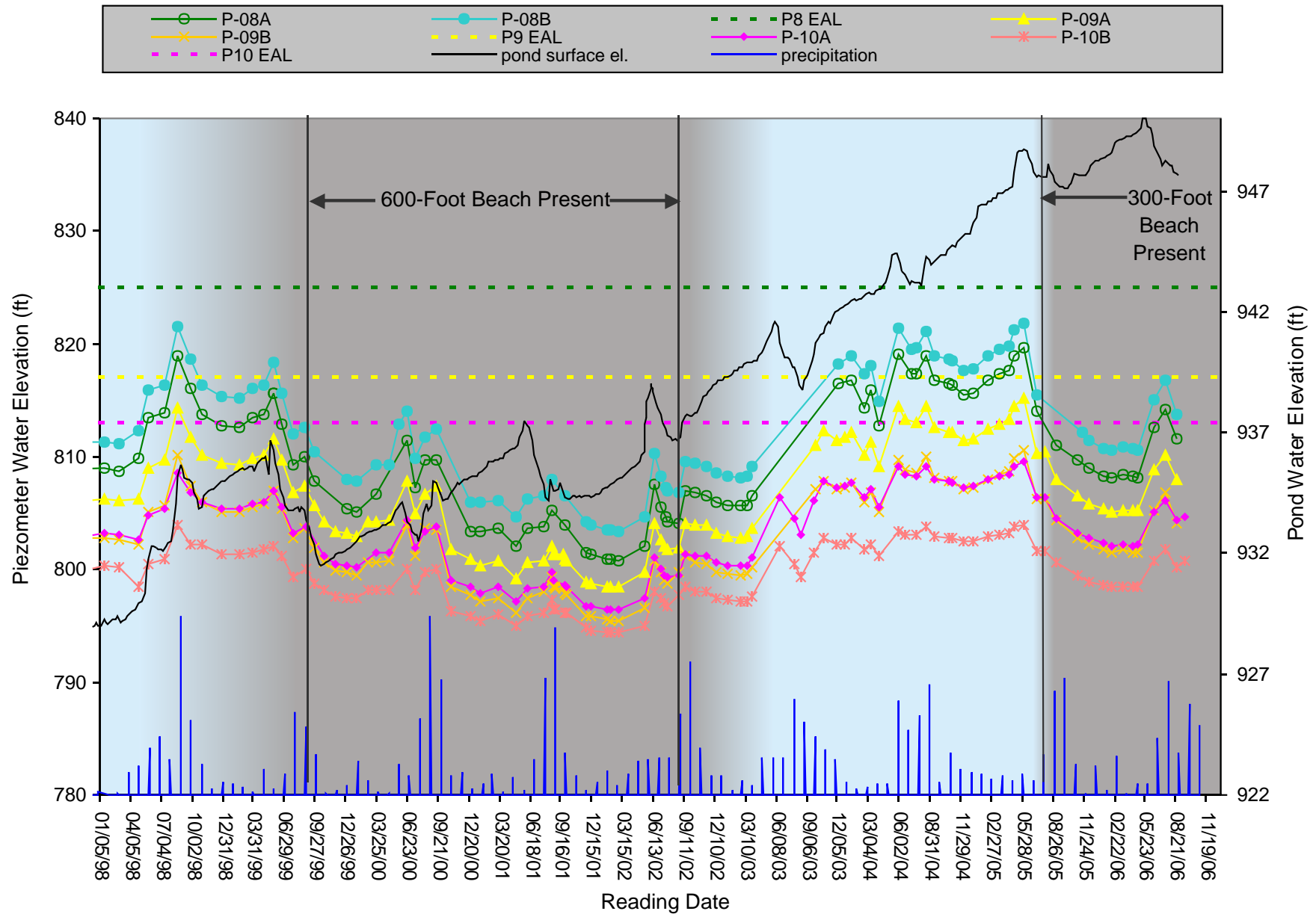


Figure 11  
**Underdrain Piezometers with EALs**



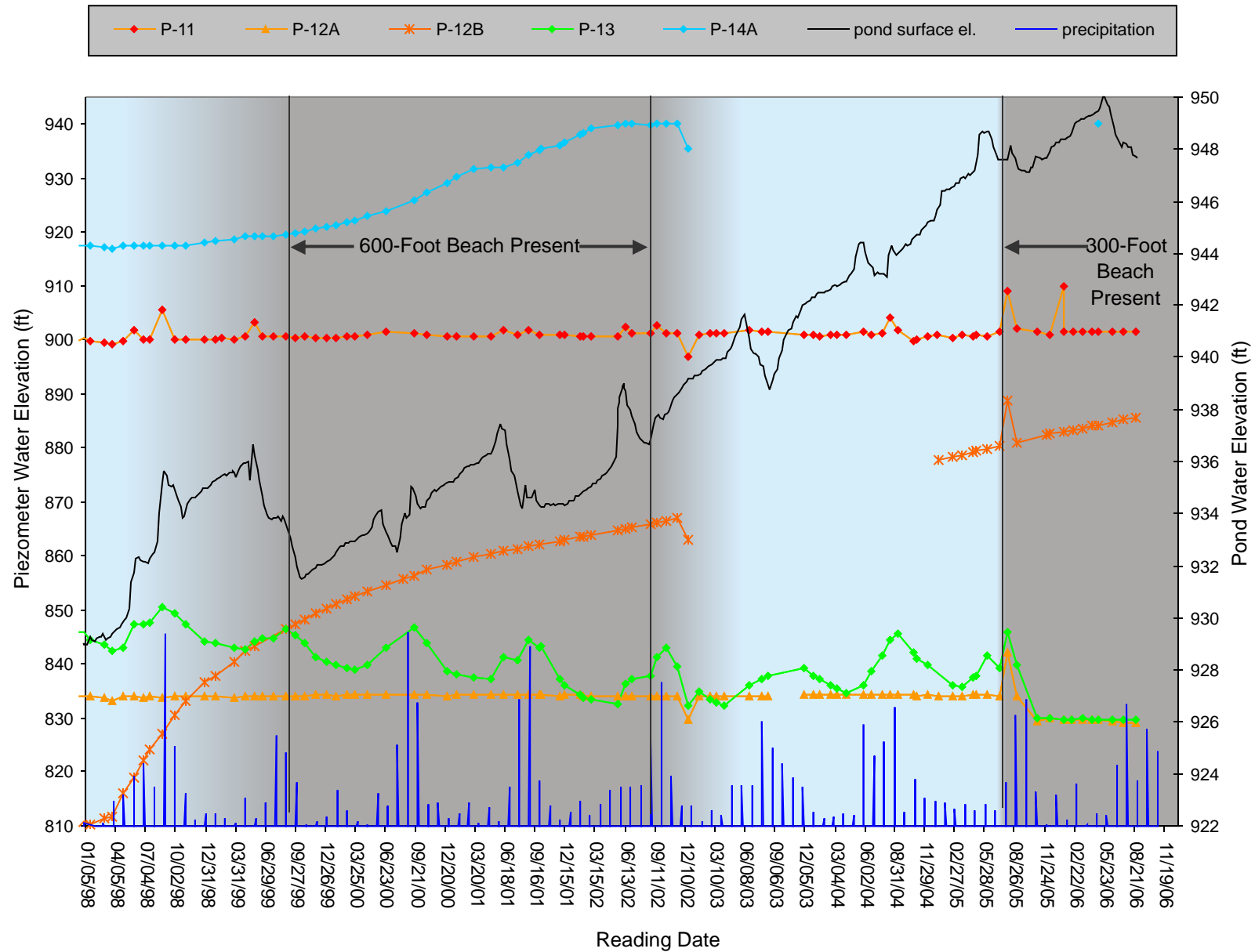


Figure 12  
**Crest Piezometers**

Job No. 33757098

**URS**

Dam History of Tailings Main Dam  
 Future Raises to Closure  
 Red Dog Mine, Alaska

