AdrianBrown

Groundwater Hydrology•Geochemistry•Remediation

# Pogo Mine Inflow **Evaluation and Control** Review

Prepared for:

**Teck-Cominco Corporation**
P.O. Box 145
Delta Junction, Alaska 99737

Prepared by:


**Adrian Brown**
Adrian Brown Consultants, Inc.
130 West 4th Ave
Denver, Colorado 80223


April 5, 2009

Project No. 1543B

*"Innovative Environmental Solutions"*


130 W. 4th Avenue
Denver, Colorado 80223
303.698.9080 Fax 303.698.9241
www.abch2o.com

**Tables**

**Figures**



**Plates**



**Attachments**

## EXECUTIVE SUMMARY

Teck/Cominco Corporation is mining the Pogo gold orebody near Fairbanks, Alaska. Ore extraction is conducted by underground mining, with onsite ore processing, dry-stack tailings storage, and cemented backfilling of stopes. Inflow to the mine is a significant proportion of the total water input to the project.

Mine inflow to the project was evaluated in 2002 during the permitting phase of the mine, and mine inflow was predicted to be as follows:

| Expected Average Inflow | Expected Maximum Annual Inflow | Maximum Credible Annual Inflow |
|---|---|---|
| 139 gpm | 230 gpm | 300 gpm |

Operation of the mine commenced in June 2006. In the 30 months following, the average inflow to the mine has been:

| Year 1 (Jun 2006-May 2007) | Year 2 (Jun 2007-May 2008) | Year 3 (June 2008-Sep 2008) |
|---|---|---|
| 60 gpm | 72 gpm | 147 gpm |

Based on the observed rate of increase of mine inflow, Teck/Cominco commissioned a review of the mine inflow for the future mine operations. This review comprised updating geological, structural, climatic and hydrological data with information collected during development, exploration, and operation of the mine. The numerical Pogo Mine Inflow model was updated using this information, and recalibrated against the pre-mining head and the observed inflow history to date.

The updated Pogo Mine Inflow model was used to reevaluate the expected future inflow. An evaluation was also made of the effect of available inflow mitigation measures, including and selective mining of stopes in permeable areas, diversion of Liese Creek, and underground grouting of permeable zones. The analysis indicates that the average annual mine inflows in the future are expected to be as follows:

| **Mine Inflow Control Strategy** | **Average Inflow** | | **Notes** |
|---|---|---|---|
| | **2009** | **2015** | |
| Uncontrolled inflow | 240 gpm | 499 gpm | Assumes selective mining in permeable zones |
| Divert Liese Creek | 197 gpm | 335 gpm | Diversion from above upper mine portal to mouth |
| Grout Liese Fault | 178 gpm | 286 gpm | Grout all stopes in fault; may not be effective |
| Grout Liese and Graphite Faults | 125 gpm | 157 gpm | Grout stopes in both faults; may not be effective |
| Grout Faults and Divert Creek | 118 gpm | 156 gpm | Maximal mitigation; diversion provides insurance |

Based on the evaluation, the following recommendations are made:

- Divert Liese Creek above the mine footprint.
- Evaluate grouting of permeable portions of the major faults and if feasible, implement.
- Upgrade mine inflow, surface water flow, and groundwater pressure monitoring.
- Perform annual review of mine inflow and mitigation.

## 1. INTRODUCTION

Teck/Cominco Corporation (Teck) is mining the Pogo Project, a gold mine/processing facility located 90 miles east of Fairbanks, Alaska. The project comprises an underground mine, a milling facility, and a surface dry-stack tailings storage facility (Plate 1). Mining is by stoping with cemented backfill.

A significant component of the water management system for the Pogo mine and mill complex is the amount of water that is produced by the mine. All water that enters the mine must be pumped to the surface, treated, and either used in the process or discharged.

Mine inflow to the project was evaluated prior to mining (ABC, 2002), and was predicted to be:

| Expected Average Inflow | Expected Maximum Annual Inflow | Maximum Credible Annual Inflow |
|---|---|---|
| 139 gpm | 230 gpm | 300 gpm |

Operation of the mine commenced in June 2006. In the intervening 30 months, inflow to the mine was:

| Year 1 (Jun 2006-May 2007) | Year 2 (Jun 2007-May 2008) | Year 3 (June 2008-Sep 2008) |
|---|---|---|
| 60 gpm | 72 gpm | 147 gpm |

The sharp increase in inflow in 2008 has resulted from intersection of water-bearing faults associated with Liese Creek. This increase has raised concerns about the future inflow to the mine.

This report presents the results of a re-evaluation of the mine inflow, and an evaluation of the available methods of mine water inflow control and prevention. The re-evaluation utilizes improved inputs for the geohydrologic system including:

- Updated geolologic and structural data based on underground development, mining and continuing exploration drilling
- Updated infiltration information based on measured precipitation and snow information at the site, and in the central Alaskan basin area.
- Updated geohydrology information including testing of fault and orebody locations
- Updated geochemistry information based on water quality of inflow to the mine
- Updated mine inflow information, which allows better and longer calibration of simulated inflow based on mine development against recorded inflow

The new information has been added to the prior data and the inflow behavior of the mine system reevaluated using the previously-developed geohydrologic numerical model of the project. The Pogo Mine hydraulic model was calibrated against pre-mining water levels, and the observed flow to the mine during development and operation, to create a more accurate mine inflow prediction tool. The model is used to predict the future inflow to the mine, and the efficacy of a range of mine inflow control strategies in controlling the inflow.

# 2. HYDROGEOLOGY UPDATE

## 2.1 Geology

The country rock is predominantly low permeability gneiss. Development, exploration, and mining have confirmed the site geology, with the following changes:

- L1 Orebody: The extent of the quartz sill that hosts the L1 Orebody has been extended to the northwest, dipping to a depth approximately 1,000 feet below the elevation of the Goodpaster River (location on Plate 1, section on Plate 3).
- L3 Orebody: The L3 Orebody is contained within a quartz sill located approximately 150 feet below the L2 orebody (location on Plate 1, section on Plate 3). The extent of this orebody has been changed to match the observed conditions.
- Hillside colluvium: The country rock is covered with a thin mantle of colluvium on the hillsides; this mantle has been explicitly included in the model to better simulate the partition of infiltration between deep infiltration to the underlying bedrock, and shallow lateral seepage to the Liese and Pogo Creek colluvial fill.
- Liese Creek Valley Fill: The valley fill in Liese Creek is capable of carrying a significant shallow groundwater flow. The Liese Creek valley fill has been explicitly added to the model. Data collected on the geometry and hydrology of the fill, particularly in the construction and operation of the Tailings Treatment Facility (“TTP”) and the Recycle Tailings Pond (“RTP”) (Plate 1) have been used. In particular, the observations that the valley fill extends to as much as 70 feet depth, is comprised of a heterogeneous mix of boulders, cobbles, gravel, sand, and in places clay, and conducts as much as 200 gpm to wells completed in the vicinity of the RTP have been used in the model.

## 2.2 Structure

The mining and geologic investigation has identified and/or confirmed a number of large-scale faults and fault zones located in the host rockmass. The faults in the vicinity of the orebodies and the ancillary structures that have been investigated or inferred for the project are shown in Plate 2. An east-west cross section through the mine (Section A-A’) has been prepared to show the locations and dip of the faults (Plate 3). The fault identifications have changed somewhat since the initial exploration program, and so the entire suite of faults is discussed below.

The significance of the faults is that the Liese Creek Fault and the Graphite Fault are in general water bearing, and act as conduits for water flow in the vicinity of the mine. The rest of the faults are not water bearing, and tend to act as aquitards, limiting flow in the already low permeability rock mass, and more importantly the orebody sills which they crosscut.

### 2.2.1 Liese Creek Fault

The Liese Creek Fault runs sub-parallel to Liese Creek, crossing it above approximately the middle of the L1 orebody. This fault also runs approximately NW-SE, is sub-vertical, and exhibits right-lateral strike-slip offset of a few hundred feet. The fault varies from a few feet to 90 feet in width, and is highly permeable in places, based on exploration drilling and intersection underground.

### 2.2.2 Graphite Fault

The Graphite Fault also runs approximately NW-SE, sub-parallel to and beneath Liese Creek. The fault dips approximately 55˚ to the NE. The fault contains graphitic constituents, and has been the locus of intense shear, as indicated by slickensides in the rockmass. The fault is typically in the order of 100 feet wide in the vicinity of the orebodies, and is moderately permeable in most locations where it is intersected, as shown by seepage from the fault.

### 2.2.3 Northeast-Trending Faults

The group of northeast-trending faults includes the C, M, and J faults. It is expected that these faults are a group of echelon faults that extend at a spacing of approximately 1000 feet to the northwest and southeast. A group of faults have been inferred and are presented on Plate 2 as Z faults. The northeast-trending faults are steep, sub-vertical faults that exhibit up to 200 ft of left-lateral offset. The faulted material is typically a few feet wide. Measurable flow is not associated with these faults when encountered in the underground or in drilling.

### 2.2.4 Transverse Faults

There are a number of transverse faults that intersect the main fault fabric, including the A, I, N, G, and F Faults. These faults are sub-vertical, and are generally not water-bearing. They are generally displaced by the northeast trending fault set. In current mine mapping, these faults have been included with the Northeast-Trending fault set above.

### 2.2.5 Basalt Fault

The Basalt Fault is an east-west trending vertical fault zone that exhibits evidence of left-lateral strike-slip motion of approximately 50 ft. The fault contains a swarm of discontinuous basalt dikes. No water is associated with this fault.

### 2.2.6 Low-Angle Faults

Several low angle faults are recognized at Pogo where they occur adjacent to mineralized quartz veins. They typically strike northeast with shallow to moderate dips to the northwest. The faults are defined by zones of fault gouge and mélange up to 4 feet thick that occur along the hangingwall and/or the footwall of the quartz veins. Measurable water flows have never been associated with these faults in drillholes or in the underground development.

A conjugate set of southeast-dipping faults is also present near the major quartz veins.

## 2.3 Permafrost

Pogo is located in a zone of “discontinuous” permafrost”. This has meant in practice that some of the ground surface in the project is permanently frozen.

The hydraulic conductivity of “discontinuous” permafrost has been evaluated in this area, and has been estimated in the previous study to be ~0.02 ft/yr ($2x10^{-8}$ cm/s). No new data has been obtained to further refine this number.

Permafrost is located in all areas of the site except south-facing slopes, and beneath major water-courses, including the Goodpaster River, Liese Creek, and Pogo Creek (Plate 4).

## 2.4 Water Levels

Water levels were measured in wells prior to development. The resulting water levels are plotted as a piezometric surface in Plate 5. These data have not changed since the original study; however the contouring has been modified to reflect the new understanding of the structure at the site, creating a zone of high water pressure along the ridge above the orebodies. The zone of high pressure also conforms generally to the presence of permafrost at the site.

## 2.5 Hydraulic Conductivity

A key parameter determining mine inflow is the hydraulic conductivity of the site materials. Measured values of hydraulic conductivity are used in the model when available. Final values depend on calibration to match head conditions prior to mining, and inflow after mining began.

Significant testing of hydraulic conductivity was performed for the initial mine inflow evaluation (ABC, 2001). Conclusions from that study were:

- Shallow Bedrock ~5 ft/yr ($5x10^{-6}$ cm/s)
- Deep Bedrock ~0.2 ft/yr ($2x10^{-7}$ cm/s)
- Orebody (quartz) ~100 ft/yr ($1x10^{-4}$ cm/s)

Limited additional information was available to add to this database for this project, in particular information on the shallow colluvium in Liese Creek:

- Liese Creek Colluvium ~365 ft/yr ($4 \times 10^{-4}$ cm/s)

## 2.6 Mine Inflow

### *2.6.1 Inflow Rate*

Mine inflow has been measured since the inception of the mine exploration. Since mine operation began, the inflow to the mine has to be computed, to correct for water input to the mine for in-mine use, and water imported to the mine with the mine backfill that bleeds off prior to cementation. Mine inflow is presented in Table 1, and plotted in Figure 1.

*Table 1 - Pogo Mine Inflow*

| Month | Days | Mine Inflow (MG/m) | Mine Inflow (gpm) | Notes |
|---|---|---|---|---|
| Jul-06 | 31 | 2.6 | 58 | |
| Aug-06 | 31 | 3.2 | 72 | |
| Sep-06 | 30 | 3.2 | 74 | |
| Oct-06 | 31 | 3.2 | 72 | |
| Nov-06 | 30 | 2.3 | 53 | |
| Dec-06 | 31 | 2.5 | 56 | |
| Jan-07 | 31 | 2.9 | 65 | |
| Feb-07 | 28 | 1.6 | 40 | |
| Mar-07 | 31 | 1.8 | 40 | |
| Apr-07 | 30 | 1.8 | 42 | |
| May-07 | 31 | 3.0 | 67 | |
| Jun-07 | 30 | 3.2 | 74 | Includes 1.3 MG assumed stored in mine |
| Jul-07 | 31 | 2.6 | 58 | |
| Aug-07 | 31 | 3.5 | 78 | |
| Sep-07 | 30 | 3.5 | 81 | Subtracts 0.5 MG from 1.3 MG stored in mine |
| Oct-07 | 31 | 3.7 | 83 | Subtracts 0.5 MG from 0.8 MG stored in mine |
| Nov-07 | 30 | 3.1 | 72 | Subtracts last 0.3 MG stored in mine |
| Dec-07 | 31 | 3.0 | 67 | |
| Jan-08 | 31 | 2.9 | 65 | |
| Feb-08 | 29 | 3.5 | 84 | |
| Mar-08 | 31 | 3.6 | 81 | |
| Apr-08 | 30 | 2.3 | 53 | |
| May-08 | 31 | 2.9 | 65 | |
| Jun-08 | 30 | 4.5 | 105 | Includes 1.0 MG stored in mine |
| Jul-08 | 31 | 7.3 | 164 | Includes 2.5 MG stored in mine (total 3.5 MG) |
| Aug-08 | 31 | 7.8 | 175 | Includes 7.3 MG stored in mine (total 10.8 MG) |
| Sep-08 | 30 | 6.2 | 144 | Includes 1.7 MG stored in mine (total 12.5 MG) |

