APPLICATION FOR ALTERNATE CONCENTRATION LIMITS FOR THE SMITH RANCH-HIGHLAND MINE UNIT-B IN-SITU URANIUM RECOVERY FACILITY

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ABBREVIATIONS AND ACRONYMS

ACL	Alternate Concentration Limit
ALARA	as low as reasonably achievable
BPT	Best Practicable Technology
Bq	bequerel
Cameco	Power Resources Inc., d.b.a. Cameco Resources
CAP	Corrective Action Program
CEC	cation exchange capacity
C_{hb}	health risk-based concentration
cm	centimeter
COC	constituent of concern
EA	Environmental Assessment
EPA	U.S. Environmental Protection Agency
ER	Environmental Report
FGR	Federal Guidance Report
FONSI	Finding of No Significant Impact
gpm	gallons per minute
GPS	Groundwater Protection Standard
GWS	groundwater sweep
HFO	hydrous ferric oxide
HUP	Highland Uranium Project
I(Bq)	lifetime acceptable radionuclide intake in bequerels
ISR	in-situ recovery
(IX)	ion exchange
km	kilometer(s)
KMC	Kerr-McGee Corporation
LQD	Land Quality Division
MCL	Maximum Contaminant Level established by EPA
MCV	Maximum Concentration Value (criterion 5(c) of Appendix A to 10 CFR part 40)
meq/100g	milliequivalents per 100 grams
meq/L	milliequivalent per liter
mg/L	milligrams per liter
mi	miles
mi^2	square miles

MP-Well	Monitoring Production Well
MU-4	Mine Unit-4
MU-A	Mine Unit-A
MU-B	Mine Unit-B
MU-K	Mine Unit-K
NOAEL	no observed adverse effects level
NRC	U.S. Nuclear Regulatory Commission
pCi/L	picocuries per liter
POC	point of compliance
POE	point of exposure
PRI	Power Resources Inc., d.b.a. Cameco Resources
PV	pore volume
R&D	Research and Development
RAMC	Rio Algom Mining Corp.
RO	reverse osmosis
RTV	Restoration Target Value
SDWA	Safe Drinking Water Act
SFC	Sequoyah Fuels Corporation
SR	Smith Ranch
SRH	Smith Ranch-Highland
TDS	total dissolved solids
TER	Technical Evaluation Report
TVA	Tennessee Valley Authority
UCL	upper confidence limit
UIC	Underground Injection Control
UPL	upper prediction limit
USGS	U.S. Geological Survey
UTL	upper tolerance limit
WDEQ	Wyoming Department of Environmental Quality
WQD	Water Quality Division

EXECUTIVE SUMMARY

This document is an application for Alternate Concentration Limits (ACLs) in accordance with Appendix A to 10 CFR, Part 40, Criterion 5(B)(6). ACLs are proposed for the Point of Compliance (POC) wells in the In-Situ Recovery (ISR) Mine Unit B (MU-B) facility owned and operated by Power Resources, Inc. (PRI), d.b.a. Cameco Resources (Cameco), located in Converse County, Wyoming (Figure 1).

Uranium was extracted at MU-B using ISR mining methods. Uranium recovery via ISR increased the concentrations of some dissolved constituents in the groundwater of MU-B; however, ambient groundwater concentrations were naturally elevated above safe levels for human use before ISR processes began. An aquifer exemption has been issued for this groundwater which does not allow the groundwater to be used as a drinking water source now or in the future. Following ISR extraction, groundwater restoration was completed in accordance with the approved Wyoming Department of Environmental Quality (WDEQ) Land Quality Division (LQD) permit No. 603, the ISR regulations in LQD Chapter 11, and the WDEQ Chapter 8 Rules and Regulations. On August 5, 2004, Cameco submitted the MU-B Groundwater Restoration report to WDEQ/LQD demonstrating that restoration was completed using "Best Practicable Technology" (BPT). The post-ISR groundwater quality met WDEQ criteria for "Class of Use." WDEQ approved the MU-B restoration on March 31, 2008 (WDEQ, 2008).

The state-approved restoration was designed to abate impacts to groundwater that were related to recovery of uranium from the 30-Sand Unit using ISR methods by reducing concentrations of constituents at POC wells to a primary goal of baseline conditions. The restoration has reduced constituent concentrations since the end of ISR; however, the concentrations have not been returned to baseline conditions for all parameters. The LQD's approval of the MU-B restoration was based on the secondary "Class of Use" criteria after demonstrating the application of BPT. The demonstration of BPT includes the requirement that the restored aquifer will not degrade downgradient groundwater. The secondary restoration standards are allowed under the State of Wyoming's ISR rules and the state's administration of the EPA's Underground Injection Control Program as described in detail in Section 1.3.1.

Constituents of concern (COCs) for MU-B have been identified as arsenic, radium-226, selenium, and uranium. These COCs were identified according to Appendix A to 10 CFR, Part 40, Criterion 5(B)(6), because the recent concentrations of these constituents exceed both baseline concentrations and the Maximum Contaminant Values (MCV) presented in Criterion 5. A hazard assessment of the COCs, which includes a source and contaminant characterization, a geochemical and hydrogeological transport assessment, and an exposure assessment for both humans and the environment, has been performed and is described in detail in Section 2.0.

Human health risk-based concentrations have been developed for the COCs. MCVs from Appendix A to 10 CFR, Part 40, Criterion 5(B) were used when available or appropriate. Otherwise, human health risk-based concentrations were calculated assuming a 1×10^{-4} target risk. Geochemical modeling indicates that there will be a reduction in constituent concentrations in groundwater over time and over distance from the POC (source) area. Based on the findings of the transport assessment (Section 2.2), the concentrations of dissolved constituents at the modeled point of exposure (POE) are predicted to remain below the calculated health risk-based values of 30 picocuries per liter (pCi/L) for radium-226 and 0.09 milligrams per liter (mg/L) for uranium, and the regulatory (Appendix A to 10 CFR 40.5C, 2012) health risk-based value of 0.05 mg/L for arsenic and 0.01 mg/L for selenium. The concentrations are predicted to remain lower than these health risk-based values for the duration of the 1,000-year modeling period.

As the "as low as is reasonably achievable" (ALARA) demonstration (Section 3.6) shows, it is not practicable or reasonably achievable to reduce the constituent concentrations at the POC to baseline levels. However, hydrologic and geochemical modeling, as presented in Section 2.2, have shown that naturally occurring geochemical and hydrologic processes will reduce constituent concentrations by removing constituents from groundwater along its flowpath, resulting in acceptable groundwater constituent concentrations that are protective of human health and the environment at the POE, which is located at the edge of the aquifer exemption boundary.

This document will demonstrate that it would not be practicable or reasonably achievable to return the groundwater in the production area to the primary goal of baseline conditions. This document will also demonstrate that current groundwater conditions, including the aquifer exemption and current concentrations of COCs at the POC wells, are protective of human health and the environment in the extremely unlikely event that the groundwater at the POE is ever used as a drinking water source.

1.0 INTRODUCTION

This document is an application for Alternate Concentration Limits (ACLs) for the Point of Compliance (POC) wells in the Power Resources, Inc. (PRI), d.b.a. Cameco Resources (Cameco), In-Situ Recovery (ISR) Mine Unit B (MU-B) facility located in Converse County, Wyoming (Figure 1).

1.1 Purpose

In accordance with Appendix A to 10 CFR, Part 40, Criterion 5(B)(6), Cameco submits this application for ACLs for the POC wells that are protective of human health and the environment. Criterion 5, although not written with ISR facilities in mind, can be applied to this particular ISR site as presented below. The ACLs discussed in this application are intended to comply with the current cleanup standards used for groundwater in U.S. Nuclear Regulatory Commission (NRC) Source Materials License SUA-1548 (previously Highland Source Material License SUA 1511). The standards set forth in the aforementioned license apply to the 30-Sand Unit at Cameco's MU-B facility.

This ACL application has certain structural differences from an ACL application at a conventional uranium milling site. At a conventional milling site, ore that has been leached of uranium and is no longer of value is deposited in a dam or tailing impoundment for dewatering and burial. Historically, tailings impoundments were typically unlined and were generally considered to be the source of contaminants in groundwater. An ISR site is considerably different. NRC considers the ISR mining method "milling underground," and the following specific site conditions are required to apply the ISR mining method:

1. An economic ore body must be defined in a permeable formation. A permeable formation is a type of rock (i.e., sandstone) that water can move or flow through. The ISR mining method is historically applied to a specific type of uranium deposit called a roll front uranium deposit. The uranium is deposited in a permeable sandstone formation by the natural movement of groundwater through the formation. The uranium in the groundwater is in a mobile, oxidized state, and as the water moves through the formation, the oxidized uranium encounters a chemically reduced area in the formation called a "redox boundary." The redox boundary chemically changes the uranium in the solution from a mobile ion to an immobile precipitate. Over time, the uranium "stacks up" and concentrates at the redox boundary. Depending on the age of the ore body, the mechanism that originally put the ore body in place could still be active. The ISR process requires (1) that mining solutions contact the uranium ore, and (2) that they can be removed from the mining zone by pumping.

