APPENDIX 11-G
TAILING MANAGEMENT FACILITY
HYDROGEOLOGICAL MODELLING ASSESSMENT

Klohn Crippen Berger

Seabridge Gold Inc.

KSM Project

TMF Hydrogeological Modelling Assessment

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Klohn Crippen Berger

June 26, 2013

Seabridge Gold Inc.
106 Front Street East, Suite 400
Toronto, Ontario
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Brent Murphy
V.P. Environmental Affairs

Dear Mr. Murphy:

KSM Project
TMF Hydrogeological Modelling Assessment

We are pleased to submit our report on the Hydrogeological Modelling Assessment for the Tailings Management Facility for the KSM Project. The study incorporates data and information from the 2008 to 2012 TMF Site Investigation programs and presents an updated hydrogeological conceptualization of the TMF valley. Details and results of the numerical groundwater flow modelling assessment are also presented.

Yours truly,
KLOHN CRIPPEN BERGER LTD.

Graham Parkinson, P.Geo., P.Geoph.
Project Manager

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Seabridge Gold Inc.

KSM Project

TMF Hydrogeological Modelling Assessment

EXECUTIVE SUMMARY

This report presents the results of the hydrogeological modelling study for the assessment of groundwater seepage, which incorporates the design basis seepage management systems, for the KSM Project Tailings Management Facility (TMF).

The TMF is located in a valley covered by discontinuous Quaternary glacial, colluvial/alluvial and fluvial overburden deposits overlying competent variably or lightly metamorphosed sandstones and siltstones of the Bowser Lake Group. Groundwater movement in the TMF valley is controlled by the topographic relief (over 1700 m) and fractures/faults in the bedrock. The lower TMF valley is an active groundwater discharge zone in which vertical hydraulic gradients and artesian conditions are frequently encountered. The geological and hydrogeological conditions within the TMF valley provide increased hydraulic containment of contact water compared to groundwater recharge zones, and were one of the criteria considered during selection of the TMF location.

Geological, hydrogeological and structural data acquired during site investigations completed between 2008 and 2012 were used as a basis for the geological and hydrogeological model of the TMF valley. A numerical groundwater flow model was constructed to assess the rate and fate of seepage from the TMF, and the performance of seepage management systems (SMS), which have been incorporated into the engineering design. The seepage management systems include:

- Seepage recovery dams downstream of terminal TMF dams at each stage of development.
- Bentonite slurry cutoff walls through overburden to low permeability till or bedrock beneath the north, splitter and southeast dams.
- A cutoff though overburden and a grout curtain extending 25 m into bedrock beneath the north, saddle and southeast seepage recovery dams.
- An HDPE liner (up to 2.5 mm thick) and underlying engineered sand filter within the base of the CIL residue cell.
- Grouting of high permeability faults where encountered within the dam foundation during investigation and construction.

The groundwater model was calibrated to existing conditions using groundwater level and stream flow data recorded during the site investigation programs. Predictive simulations were subsequently completed to assess downgradient seepage from the TMF during Stage 1 operation and closure. These scenarios were selected as they represent developing design stages where seepage from the TMF will be highest. Simulations with and without the proposed seepage management systems were completed.

Predicted flow of natural groundwater[1] into the TMF from regional groundwater exceeded contact seepage[2] loss through the base of the impoundment for all completed model simulations. This is due to the TMF being located in a zone of regional groundwater discharge. The predicted rate of contact water seepage loss through the base of the impoundment was 24 L/s during Stage 1 for the scenario which included seepage management systems. During closure, the predicted rate of contact water seepage loss with the proposed seepage management systems was 32 L/s. Without the proposed SMS contact water seepage loss from the TMF was 30 L/s and 39 L/s during Stage 1 and closure, respectively. The seepage management system therefore reduces contact seepage from the TMF by 20% during Stage 1 and 18% during closure compared to corresponding scenarios without SMS.

Particle tracking analyses indicate that flow of contact water beneath the main dams reports to surface downstream of the TMF dam toes, and within the catchment of the seepage recovery dams. Accordingly, contact seepage from the TMF will be collected and pumped back to the TMF.

Total groundwater flow, comprising contact seepage and natural groundwater beneath the north and saddle dams during Stage 1 was predicted to be 24 L/s and 13 L/s, respectively. Total groundwater flows beneath the north and southeast dams during closure were predicted to be 23 L/s and 22 L/s, respectively. These flows are given for design of the seepage recovery ponds and are for the maximum height of the TMF; flow rates will be less at lower dam heights.

The inclusion of cutoffs through overburden beneath the north dam reduced contact seepage flow through overburden by 97% (Stage 1) and 98% (closure). The addition of a cutoff beneath the southeast dam reduced seepage through overburden by 96% at closure. An increase in non-contact natural groundwater flow occurred in deep bedrock due to increased pore pressures beneath the facility following the addition of seepage barriers. These results indicate the seepage barriers are effective at reducing contact water seepage from the TMF through the overburden.

Total groundwater flow beneath the seepage dams (which flows to surface water downstream of these dams) was reduced by up to 19% following the addition of the proposed cutoff through overburden and grout curtain into bedrock. Total groundwater flow bypassing the north seepage recovery dam with seepage management was 0.3 L/s at Stage 1, and 0.5 L/s at closure. Total groundwater flow beneath the seepage recovery dam downstream of the saddle dam (operational during Stage 1) was 0.1 L/s with seepage management. Flow beneath the southeast seepage recovery dam was 1.3 L/s at closure with seepage management. Flow beneath the saddle dam seepage recovery dam is lowest as this area is a natural groundwater divide with low gradients.

[1] Natural groundwater flow is from outside the TMF footprint that does not interact with porewater from the TMF. The quality of natural groundwater is the same as background groundwater.

[2] Contact seepage is water originating from the TMF, which discharges through the dams and the base of the facility. Natural groundwater that comes into contact with tailings porewater is also referred to as contact seepage. The quality of contact seepage reflects that of the tailings porewater mixed with natural groundwater.

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1 INTRODUCTION

Klohn Crippen Berger Limited (KCB) was commissioned by Seabridge Gold to complete a groundwater flow modelling assessment for the KSM Project Tailings Management Facility (TMF). This report details the conceptual hydrogeological setting of the TMF valley and documents the process of numerical model development, calibration and simulation.

The groundwater flow modelling assessment was undertaken to support Engineering design of the TMF, with a focus on evaluating the performance of the seepage management systems (SMS). These systems were included in the design to minimize loss of contact seepage from the TMF to nearby streams. The objectives of this assessment were to:

- Quantify seepage loss from the TMF, and assess the performance of the proposed seepage management systems.
- Assess the fate of contact seepage (defined as seepage that includes tailings pore water) through pathline analysis to support location of seepage recovery dams downstream of the TMF.

1.1 Report Disclaimer

This report was prepared by Klohn Crippen Berger Ltd. for the account of Seabridge Gold Inc. The material in it reflects Klohn Crippen Berger's best judgement in light of the information available to it at the time of preparation. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. Klohn Crippen Berger Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

1.2 Project Description

1.2.1 Regional Setting

The KSM project is located in the Boundary Ranges of the Coast Mountains in northwestern BC, a region of glaciated peaks, icefields, and forested valleys. The KSM TMF Area is located approximately 24 km northeast of the Mine Area, separated by a region of glaciers and icefields with high relief in a northwest-southeast trending valley continuous across a low drainage divide at roughly the valley midpoint.

The TMF valley is covered by discontinuous Quaternary glacial, colluvial/alluvial and fluvial overburden deposits overlying competent and weakly metamorphosed sandstones and siltstones of the Bowser Lake Group. The Bowser Lake Group has been subject to substantial folding and faulting. The project area lies on the western edge of the Intermountain Tectonic Belt with the Paleozoic to mid-Jurassic age Stikine Terrane on the west, and the mid- to upper-Jurassic Bowser Lake sedimentary basin to the east.

1.2.2 Tailing Management Facility (TMF)

Design of the TMF structures is summarized below. The 2012 Engineering Design Update of Tailing Management Facility Report (KCB, 2012) presents details and drawings of the TMF designs. The proposed TMF consists of two primary outer dams: the North Dam across the South Teigen Creek at the north end of the valley, and the Southeast Dam across North Treaty Creek at the south end of the valley.

Construction of the two inner dams, the Splitter Dam and the Saddle Dam, at the drainage divide between the North and Southeast Dams is proposed to allow for staging of the TMF into the North and South Cells and to define the lined CIL Residue Cell.

The North, Saddle and Southeast Dams will be compacted cyclone sand dams, constructed by the centreline method. The Splitter Dam separates the North and CIL Residue Cell. Crest elevation rises with the North Cell tailing level and the toe elevation rises with the CIL tailings level. The dam will be built with the centerline method. The Saddle and Splitter dams include a geosynthetic liner which extends across the basin between the dams to form the fully lined CIL cell.

A key trench will be excavated below the North Dam starter dam to tie the till core into lower permeability till or to bedrock. Slurry trench cutoff walls will be built within overburden where weathered near surface soils and permeable strata are too thick to dig key trenches. The cutoff walls will comprise a 1 m wide excavated trench, backfilled with native soils amended with 2% to 4% bentonite, to achieve a hydraulic conductivity less than $1x10^{-8}$ m/s.

At the Splitter and Southeast Dams, a 1 m wide soil-bentonite slurry trench cutoff wall will also be excavated through the permeable alluvial soils below the centreline of the Starter Dam. These walls will extend 3 m into low permeability basal till or to bedrock. The maximum wall depth is 25 m. The wall backfill will be comprised of the excavated alluvial soils amended with 2% to 4% bentonite.

Underneath the Saddle Dam there will be no slurry wall installed, as the liner under-drain for artesian pressure relief below the CIL Residue Cell extends under the starter dam to the primary finger drains.

The North, Saddle and Southeast Seepage Recovery Dams will be constructed of compacted till in a similar manner as for the tailing starter dam, but with flatter 3H:1V upstream and downstream slopes. An inclined till core is provided on the upstream face to restrict seepage. The North and Southeast Seepage Recovery Dams will have a slurry trench cutoff wall in alluvium and excavated 3 m into basal till or bedrock depending on thickness of overburden, and three row grout curtains drilled 25 m into bedrock. The Saddle Seepage Recovery Dam will have a slurry trench cutoff wall in alluvium and excavated 3 m into basal till or bedrock.

2 HYDROGEOLOGICAL CONCEPTUALIZATION

A hydrogeological conceptualization describes the various components and elements which control groundwater recharge, discharge, flow and levels within an area of interest. The conceptualization also forms the framework for development of a numerical groundwater flow model.

A block diagram showing the various components of the TMF hydrogeological conceptualization is shown in Figure 1. Further details of the components which contribute to the conceptualization are described in the following sections.

2.1.1 Geomorphology/Topography and Structural Elements

The overall shape of the TMF valley is a function of the underlying bedrock structure. The valley consists of a syncline with a fold axis roughly coincident with the valley bottom. The synclinal fold geometry of the valley is complicated by an inferred northeast-southwest striking fault with a left-lateral sense of motion that underlies the East Catchment Valley and intersects the TMF valley near the drainage divide. The TMF valley does not appear to be offset by faulting; rather, erosional processes appear to have exploited the weaker bedrock present along a pre-existing fault. The offset axis of the syncline may have resulted in erosion and glaciations having carved an irregular course for the valley that mirrors the structure of the underlying bedrock. The results of the structural geology assessment for the TMF valley are discussed in the structural geology report (ERSI/KCB, 2011) on the KSM Project Area.

Drilling and seismic survey results indicate that a glacier-scoured bedrock trough underlies the present valley surface and this bedrock trough is partly filled with dense, basal glacial till overlain by stream alluvium and marsh deposits.

Overlying the till and alluvium along the valley margins are alluvial fans and colluvial deposits. These have modified the shape of the valley by deflecting the course of the central stream such that the deepest part of the bedrock trough lies southwest of the present valley bottom in the northern section of the valley, and northeast of the present valley bottom in the southern section. The overburden thickness is generally greatest along the valley flanks, with thinner successions observed along the valley bottom. Incision by creeks at the north and south ends of the valley has limited sediment thicknesses along the path of present drainages.

Valley side slopes at the TMF site are moderate to very steep (slope grade is about 45% at the proposed level of ultimate tailings), with thick conifer forests extending up to the tree line at approximately 1200 m. The valley floor is flat, wide, and marshy at the saddle near the drainage divide and gently sloping and constricting to the north and south, where the central streams are incised into the valley bottom. Slopes in the south end of the TMF valley are typically steeper than in the north end of the valley.

2.1.2 Precipitation

The site receives annual precipitation in the range of 1341 mm to 1773 mm depending upon elevation. Approximately 62% of the annual precipitation falls as snow between October and May. Peak rainfall is connected to storms coming in from the Pacific Ocean in August to October.

Climate data for the TMF site has been established by correlation of regional climate stations with local climate data obtained from weather stations at the mine and TMF sites, as well as interpretation of stream flow records within the mine site and TMF catchments.

2.1.3 Drainage

The KSM TMF occupies a northwest-southeast trending valley continuous across a low drainage divide located at the valley midpoint. The drainage divide is located where the creek draining from the East Catchment Valley joins the TMF valley; the presence of the drainage divide in the middle of the valley causes surface waters in the northern end of the valley to drain northward to Teigen Creek and surface waters in the southern end of the valley to drain southward to Treaty Creek.

The distribution of alluvial fan sediments deposited where the East Catchment hanging valley enters the TMF valley indicates that flow from the East Catchment Valley has alternated between Teigen and Treaty Creeks. During the spring freshet, sheet-flow has been observed draining toward both creeks. During low-flow periods the East Catchment Valley currently drains northward toward Teigen Creek.

2.1.4 Groundwater Movement

Groundwater movement in the TMF valley is controlled by the adjoining topographic relief (over 1700 m), faults and discontinuities in the bedrock. The lower TMF valley is an active groundwater discharge zone in which upward vertical hydraulic gradients and artesian conditions are frequently encountered. The geological and hydrogeological conditions within the TMF valley provide increased hydraulic containment of contact water compared to groundwater recharge zones, and were one of the criteria considered during selection of the TMF location. Furthermore, elevated groundwater levels in the TMF ridgelines minimize the potential for cross-catchment seepage, and eliminate the need for seepage management systems in areas other than the terminal dams.

2.2 Data Review

2.2.1 General

A review of field and laboratory data was undertaken to derive representative hydrogeological parameters for the pre-feasibility TMF groundwater model. Site investigations completed in 2012, 2011 and 2010 improved upon the 2010 hydrogeological conceptualization. These programs included:

- geological/geotechnical drilling at 7 locations in 2012 and 13 locations in 2011;
- groundwater level monitoring, including site-wide monitoring in 2012;
- *in situ* hydraulic conductivity testing:

- borehole packer tests;
- slug tests;
- soil permeability/infiltration tests; and
- CPT Pore-Pressure Dissipation Tests.

- grain size analyses; and
- updated structural geological mapping and interpretation.

Data and results from the 2010, 2011 and 2012 KCB Site Investigation programs are presented in the KCB Site Investigation reports for the TMF area (KCB 2010b, 2011, 2012).

The 2011 Site Investigation (SI) field program provided additional information on the character, distribution, and physical and hydrogeological properties of bedrock and overburden geologic materials in the TMF area. The 2012 SI further characterized the overburden materials and assessment of the till resource for construction of the starter dams. Updated hydraulic conductivity data for incorporation into the groundwater flow model were derived from subsets of the testing programs undertaken since 2008 and are discussed further in Section 2.5.

2.2.2 Borehole Locations and Summary of Borehole Results

Borehole locations are shown in Figure 2. Hydraulic conductivity testing and groundwater levels indicate bedrock fracture zones and faults act as preferential pathways for groundwater movement. Within the TMF valley these were commonly associated with artesian and flowing artesian conditions. A suspected local fault zone with fractured rock and associated artesian conditions was intersected in the north dam footprint at drill holes KC10-24 and KC10-OVB1. Zones of low RQD (Rock Quality Designation) and circulation loss, together with slickensides and shearing, were also encountered in the footprint of each dam. These zones represent areas of higher permeability. Fault gouge and fracture infilling was observed at some locations suggesting that not all discontinuities in the bedrock are of higher permeability than the surrounding bedrock.

A review of the borehole logs and drilling data indicated the following:

- Dense glacial basal till comprised of clay with gravel, sand and occasional cobbles/boulders cover most of the TMF valley below elevation 1000 m. The thickness of the glacial till is up to approximately 60 m, and thins with elevation on the valley slopes.
- Alluvial deposits up to 20 m thick were encountered in poorly drained areas and form a wide meandering fan at the outlet of the east catchment creek. Alluvium is present beneath the saddle dam and, to a lesser extent, the southeast dam. Alluvium distribution is limited in the North Dam area, with a single intersection of alluvium observed during drilling (3 m thick at KC10-25).
- Distribution of fluvial deposits is restricted to recent creeks.

- Colluvial cover is present on the upper slopes of the east valley wall above elevation 1050 m, and at the base of steeper slopes as a component of fan deposits.
- Bedrock underlies overburden and consists of mainly black and grey meta-siltstones, -mudstones and -sandstones of the Bowser Lake Group which have undergone variable and low-grade metamorphism.
- Bedrock at the overburden contact was typically slightly weathered to un-weathered, and typically more fractured in the upper 5 m than underlying rock.
- Zones of fracture and shear concentration were present in boreholes throughout the site, with thicknesses ranging from tens of centimetres to several metres. These zones were typically associated with poor recovery and low RQD and were associated with flowing artesian groundwater conditions.
- Discrete fractures were common and often contained calcite and quartz with occasional pyrite.
- Bedding and discontinuity angles vary spatially. Bedding is generally sub-horizontal in the centre of valley, steepening towards vertical away from syncline fold axis.

2.3 Hydrostratigraphy and Groundwater Flow

2.3.1 Overburden

Overburden in the TMF valley bottom is generally saturated near-surface due to restricted drainage in the U-shaped valley, and artesian flows from the underlying bedrock. Permeable sands and gravels encountered during drilling in the valley centre were typically less than 10 m thick, and were not laterally continuous within the dam footprints. Where present these are underlain by dense basal tills which contribute to localized perching within the relatively permeable overburden units (based on observed gradients).

2.3.1.1 Colluvium/Alluvium

Colluvium is generally derived from erosion of moraine soils and weathered bedrock, and consists of angular boulders and gravel with silt and sand. The colluvium is surficial, and restricted to talus, slope ash, and steep-sided debris cones deposited on, or at the base of slopes.

Alluvial fan and debris flow deposits were deposited on the valley floor by streams descending the steep sides of the valley. These occur as gently sloping and wide debris fans. Alluvium distribution is generally restricted to the lower slopes of the TMF valley.

Groundwater storage in the alluvium and colluvium units is a function of primary porosity. While generally high hydraulic conductivities are observed in coarse grained overburden units, the limited spatial distribution, small-scale gradation or sorting variances, and lateral discontinuity suggest that the alluvium is not a significant aquifer.

2.3.1.2 Bog and Fluvial

Bog and fluvial fine to coarse grained sediments were deposited by fringing marshes and meandering streams, respectively. The distribution of these overburden units is restricted to flat areas within the valley. The thickness of these deposits is up to 20 m (average approximately 5 m) including up to 2 m of peat and organic-rich silt. Bogs are typically highly stratified hydrostratigraphic units, (Letts *et al*., 2000); the limited spatial distribution and thickness of the bog units at the TMF indicates bogs are not likely hydrogeologically significant in controlling seepage from the TMF.

2.3.1.3 Till

Lateral Moraine (Morainal Till)

Lateral moraine is present on the lower slopes of the valley walls as a thin veneer up to 10 m thick. Morainal till forms a loose, discontinuous cover over bedrock and is composed of silty sand with some gravel, cobbles, and trace boulders. Lateral moraine has not been targeted for site investigation as it has a relatively limited distribution and is not present in the valley bottom. This relatively thin unit is likely unsaturated and not of hydrogeological significance.

Basal Till

A blanket of dense, consolidated, grey, basal till (clay, silt, sand and gravel) with a plastic matrix covers the bedrock along the valley bottom and underlies the younger alluvial and colluvial sediments. Where present, till thickness varies from approximately 10 m to 60 m. The till is thickest along the course of the buried bedrock trough that underlies the present valley surface. Discrete lenses of coarse-grained material have been observed within the till during site investigations; these lenses host localized and confined groundwater, and have been accounted for in bulk till parameterization included in the model. Based on groundwater gradients, the till is a confining layer which controls vertical groundwater gradients where present.

2.3.2 Bedrock

Bedrock in the TMF valley consists of competent to fractured weakly metamorphosed siltstone, sandstone, and mudstone. Bedding angles in the siltstone and sandstone have largely been preserved during metamorphism, and hydraulic conductivity is higher along bedding planes. Groundwater flow in the upper weathered and fractured zone occurs as interface drainage. Within deeper bedrock geological structure (i.e. faults) and rock defects control groundwater flow. Zones of competent bedrock have limited primary porosity and confine more permeable zones locally. Groundwater flow through competent, non-fractured bedrock is expected to be negligible compared to fractured and faulted bedrock.

2.3.3 Recharge and Discharge

Groundwater recharge occurs predominantly through infiltration of rainfall and snowmelt into permeable overburden materials and shallow bedrock. Groundwater discharge occurs at low elevations and in the base of the TMF valley where artesian conditions and upward vertical gradients are recorded. Baseflow from groundwater discharge maintains streamflow during low precipitation periods.

2.4 Groundwater Levels and Movement

2.4.1 Groundwater Levels

The monitoring network within the TMF includes 66 locations, of which 56 have been monitored for water levels since 2008. The remaining locations are flowing artesian[3] or are obstructed, damaged, or sealed. The most recent water levels were used for the modelling inputs, the majority of which are from the 2012 monitoring program, and are presented in Table 2.1 below. These results are similar to groundwater level readings for each location recorded prior to 2012, and the range of level variation is typically less than one metre.

Table 2.1 Groundwater Level Monitoring Data

Point ID	Site Location	Reading Date	Easting (m)	Northing (m)	Elevation (masl)	Water Depth (mbgs)	Ground-water Elevation (m)	Comments
KC08-04	Southeast Dam	9/19/2012	446893	6274454	855	18.3	837.1	
KC08-05	Saddle Dam	6/27/2012	444400	6275949	886	3.7	882.5	
KC08-06	North Dam	6/26/2012	440916	6279558	871	22.4	849.0	
KC10-20	Saddle Dam	9/19/2012	443846	6276092	898			Flowing Artesian
KC10-21	Saddle Dam	9/19/2012	443290	6276148	889	-0.3	888.9	
KC10-22	Saddle Dam	9/19/2012	443392	6276612	952	15.3	937.1	
KC10-23	North Dam	9/19/2012	440543	6279056	983	-0.5	983.9	
KC10-23A	North Dam	9/19/2012	440544	6279056	983	-0.1	983.3	
KC10-24	North Dam	6/26/2012	441380	6279561	958	20.6	937.1	
KC10-25	North Dam	9/20/2012	440663	6279816	818			Flowing Artesian
KC10-25A	North Dam	9/20/2012	440664	6279816	818	1.0	816.7	
KC10-28	Saddle Dam	6/27/2012	443256	6275751	956	12.7	943.0	
KC10-29	Southeast Dam	9/19/2012	446071	6274535	880			Flowing Artesian
KC10-30	Southeast Dam	9/20/2012	446378	6274850	842	-3.5	845.9	Flowing Artesian
KC10-31	Southeast Dam	9/19/2012	446523	6275018	888			Flowing Artesian
KC10-OVB1	North Dam	6/26/2012	441161	6279748	920	-0.5	920.9	
KC10-OVB10	Splitter Dam	9/19/2012	442798	6276881	927	2.4	924.3	
KC10-OVB13	Saddle Dam	9/19/2012	443593	6276348	898	2.3	895.5	
KC10-OVB14	Saddle Dam	6/27/2012	443521	6276178	895	2.9	891.7	
KC10-OVB14	Saddle Dam	9/20/2012	443521	6276178	895	6.0	888.5	
KC10-OVB15	Saddle Dam	6/27/2012	443232	6276030	901	1.9	899.1	
KC10-OVB15	Saddle Dam	9/19/2012	443232	6276030	901	2.1	898.9	
KC10-OVB17	Saddle Dam	6/27/2012	444036	6275696	962	6.9	955.0	
KC10-OVB29	Southeast Dam	9/20/2012	446460	6274498	825	2.0	823.0	
KC10-OVB3	North Dam	9/20/2012	441237	6279454	915	-3.5	918.6	Flowing Artesian
KC10-OVB31	Southeast Dam	9/19/2012	447066	6274107		27.8		
KC10-OVB32	Southeast Dam	9/19/2012	446089	6274943		13.2		
KC10-OVB4	North Dam	9/19/2012	441072	6279368	874	-4.3	878.7	Flowing Artesian

[3] Head data was not available for most flowing artesian wells.

Point ID	Site Location	Reading Date	Easting (m)	Northing (m)	Elevation (masl)	Water Depth (mbgs)	Ground-water Elevation (m)	Comments
KC10-OVB4A	North Dam	6/26/2012	441072	6279368	874	1.6	872.7	
KC10-OVB5	North Dam	6/26/2012	440804	6279210	899	-0.9	899.8	
KC10-OVB6	North Dam	9/19/2012	441579	6279091	929		928.7	Flowing Artesian
KC10-OVB7	North Dam	9/19/2012	441431	6278956	886	0.3	885.7	
KC11-35	East Catchment	9/19/2012	444461	6278080	1241	55.3	1185.7	
KC11-36	East Catchment	9/20/2012	444814	6278280	1224			Flowing Artesian
KC11-37	Treaty OPC	9/19/2012	439110	6279770	1076	1.6	1074.5	
KC11-38	Treaty OPC	9/19/2012	438827	6280188	1062	1.2	1060.8	
KC11-CPT1	North Cell	9/19/2012	443595	6276351	900	2.6	897.5	
KC11-CPT2	Saddle Dam	6/27/2012	443524	6276183	896	3.9	892.1	
KC11-CPT2	Saddle Dam	9/20/2012	443524	6276183	896	7.8	888.2	
KC11-CPT3	Saddle Dam	6/27/2012	443238	6276031	910	3.2	906.8	
KC11-CPT3	Saddle Dam	9/19/2012	443238	6276031	910	3.5	906.5	
KC11-CPT4	Saddle Dam	7/5/2011	443835	6276095	898	1.58	896.5	
KC11-CPT5	Saddle Dam	6/27/2012	443285	6276151	889	-1.0	890.0	
KC11-CPT5	Saddle Dam	9/19/2012	443285	6276151	889	1.3	887.8	
KC11-CPT6	Saddle Dam	6/27/2012	444403	6275945	889	0.4	888.6	
KC11-CPT7	South Cell	9/19/2012	446713	6274794	867	9.6	857.5	
KC11-CPT9	Southeast Dam	9/19/2012	446886	6274456	856	10.4	845.6	
KC11-OVB33	North Dam	6/26/2012	441577	6278315	881			Dry
KC11-OVB34	Splitter Dam	9/19/2012	442072	6277715	893	4.7	888.3	
KC11-OVB35	Splitter Dam	9/19/2012	442473	6277101	892	1.1	890.9	
KC11-OVB36	Saddle Dam	9/19/2012	442986	6276551	906	1.2	904.8	
KC11-OVB37	Saddle Dam	6/27/2012	444797	6276197	887	7.2	879.9	
KC11-OVB38	Southeast Dam	9/3/2011	445648	6275562	911	16.2	894.8	
KC11-OVB39	Southeast Dam	9/3/2011	445665	6275089	853	7.6	845.4	
KC11-OVB40	Saddle Dam	6/27/2012	444170	6276282	903	16.6	886.4	
KC11-OVB41	Splitter Dam	9/19/2012	442242	6276978	875			Flowing Artesian
KC12-64	Treaty OPC	9/20/2012	439500	6280443	1091	2.7	1088.3	
KC12-OVB44	Splitter Dam	9/21/2012	441552	6276636	1038	4.3	1033.7	
KC12-OVB45	Splitter Dam	9/21/2012	442397	6276203	934	5.4	928.6	
KC12-OVB46	Saddle Dam	9/21/2012	444414	6275650	894	2.4	891.6	
KC12-OVB47	Southeast Dam	9/21/2012	445202	6275175	845	3.9	841.1	
KC12-OVB48	Southeast Dam	9/21/2012	446848	6273719	897	0.5	896.5	
KC12-OVB49	Southeast Dam	9/20/2012	447264	6273954	824	6.2	817.8	
MW-01A	North Dam	9/19/2012	440372	6280549	855			Flowing Artesian
MW-01B	North Dam	9/19/2012	440370	6280549	855	3.5	851.2	
MW-02A	Southeast Dam	9/19/2012	447274	6273460	744	5.8	738.1	
MW-02B	Southeast Dam	9/19/2012	447280	6273458	744	9.7	734.6	
MW-03A	Treaty OPC	9/19/2012	439200	6279264	1114	9.4	1104.3	
MW-03B	Treaty OPC	9/19/2012	439206	6279268	1114	9.4	1104.3	

Groundwater levels relative to topographic elevation and screen/sand-pack mid-point are shown in Figures 3 and 4, and indicate a roughly linear correlation. This indicates that the water table is a subdued reflection of topography. This relationship was used to assist in assessment of groundwater levels at higher elevations during model setup and calibration.

2.4.2 Time-series Water Level Data

Pressure transducers were installed to monitor long term water levels at four KCB locations and four Rescan locations:

- KC10-OVB14 and KC11-CPT2;
- KC10-OVB15 and KC11-CPT3;
- MW-01B;
- MW-02A and MW-02B; and
- MW-03A.

Water level monitoring data for these locations are provided in Figures 5 to 9. The amplitude and character of the water levels observed in adjacent monitoring locations KC11-CPT2 and KC10-OVB14 indicate that there is a direct hydraulic connection between the alluvium and underlying fractured bedrock. Seasonal variations were recorded, with highest groundwater elevations associated with spring freshet and late summer to early fall precipitation. Groundwater elevations are lowest during snowpack accumulation in winter months. Water levels in the underlying bedrock at KC10-OVB14 are higher than those observed in the overburden during periods of low recharge (snowpack accumulation over winter), indicating upward vertical gradients; however, during freshet effect and late summer to early fall precipitation, there appears to be a reverse in gradient (to downwards) due to recharge.

While the same seasonal variation is observed in adjacent monitoring locations KC11-CPT3 and KC10-OVB15, the responses are muted relative to the KC11-CPT2/KC10-OVB14 water levels. This reflects the lower conductivity and increased clay (fines) fraction in glacial till relative to alluvium. The deviation in trends between the overlying till/fractured bedrock and the underlying fractured bedrock suggests that the till acts as a low permeability confining layer.

Seasonal variability and the effects of freshet are most pronounced in the Rescan transducer data for MW-02A/B, with a clearly defined freshet between April and June. This response is expected as these wells are located adjacent to the creek. Similar to the trend observed for KC11-CPT2/KC10-OVB14, there is good agreement in the amplitude and water level patterns in the overburden and bedrock, with a slightly higher amplitude change in the bedrock unit. Water levels are higher in the bedrock throughout the monitoring period at MW-02, indicating upward vertical gradients year-round.

The effects of freshet and late summer to early fall precipitation are also observed at higher elevation MW-01A. Limited data is available for MW-03A, and a decreasing trend in groundwater level coinciding with the seasonal transition from rainfall to snowpack accumulation is observed.

2.4.3 Vertical Gradients

Vertical gradients were calculated at five locations with the following paired monitoring points. The recorded gradients between these locations were used for model verification:

- KC08-04 and KC11-CPT9 (South-East Dam);
- KC08-05 and KC11CPT6 (Saddle Dam);
- KC10-OVB13 and KC11-CPT1 (Saddle Dam);
- KC10-0VB14 and KC11-CPT2 (Saddle Dam); and
- KC10-OVB15 and KC11-CPT3 (Saddle Dam).

Table 2.2 Vertical Gradients

Monitor	Screen Midpoint (masl)	Elevation Diff.	GW Elevation (masl)	Head Diff.	Vertical Gradient*
KC08-04	789.64	52.46	837.09	-59.57	-1.14
KC11-CPT9	842.10		845.40		
KC08-05	866.50	17.01	882.47	-17.49	-1.03
KC11-CPT6	883.52		888.62		
KC10-OVB13	878.82	13.94	895.45	-11.48	-0.82
KC11-CPT1	892.75		897.45		
KC10-OVB14	834.17	40.55	888.51	-37.31	-0.92
KC11-CPT2	874.72		888.23		
KC10-OVB15	855.43	39.42	898.91	-37.97	-0.96
KC11-CPT3	894.85		897.48		

*: negative values indicate upward gradients

Upward vertical gradients were recorded at all five locations, ranging from 0.82 m/m at KC10-OVB13/KC11-CPT1 to 1.1 m/m at KC08-04/KC11-CPT9. As discussed in Section 2.3, artesian and flowing artesian conditions were recorded throughout the TMF valley.

2.4.4 Groundwater Movement

Most groundwater flow in the bedrock occurs through fracture zones and faults. Overburden and shallow bedrock aquifers are generally unconfined, with localized and laterally discontinuous confined horizons and perched lenses. Fracture networks in the bedrock provide secondary porosity and control groundwater flow, depending upon distribution, interconnectivity and condition. Several faults intersected during drilling in the TMF valley contain fault gouge and in-fill material, limiting the potential for these features to act as preferential pathways for groundwater migration.

2.5 Hydrogeological Properties

2.5.1 Hydraulic Conductivity

Hydraulic conductivity data was reviewed to establish initial inputs for the groundwater model. These results were compared to other data recorded during the site investigations to identify trends in the dataset and characterize factors which may influence hydraulic conductivity values and distribution.

2.5.1.1 Overburden

Overburden hydraulic conductivity in colluvium, alluvium, and till units has been measured using slug tests, infiltration tests (constant head permeameter), CPT pore-pressure dissipation tests, and Hazen (1911) determinations from grain size analyses. No testing has been completed for the bog and lateral moraine units as these have limited distribution and thickness and are not of geotechnical or hydrogeological significance compared to targeted overburden units discussed below.