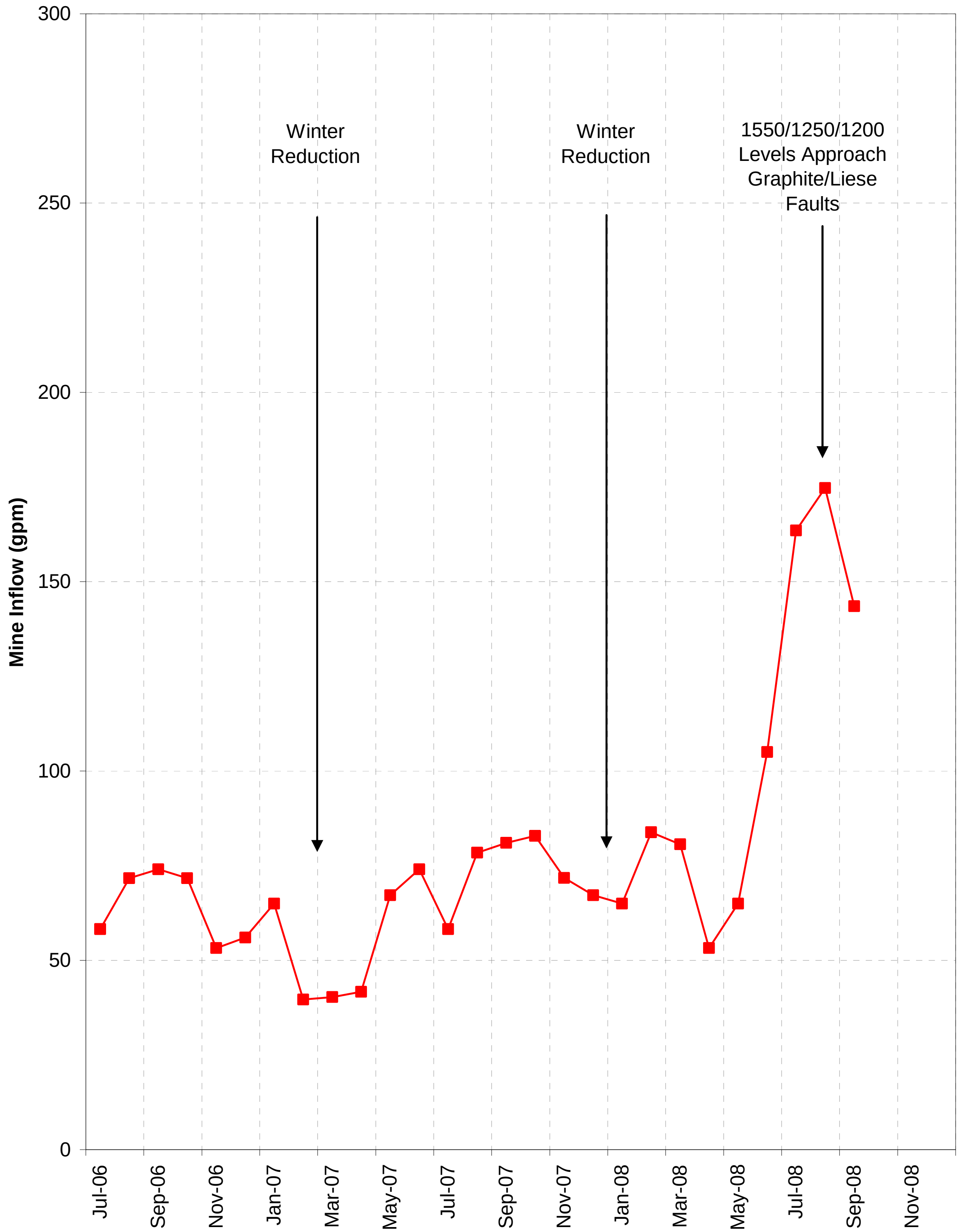
Source: Teck/Cominco - Pogo Mine Operations, October, 2008

Prior to the summer 2008 the inflow built up to slowly ~60 gpm. The flow increased significantly in summer of 2008 due to inflows on several levels as stoping approached the permeable fault system:

- 1550’ Level: 70 gpm (penetrated Graphite Fault)
- 1300’ Level: ~0 gpm (short of Graphite Fault)
- 1250’ Level: 25 gpm (approaching Graphite Fault)
- 1200’ Level: 25 gpm (approaching Graphite Fault)

In this period, water was stored in the mine due to insufficient treatment system capacity. A maximum of 12.5 million gallons was stored in this way.

*Figure 1 - Pogo Mine Inflow*



### *2.6.2 Reasons for Inflow Increase*

The reasons for the increasing inflow experienced in the mine include the following:

- Penetration of Permeable Faults: The underground mining has demonstrated that both the Graphite and Liese Creek faults are significantly permeable. Both are located in such a way as to interconnect Liese Creek with the L1 orebody, and the east side of L2 and L3 orebodies.
- Deeper mining: The mine is now developing on 1200' Level, and is now below the elevation of the Goodpaster River (~1340 ft msl). This puts both the Goodpaster River and Liese Creek into play as water sources for inflow to the mine.
- Imported water: Water is imported to the mine to satisfy requirements for mine services (such as drilling). In addition, water is imported to transport the mine backfill, and some bleeds off before the completion of the cementation process.

### *2.6.3 Source of Inflow*

Mine inflow appears to be sourced as follows:

1. <u>Direct seepage from infiltration at surface.</u> Direct seepage is limited due to permafrost which covers the majority of the site (Plate 4), and the generally low permeability country rock. Infiltration provides an essentially constant flow to mines, at a rate that averages approximately 60 gpm to the current mine footprint.
2. <u>Flow through orebodies.</u> The ore is present in quartz sills, which are of significantly higher permeability than the country rock. These sills act as a collector for water from near the mines, and deliver water to the open stopes.
3. <u>Flow through faults.</u> The major faults (Liese Creek Fault and Graphite Fault – Plate 2) are of higher permeability than the country rock and the orebodies. The major faults therefore act as conduits for flow from (particularly) Liese Creek to the mine. The minor faults are, in general, of similar permeability to the country rock, and are therefore not expected or observed to conduct significant flow to the mine.
4. <u>Flow from Goodpaster River.</u> The Goodpaster River is located at an elevation of 1340 ft msl. The elevations of the lower levels of the L1 and L3 orebodies are up to 1,000 feet below river level. Flow from the Goodpaster can reach the mine through country rock (at a slow rate), and through the main faults (at a greater rate).

## 2.7 Inflow Chemistry

Water quality samples have been taken in the mine on a number of occasions, and analyzed for major ionic species, cyanide, and metals. The results are summarized in Table 2.

*Table 2 - Pogo Mine Inflow Chemistry*

| PARAMETER | | 1200 STOPE | 1250 STOPE | | 1300 STOPE | 1550 STOPE | BOREHOLE DH98C |
|---|---|---|---|---|---|---|---|
| | | 21-Aug-08 | 04-Jul-07 | 21-Aug-08 | 21-Aug-08 | 21-Aug-08 | 04-Jul-07 |
| TDS | mg/L | 970 | 349 | 900 | 540 | 390 | 323 |
| TSS | mg/L | 74 | 77 | 227 | 367 | 3 | <4 |
| ALK-T | mg/L | 127 | 156 | 144 | 164 | 187 | 153 |
| SO4 | mg/L | 391 | 90 | 355 | 202 | 136 | 87 |
| NITRATE | mg/L | 48 | 5 | 43 | 20 | 4 | 1 |
| CN-WAD | µg/L | 24 | 1 | 20 | 5 | 32 | <1 |
| AS-T | µg/L | 1790 | 98.5 | 4560 | 2620 | 175 | 156 |
| CU-D | µg/L | 4 | 1 | 4 | 0 | 1 | 1 |
| FE-D | µg/L | 650 | -6 | 707 | 452 | 135 | 14 |
| NA-D | mg/L | 152 | 8 | 156 | 99 | 54 | |
| SB-D | µg/L | 10 | 5 | 12 | 10 | 8 | 2 |
| SE-D | µg/L | 26 | 0 | 27 | 7 | 9 | 0 |
| ZN-D | µg/L | 1 | 1 | 1 | 3 | 1 | 2 |

The mine water chemistry may provide insight into the source of the water in the mine:

- Arsenic: Arsenic is generally elevated in bedrock, with concentrations ranging from 19 µg/L to 3679 µg/L, and averaging 1,350 µg/L (ABC, 2001). The early inflow into the stopes is low in arsenic, typically in the order of the concentration seen in the bedrock (but not in Liese Creek, which is close to nondetect in arsenic). Later inflows are higher in arsenic, apparently due to the effect of mixing of mine inflow water with bleed-water from the backfill. There is no evidence of low arsenic inflow from Liese Creek, although this signature may have been overwhelmed by arsenic from the backfill.
- Cyanide: Early inflow into stopes is low in cyanide, which is consistent with the water being sourced from the bedrock. The later flow into stopes is higher in cyanide, due to bleed water from backfill paste.

Based on the chemistry, it is concluded that there is to date little evidence that water sourced in Liese Creek has up till now displaced water in the bedrock sufficiently to result in low metal, low TDS inflow to the mine. Mine inflow water appears instead to still be coming predominantly from bedrock storage.

## 2.8 Infiltration

### *2.8.1 Concept*

Infiltration to the surface from precipitation is the principal source of inflow to the mine. Other sources are the Goodpaster River, backfill slurry and underground mine operations water.

Infiltration as used in the modeling of the inflow to the mine is considered to be any water that penetrates into the soil cover from the ground surface at the site. This is a change in definition from earlier modeling of the site, where infiltration was considered to be, and modeled as, infiltration into the bedrock system at the site. This change was made to include all water that does not run off or evaporate in the model water system. This ensures that particularly peak inflows to the mine from streams, stream alluvium, and other water bodies are explicitly included in the model, and are available to flow into the mine if the hydraulic conduits exist.

This is particularly important with respect to Liese Creek. Liese Creek has been observed to receive a relatively large amount of flow from the shallow alluvium/colluvium layer on the adjacent hillsides. This water flows in the colluvial fill in the creek valley, and when the flow exceeds the carrying capacity of the valley fill, it emerges as surface flow. Because there appear to be significant hydraulic connections between the creek alluvium and the mine, via the Liese Creek and Graphite faults, this flow component is the largest single contributor to the inflow to the mine, and the largest single contributor to the variability of estimates of the inflow.

A direct estimate of infiltration is obtained in two ways:

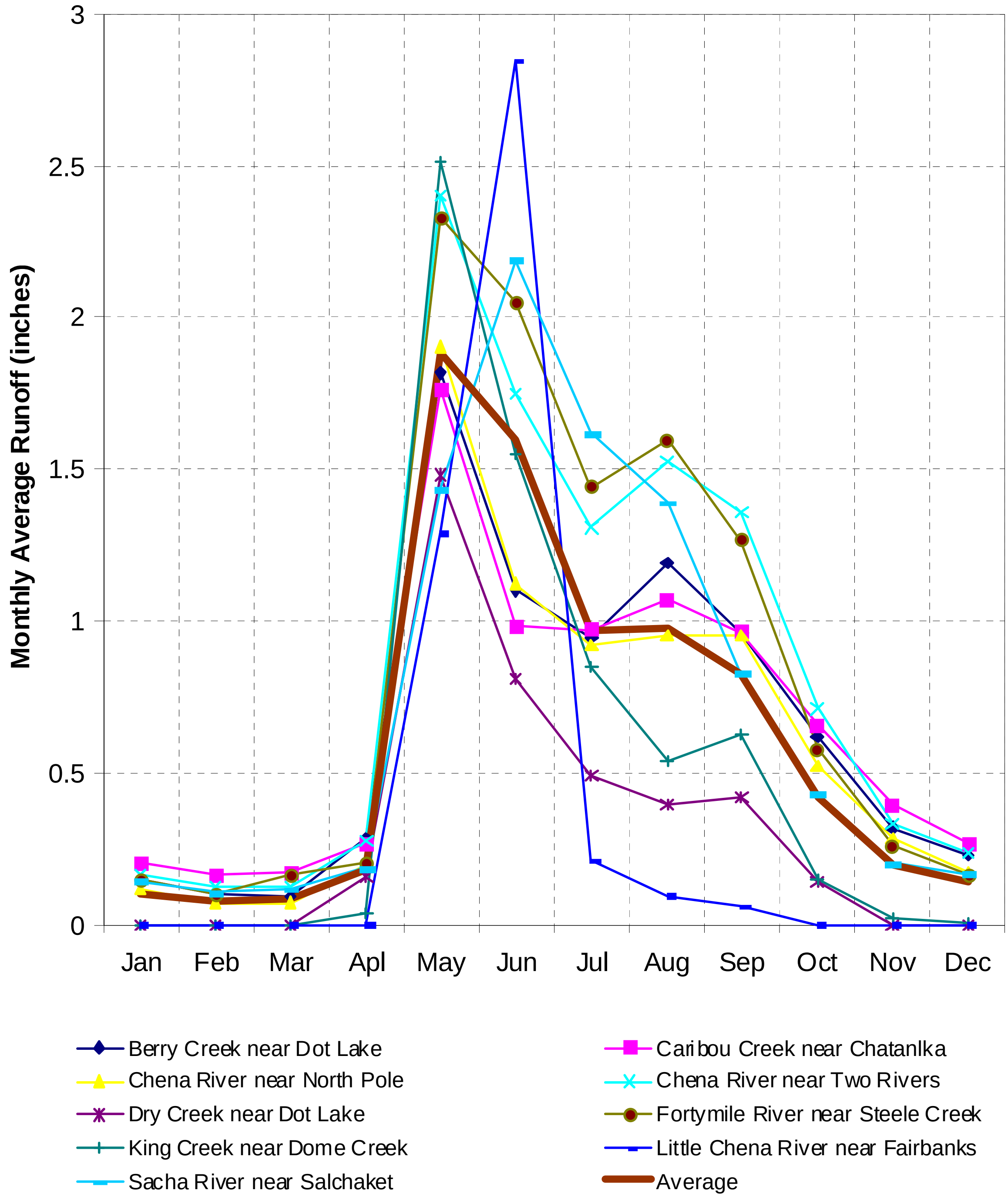
- River basin productivity considerations
- Local water balance

In addition, infiltration is revisited as a model calibration parameter.

### *2.8.2 River Basin Productivity*

There are a number of large inland river basins in central Alaska that have been monitored for many years. The monthly average runoff (flow per unit area of catchment) for these rivers is presented in Figure 2. The data show little evidence of major variation between river basins. The flow from these rivers is considered representative of the flow productivity of the region, which includes Pogo.

*Figure 2 - Basin Productivity of Alaskan Rivers*



The monthly average flow is tabulated in Table 3. The average annual river basin productivity is 7.6 inches per year, with a peak productivity of 1.8.inches per month.

*Table 3 - Productivity of Alaskan River Basins*

| Month | Stream Basin Productivity (in) |
|---|---|
| Jan | 0.15 |
| Feb | 0.1 |
| Mar | 0.1 |
| Apr | 0.2 |
| May | 1.8 |
| Jun | 1.6 |
| Jul | 1 |
| Aug | 1 |
| Sep | 0.8 |
| Oct | 0.4 |
| Nov | 0.25 |
| Dec | 0.2 |
| **Annual** | **7.6** |

The productivity is a reasonable estimate of the average infiltration in the basins. This is because there is little surface runoff that has not emerged from the ground surface, and was once groundwater flow.

### *2.8.3 Water Balance*

Infiltration quantity has been estimated from water balance considerations:

Infiltration = Precipitation – Runoff - Evapotranspiration – Sublimation - Snowpack buildup

Due to the need to have reliable data for each of these parameters to perform the water balance, the gauging station at Big Delta, 34 miles southwest of Pogo and approximately 70 feet lower than the base camp at Pogo was used (Table 4).