2. The mining plan must demonstrate the ability to control the mining solutions. Typically, ore bodies to which the ISR mining method is applied are confined. A confined ore body usually consists of sandstone that is submerged with an impervious rock layer above and below. During mining, wells are installed around the ore body and in water-bearing sandstones above and below the ore body to monitor the groundwater quality during the mining process.
3. The ore body must be submerged. Native groundwater in the mining zone is used as the leaching solution during the mining process. The mine unit needs to have hydraulic pressure (known as "hydraulic head") on the formation to keep mining chemicals, such as gaseous oxygen and carbon dioxide, in solution until the chemicals can interact with the uranium in the sandstone formation.

An ore body that meets all of these conditions can be mined using the ISR mining method. The ISR mining method uses the following steps to extract the uranium from the ore body.

1. A series of monitoring wells are installed above, below, and surrounding the ore body. A pump test is conducted to show that the monitoring wells in the mining formation are in communication when water is removed from the mining formation. Additionally, the overlying and underlying monitoring wells are monitored during the pump test to make sure that water is not being extracted from the formations where mining is not occurring. The pump test demonstrates that the mine unit is confined and can be controlled during the mining process.
2. Production and injection wells and the extraction plant or satellite plant are installed. The production and injection wells are installed over the ore body, and the native groundwater is pumped from the formation. The groundwater is fortified with oxygen and carbon dioxide/bicarbonate and becomes the leach solution that solubilizes the uranium. The uranium-rich groundwater is pumped from the mine unit to the satellite plant where the uranium is removed using ion exchange (IX) resin. The (IX) resin acts like a sponge for the uranium and removes the metal from the leach solution. A small amount of fluid is removed from the leach solution (1% of the total flow) before adding more oxygen and carbon dioxide/bicarbonate to the leach solution and injecting the water back into the ground to recover more uranium. The water removed from the production solution or "bleed" is disposed of in a deep disposal well, which is typically an old oil well in a deep geologic formation, or is treated to remove any residual radionuclides and metals and then disposed of using land application.
3. After the mining process is completed, the groundwater is restored to pre-mining condition. The restoration process begins when the uranium concentrations have reached a point where recovery is no longer economical. MU-B started restoration with a process

called groundwater sweep (GWS). During GWS, the injection wells are turned off and a minimum of one pore volume (PV), which is the pattern volume plus an additional volume of water called flare, is removed from the formation and disposed of using the deep disposal well or land application. The GWS lowers the total dissolved solids (TDS) and removes some of the constituents from the groundwater in the pattern area. The next step following GWS is to treat the groundwater using reverse osmosis (RO). RO removes mineral salts and other ions from a portion of the water called permeate and concentrates the salts into a stream referred to as concentrate. The recovered permeate is extremely clean water that is reinjected into the mine unit to sweep dissolved metals and TDS left from the mining process out of the formation. The concentrate of the salts is disposed of using the deep disposal well. Recently operators have been using more RO sweep during restoration instead of GWS because the RO sweep cleans the formation faster and uses less groundwater than GWS. RO sweep is continued until the pattern being treated shows asymptotic concentrations of TDS and other constituents in the groundwater. Once the constituent trends become asymptotic during RO sweep, cleaning the pattern further will not yield great improvements in water quality for the quantity of groundwater removed from the formation. A chemical reductant or biological amendment is added during the final stages of RO sweep to remove any residual oxidant from the formation and stop the mining process.

The restored ore body provides the basis for establishing the ACLs for an ISR mine. The uranium extraction has taken place in the ore body, and the solids from the ore were not removed from the ground, but were left in the same place as before mining began. This process differs from the conventional mine process in which the residual ore containing other radionuclides and metals is placed in a containment cell in a new area on the surface after uranium extraction.

Pre-ISR groundwater in the ore zone at an ISR site typically contains high concentrations of radionuclides in the mineralized formation due, in large part, to the presence of uranium, uranium daughter products, and other associated ore minerals in the aquifer matrix. Commonly, concentrations of uranium, radium, and radon are much higher in the ore zone than the concentration of these constituents in either upgradient or downgradient pre-ISR groundwater. The ISR requires that the applicant demonstrate that an ore body contains economically extractable minerals and apply for an aquifer exemption from the Wyoming Department of Environmental Quality (WDEQ), which administers the U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) Program. Therefore, for purposes of this ACL application, background groundwater quality will be based on pre-ISR data from baseline wells, known as the monitor production wells (MP wells) in the ore zone. The MP wells will be used as POC wells, and the proposed point of exposure (POE) will be defined by the aquifer exemption boundary. The aquifer exemption boundaries for ISR mine units vary between mine units and need to be defined on a site-specific basis. The aquifer exemption boundary is set by EPA in consultation with the State of Wyoming as part of the UIC Program. The aquifer exemption boundaries in Wyoming that have been set by EPA Region 8 range from the monitor well ring, an area beyond the monitor well ring that is determined by hydrologic modeling, or the nearest ¼-acre to the monitor well ring. The aquifer exemption boundary for MU-B is defined by the wells that comprise the monitor well ring, which will act as POE wells.

Although uranium recovery via ISR mining increased the concentrations of some dissolved constituents in the groundwater of the 30-Sand Unit, ambient concentrations were naturally elevated above safe levels for human use before ISR mining began. An aquifer exemption has been issued for this groundwater which does not allow the groundwater to be used as a drinking water source now or in the future. As the "as low as is reasonably achievable" (ALARA) demonstration shows (Section 3.6), it is not practicable or reasonably achievable to reduce the constituent concentrations at the POC to background levels. However, hydrologic and geochemical modeling, as presented in Section 2.2, have shown that naturally occurring geochemical and hydrologic processes will reduce constituent concentrations by removing constituents from groundwater along its flowpath, resulting in acceptable groundwater constituent concentrations that are protective of human health and the environment at the POE, which is located at the edge of the aquifer exemption boundary.

This application includes several appendices that support the decision to apply for ACLs, as well as how the ACLs were determined. Appendix A is a Geochemical Assessment of constituents in groundwater at the Site, Appendix B is a Hydrologic Assessment of the groundwater at the Site, Appendix C contains the Restoration Report submitted to WDEQ and supporting documents, Appendix D contains supporting information related to monitoring well BM-42, and Appendix E contains supporting data used in these analyses. Each appendix is discussed in further detail in the sections below.

1.2 Physical Setting and Facility Background

1.2.1 Location

MU-B is an ISR wellfield within the Smith Ranch-Highland (SRH) property, located in the southern Powder River Basin in Converse County, Wyoming (Figures 1 and 2). The Powder River Basin is bounded on the west by the Bighorn Mountains and the Casper Arch, and on the south by the Laramie Range-Hartville Uplift. The northern and eastern margins of the basin are less distinct. The broad Black Hills Uplift forms the eastern demarcation, and the Miles City Arch forms the northern boundary (Figure 2). The topography in the permit area is characterized by gently rolling upland areas and broad stream valleys that are dissected by numerous ephemeral draws with relatively steep slopes and rounded ridge crests.

The main office complex for the SRH property is located 22 miles (mi) northeast of the town of Glenrock and 25 mi northwest of Douglas (Figure 1). The SRH property occupies approximately 40,000 acres. The project is licensed by the NRC under Source Material License SUA-1548 and consists of three contiguous projects including SRH, the Highland Uranium Project (HUP) (formerly License No. SUA-1511), and the Reynolds Ranch Satellite facility and mine unit area. MU-B is located within the HUP on the eastern side of the SRH property (Figure 1).

The main office complex can be accessed by turning onto Converse County Road 31 (also known as Ross Road) from the intersection of State Highway 93 and State Highway 95. MU-B can be accessed by continuing north on State Highway 93 from the intersection with State Highway 95, and then traveling east on County Road 32 (also known as Highland Loop Road). Figure 1 shows the general project location and access routes to the project.

1.2.2 Facility History

The southern Powder River Basin has a long uranium recovery history. From the early 1970s through the mid-1980s, companies such as Bear Creek Uranium, Kerr McGee Nuclear, Tennessee Valley Authority (TVA), and Exxon Minerals produced uranium from the sandstone deposits within or near the current license boundary by conventional open-pit or underground mining methods. Most of these mines were shut down and/or reclaimed by 1985 because of poor uranium market conditions.