Falling head tests (FHTs) completed during drilling were performed by filling the drilling rods with a water and monitoring the rate at which the water drained into the material at the base of the rods. While these provide an estimate of hydraulic conductivity, they do not represent the same controlled conditions as slug tests in completed wells. Hydraulic conductivity data from these FHTs were considered only for the colluvium, as piezometers and monitoring wells were installed preferentially in the underlying alluvium.

Colluvium

Colluvium hydraulic conductivity estimates were determined from three infiltration tests and five falling-head tests (FHT) undertaken during drilling. The range of results is presented in Table 2.3 with the distribution of colluvium hydraulic conductivities shown on Figure 10.

Table 2.3 Estimated Hydraulic Conductivity - Colluvium

Colluvium	Hydraulic Conductivity
Count	8
Min	2×10^{-7} m/s
Max	2×10^{-5} m/s
Geomean	4×10^{-6} m/s

Alluvium

Alluvium hydraulic conductivity was determined from one infiltration (constant head permeameter) test and twelve (12) CPT pore-pressure dissipation tests. Summary results are shown in Table 2.4 with the distribution of alluvium hydraulic conductivity shown on Figure 10.

Table 2.4 Estimated Hydraulic Conductivity - Alluvium

Alluvium	Hydraulic Conductivity
Count	13
Min	2×10^{-8} m/s
Max	3×10^{-5} m/s
Geomean	2×10^{-7} m/s

Till

Hydraulic conductivity of the till was determined from ten (10) slug tests, six (6) CPT pore-pressure dissipation tests and one (1) packer test straddling till and the underlying bedrock. Summary results are shown in Table 2.5 with the distribution of alluvium hydraulic conductivity shown on Figure 10.

Table 2.5 Estimated Hydraulic Conductivity - Till

Till	Hydraulic Conductivity
Count	17
Min	4×10^{-8} m/s
Max	4×10^{-6} m/s
Geomean	3×10^{-7} m/s

Bog and Lateral Moraine

No field data was available for estimating the hydraulic conductivity of the bog and lateral moraine units. A hydraulic conductivity value of 1×10^{-5} m/s was assigned to the lateral moraine unit based on field descriptions and literature values for coarse grained, non-plastic till.

Bog hydraulic conductivity estimates for the site were based off the Canadian land Surface Scheme (Letts *et al.*, 2000). For the purposes of the modeling, the characteristic hydraulic conductivity of the hemic bog layer (middle layer; 2×10^{-6} m/s) was selected as an initial input.

2.5.1.2 Bedrock

Packer tests conducted between 2008 and 2011 were reviewed to determine representative hydraulic conductivity values, and to assess the influence of the following variables:

- depth;
- fracturing;
- bedding angle; and
- lithology.

A total of 78 bedrock packer tests at depths from 5 m to 125 m below ground surface, and 31 slug tests across screened and open hole intervals were included in the data reduction, with data subsets used for specific trend analysis (bedding angle, lithology, fracturing) where applicable. Determination of 'fractured' versus 'non-fractured' bedrock was based on a review of rock strength, RQD, and borehole log descriptions. The results of the packer tests distributed along each dam centreline are presented in Appendix I.

Depth

Packer test derived hydraulic conductivity estimates by depth and location are presented in Figure 11. The hydraulic conductivity of both fractured and non-fractured bedrock decreased with depth. As expected, this trend is less pronounced in the non-fractured bedrock as increased compression is less effective at reducing hydraulic conductivity with depth in competent intact rock than in fractured rock. Three depth groupings were identified from assessment of the plotted data on Figure 11. A summary of the hydraulic conductivities for the depth groupings is provided in Table 2.6.

Table 2.6 Hydraulic Conductivities by Depth (Packer Tests and Slug Tests)

Statistic	0-40 mbgs		40-80 mbgs		80-140 mbgs	
	Fractured	Non-Fractured	Fractured	Non-Fractured	Fractured	Non-Fractured
Count	24	38	10	24	8	7
Min	$3x10^{-9}$ m/s	$5x10^{-10}$ m/s	$9x10^{-9}$ m/s	$6x10^{-9}$ m/s	$1x10^{-8}$ m/s	$4x10^{-8}$ m/s
Max	$6x10^{-5}$ m/s	$5x10^{-6}$ m/s	$5x10^{-6}$ m/s	$3x10^{-6}$ m/s	$3x10^{-6}$ m/s	$3x10^{-6}$ m/s
Geomean	$8x10^{-7}$ m/s	$1x10^{-7}$ m/s	$9x10^{-8}$ m/s	$2x10^{-7}$ m/s	$1x10^{-7}$ m/s	$3x10^{-7}$ m/s

As shown on Figure 11, the majority of packer tests were undertaken at depths less than 80 mbgs; testing at greater depths was undertaken only at the North Dam and East Catchment. A decreasing trend in hydraulic conductivity with depth is apparent when these data are plotted (Figure 11). This is not readily apparent in the data presented in Table 2.6 as most testing was performed at shallow depths.

Single packer assemblies were used during drilling. This methodology allows for bulk characterization of relatively large intervals (typically greater than 25 m). As such, determination of hydraulic conductivities for discrete features and zones (e.g. fractured and unfractured bedrock) was not always recorded and the resulting hydraulic conductivity estimates are effectively normalized or averaged.

Fracturing

Cross sections illustrating the relationship between hydraulic conductivity, RQD and core recovery for the North Dam, South-East Dam, Splitter Dam and Saddle Dam are provided in Appendix I. A plot of Rock Strength (R#) as recorded during drilling is presented as Figure 12.

Test intervals were classified as "predominantly fractured" or "predominantly non-fractured" based on drill hole logs and core photographs. Comparison of hydraulic conductivity values in fractured and non-fractured intervals with depth, independent of lithology and bedding angle, indicates that the bulk hydraulic conductivity of both units are similar (Figure 13). Similarities between the fractured and non-fractured bulk hydraulic conductivity estimates is a function of the large test interval and the averaging effects of bulk testing across units with variable hydraulic conductivities. While the calculated geomean hydraulic conductivity values of fractured and non-fractured intervals are similar, the minimum and maximum conductivity values estimated in the fractured intervals are approximately an order of magnitude greater than that observed in non-fractured intervals.

A summary of hydraulic conductivities for testing in fractured and non-fractured bedrock is provided in Table 2.7 below.

Table 2.7 Summary of Bedrock Hydraulic Conductivities from Packer and Slug Tests

Statistic	Fractured	Non-Fractured
Count	42	69
Min	$3x10^{-9}$ m/s	$5x10^{-10}$ m/s
Max	$6x10^{-5}$ m/s	$5x10^{-6}$ m/s
Geomean	$3x10^{-7}$ m/s	$2x10^{-7}$ m/s

Bedding Angle

Bedding angles recorded during drilling were grouped into three classes: sub-vertical (< 40^o), intermediate (40^o - 60^o), and sub-horizontal (>60^o). Evaluation of discrete bedding angles was complicated by some packer test intervals spanning multiple bedding angles[4]. The distribution of hydraulic conductivity by bedding angle is shown on Figures 14 and 15 for fractured and non-fractured bedrock, respectively. Hydraulic conductivities were generally higher in beds approaching horizontal, and lower in beds approaching vertical. This indicates the bedrock is anisotropic, with hydraulic conductivity being higher parallel to bedding due to orientation of bedding-parallel defects. Statistics for the three bedding planes groupings are shown in Table 2.8.

Table 2.8 Summary of Hydraulic Conductivities by Approximate Bedding Angle

Statistic	Sub-vertical (<40^o)		Intermediate (40-60^o)		Sub-horizontal (>60^o)	
	Fractured	Non-Fractured	Fractured	Non-Fractured	Fractured	Non-Fractured
Count	N=4	N=7	N=13	N=23	N=10	N=14
Minimum	$3x10^{-6}$ m/s	$5x10^{-8}$ m/s	$9x10^{-9}$ m/s	$1x10^{-8}$ m/s	$1x10^{-8}$ m/s	$3x10^{-8}$ m/s
Maximum	$5x10^{-6}$ m/s	$8x10^{-7}$ m/s	$5x10^{-6}$ m/s	$5x10^{-6}$ m/s	$6x10^{-6}$ m/s	$5x10^{-6}$ m/s
Geomean	$4x10^{-6}$ m/s	$2x10^{-7}$ m/s	$4x10^{-7}$ m/s	$2x10^{-7}$ m/s	$5x10^{-7}$ m/s	$4x10^{-7}$ m/s

Lithology

Three bedrock lithology groupings have been identified in the TMF area:

- meta-sandstone and meta-siltstone;
- meta-sandstone and meta-mudstone; and
- meta-siltstone and meta-mudstone.

[4] Lithology, rock continuity and depth were the primary selection criteria for packer test intervals. Bedding angle was not considered when selecting test intervals, and varied at the meter scale.

Hydraulic conductivities by lithology grouping are presented on Figure 16 versus depth and on Figures 17 and 18 as statistical distributions for fractured and non-fractured intervals, respectively.

Hydraulic conductivity values for non-fractured intervals do not vary significantly across lithology types, with geomean conductivities ranging from 1.7×10^{-7} m/s to 3.0×10^{-7} m/s. A greater variation is recorded in fractured sections with hydraulic conductivities in meta-siltstone and meta-mudstone an order of magnitude higher than those in meta-sandstone/meta-siltstone and meta-sandstone/meta-mudstone. The higher conductivity meta-siltstone/meta-mudstone intervals which influence statistics are predominantly from the North Dam area where faulting has been recorded in this unit. Removing the North Dam locations from the distribution plot results in hydraulic conductivities consistent with those observed for the other lithologies.

As statistics for the three lithology types are similar, and interbeds of the different units are at the centimeter to metre scale, it is appropriate to consider the Bowser Lake meta-sediments as a single 'bulk' lithological bedrock unit. Table 2.9 provides a summary of calculated bedrock hydraulic conductivities by lithology.

Table 2.9 Summary of Bedrock Hydraulic Conductivities by Lithology

	Meta-Siltstone/Meta-Sandstone		Meta-Sandstone/Meta-Mudstone		Meta-Siltstone/Meta-Mudstone	
	Fractured	Non-Fractured	Fractured	Non-Fractured	Fractured	Non-Fractured
Count	8	17	10	8	15	24
Min	9×10^{-9} m/s	6×10^{-9} m/s	1×10^{-8} m/s	3×10^{-8} m/s	1×10^{-8} m/s	2×10^{-8} m/s
Max	3×10^{-6} m/s	2×10^{-6} m/s	3×10^{-6} m/s	3×10^{-6} m/s	6×10^{-6} m/s	5×10^{-6} m/s
Geomean	1×10^{-7} m/s	2×10^{-7} m/s	2×10^{-7} m/s	2×10^{-7} m/s	1×10^{-6} m/s	3×10^{-7} m/s

2.5.2 Anisotropy

2.5.2.1 Overburden Anisotropy

Overburden anisotropy is a function of depositional mechanisms, textures and external influences. Bog deposits are typically texturally stratified (Letts *et al.*, 2000); in the model these were assigned an initial Kh:Kv ratio of 5:1. Colluvium is a rapidly deposited debris flow unit with little differentiation and, as such, will be isotropic in bulk. Till, alluvial, fluvial and lateral moraine deposits are typically isotropic when considered as individual units.

2.5.2.2 Bedrock Anisotropy

A bedrock anisotropy of 2:1 (Kh:Kv) was estimated from the lithological descriptions and assessment of hydraulic conductivity variance with bedding angle, and was incorporated into the model and refined during calibration. Hydraulic conductivity was higher in the horizontal plane in agreement with the analysis of hydraulic conductivity versus bedding angle data. As depth increases, increased lithostatic pressure results in the closing of bedding planes. As such, isotropic conditions are more likely to develop in bedrock at depth.

3 TMF GROUNDWATER MODEL

3.1 General

A groundwater modelling assessment was undertaken to quantify seepage loss from the TMF and to support placement and design of the seepage management system. This system will be installed to minimize loss of contact seepage from the impoundment cells to groundwater flows that may feed into the regional groundwater flow system, therefore mitigating potential environmental impacts to downstream receptors.

The model was based on the hydrogeological conceptualization documented in Section 2, and incorporated data from KCB and Rescan site investigation programs undertaken in the TMF area between 2008 and 2012.

The model was initially setup and run to represent average seasonal pre-development conditions and was calibrated to monitored groundwater levels and flows. Following calibration, a series of simulations were undertaken to reflect the addition of the TMF under Stage 1 Water Management and closure conditions. These are the key stages of TMF development in terms of variation in layout, and seepage is expected to be highest under these conditions. All model simulations were run in transient (time variant) mode, until steady-state conditions were achieved.

The conceptual model identified that geological structure is a potentially important component of the TMF hydrogeological flow regime. Mapped and inferred faults were incorporated into the model as discrete feature elements. These features were assigned a higher permeability than the surrounding bedrock and allow for preferential movement of groundwater. The modelling of all faults in the model as permeable zones along their full extent was a conservative assumption, as infilling with clay gouge (as observed in several drill holes) and compressional closure will result in some faults acting as low permeability barriers to groundwater flow rather than higher permeability conduits as modelled. The modelling approach used for the faults is further discussed in Section 3.6.

3.2 Modelling Software

The key software selection criteria for the TMF hydrogeological modelling were:

- ability to simulate three-dimensional flow in a complex hydrogeological setting;
- numerically stable in an environment with variable terrain and steep hydraulic gradients;
- ability to simulate anisotropy and discrete faults within the bedrock; and
- a recognized and industry standard software package.

The three-dimensional finite element modelling package FEFLOW was selected as it meets these objectives. FEFLOW is a numerical modelling package capable of simulating groundwater flow in overburden and bedrock materials with representation of faults. The water table elevation and flux rates are predicted as part of the model solution.

3.3 Mesh and Element Discretization

The model extent and mesh distribution is shown in Figures 19 and 20. The model domain covers a planar area of 138 km^2 and includes the Teigen Creek South tributary, Treaty Creek North, the TMF valley and the north, CIL and south cells of the TMF. The model domain extends to the following surface water flow boundaries, which also represent groundwater flow system divides:

- Treaty Creek to the south;
- South Teigen Creek to the northwest; and
- elevated ridgelines to the north and west, which are up to 950 m above the final tailings elevation.

The model mesh was defined in FEFLOW, which allows mesh refinement based on point, line or polygon features, and allows for user definition of finer mesh density in areas of interest. The model is comprised of 10 layers with a total of 561,080 prismatic triangular elements bound by 310,167 nodes. In plan, the elements varied from approximately 1 m to 180 m in equivalent diameter. Mesh density was increased in areas of sloping terrain where hydraulic gradients will likely be steepest. The mesh was also refined around watercourses, faults and the TMF dams and ponds which are focus areas for groundwater level and flux prediction.

3.4 Layers

The TMF model was setup with 10 elemental layers (11 nodal slices). Model slices were of variable elevation across the domain and defined the upper and lower surface of the model layers. Model slices were defined to approximately parallel topography as data from the site investigation program indicates elevation differences are an important controlling factor on groundwater levels and flow. The bottom slice of the model was set at a constant elevation of 100 masl. The layer assignment and thickness for the TMF model is summarized in Table 3.1. A cross section of the model mesh showing layer distribution (and equipotential contours) is presented on Figure 31 and Figure 32.

Table 3.1 FEFLOW Model Layer Distribution

Layer No.	Thickness (m)	Lithologic Unit	Primary Geological Units
1	5	Overburden/Surficial Bedrock	Bog, fluvial and colluvium/scree deposits, till, lateral moraine, surficial rock
2	Varies (0.1 – 39)		Alluvium (fan deposits), till, surficial rock
3	Varies (0.1 – 64)		Till, surficial rock
4	Varies (12 – 56)	Bedrock (Bowser Lake Group)	Bedrock (anisotropic; faulted)*
5	Varies (12 – 56)		
6	Varies (50 – 228)		Bedrock (anisotropic; faulted)
7	Varies (100 – 348)		
8	Varies (100 – 348)		Bedrock (isotropic, compressional)
9	Varies (100 – 348)		
10	Varies (32 – 529)		

* Development layers to allow simulation of seepage dam grout curtains into bedrock.

The thickness of the overburden was variable and was assigned based on depth to bedrock contours generated from seismic survey and borehole records from the 2008 to 2012 site investigation programs. The distribution of overburden assigned to model layers 1 is presented as Figure 21; this is a mapped overburden distribution, and local scale heterogeneity for each individual borehole was not included in the model. The thicknesses of the remaining model layers were selected to permit representation of:

- variations in hydraulic conductivity with depth consistent with site investigation data; and
- seepage dam grout curtains.

Model slice 1 corresponded to surface topography and was assigned elevations based on the LiDAR data provided by Seabridge. Areas outside zones of high resolution coverage were assigned from 1:50,000 digital elevation model (DEM) data obtained from regulatory sources.

The upper model slice was set as 'phreatic' to simulate unconfined conditions in the overburden materials. This option allows the layer to dry and rewet as required. The remaining slices were set to 'unspecified' which allows FEFLOW to control whether confinement occurs based on simulation results. This setup allowed the bedrock layers to remain saturated, with the water table present in upper model layers 2 and 3, depending upon heads calculated during the simulation. By default, the bottom model slice is set to as 'fixed' (i.e. constant elevation).

3.5 Model Boundaries

Boundary conditions are constraints imposed on the model to represent the influence of head and/or flow from the surrounding environment. The following boundary conditions were included in the model:

- Constant head (1st type) boundary conditions set at topography were assigned along the edges of the model represented by Treaty Creek and Teigen Creek. This boundary condition allows groundwater to discharge from the model in topographic low areas, consistent with the conceptualization. The constant head boundary condition was applied to model layers 1 to 7 as open faults in bedrock within these layers can allow hydrostatic pressures at depth.
- A seepage face condition set at topography was applied to all nodes on model slice 1 (i.e. across the entire model domain). This allows groundwater discharge to occur in low lying areas and along streams where the water table intersects ground surface. The seepage face was represented using a constant head boundary with a constraint condition that allows for groundwater discharge from the model only; head boundaries representing seepage faces cannot introduce flux into the model (as would be expected along topographic divides).
- A recharge boundary condition was applied to the top model slice across the entire domain. This allows recharge from precipitation (rainfall and snowmelt) to enter groundwater.

3.6 Discrete Feature Elements (Faults)

FEFLOW 2D quadrilateral vertical discrete feature elements (representing planar features) were incorporated into bedrock in layers 4 to 8 to represent mapped and inferred faults. Discrete elements were assigned a thickness of 1 m and a hydraulic conductivity (conductance) of $5x10^{-05}$ m/s. The applied hydraulic conductivity for faults is two orders of magnitude greater than the highest (calibrated) hydraulic conductivity value assigned to bedrock (Section 4.2) and is the highest value estimated from packer tests which were not able to be pressurized due to formation take being higher than drilling rig pump capacity. The effects of fault width on model results were assessed through sensitivity analysis (Section 6).

Faults were modelled as being more permeable than the surrounding rock mass along their full extent. This is a conservative assumption as low hydraulic conductivity gouge infill within faults was encountered in some faults in the north dam footprint during drilling. Discrete elements were not included in model layers 1 to 3 (0 m to 5.2 m depth) as surficial bedrock was already assigned a higher hydraulic conductivity to account for open jointing from pressure relief and weathering. Discrete elements were also not included in deep bedrock in model layers 8 to 10 as faults were conceptualized to be under compression at depths below 270 m (minimum depth to slice 8); this is below the deepest drilling completed during the site investigation programs and the depth at which seepage from the TMF could be expected in an area dominated by upward vertical flow gradients.

The distribution of discrete feature elements is shown in Figure 22. Fault locations included in the model were based on structural mapping and stereo-pair air-photo lineament analysis undertaken by KCB. All faults were modelled as vertical 2D feature elements assigned to vertical faces of FEFLOW mesh elements.

4 MODEL CALIBRATION

4.1 Introduction

This section of the report describes the process and results for calibration of the pre-development TMF model. Iterative review of the model setup, layering and boundary conditions was performed prior to calibration to achieve a model output consistent with the conceptual model, with groundwater flow mimicking topography and groundwater discharge occurring within the TMF valley.

Calibration was performed by adjusting recharge, boundary conditions and the hydraulic conductivity of each overburden and bedrock unit until a fit between model predicted and observed data was achieved. Groundwater levels from 57 piezometers and monitoring wells with readings taken between 2008 and 2012 were used for model calibration, with 2012 measurements used preferentially as primary calibration targets as these comprise the most extensive dataset collected within a single period. Historical data was used in the assessment of trends and verification of 2012 measurements. Calculated low flows for two dedicated Rescan monitoring stream gauging sites in the TMF valley were also used as calibration targets. The calibration process was manual as the complexity of the site hydrogeology and distribution of data was not commensurate with the use of an automated approach.

The performance of model calibration is evaluated through statistical methods. Typically, these involve the correlation coefficient (r^2) and the normalized RMFS (root mean fraction squared) as defined by ASTM Standard D 5918-96. A model is typically considered calibrated when the correlation coefficient is about 0.95 and the normalized RMFS is under 10%, and there is no bias in under or over-prediction of heads.

Calibration statistics are presented in Table 4.1, with a plot of observed versus predicted heads shown in Figure 23. The correlation coefficient obtained was 0.98 with an RMFS error of 2.1%. Calibration performance data from all sites was assigned a weighting of 1 (maximum possible). However, the groundwater level recorded at KC12-64 may not have stabilized following drilling, and pressure readings were not available for some flowing artesian wells; for calibration groundwater levels in these wells were assumed to be equal to surface. A lower weighting assigned to these data would improve the quantitative performance of the calibration slightly, particularly at lower elevations.

Table 4.1 Calibrated TMF Model Hydraulic Parameters

Statistic	Value	Units
Number of Head Calibration Targets	57	--
RMS (unweighted)	18.6	m
RMFS (unweighted)	2.1	%
Minimum Residual	+0.28	m
Maximum Residuals (-/+)	-38.1 / +71.6	m
Correlation Coefficient	0.98	--

4.2 Parameters

Pre-calibration input parameters for bedrock were selected through analysis of packer and slug test data. Initial values for overburden materials were selected from slug, pore pressure dissipation, grain size analyses, triaxial test results and literature. Reference was also made to calibrated hydraulic conductivity data used in the regional environmental impact assessment groundwater model for the TMF (Rescan, 2010).

The calibrated parameters optimized from initial inputs that were adopted for the model are summarized in Table 4.2. The following should be noted regarding the initial and final input parameters:

- A higher hydraulic conductivity was applied in layer 1 (0 m to 5 m) of the alluvial fans, which typically have colluvial and scree cover. Reworking of the fan deposits by surface water and gravity results in redistribution of fan sediments and fining with depth. Together with consolidation, this results in a decrease in hydraulic conductivity with depth.
- Bedrock hydraulic conductivity calibration targets collectively included slug and packer testing completed in both non-fractured and fractured bedrock. This is conservative, as tests in fractured bedrock include faults, which are also represented in the model as discrete elements.
- A Kh:Kv ratio of greater than one was maintained for bedrock in layers 1 to 7 to account for hydraulic conductivity being higher parallel to bedding (Section 2.5.1.2). The anisotropy ratio and direction (horizontal) were uniform throughout each model layer; local areas of dipping bedding observed in the TMF ridgelines were not individually discretized.
- Hydraulic conductivity of bedrock in the calibrated model decreased with depth, in-line with packer test results. This trend was maintained beyond the maximum test depth (135 m) to account for the effects of increased lithostatic pressure with depth resulting in compression of rock defects and a decrease in hydraulic conductivity (Rutqvist and Stephannson, 2003). Isotropic conditions were assigned to model layers 8 to 10 to represent effective closing of rock defects (preferential pathways for groundwater flow) under pressure below 270 m.

Table 4.2 Calibrated TMF Model Hydraulic Parameters

Layer No.	Unit	Geologic Description	Kh (m/s)	Kv (m/s)	Specific Yield*	Specific Storage* (m^{-1})
1	Overburden	Fluvial Deposits (in-stream)	$1.00x10^{-05}$	$1.00x10^{-05}$	0.20	$1.00x10^{-05}$
1		Bog Deposits	$2.00x10^{-06}$	$4.00x10^{-07}$	0.10	$5.00x10^{-04}$
1		Alluvial fans (surficial colluvium/scree)	$4.23x10^{-06}$	$4.23x10^{-06}$	0.20	$1.00x10^{-04}$
1		Lateral Moraine	$1.00x10^{-05}$	$1.00x10^{-05}$	0.20	$1.00x10^{-04}$
2		Alluvial fans	$6.75x10^{-07}$	$6.75x10^{-07}$	0.10	$1.00x10^{-04}$
1-3		Glacial Till	$1.00x10^{-07}$	$1.00x10^{-07}$	0.03	$5.00x10^{-04}$
1-3	Bedrock	Surficial bedrock (open jointing/weathered)	$6.00x10^{-06}$	$3.00x10^{-06}$	0.05	$1.00x10^{-05}$
4		Interbedded Bowser Lake Group (sandstone / siltstone / mudstone)	$4.81x10^{-07}$	$2.41x10^{-07}$	0.01	$1.00x10^{-04}$
5			$1.63x10^{-07}$	$8.15x10^{-08}$	0.01	$1.00x10^{-04}$
6			$1.2x10^{-07}$	$6.00x10^{-08}$	0.01	$1.00x10^{-04}$
7			$8.00x10^{-08}$	$4.00x10^{-08}$	0.01	$1.00x10^{-04}$
8			$8.00x10^{-08}$	$8.00x10^{-08}$	0.005	$1.00x10^{-04}$
9			$5.00x10^{-08}$	$5.00x10^{-08}$	0.005	$1.00x10^{-04}$
10			$8.00x1\text{-}^{-09}$	$8.00x10^{-09}$	0.005	$1.00x10^{-04}$

* Initial input value – not optimized during calibration as model runs were completed to achieve steady state conditions (at which time storage parameters are not applicable).

4.3 Recharge

Calibrated recharge increased linearly from 75 mm at elevation 600 m to 139 mm above 1500 m and corresponds to approximately 5.5% to 10.1% of mean annual rainfall (MAR) recorded at the plant site (1372 mm/yr at elevation 1085 m). A positive correlation between recharge and elevation was maintained throughout calibration trials to account for orographic effects; precipitation rates typically increase with elevation in mountainous terrain due to advection. High elevation ice fields on ridgelines above the TMF valley were assigned a constant recharge rate of 40 mm/yr.

4.4 Heads

The steady state head distribution for layer 1 and layer 10 under pre-development conditions is presented as Figure 24. Heads in layer 1 are an approximation of the water table; FEFLOW 5.3 does not allow for direct export of the true water table (zero pressure isosurface), however, this was assessed using the 3D viewer. Groundwater levels and gradients mimic topography being elevated within the TMF ridgelines (recharge zones) and at or near surface in the valley bottom (discharge zone coincident with south tributary of Teigen Creek and Treaty Creek North). The east and west ridgelines represent hydraulic divides which constrain groundwater movement to within the TMF valley; this is illustrated in the pre-development cross sections through the TMF north and south cells in Figure 31 and Figure 32 which shows elevated heads in the ridgelines adjoining the TMF and vertical gradients consistent with artesian conditions in the valley bottom.

4.5 Groundwater Discharge and Flows

The predicted distribution of recharge and discharge zones is consistent with the hydrogeological conceptualization and is shown on Figure 25. Recharge to groundwater is through precipitation (rainfall and snowmelt). Constant head boundaries assigned to Treaty and Teigen Creek represent zones of groundwater discharge at the model perimeter.

Groundwater discharge at surface to seepage face nodes inside the model domain occurs primarily at low elevations in the base of the TMF valley, with localized discharge along incised drainage lines at higher elevations within the east catchment and other minor tributaries flowing to the TMF valley.

Model predicted flux for the catchment areas for Rescan gauging stations NTMW-1 (Treaty North Tributary Mouth) and STMW-1 (Teigen South Tributary Mouth) is summarized in Table 4.3. These flows are comparable to the low flows recorded by Rescan at these stations. Low flows at these locations will represent minimum baseflow, comprised primarily of groundwater discharge. As the groundwater level measurements used as primary calibration targets were not recorded during annual or decadal dry periods the low flow estimates were used as lower bound flow calibration targets.

Table 4.3 Comparison of Estimated Surface Water Low flows and Model Predicted Groundwater Discharge

Station ID	Estimated Annual Low Flow (m^3/s)		Model Predicted Discharge (m^3/s)
	7-day	7-day Q10[1]	
NTWM-H1	0.28	0.13	0.45
STWM-H1	0.15	0.07	0.15

[1] Average estimated baseflow for the lowest consecutive seven day period per 10 year recurrence interval.

5 MODELLING SCENARIOS

Two model setups were developed from the calibrated pre-development model to simulate the TMF under varying stages of development. The revised setups were:

- TMF Water Management Plan Stage 1 model: includes the north and splitter dams at full height and the saddle dam at 1004 m. The north cell TMF cell is at final capacity with saturated tailings to 1060 m. The CIL cell has a full water cover to 989 masl. This model represents the TMF at year 29, prior to construction of the south cell.
- TMF Final Closure model: includes the north, southeast, splitter and saddle dams at full height. The north and south cells are at final capacity with saturated tailings to 1060 m. The TMF closure channels are commissioned and join the north, south and CIL cell ponds which have an elevation on 1054 masl.

The following elements were incorporated into the calibrated model to account for TMF structures and tailings. Unless specified, these were incorporated in both the Stage 1 and closure scenario models.

- The upper model slice was re-profiled to account for the TMF dams and tailing at their final elevation.
- Floatation and CIL tailings were assigned horizontal hydraulic conductivity values of $5.0x10^{-07}$ m/s and $2.0x10^{-07}$ m/s, respectively with a Kh:Kv ratio of 16:1. This ratio was selected based on previous experience at operational mine sites in British Columbia. Anisotropy in the tailings accounts for seasonal deposition of the low hydraulic conductivity overflow tailings within the floatation TMF cells.
- The TMF cyclone sand dams were assigned a horizontal hydraulic conductivity of $1.2x10^{-05}$ m/s with a Kh:Kv ratio of 4:1. A till core with an isotropic hydraulic conductivity of $1.0x10^{-08}$ m/s was included in the final dams in all simulations.
- The TMF ponds were represented using Cauchy (3rd type) boundary conditions. The elevation of these boundaries was equivalent to the pond elevation in the individual TMF cells during Stage 1 and closure.
- Till borrow excavation within the dam footprint was modelled by reassigning elevations for slice 3 within designated till borrow areas. In these areas the till thickness was halved and the void space filled with the corresponding engineered materials in the overlying layer (floatation tailings, CIL tailings or cyclone sand).
- FEFLOW transfer rates were assigned beneath the tailings. A transfer rate is a model assigned parameter which accounts for the effects of low hydraulic conductivity layers beneath Cauchy boundaries when calculating heads and flow. Hydraulic conductivity and thickness are the inputs used to calculate transfer rates. In and out transfer rates were the same for all simulations. The effects of transfer rates on model predictions was assessed through sensitivity analyses (Section 6).

A transfer rate of 8.64 d^{-1} was assigned in layer 1 beneath Cauchy boundaries representing the active ponds (Figure 29 – Stage 1, Figure 30 – Closure). This rate allowed pond heads and seepage to transfer through the base of the TMF impoundment with no artificially imposed restriction. Under this setup seepage in and out of the tailings is passively controlled by the hydraulic properties of the tailings/foundation materials and vertical/lateral hydraulic gradients.

- Transfer rates for floatation and CIL tailings outside the ponds accounted for the effects of saturated low hydraulic conductivity tailings in controlling flow. A transfer rate of 3.3×10^{-04} d^{-1} was assigned to the floatation tailings in layer 1 outside the ponds. This value was calculated using the horizontal hydraulic conductivity of the floatation tailings and 66th percentile of the final tailings thickness in the TMF valley (130 m). The transfer rate for the CIL residue outside the pond under closure conditions was calculated using the same approach, and yielded a rate of 8.3×10^{-06} d^{-1}. The transfer rate assigned to the Stage 1 CIL residue was 1.7×10^{-05} d^{-1}; this was calculated using a 65 m CIL residue thickness (half the 66th percentile thickness used in the closure scenario).
- A recharge rate of 108.3 mm/yr (8% MAR) was assigned to the dams and upper tailings surface in all TMF models. In practice, surface recharge to the cyclone sand dams (during operations and closure) and construction seepage (during operations) will be intercepted by internal drainage within the dam and managed as surface water. Recharge to the dams is therefore unlikely to contribute significantly to groundwater, and the applied rate is conservative. The recharge rate assigned to tailings in the model does not affect seepage as the Cauchy boundary condition assigned across the entire tailings surface and the transfer rate controls seepage.

5.1 Seepage Management Systems

The following seepage management systems (SMS) will be incorporated into the TMF Engineering design to minimize loss of contact seepage from the facility. These passive systems were incorporated into the TMF design from the outset and will be installed prior and during dam construction. Similar seepage management systems are in use at TMFs at other operating mines in British Columbia. The seepage management system for the TMF includes:

- Seepage recovery dams downstream of terminal TMF dams at each stage of operation to capture seepage from the dams and impoundment. Recovered seepage will be pumped back to the TMF.
- Bentonite slurry cutoff walls through overburden to low permeability till or bedrock beneath the north, splitter and southeast dams.
- A cutoff though overburden and a grout curtain extending 25 m into bedrock beneath the north, saddle and southeast seepage recovery dams.

- An HDPE liner (up to 2.5 mm thick) and underlying engineered sand filter within the base of the CIL residue cell. Depressurization wells will be operated during initial construction to control uplift pressures beneath the liner.
- Grouting of permeable faults where encountered within the dam foundation during investigation and construction.

Internal drainage layers within the dams were not incorporated into the model due to their complexity and dimensions relative to the scale of the model. This is a conservative assumption, and drainage elements within the dam fill will collect groundwater seepage and convey these to the seepage collection ponds as surface water flows, together with construction water from the placed sand during operations.