*Table 4 - Climatological Data - Big Delta, AK - 1937-2007*

| Element | Temperature (C) | Total Precipitation (in) | Snowfall (in) | Snow Depth (in) | Snowfall (in. equiv) | Snow depth (in. equiv) |
|---|---|---|---|---|---|---|
| Jan | -19.6 | 0.32 | 5.4 | 8 | 0.33 | 0.8 |
| Feb | -15.9 | 0.32 | 5.1 | 10 | 0.31 | 1 |
| Mar | -10.6 | 0.25 | 4.3 | 9 | 0.26 | 0.9 |
| Apr | -0.5 | 0.25 | 2.9 | 4 | 0.18 | 0.4 |
| May | 8.4 | 0.85 | 0.6 | 0.5 | 0.04 | 0.05 |
| Jun | 14.1 | 2.21 | | | | |
| Jul | 15.6 | 2.65 | | | | |
| Aug | 12.9 | 1.96 | | | | |
| Sep | 6.6 | 1.10 | 1.7 | 0.5 | 0.10 | 0.05 |
| Oct | -3.9 | 0.63 | 9.3 | 2 | 0.57 | 0.2 |
| Nov | -14 | 0.48 | 8.4 | 5 | 0.52 | 0.5 |
| Dec | -18.8 | 0.38 | 6 | 7 | 0.37 | 0.7 |
| **Annual** | **-2.1** | **11.36** | | | **2.68** | |

The water balance evaluation of infiltration is shown on Table 5, using average monthly data for Big Delta from 1937 to 2007.

*Table 5 - Infiltration Mass Balance - Big Delta*

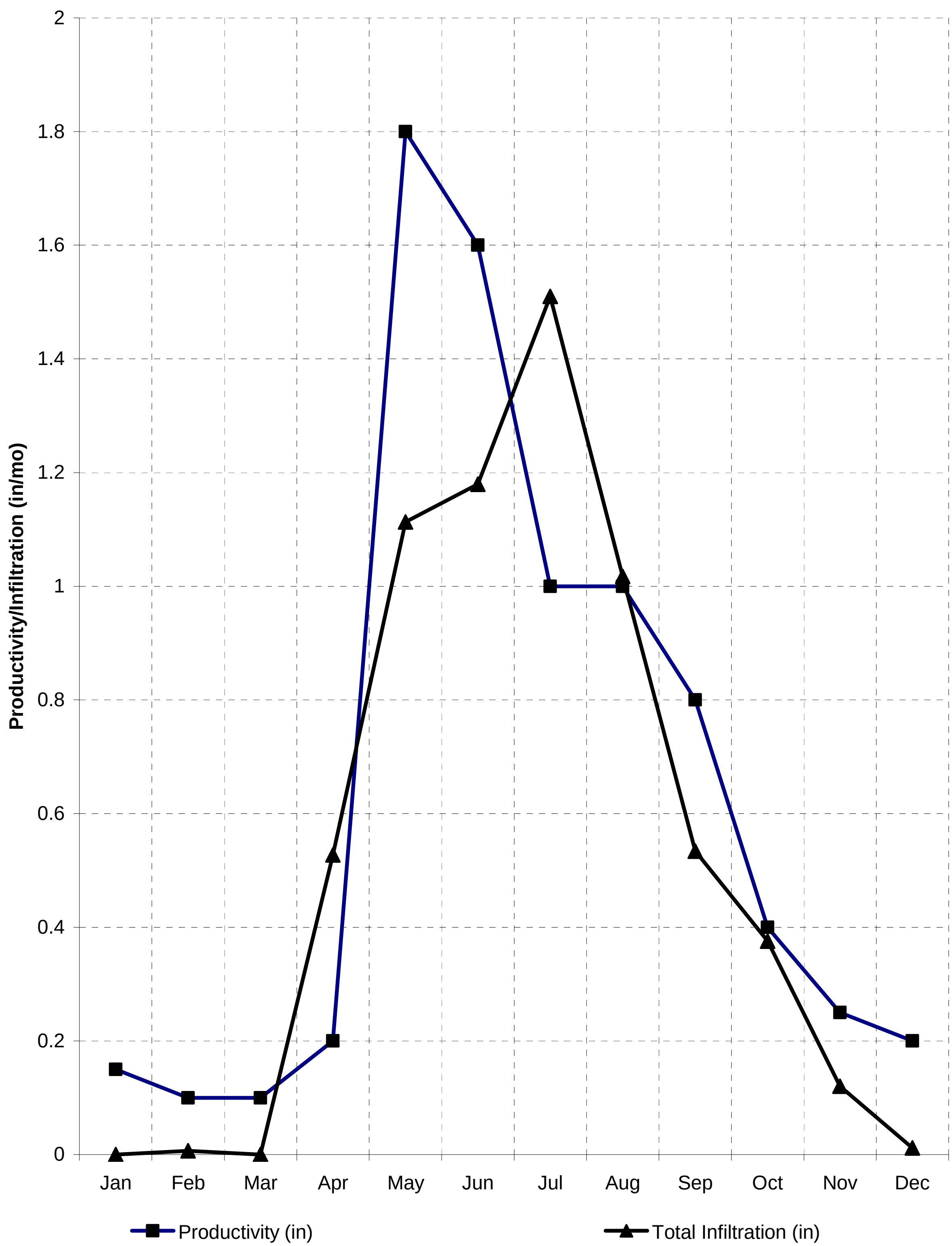
| Month | Temperature (C) | Precipitation (in) | Snowfall (in) | Snowfall (in. equiv) | Rainfall (in) | Sublimation (in) | Evapotranspiration (in) | Infiltration (in) | Meltwater (in) | Total Infiltration (in) |
|---|---|---|---|---|---|---|---|---|---|---|
| Jan | -19.6 | 0.32 | 5.4 | 0.32 | 0.00 | 0.084 | | 0.00 | 0.00 | 0.00 |
| Feb | -15.9 | 0.32 | 5.1 | 0.31 | 0.01 | 0.084 | | 0.01 | 0.00 | 0.01 |
| Mar | -10.6 | 0.25 | 4.3 | 0.25 | 0.00 | 0.084 | | 0.00 | 0.00 | 0.00 |
| Apr | -0.5 | 0.25 | 2.9 | 0.18 | 0.07 | 0.084 | | 0.07 | 0.46 | 0.53 |
| May | 8.4 | 0.85 | 0.6 | 0.04 | 0.81 | 0.084 | 0.6 | 0.20 | 0.91 | 1.11 |
| Jun | 14.1 | 2.21 | 0 | 0.00 | 2.21 | 0.084 | 1.0 | 1.18 | | 1.18 |
| Jul | 15.6 | 2.65 | 0 | 0.00 | 2.65 | | 1.1 | 1.51 | | 1.51 |
| Aug | 12.9 | 1.96 | 0 | 0.00 | 1.96 | | 0.9 | 1.02 | | 1.02 |
| Sep | 6.6 | 1.10 | 1.7 | 0.10 | 1.00 | 0.084 | 0.5 | 0.51 | 0.02 | 0.53 |
| Oct | -3.9 | 0.63 | 9.3 | 0.57 | 0.06 | 0.084 | | 0.06 | 0.32 | 0.38 |
| Nov | -14 | 0.48 | 8.4 | 0.48 | 0.00 | 0.084 | | 0.00 | 0.12 | 0.12 |
| Dec | -18.8 | 0.38 | 6 | 0.37 | 0.01 | 0.084 | | 0.01 | 0.00 | 0.01 |
| **Annual** | **-15.4** | **11.40** | **43.70** | **2.62** | **8.78** | **0.84** | **4.21** | **4.57** | **1.83** | **6.40** |
| **Annual %** | | **100%** | | **23%** | **77%** | **7%** | **37%** | **40%** | **16%** | **56%** |

Notes:
1. Evapotranspiration computed from potential evapotranspiration of 1.14” per month, pro-rated by temperature above freezing, with full evapotranspiration in July.
2. Snow meltwater is computed based on a model of snowfall melting based snowfall, change in snow depth, snowpack moisture content, and spring temperature. Snow melts in April and May, with melting of some of the snowfall in October.
3. Infiltration is assumed to include any surface runoff, as this would be available for infiltration if the geohydrology of the location allowed.

The water balance indicates that the precipitation of 11.4 inches per year causes an infiltration of 6.4 inches per year, with a peak of 1.18 inches per month (a rate of 18.1 inches per year) in July. There is essentially no infiltration in the months of December through March.

This monthly infiltration estimate is compared with the infiltration estimate based on the river productivity above, in Figure 3. The two estimates of infiltration are very similar. Based on this similarity, the Big Delta infiltration distribution is used for initial calibration of the revised model.

*Figure 3 - Stream Productivity and Infiltration Estimate*



# 3. POGO MINE INFLOW MODEL

## 3.1 Model

Inflow to the mine was evaluated using an updated version of the original USGS MODFLOW numerical model that was used in the permitting process (ABC, 2001):

- Domain divided into 17 layers, averaging 180 feet thick.
- The domain divided into 100’x100’ cells.
- The geology remains the same as the prior model.
- Location of fault zones modified as described above.
- Hydraulic conductivity of the materials in the analysis initially adopted from the prior model.
- External boundary conditions remain unchanged.
- Goodpaster River constant head boundary remains unchanged.
- Liese Creek input as a stream boundary, with flow from the eastern edge of the basin to close to the Goodpaster River.

The modeled geology of the L1 Orebody Layer is presented in Plate 6, superimposed on the orebody locations and the project facilities.

## 3.2 Boundary Conditions

The following boundary conditions remained the same as in the initial modeling:

- Constant head at the Goodpaster River
- No flow on all side and bottom boundaries

The following boundary conditions were modified for the update:

- Time-variant infiltration on the upper surface. The infiltration was varied monthly as shown in Table 5 for transient runs, or set equal to the average regional infiltration of 6.4 in/yr for steady state runs.
- A “stream” boundary along Liese Creek which collects water from above, and either loses or gains water from the model.
- A “drain” boundary at each node at an open mined stope or development drift, set to drain water down to the elevation of the node.

## 3.3 Calibration

Calibration is necessary to ensure that the model reasonably replicates the performance of the real system. Calibration involves the analysis of known situations with the model, and comparison of the observed behavior of the systems against the predicted behavior of the model.

In general, parameters were varied in the model within the reasonably available ranges until the model behavior was a reasonable simulation of the actual behavior.

Calibration is most effective when the measured quantity being modeled is the output of interest (in the current mine inflow analysis, calibration is best done by measuring and predicting flow from the mine.)

### *3.3.1 Calibration against Pre-Mining Head*

The model was calibrated against the initial head that was measured prior to the start of mining (Plate 5). The model was run with no mining or development-drift drainage, and the resulting heads were compared with the measured pre-mining head in 19 wells.

The following conditions and parameters in the model were varied to obtain the best fit between modeled and observed pre-mining head:

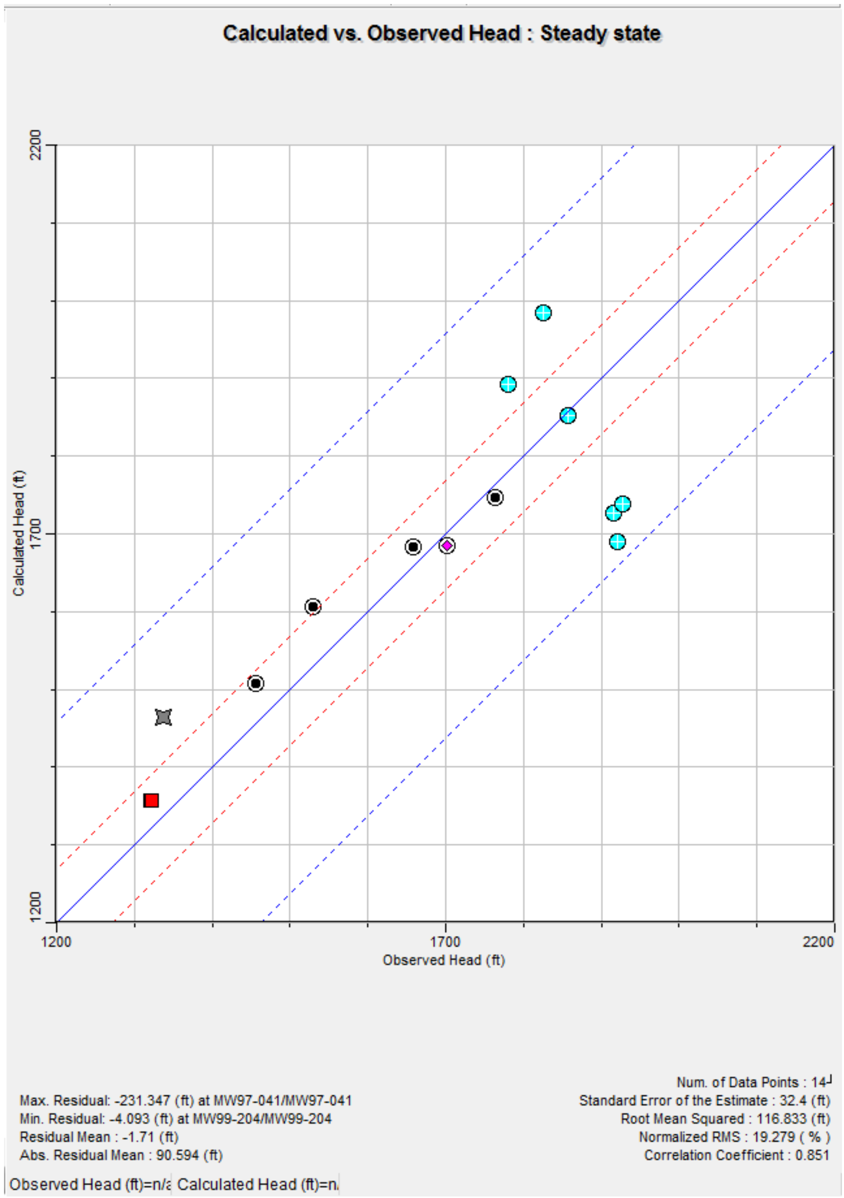
- Vertical hydraulic conductivity of the country rock. The general head conditions were sensitive in the model to the ability for water to infiltrate from precipitation at the surface. This is mainly controlled by the vertical hydraulic conductivity of the country rock, which was varied within the measured values to obtain the best fit.
- Fault hydraulic conductivity. The head conditions, particularly the head “mound” along the ridge, were sensitive to the hydraulic conductivity of the Liese and Graphite faults. The hydraulic conductivities of all the faults are able to be independently varied in the model, and the values obtained provided the best fit between measured and observed head (note that this calibration was performed cyclically with calibration against inflow, which is heavily dependent on fault hydraulic conductivity).
- Lateral hydraulic conductivity in the hillside colluvium. The split in the infiltration between vertical infiltration through the country rock and lateral flow along the colluvial layer on top of the bedrock is important in determining the head in the bedrock. Accordingly, this was calibrated using the head data.

The final head calibration result is presented in Figure 4. The calibration is reasonably good for a highly faulted low permeability rock aquifer:

- Residual Mean = -1.7 ft
- Std Error of the Estimate = 32.4 ft
- Normalized RMS = 19.3%

The lack of fit in the three wells below the hinge line is likely due to impact on their heads by exploration development nearby underground by the time that readings were taken.

*Figure 4 - Final Head Calibration*



### *3.3.2 Calibration to Mine Inflow 2006-2007*

The second calibration point was to the mine inflow in the period July 2007-June 2008. The inflow to the mine averaged 60 gpm; 80 gpm in the summer, and 40 gpm in the winter (Figure 1).

During this period there was mining on the southwest of the L1 orebody, not penetrating the permeable Liese or Graphite faults, except in development below the more permeable orebody zones.