NRC first authorized Kerr-McGee Corporation (KMC) to conduct Research and Development (R&D) ISR operations at the Smith Ranch (SR) site in June 1981 under WDEQ Permit to Mine 304-C and Source Material License SUA-1387, with a corresponding Environmental Impact Assessment issued at that time (46 FR 30924). In February 1984, SUA-1387 was amended to reflect that Sequoyah Fuels Corporation (SFC), a wholly owned subsidiary of KMC, was the NRC licensee for the SR R&D operations. NRC renewed SFC's NRC license (SUA-1387) for continued R&D operations by letter dated January 29, 1988. In support of the license renewal, NRC staff published a Finding of No Significant Impact (FONSI) in the Federal Register on January 7, 1988 (53 FR 459). Rio Algom Mining Corp. (RAMC) acquired the SR ISR site in December 1988. On June 18, 1991, WDEQ issued Permit to Mine 633 to RAMC. On March 12, 1992, NRC issued Source Material License SUA-1548 to RAMC, which authorized expansion of the SR R&D operations into commercial-scale production. An Environmental Assessment (EA) documenting NRC staff's environmental review was published in the Federal Register on January 10, 1992. Cameco acquired PRI and the HUP in 1997. Source Material License SUA-1548 was renewed on May 8, 2001 (NRC, 2001), and the FONSI was published in the Federal

Register on May 4, 2001 (66 FR 22620). PRI acquired RAMC's SR properties in July 2002 and, by letter dated August 18, 2003, NRC approved the integration of the HUP license (SUA-1511) into the SR license (SUA-1548) (ML032320650). With that integration, combined operations at SRH were authorized under Source Material License SUA-1548. The NRC staff did not prepare an EA/FONSI as this action was considered administrative and organizational in nature.

The HUP is located adjacent to portions of the reclaimed Exxon Highland Uranium Mine, which used conventional open-pit and underground mining methods, and was in operation from 1971 to 1984.

Two pilot R&D projects were completed at the HUP by Exxon during the period 1972 to 1981. These projects were operated under WDEQ Permit No. 218-C and NRC License SUA-1064. The first pilot R&D project, known as the "Original R&D" was operated from 1972 to 1976. This project investigated the technical feasibility of ISR using different concentrations of sodium bicarbonate and hydrogen peroxide within the leach fluid.

The second pilot R&D project, known as the "Expanded R&D," was operated from December 1978 to September 1981. This project demonstrated the technical feasibility of ISR using oxygen, sodium bicarbonate, and carbon dioxide within the leach fluid; the ability to control leach fluids within the ISR zone; and the restorability of the affected groundwater to its original use suitability. Reports concerning the results of the pilot activities, including restoration of affected groundwater, were previously submitted to NRC and WDEQ.

The underground mine was shut down with the shaft sealed by 1985. In 1985, Exxon sold their remaining uranium reserves to Everest Minerals Corp., which developed the HUP, a uranium ISR operation. Mine Units A and B were the first ISR wellfields installed at the HUP, with production beginning in 1988. Between 1989 and 2000, the HUP produced approximately 1 million pounds of uranium per year. Active groundwater restoration was completed in the Mine Unit-A wellfield in 1999 and approved by WDEQ in 2003 and NRC in 2004.

1.2.3 Geology

1.2.3.1 Depositional Environment and Stratigraphy

MU-B is located in the Powder River Basin. The Powder River Basin is a late Cretaceous- to early Tertiary-age structural asymmetrical syncline, with its axis oriented in a general northwest-southeast direction along the western margin of the basin (Figure 2). East of the axis, the sedimentary rock strata exposed at the surface gently dip at approximately 1° to 2° to the west. West of the axis, the strata dip more steeply (as much as 20°) to the east (Figure 3). No major faults or folds in the bedrock occur within the permit area. However, a series of subparallel anticlines and synclines with relief ranging from 10 to 20 feet were identified in the northeast portion of the SRH permit area.

The basin incorporates a sedimentary rock sequence that has a maximum thickness of approximately 15,000 feet along the synclinal axis. The sediments range in age from Recent (Holocene) to early Paleozoic (Cambrian) (500 to 600 million years ago) and overlie a basement complex of Precambrian-age (more than a billion years old) igneous and metamorphic rocks.

The stratigraphic units of interest within the SRH licensed area are the Tertiary-age deposits of the Wasatch and Fort Union Formations (Figure 4). The Wasatch Formation is the youngest bedrock unit throughout most of the permit area. It consists of interbedded claystones, silty sandstones, and relatively clean sandstones. In the vicinity of the Pumpkin Buttes, approximately 40 mi north of the permit area, it is 1,575 feet thick (Sharp and Gibbons, 1964). However, active stream erosion has left only about 500 feet of the formation in the central and east-central portions of the permit area and none of the formation in the southwestern portion of the area. The surface contact between the Wasatch Formation and the underlying Fort Union Formation roughly parallels the axis of the Powder River Basin through the southwestern portion of the permit area. The interbedded claystones, siltstones, and relatively clean sandstones in the Wasatch vary in degree of lithification from uncemented to moderately well-cemented sandstones, and from weakly compacted and cemented claystones to fissile shales.

The Fort Union Formation in the Powder River Basin is lithologically similar to the Wasatch Formation. Throughout the permit area, the Fort Union includes interbedded silty claystones, sandy siltstones, relatively clean sandstones, and claystones with a few thin coal seams occurring locally. The degree of lithification is variable, ranging from virtually uncemented sands to moderately well-cemented siltstones and sandstones. The total thickness of the Fort Union in the area is approximately 3,000 feet.

Both the Wasatch and Fort Union strata are lenticular, with numerous facies changes within short lateral distances. In some cases, it is essentially impossible to trace even relatively thick stratigraphic units more than a few thousand feet. On the other hand, some units can be traced for miles.

1.2.3.2 Site Specific Geology

The uranium-bearing sandstones lie within the upper Fort Union and lower Wasatch formations. As many as 10 separate, potentially uranium-bearing sandstone units have been identified within the permit area, depending on the specific location. Individual sandstone units may be discontinuous in some areas or merge with over- or underlying sandstone units. In particular, the 30-Sand has been documented to be hydraulically connected to the overlying 20-Sand in the northwestern portion of MU-B. Historically, the sandstone units within the eastern portion (Highland) of the permit area have been identified from bottom to top as the 0, 10, 20, 30 ... 120 Sands. In the western and northern portion (Smith Ranch and Reynolds Ranch) of the permit area, the same sandstone units are identified from bottom to top as the K, M, O, Q ... W Sands. The sandstone units in the Wasatch Formation are identified from bottom to top as the E and G Sands. The individual sandstone units are separated by confining units that are as much as 200 feet thick. The 30-Sand is the principle uranium ore zone sand member within MU-B, ranging in thickness locally from 20-50 feet. The 30-Sand Unit (MU-B) is comprised of lenticular, fluvial, arkosic sandstones ranging from 20-50 feet in thickness. Some data from the 20-Sand Unit are used in the geochemical modeling for the 30-Sand aquifer because applicable work from the 20-Sand is available and is considered to be representative of the entire sand package in the area. Mine Unit-A (MU-A), which is contained geographically within MU-B, was produced from the 20-Sand package. The 20-Sand had an area of communication with the 30-Sand; however, Cameco demonstrated to WDEQ and NRC that the restoration of MU-A was complete and that the restoration of the overlying 30-Sand would not affect the restored MU-A (20-Sand). MU-A restoration was approved by WDEQ on Nov. 25, 2003, and by NRC on June 29, 2004.

Figures 5–13 show cross sections of several locations within MU-B, with Figure 14 showing the location of each cross section.

1.2.3.3 Geomorphic Features

The Powder River Basin is a major intermontane basin of Laramide origin in the northern Rocky Mountains and occupies northeastern Wyoming and a small part of southeastern Montana (Figure 2). It constitutes the major part of the encompassing province, and together with portions of adjoining uplifts, comprises more than 34,000 square miles (mi^2).

The basin is a deep, northerly trending, asymmetric, mildly deformed trough, approximately 250 mi long and 100 mi wide. Its structural axis is close to its western margin, which is defined by reverse and thrust faults and by hogbacks of steeply dipping and overturned strata along the Bighorn Mountains uplift and by the Casper Arch (Figure 2). It is bounded on the south by reverse or thrust faults along the Laramie and Hartville Uplifts, and on the east by the Black Hills where strata are mildly folded and locally faulted along monoclines associated with the Black Hills Uplift. The northern margin is described by the structurally subtle northwest-trending Miles City Arch (Dolton and Fox, 1996).

A variety of surficial materials overlie the Wasatch and Fort Union formations within the permit area. They include residual soils, slopewash formed by the downslope movement of soils and weathered rock fragments, playa deposits, and stream-deposited alluvium. A geologic outcrop map is presented on Figure 15.

1.2.4 Seismology

The area of east-central Wyoming where the project site is situated lies in a seismically quiet region of the United States. Although distant earthquakes may produce shocks strong enough to be felt on the Powder River Basin, the region is ranked to be one of minor seismic risk, as shown on the seismic hazard maps in Figures 16 and 17. Seismic risk was evaluated using the best available science in earthquake hazards estimation for the United States. Seismic hazard maps developed by the U.S. Geological Survey (USGS) National Seismic Hazard Mapping Project incorporate information on potential earthquakes and associated ground shaking obtained from interaction in science and engineering workshops involving hundreds of participants, reviews by several science organizations and state surveys, and advice from two expert panels. The maps, which were last updated in 2008, display earthquake ground motions for various probability levels across the United States and are applied in seismic provisions of building codes, insurance rate structures, risk assessments, and other public policy. The 2008 update incorporated new findings on earthquake ground shaking, faults, seismicity, and geodesy, resulting in maps that are derived from seismic hazard curves calculated on a grid of sites across the United States that describe the probability of exceeding a set of ground motions within a given time period (Petersen et al., 2008).