Site investigation findings and the model results indicate the greatest potential for seepage from the TMF is through locally permeable zones that may exist in overburden beneath the dams. The above seepage management systems were selected to reduce lateral flows through these units beneath the main dams and the seepage recovery dams, and function as barriers to groundwater movement through relatively permeable units. Design and placement of the proposed seepage barriers was selected based on site investigation and preliminary model results.

Model simulations with and without SMS were completed, and were based on the base case model setup outlined in previous sections. The seepage recovery dams and ponds were not represented as physical structures in the model; this allows contact seepage passing beneath the dam in the foundation to passively discharge at surface without influence from assigned head conditions representing ponds, and is consistent with the operational strategy for pond operation (seepage will be pumped as appears). The approach used to simulate the SMS in the model is described below:

- Bentonite slurry cutoff walls beneath the north, splitter and southeast dams were modelled as vertical features along the dam centreline. These walls had a thickness of 20 m and a hydraulic conductivity of $1x10^{-08}$ m/s. The cutoff walls were assigned to layers 2 to 3 (beneath the dam core, above the bedrock contact) and had a length equivalent to the dam crest length.
- Grout curtains and cutoffs beneath the seepage recovery dam locations[5] were modelled as vertical walls (nominally 20 m in thickness) beneath the dam centreline. The cutoff walls were assigned a hydraulic conductivity of $1x10^{-08}$ m/s and extended from surface into layer 4 (upper bedrock layer). The length of the grout curtains/cutoffs was equivalent to the seepage recovery dam crest length.
- The CIL residue cell liner was simulated by revising the hydraulic conductivity of model layer 2 (immediately beneath the tailings) to $1x10^{-08}$ m/s. The predominant thickness of this layer within the CIL residue cell is 0.1 m. A horizontal 2D triangular discrete element with a hydraulic conductivity of $1x10^{-08}$ m/s and a thickness of 0.5 m was also assigned to slice 3 (beneath the simulated liner).

[5] The seepage recovery dams were not modeled as physical structures, however, the locations were used to reference seepage management systems included in the model.

- The modelled liner extent for Stage 1 and closure scenarios corresponded with the CIL tailings cell extent for each respective development stage.
- Fault grouting was simulated by removing discrete feature elements representing the faults from model element faces in layer 4 within approximately 50 m of the north dam centreline. The (horizontal) hydraulic conductivity of the intact bedrock in layer 4 is 4.81E-07 m/s, which is higher than the effective hydraulic conductivity that will be achieved with grout. Mapped and inferred faults did not extend below the splitter, saddle and southeast dams and fault modification was therefore restricted to the north dam. North dam faults in the deeper model layers of 5 to 7 were not modelled as 'grouted' as a grouting program for seepage control beneath a dam would normally target shallow depths preferentially (where seepage typically is highest).

5.2 Model Results

Groundwater fluxes were measured using FEFLOW fluid flux analysis sections. Horizontal flux beneath each TMF dam and seepage recovery dam was measured perpendicular to the dam crest along the dam centreline. The location of horizontal flux sections which were used to estimate groundwater flow is shown in Figure 26. Vertical flux through the base of the north, CIL and south cells was measured across layer 2 using a flux section polygon equal to the north, CIL and south cell extent.

Total groundwater flows are reported. These flows are comprised of both contact seepage and natural groundwater, which are defined below.

- Contact seepage: seepage from the TMF that discharges though the dams and the base of the facility, and enters groundwater. Seepage through the base of the impoundment that mixes with natural groundwater is also referred to as contact seepage as it has come into contact with seepage form the facility. Contact seepage originates from the tailings pond, pore water and cyclone sand construction water. The quality of contact seepage reflects the tailings supernatant mixed with natural groundwater and recharge from precipitation.
- Natural groundwater: groundwater flow from outside the TMF footprint that does not interact with seepage from the facility. The quality of natural groundwater is the same as background groundwater quality. Natural groundwater flows originate from the TMF ridgelines (recharge zones) and under current conditions discharge in the TMF valley. Following construction, the low permeability tailings placed in the valley will restrict discharge of natural groundwater. Natural groundwater flows which do not discharge into the TMF will flow along the base of the valley beneath the main dams.

5.2.1 Heads and Flow Directions

Model predicted heads and flow directions for Stage 1 and Closure scenarios which incorporated seepage management systems are shown in Figures 27 and 28. In all scenarios there was a groundwater flow gradient toward the TMF from the elevated ridgelines, with upward vertical gradients in the bottom of the valley beneath the impoundment. These gradients are driven by and are comprised of natural groundwater flows. Vertical flow gradients provide lateral containment of contact seepage within the bottom of the TMF valley, and restrict seepage of contact water through the base of the impoundment. Longitudinal flow in the along the valley bottom was toward South Teigen Creek to the north and Treaty Creek to the south (mimicking topography). Flow patterns away from the TMF for each scenario were comparable to the pre-development (existing) flow regime (Figure 24).

A local steepening of regional hydraulic gradients in the ridgelines adjoining the TMF cells was recorded following TMF development (Figures 31 and 32). This occurred as a result of groundwater having a locally restricted ability to leave the model in the TMF valley. This will result in increased natural groundwater discharge from springs and seeps at elevations above the ultimate tailings level; these flows would be intercepted in diversion drains with surface water flows and diverted downstream.

5.2.2 Impoundment Loss/Gain

Vertical flux through the base of the impoundment for each simulation is summarized in Table 5.1 (Stage 1) and Table 5.2 (Closure). Presented values represent the following:

- total TMF Inflow is flow into the TMF from regional (natural) groundwater; and
- total TMF seepage loss is contact seepage which discharges from the tailings to natural groundwater.

Table 5.1 Total Groundwater Flow in and out of the TMF – STAGE 1 (all flows are through the base of the impoundment)

TMF Stage 1 Cell	No Seepage Management Systems (L/s)		With Seepage Management Systems (L/s)	
	Total TMF Inflow (natural groundwater)	Total TMF Seepage Loss (contact water)	Total TMF Inflow (natural groundwater)	Total TMF Seepage Loss (contact water)
North Cell	30	25	30	24
CIL Residue Cell	7	5	2	<1
Total	37	30	32	24

Table 5.2 Total Groundwater Flow in and out of the TMF – CLOSURE (all flows are through the base of the impoundment)

TMF Closure Cell	No Seepage Management Systems (L/s)		With Seepage Management Systems (L/s)	
	Total TMF Inflow (natural groundwater)	Total TMF Seepage Loss (contact water)	Total TMF Inflow (natural groundwater)	Total TMF Seepage Loss (contact water)
North Cell	34	16	31	15
CIL Residue Cell	7	4	<1	<1
South Cell	34	19	31	17
Total	75	39	63	32

Contact seepage lost through the base of the impoundment is contained within the bottom of the TMF valley by vertical gradients and flow of natural groundwater from the adjoining ridgelines. Seepage mixes with natural groundwater and flows beneath the terminal containment dams primarily in overburden (Section 5.2.3) and discharges into the seepage collection ponds downstream of the dam toes (Section 5.2.5).

Figures 29 and 30 present the distribution of model predicted net recharge and discharge from the model boundary conditions for the Stage 1 and Closure conditions, which include SMS, respectively. Model recharge areas represent zones in which a net input to groundwater occurs; outside the tailings footprint recharge is from precipitation, whereas inside the TMF footprint recharge is from tailings pore water. Discharge areas represent zones where groundwater discharges to surface as seepage. Above the elevation of the TMF and downstream of the seepage dams discharge into valley areas is natural groundwater driven by topographically-induced gradients (assessed through particle tracking in Section 5.2.5). Discharge at the toes of the dams is a combination of pore water seepage from the TMF and natural groundwater from upgradient areas.

Flux into the impoundment exceeded loss for all scenarios due to the TMF being located in a zone of active natural groundwater discharge. Vertical hydraulic gradients and the low permeability of the till overburden and tailings contribute to elevated pore pressures beneath the facility, provide hydraulic containment and reduce seepage loss from the TMF to natural groundwater.

Cross sections showing the distribution of heads across the north and south TMF cells for the pre-development, Stage 1 and Closure scenarios are presented as Figure 31 and Figure 32, respectively. Long sections along the TMF valley for Stage 1 and closure scenarios are presented as Figure 33 and figure 34, respectively. The location of the section lines is presented as Figure 35.

A discussion of the results for the Stage 1 and Closure model scenarios is presented in Sections 5.2.2.1 and 5.2.2.2. In all scenarios, inflow and seepage loss to and from the TMF is controlled primarily by the permeability of the tailings and overburden, and vertical flow gradients.

5.2.2.1 Stage 1

The distribution of recharge and discharge for Stage 1 is shown in Figure 29. Discharge of natural groundwater into the TMF during Stage 1 was predicted throughout the north cell footprint, except for in the area behind the North Dam which represents a local zone of groundwater discharge. Natural groundwater inflow to the impoundment was also predicted to occur within the CIL residue cell[6], excepting immediately behind the saddle dam. Inflow rates of natural groundwater into the impoundment with and without the proposed liner were 2 L/s and 7 L/s, respectively. During initial CIL residue placement, inflows of natural groundwater beneath the liner in the CIL cell will be controlled through pumping from depressurization wells installed in the filter beneath the liner to control uplift of the liner.

Contact water seepage through the Stage 1 TMF impoundment decreased by 23% (from 30 L/s to 24 L/s) following the addition of the proposed SMS. The reduction occurred primarily as a result of inclusion of the HDPE liner beneath the CIL residue cell (>4 L/s seepage reduction). The reduction in

[6] The liner was simulated using an equivalent porous media (EPM) approach as FEFLOW cannot specifically represent very thin essentially impermeable features. Inflow and outflow estimates for the CIL Residue Cell are therefore likely conservative.

seepage from the north cell (1 L/s) occurred due to a local increase in mounding beneath this cell which restricted seepage loss from the impoundment.

5.2.2.2 Closure

Contact seepage discharge from the north and south TMF cells to the foundation without the SMS was 16 L/s and 19 L/s, respectively. The addition of the SMS reduced seepage discharge from the north and south cells to 15 L/s and 17 L/s (a 6% and 10% reduction, respectively). Addition of the liner to the CIL residue cell reduced seepage discharge by 3 L/s (75% reduction).

The distribution of recharge and discharge at Closure is shown in Figure 30. The distribution of natural groundwater inflow into the tailings and contact seepage discharge through the foundation for the north cell at closure is similar to Stage 1, with discharge (through the foundation) occurring immediately behind the dams and inflow (into the TMF) occurring throughout the remainder of the cell. A similar distribution of inflow and discharge was predicted for the south cell.

Natural groundwater inflow into the TMF north cell at closure is higher than during Stage 1. Comparatively, contact seepage discharge through the base of the north cell impoundment is 9 L/s less at closure compared to Stage 1 (for cases with and without the seepage management). These changes occurred because the addition of the south cell to the TMF valley restricts the area in which natural groundwater can discharge in the TMF valley. This in turn increases pore pressures beneath the tailings which reduces seepage discharge and increases inflow.

Flow divides within the facility are located at the splitter dam (north cell) and saddle dam (south cell). Pathline analyses indicate groundwater flow in the tailings and foundation is away from these areas towards respective terminal dams. Head gradients decrease away from the north and south dams, and there is a groundwater flow 'stagnation zone' in the centre of the facility where groundwater flow rates are low (Figure 34) in the area of the CIL Residue Cell.

The CIL Residue Cell with the liner installed is a zone of groundwater discharge, however, the rates of inflow and discharge are both low (<1 L/s) as the HDPE liner reduces exchange between pore and pond water in the CIL Residue Cell and natural groundwater. Without the liner installed, the CIL Residue Cell receives net natural groundwater inflow, with some discharge of contact seepage through the foundation at the pond margins.

5.2.3 Lateral Seepage beneath TMF Tailings Dams

Lateral flow beneath the tailings dams is a combination of contact seepage from the tailings through the TMF foundation (Section 5.2.2) and regional flows of natural groundwater along the valley bottom beneath the TMF.

Natural groundwater flow occurs in deeper model layers (bedrock) and is induced by gradients toward the valley from the adjoining ridgelines (Figures 32 and 33). Under pre-development conditions, these gradients result in artesian discharge within the TMF valley. The addition of the TMF to the model restricts vertical discharge of natural groundwater and results in increased longitudinal flow of natural groundwater downgradient along the valley beneath the facility. The low hydraulic conductivity of the tailings will restrict natural groundwater discharge, and flows of natural groundwater beneath the dams will be higher than under current conditions. Vertical gradients beneath the facility also restrict contact seepage discharge from the facility and provide lateral hydraulic containment of seepage within the TMF valley.

Total flows beneath each of the tailings containment dams are summarized in Table 5.3. The location of the fluid flux section lines used to calculate flow beneath each dam is shown in Figure 26. The flow from beneath the dams report to the Seepage Recovery Ponds as described in Section 5.2.4.

Table 5.3 Total Groundwater Flow beneath Tailings Containment Dams

TMF Dam	Total Flow beneath Dam (L/s) Basecase	Total Flow beneath Dam (L/s) Stage 1**		Total Flow beneath Dam (L/s) Closure**	
		No Seepage Management	With Seepage Management*	No Seepage Management	With Seepage Management*
North Dam	5	26	24	24	23
Saddle Dam	<1	14	13	--	--
Southeast Dam	4	--	--	24	22

*Note that the slurry cutoff walls in the seepage management systems are provided to address localized permeable zones in the overburden that cannot be incorporated or assessed directly in the model due to scale.

A discussion of the performance of the overburden cutoffs beneath the north and southeast dams is included in Sections 5.2.3.2 and 5.2.3.4 (respectively). The performance of the cutoff beneath the splitter dam is not discussed as this is not a terminal containment dam for the TMF during operation.

The cutoffs (SMS) are included in the design to minimize flow of contact seepage through overburden beneath the dams. In particular, these will reduce contact seepage through local (sub-meter) scale permeable zones within the till and alluvium. These zones were not discretized in the model due to their localized scale, but were occasionally encountered during site investigations. As these zones were not represented in the model, the estimated performance of the cutoffs will be conservative.

Furthermore, the cutoffs will extend to a low permeability overburden or bedrock contact, which will be confirmed during dam construction and prior to cutoff installation. This design approach will reduce pathways for contact seepage migration through the overburden and any zones of relatively permeable surficial bedrock.

5.2.3.1 General Results

- Results for the pre-development scenario are presented for reference. Regional groundwater flow in the pre-development model is toward the valley and parallel to the alignment of the fluid flux sections; by comparison, flow in models which included the TMF is always perpendicular to the section line.
- Model predicted total flows beneath the Saddle Dam were lower than the North and Southeast dams as the dam height is lower and the dam is located on an existing groundwater divide.

- Cross sections (Figures 18 and 19) and long sections (Figures 20 and 21) through the TMF indicate flow in bedrock (lower model layers) is comprised of natural groundwater from the upgradient east and west ridgelines which adjoin the TMF. These flows are included in the reported total flows beneath the dams. Upward vertical gradients minimize the potential for contact seepage discharging from the TMF foundation from reaching deep bedrock.
- Long sections though the Stage 1 (Figure 20) and Closure (Figure 21) TMF layouts indicate vertically-inclined upward hydraulic gradients exist at the toe of each dam in the upper model layers (overburden and shallow bedrock). This will result in contact seepage and natural groundwater discharge into the catchment of seepage recovery dams downstream of the main TMF dam, consistent with the particle tracking analyses (Section 5.2.5).

5.2.3.2 North TMF Dam Results

- The addition of a low permeability cutoff beneath the north dam reduced total seepage by 2 L/s during Stage 1 and 1 L/s at closure. The reduction in flow occurred in overburden layers through which the cutoff is installed. Head sections (Figures 33 and 34) and particle pathlines (Section 5.2.5) indicate flow in these layers is contact seepage discharge from the impoundment.
- Contact seepage through the overburden (model layers 2 and 3) beneath the north dam reduced from 3.9 L/s to 0.1 L/s during Stage 1 and from 3.5 L/s to 0.1 L/s during closure following addition of the cutoff to the model. This represents a 97% and 98% reduction in contact seepage flow through the overburden.
- Flow beneath the north dam during closure was less than Stage 1 as the north cell pond area is smaller.

5.2.3.3 Saddle Dam Results

- Flows beneath the saddle dam decreased by 1 L/s following addition of the CIL liner and the cutoff beneath the splitter dam to the model.

5.2.3.4 Southeast Dam Results

- The addition of a low permeability cutoff beneath the southeast dam reduced total seepage beneath the dam by 2 L/s at closure. As for the north dam, the reduction in flow occurred within overburden model layers; head sections and particle pathlines indicate these flows are comprised of contact seepage from the impoundment.
- Contact seepage through the overburden (model layers 2 and 3) beneath the southeast dam reduced from 11.2 L/s to 0.4 L/s during closure following addition of the cutoff to the model. This represents a 96% reduction in contact seepage flow through the overburden.
- The addition of the low permeability cutoff beneath the southeast dam did not change flows of natural groundwater in the lower bedrock.

5.2.4 Total Flow beneath Seepage Recovery Dams

Model predicted total flows beneath the north, saddle and southeast seepage recovery dams are summarized in Table 5.4. Total flow beneath the seepage recovery dams was estimated using the FEFLOW fluid flux analyzer dissecting all model layers.

Table 5.4 Total flow beneath the Seepage Recovery Dams

TMF Seepage Dam	Total Flow beneath Seepage Dam (L/s) Base case*	Total Flow beneath Seepage Dam (L/s) Stage 1		Total Flow beneath Seepage Dam (L/s) Closure	
		No Seepage Management	With Seepage Management	No Seepage Management	With Seepage Management
North Dam	0.4	0.3	0.3	0.6	0.5
Saddle Dam	0.3	0.3	0.1	--	--
Southeast Dam	1.5	--	--	1.6	1.3

*Base case results are presented for reference, and cannot be directly compared to simulations which include the TMF. Under the Base case condition flow is primarily towards the valley bottom, parallel to the flux section. For models which include the TMF flow is primarily perpendicular to the sections.

Total flows beneath the seepage recovery dams during Stage 1 and closure conditions were similar, and are comparable to estimated flows for pre-development conditions. When considered in conjunction with the particle tracking results (Section 5.2.5) and head contours in ridgelines near the seepage dams (Figures 27 and 28), these results indicate the flow beneath the seepage recovery dams is comprised of natural groundwater. The addition of a cutoff through overburden and grout curtain into bedrock reduced total flow beneath each seepage recovery dam. The reduction in flow occurred in model layers in which these seepage management systems were installed (layers 1 to 4). Long sections along the TMF valley and fluid flux analyses results by model layer indicate contact seepage flow will be highest in these layers.

5.2.5 Particle Tracking

Forward steady state particle tracking was undertaken to assess patterns of groundwater movement from the TMF and identify whether seepage from the impoundments beneath each TMF dam daylights within the catchment of the seepage recovery dams. Pathlines show the flow direction of a non-reactive solute travelling from these facilities within groundwater via advection only, and do not indicate the magnitude of flux. Particles which are effectively stationary (e.g. in the centre of each TMF cell) are located in zones with very low flow velocities (i.e. groundwater is almost stagnant). Particle tracking does not consider secondary processes which will change the solute concentration with time and distance travelled (adsorption, chemical reaction and dispersion).

For Stage 1 and Closure particles were assigned within the tailings cells behind the dam. Figures 36 to 37 show particle movement beneath the dam in layer 1 (tailings) and layer 3 (deep overburden) of the model. Pathlines for Stage 1 and Closure simulations which included SMS are presented, and are comparable to those for the simulations which did not include SMS; this is expected given particle tracking was undertaken for steady state flow conditions. The pathlines are assigned to each slice and show the full distance particles from respective slices travel.

Regional particle movement outside the TMF mimicked topography. This confirms that the elevated hydraulic heads in the upgradient areas around the TMF provide lateral hydraulic containment of contact water within the TMF valley. Given the TMF is located in a zone of regional groundwater discharge, no cross-catchment particle movement was observed. This indicates that the TMF is hydraulically contained by elevated groundwater levels in the ridgelines.

5.2.5.1 North Dam

Particle movement in model layers 1 and 3 (representing contact seepage) indicates flows through the overburden and shallow bedrock emerge at the toe of the main dam (within the seepage recovery dam catchment downstream of the TMF dam). These flows can be recovered and managed with other seepage collection at this location. In practice, most of these flows will likely be recovered in the internal drainage within the downstream portion of the dam, and the migration pathway for seepage will be shorter.

In deep bedrock (layers 6 to 10) particles migrate to both the seepage recovery dam catchment and the Teigen Creek head boundary at the western edge of the model. As presented in Figures 33 and 34, flows in lower model layers in the valley bottom are natural groundwater from the elevated ridgelines of the TMF valley. This flow pattern in deeper bedrock is also consistent with the groundwater flow regime under pre-development conditions.

Particles in the eastern portion of the dam travel approximately 300 m along the strike of a modelled fault in the underlying layer prior to the dam centerline, where the faults are grouted. Further migration to the northeast along the fault is restricted by elevated heads in upgradient areas and the simulated grouting. Flow along the fault discharges into the seepage recovery pond together with the more diffuse seepage through overburden and shallow bedrock.

5.2.5.2 Saddle Dam

Particle pathlines for layer 1 (within the CIL residue pond) in Stage 1 have short travel distances (<500 m) and do not extend beyond the saddle dam. The short pathlines are due to the low groundwater flow velocities within the CIL residue arising from the liner effectively separating this material from the underlying groundwater regime. Pathlines in the lower overburden (layer 3) discharge at the toe of the saddle dam. These flows can be managed together with seepage from the dam which collects in the seepage recovery pond.

5.2.5.3 Southeast Dam

Particle pathlines in upper model layers beneath the southeast dam terminated at the dam toe within the seepage recovery dam catchment, downstream of the TMF. These results indicate contact seepage from the TMF beneath the southeast dam emerges in the seepage recovery dam catchment and can be pumped back to the TMF.

Particles in deep bedrock (layers 6 to 10) migrate along the alignment of the TMF valley to the constant head boundary representing Treaty Creek. These flows are comprised of natural groundwater from the elevated ridgelines into the TMF valley, consistent with the groundwater flow regime under pre-development conditions (Figures 33 and 34).

6 MODEL SENSITIVITY ANALYSIS

Sensitivity trials were undertaken to assess the effect that changes in model inputs had on groundwater flows, and to identify which parameters primarily influence TMF seepage. Sensitivity scenarios assessed are detailed in Table 6.1.

Table 6.1 Sensitivity Analyses Performed on the closure model which includes Seepage Management Systems

Parameter Varied	Original Value	New Value	Purpose/Notes
Vertical hydraulic conductivity of the tailings - floatation and CIL residue (Tailings anisotropy ratio changed from 16:1 to 4:1)	Floatation = 3.13x10^{-08} m/s CIL residue = 1.25x10^{-08} m/s	Floatation = 1.25x10^{-07} m/s CIL residue = 5.00x10^{-08} m/s	Assess the effects of varied tailings hydraulic conductivity on seepage. Only the vertical hydraulic conductivity was varied as the anisotropy ratio is estimated (cannot be directly measured).
Hydraulic Conductivity of overburden	Till = 1x10^{-07} m/s Alluvium = 6.75x10^{-07} m/s Colluvium = 4.23x10^{-06} m/s	Till = 5x10^{-07} m/s Alluvium = 1x10^{-06} m/s Colluvium = 1x10^{-05} m/s	Assess the effects of 85th percentile of field measured values for till, alluvium and colluvium were assigned. Only overburden K was sensitized as the model indicates seepage is highest in these materials. The permeability of the upper bedrock was not changed as this is already based on high-end field measured values.
Fault Width	1.0 m	1.0 m (x10) 0.1 m (÷10)	Assess the effects of differing fault widths on seepage. Fault hydraulic conductivity was not varied through sensitivity as this is one order of magnitude higher than the hydraulic conductivity of other units.

Initial model runs indicated overburden hydraulic conductivity was the primary control on seepage. The sensitivity scenario which assesses the 85 percentile overburden hydraulic conductivity values was undertaken to estimate an ‘upper bound’ seepage rate for seepage management design. Assessing seepage for an upper bound case adds a factor of safety to seepage and flow predictions, and accounts for variability in field measured hydraulic conductivity values.

Sensitivity trials were completed for the closure scenario which included SMS. This scenario was selected as it represents the final layout of the TMF and had higher seepage rates that the Stage 1 model. Results of the sensitivity trials are summarized in Table 6.2 to Table 6.4.

Table 6.2 Vertical Flux (in and out) of the TMF Foundation – Sensitivity Trials (all flows are through the base of the impoundment)

TMF Scenario	Total TMF Inflow (natural groundwater); (L/s)	Total TMF Seepage Loss (contact water); (L/s)
Calibrated Model	*63*	*32*
Tailings anisotropy 4:1	86	40
Overburden hydraulic conductivity (85%ile values)	63	46
Fault width x 10	63	34
Fault width ÷ 10	63	33

Table 6.3 Total Flow Beneath TMF Dams – Sensitivity Trials

Scenario	Flow beneath North Dam	Flow beneath Southeast Dam
Calibrated Model	*23*	*22*
Tailings anisotropy 4:1	28	25
Overburden hydraulic conductivity (85%ile values)	25	25
Fault width x 10	*23*	22
Fault width ÷ 10	*23*	23

Table 6.4 Total Flow Beneath Seepage Recovery Dams - Sensitivity Trials

Scenario	North Seepage Dam (L/s)	Southeast Seepage Dam (L/s)
Calibrated Model	*0.5*	*1.3*
Tailings anisotropy 4:1	0.5	1.3
Overburden hydraulic conductivity (85%ile values)	0.5	1.3
Fault width x 10	0.5	1.3
Fault width ÷ 10	0.4	1.3

In all sensitivity runs the TMF maintained a positive water balance with natural groundwater inflow exceeding seepage loss; this indicates vertical flow gradients and associated hydraulic containment of the TMF was maintained in all assessed conditions. Particle tracking patterns for all sensitivity scenarios were similar to the calibrated model, and indicate that contact seepage from the TMF discharges into the catchment of the seepage recovery dams for all conditions assessed. Analysis of the results identified the following:

- An increase in the hydraulic conductivity of the overburden resulted in a 14 L/s (44%) increase in seepage loss through the TMF foundation. A smaller increase in seepage was recorded for the 4:1 tailings anisotropy sensitivity scenario (8 L/s or 25% increase). The overburden hydraulic conductivity and tailings were the primary controls on seepage rates from the TMF for the scenarios considered.

  For the upper bound overburden hydraulic conductivity scenario the increase in seepage beneath the main dams was less than the increase in seepage loss through the base of the impoundment. This indicates the cutoff through the overburden is an effective means of reducing lateral seepage of contact water beyond the main dams.

- An increase in natural groundwater flow from the foundation into the tailings occurred for the 4:1 tailings anisotropy ratio scenario. This indicates the low hydraulic conductivity of the tailings controls vertical groundwater gradients in the TMF during operations and closure.
- Total flow beneath the seepage recovery dams was insensitive to changes in model inputs. Changes were not recorded for the 85th percentile overburden sensitivity case, which indicates the cutoff wall through the overburden is effective means of controlling seepage. There was no change in seepage for the tailings anisotropy case as flow beneath the seepage recovery dams is comprised primarily of natural groundwater and is not influenced by changes in TMF simulation in the model.
- Sensitivity trials, which varied fault width, had a slight (<1 L/s) effect on seepage through the TMF foundation and beneath the main and seepage dams. Although the faults are more permeable than the surrounding bedrock, increasing their relative area in the foundation footprint had minimal effect on contact seepage from the TMF and total flow beneath the main and seepage dams. This indicates the dam foundation grouting program effectively minimizes the potential role of faults in conveying seepage beneath the dams.

7 MODEL LIMITATIONS

Numerical simulation of the hydrogeological regime at the TMF has inherent limitations due to the complexity of the geology at a local scale, the large topographic relief and the restrictions imposed by the software, as follows:

- FEFLOW is a pseudo-3D model and requires simplification of the 3D nature of the hydrogeological system and tailings workings.
- FEFLOW is not a directly coupled surface water/groundwater model and simplifying assumptions are necessary in order to simulate the interaction of these components of the hydrogeological regime.

8 CONCLUSIONS

The primary conclusions from the TMF groundwater modelling assessment are:

- Seepage from the TMF is hydraulically contained within the facility due to elevated groundwater levels in the adjoining ridgelines and associated regional groundwater discharge into the valley bottom (Sections 2.4, 4.4 and 5.2.1). This limits the potential for seepage of contact water from the facility to deep regional groundwater. Seepage from the base of the TMF within overburden flows towards the seepage collection ponds in the valley bottom beneath the TMF.
- The addition of the seepage management system elements to the TMF design reduces impoundment loss to regional groundwater (Section 5.2.2), and reduces lateral flow of contact seepage in overburden beneath the dams (Section 5.2.3). Seepage recovery dams downstream of terminal dams at each stage of TMF development provide control of seepage beyond the TMF footprint (Section 5.2.4).
- Particle tracking analyses (Section 5.2.5) indicate contact seepage in overburden layers beneath the TMF dams will emerge downstream of the tailings containment dam toes, within the respective seepage recovery dam catchment (Figures 36 and 37). Regional groundwater flow in deep bedrock bypasses the seepage recovery dams, but is comprised of natural groundwater as for current (pre-development) conditions.

9 CLOSING

This report has summarized the results of 3D FEFLOW Modelling for the KSM TMF.

KLOHN CRIPPEN BERGER LTD.

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Senior Hydrogeologist

Graham Parkinson, P. Geo., P. Geoph.
Project Manager

Harvey McLeod, P. Eng., P. Geo.
Principal, Project Director

REFERENCES

ERSI / KCB. 2011. KSM Project Area Structural Geology Assessment, April.

Klohn Crippen Berger. 2012a. 2012 Engineering Design Update of Tailing Management Facility, Final Report, December.

Klohn Crippen Berger. 2012b. 2012 TMF Site Investigation Report, December.

Klohn Crippen Berger. 2010a. Pre-Feasibility Tailings Management Facility Hydrogeology Modelling Report.

Klohn Crippen Berger. 2010b. Kerr-Sulphurets-Mitchell Project 2010 Site Investigation Report – Draft.

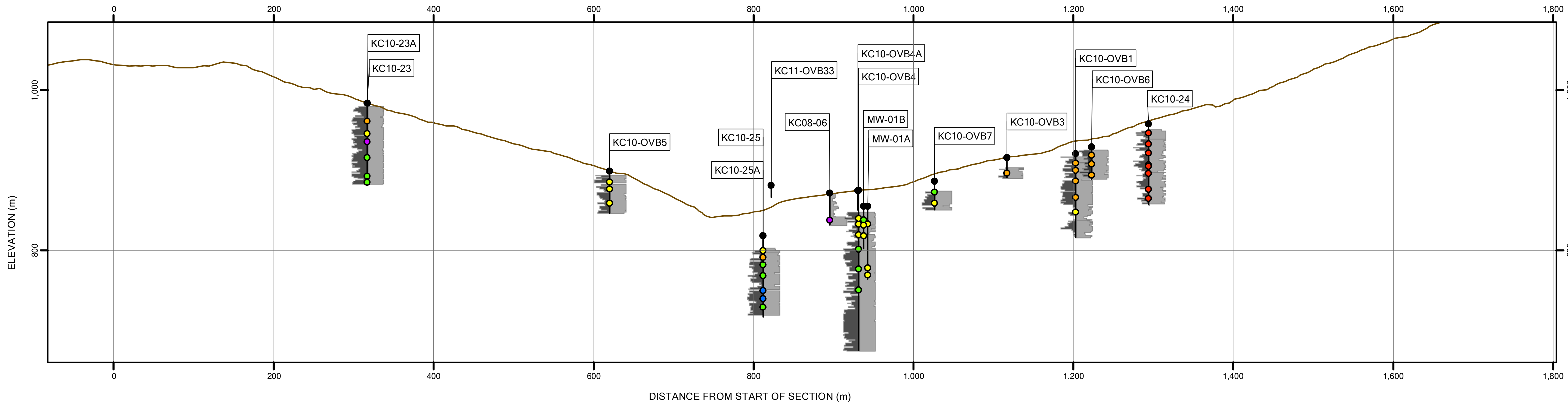
Letts, M., Roulet, N., Comer, N., Skarupa, M. and Verseghy, D. 2000. Parameterization of Peatland Hydraulic Properties for the Canadian Land Surface Scheme. Atmosphere-Ocean vol. 38 (1), pp. 141-160.

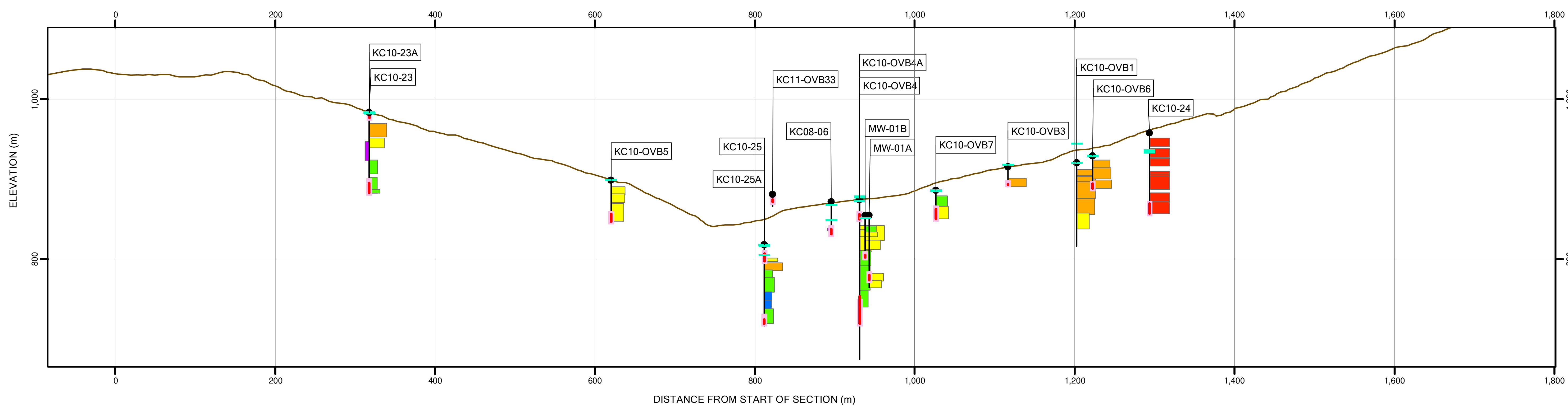
Rescan. 2010. KSM Project – Draft Hydrogeological Modeling Report, October.