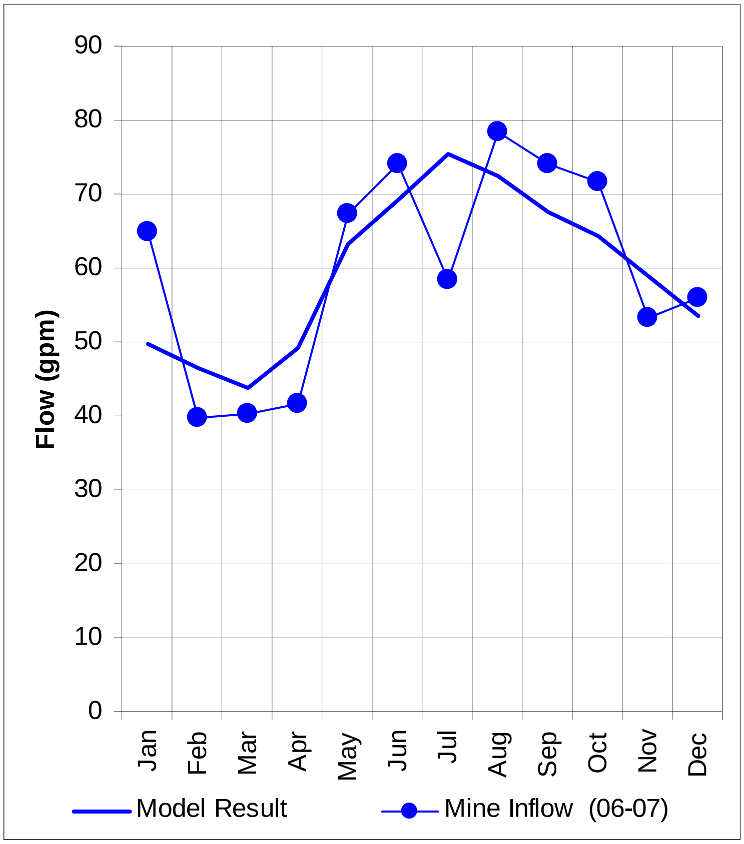
Calibration involved variation of the hydraulic conductivity of the Liese and Graphite faults, which control most of the inflow to the mine, as they are direct conduits between Liese Creek and the orebodies, and they conduct groundwater from the general rockmass to the mining zones.

The computed and measured flows for the final transient calibration run are presented in Figure 5:

- Residual Mean = -0.5 gpm
- RMS Error = 8.4 gpm
- Normalized RMS = 14.1%

The calibration is considered satisfactory for prediction of inflow to the mine from the materials on the south western side of the project. The seasonality of both the observed and modeled flows is a reflection of the availability of significant amounts of water in the summer from flow in Liese Creek due to snowmelt, thawing, and increased precipitation.

*Figure 5 - Calibration to Low Inflow (2007-8)*



### *3.3.3 Calibration to Fault Flow*

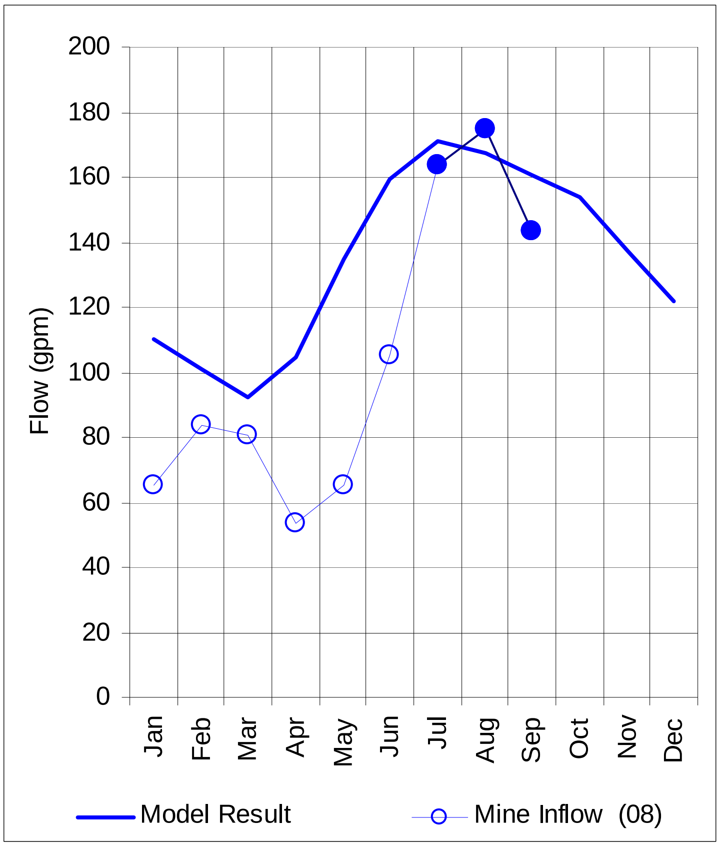
In June 2008 mining at Pogo had developed to elevations that were below the adjacent Liese Creek. In addition, mining was progressing towards the northeast of the L1 orebody, for the first time penetrating the Graphite Fault at the 1550' level. Later in the year, the mining approached the Graphite Fault on the 1250' Level, the 1200' Level, and the 1300' level.

As can be seen on Figure 1, the mine inflow increased significantly, from 60 gpm to 170 gpm. This period was used for calibration, with the results presented in Figure 6 below. The calibration analysis reflected the expected inflow for an entire year with the Graphite Fault crossed and the Liese Fault approached. The fault was actually crossed in June 2008. Accordingly, only the last three points of the actual inflow data (filled in) are relevant. For these three points, the calibration statistics are:

- Residual Mean = 5.7 gpm
- RMS Error = 11 gpm
- Normalized RMS = 7.1%

The pattern and the results represent a reasonable calibration against this data.

*Figure 6 - Calibration to High Mine Inflow (2008)*



### 3.3.4 Calibration Summary

The model has been calibrated to simulate with acceptable precision the behavior of the groundwater flow system for three important conditions:

- Head under natural infiltration through discontinuous permafrost
- Flow through the low permeability rockmass
- Flow when major permeable faults are encountered

The hydraulic conductivity regime that resulted from this calibration is presented in Table 6.

*Table 6 - Hydraulic Conductivity for Pogo Materials*

| Material | Kx (ft/d) | Ky (ft/d) | Kz (ft/d) |
|---|---|---|---|
| Country Rock | 0.004 | 0.004 | 0.004 |
| Alluvium (valley) | 10 | 10 | 10 |
| Colluvium (hillside) | 0.001 | 0.001 | 0.001 |
| Liese Creek Fault | 1.2 | 1.2 | 1.2 |
| Graphite Fault | 0.12 | 0.12 | 0.12 |
| Basalt Fault | 0.001 | 0.001 | 0.001 |
| Northeast Faults | 0.001 | 0.001 | 0.001 |
| “G” Faults | 0.001 | 0.001 | 0.001 |
| “A” Fault | 0.001 | 0.001 | 0.001 |
| Permafrost | 0.001 | 0.001 | 0.001 |
| Orebody Quartz | 0.15 | 0.15 | 0.15 |
| Liese Creek Colluvium | 1 | 1 | 1 |

Note: K denotes hydraulic conductivity

# 4. MINE INFLOW ANALYSIS

## 4.1 General

Mine inflow analyses have been performed to identify the inflow that may be expected to the mine as it develops, and to evaluate the effectiveness of a range of inflow control strategies that could be employed at the mine.

The developments that have been evaluated are:

- Mine development in mid-2009
- Mine development in mid-2015

The evaluation has been made with the following assumptions:

- The worked-out stopes are backfilled with paste which seals backfilled stopes against inflow
- Approximately 24 stopes are open at any time, distributed around the mine
- Only a limited number of stopes are open at any one time to the Liese and Graphite faults

The files of the analyses performed and presented in this report are presented in Attachment 1.

## 4.2 Mine Inflow Analysis – 2009

### *4.2.1 Conditions*

Mining conditions for the 2009 inflow evaluation are as follows (Plate 7):

- L1 Orebody:
  - 19 stopes open
  - 1 breaching Liese Fault
  - 5 breaching Graphite fault
  - All other stopes backfilled
- L2 Orebody:
  - 5 stopes open
  - None breaching Graphite or Liese fault
  - Mine backfill plugging
  - All stopes other stopes backfilled
- L3 Orebody:
  - Not developed at this time

All analyses used the following conditions:

- Infiltration rate of the annual average of 6.4 inches per year, typical for the month of September.
- Liese Creek permeability set equal to highest value measured (U098 – 338 ft/d)

### 4.2.2 Pre-Mining Flow

A steady-state analysis was performed to establish the baseline for flow conditions prior to mining. The flows for this case are presented in Table 7.

*Table 7 – Flows – Pre-Mining*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 335 | 509 | Inflow to the model << outflow from model |
| Dewatering | | **0** | No dewatering |
| Goodpaster | | 489 | Mine water not discharged to river in model |
| Total | 999 | 999 | Flow balance |

The evaluation showed the following:

1. Inflow to the model from Liese Creek is relatively small, and outflow from the model to Liese Creek is relatively large.
2. The net creek outflow (outflow – inflow) is removed from the model (at the mouth of the creek).
3. The balance of the total water that enters the model as infiltration exits to the Goodpaster.
4. Pogo Creek is not modeled as a stream; water in this valley exits via the colluvium to the Goodpaster.

### 4.2.3 Uncontrolled Inflow – 2009

A steady-state analysis was performed for uncontrolled inflow to the mine in 2009. The analysis used the following conditions:

- Infiltration rate of the annual average of 6.4 inches per year, typical for the month of September.
- Liese Creek permeability set equal to highest value measured (U098 – 338 ft/d)

The flows for this case are presented in Table 8.

*Table 8 - Flows – 2009 – Uncontrolled Inflow*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 398 | 400 | All flow re-infiltrates at the mouth of the creek |
| Dewatering | | **240** | Dewatering from L1 and L2 levels |
| Goodpaster | | 423 | No net inflow to the model at any river location |
| Total | 1062 | 1062 | Flow balance |

The evaluation showed the following:

1. Expected mine inflow is 240 gpm, much of it the one penetration of the Liese Fault.
2. Mine inflow represents half of the flow in Liese Creek.
3. Inflow is mainly limited by permeability of the fault system, and the low rock permeability.
4. Essentially all streamflow that enters Liese Creek exfiltrates before reaching the Goodpaster River.

### 4.2.4 Stream Diversion – 2009

Mine inflow could be reduced by diverting Liese Creek (Plate 9). This would limit the availability of water in the Liese Creek valley, both flowing in the stream and flowing in the underlying valley fill alluvium.

Streamflow would be collected at the 1875 Portal, from which it would be piped 4,500 feet to close to the mouth of Liese Creek at elevation 1500 ft msl.

The flows for this case are presented in Table 9:

*Table 9 –Flows - 2009 – Stream Diversion*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 346 | 347 | Flow reduced because pipe excludes collection |
| Dewatering | | **197** | Mine inflow reduction of 43 gpm |
| Goodpaster | | 465 | Increased by 42 gpm not intercepted by mine |
| Total | 1010 | 1010 | Flow balance |

The evaluation showed the following:

1. Installation of a diversion pipe would reduce peak mine inflow by 18% to ~200 gpm.
2. Flow in Liese Creek is actually reduced; there is an increase in drawdown around the mine caused by "starving" the Liese Creek alluvium of water. This results in greater capture of water by the mine above the diversion point. In addition, the model allows no inflow to the creek in the reach where the pipe is installed, so the total inflow is reduced[1].

[1] The pipeline is modeled as a "stream", with a very low hydraulic conductivity substrate. This prevents water from flowing out of the "stream" into the colluvium over the stretch where the pipe is located, and also (realistically) prevents any water that would flow to the stream valley in the area where the pipeline is installed from entering the pipe. This water is available for infiltration in the streambed, and ultimate entry into the mine. This flow could be collected in the stream bed and introduced into the pipe at various points along its length, but is not in the modeled case. At the bottom of the pipe the "stream" reverts to its former condition, with a high permeability substrate.

### *4.2.5 Grouting Liese Creek Fault – 2009*

Mine inflow can be reduced by grouting Liese Creek fault, the main conductor of water to the mine. For the purpose of evaluating the effect, grouting is assumed to return the rock around the stope to the permeability of the orebody. The feasibility of grouting the Liese Creek fault in the orebody is not demonstrated. However, test experience in U098 in 2000 indicates that the water enters in less than 1 foot of rock, which suggests ready groutability.

The flows for this case are presented in Table 10.

*Table 10 - Mine Inflow - 2009 – Grout Liese Creek Fault*

| Flow Element | Inflow (gpm) | Outflow (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 394 | 414 | Outflow to creek increased as mine accepts less |
| Dewatering | | **178** | Mine inflow reduction of 62 gpm |
| Goodpaster | | 466 | Increased by 42 gpm not intercepted by mine |
| Total | 1058 | 1058 | Flow balance |

The evaluation showed the following:

1. Successfully grouting the Liese Fault would on its own reduce mine inflow 25% to ~180 gpm. In this case, the grouting is required in only one location (the 1574 ft stope, Plate 7).
2. Inflow to the rockmass from the stream would remain unchanged from the uncontrolled inflow case, but outflow from the rockmass to the stream would be greater, due to the reduced inflow to the mine.

### 4.2.6 Grouting Liese Creek and Graphite Faults – 2009

Mine inflow may be further reduced by grouting Liese Creek Fault and Graphite Fault, the two main conductors of water to the mine. The Graphite fault is approximately 100 feet wide, and has been observed to be permeable over much of that width.

The feasibility of grouting the Graphite Fault has not been demonstrated, at least in locations where the fault produces substantial inflow. Due to the generally low hydraulic conductivity [estimated by calibration to be 0.12 ft/day (4 x $10^{-5}$ cm/sec)], grouting may require superfine Portland cement and/or high pressure injection.

The flows for this case are presented in Table 11.

*Table 11 - Mine Inflow - 2009 – Grout Liese and Graphite Faults*

| Flow Element | Inflow (gpm) | Outflow (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 360 | 432 | Grouting Graphite fault reduces inflow from creek |
| Dewatering | | **125** | Mine inflow reduction of 115 gpm |
| Goodpaster | | 468 | Increased by 42 gpm not intercepted by mine |
| Total | 1024 | 1024 | Flow balance |

The evaluation showed the following:

1. Successfully grouting the Liese and the Graphite Faults would reduce mine inflow 48% to ~125 gpm. This is a highly effective mitigation measure, as the remaining inflow to the mine is similar to the inflow to the developmental drifts.
2. Inflow from the creek to the bedrock is reduced, presumably due to the reduced water demand by the mine. Outflow from the rock to the creek is also increased, due to the reduced interception by the mine.

### 4.2.7 Grouting Faults and Stream Diversion – 2009

Mine inflow may be further addressed by grouting Liese Creek Fault and Graphite Fault, and by diverting Liese Creek at the surface.

The flows for this case are presented in Table 12.

*Table 12 - Mine Inflow - 2009 – Grout Liese and Graphite Faults*

| Flow Element | Inflow (gpm) | Outflow (gpm) | Notes |
|---|---|---|---|
| Infiltration | 538 | | Infiltration less due to fixed head in stream bed |
| Liese Ck | 328 | 330 | Grouting Graphite fault reduces inflow from creek |
| Dewatering | | **118** | Mine inflow reduction of 122 gpm |
| Goodpaster | | 419 | Increased by 42 gpm not intercepted by mine |
| Total | 867 | 867 | Flow balance |

The evaluation showed the following:

1. Diverting the creek while successfully grouting the Liese and the Graphite Faults is computed to slightly decrease the mine inflow beyond grouting the faults; the mine inflow would be reduced 51% to ~118 gpm.
2. The addition of the stream diversion reduced the inflow by 7 gpm. However, the principal benefit is that the diversion provides insurance against an unexpected direct connection between the stream and the mine.