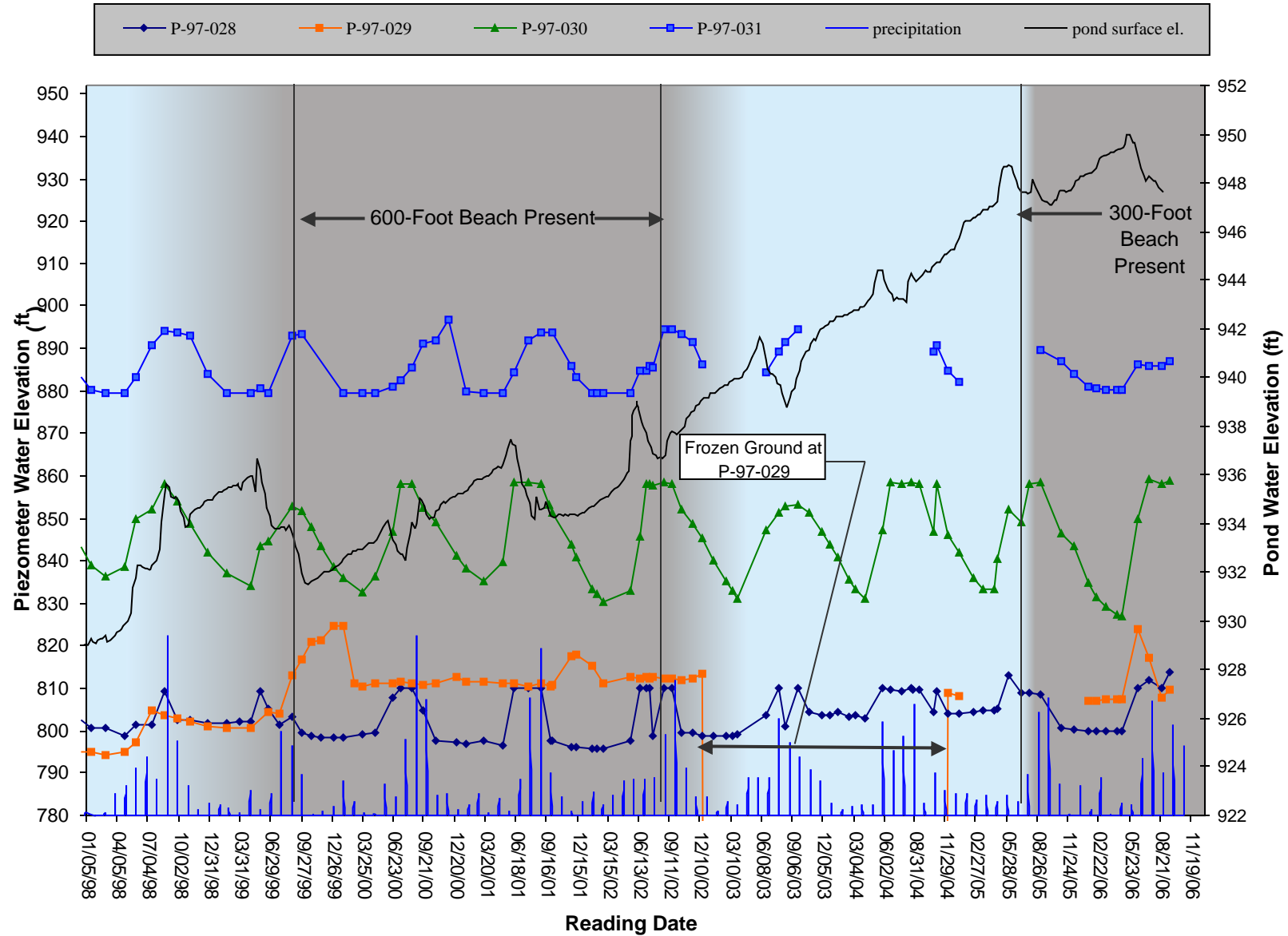


Figure 13  
**Buttress Piezometers**

Job No. 33757098

**URS**

Dam History of Tailings Main Dam  
 Future Raises to Closure  
 Red Dog Mine, Alaska