Rutqvist, J. and Stephannson, O. 2003. The role of hydromechanical coupling in fractured rock engineering. Hydrogeology Journal, Vol 11 (1), pp. 7-40.

APPENDIX I

Packer Test Results – Cross Sections





LEGEND

- DRILLHOLE
- STANDPIPE READING
- STANDPIPE SCREEN
- STANDPIPE FILTER PACK
- CORE RECOVERY
- RQD

HYDRAULIC CONDUCTIVITY (m/s)

- TOO HIGH TO MEASURE
- 10^-6 < K < 10^-5
- 10^-7 < K < 10^-6
- 10^-8 < K < 10^-7
- 10^-9 < K < 10^-8
- TOO LOW TO MEASURE

NOT FOR CONSTRUCTION

0 100 m

CLIENT: SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT: KSM PROJECT HYDROGEOLOGY MODELLING STUDY

TITLE: TMF NORTH DAM PACKER TESTS

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	A-1

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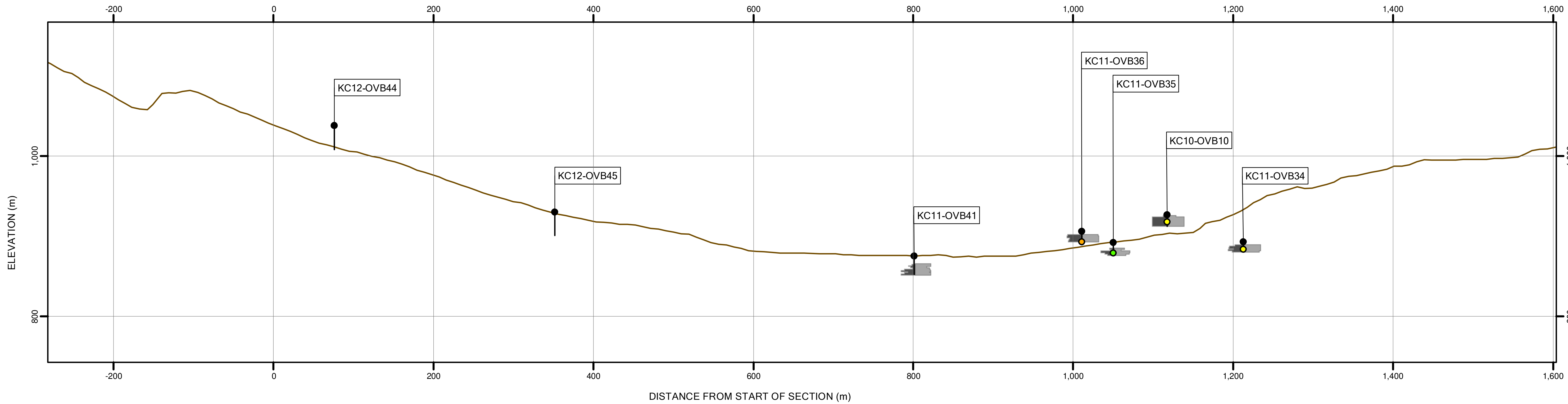

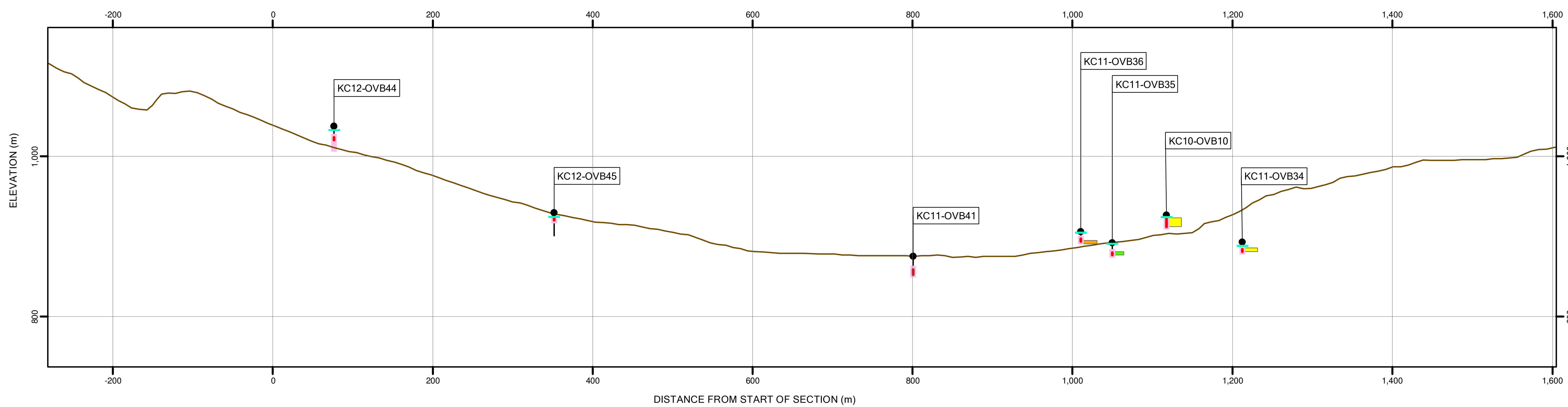

LEGEND

- DRILLHOLE
- STANDPIPE READING
- STANDPIPE SCREEN
- STANDPIPE FILTER PACK
- CORE RECOVERY
- RQD

HYDRAULIC CONDUCTIVITY (m/s)

- TOO HIGH TO MEASURE
- 10^-6 < K < 10^-5
- 10^-7 < K < 10^-6
- 10^-8 < K < 10^-7
- 10^-9 < K < 10^-8
- TOO LOW TO MEASURE

NOT FOR CONSTRUCTION

0 100 m

CLIENT: SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: TMF SPLITTER DAM
PACKER TESTS

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	A-2

afischer
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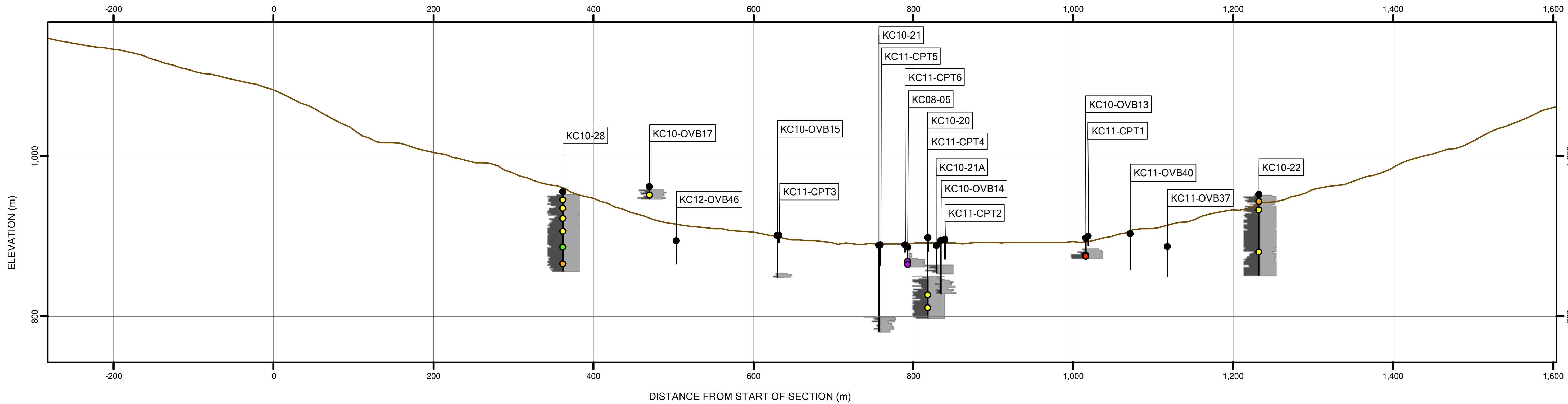
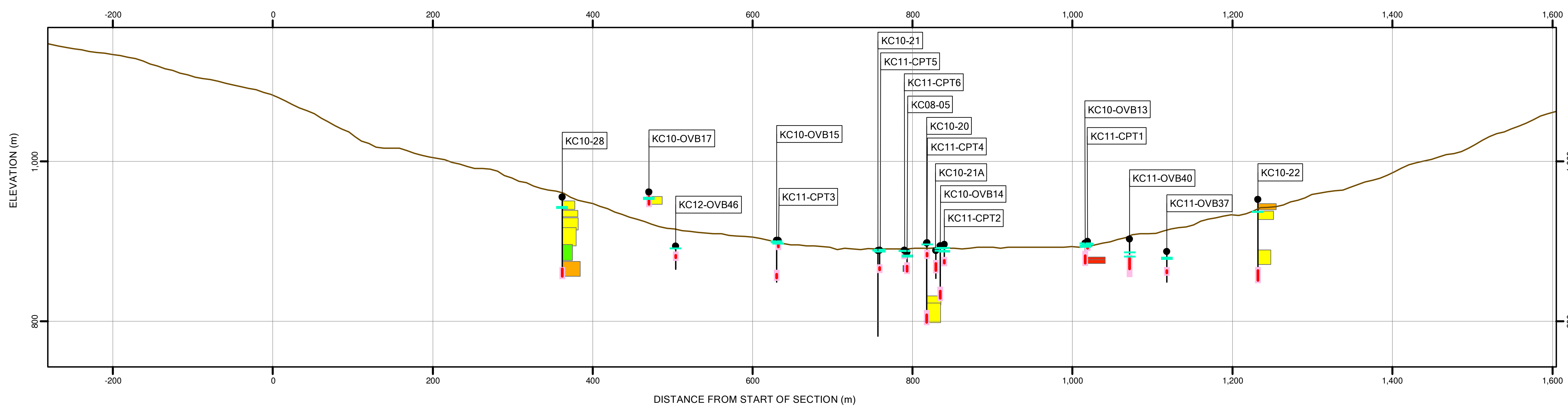




LEGEND

- DRILLHOLE
- STANDPIPE READING
- STANDPIPE SCREEN
- STANDPIPE FILTER PACK
- CORE RECOVERY
- RQD

HYDRAULIC CONDUCTIVITY (m/s)

- TOO HIGH TO MEASURE
- 10^-6 < K < 10^-5
- 10^-7 < K < 10^-6
- 10^-8 < K < 10^-7
- 10^-9 < K < 10^-8
- TOO LOW TO MEASURE

NOT FOR CONSTRUCTION

0 100 m

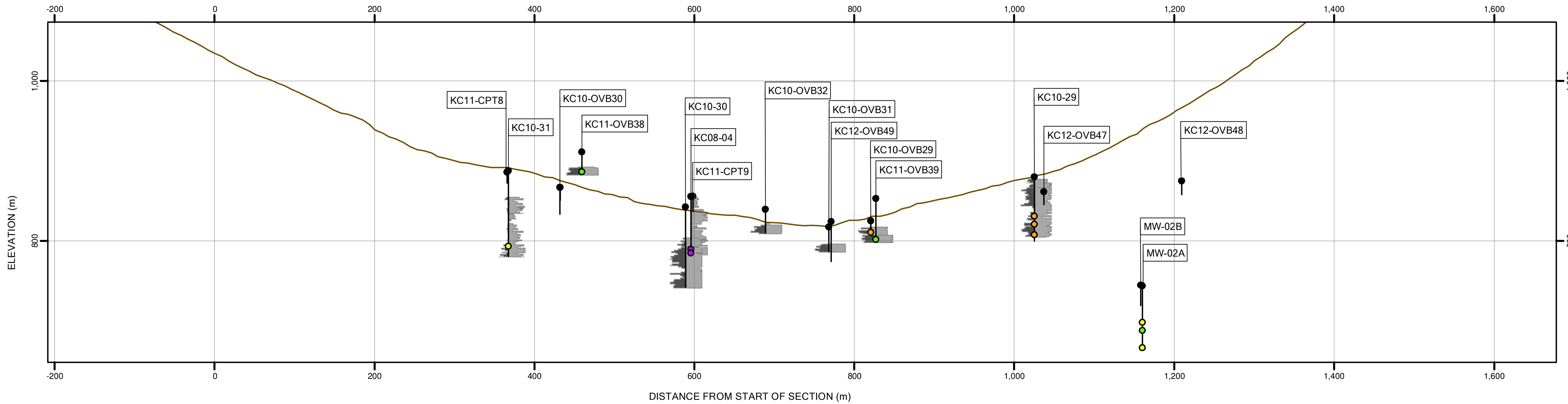
CLIENT: SEABRIDGE GOLD

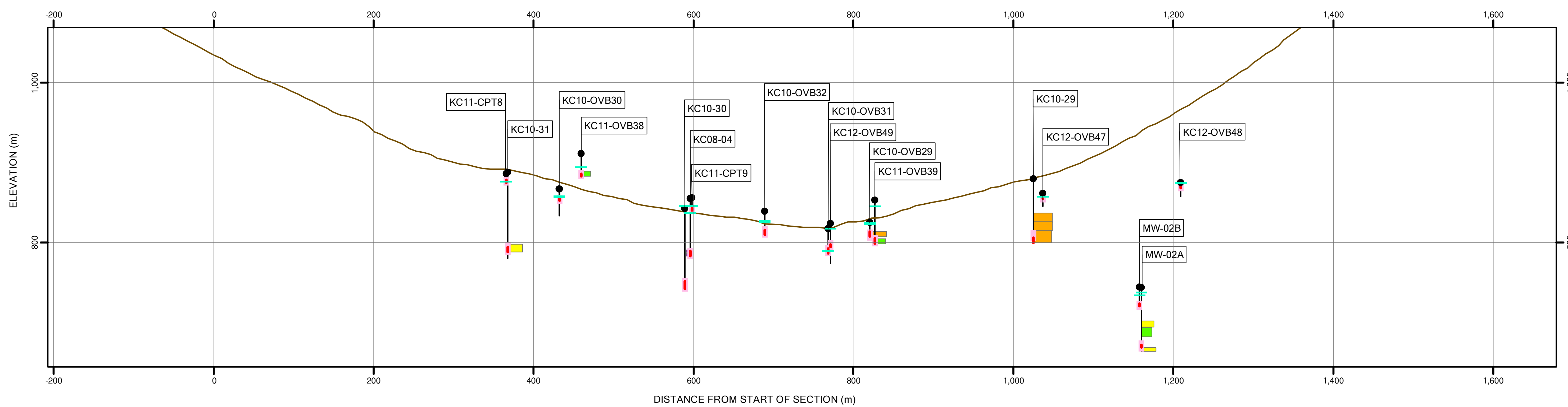
Klohn Crippen Berger

PROJECT: KSM PROJECT HYDROGEOLOGY MODELLING STUDY

TITLE: TMF SADDLE DAM PACKER TESTS

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	A-3





LEGEND

- DRILLHOLE
- STANDPIPE READING
- STANDPIPE SCREEN
- STANDPIPE FILTER PACK
- CORE RECOVERY
- RQD

HYDRAULIC CONDUCTIVITY (m/s)

- TOO HIGH TO MEASURE
- 10^-6 < K < 10^-5
- 10^-7 < K < 10^-6
- 10^-8 < K < 10^-7
- 10^-9 < K < 10^-8
- TOO LOW TO MEASURE

NOT FOR CONSTRUCTION

0 100 m

CLIENT
SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE
TMF SOUTHEAST DAM
PACKER TESTS

DATE: JUN 2013
PROJECT No.: M09480A04
FIG No.: A-4

afischer
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FIGURES

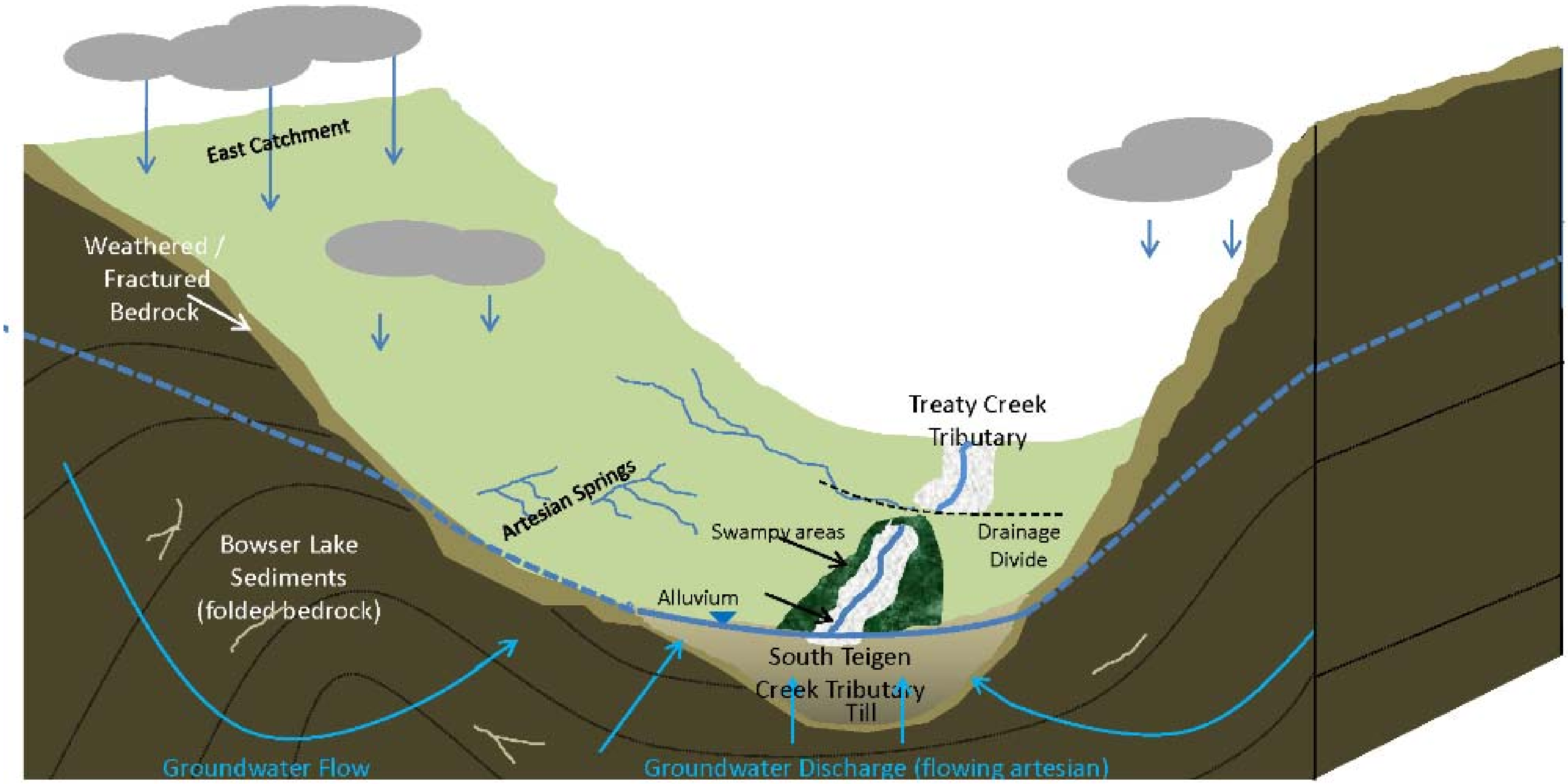
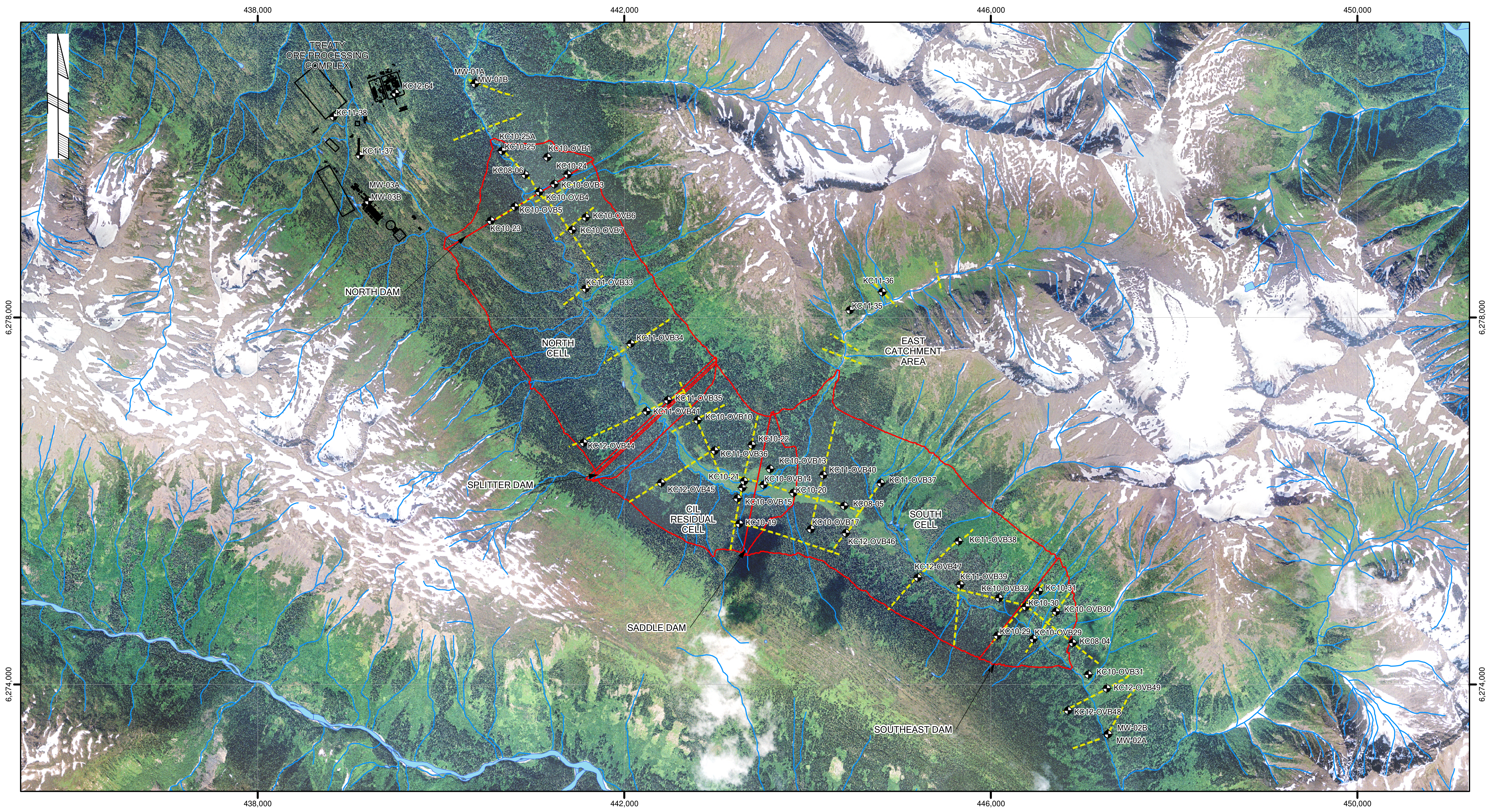


Figure 1 **Hydrogeological Conceptualization for the TMF Valley under Current Conditions**



NOT FOR CONSTRUCTION

0 1,000 m

SCALE:

LEGEND

Existing Drillhole

Existing Seismic Line

Tailings Management Facilities

Notes:

1. UTM Zone 9N, NAD83
2. 2008 orthophoto

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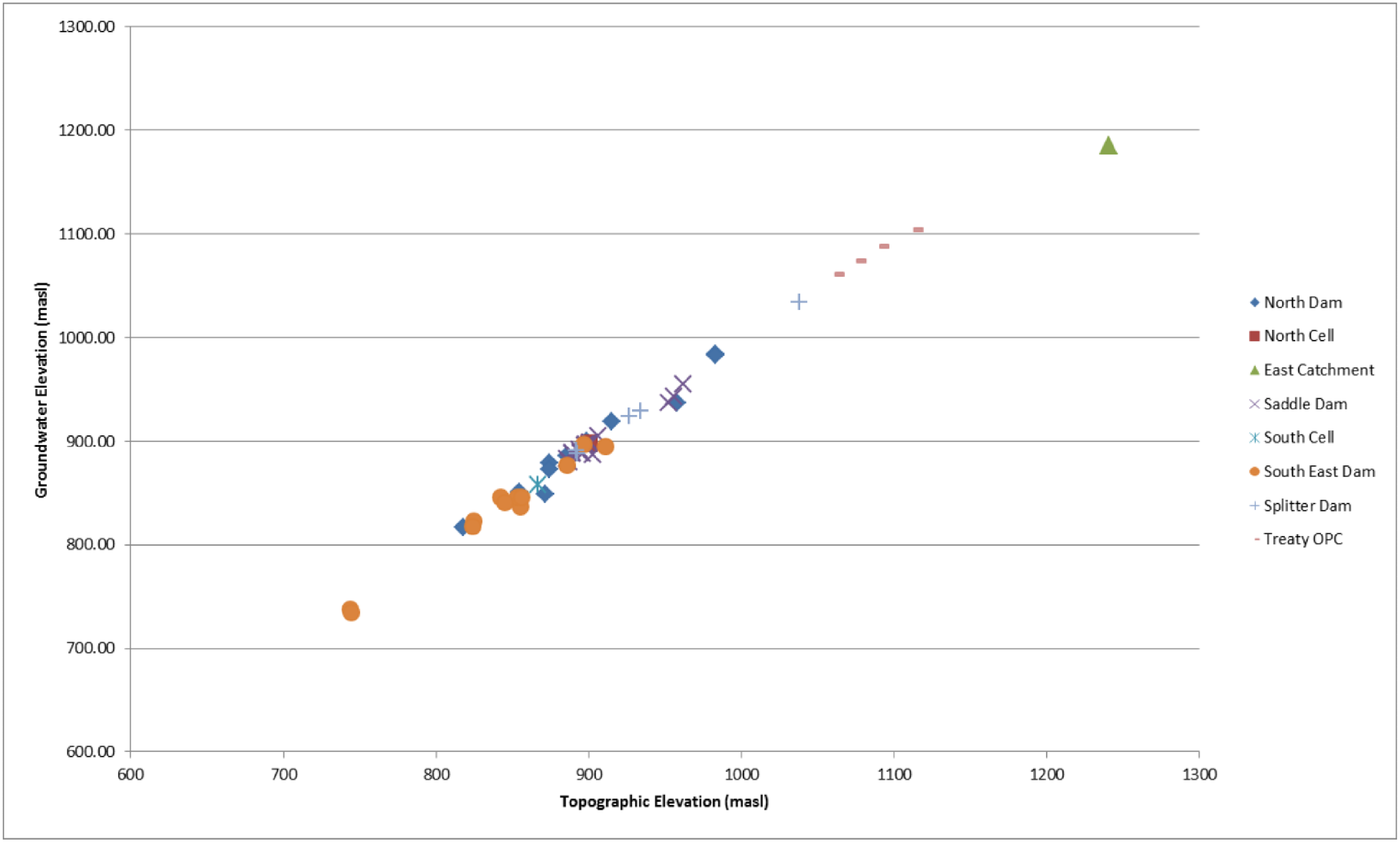
HYDROGEOLOGY MODELLING STUDY

TITLE

TAILINGS MANAGEMENT FACILITY
SITE INVESTIGATION LOCATIONS

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	2

afischer
Z:\M\VCR\M09480A04 - KSM 2012 PFS\400 Drawings\GIS\mxd\SI 2012\SI Report TMF area2012\hydrogeo\ SI locations.mxd 6/26/2013



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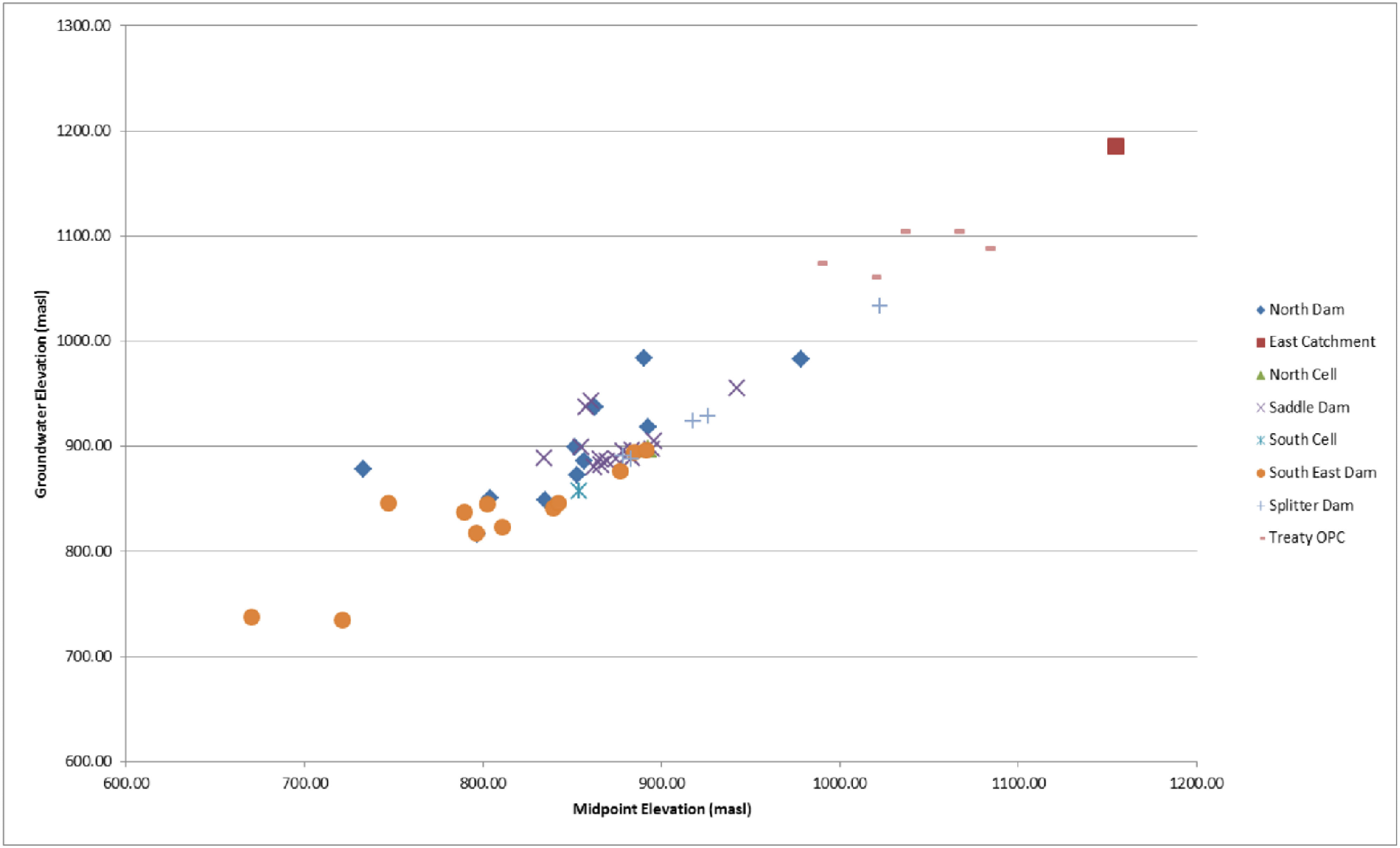
HYDROGEOLOGY MODELLING STUDY

TITLE

Groundwater Elevation versus Topographic Elevation

PROJECT No: M09480A04

FIG. No: FIGURE 3



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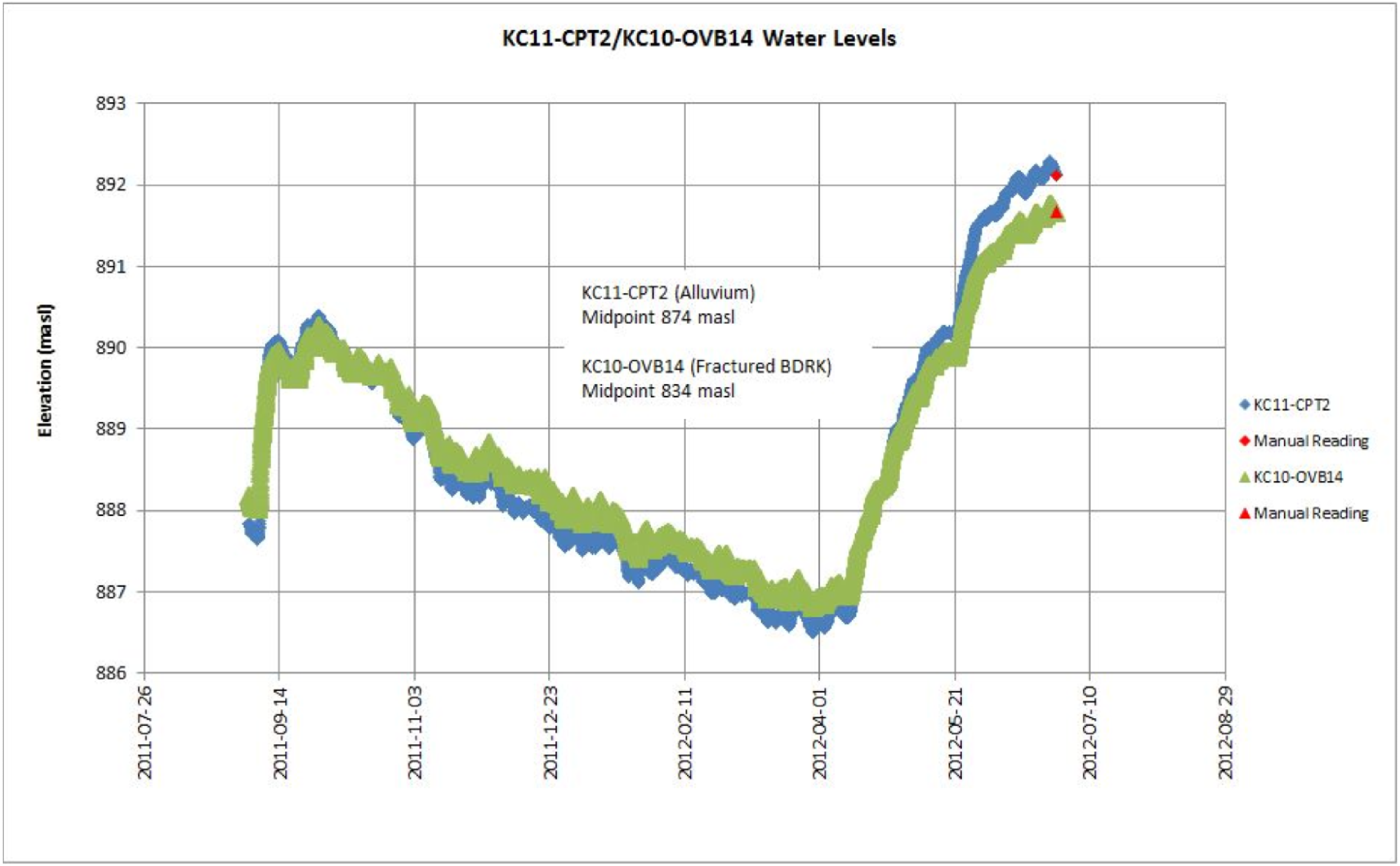
PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: Groundwater Elevation versus Mid-Point Elevation