### 4.2.8 Summary of Flow Control Actions – 2009

The flow control actions and their effect on flow are summarized in Table 13.

*Table 13 - Summary of Inflow Control - 2009*

| | |
|---|---|
| Uncontrolled Inflow | 240 gpm |
| Liese Creek Diversion | 197 gpm |
| Grout Liese Fault | 178 gpm |
| Grout Liese and Graphite Faults | 125 gpm |
| Grout Liese and Graphite Faults and Divert Creek | 118 gpm |

Diverting Liese Creek provides an approximately 20% reduction in flow to the mine. If the faults are grouted where permeable a 48% reduction in flow could be achieved. Plugging the faults and diverting the creek produces the maximum reduction of 51% of inflow.

## 4.3 Mine Inflow Analysis – 2015

### *4.3.1 Conditions*

Mining conditions for the 2015 inflow evaluation are as follows (Plate 8):

- L1 Orebody:
  - 26 stopes
  - 8 breaching Liese Fault
  - 6 breaching Graphite Fault
  - All other stopes backfilled
- L2 Orebody:
  - 5 stopes
  - 2 breaching both Graphite and Liese faults
  - All other stopes backfilled
- L3 Orebody:
  - 2 stopes
  - 1 breaching Graphite Fault
  - All other stopes backfilled

All analyses used the following conditions:

- Infiltration rate of the annual average of 6.4 inches per year, typical for the month of September.
- Liese Creek permeability set equal to highest value measured (U098 – 338 ft/d)

### 4.3.2 Uncontrolled Inflow – 2015

A steady-state analysis was performed for uncontrolled inflow to the mine in 2015.

The flows for this case are presented in Table 14.

*Table 14 - Flows – 2015 – Uncontrolled Inflow*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 308 | 309 | Inflow = outflow (all inflow intercepted by mine) |
| Dewatering | | **499** | Uncontrolled peak inflow |
| Goodpaster | | 165 | Most of the infiltration is intercepted by mine |
| Total | 972 | 972 | Flow balance |

The evaluation showed the following:

1. Expected mine inflow is 499 gpm.
2. Essentially all the flow in Liese Creek is intercepted and directed into the mine.
3. Inflow is mainly limited by water availability at surface.

### *4.3.3 Stream Diversion – 2015*

Mine inflow can be reduced by diverting Liese Creek (Plate 9), limiting the availability of water in the Liese Creek valley, both flowing in the stream and flowing in the underlying valley fill alluvium.

Streamflow would be collected at the 1875 Portal, from which it would be piped 4,500 feet to close to the mouth of Liese Creek at elevation 1500 ft msl.

The flows for this case are presented in Table 15:

*Table 15 – Flows – 2015 – Stream Diversion*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 294 | 295 | Inflow = outflow |
| Dewatering | | **335** | Flow reduction = 164 gpm (33%) |
| Goodpaster | | 328 | 163 gpm more infiltration reaches Goodpaster |
| Total | 958 | 958 | Flow balance |

The evaluation showed the following:

1. Installation of a diversion pipe would reduce peak mine inflow by 164 gpm (33%) to 335 gpm.
2. The reduction of mine inflow reflects directly in the amount of groundwater that reaches the Goodpaster River; diverting Liese Creek reduces the availability of water for infiltration.

### *4.3.4 Grouting Liese Creek Fault – 2015*

Mine inflow can be reduced by grouting Liese Creek fault, the main conductor of water to the mine. For the purpose of evaluating the effect, grouting is assumed to return the rock around the stope to the permeability of the orebody.

The flows for this case are presented in Table 16.

*Table 16 – Mine Inflow – 2015 – Grout Liese Creek Fault*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 383 | 385 | Inflow = outflow |
| Dewatering | | **286** | Flow reduction = 212 gpm (43%) |
| Goodpaster | | 377 | 212 gpm more infiltration reaches Goodpaster |
| Total | 1047 | 1047 | Flow balance |

The evaluation showed the following:

1. Successfully grouting the Liese Fault would on its own reduce mine inflow 43% to 212 gpm. In this case, the grouting is required in five locations (Plate 8).
2. All the water excluded from the mine would flow to the Goodpaster down Liese Creek.

### *4.3.5 Grouting Liese Creek and Graphite Faults – 2015*

Mine inflow may be further reduced by grouting Liese Creek Fault and Graphite Fault, the two main conductors of water to the mine. The Graphite fault is approximately 100 feet wide, and has been observed to be permeable over much of that width.

The feasibility of grouting the Graphite Fault has not been demonstrated, at least in locations where the fault produces substantial inflow. Due to the generally low hydraulic conductivity [estimated by calibration to be 0.12 ft/day (4 x $10^{-5}$ cm/sec)], grouting may require superfine Portland cement and/or high pressure injection.

The flows for this case are presented in Table 17.

*Table 17 - Mine Inflow - 2015 – Grout Liese and Graphite Faults*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 664 | | Over Liese and Pogo Catchments |
| Liese Ck | 368 | 419 | Inflow ≠ outflow; some streamflow rejected |
| Dewatering | | **157** | Flow reduction = 342 gpm (69%) |
| Goodpaster | | 456 | 292 gpm more infiltration reaches Goodpaster |
| Total | 1032 | 1032 | Flow balance |

The evaluation showed the following:

1. Successfully grouting the Liese and the Graphite Faults would reduce mine inflow 69% to ~157 gpm.
2. This inflow is only 32 gpm more inflow than occurs with this mitigation in the 2009 mine case. The grouting largely eliminates inflow from the creek, with the residue being flow from surface infiltration and flow from the Goodpaster River.

### *4.3.6 Grouting Faults and Stream Diversion*

Mine inflow may be further addressed by grouting Liese Creek Fault and Graphite Fault, and by diverting Liese Creek at the surface.

The flows for this case are presented in Table 18.

*Table 18 - Mine Inflow - 2015 – Grout Faults and Divert Creek*

| Flow Element | INFLOW to the model (gpm) | OUTFLOW from the model (gpm) | Notes |
|---|---|---|---|
| Infiltration | 550 | | Over Liese and Pogo Catchments |
| Liese Ck | 323 | 324 | Inflow ≠ outflow; some streamflow rejected |
| Dewatering | | **156** | Flow reduction = 342 gpm (69%) |
| Goodpaster | | 392 | 228 gpm more infiltration reaches Goodpaster |
| Total | 873 | 873 | Flow balance |

The evaluation showed the following:

1. Diverting the creek and successfully grouting the main faults has no greater effect on modeled mine inflow than grouting the faults. This is because the net infiltration in the reach of the creek that is being diverted is zero.
2. The creek diversion still continues to provide insurance against the possible existence of a direct connection conduit between Liese Creek and the mine.

### 4.3.7 Summary of Flow Control Actions - 2015

The flow control actions and their effect on flow are summarized in Table 19.

*Table 19 – Summary of Inflow Control – 2015*

| | |
|---|---|
| Uncontrolled Inflow | 499 gpm |
| Liese Creek Diversion | 335 gpm |
| Grout Liese Fault | 286 gpm |
| Grout Liese and Graphite Faults | 157 gpm |
| Grout Liese and Graphite Faults and Divert Creek | 156 gpm |

Diverting Liese Creek alone provides an approximately 33% reduction in flow to the mine. If the faults are grouted where permeable a 69% reduction in flow could be achieved. Plugging the faults and diverting the creek produces the same reduction of 69% of inflow, but the diversion pipe provides insurance against the existence of a direct conduit between the mine and Liese Creek.

## 5. WATER MANAGEMENT

Mine inflow is dependent on the mitigation measures that are taken. The estimated mine inflow is presented in Table 20 below, based on the water management approach taken.

*Table 20 - Water Management Strategy*

| Water Management Strategy | 2009 | 2015 | Average |
|---|---|---|---|
| Uncontrolled Inflow | 240 gpm | 499 gpm | 370 gpm |
| Divert Liese Creek | 197 gpm | 335 gpm | 266 gpm |
| Grout Liese Fault | 178 gpm | 286 gpm | 232 gpm |
| Grout Liese and Graphite Faults | 125 gpm | 157 gpm | 141 gpm |
| Grout Liese and Graphite Faults and Divert Liese Creek | 118 gpm | 156 gpm | 137 gpm |

A cost evaluation has been made for each strategy, based on the following assumptions:

1. The residual inflow in each case will require treatment and discharge (together with other excess project waters).
2. The mine will continue to operate until 2015, for a remaining mine-life of 7 years.
3. The discount rate for annual costs is zero (that is, escalation in costs will be offset by the time-value of money).
4. Unit costs are computed in 2009 estimated costs, based where available on current Pogo onsite costs.

### 5.1 Treatment of Uncontrolled Inflow

If no inflow mitigation is undertaken, it will be necessary to treat and discharge the entire inflow to the mine. This is estimated to average 370 gpm over the remaining life of the mine. An estimate of the cost of this treatment is presented in Table 21.

*Table 21 - Water Costs - No Action*

| | | | | | |
|---|---|---|---|---|---|
| Treatment Plant Expansion | 1 | @ | $2,000,000 | lump sum | $ 2,000,000 |
| Annual Treatment Cost | 370 | gpm @ | $ 4.14 | $/1000 gal | $ 804,000 |
| Present value 2009-2015 | | | | | $ 7,628,000 |

Present value of this strategy is approximately $7.6 million.

There are additional costs associated with treating the full inflow:

- Permitting costs to obtain approval for discharge
- In-mine collection, piping, and pumping costs
- Equipment down-time
- Waste disposal from treatment

### 5.2 Liese Creek Diversion

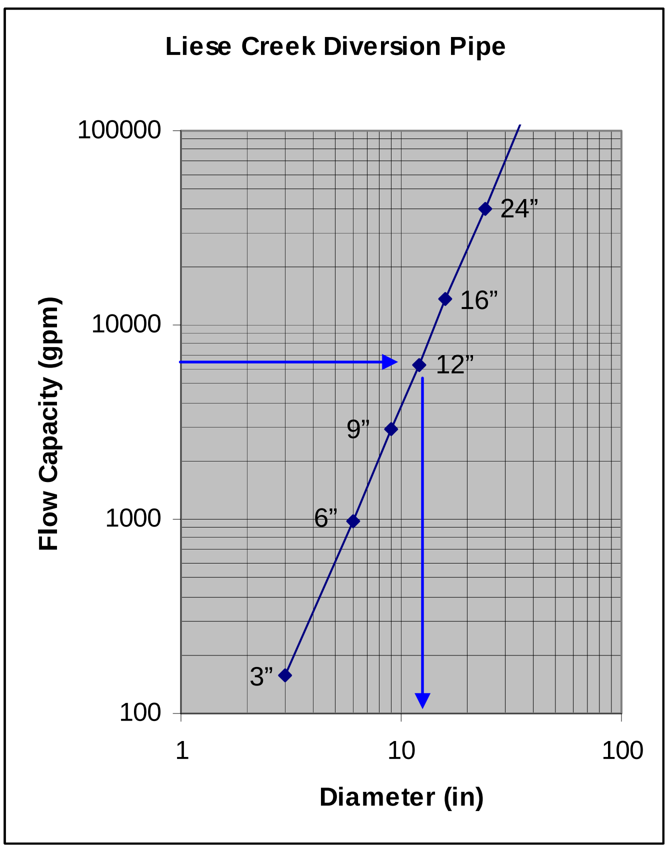
Diverting Liese Creek reduces the inflow to the mine an average of 100 gpm. This results in a reduction of treatment costs, which is offset by the construction cost of the diversion pipe.

The diversion pipe runs 4500 ft down Liese Creek (Plate 9). The pipe would be designed to accept the normal groundwater flow, plus some portion of the runoff from a maximal storm.

| | |
|---|---|
| Peak groundwater flow | = 650 gpm |
| 24-hour storm (2.63 in) runoff | = 45,000 gpm |
| Design pipe flow capacity | = 6,500 gpm (groundwater + 15% of design storm runoff) |
| Pipe diameter | = 12 inches |

The diameter – flow relation for the pipe is presented in Figure 7.

*Figure 7 - Liese Creek Diversion Pipe Design*




Note that the flow velocity when running full is 18 ft/sec, requiring thrust blocks and energy dissipation.

The diversion pipe would have two potential input points:

- 1875’ portal
- 1690’ portal

The cost of mine water management with diversion of Liese Creek comprises the cost of construction of the pipe plus the cost of treating the remaining flow (266 gpm). This is presented in Table 22.

*Table 22 - Mine Water Cost - Creek Diversion*

| | | | | | |
|---|---|---|---|---|---|
| **Diversion System** | | | | | |
| Pipe construction | 1 | @ | $ 300,000 | each | $ 300,000 |
| Cutoff wall construction | 2 | @ | $ 200,000 | each | $ 400,000 |
| Maintenance | 5% | of | $ 700,000 | per year | $ 35,000 |
| Present value 2009-2015 | | | | | $ 945,000 |
| **Water Treatment** | | | | | |
| Treatment Plant Expansion | 1 | @ | $1,000,000 | lump sum | $ 1,000,000 |
| Annual Treatment Cost | 266 | gpm @ | $ 4.14 | $/1000 gal | $ 578,000 |
| Present value 2009-2015 | | | | | $ 5,046,000 |
| **Total Project** | | | | | |
| Present Value 2009-2015 | | | | | $ 5,991,000 |

The present value of this strategy is $6.0 million. This represents a reduction in mine water treatment costs of approximately $2 million over the no action case, making the option independently cost effective.

Additional costs that would be incurred include:

- Permitting costs
- In-mine collection, piping, and pumping costs
- Equipment down-time
- Waste disposal from the water treatment plant (less than the cost for the no-action case)

### 5.3 Grout Liese Fault

Grouting the Liese Creek Fault at all locations where it is found to make water will have the effect of reducing the mine inflow to an average of 232 gpm over the project life. This remaining flow will require treatment.

It is known that the Liese Creek fault is permeable in some locations, and not in others. For the purposes of cost estimation, it is assumed that 20% of the Liese Creek intersections will require grouting.

The costs associated with this mitigative option are shown in Table 23 below:

*Table 23 – Mine Water Cost – Grouting Liese Fault*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Grout Liese Fault** | | | | | | | |
| Grouting | 720 | ft/yr | $ | 116 | per foot | $ | 84,000 |
| Present value 2009-2015 | | | | | | $ | 588,000 |
| **Water Treatment** | | | | | | | |
| Treatment Plant Expansion | 1 | @ | $1,000,000 | | lump sum | $ | 1,000,000 |
| Annual Treatment Cost | 232 | gpm @ | $ | 4.14 | $/1000 gal | $ | 504,000 |
| Present value 2009-2015 | | | | | | $ | 4,528,000 |
| **Total Project** | | | | | | | |
| Present Value 2009-2015 | | | | | | $ | 5,116,000 |

The present value of grouting the Liese Creek fault to control inflow is $5.1 million. This is $2.5 million less than the no-action alternative.