Ground-motion prediction equations or attenuation relations relate the source characteristics of the earthquake and propagation path of the seismic waves to the ground motion at a site. The predicted ground motion is typically quantified in terms of a median value (a function of magnitude, distance, style of faulting, and other factors) and a probability density function of peak horizontal ground acceleration or spectral accelerations. In the western United States, ground motion from crustal sources less than 200 kilometers (km) and subduction sources less than 1,000 km from the site were calculated (Petersen et al., 2008). Figure 16 shows a set of ground motions for which there is a 2% probability of being exceeded in 50 years, while Figure 17 shows the set of ground motions with a 10% probability of being exceeded in the same time period, along with faults and earthquakes in Wyoming and surrounding states. The ground accelerations displayed in Figure 17 are not considered to be of a magnitude that would disturb the operations or facilities in the unlikely event that an earthquake occurred during the life of the mine. Although there are some mapped faults located within about 20 mi of MU-B, there are no known exposed active faults with a surficial expression (Quaternary Faults) in Converse County, and the nearest Quaternary Fault is about 100 mi from the site. As a result, no fault-specific analysis can be generated for Converse County (Case et al., 2002).

However, many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are associated with buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. Random distribution may not be the case, as nearly all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random (Converse County, 2012). "Floating earthquakes" are earthquakes that are considered to occur randomly in a tectonic province (Case et al., 2002).

Geomatrix (1988) suggested basing seismic analysis on a regional tectonic province, called the "Wyoming Foreland Structural Province," which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988) estimated that the largest "floating" earthquake in the "Wyoming Foreland Structural Province" would have a magnitude in the 6.0–6.5 range, with an average value of magnitude 6.25 (Case et al., 2002). A magnitude 6.25 "floating" earthquake, placed 15 km from any structure in Converse County, would generate horizontal accelerations of approximately .15 g at the site (Converse County, 2012). Based upon probabilistic analyses of random earthquakes in an area distant from 30 exposed active faults (Geomatrix, 1988), placing a magnitude 6.25 earthquake at 15 km from a site will provide a fairly conservative estimate of design ground accelerations (Case et al., 2002).

Historically, few earthquakes capable of producing damage have originated in this region, as indicated on the Regional Seismicity Map provided in Figure 17. The seismically active region closest to the site is the Intermountain Seismic Belt of the Western United States, which extends in a northerly direction between Arizona and British Columbia. It is characterized by shallow earthquake foci between 10 and 25 mi in depth, and normal faulting. Part of this seismic belt extends along the Wyoming-Idaho border, more than 250 mi west of the permit area, and would be the most probable source of earthquakes affecting the project site.

Table 1 lists the largest recorded earthquakes that have occurred within 300 mi of the SRH licensed area from the period 1870 through 1995 (NRC, 2012). The earthquake that generated the highest probable intensity at the site is presumed to be the Casper, Wyoming, earthquake of 1897. This earthquake has been assigned a maximum epicentral intensity of VII, based on damage incurred.

Table 1
Maximum Expected Earthquake Intensities and Ground Accelerations at the Smith Ranch Site

	Maximum Epicentral Intensity of Record	Distance from Epicenter to Smith Ranch Site (miles)	Maximum Probable Intensity at Smith Ranch Site
Hebgen Lake, Montana (1959)	X	285	III-IV
Northeastern Nebraska (1934)	VI	121	IV
Black Hills, South Dakota (1928)	V	100	III-IV
Powder River Basin (1967)	VI	36	IV
Casper, Wyoming (1897)	VII	47	V-VI

1.2.5 Hydrogeology

The SRH licensed area consists of approximately 40,000 acres and is located in the southern part of the Powder River Basin in the Sage Creek drainage of the North Platte River drainage system, and the Box Creek, Duck Creek, Willow Creek, and Brown Springs Creek drainages of the Cheyenne River drainage system. The topography in the permit area is characterized by gently rolling upland areas and broad stream valleys that are dissected by numerous draws with relatively steep slopes and rounded ridge crests. All streams in the drainage system are ephemeral and flow only in response to snow melt and heavy thunderstorms that account for approximately 12 inches of precipitation annually.

The land along Box Creek and the middle and east forks of Willow Creek is predominantly rangeland, and surface water, when collected, is used for livestock and wildlife watering. Most surface water rights are limited to these creeks and associated small stock ponds. The waters collected in the stock ponds meet Wyoming livestock use suitability standards (Class III) and are suitable for stock and wildlife consumption.

The hydrogeologic units beneath the permit area and in the general vicinity include the following: Holocene-age alluvial deposits, the Eocene-age Wasatch Formation, the Paleocene-age Fort Union Formation, and the Cretaceous-age Lance and Fox Hills formations. Individual sandstones within these units may be classified as aquifers depending on their hydrologic characteristics and potential yield to wells and/or springs.

The potential for future development of alluvial groundwater supplies in the license area is considered very poor since only small amounts of precipitation infiltrate the alluvium to provide recharge. The Wasatch Formation is one of the more important shallow aquifers in the Powder River Basin, and in the permit area, generally yields between 5 and 15 gallons per minute (gpm) to wells. The Fort Union Formation is an important aquifer in the Powder River Basin, and nearly all of the project's wells are completed in this formation. While most of the wells are designated for yields between 5 and 30 gpm, wells completed in the Fort Union Formation are reported to have produced as much as 560 gpm. The Lance and Fox Hills formations underlie the Fort Union Formation, and yields from these formations are not expected to exceed 100 gpm, with limited groundwater reserves. Little is known of the hydrologic characteristics of the Lance and Fox Hills formations as no water wells have been completed in these aquifers in the vicinity of MU-B.

1.2.5.1 Hydrostratigraphic Units

The following descriptions summarize the site-specific units within the SRH licensed area.

Alluvium – The alluvium in the SRH licensed area consists of thin, unconsolidated, poorly stratified clays, silts, sands, and gravels. The total thickness of these deposits is estimated to range from less than 1 foot to 30 feet. Small amounts of precipitation infiltrate the alluvium during part of the year, and intermittent flows across the alluvium may provide some recharge. The water table is typically more than 100 feet below the land surface throughout most of the licensed area. Therefore, most of the recharge flows through the lower portion of the alluvium. The potential for future development of alluvial groundwater supplies in the permit area is considered very poor.

Wasatch Formation – The Wasatch Formation typically is lenticular, fine- to coarse-grained sandstones with interbedded claystones and siltstones. This formation overlies all except the southwestern and extreme western portions of the licensed area and ranges in thickness from 0 to approximately 500 feet. The Wasatch Formation is one of the more important shallow aquifers in the Powder River Basin.

Properly constructed wells penetrating the Wasatch Formation in the vicinity of the SRH generally yield from 5 to 15 gpm. A water supply well (WW-103) completed in the Wasatch near the former Bill Smith mine initially produced 140 gpm; however, production was from a composite thickness of approximately 120 feet of sandstone, including four separate sandstone units commingled within the well. This well, which is 474 feet deep, taps the Wasatch Formation in one of its thicker zones in the permit area.

Groundwater in the Wasatch Formation generally exists under water table (unconfined) conditions, and its primary use in the permit area includes low-yielding wells used for watering livestock. Artesian (confined) zones near the base of the formation are separated from near-surface deposits and from each other by impermeable shale layers.

The Wasatch Formation is considered to have good potential for possible development as a future water supply. Hodson et al. (1973) could not quantify its hydrologic characteristics adequately to estimate the maximum amount of groundwater that could be available from the licensed area.

Fort Union Formation – The Fort Union Formation underlies the Wasatch Formation in the SRH licensed area. The top of the Fort Union Formation is exposed at the surface in the southwestern and western (Smith Ranch) portions of the SRH licensed area, but may be at depths of 500 feet or more in the eastern and northeastern (Highland) part of the SRH licensed area. Typically, the Fort Union Formation is comprised of lenticular fine- to coarse-grained sandstones with interbedded claystones, siltstones, and coal. The formation is as much as 3,000 feet thick beneath the license area.

The Fort Union Formation is an important aquifer in the Powder River Basin, and nearly all of the project's injection, production, and monitoring wells are completed in this formation. While most of the wells are designated for limited yields (5 to 30 gpm of water), wells completed in the Fort Union Aquifer associated with the former Bill Smith mine dewatering program produced as much as 560 gpm. Substantial volumes of groundwater can be produced from the Fort Union Formation over extended periods, as demonstrated by the various historical and current mineral recovery operations in the southern Powder River Basin.