PROJECT No: M09480A04

FIG. No: FIGURE 4



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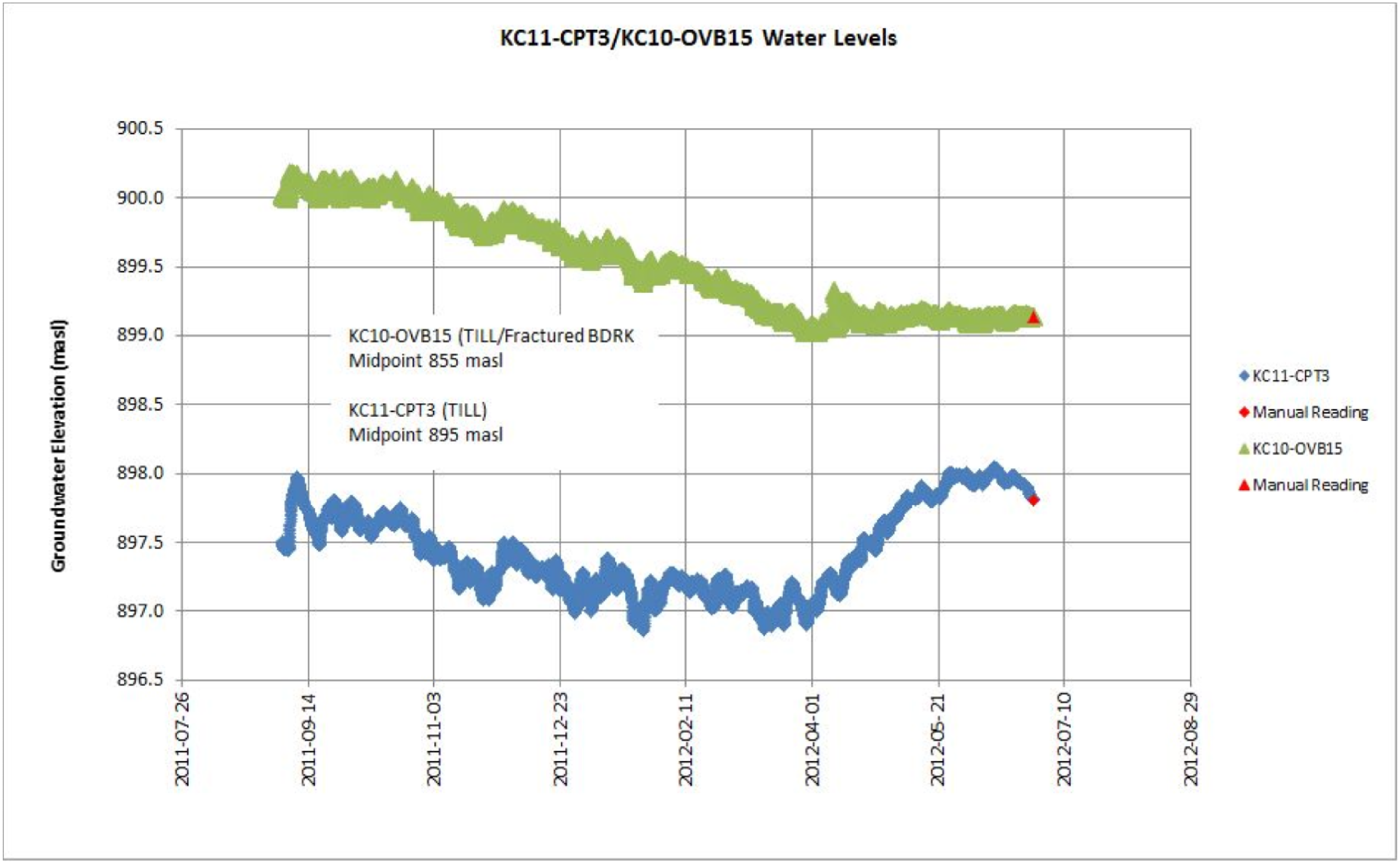
Klohn Crippen Berger	TITLE: Continuous Groundwater Monitoring KC11-CPT2/KC10-OVB14
PROJECT No: M09480A04	FIG. No: FIGURE 5



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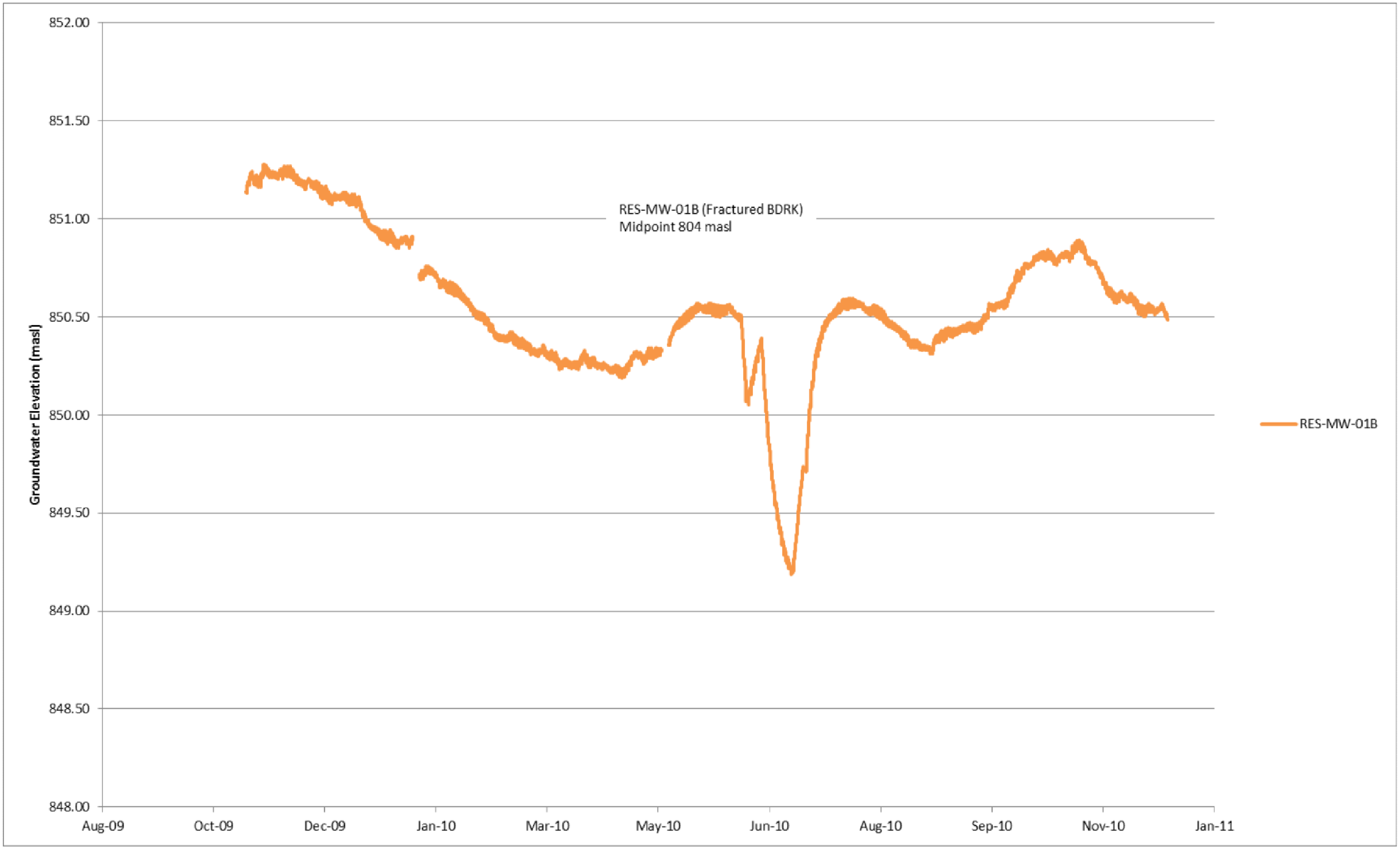
HYDROGEOLOGY MODELLING STUDY

TITLE: Continuous Groundwater Monitoring
KC11-CPT3/KC10-OVB15

PROJECT No: M09480A04

FIG. No: FIGURE 6



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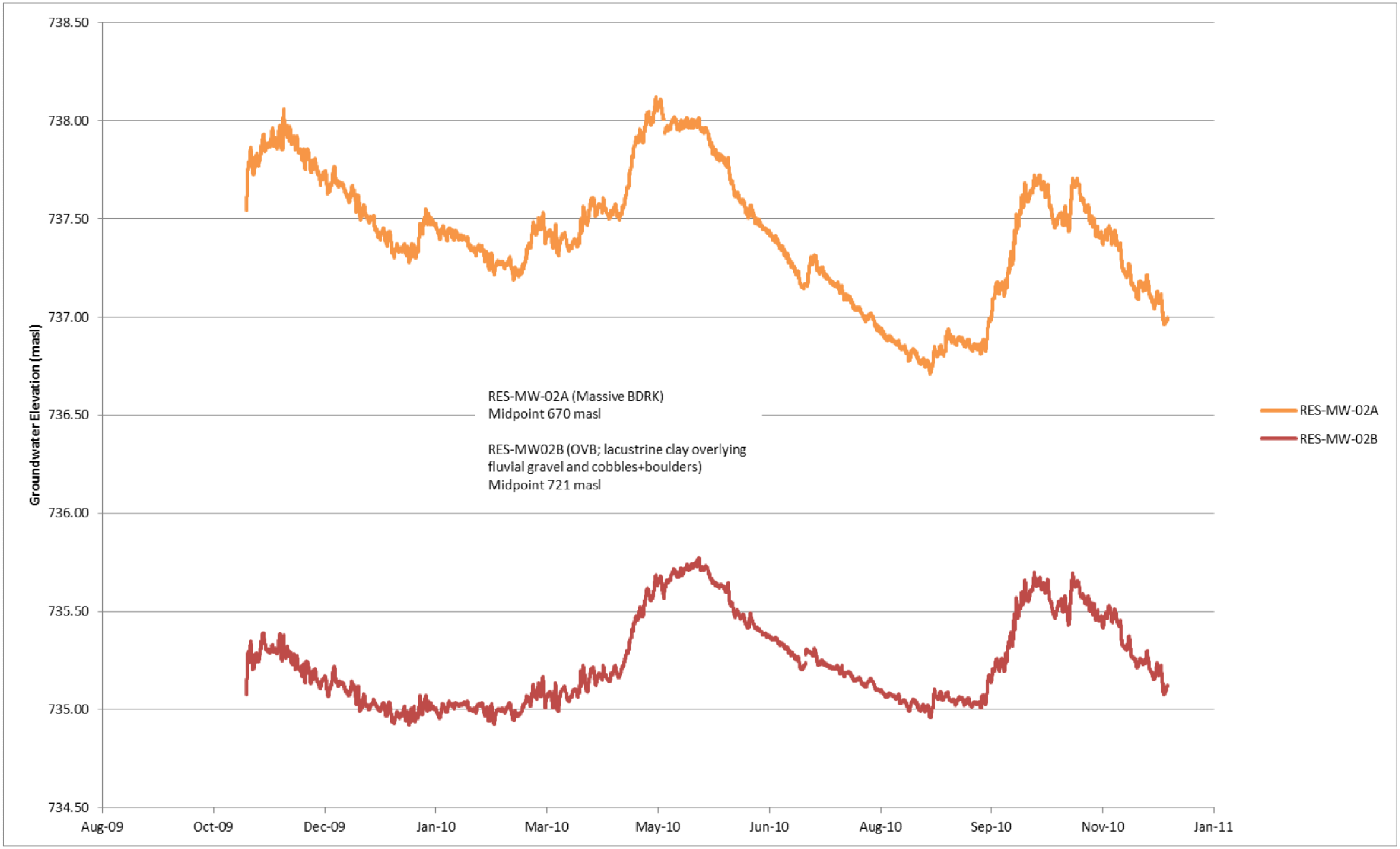
PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: **Continuous Groundwater Monitoring RES-MW-01B**

PROJECT No: M09480A04

FIG. No: FIGURE 7



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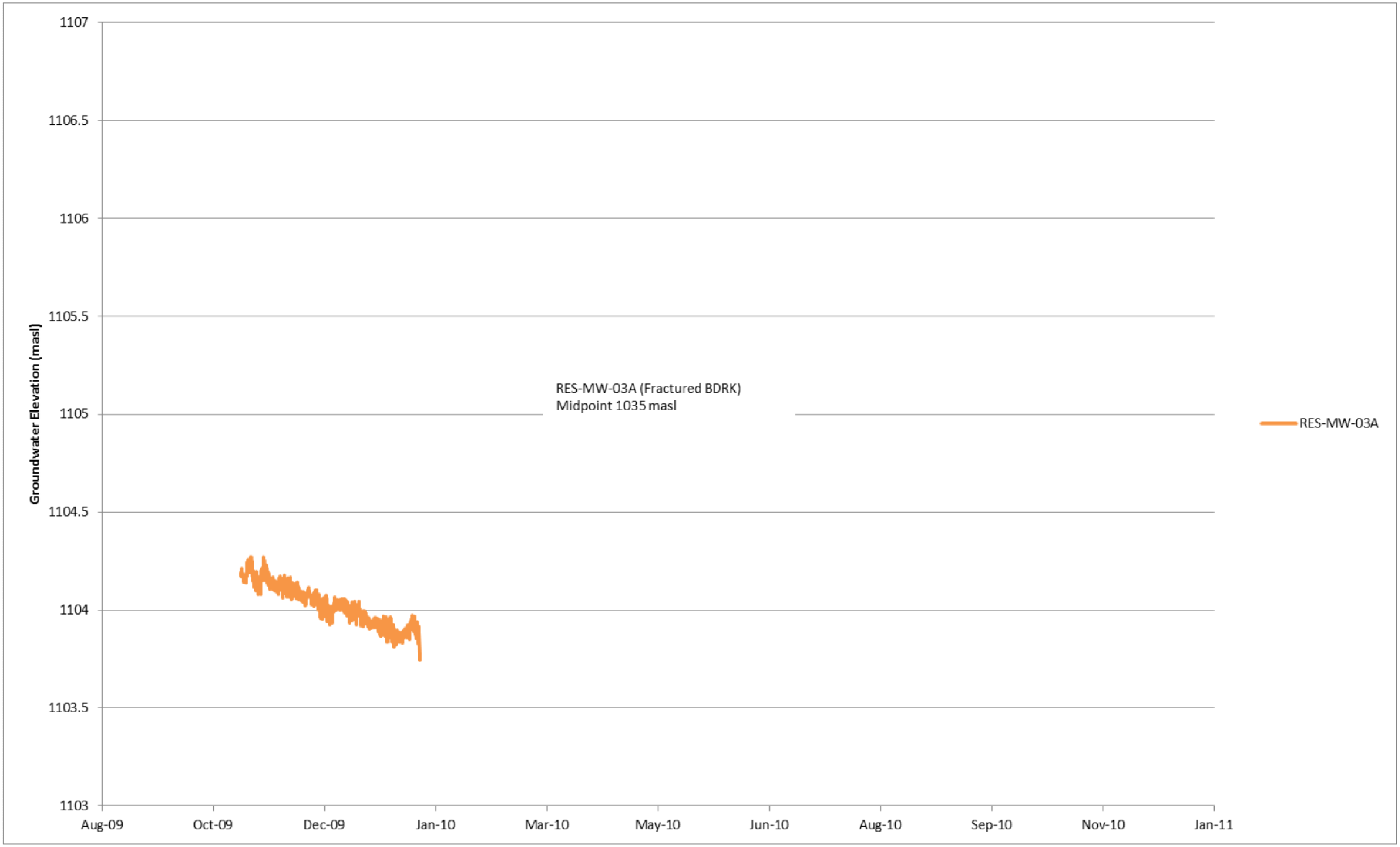
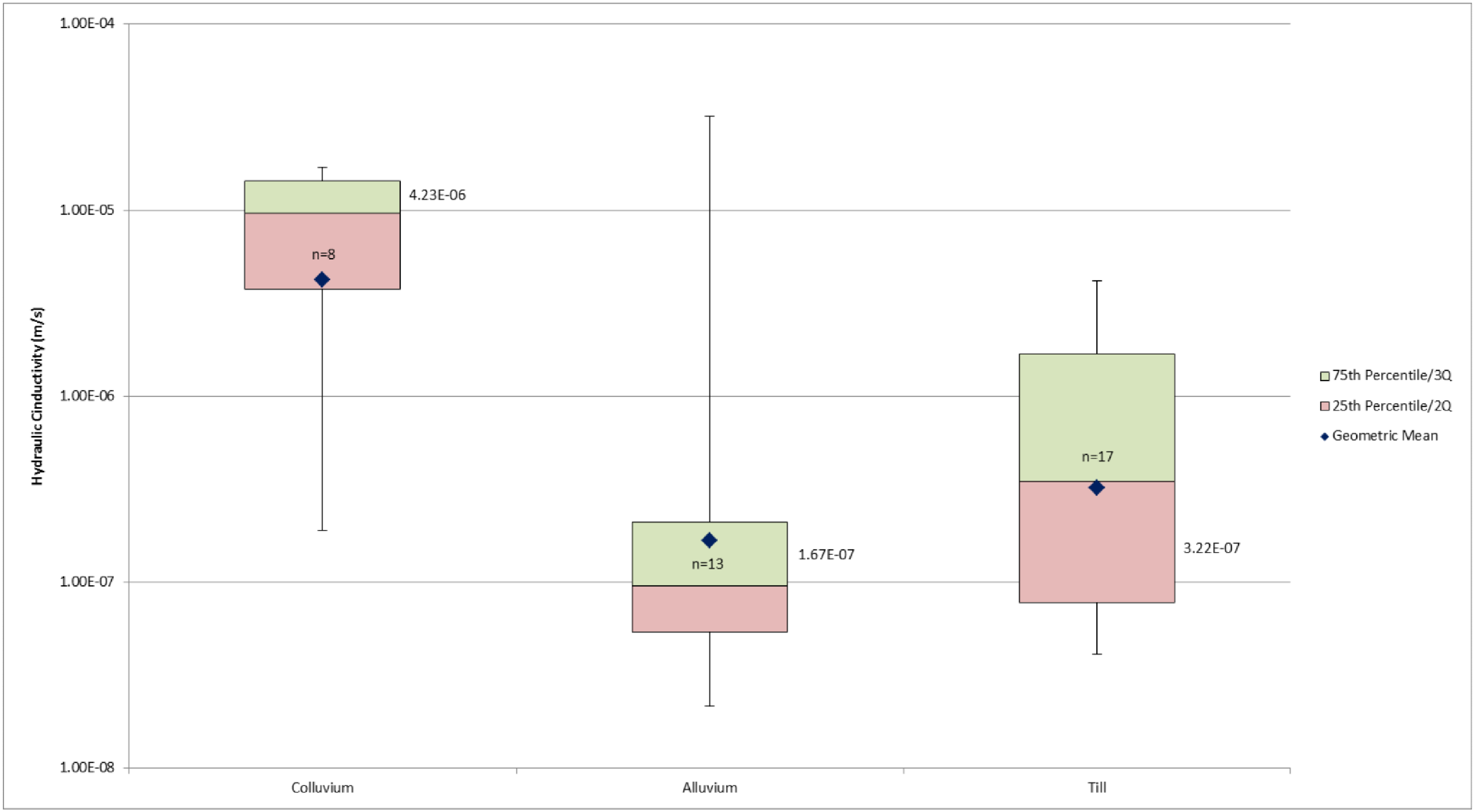
CLIENT	PROJECT	
SEABRIDGE GOLD	KSM PROJECT HYDROGEOLOGY MODELLING STUDY	
Klohn Crippen Berger	TITLE: Continuous Groundwater Monitoring RES-MW-02A/B	
	PROJECT No: M09480A04	FIG. No: FIGURE 8



CLIENT	SEABRIDGE GOLD
	Klohn Crippen Berger
PROJECT	KSM PROJECT HYDROGEOLOGY MODELLING STUDY
TITLE	Continuous Groundwater Monitoring RES-MW-03A
PROJECT No:	M09480A04
FIG. No:	FIGURE 9



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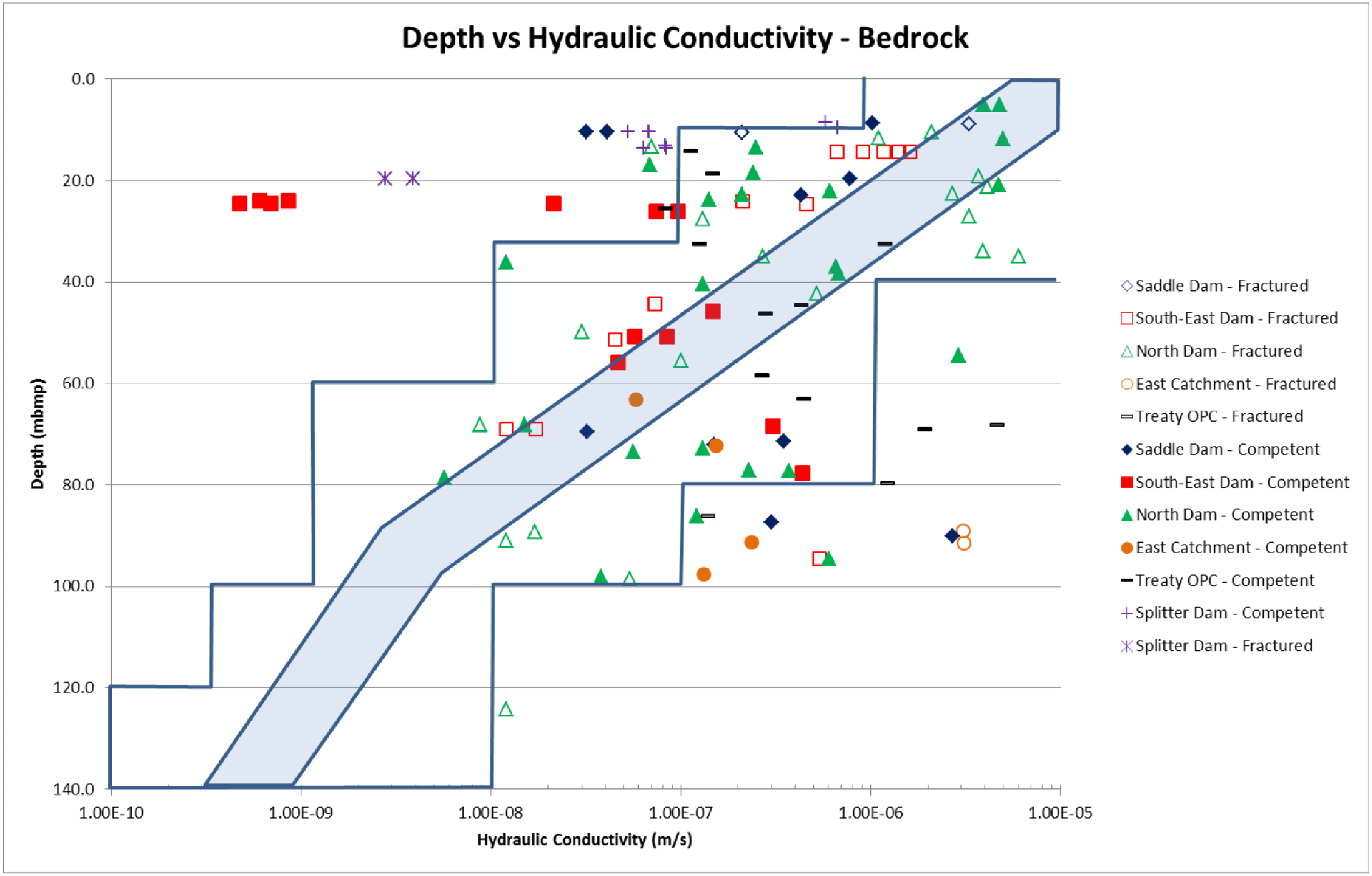
PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: Overburden Hydraulic Conductivity Distribution

PROJECT No: M09480A04

FIG. No: FIGURE 10



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PROJECT

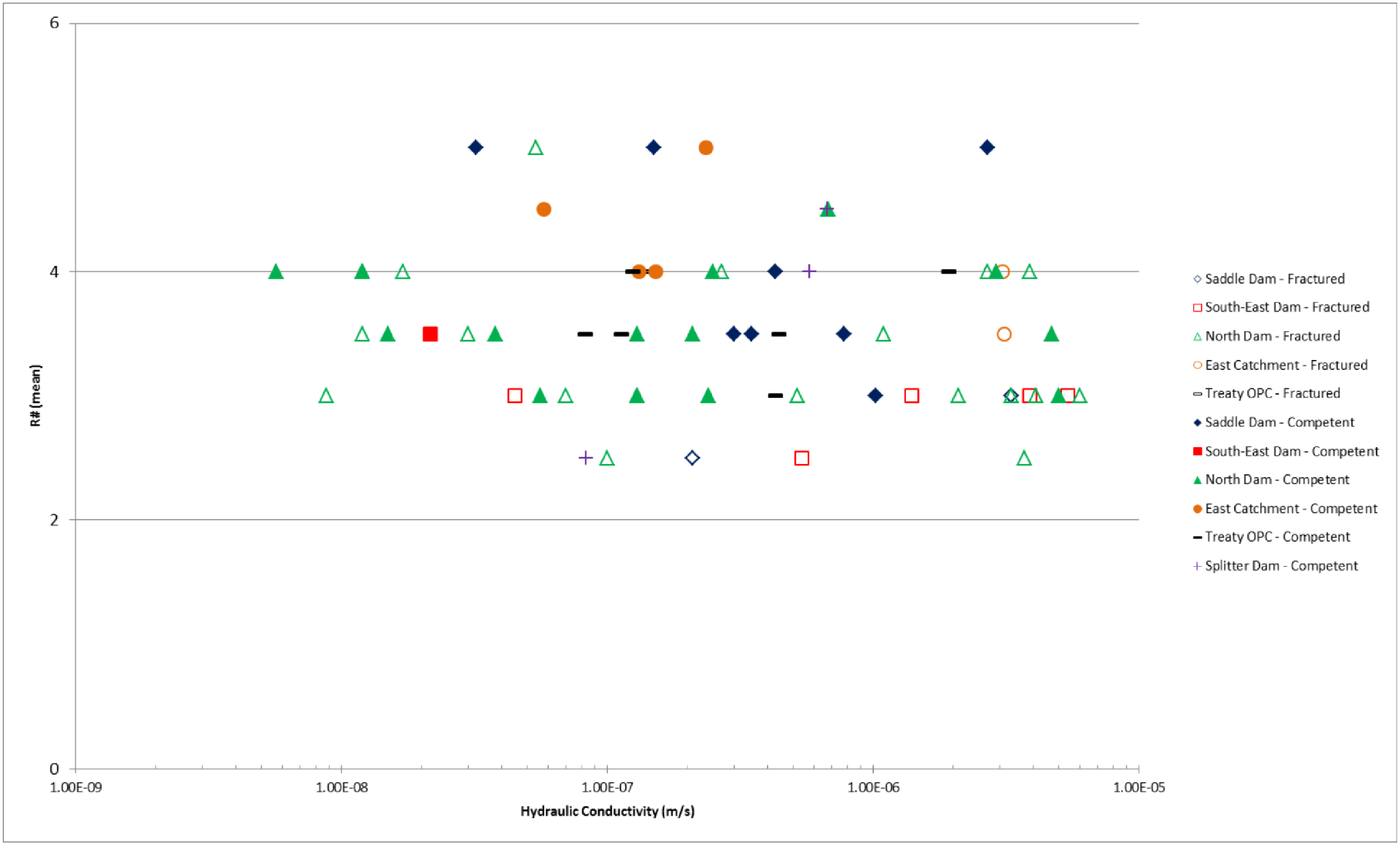
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

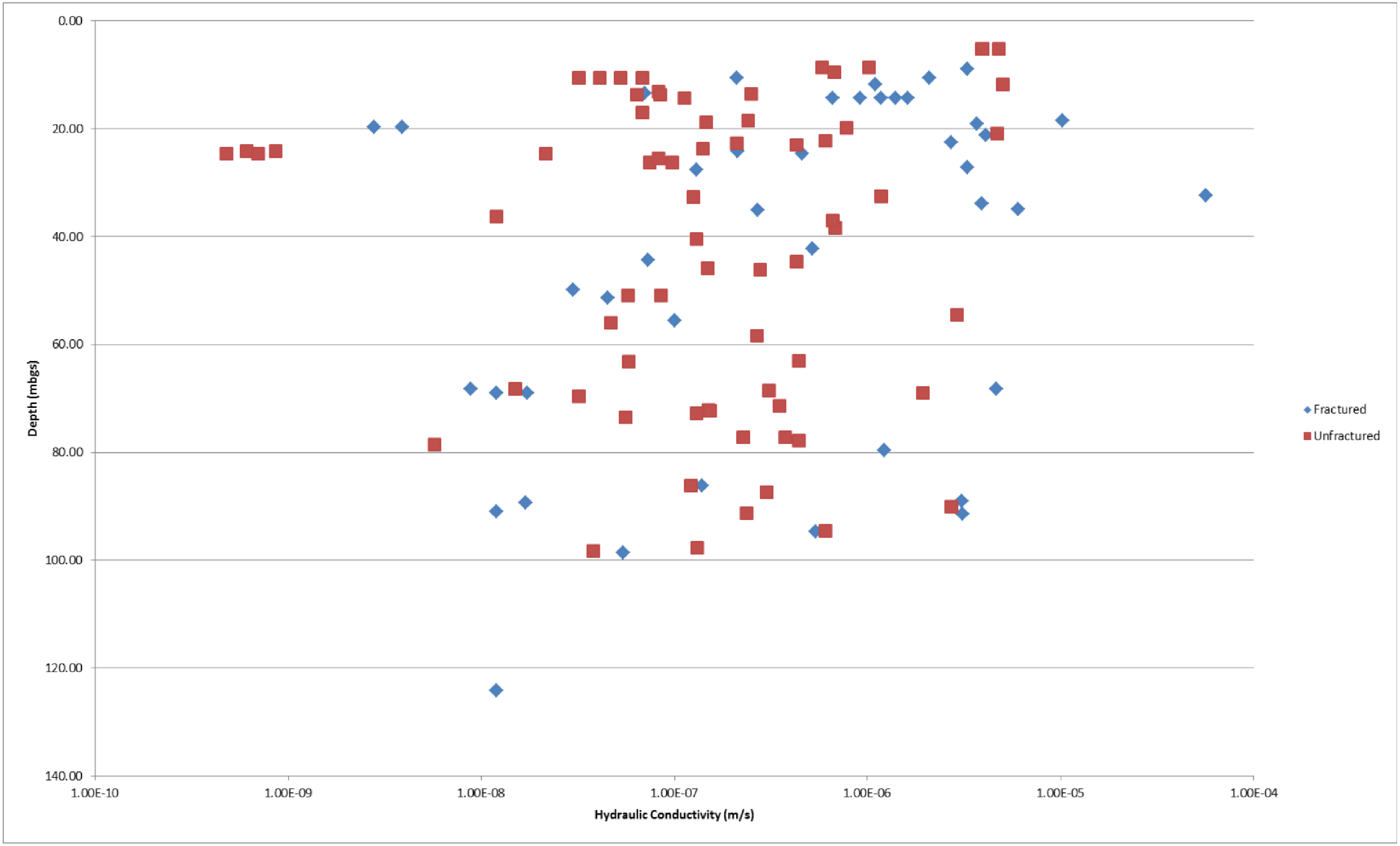
Depth versus Hydraulic Conductivity
Bedrock (By Location)

PROJECT No: M09480A04

FIG. No: FIGURE 11



CLIENT	SEABRIDGE GOLD / Klohn Crippen Berger
PROJECT	KSM PROJECT HYDROGEOLOGY MODELLING STUDY
TITLE	R# versus Bedrock Hydraulic Conductivity (Packer Test Data)
PROJECT No: M09480A04	FIG. No: FIGURE 12



CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

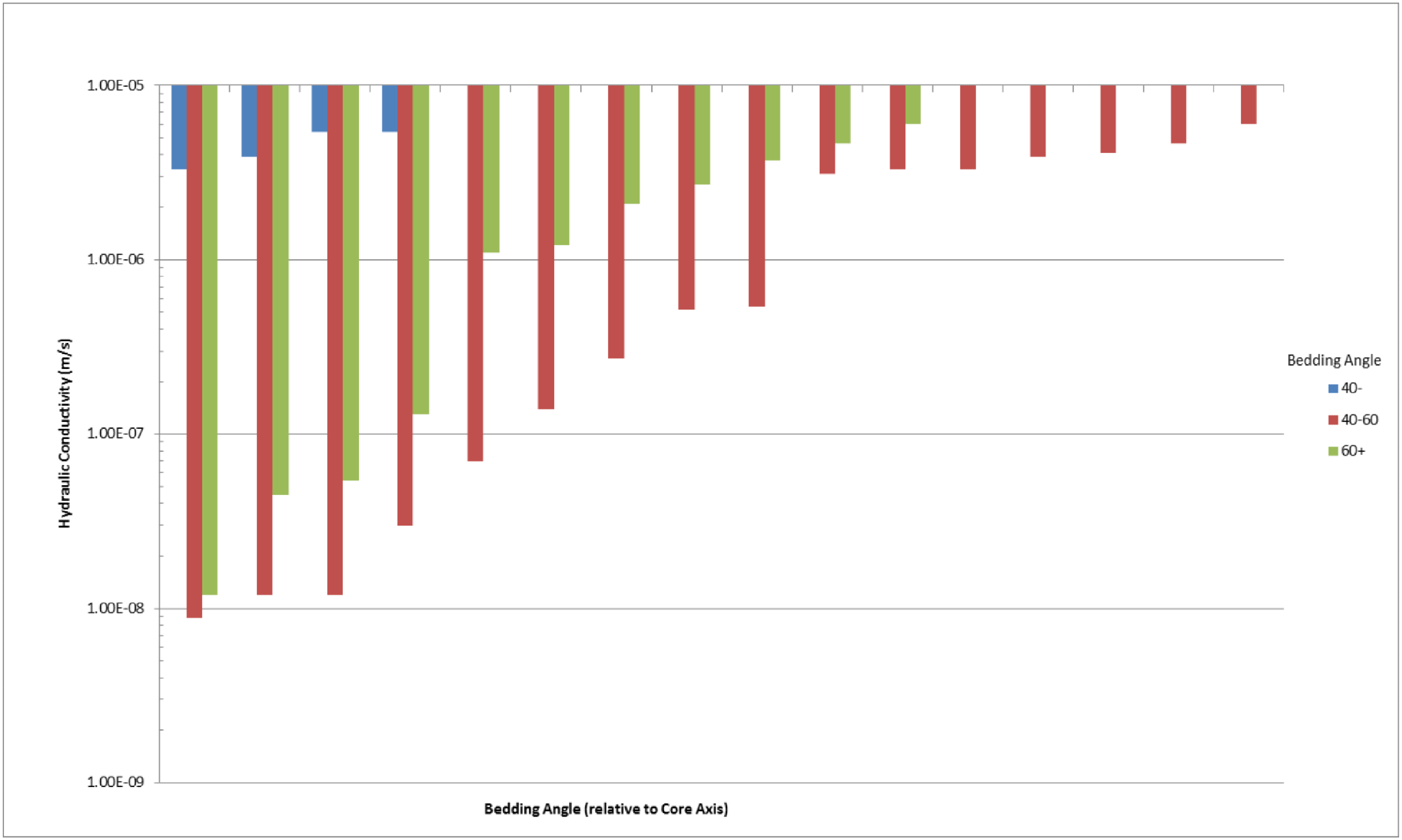
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

Depth versus Hydraulic Conductivity
Bedrock (Fractured/Non-Fractured)

PROJECT No: M09480A04

FIG. No: FIGURE 13



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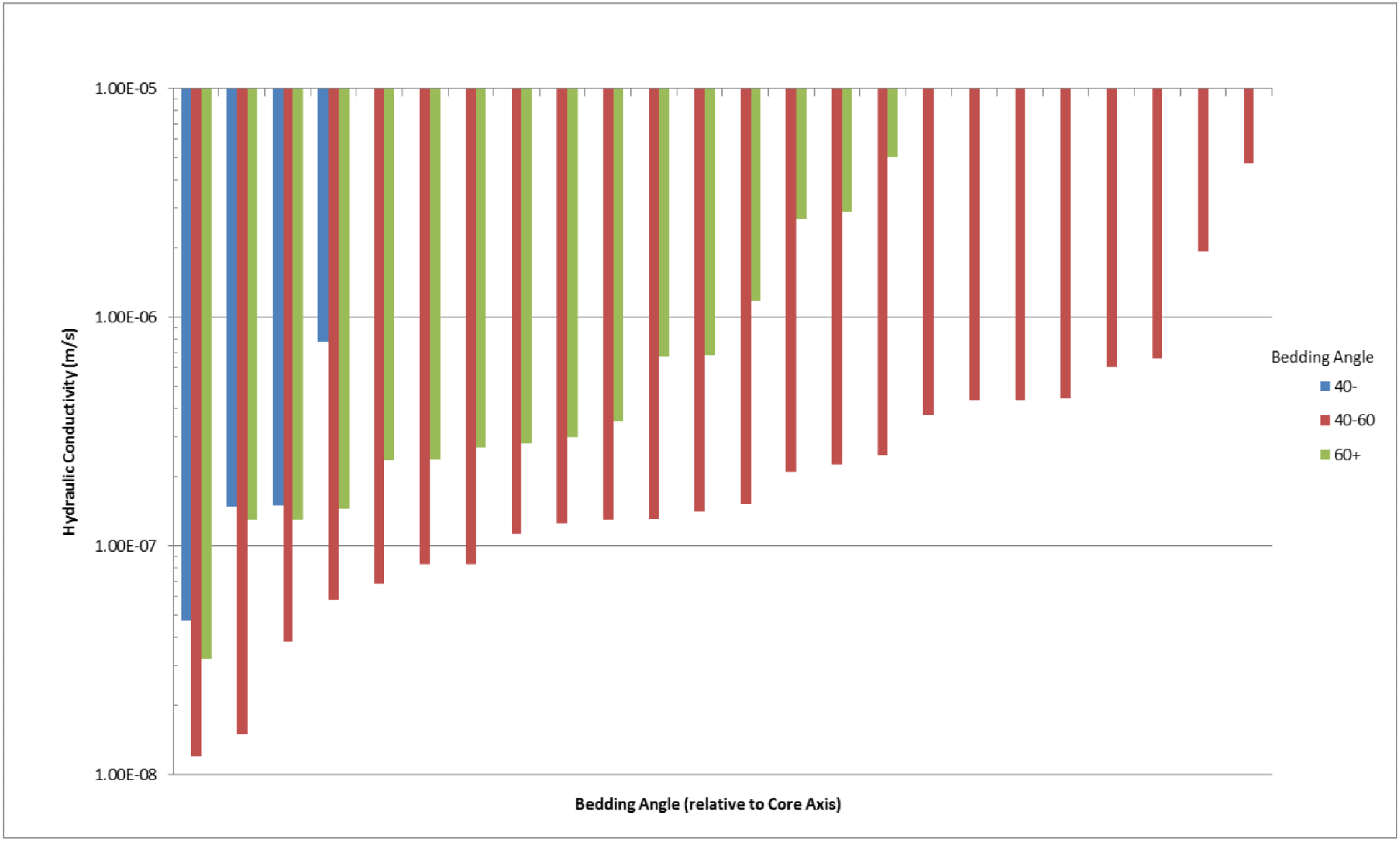
		TITLE: Bedrock Hydraulic Conductivity (Fractured) versus Approx Bedding Angle
		PROJECT No: M09480A04 / FIG. No: FIGURE 14



CLIENT: Seabridge Gold

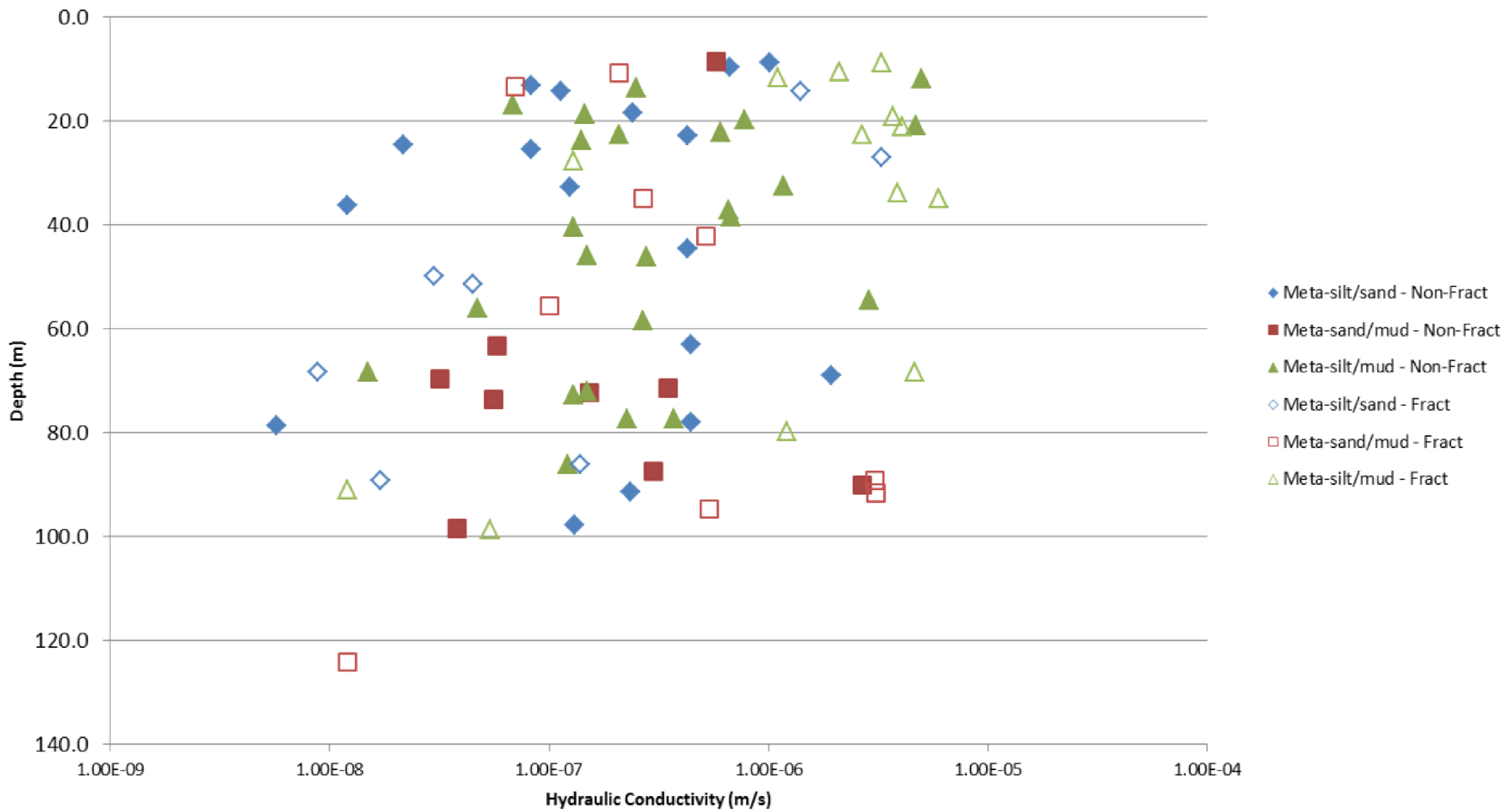
Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: **Bedrock Hydraulic Conductivity (Non-Fractured) versus Approx Bedding Angle**

PROJECT No: M09480A04

FIG. No: FIGURE 15



CLIENT: SEABRIDGE GOLD

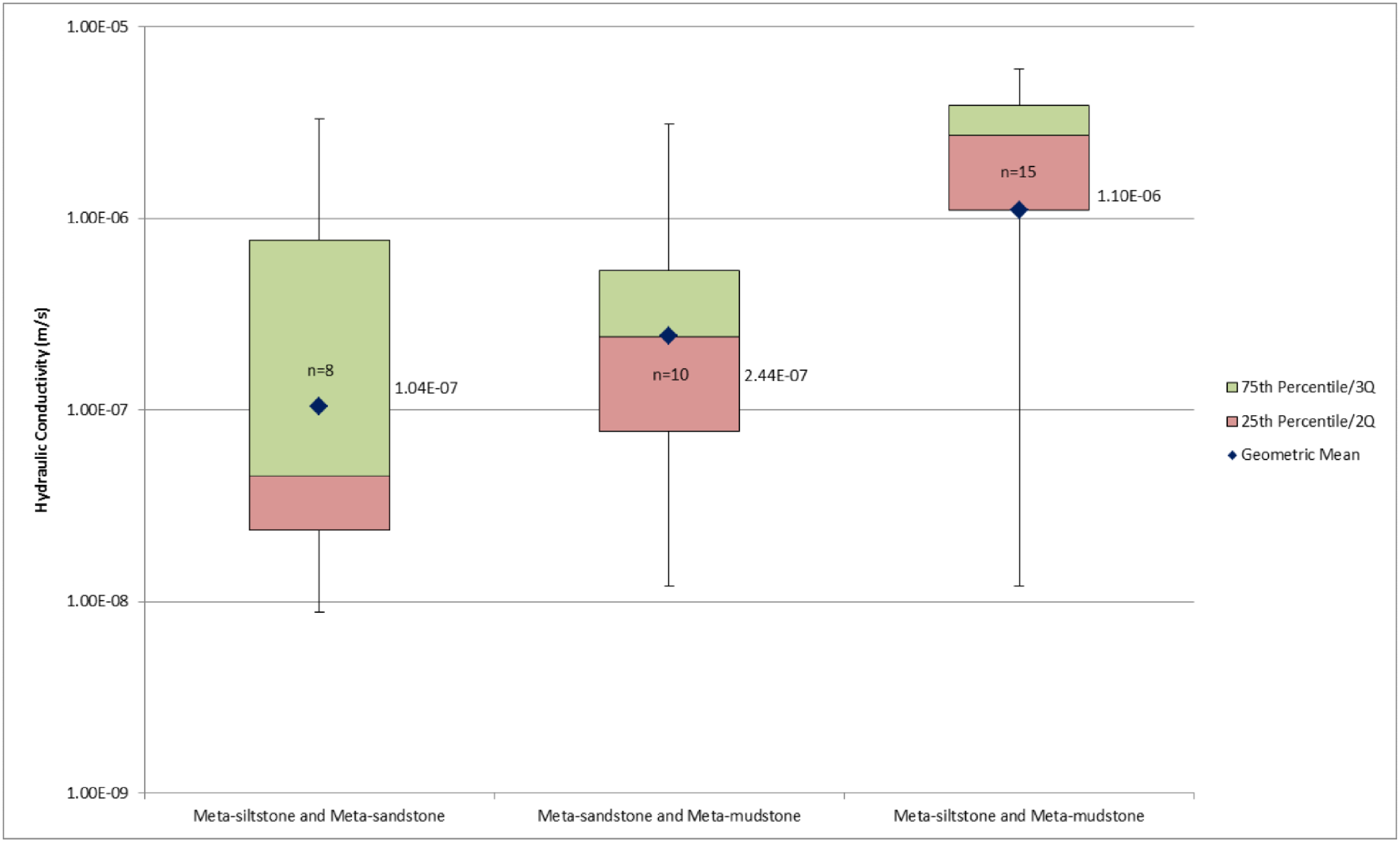
Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: **Bedrock Depth versus Hydraulic Conductivity by Lithology**

PROJECT No: M09480A04

FIG. No: FIGURE 16



CLIENT: SEABRIDGE GOLD

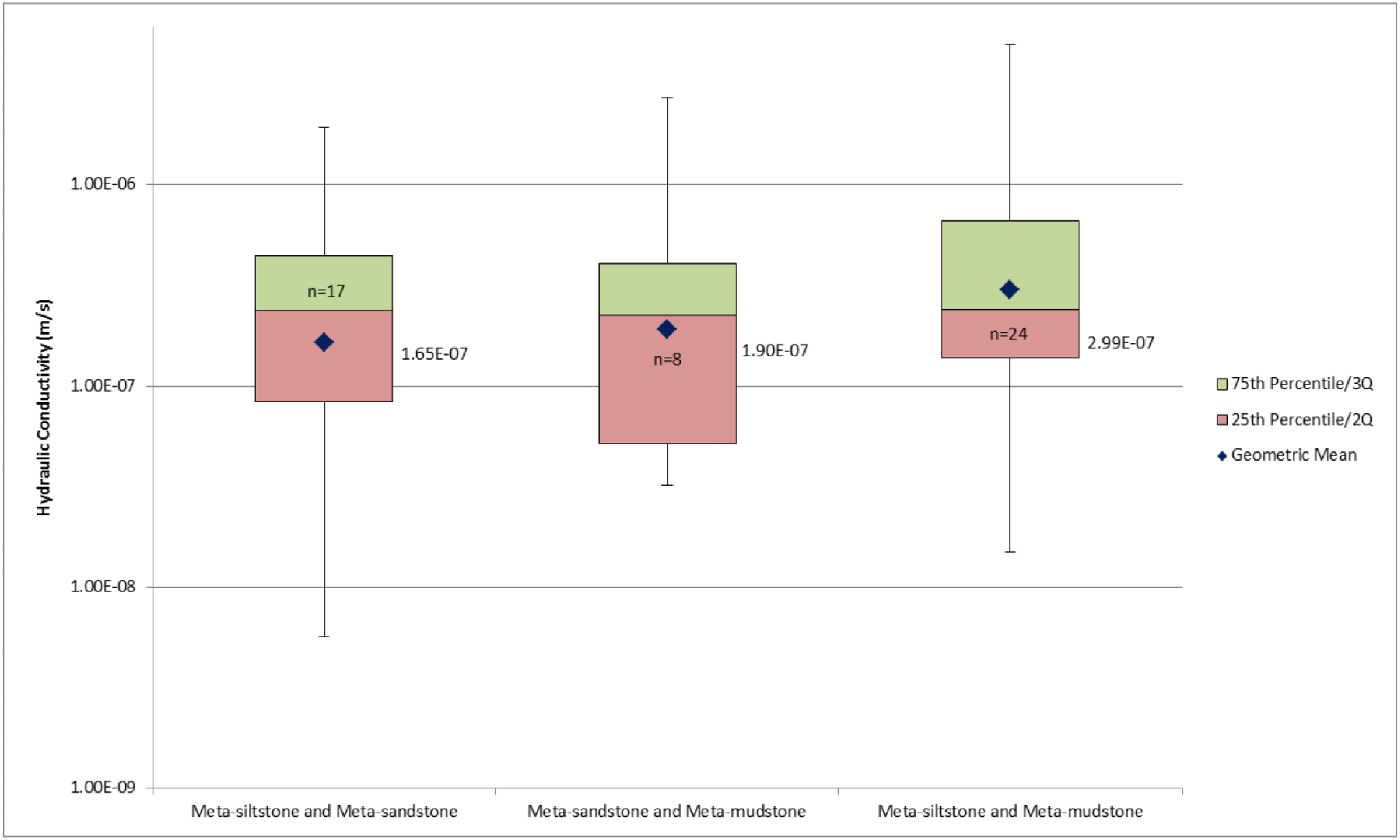
Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

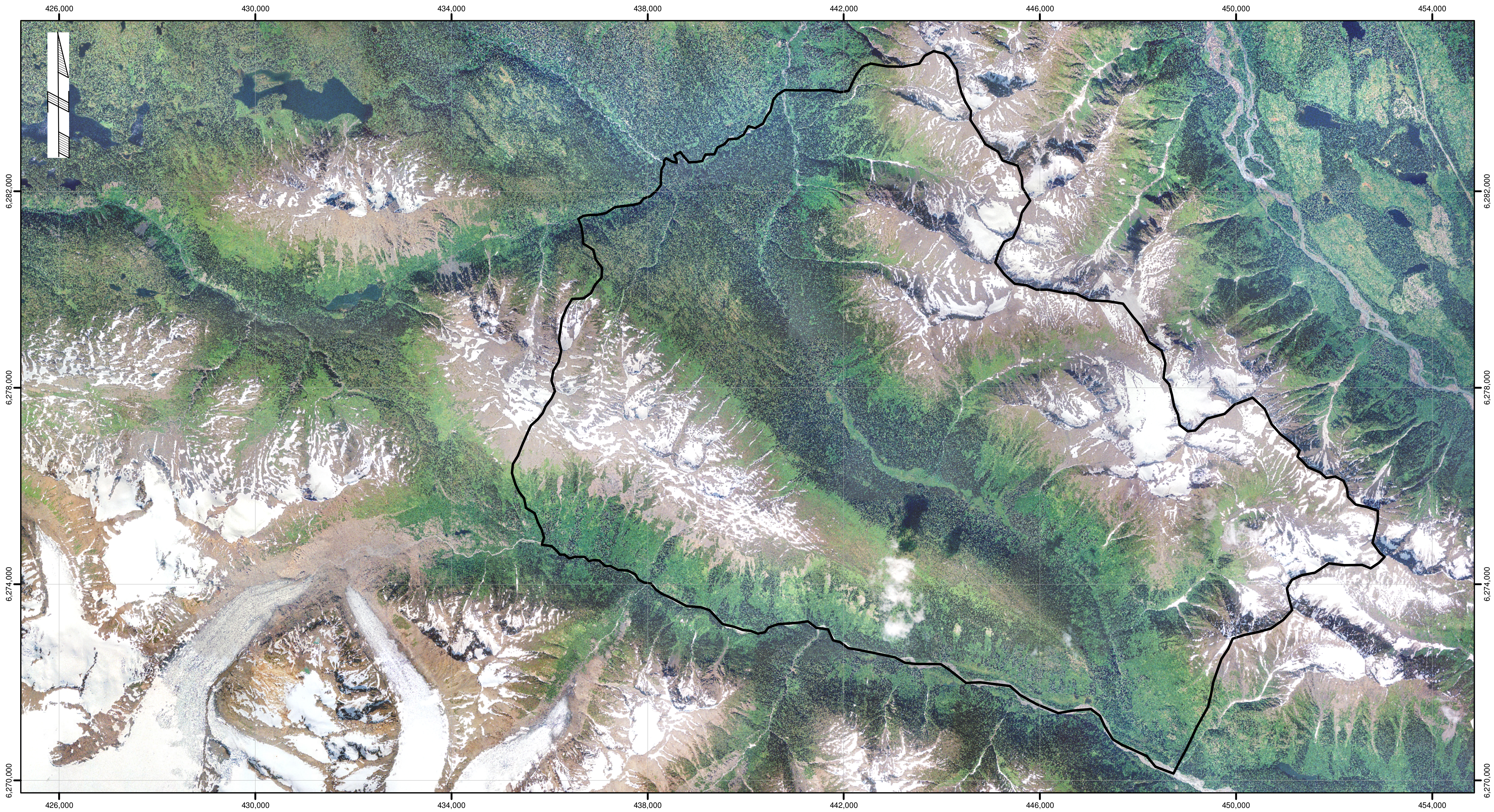
TITLE: Bedrock Hydraulic Conductivity Distribution by Lithology (Fractured)

PROJECT No: M09480A04

FIG. No: FIGURE 17



CLIENT	SEABRIDGE GOLD
	Klohn Crippen Berger
PROJECT	KSM PROJECT HYDROGEOLOGY MODELLING STUDY
TITLE	Bedrock Hydraulic Conductivity Distribution by Lithology (Non-Fractured)
PROJECT No:	M09480A04
FIG. No:	FIGURE 18



LEGEND

MODEL LIMIT

Notes:
1. UTM Zone 9N, NAD83
2. 2008 orthophoto

NOT FOR CONSTRUCTION

AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

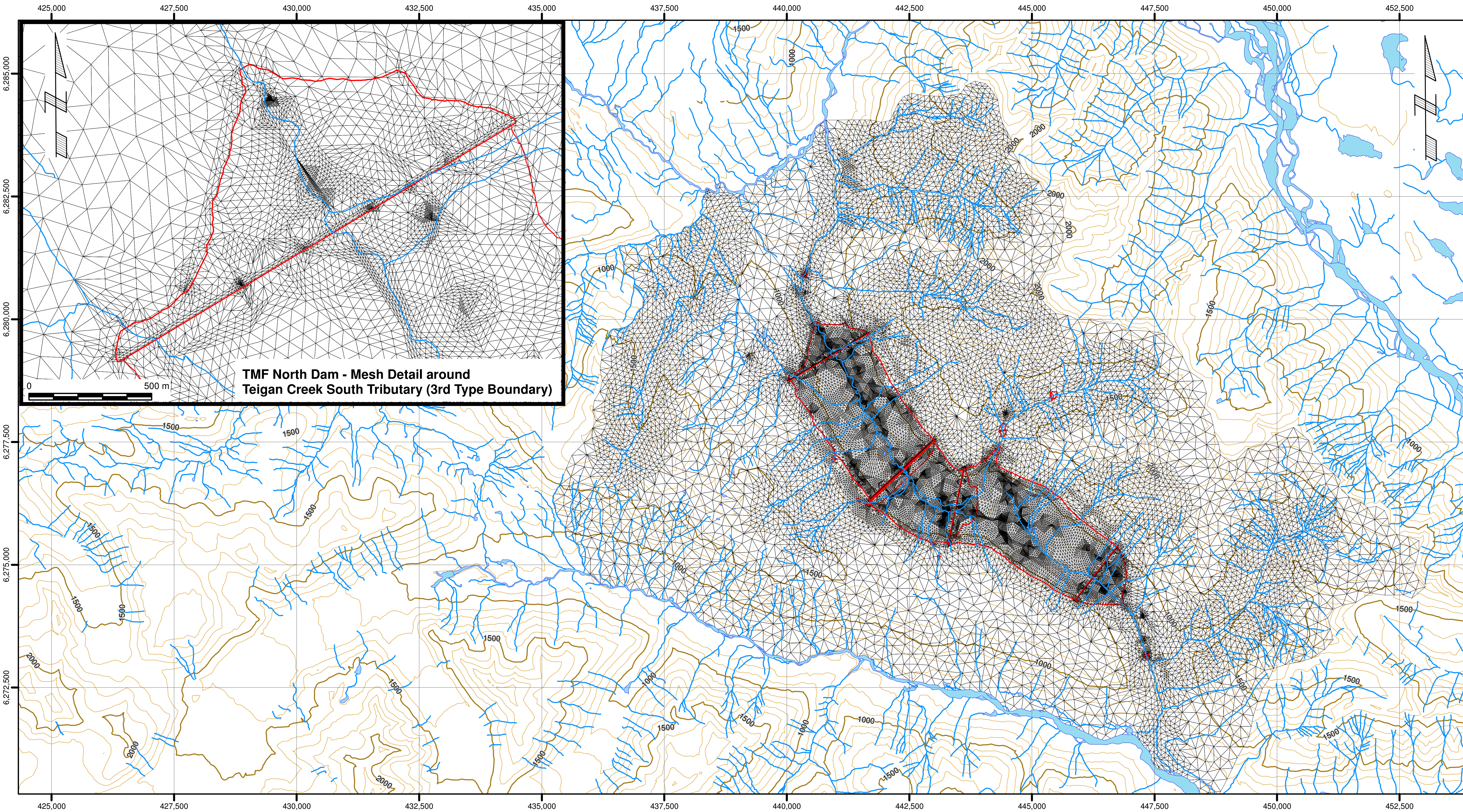
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TAILINGS MANAGEMENT FACILITY
MODEL LIMIT

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	19

afischer
Z:\M\VCR\M09480A04 - KSM 2012 PFS\400 Drawings\GIS\mxd\SI_2012\SI_Report_TMF_area2012\hydrogeo_TMF_model_limit.mxd 6/26/2013



NOT FOR CONSTRUCTION

LEGEND

- FEFLOW Mesh
- Tailings Management Facilities
- Streams and Creeks
- Major Contours
- Minor Contours

Notes:
1. UTM Zone 9N, NAD83
2. Main Map Contours: 20m from lidar survey (2008)
3. Inset Map Contours: 100m from BC TRIM (1995)

CLIENT
SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE
TAILINGS MANAGEMENT FACILITY
FEFLOW MESH AND DISCRETIZATION

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	20

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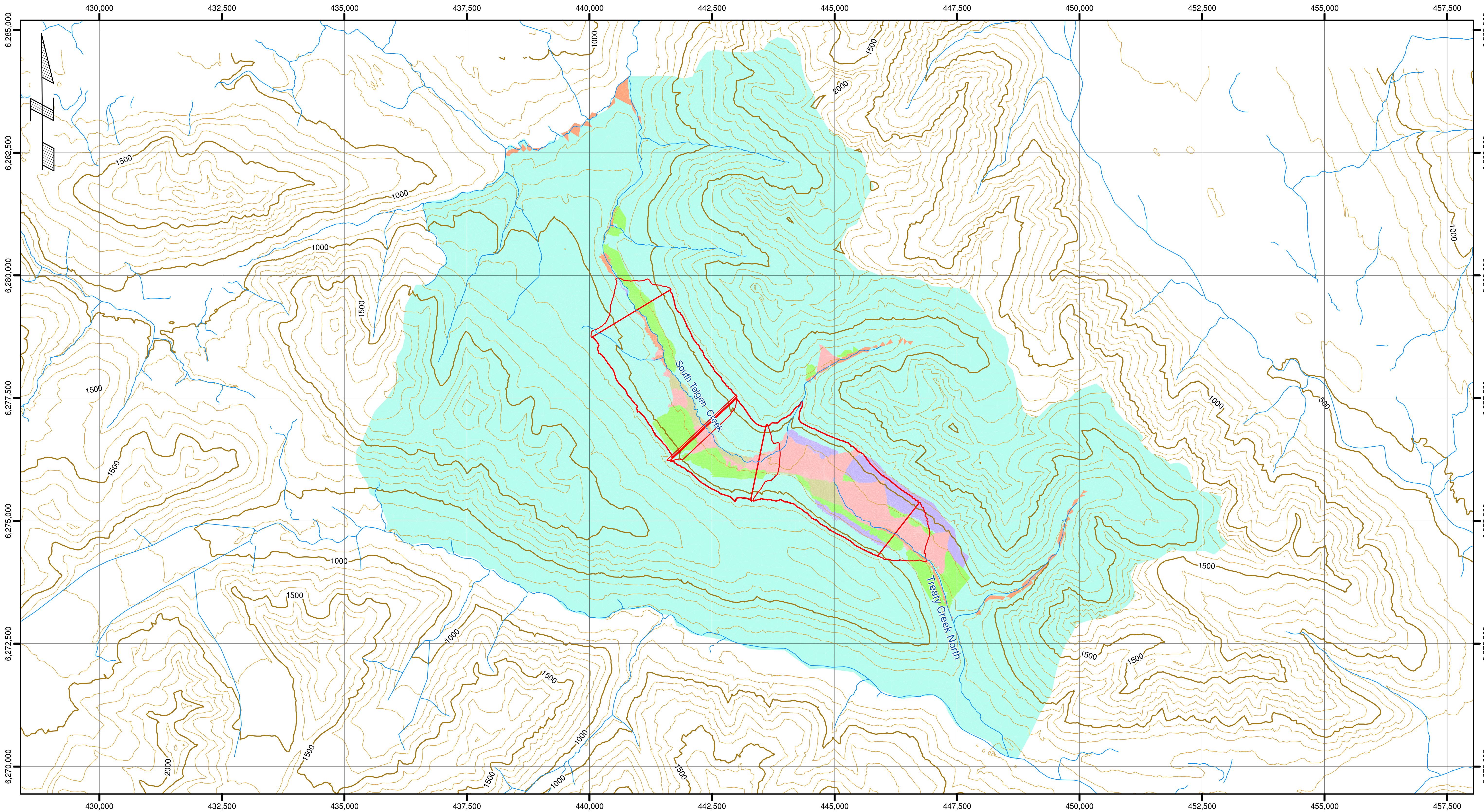


NOT FOR CONSTRUCTION

0 2,500 m

LEGEND

Tailings Management Facilities	Alluvium/Colluvium
	Bog
	Fluvial Sediments
	Glacial Till
	Lateral Moraine
	Weathered Rock
Rivers and Streams	
Major Contours	
Minor Contours	

Notes:
1. UTM Zone 9N, NAD83
2. Rivers and Streams from BC TRIM (1995)
3. Contours: 100m from BC TRIM (1995)