Additional costs:

- In-mine collection, piping, and pumping costs
- Equipment down-time
- Water treatment waste disposal

### 5.4 Grout Liese and Graphite Faults

This mitigative measure involves grouting both Liese and Graphite Faults at all locations where they are found to be significantly water bearing. Successful grouting of these structures will reduce the mine inflow to an average of 141 gpm, approximately 70% less than the un-mitigated inflow.

It is known that the Liese Creek fault is permeable in some locations, and not in others. The Graphite fault is not very permeable generally, but is sufficiently permeable to require grouting in at least some locations where it is crossed. For the purposes of cost estimation, it is assumed that 20% of the Liese Creek intersections will require grouting.

The cost of providing this mitigation is summarized in Table 24 below:

*Table 24 - Mine Water Mitigation - Grout Liese and Graphite Faults*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Grout Faults** | | | | | | | |
| Grouting | 1800 | ft stope/yr | $ | 116 | each | $ | 208,800 |
| Present value 2009-2015 | | | | | | $ | 1,461,600 |
| **Water Treatment** | | | | | | | |
| Treatment Plant Expansion | 1 | @ | $ | 500,000 | lump sum | $ | 500,000 |
| Annual Treatment Cost | 141 | gpm @ | $ | 4.14 | $/1000 gal | $ | 306,000 |
| Present value 2009-2015 | | | | | | $ | 2,642,000 |
| **Total Project** | | | | | | | |
| Present Value 2009-2015 | | | | | | $ | 4,103,600 |

The present value of grouting the two main fault sets in the property is $4.1 million. This amount covers the cost of the grouting, and the cost of the treatment of the remaining mine inflow.

Additional costs of this option are:

- In-mine collection, piping, and pumping costs
- Equipment down-time
- Waste disposal

### 5.5 Divert Liese Creek, and Grout the Liese and Graphite Faults

The final mitigative measure considered is to divert the creek, and to grout the Liese and Graphite Faults as well. Successful completion of this mitigation will result in an average mine inflow of 139 gpm.

Making the same assumptions as in the sections above relating to expenses, the cost of the full mitigative system is as follows:

*Table 25 - Mine Water Control - Full Mitigation*

| | | | | | | |
|---|---|---|---|---|---|---|
| **Diversion System** | | | | | | |
| Pipe construction | 1 | @ | $ 300,000 | each | $ | 300,000 |
| Cutoff wall construction | 2 | @ | $ 200,000 | each | $ | 400,000 |
| Maintenance | 5% | of | $ 700,000 | per year | $ | 35,000 |
| Present value 2009-2015 | | | | | $ | 945,000 |
| **Grout Faults** | | | | | | |
| Grouting | 1800 | ft stope/yr | $ 116 | each | $ | 208,800 |
| Present value 2009-2015 | | | | | $ | 1,461,600 |
| **Water Treatment** | | | | | | |
| Treatment Plant Expansion | 1 | @ | $ 500,000 | lump sum | $ | 500,000 |
| Annual Treatment Cost | 137 | gpm @ | $ 4.14 | $/1000 gal | $ | 298,000 |
| Present value 2009-2015 | | | | | $ | 2,586,000 |
| **Total Project** | | | | | | |
| Present Value 2009-2015 | | | | | $ | 4,992,600 |

The present value of diverting Liese Creek and grouting the two main fault sets in the property is $5.0 million. This amount covers the cost of the pipeline, grouting, and the cost of the treatment of the remaining mine inflow.

Additional costs of this option are:

- In-mine collection, piping, and pumping costs
- Equipment down-time
- Waste disposal

This option is more expensive than grouting the two fault sets, but offers considerably more protection than underground grouting, as it removes the uncertainty about encountering an unexpected conduit from Liese Creek to the mine workings.

### 5.6 Summary

Mine water inflow management strategies are available at Pogo. The strategies, the flows that they will create, and the cost of implementation for the life of the mine are summarized in Table 26.

*Table 26 - Mine Water - Summary of Mitigation*

| STRATEGY | ACTION | TREATMENT | TOTAL |
|---|---|---|---|
| No mitigation action | 0 | $ 7,628,000 | $7,628,000 |
| Divert Liese Creek | $ 945,000 | $ 5,046,000 | $5,991,000 |
| Grout Liese fault | $ 588,000 | $ 4,528,000 | $5,116,000 |
| Grout Liese and Graphite faults | $1,461,600 | $ 2,642,000 | $4,103,600 |
| Divert Liese Creek, grout Liese and Graphite faults | $2,406,600 | $ 2,586,000 | $4,992,600 |

Note that the cost of grouting is spread over the life of the mine, while the cost of diversion of Liese Creek is assumed to occur during the current year (2009).

# 6. RECOMMENDATIONS

## 6.1 Recommendation #1: Divert Liese Creek

### *6.1.1 Recommendation*

**Pogo should divert Liese Creek above the mine, by collecting water from above the 1875' Portal and piping it to the 1500' elevation in Liese Creek.**

### *6.1.2 Rationale*

- Successful diversion of Liese Creek above the mine will reduce the mine inflow by 33%.
- The diversion is cost-effective, as the reduced inflow resulting from the diversion will reduce the cost of treatment of mine water by more than the cost of the diversion.
- Diverting Liese Creek provides insurance against potentially mine-flooding inflow from Liese Creek during flood events in the event of the existence of the intersection of a direct flow connection between the creek bed and the mine.

## 6.2 Recommendation #2: Evaluate Grouting of Major Faults

### *6.2.1 Recommendation*

**Pogo should evaluate the feasibility and cost of grouting the Liese and Graphite Faults**.

### *6.2.2 Rationale*

- Successful grouting of the permeable portions of the main faults in the mine area (Liese and Graphite Faults) will reduce the inflow to the mine by 70%.
- Successful grouting of the faults would allow the mine to continue to operate with the existing treatment capacity of 200 gpm.
- Grouting appears to be cost-effective, as the reduced inflow reduces the cost of water treatment by ~$5 million, which is substantially more than the ~$1.5 million expected cost of grouting.

## 6.3 Recommendation #3: Monitoring

### *6.3.1 Recommendation*

**Pogo should upgrade mine inflow measurement, surface flow measurement, and groundwater pressure monitoring, and review and optimize the water management system annually.**

### *6.3.2 Rationale*

- Knowledge of inflow to the mine and other project flows is required to evaluate and optimize the mitigation of mine inflow. Flow should be directly measured by cumulative flow meters in strategic locations in the mine water system, with no less than daily reading, and sufficient coverage to allow cumulative monthly inflow to be computed.

- Knowledge of the surface flow in Liese Creek and the groundwater flow in the Liese Creek valley fill is required to evaluate and mitigate mine inflow. This flow is the principal source of water for mine inflow. Flow measurement should be conducted with a recording flume in the creek above the mine, and at the entry to the creek diversion. Monitoring of groundwater flow in the valley fill should be conducted by the installation of three wells distributed along the length of the creek from the RTP to the mouth. Water levels should be recorded by transducer on an hourly basis.
- Knowledge of the response of the mine groundwater system pressures to mine dewatering is required to determine the principal input locations of water to the mine system. The following monitoring is recommended:
    - Monitor wells drilled and completed from the mine, with completions above, beside, and below the mining horizons. A total of 12 monitor points are recommended, distributed among the three orebodies. Three of the wells should be completed in the intersection of the Liese Creek Fault with the L1 orebody along its length. All wells should be tested for hydraulic conductivity during drilling, and after completion.
    - Locate and if possible rehabilitate monitor wells previously drilled and completed from surface to locations outside the mine. Install electronic transducers, and monitor continuously from the surface.

## 7. CONCLUSIONS

- Uncontrolled inflow to the Pogo Mine is expected to increase over time, to as much as an annual average of 500 gpm at project end.
- Control of inflowing water at Pogo can be achieved by the following strategies:
  - Diversion of Liese Creek (335 gpm at project end)
  - Grouting of Liese Fault (286 gpm at project end)
  - Grouting of Liese Fault and Graphite Fault (157 gpm at project end)
  - Diversion of Liese Creek and grouting of Liese Fault and Graphite Fault (156 gpm at project end)
- The reductions in the cost of treating the mine inflow outweigh the expected cost of all mitigation options
- Diversion of Liese Creek and grouting of high-inflow intersections of the Liese fault and the Graphite fault is recommended.
- Upgraded monitoring of mine inflow, surface water flow, and groundwater pressures are recommended.
- Annual review of mine inflow and mitigation is recommended.

## 8. REFERENCES

ABC, 2000a. *Pogo Project Mine Inflow, Alaska*, preliminary consultant report prepared for Teck Corporation, May 1.

ABC, 2000b. *Pogo Project Mine Inflow, Alaska*, preliminary consultant report prepared for Teck Corporation, July 15.

ABC, 2002. *Inflow to the Pogo Mine, Alaska*. Report prepared by Adrian Brown Consultants, Inc., for Teck Corporation. Dated January 22, 2002.

AMEC, 2000. Memorandum from Gary Beckstead, AMEC Consultants, to Karl Hanneman, Teck Corporation, re: *Baseflows*, December 1, 2 pp.

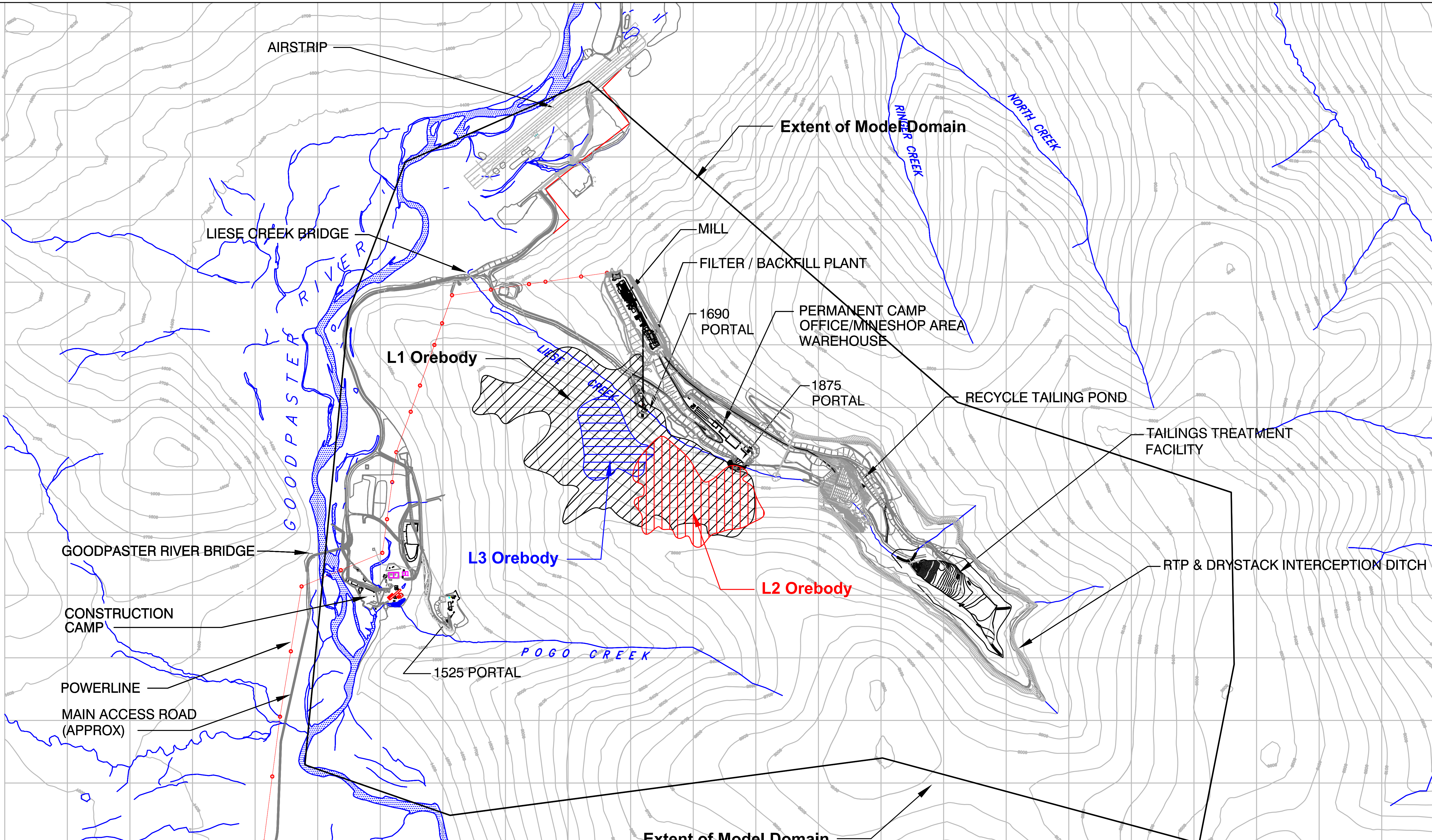
McDonald, M.G., and Harbaugh, A. W., 1988. *MODFLOW – A Modular Three-Dimensional Finite-Difference Groundwater Flow Model*, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6, Modeling Techniques, USGPO, Washington.

Teck, 1999. *Pogo Project – Draft Pre-Feasibility Study - Geology*, September 30.

Teck-Sumitomo, 2000. *Pogo Project Environmental Baseline Document*, April.

Teck-Pogo, 2000. *Pogo Project, Water Management Plan*, August.