Lance and Fox Hills Formations – The Lance and Fox Hills formations underlie the Fort Union Formation at depths of approximately 3,500 feet and 5,500 feet, respectively, in the MU-B area. The formations are comprised of fine- to medium-grained sandstones, interbedded sandy shales, and claystones. Well yields from these formations are not expected to exceed 100 gpm, and the groundwater reserves may be limited. Little is known of the hydrogeologic characteristics of the Lance and Fox Hills Formations as no water wells tap these aquifers in the vicinity of the licensed area. Because of the depths of these formations and the availability of water from other shallow aquifers, it appears unlikely that these formations will be tapped for water supplies in the future in the permit area.

1.2.5.2 Confining Unit Characteristics

Characterization of the confining layers was completed for the eastern (Highland) portion of the licensed area and is considered representative of the entire SRH area. Low-permeability confining units (aquitards) are present between the various sandstone aquifers. These units are typically 20 to 45 feet in thickness, but may be thicker in areas where the sandstone pinches out. These siltstone and claystone units are usually continuous over relatively large areas. Where individual sandstone units converge (facies change), the previous overlying claystone is non-existent. Figure 18 is a representative cross section showing the relative thicknesses of the sand and confining units, while Figures 5–13 show cross sections from within MU-B.

Vertical permeability of confining units has been determined in the laboratory from actual cored material and from pump test results using the Neuman-Witherspoon Method. Table D6-5 of DEQ Addendum D-6 B1 (Appendix E) contains estimates of the vertical permeability of the confining units. These vertical permeabilities should be representative of conditions found throughout the permit area in similar units.

1.2.5.3 Aquifer Potentiometric Surfaces

As discussed by Aqui-Ver (2011), with the termination of active restoration in June of 2004, groundwater flow conditions in MU-B have been influenced largely by the recovery of MU-B, Highland pit lake, and the Exxon underground mine. The current rate of water-level recovery is about 0.5 to 1 foot/year (Aqui-Ver, 2011). The groundwater elevation data for the 30-Sand and 20-Sand were collected by Cameco personnel in December 2010. In both the 30-Sand and 20-Sand aquifers, the aquifer potentiometric surfaces are about 5,050 to 5,060 feet above mean sea level. In general, groundwater in the 30-Sand flows steeply toward the southwest and the recovering Highland pit lake in the southern portion of MU-B; however, in the northern portion of MU-B, groundwater flows toward the underground mine (Figure 19). Groundwater flow in the 20-Sand has a similar pattern as that in the 30-Sand, but has a flatter hydraulic gradient (Aqui-Ver, 2011). Groundwater in the 20-Sand generally flows toward the south in the southern and central portions of MU-B, but toward the underground mine in the northern portion of MU-B (Figure 20). In both aquifers, a groundwater flow divide is present in the central portion (30-Sand) or northern portion (20-Sand) of MU-B. Aqui-Ver (2011) estimated that the groundwater velocity is approximately 20 to 60 feet/year in the 30-Sand and 5 to 20 feet/year in the 20-Sand across the mine unit.

1.2.5.4 Surrounding Land and Water Use

The Powder River Basin is primarily rural in nature with abundant reserves of natural resources. Development of these natural resources, including coal, oil and gas, coal bed methane extraction, wind energy, and uranium, drive the economic growth of the region now and presumably in the near future. Along with the energy industry, agriculture, manufacturing, and tourism also contribute to the economy of this part of Wyoming.

Converse County is a rural county that comprises approximately 2.74 million acres of land. The urban areas of Douglas and Glenrock constitute less than 2% of the total acreage, while transportation systems account for approximately 4.5%. Historically, the area was homesteaded and dry-land farmed. Today the area remains remote and contains a low population density primarily dominated by agricultural pursuits. The majority of people living in the area reside on dispersed ranches. Sheep and cattle grazing comprise the major past and present land use in the area and at the project site. The Vollman Ranch is the only inhabited residence located within the current permit area.

From the 1970s to the early 1980s, areas within and adjacent to the SRH permit area were extensively mined for uranium. Both surface and underground mining methods were employed, with the majority of uranium ore being recovered by surface mining methods. Within the project site boundaries, there is limited disturbance from both underground and surface mining activities.

Streams within the project area are all ephemeral and many areas drain internally to small playas. Small stock ponds have been constructed on some of the ephemeral streams. Surface waters in the area are used for stock watering and are also used by wildlife.

There are more than 3,000 groundwater rights within the license area and a 3-mi area of the license boundary. The vast majority of these groundwater rights are for wells installed for hydrologic monitoring or dewatering purposes at decommissioned conventional uranium mining operations, and for ISR activities at SRH. A small number of the groundwater rights are associated with wells installed for livestock water and irrigation purposes. Three groundwater rights are for wells used intermittently for domestic supply.

1.2.5.5 Water Use and Quality

Exxon regularly analyzed water samples from selected points in the Box Creek drainage during the period of surface mining activities. The data, which historically have been considered to be representative of surface water quality from the entire license area, are included in Table D6-3 of Appendix D6 - Hydrology (Appendix E). Sampling locations are shown on Figure D6-1 of Appendix D6 - Hydrology (Appendix E). These data indicate that water quality in these surface waters does not meet Wyoming domestic water use suitability standards (Class I) or EPA public health standards for chloride, sulfate, and TDS. These waters do, however, meet Wyoming livestock use suitability standards (Class III) and are suitable for stock and wildlife consumption.

1.3 Groundwater Regulatory History

The following sections outline regulatory history for groundwater in MU-B and present the differences between the two regulatory agencies that have regulatory jurisdiction of groundwater at this Site. Although this application is prepared for NRC in accordance with the most applicable federal guidance available, Cameco believes it is both relevant and important to highlight the WDEQ regulatory framework, in which Cameco has restored the groundwater of the MU-B facility to pre-ISR WDEQ "Class of Use" groundwater standards.

Uranium was extracted at MU-B using ISR methods, and groundwater restoration was completed in accordance with approved WDEQ Land Quality Division (LQD) permit No. 603, the ISR regulations in LQD Chapter 11, and the WDEQ Chapter 8 Rules and Regulations. Cameco submitted the MU-B Groundwater Restoration report on August 5, 2004, to WDEQ/LQD demonstrating that restoration was completed using "Best Practicable Technology" (BPT). The post-ISR groundwater quality met WDEQ criteria for "Class of Use." The WDEQ approved the MU-B restoration on March 31, 2008.

Mine Unit B was in production from January 1988 to July 1991. Active groundwater restoration was conducted from July 1991 to June 2004, followed by a six-month stability period that began on June 28, 2004, with the collection of the post-restoration groundwater samples from the MP wells. During the six-month stability period, four rounds of required samples were collected from the MP wells 28 to 34 days apart. The sampling consisted of two short-list samples and two long-list Guideline 8 (WDEQ) sample rounds, which were completed on December 28, 2004.

The final PVs of groundwater extracted and/or treated and reinjected for the restoration of Mine Unit B were as follows:

- 2.93 PV of GWS
- 13.47 PV of RO sweep
- .92 PV of recirculation for uranium removal
- .88 PV of bioremediation treatment
- 1.09 PV of sodium sulfide treatment
- 5.22 PV of bleed for hydraulic control

The final calculation of one PV with flair for MU-B is approximately 61,535,000 gallons (188.8 acre-feet). During the 13 years of active restoration, almost one billion gallons of water was pumped and treated.

During 2005, discussions took place between Cameco and WDEQ regarding the status of wells that were on excursion during restoration (particularly BM-42) and elevated arsenic levels in three MP wells. Eight additional arsenic samples were taken during 2005 which showed that the arsenic levels were declining. Cameco discussed the status of monitor well BM-42 with WDEQ and came to a resolution that the well was restored to "Class of Use" and that the restoration effort could be completed. An additional round of uranium samples was requested in 2006. Sampling results showed that post-restoration wellfield uranium and arsenic concentrations were declining during the post-stability sampling. Cameco received the final approval for restoration on March 31, 2008. The decision record from the LQD stated that MU-B had been restored to its pre-mining "Class of Use" and was released (TFN 4 3/170, Mine Unit-B Ground Water Restoration Review, Permit 603, Highland Uranium Project (PRI)).

Cameco submitted the MU-B restoration report to NRC for review under cover letter dated June 26, 2009 (K. Wenzel, Cameco Resources, to D. Manderville, NRC) (ML091831100). NRC did not accept the report for detailed technical review and informed Cameco in correspondence dated September 29, 2009 (ML092680122), that Cameco needed to explain the excursion status of well BM-42 and why pumping occurred in the mine unit during the stability period. Cameco decided that, in light of NRC RIS 2009-05 (ML083510622) and upon review of the MU-B restoration data and acceptance response from NRC, the preparation of an ACL license amendment would be the best regulatory pathway for the review of the MU-B restoration.

Cameco informed NRC at a public meeting on October 18, 2011 (ML113080033), of the intent to pursue an ACL License Amendment for the restoration of MU-B and described the approach that would be taken for the application. Cameco had a follow-up meeting with NRC on September 5, 2012 (ML12257A023), to discuss progress on the application and the path forward for submittal. Appendix D of this Application contains well logs and completion data, water quality data, and regulatory correspondence for BW-42.

The time period from the start of restoration on MU-B until approval of the restoration by WDEQ was 17 years.