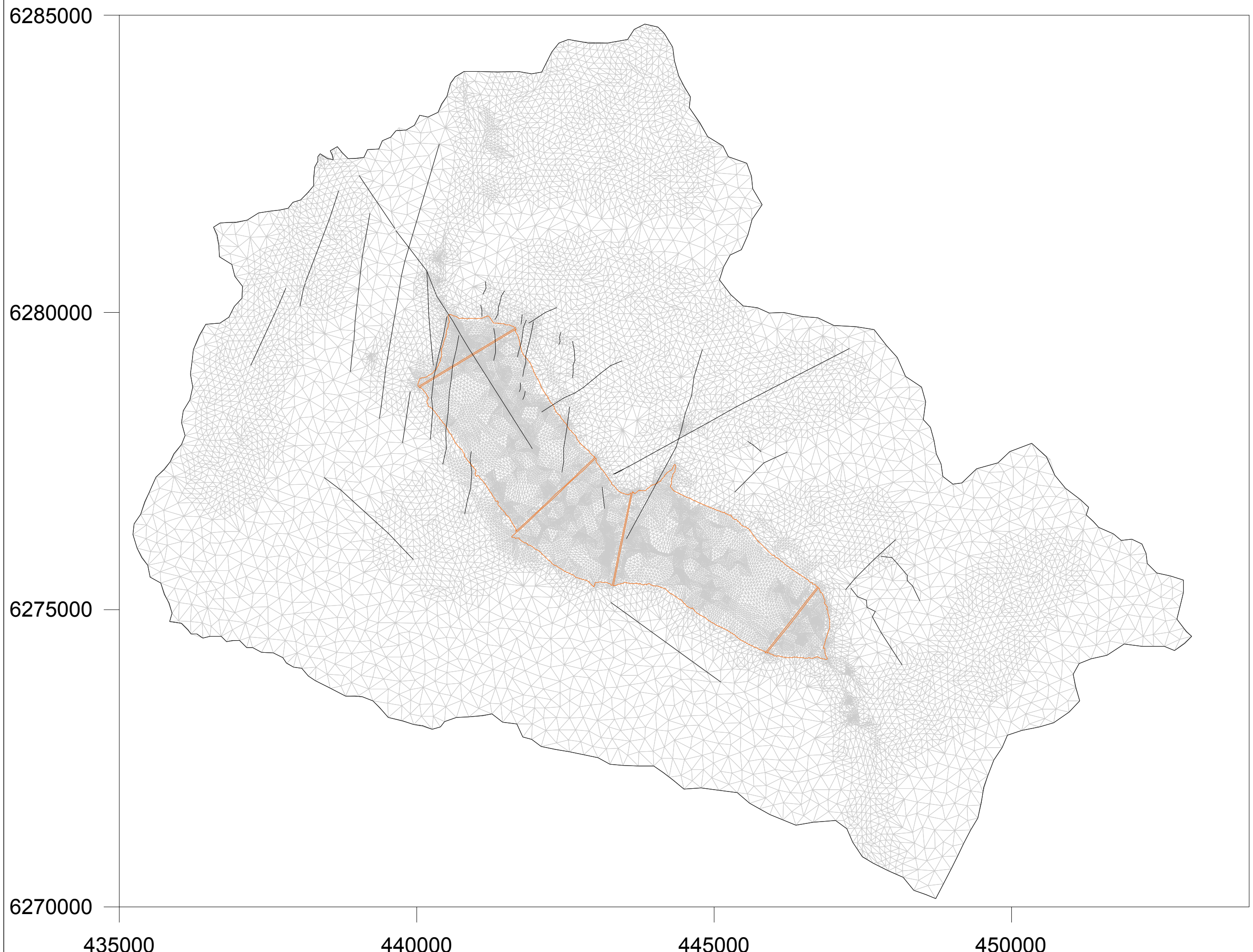
CLIENT
SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE
TAILINGS MANAGEMENT FACILITY
MODEL OVERBURDEN DISTRIBUTION

DATE: JUN 2013 | PROJECT No.: M09480A04 | FIG No.: 21



NOT FOR CONSTRUCTION

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

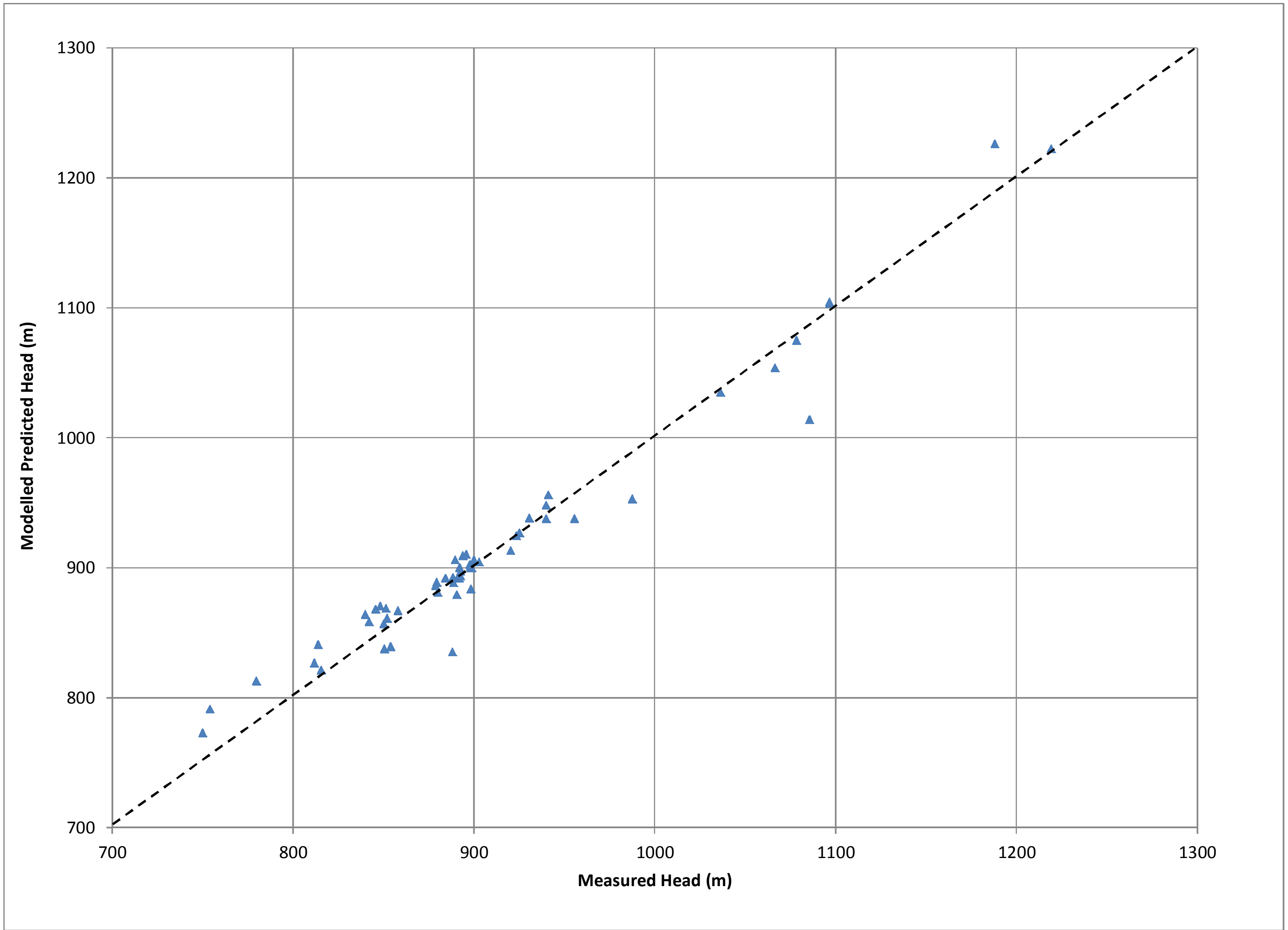
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TMF FEFLOW MODEL
DISCRETE ELEMENT (FAULT) LOCATIONS

PROJECT No: M09480A04

FIG. No: FIGURE 22



CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

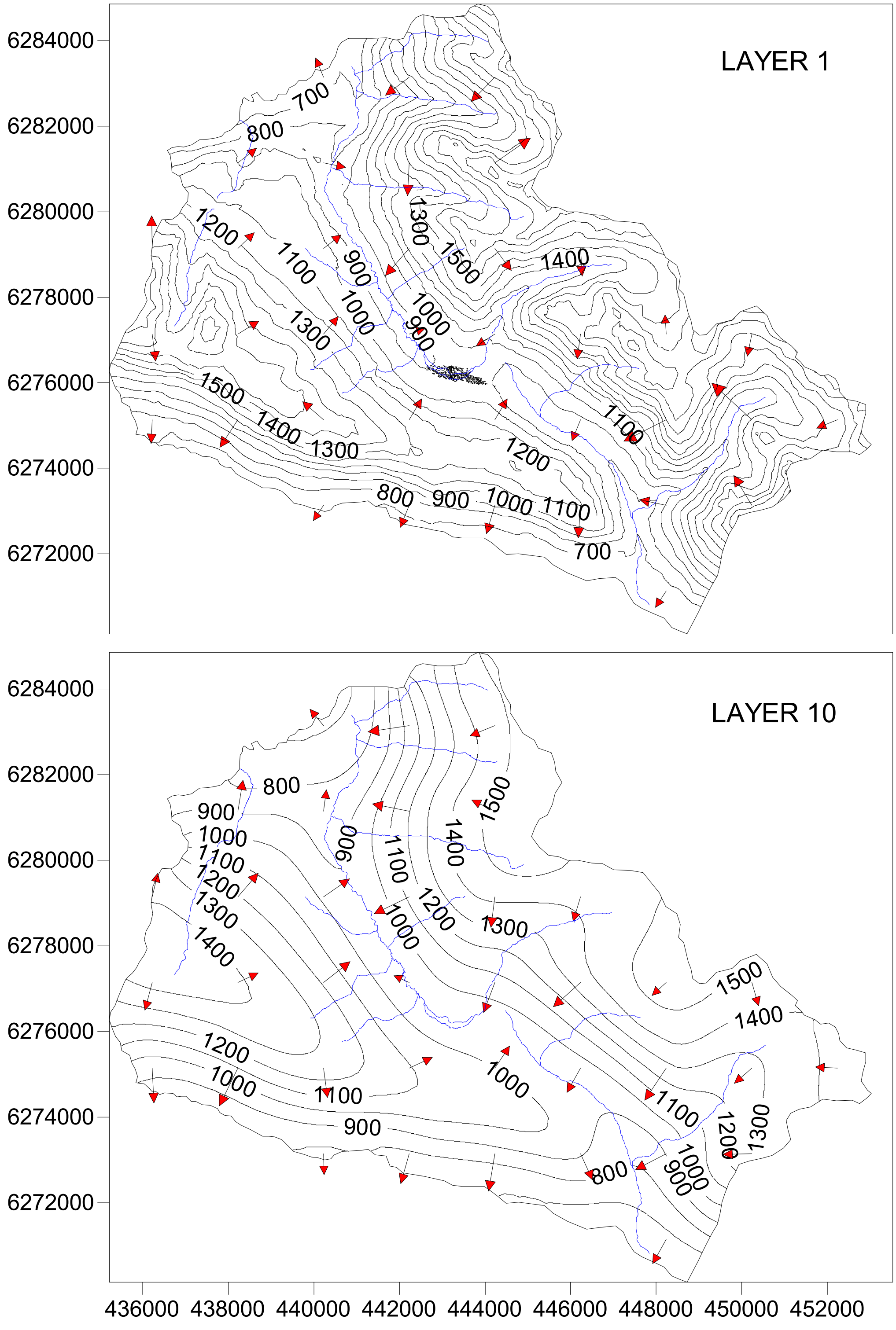
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TMF FEFLOW MODEL
PREDICTED VERSUS MEASURED HEADS

PROJECT No: M09480A04

FIG. No: FIGURE 23



NOT FOR CONSTRUCTION
Contour Interval: 100m

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

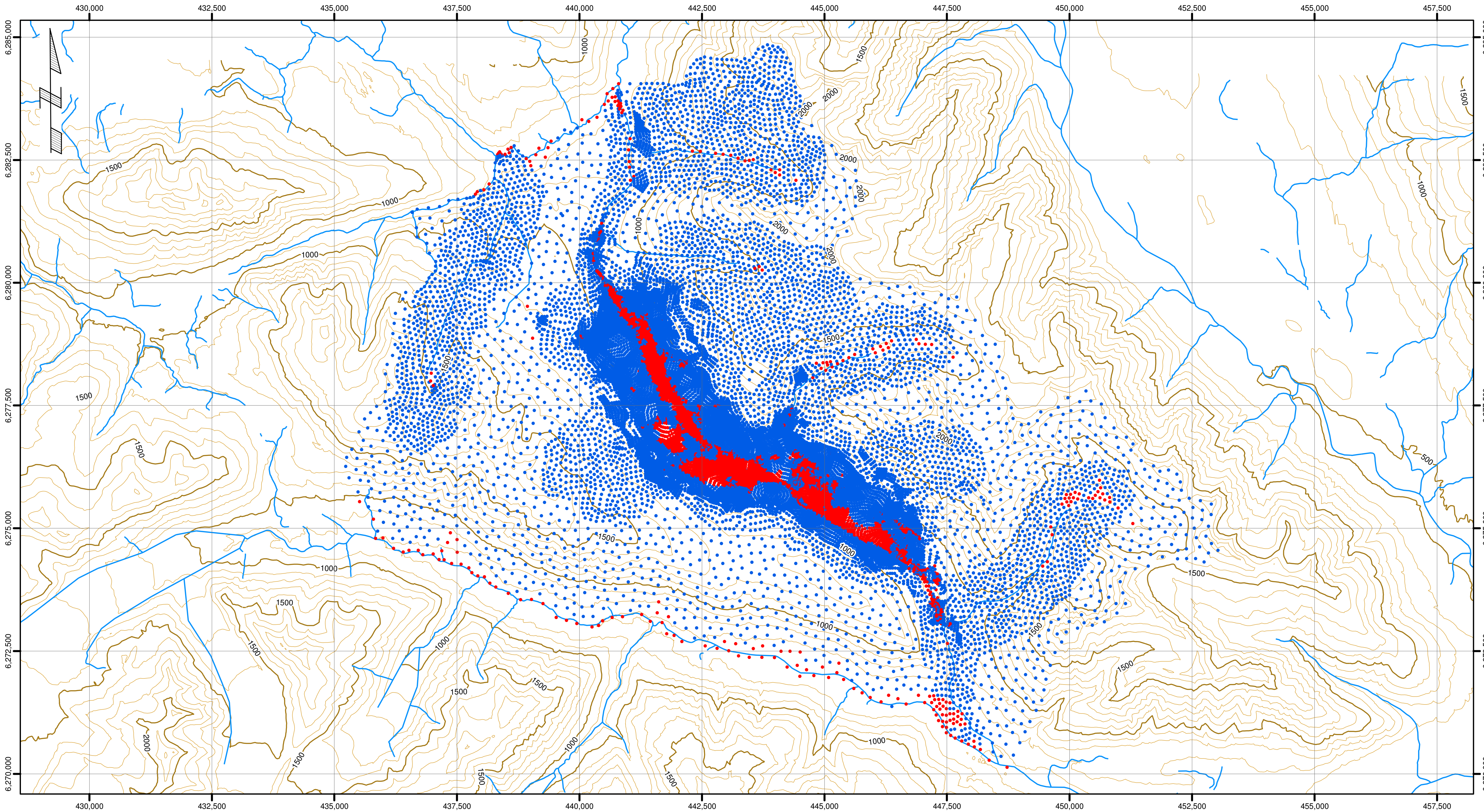
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TMF FEFLOW MODEL
PREDICTED HEADS / FLOW - BASECASE

PROJECT No: **M09480A04**

FIG. No: **FIGURE 24**



NOT FOR CONSTRUCTION

0 2,500 m

LEGEND

- Recharge
- Discharge
- Rivers and Streams
- Major Contours
- Minor Contours

Notes:
1. UTM Zone 9N, NAD83
2. Rivers and Streams from BC TRIM (1995)
3. Contours: 100m from BC TRIM (1995)

CLIENT
SEABRIDGE GOLD

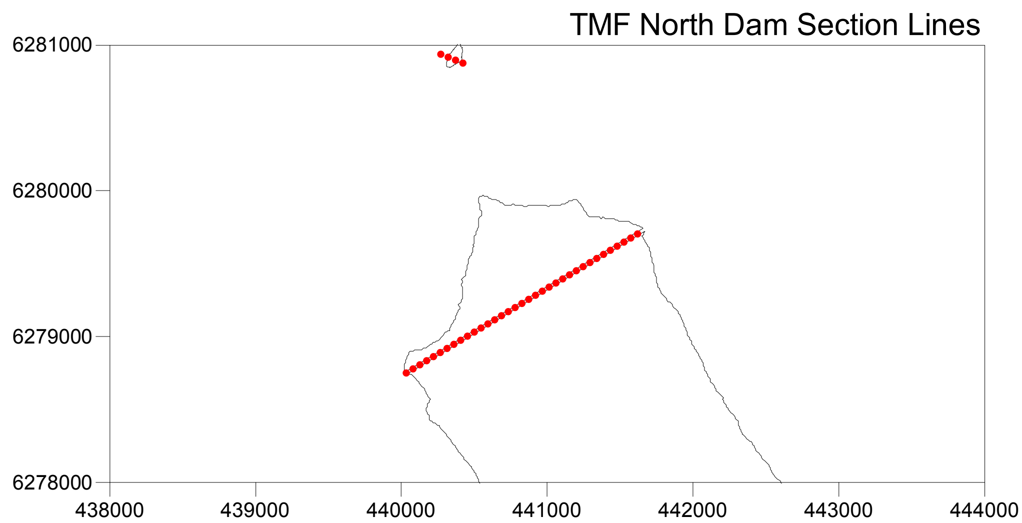
Klohn Crippen Berger

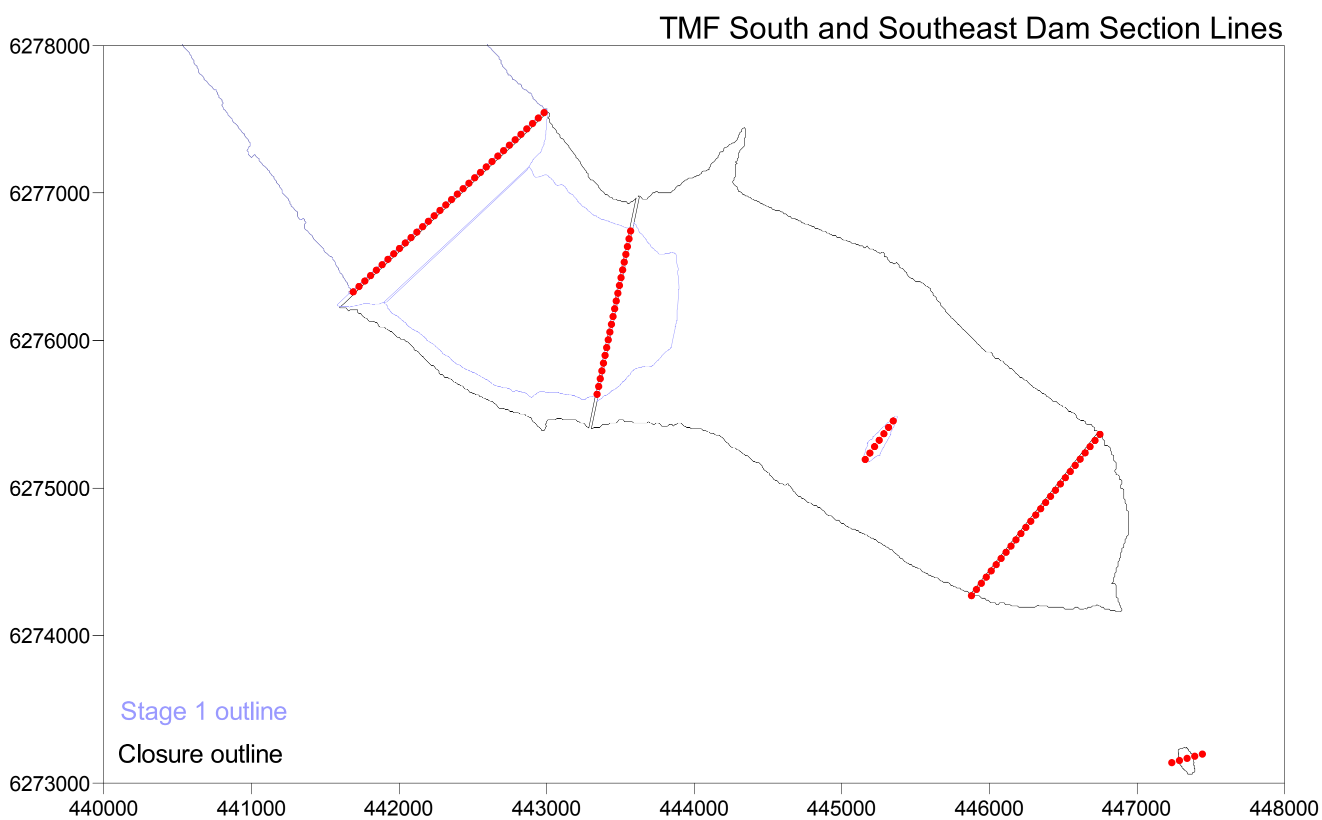
PROJECT
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE
TMF BASE CASE
STEADY STATE CALIBRATED MODEL
RECHARGE AND DISCHARGE

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	25

Path: Z:\VCR\M09480A04 - KSM 2012 PFS\400 Drawings\GIS\mxd\SI_2012\SI_Report_TMF_area2012\hydrogeo_TMF_recharge-discharge_basecase.mxd



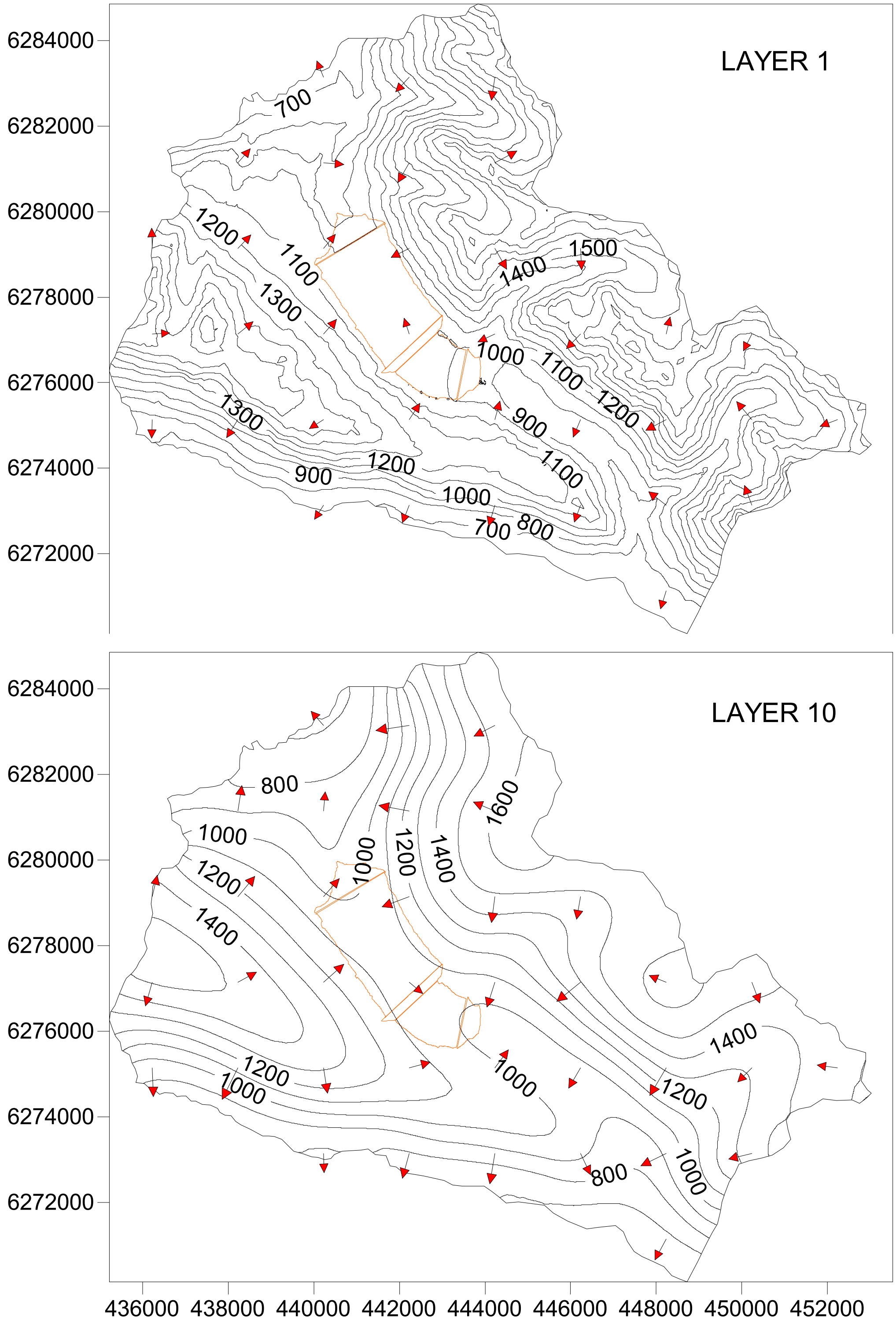


Flux Section Line

NOTES
1. Horizontal Datum: NAD83
2. Grid Zone: Zone 9
3. Vertical Datum: Mean Sea Level

NOT FOR CONSTRUCTION

CLIENT SEABRIDGE GOLD	PROJECT KSM PROJECT HYDROGEOLOGY MODELLING STUDY
Klohn Crippen Berger	TITLE TMF DAMS FLUX SECTION ANALYSIS LINES
PROJECT No: M09480A04	FIG. No: FIGURE 26



NOT FOR CONSTRUCTION
Contour Interval: 100m

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

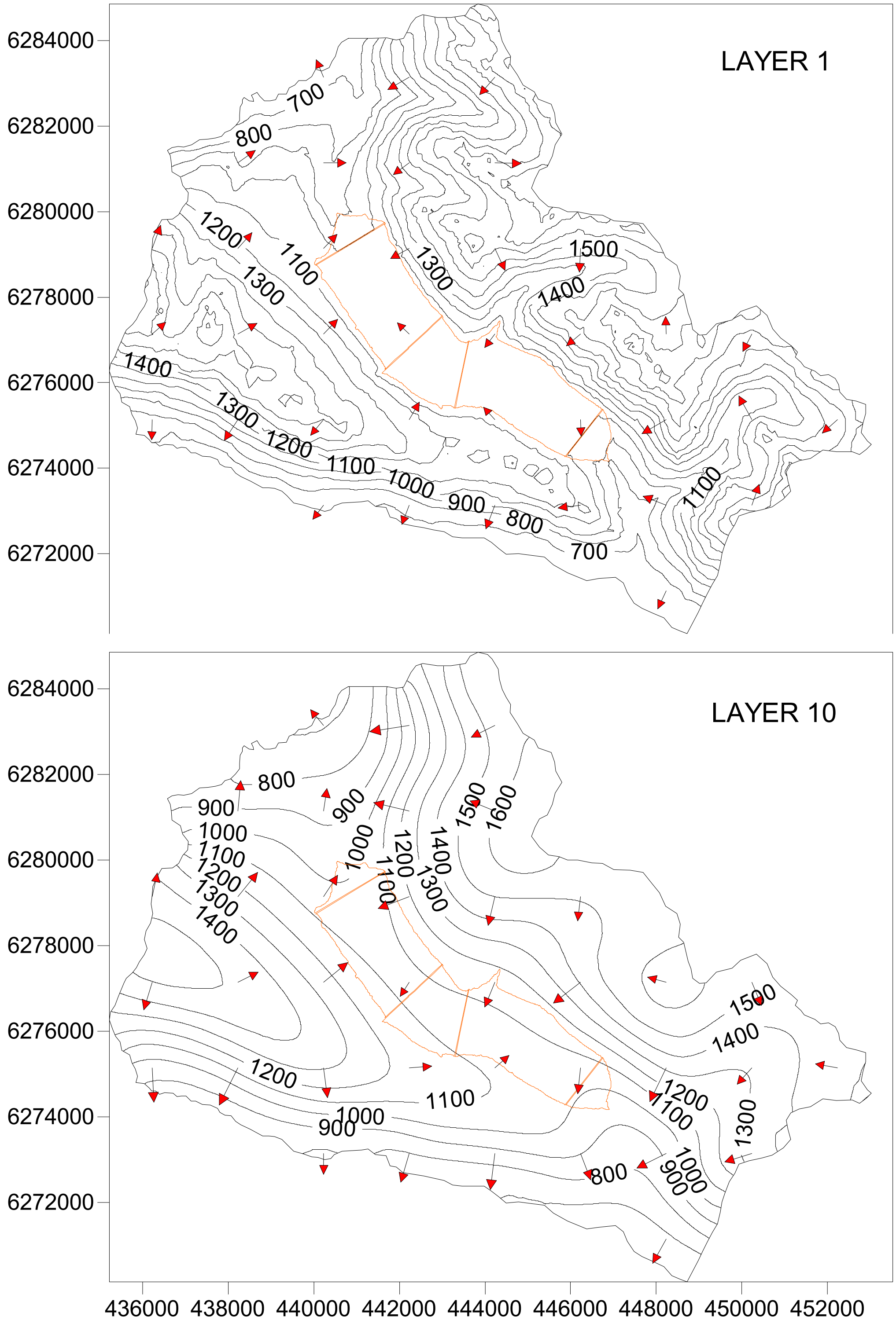
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TMF FEFLOW MODEL
PREDICTED HEADS / FLOW - STAGE 1 SMD

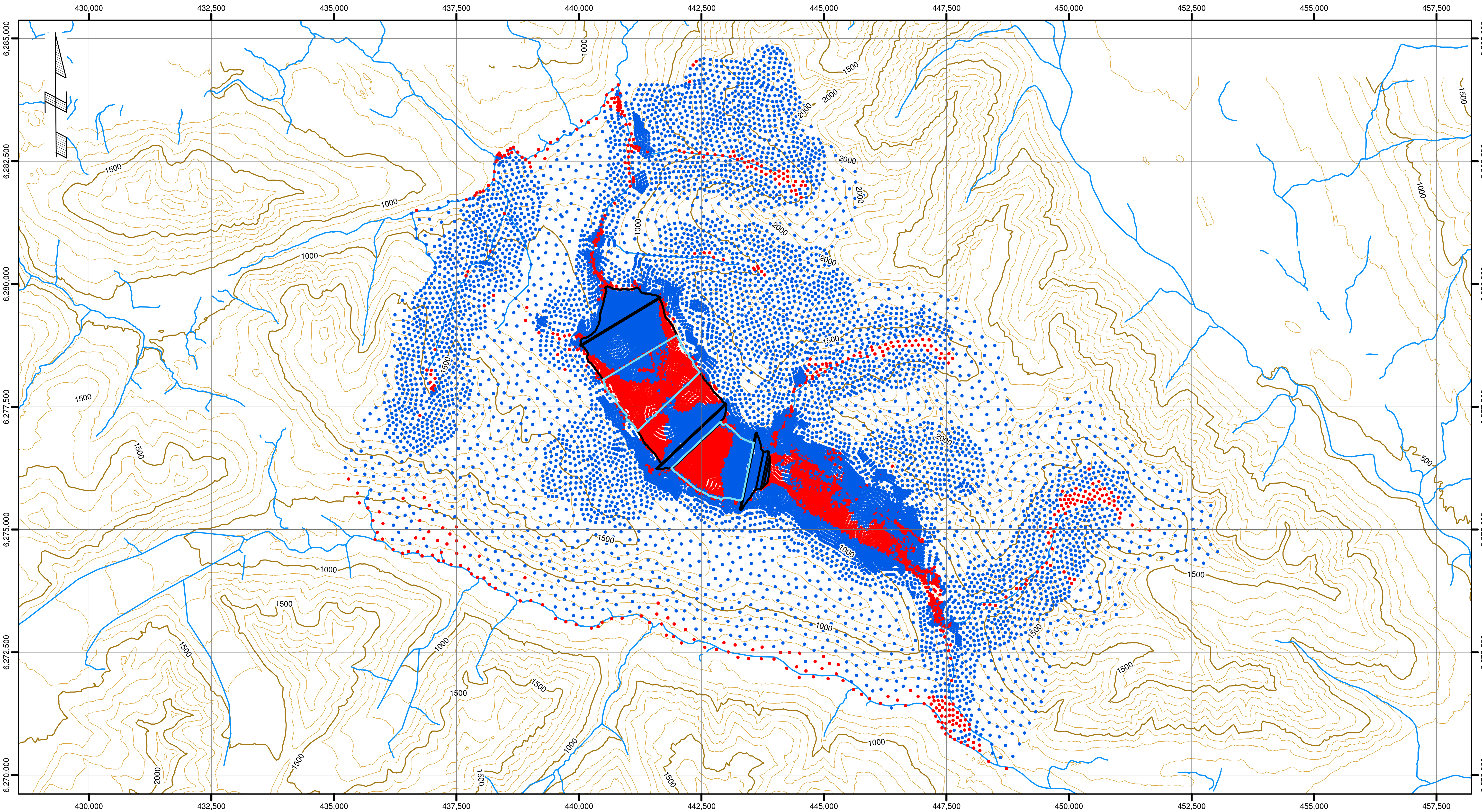
PROJECT No: **M09480A04**

FIG. No: **FIGURE 27**



NOT FOR CONSTRUCTION
Contour Interval: 100m

CLIENT SEABRIDGE GOLD	PROJECT KSM PROJECT HYDROGEOLOGY MODELLING STUDY
Klohn Crippen Berger	TITLE TMF FEFLOW MODEL PREDICTED HEADS / FLOW - CLOSURE SMD
PROJECT No: M09480A04	FIG. No: FIGURE 28



NOT FOR CONSTRUCTION

0 2,500 m

LEGEND

- Groundwater Recharge
- Groundwater Discharge
- Tailing Pond
- Tailing and Dam
- Rivers and Streams
- Major Contours
- Minor Contours

Notes:
1. UTM Zone 9N, NAD83
2. Rivers and Streams from BC TRIM (1995)
3. Contours: 100m from BC TRIM (1995)

Path: Z:\M\VCR\M09480A04 - KSM 2012 PFS\400 Drawings\GIS\mxd\SI_2012\SI_Report_TMF_area2012\hydrogeo_TMF_recharge-discharge_stage1_130624.mxd