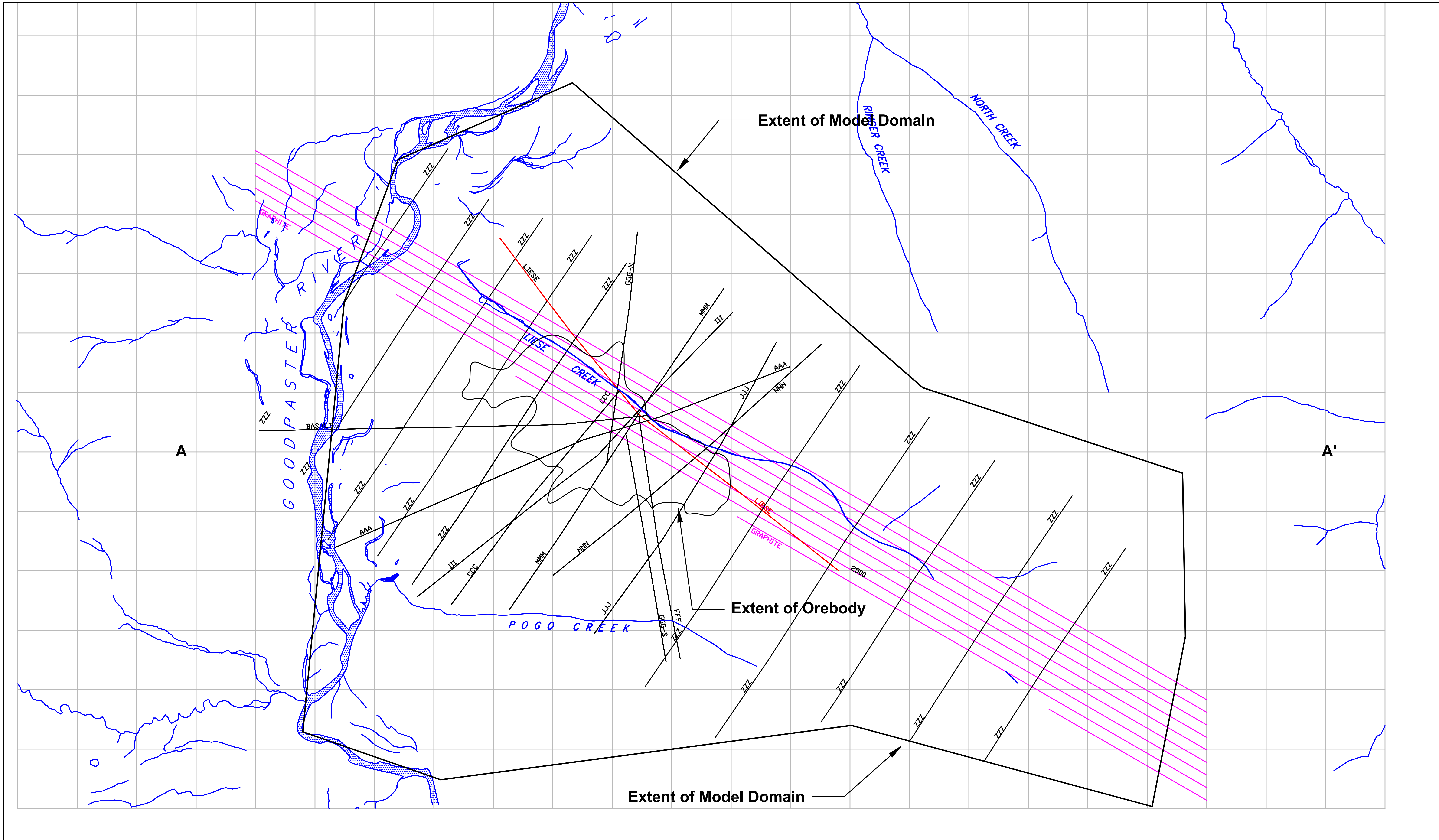
# PLATES




AdrianBrown

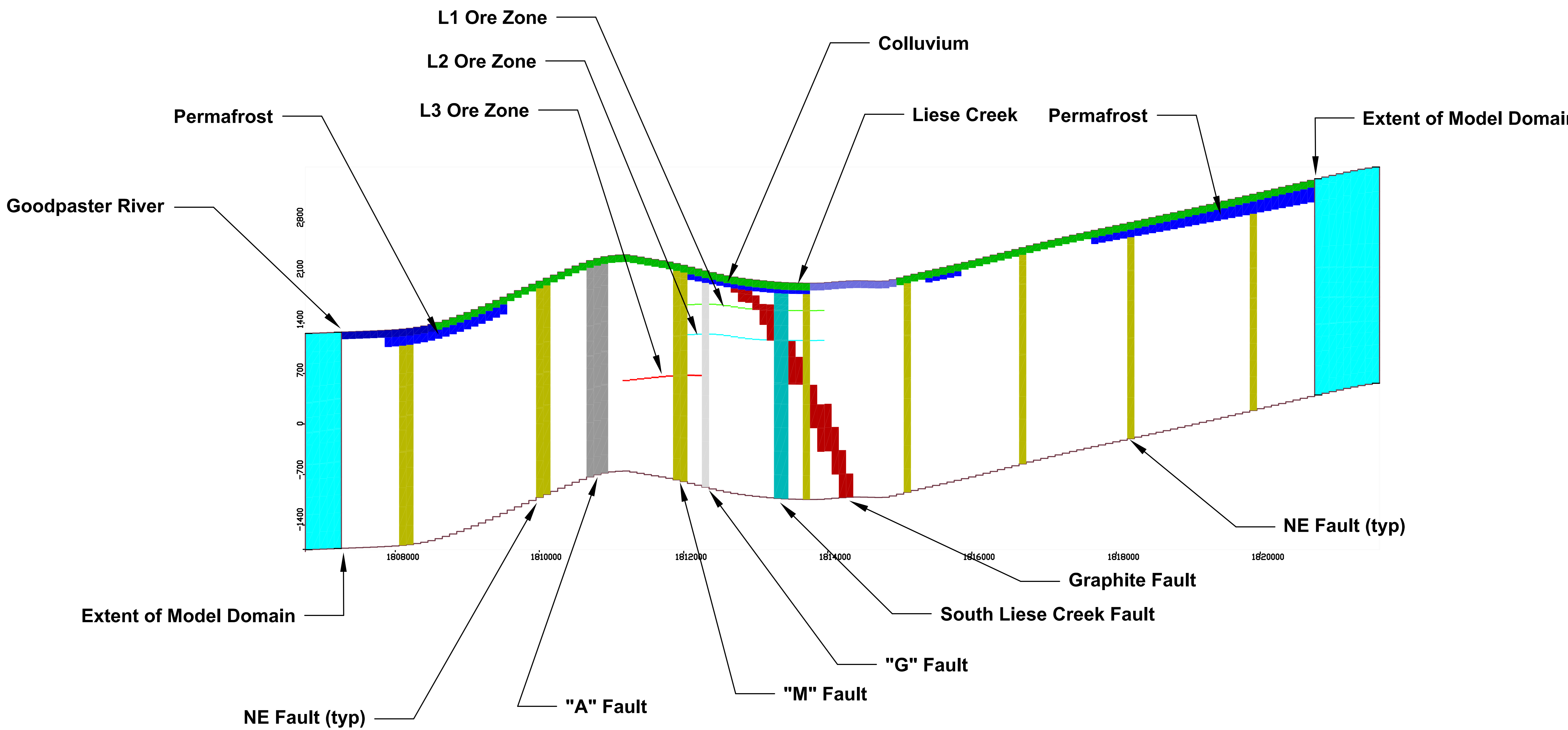
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

| | | |
|---|---|---|
| Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 1 |
| Drawing: | 154302-01-1 | SITE PLAN |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |



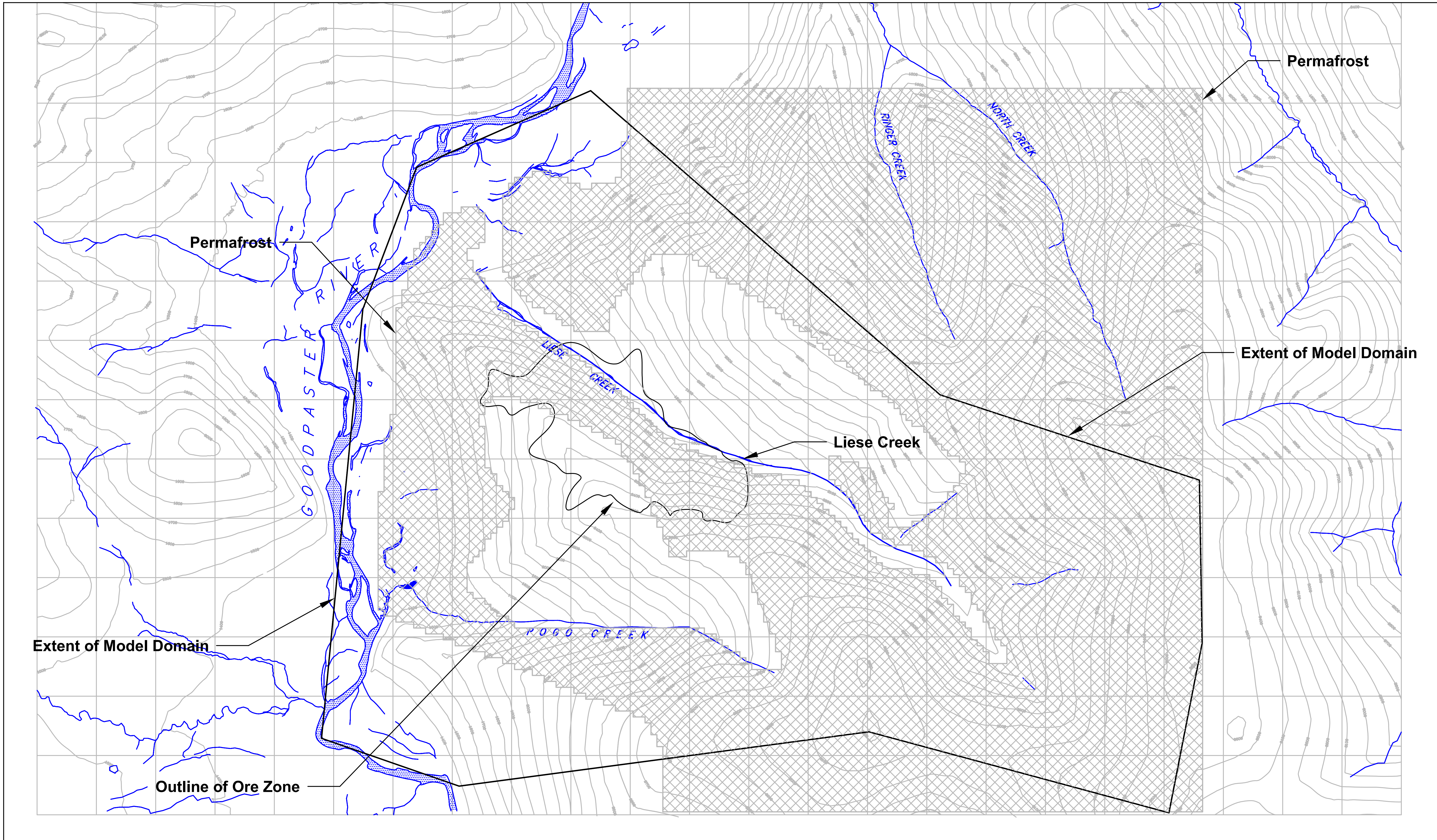

Adrian Brown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

| | | |
|---|---|---|
| Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 2 |
| Drawing: | 154302-01-1 | GEOLOGY AND STRUCTURE |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |




AdrianBrown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

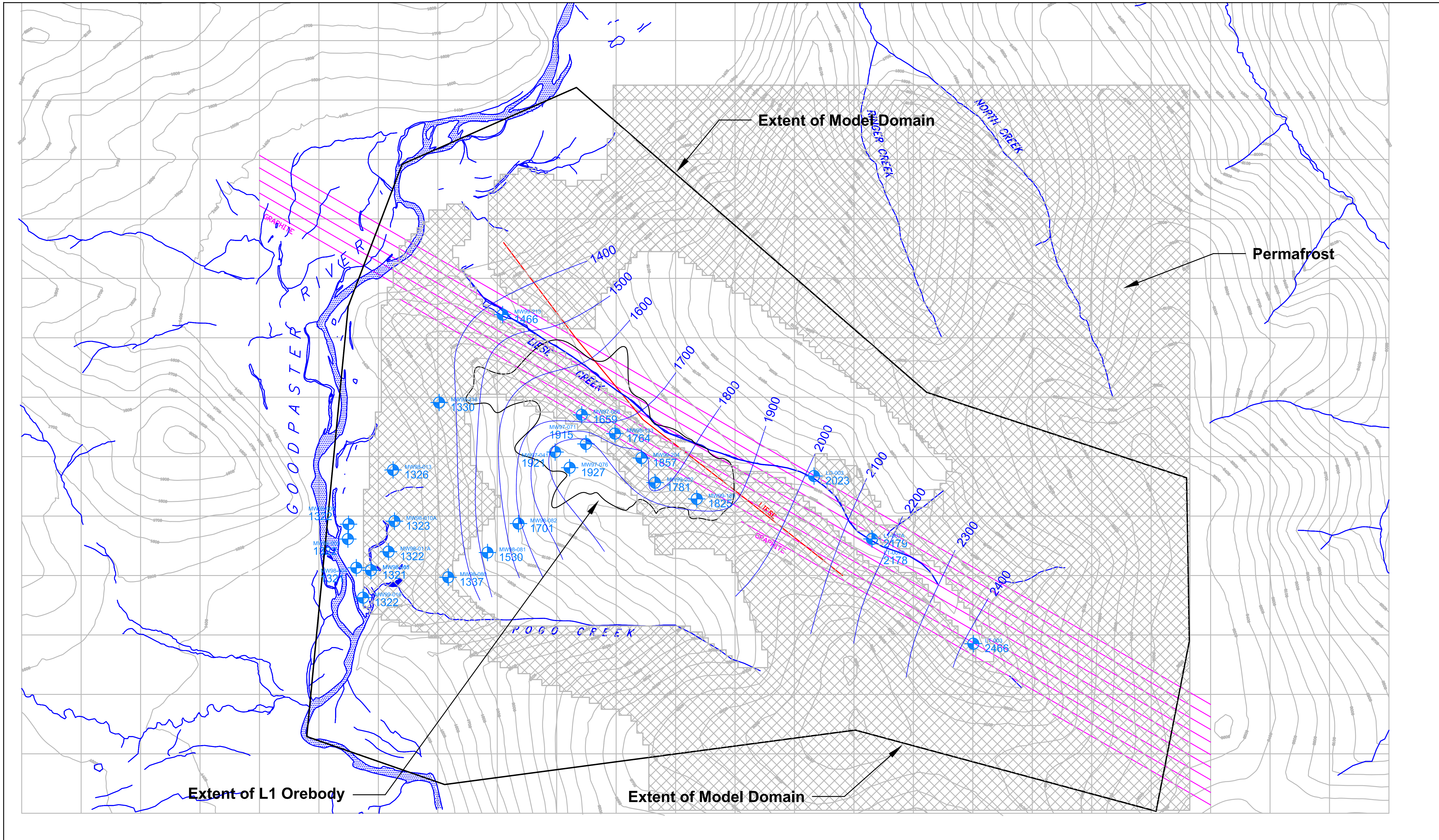
| | | |
|---|---|---|
| Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 3 |
| Drawing: | 154302-01-1 | GEOLOGICAL SECTION A-A' |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |





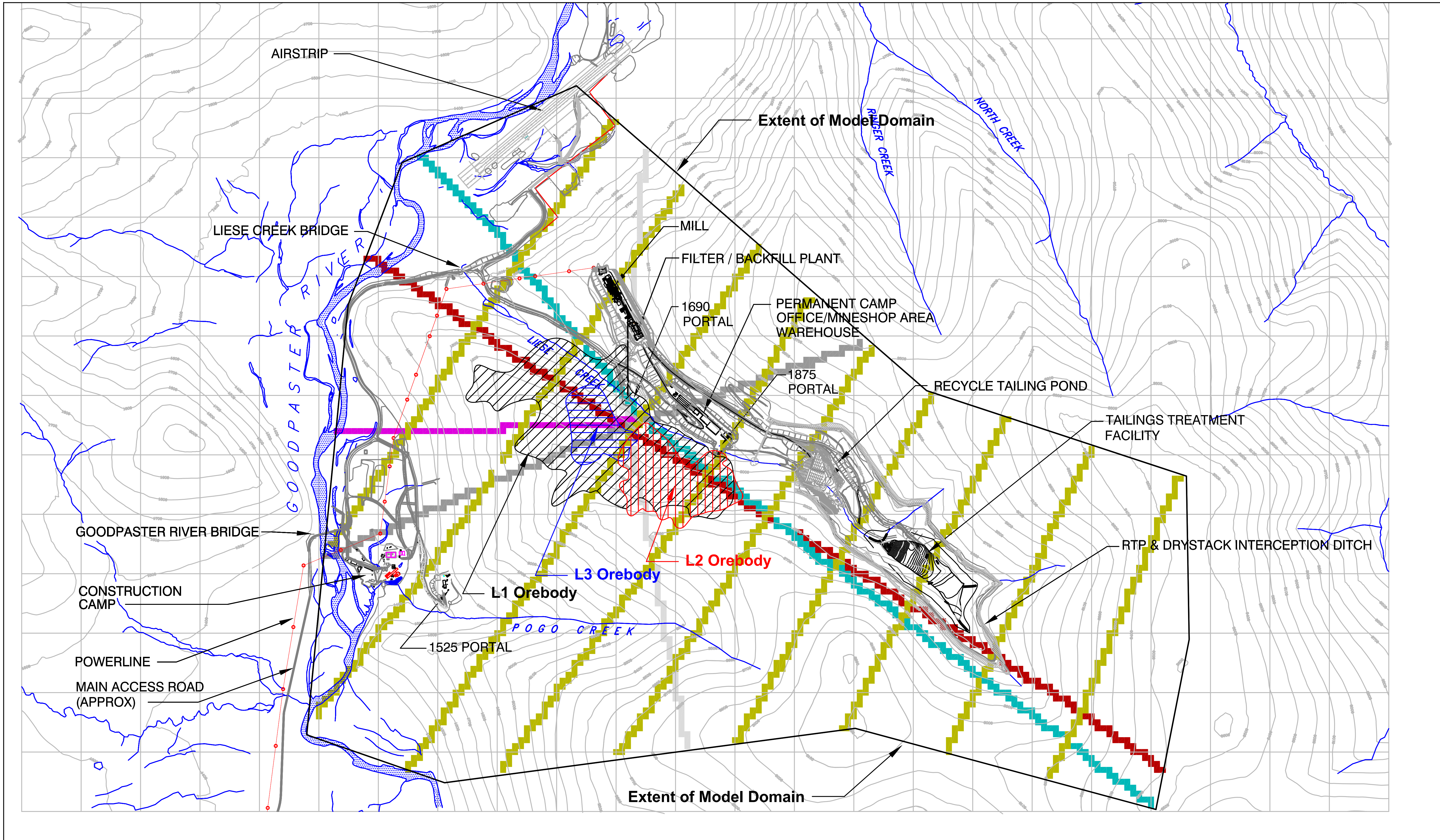
AdrianBrown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080


| | | |
|---|---|---|
| Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 4 |
| Drawing: | 154302-01-1 | EXTENT OF PERMAFROST |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |

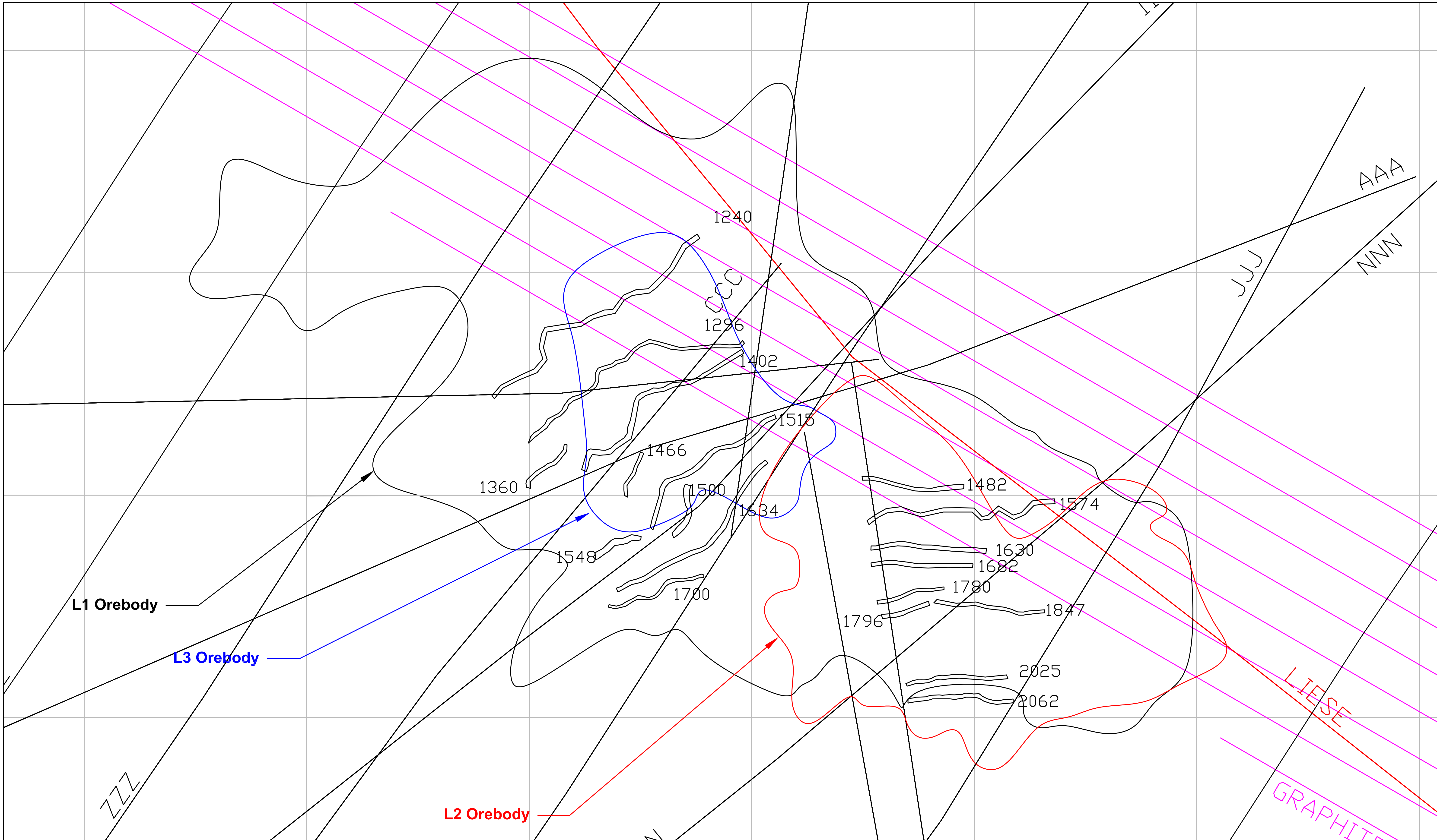



Adrian Brown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

| | | |
|---|---|---|
| Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 5 |
| Drawing: | 154302-01-1 | PRE-MINING GROUNDWATER LEVELS |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |

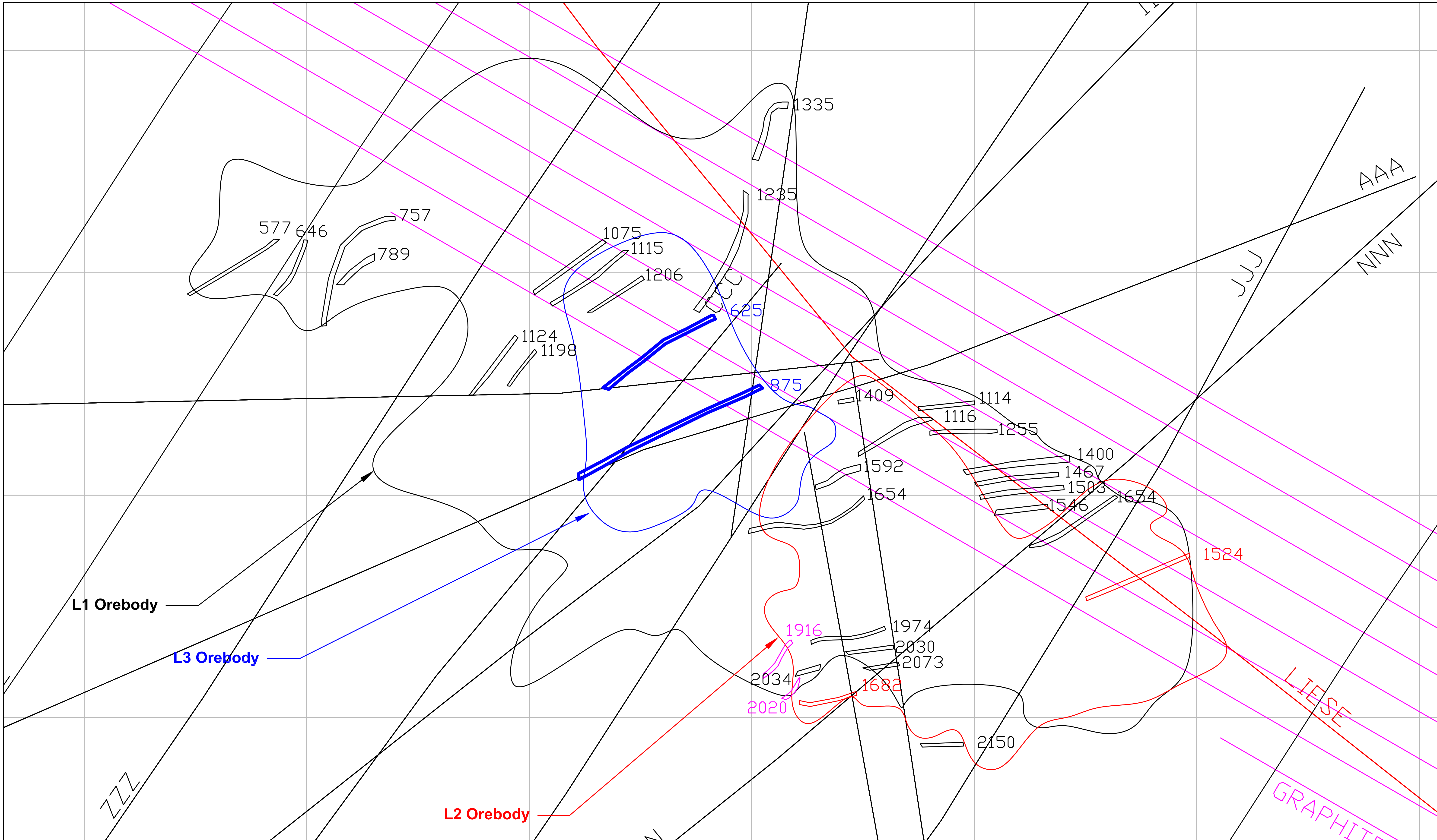



| | | | |
|---|---|---|---|
| AdrianBrown<br>Adrian Brown Consultants, Inc.<br>130 West 4th Ave, Denver CO<br>303-698-9080 | Scale | 1" = 1,500' (750 0 750 1500) | POGO MINE WATER INFLOW STUDY |
| | Drawn: | A. Brown 5-May-2009 | PLATE 6 |
| | Drawing: | 154302-01-1 | MODEL GEOLOGY - L1 OREBODY LAYER |
| | File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |




AdrianBrown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

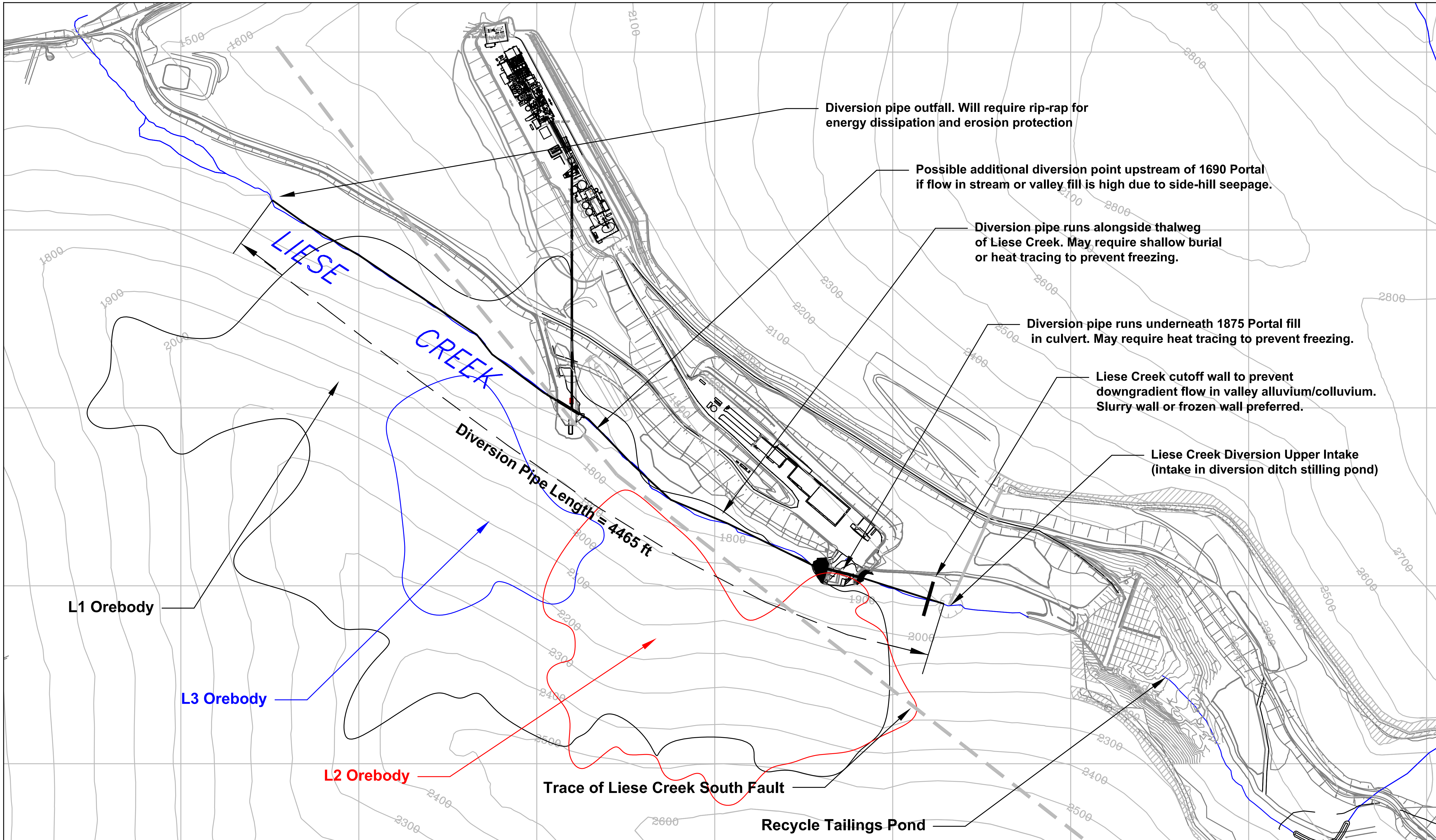
| | | |
|---|---|---|
| Scale | 1" = 400' (200 0 200 400) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 7 |
| Drawing: | 154302-01-1 | STOPES DEVELOPED - 2009 |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |





AdrianBrown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080


| | | |
|---|---|---|
| Scale | 1" = 400' (200 0 200 400) | **POGO MINE WATER INFLOW STUDY** |
| Drawn: | A. Brown 5-May-2009 | **PLATE 8** |
| Drawing: | 154302-01-1 | **STOPES DEVELOPED - 2015** |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |




AdrianBrown
Adrian Brown Consultants, Inc.
130 West 4th Ave, Denver CO
303-698-9080

| | | |
|---|---|---|
| Scale | 1" = 500' (250 0 250 500) | POGO MINE WATER INFLOW STUDY |
| Drawn: | A. Brown 5-May-2009 | PLATE 9 |
| Drawing: | 154302-01-1 | LIESE CREEK DIVERSION |
| File: | D:\...\1543B-pogo\4_Maps\mine-master-23.dwg | |

# Attachment**One.**
# MODFLOW FILES (CD)