1.3.1 Groundwater Regulations under WDEQ

The UIC Program is authorized under the Safe Drinking Water Act (SDWA) (42 U.S.C. 300f). The UIC Program regulates the injection of fluid into the subsurface in the United States. The State of Wyoming is a primacy state under Section 1422 and Section 1425 of the SDWA. Under Section 1422, the WDEQ has been delegated the authority to regulate Class I, III, IV, and V UIC facilities. Section 1425 gives the Wyoming Oil and Gas Commission primacy for Class II wells.

A mine operator is required to obtain an aquifer exemption from the EPA before commencing injection into an Underground Source of Drinking Water. The criteria for an exempted aquifer in Wyoming is found in Section 10 of the WDEQ, LQD, Chapter 11 Rules (May 5, 2005) that govern ISR mining. Part of the criteria found in Section 10 of the LQD, Chapter 11 Rules for the exempted aquifer is as follows:

> (a) *Injections from Class III Wells shall be restricted to those production zones that:*
>
> > (i) *Have been classified by the WDEQ as Class V aquifers under Chapter 8 of the WQD [Water Quality Division] Rules and Regulations (as amended March 12, 1993); and*

(ii) Have concentrations of Total Dissolved Solids;

(A) Less than 10,0000 mg/L; meet the definition of an "Underground source of Water" as defined in Section 1 of this Chapter; and have been approved as an exempted aquifer by the U.S. EPA pursuant to section 10(b) of this Chapter; or

(B) Greater than 10,000 mg/L; and

(iii) Are located in a geologic and hydrologic setting in which the movement of fluid, containing any contaminant, into unauthorized zones can be prevented.

(b) An aquifer, or portion thereof, which meets the criteria for an "Underground Source of Water" as defined in Section 1 of this Chapter may be designated as an "exempted aquifer":

(i) If it meets the following criteria:

(A) It does not currently serve as a source of water for Class I, II, III, Special (A) or Class IVA uses as described in Chapter 8 of the Water Quality Rules and Regulations (as amended March 12, 1993), and

(B) It cannot now and will not in the future serve as a source of water because:

(I) It is mineral, hydrocarbon, or geothermal energy producing, or can be demonstrated by permit or Research and Development Testing License application or operator to contain minerals or hydrocarbons that, considering their quantity and location, are expected to be commercially producible; or

(II) It is situated at a depth or location which makes recovery of water for Class I, II, III, Special (A) or Class IV A as described in Chapter 8 of the Water Quality Division Rules and Regulations (as amended March 12, 19930 economically or technologically impractical; or

(III) It is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(IV) It is located over a Class III mining area subject to subsidence or catastrophic collapse; or

(V) The total dissolved solids content of the groundwater is less than 10,000 mg/l and it is not reasonably expected to supply a public water system as defined by W.S. 35-11-103©(viii) (2003).

The State of Wyoming administers the EPA UIC Program, so the request for the aquifer exemption is presented by the Administrator to the EPA as a state program revision pursuant to

40 CFR 145.32. The State of Wyoming's requirements for receiving an aquifer exemption for a Class III mining area mirror the federal regulations found in 40 CFR 146, but include language to fit the definitions of water quality standards specific to Wyoming's administration of EPA programs.

The pre-mining water quality for MU-B was Class IV (A) because of the elevated levels of radium. Class IV (A) was the "Class of Use" standard set for restoration. The original aquifer exemption for MU-B classified the water as Class V for mining with the boundary for the aquifer exemption being the monitor well ring (W. Garland; WQD to M. Dodson; Region 8 EPA).

WDEQ's restoration standard is defined in W.S. 35-11-103(f)(iii)(2003) and is set forth in Section 5 of the LQD Chapter 11 rules that govern in-situ mining. The Wyoming statute states that:

> *"Groundwater restoration" means the condition achieved when the quality of all groundwater affected by the injection of recovery fluids is returned to a quality of use equal to or better than, and consistent with the uses for which the water was suitable prior to the operation by employing the best practicable technology.*

Guideline 4 of the LQD Chapter 11 Rules further instructs the mining operator that the goal of any restoration effort is baseline with the secondary goal of "Class of Use" after the application of BPT has been demonstrated. While the UIC Program "exempts" the designated aquifer from protections under the SDWA for the production of uranium, the operator is required, regardless of the restored groundwater quality, to protect the adjacent aquifers and aquifers outside the exemption boundary to the applicable EPA Maximum Contaminant Levels (MCLs) (LQD, Chapter 11(a) (ii) D). Additionally, the rules state that if a model is employed to demonstrate the protection of the downgradient aquifer, a monitoring program to verify the model may be required.

Cameco submitted the MU-B Groundwater Restoration report on August 5, 2004, to WDEQ/LQD demonstrating restoration was completed by using BPT. The post-ISR groundwater quality met WDEQ criteria for "Class of Use." The WDEQ approved the MU-B restoration on March 31, 2008.

The state-approved restoration was designed to abate impacts to groundwater that were related to recovery of uranium from the 30-Sand Unit using ISR methods by reducing concentrations of constituents at POC wells to a primary goal of baseline conditions. The restoration has reduced constituent concentrations since the end of ISR; however, the concentrations have not been returned to baseline conditions for all parameters. The LQD's approval of the MU-B restoration was based on the secondary "Class of Use" criteria after demonstrating the application of BPT.

The demonstration of BPT includes the requirement that the restored aquifer will not degrade downgradient groundwater. The secondary restoration standards are allowed under the State of Wyoming's ISR rules and the State's administration of the EPA's UIC Program

1.3.2 Groundwater Regulation under NRC

The NRC position on the applicable restoration standard has changed since the 1990s when the goal was to eliminate the duplicative restoration regulations to the current position that NRC has a duty under the Uranium Mine Tailings Radiation Control Act to regulate the restoration of ISR facilities.

The historical pathway that mining companies used for the submittal and approval of the restoration of ISR mine units was to obtain restoration approval from the state, and then submit the restoration package to NRC for review and approval (Power Resources, Highland Uranium Project, Mine Unit A (ML041840470), Crow Butte Resources, Mine Unit 1 (ML030440055)).

The guidance for the acceptance criteria used during NRC review of previous restoration efforts was from NUREG-1569, 6.1.3 Acceptance Criteria. The guidance at the time was that the State's "Class of Use" standards under the SDWA were acceptable secondary standards for restoration. The "Class of Use" as secondary standard is included in the current SRH License (SUA- 1548).

WDEQ approved the restoration of Cogema's Irigaray Mine Units 1 through 9 as meeting the "Class of Use" standard on November 1, 2005. NRC approval of Irigaray Mine Units 1 through 9 occurred on September 20, 2006 (ML 062570175). NRC staff in the Technical Evaluation Report (TER) (ML062570175) stated the following:

> *Cogema had not restored ground water to primary or background, standards. However, because of the restoration efforts made by Cogema and the use of best practicable technology, the NRC considers the WDEQ secondary restoration standards and the NRC pre-mining use category as the applicable restoration standards in lieu of the primary goal of restoration.*

NRC staff was directed in 2006 to resume rulemaking specifically tailored to groundwater protection programs at ISR uranium recovery facilities (COMJSM-06-001). NRC staff was advised to implement the interim solution of exercising enforcement discretion to allow current licensees to meet state groundwater requirements in lieu of alternate conditions that may exist in their licenses (COMJSM-06-001). NRC staff recognized the dual regulatory requirements in 40 CFR Part 144 and Appendix A to 10 CFR Part 40 and followed the direction of the Commission that NRC staff give substantial deference to groundwater restoration approvals by the state.

The last restoration package submitted to NRC using "Class of Use" as a secondary standard was Cogema's Christensen Ranch Mine Units 2 through 6 Restoration Report.

In the Christensen Ranch Mine Unit 2 through 6 Restoration Report TER (ML 12174A048), the NRC stated:

> *The NRC staff's evaluation of ground water restoration is based on the uranium mill regulations in 10 CFR Part 40, Appendix A, which were written primarily for conventional uranium mills and latter applied to ISRs. In 2009, Regulatory Issue Summary 2009-05 (RIS 2009-05) stated that 10 CFR Part 40 Appendix A, Criterion 5B standards, are the applicable restoration standards for groundwater at ISR facilities (NRC, 2009c).*

The Christensen Ranch TER further states:

> *Prior to 2009, a groundwater "class-of-use" restoration standard, based on the State of Wyoming's groundwater classification system was considered acceptable.*

NRC stated in the Willow Creek (formerly Christensen Ranch) TER that they would evaluate the restoration effort (Willow Creek) based on the secondary standards ("Class of Use") that were documented in the current Willow Creek License (SUA-1341) and in NUREG-1569 (NRC, 2003). NRC also stated in the Willow Creek (Christensen Ranch) TER (NRC, 2012) that the State of Wyoming's "Class of Use" standard is not the appropriate secondary standard because NRC statutory authority to regulate ISR recovery facilities is found in the Atomic Energy Act of 1954 as amended, but the "Class of Use" standard is part of the EPA UIC Program that is administered by the states under the statutory authority of the SDWA.