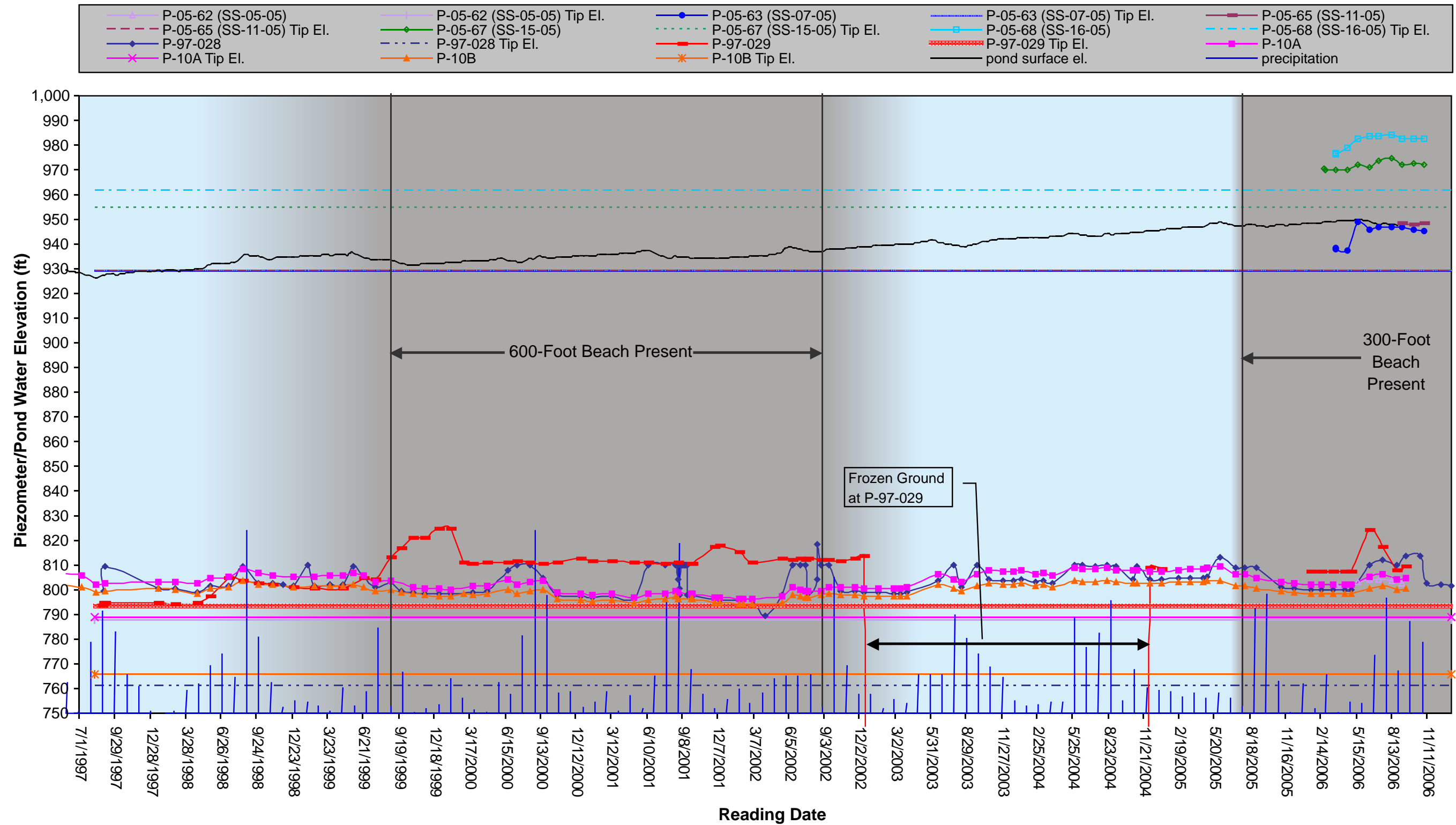


Figure 14

**Piezometer Readings and Piezometer Tip Elevations**

## **PHOTOS**



Left shoulder of Starter Dam Sta. 9+00 looking to the north. Polishing pond in top part of photo. Observe standing water on top of Stage 2 material.



Left shoulder of Starter Dam Sta. 11+00 looking to the north. Edge of lift placed August 16 and 17, random rock from millsite.



Fill material placed August 20, from millsite excavation (highly weathered/high moisture content).



Taken from the seepage dam access road looking towards the east. Lift is estimated to be approximately 5 to 6 feet thick in the middle and tapered on the edges. Noticeable drainage from under lift.





Taken from the seepage dam access road looking towards the starter dam. Area where D6 got stuck. Random rock fill placed over very soft and wet silty material.



Edge of random rock fill looking towards starter dam. Very soft material approximately 6 to 7 feet thick.





Right shoulder of starter dam. Crest, thermistor locations; T-11 to right of the black pickup in right corner, individual placing string; T-10 in the area of the Tamrock; T-9 left corner of photo with white PVC above ground.



Starter Dam crest viewing seepage dam.



Tailings dam and seepage dam from the oxide dump road.