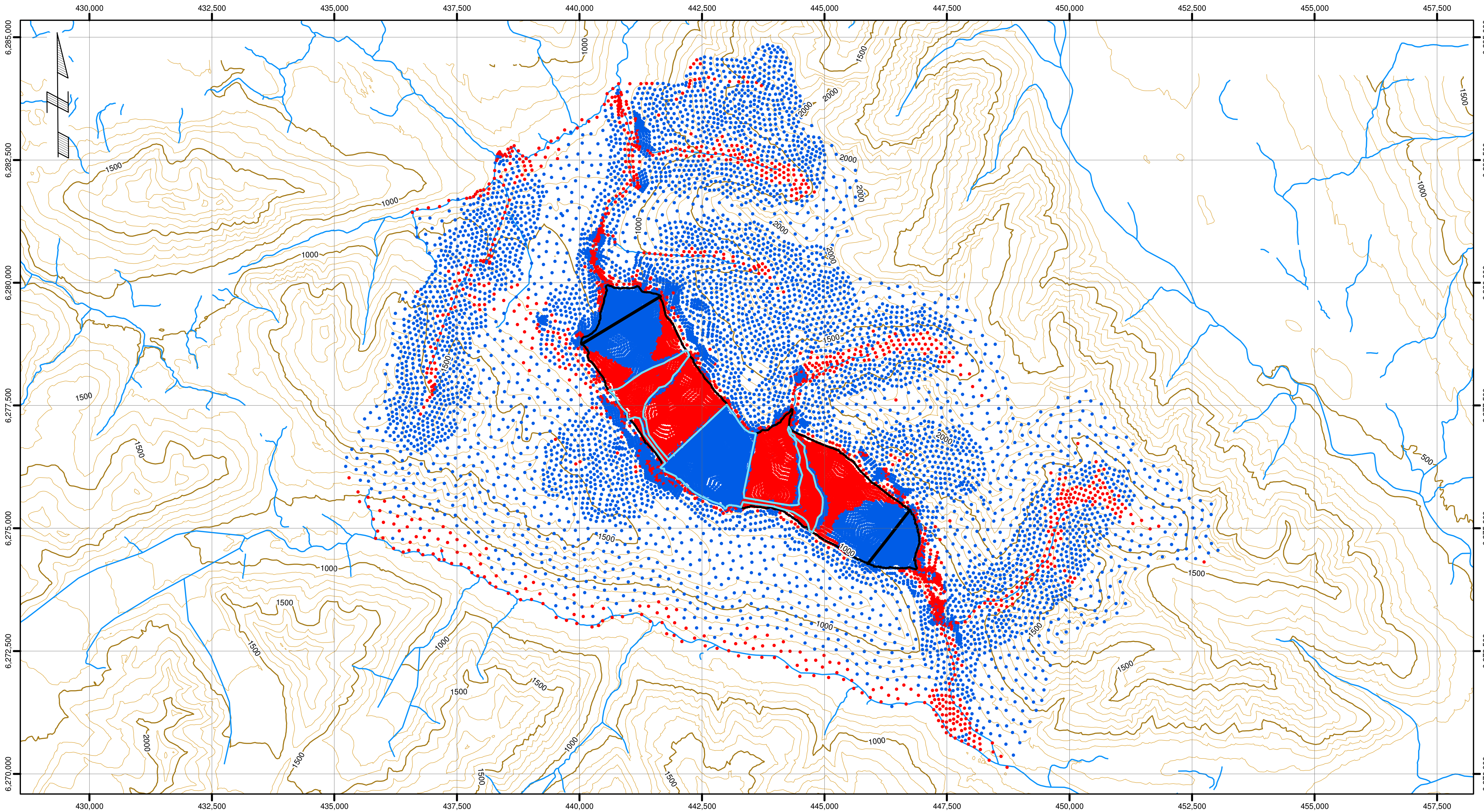
CLIENT: SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT: KSM PROJECT HYDROGEOLOGY MODELLING STUDY

TITLE: TMF STAGE 1 RECHARGE AND DISCHARGE

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	29



NOT FOR CONSTRUCTION

0 2,500 m

LEGEND

- Groundwater Recharge
- Groundwater Discharge
- Tailing Pond
- Tailing and Dam
- Rivers and Streams
- Major Contours
- Minor Contours

Notes:
1. UTM Zone 9N, NAD83
2. Rivers and Streams from BC TRIM (1995)
3. Contours: 100m from BC TRIM (1995)

Document Path: Z:\M\VCR\M09480A04 - KSM 2012 PFS\400 Drawings\GIS\mxd\SI_2012\SI_Report_TMF_area2012\hydrogeo_TMF_recharge-discharge_stage4_130624.mxd

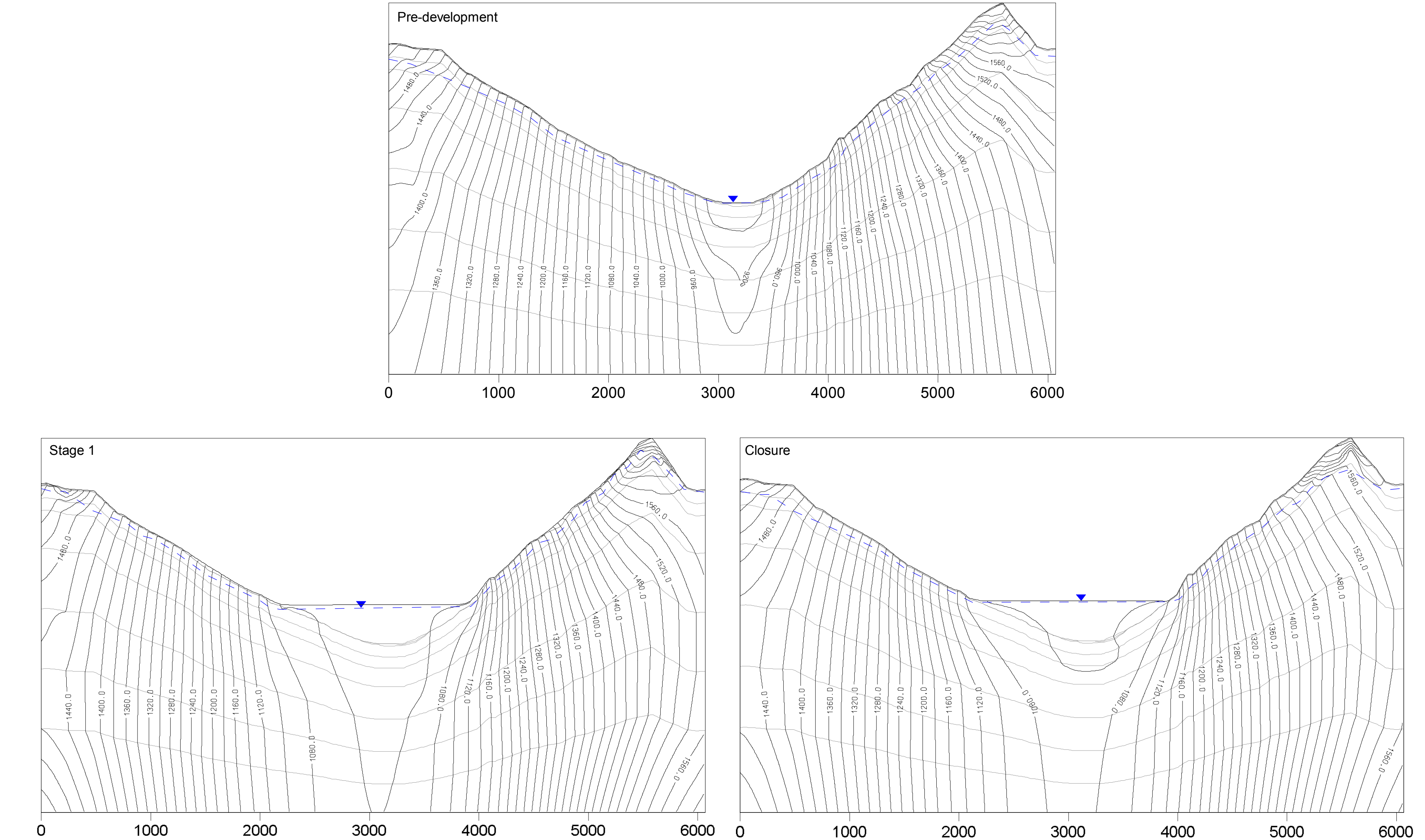
CLIENT
SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE
TMF CLOSURE
RECHARGE AND DISCHARGE

DATE	PROJECT No.	FIG No.
JUN 2013	M09480A04	30



NOTES
1. V:H Exag.: 2:1
2. Contour Interval: 10 m
3. Cross Sections do not extend across entire model domain
4. Water Table defined at Slice 1 heads; indicative only.

CLIENT: SEABRIDGE GOLD

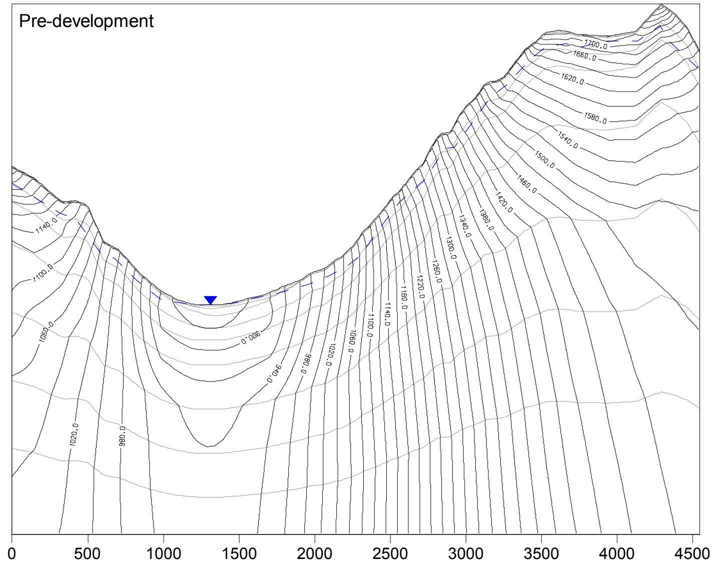
Klohn Crippen Berger

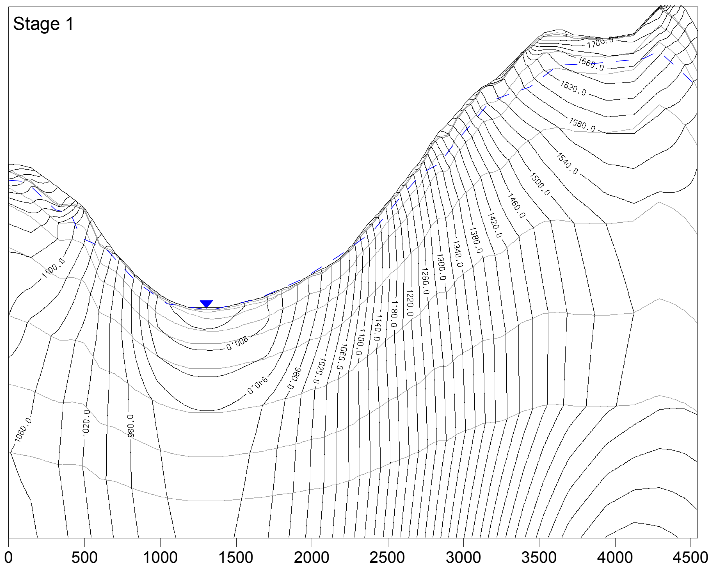
PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

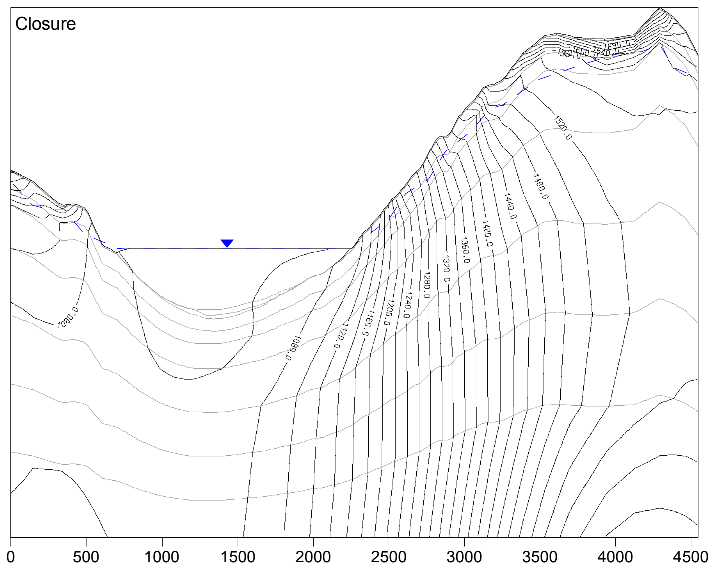
TITLE: TMF FEFLOW MODEL
SECTION A-A' (TMF NORTH CELL)

PROJECT No: M09480A04

FIG. No: FIGURE 31







NOTES
1. V:H Exag.: 2:1
2. Contour Interval: 10 m
3. Cross Sections do not extend across entire model domain
4. Water Table defined at Slice 1 heads; indicative only.

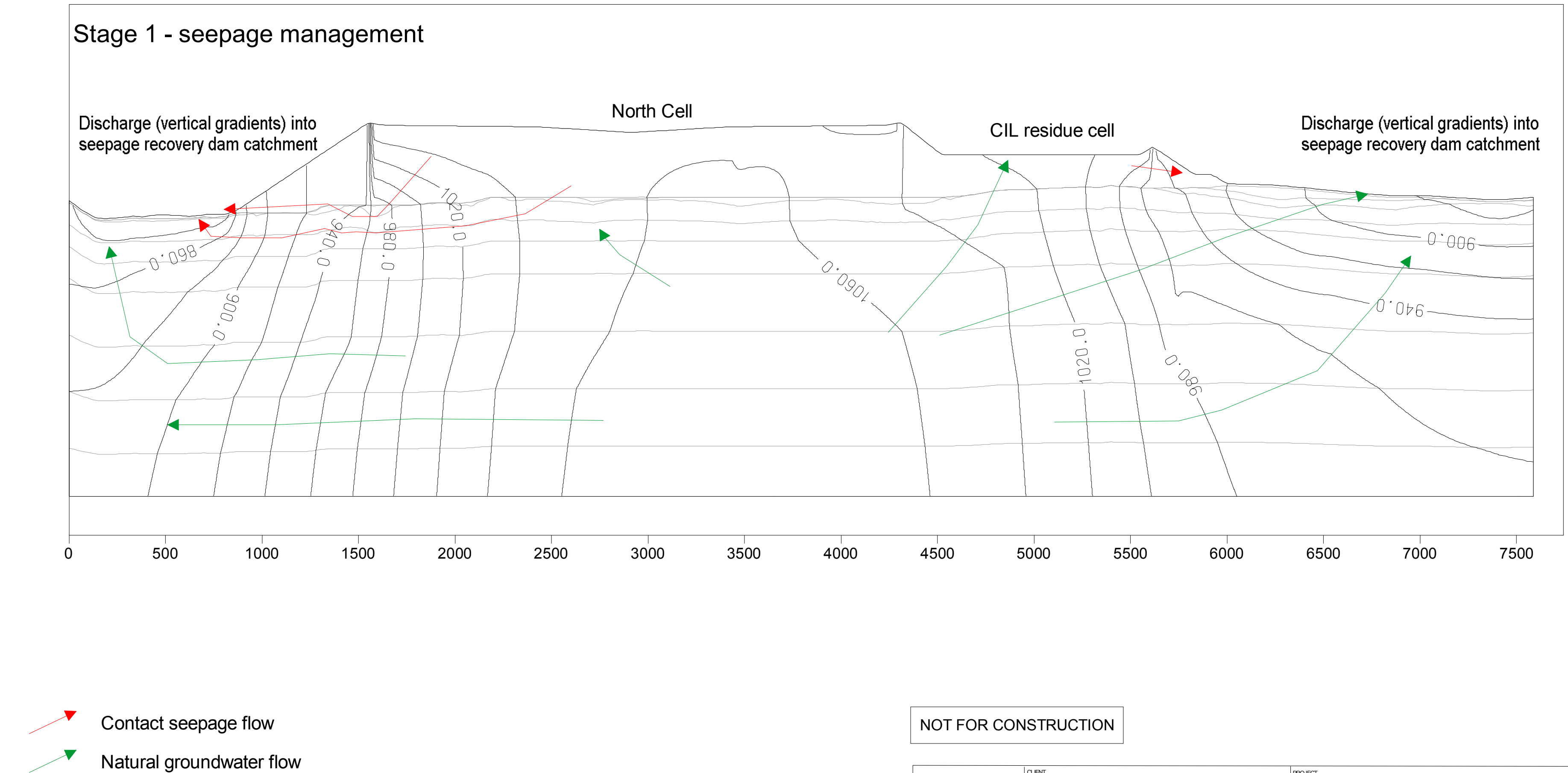
CLIENT: SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: TMF FEFLOW MODEL
SECTION B-B' (TMF SOUTH CELL)

PROJECT No:	FIG. No:
M09480A04	FIGURE 32



NOTES
1. V:H Exag.: 2:1
2. Contour Interval: 10 m

NOT FOR CONSTRUCTION

CLIENT: SEABRIDGE GOLD

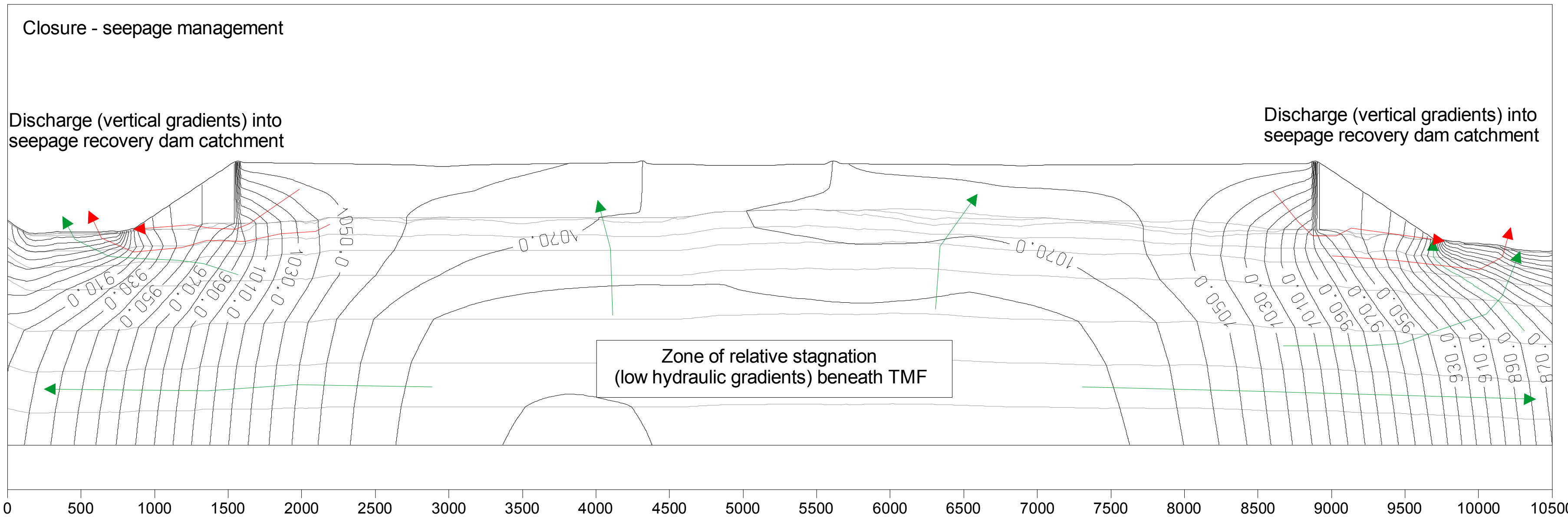
Klohn Crippen Berger

PROJECT: KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE: TMF FEFLOW MODEL
SECTION C-C' (STAGE 1)

PROJECT No: M09480A02

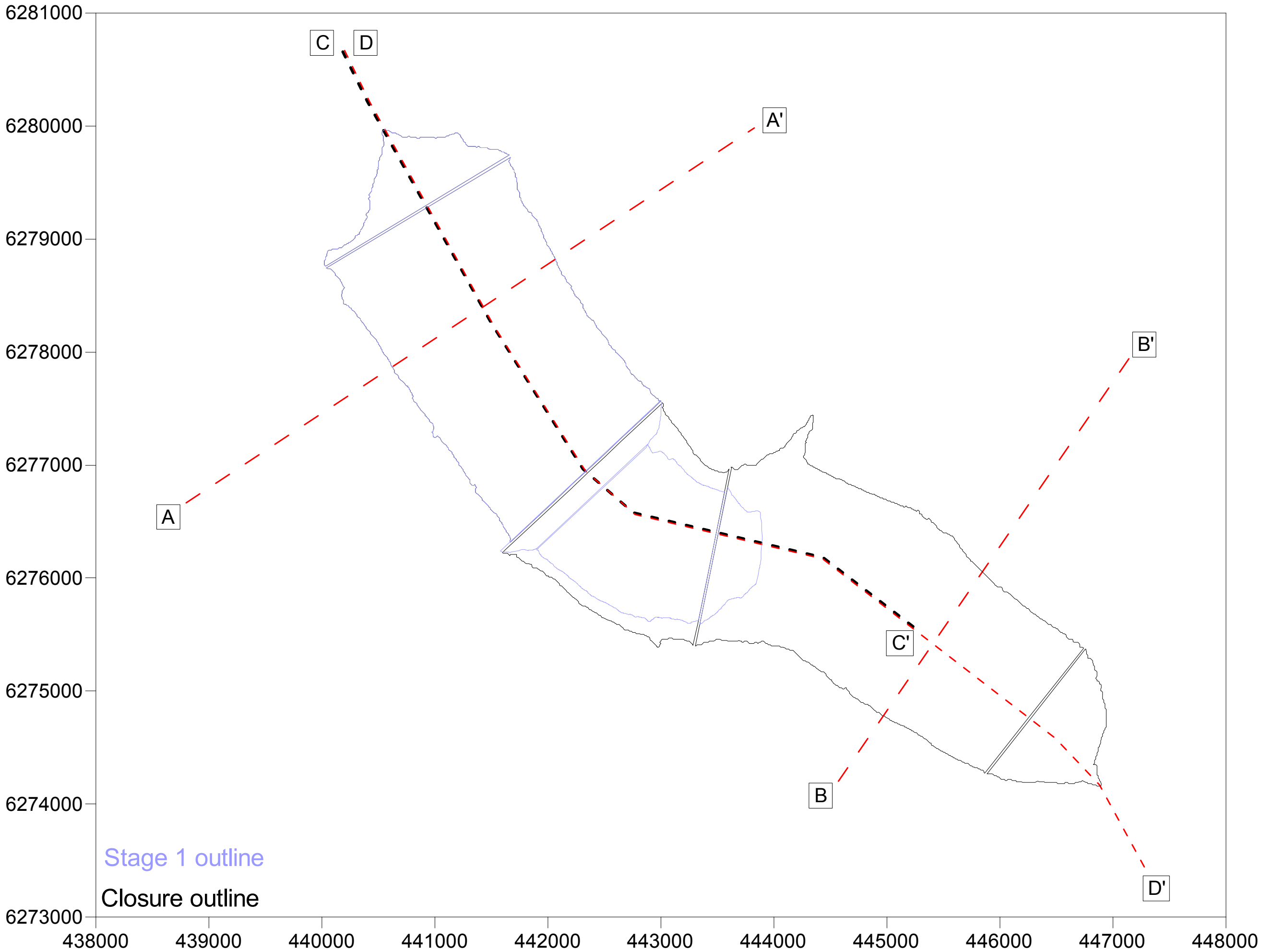
FIG. No: FIGURE 33



NOTES
1. V:H Exag.: 2:1
2. Contour Interval: 10 m
3. Semi-circular contour at base of section is due to 3D effects (flow perpendicular to Section)

NOT FOR CONSTRUCTION

CLIENT	SEABRIDGE GOLD
	Klohn Crippen Berger
PROJECT	KSM PROJECT HYDROGEOLOGY MODELLING STUDY
TITLE	TMF FEFLOW MODEL SECTION D-D' (TMF CLOSURE)
PROJECT No:	M09480A04
FIG. No:	FIGURE 34



NOTES
1. Cross Sections do not extend across entire model domain

NOT FOR CONSTRUCTION

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

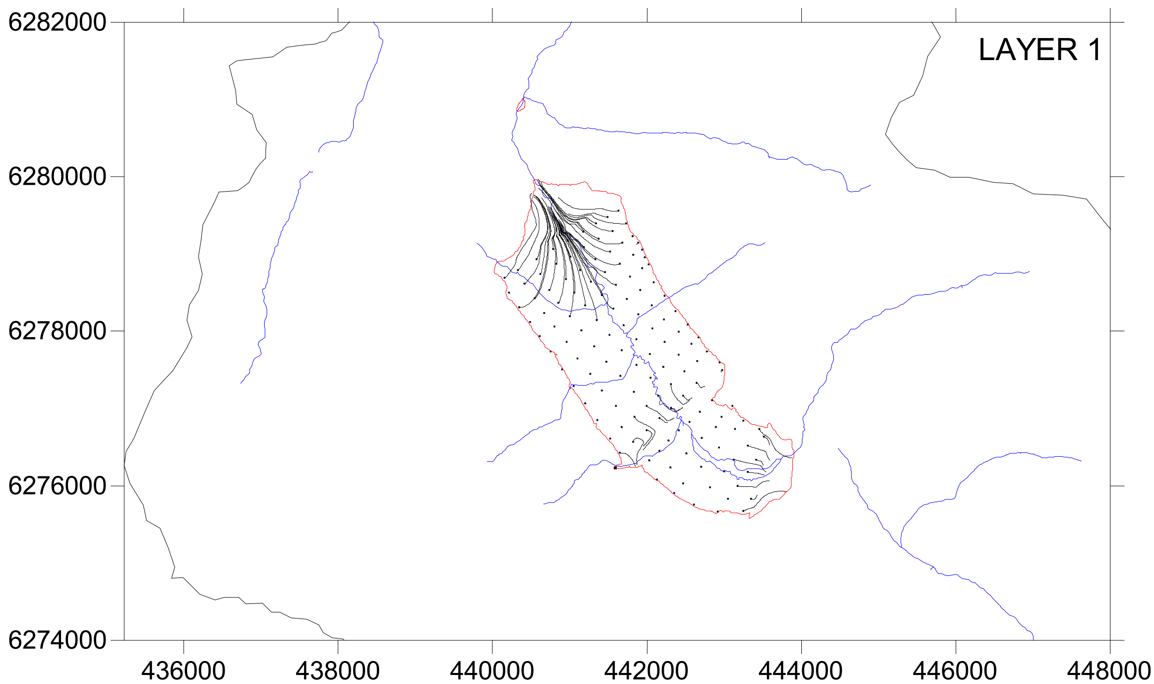
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

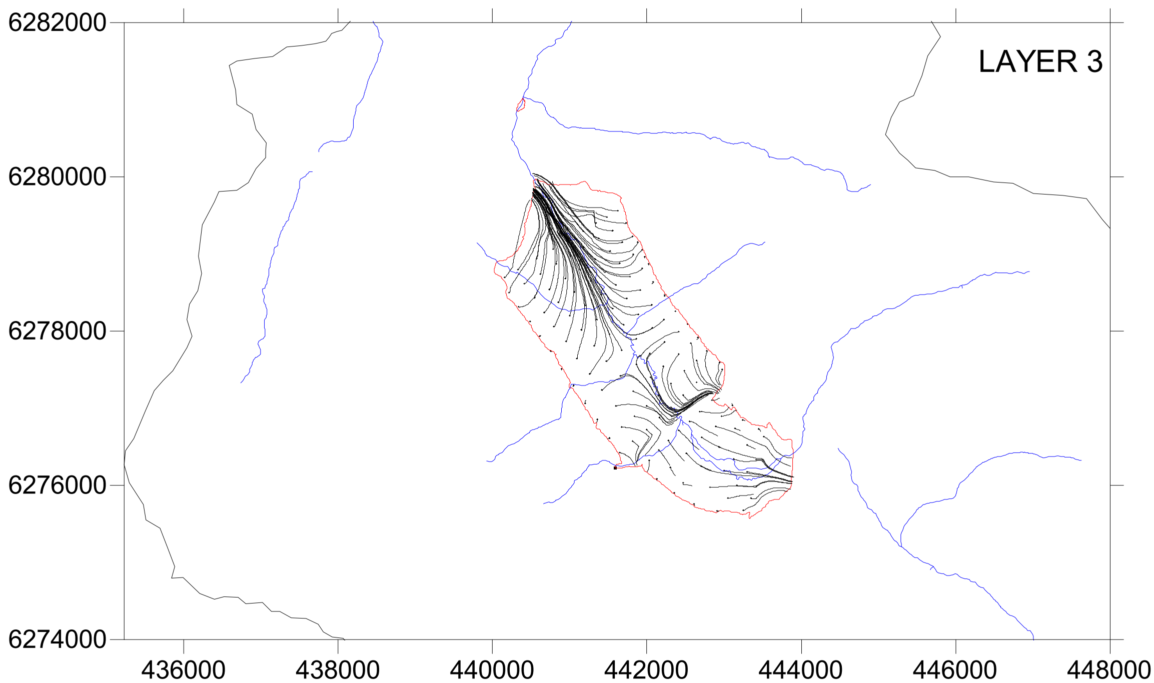
TITLE

TMF FELFOW MODEL
LONG / CROSS SECTION LOCATIONS

PROJECT No: M09480A04

FIG. No: FIGURE 35





NOT FOR CONSTRUCTION

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

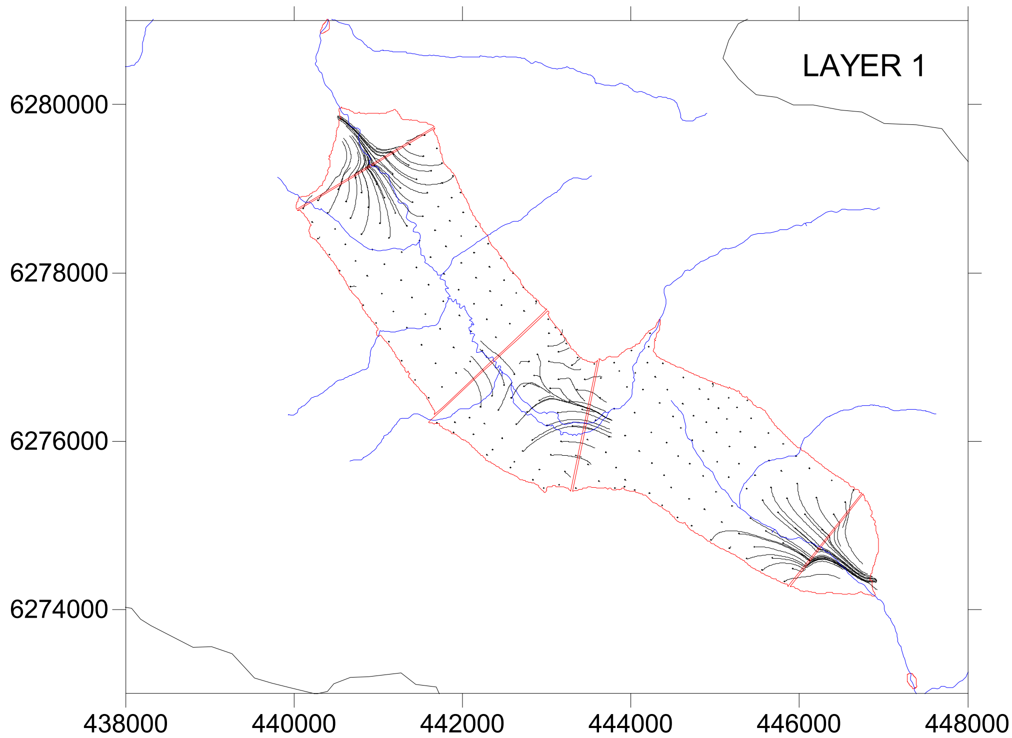
KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

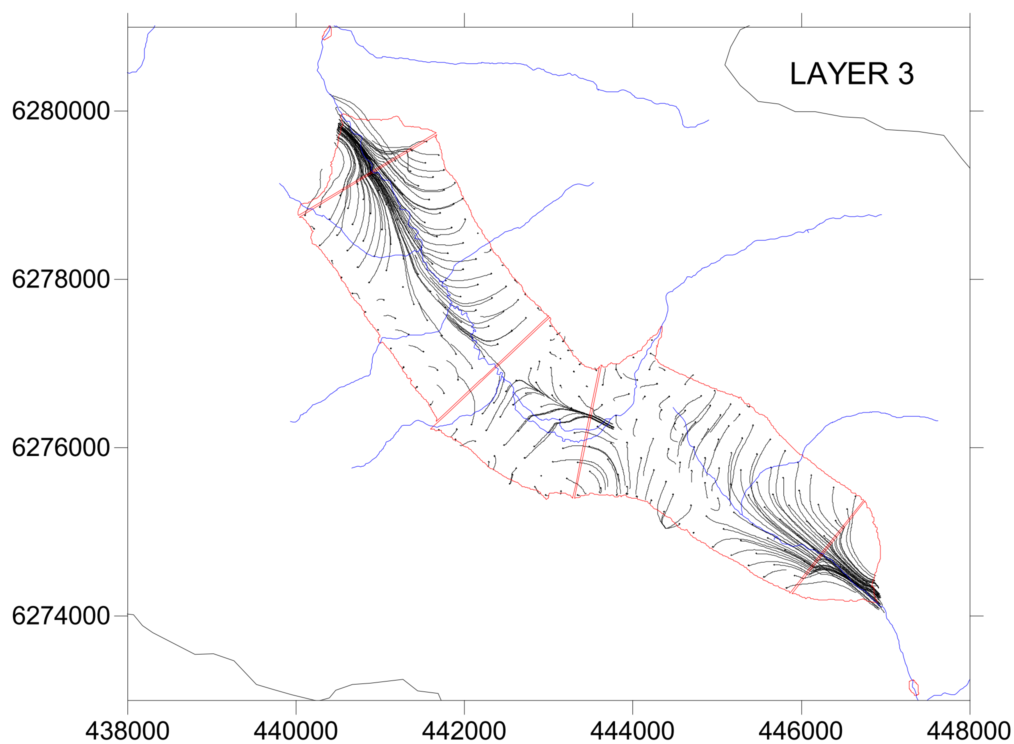
TITLE

TMF STAGE 1 WITH SMD
PARTICLE TRACKING

PROJECT No: M09480A04

FIG. No: FIGURE 36





NOT FOR CONSTRUCTION

CLIENT

SEABRIDGE GOLD

Klohn Crippen Berger

PROJECT

KSM PROJECT
HYDROGEOLOGY MODELLING STUDY

TITLE

TMF CLOSURE WITH SMD
PARTICLE TRACKING

PROJECT No: **M09480A04**

FIG. No: **FIGURE 37**