The difference between the Christensen Ranch Mine Unit 2 through 6 restoration submittal and the SRH MU-B submittal is that Christensen Ranch was submitted concurrently to the WDEQ and the NRC. MU-B has received restoration approval from the WDEQ to "Class of Use" based on the application of BPT. The current restoration status of SRH MU-B has more in common with the Cogema Irigaray Mine than Willow Creek (Christensen Ranch).

The "Class of Use" standard is documented in the current license SUA-1548 (Amendment 17, LC 10.1.9, a.) for SRH, but Cameco has recognized that the NRC is going to evaluate all future mine unit restoration efforts based on 10 CFR Part 40 Appendix A, Criterion 5B, and has chosen to submit an ACL License Amendment for MU-B.

1.3.3 The Current Status of Mine Unit B

Following the end of the stability period in 2004, samples were collected from the MP wells. MU-B constituent averages collected from 2004 (end of stability sampling), which are presented in Table 2, can also be summarized as follows with respect to baseline concentrations and WDEQ "Class of Use" standards: Of the 34 constituents that were analyzed for, six met baseline, 16 met the WDEQ Class I standards that were in place at the time baseline was established, three met WDEQ Class II (agriculture) standards, and eight did not meet baseline constituent concentrations. Six of the constituents did not have a WDEQ water quality standard, and the other two constituents that were above baseline are manganese and radium. The wellfield average for radium was above baseline, but the final MU-B average was below the maximum baseline sample.

Table 2
Groups of MU-B Post-Restoration Water Quality

Parameter	Units	Baseline (Oct/Nov 1987)	End In-Situ Recovery (July 1991)	End Stability Period (Dec 2004)	2011 Average
Group I - Meet Baseline					
Ca	mg/L	49.5	349	86.35	71.3
Mg	mg/L	10.2	65.5	17.7	14.4
Na	mg/L	57.2	83.4	43.45	48.9
K	mg/L	8	16.7	5.75	6.1
CO_3	mg/L	0.15	0	<1	<1
SO_4	mg/L	117	402	64.65	66.5
NO_2	mg/L	0.01	0.1	<0.1	<0.05
NO_3	mg/L	0.14	0.3	<0.1	<0.05
F	mg/L	0.22	0.1	0.16	0.12
SiO_2	mg/L	15.8	18.8	14.69	14.7
COND	umho/cm	564	2580	619*	660
Al	mg/L	<0.1	0.1	<0.1	0.4
Ba	mg/L	<0.1	0.1	0.1115	<0.1
Bo	mg/L	<0.1	0.1	<0.1	<0.1
Cd	mg/L	<0.01	0.01	0.005	<0.005
Cr	mg/L	<0.05	0.1	<0.05	<0.05
Cu	mg/L	<0.01	0.01	<0.01	<0.01
Pb	mg/L	<0.05	0.1	<0.05	<0.05
Hg	mg/L	<0.0001	0	<0.001	<0.0001
Mo	mg/L	<0.1	0.1	<0.1	<0.1
Ni	mg/L	<0.05	0.07	0.05	<0.05

Parameter	Units	Baseline (Oct/Nov 1987)	End In-Situ Recovery (July 1991)	End Stability Period (Dec 2004)	2011 Average
Ra-226	pCi/L	316	1478	567.25	922
V	mg/L	<0.1	0.1	<0.1	<0.1
Zn	mg/L	<0.01	0.11	<0.01	<0.01
Group II – Meet Class I or II					
NH_4	mg/L	0.16	0.52	.299	1.32
Cl	mg/L	5.3	232	12.65	12.5
TDS	mg/L	350	1672	414.75	393
pH	std. units	8.12	6.9	7.14	7.4
As	mg/L	<0.001	0.008	0.07	0.048
Fe	mg/L	0.052	0.1	1.85	6.5
Se	mg/L	<0.001	0.806	0.012	0.048
U-nat	mg/L	0.062	22.3	2.93	2.96
Group III – Exceed Class I or II or no standard					
HCO_3	mg/L	206	824	344.25	315
ALK	mg/L	171	686	282.2	259
Mn	mg/L	0.032	0.9	0.522	0.36

Notes:

*Value was calculated using the following: (TDS) parts per million = Conductivity µmho/cm x 0.67
mg/L = milligrams per liter
std. units = standard units
pCi/L = picocuries per liter
umho/cm = micromhos

Results of the 2011 selective sampling event show that, with the exception of radium, selenium, manganese, and iron, constituent concentrations have not significantly changed. The 2011 sampling program only sampled 10 of the 20 total MP wells in MU-B and doesn't represent a complete data set. However, most of the wells in the program were chosen because they contained elevated arsenic and uranium concentrations. MU-B average concentrations from the 2011 sampling event are presented on Table 2. The following is the breakdown of the average concentrations with respect to baseline and WDEQ "Class of Use" standards: of the 34 constituents sampled during the 2011 selective sampling program, 16 met baseline, nine met the WDEQ Class 1 standards, five did not meet baseline nor was there a WDEQ standard, one constituent did not meet baseline or WDEQ Class I but did meet WDEQ Class III (Livestock) standards, and three constituents did not meet WDEQ Class I, II, or III standards and were elevated above baseline. Selenium was elevated above the WDEQ Class I, and II, standards but met the WDEQ Class III livestock standard. Two of the elevated constituents are on the EPA secondary constituent list and met the WDEQ Class IV A standard that was the original WDEQ groundwater classification.

The MU-B average concentrations of uranium, arsenic, selenium, and radium are elevated above baseline concentrations and do not meet the limits from Criterion 5B of Appendix A and were therefore selected as COCs. This application for ACLs has been prepared so that MU-B restoration can be evaluated and approved under the guidelines stated in 10 CFR Part 40, Appendix A, Criterion 5 (C).

When approved, the MU-B ACL License Amendment would be the first ACL for the restoration of an ISR Mine Unit. Cameco has been in consultation with NRC staff during two public meetings (October 18, 2011, and September 5, 2012) to discuss the ACL format.

Except for the public consultation meetings with NRC and the conceptual description of an ACL License amendment included in the Willow Creek (Christensen Ranch) restoration TER, NRC guidance documents for the preparation of an ISR mine unit ACL do not exist. Cameco is proceeding with the ACL License Amendment in consultation with NRC based on available guidance and references.

Cameco believes that the "Class of Use" standards are a relevant part of this ACL application and will use these standards to address the water quality of constituents not specifically listed in 10 CFR 40 Appendix A, Criterion 5C, Table of Maximum Contamination Values for Ground-Water Protection. The purpose of including the "Class of Use" standards into the ACL is to align the groundwater protection standards of the State of Wyoming-administered UIC Program with the ACL License Amendment.

1.4 Groundwater Protection Program

The current groundwater protection program, including the procedures for the monitoring and inspection program, for the SRH facility is contained in License SUA-1548. The groundwater protection program for the facility must be approved by NRC as well as WDEQ, which administers the EPA UIC Program. Baseline water quality for the groundwater protection program was established on a mine-unit-specific basis prior to extraction and is described in detail below.

For purposes of WDEQ, baseline water quality was determined by averaging the data collected for each parameter for each zone that is monitored. The variability of the data was also calculated. Outliers were determined in accordance with methods presented in WDEQ LQD Guideline 4, or other accepted methods. Values determined to be outliers were not used in the baseline calculations. Where wells are not uniformly distributed, the average was determined by weighting the data according to the fraction of area, or water volume, represented by the data. The aquifer in the production area was determined to be Wyoming Class IV (a) before the mine began production, and was classified as Wyoming Class V during mine operation (Figure 21). Because ISR operation has ceased, water inside the production zone is once again classified as Class IV (a).

Baseline conditions were determined on a mine-unit-specific basis with a sampling program immediately preceding or following the hydrologic pump testing program. The baseline conditions for the MU-B groundwater protection program were determined as follows:

- Mineralized Zone MP Wells – The MP wells are typically spaced in the production zone at approximately one well for every three acres. Data for each parameter were averaged. If the data collected for the entire mine unit indicated that waters of different underground water classes (WDEQ WQD Rules and Regulations, Chapter 8) existed together, the data were not averaged together, but treated as sub-zones. Data within specific sub-zones were averaged. Boundaries of sub-zones, where required, were delineated half-way between the sets of sampled wells which define the sub-zones. The baseline MP well data are used to establish Restoration Target Values (RTVs) for the groundwater restoration. The RTVs represent parameter-specific restoration goals that must be reached by end of ISR.
- Ring Monitoring Wells and Underlying and Overlying Monitoring Wells – The data for each parameter were averaged to establish the upper confidence limits (UCLs). The UCLs are the monitoring parameters used to monitor for excursions of production fluid into a non-exempted aquifer. As with the mineralized zone wells, if sub-zones are present that differ in underground water classes, data within the specific sub-zones were averaged separately. The UCLs are used for the monitoring program in the underlying and overlying formations and the ISR formation outside of the mining zone. The monitoring wells are also used during the pump test to establish that the ISR zone is isolated from the overlying and underlying formations and that the ring monitoring wells are in hydraulic communication with the production zone.