View of Tailings Main and Seepage Collection Dam



View of Tailings Main Dam and Seepage Collection Dam



View of Tailings Main Dam and Seepage Collection Dam, Looking South/Southeast





Upstream Face of Dam - Liner & Cutoff Trench



Liner and Anchor Trench



Geomembrane Panels and Seams Held Down



Geomembrane Panel Seam Welding



Anchor Trench Backfill at Top of Dam



12-Perforated Pipe Toe Drain in Cutoff Trench to Intercept Seepage





Cutoff Trench to Bedrock at Upstream Toe of Dam



Cutoff Wall below Bottom of Cutoff Trench to Better Bedrock





Pumpback System in Seepage Collection Pond



Stage VI Liner after Surface Scraped Off



Bedding between Geomembrane & Geotextile



Bedding for Geomembrane Placement



Geomembrane on top of Bedding





Cover Material over Geomembrane



Geomembrane Advancing West



Geomembrane Panel Seam Welding



Vertical Seam between Geomembrane Panels





Bedding, Geomembrane, Cover & Buttress



Welding New & Old Geomembranes



Placement and Grading of Liner Cover

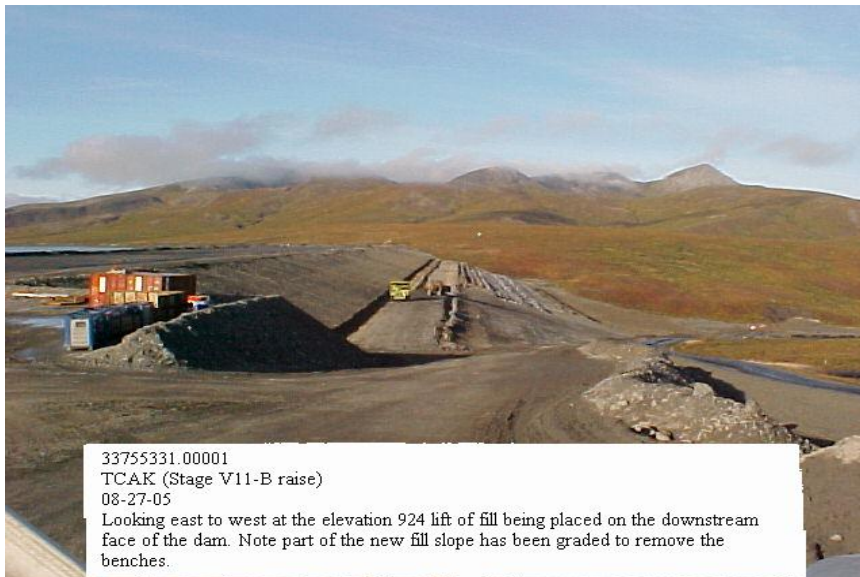


Placement of Buttress to Protect Liner





Widening Downstream Slope of Dam



Widening & Grading Downstream Slope of Dam



Exposed Stage VII-A Geomembrane at West Abutment



Excavating Left Abutment to Cutoff Trench





Exposing Stage VI Geomembrane for Cutoff Wall Extension



Exposing Stage IV Cutoff Wall and Stages IV, V, VI & VII-A Liner



Cutoff Trench and Excavation for Cutoff Wall Extension



Exposed End of Stage IV Cutoff Wall





South Face & Bottom of New Cutoff Wall Excavation



Excavation & Geomembrane for Cutoff Wall



Cutoff Wall Excavation & Geomembrane



Grout Poured to Top of Cutoff Wall Excavation





Cutoff Wall Extension at Left Abutment



Fill on Geotextile at Toe of Cutoff Trench Subgrade



Liner Berm Fill at Toe of Cutoff Trench



Fill to Cutoff Trench Subgrade



Geotextile on Cutoff Trench Subgrade



Fill in Cutoff Trench for Geomembrane Installation





Placing Fill for Geotextile Installation



Placing Geotextile over Fill





Exposed VII-A Geotextile, Bedding & Geomembrane



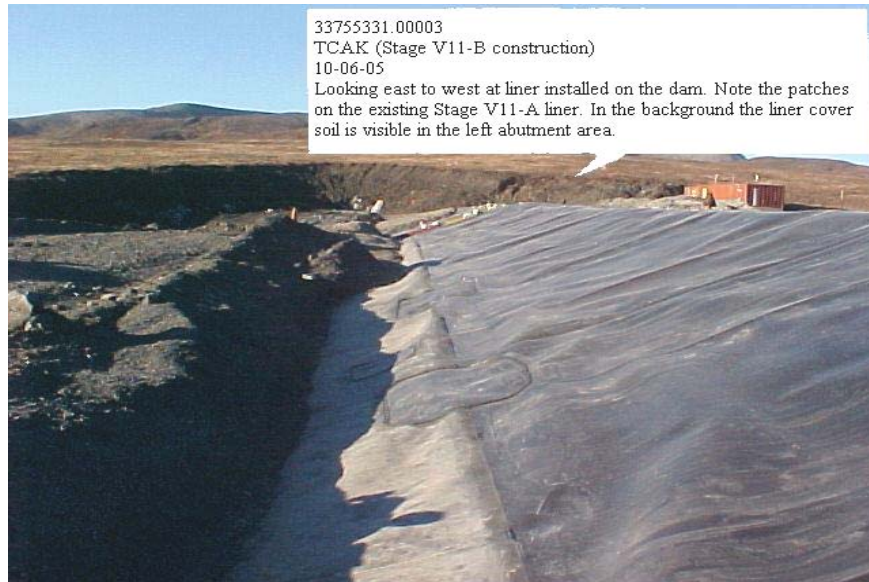
Type II Geotextile over Type 3 Fill



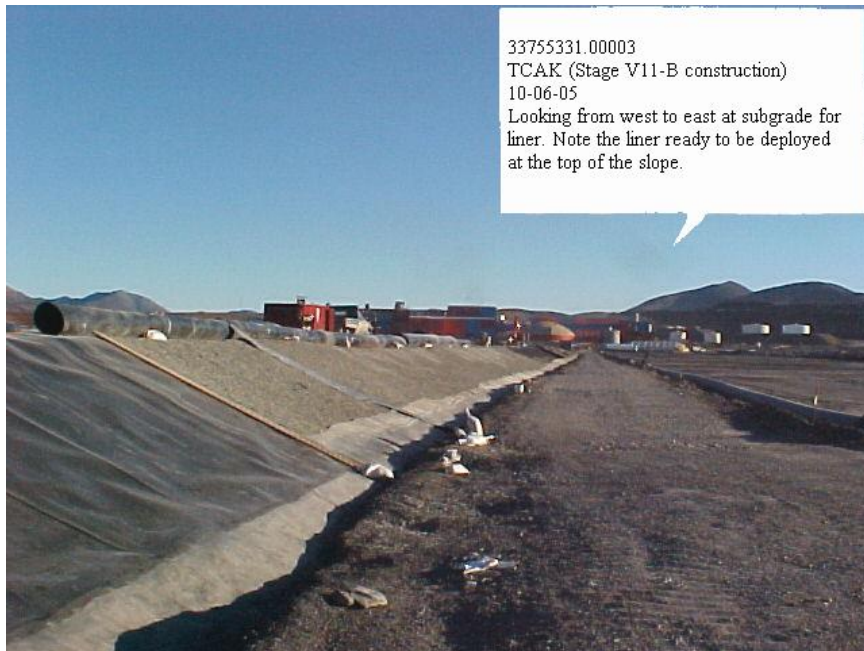
Extending Geotextile & Liner Bedding up to El. 960



Compacting Liner Bedding on Type II Geotextile



Interface of Stage VII-A & B Geomembrane



Stage VII-B & A Geomembrane and VII-B Subgrade





Backfilling Anchor Trench at Top of Dam



Welding in Stage VII-B Cutoff Trench





Seam Welding between Stage VII-B & A Geomembrane



Bedding Around Relocated Pipelines



East End of Dam Crest



Stage IV Cutoff Wall East End





Cutoff Wall to Curtain Wall Concrete Tie-in



Start of Curtain Wall Excavation



Cutoff Wall to Curtain Wall Transition



Liner System to Curtain Wall Transition





Curtain Wall Start of Excavation



Liner Sloped to Vertical Transition



Culvert Raise/Pipe Bench Lining Project



Curtain Wall Panel Interlock





Curtain Wall Frame and Panel



Curtain Wall Panel Insertion



Curtain Wall First Four Panels



Curtain Wall Control Density Fill Pour





Curtain Wall Backfill and Continuation



Curtain Wall Backfill Up Abutment



Non-Destructive Vacuum Test of Welds



Quality Assurance Density Test on Compacted Bedding





Aerial Photo of Tailings Main Dam Stage VII-B, May 25, 2007



Aerial Photo of Tailings Main Dam Wing Wall During  
Stage VII-B Construction, May 25, 2007