Following the review of data from the pre-ISR well sampling program, WDEQ established RTVs for all constituents in groundwater at the POC wells for the 30-Sand. UCLs for monitoring the mining zone and overlying and underlying formations for excursions were also set at that time. The RTVs for all constituents were determined using the mine unit average concentrations using data collected during the required four sampling events in October/November 1987. Baseline groundwater conditions for the WDEQ groundwater protection program, as described above, were derived in a different manner than the baseline upper tolerance limits (UTLs) that have been calculated for the purposes of this ACL application. Section 2.1.1 (Background Evaluation) describes the methods for determining baseline UTLs for the purposes of this ACL application.

1.4.1 Current Groundwater Protection Standards

As described above, RTVs were determined from baseline groundwater concentrations representative of water quality before ISR operations began. Baseline groundwater conditions were calculated as part of the WDEQ permitting process by averaging the groundwater constituent concentrations from the MP wells during the baseline time period (Table 2). As detailed in Section 2.3.2 of this document, the production zone wells (POC) were classified as Class IV (A) before ISR and as Class V during production. Because the mine unit is no longer in production, it is once again classified as Class IV (A), as shown in Figure 21. As can be seen in Table 2, some of the average constituent concentrations from the 2011 sampling event were higher than the project wide MP-well baseline average.

Cameco believes that continuing active restoration to restore constituent concentrations to baseline in MU-B is not practicable. Restoration cost estimates exceed NRC ALARA guidance of $2000 per person-rem, and nearly exceed the "prohibitively expensive" criteria as specified in Section 4.0 of Appendix D of NUREG-1727. Further, continuing active restoration would be an excessive use of substantial volumes of groundwater to produce a potentially limited benefit to protect human health and the environment.

1.4.2 Extent of Current Groundwater Contamination

Due to the nature of ISR mining, the groundwater contamination at the MU-B facility is co-located at the source. The MU-B wellfield contains overlying (MO), underlying (MU), and ring monitor wells (M) which, during production and restoration, were used to identify potential excursions of contaminants horizontally and vertically from the production area. Additional discussion and characterization of contamination is located in Section 2.1.

1.5 Proposed Alternate Concentration Limits

Appendix A to 10 CFR Part 40 states:

> *Licensees or applicants may propose alternatives to the specific requirements in this appendix. The alternative proposals may take into account local or regional conditions, including geology, topography, hydrology, and meteorology. The Commission may find that the proposed alternatives meet the Commission's requirements if the alternatives will achieve a level of stabilization and containment of the sites concerned, and a level of protection for public health, safety, and the environment from radiological and nonradiological hazards associated with the sites, which is equivalent to, to the extent practicable, or more stringent than the level which would be achieved by the requirements of this*

> *Appendix and the standards promulgated by the Environmental Protection Agency in 40 CFR Part 192, Subparts D and E.*
>
> *All site specific licensing decisions based on the criteria in this Appendix or alternatives proposed by licensees or applicants will take into account the risk to the public health and safety and the environment with due consideration to the economic costs involved and any other factors the Commission determines to be appropriate. In implementing this Appendix, the Commission will consider "practicable" and "reasonably achievable" as equivalent terms. Decisions involved these terms will take into account the state of technology and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.*

Based on the results of the hazard assessment, geochemical modeling, and statistical analysis of current data associated with the POC wells (MP wells), ACLs that are protective of human health and the environment (as presented in Section 2.3 Exposure Assessment) and meet ALARA criteria (as demonstrated in Section 3.6) have been developed. ACLs have been developed for identified COCs at the Site, arsenic, radium-226, uranium, and selenium. Section 2.1.4 discusses identification of COCs in more detail. The proposed ACLs for POC wells at MU-B are presented in Table 3.

Table 3

Proposed Alternate Concentration Limits

Constituent from 10 CFR, Part 40, Appendix A, Criteria 5 and 13	MCV	Background (UTL95) Concentration	POC Highest Post-Restoration Value*	Well with Highest Value	Proposed ACL
Arsenic and compounds, N.O.S.*	0.05 mg/L	0.00319 mg/L	0.141 mg/L	MP-21	0.141 mg/L
Radium-226 and radium-228	5 pCi/L	829.6 pCi/L	2230 pCi/L	MP-26	2230 pCi/L
Uranium and compounds, N.O.S.*	no MCV	0.225 mg/L	6.30 mg/L	MP-14	6.30 mg/L
Selenium and compounds, N.O.S.*	0.01 mg/L	0.0029 mg/L	0.134 mg/L	MP-31	0.134 mg/L

Notes:

*When MU-B was permitted in 1987, the WDEQ Class I standard for uranium was 5 mg/L (WDEQ, 2008).
Post-Restoration data collected in 2011. The abbreviation N.O.S. (not otherwise specified) signifies those members of the general class not specifically listed by name in Appendix A to 10 CFR, Part 40, Criterion 13.
ACL = Alternate Concentration Limit
MCV = Maximum Concentration Value as defined in 10 CFR Part 40 Appendix A to Part 40 5C
POC = point of compliance
mg/L = milligrams per liter
pCi/L = picocuries per liter

ACLs were selected from the 95% UTL on baseline groundwater concentrations or from the highest observed concentration in the MU-B production zone post-restoration, whichever is higher. In this case, each of the ACLs were selected from the highest post-restoration value for that constituent in the MP wellfield from the 2011 sampling event. The hazard assessment indicates that natural geochemical conditions result in the attenuation of constituent concentrations within short distances from the POC wells. Results of geochemical and groundwater flow modeling indicate that proposed ACL concentrations will attenuate to levels below human health risk-based thresholds before reaching the ring monitoring wells of MU-B, which form the proposed POE.

Additional discussion of the geochemical and groundwater modeling is provided in Section 2.2. Appendix A contains the results of the geochemical model, and the groundwater flow model is presented in Appendix B.

2.0 HAZARD ASSESSMENT

2.1 Source and Contaminant Characterization

This section delineates the areas where contamination exists, documents the individual chemical constituents that contribute to the contamination, and estimates the amount of contamination that exists in groundwater as a result of uranium ISR mining at the SRH facility. This information is used in the development of a conceptual model of the SRH facility.

This section will identify and discuss the following:

- Background (baseline) groundwater quality.
- Uranium ISR methods and processes.
- ISR-related potential constituents of concern (COCs) that are of concern to human health and the environment.
- The extent and magnitude of contamination of groundwater contributed by ISR-related activities.
- Attenuation or fate and transport characteristics of COCs.

2.1.1 Background Evaluation

Pre-ISR baseline groundwater quality for purposes of WDEQ was determined through an approved sampling program for each set of monitoring wells. The baseline groundwater parameter concentrations were calculated as a mine unit average. The production zone baseline groundwater quality for MU-B was determined using averaged concentrations from Guideline No. 8 parameters for Wells MP-11 to MP-16 and MP-18 to MP-31 (Appendix C). The methods for determining baseline groundwater quality for purposes of WDEQ are described above in Section 1.4, Groundwater Protection Program.

For purposes of this ACL application hazard assessment, background was determined by calculating a UTL on baseline data. UTLs were calculated using ProUCL 4.0 for the baseline data for each constituent in both the MP and M wells, separately. ProUCL 4.0 is software developed by the EPA to calculate UTLs, UCLs, and upper prediction limits (UPLs) based on the statistical methods and recommendations presented in the Background Guidance Document for CERCLA Sites (EPA, 2002).

Baseline UTLs were calculated using all of the available data collected in 1987 and 1988, prior to commencement of ISR activities at the HUP beginning in 1988. The data were organized by constituent and unit. For example, arsenic results from all of the POC wells were combined into one data set. The UTLs were calculated in the ProUCL software program, which identifies the distribution of the data set and recommends an appropriate UTL. Data were entered into ProUCL as two columns, one being the analytical result of the constituent and one being a qualifier column that identifies detected and non-detected results of the same constituent. Baseline arsenic data were 68% non-detected results. Out of 31 total data points for arsenic, 21 were non-detected values. Of the 10 detected values, only 3 were distinct. Three unique data points are not enough to provide accurate or reliable statistical results; however, using nonparametric statistics (the Kaplan-Meier method), ProUCL was able to estimate a UTL at 0.00319 mg/L. Background UTLs for the COCs are presented in Table 3.

2.1.2 Solution Extraction Method and Recovery Process

The process of uranium extraction during ISR follows this general methodology: Native groundwater is pumped from the formation through a series of wells that have been drilled, cased, cemented, and tested for mechanical integrity. The native groundwater is fortified with oxidant and carbon dioxide/sodium bicarbonate (baking soda). The fortified groundwater is re-injected into the ore-bearing sandstone formation to leach the uranium mineral. As the leaching solution moves through the formation and contacts the ore, the uranium is oxidized, becomes soluble, and dissolves into the leaching solution. The uranium-bearing solution is drawn to a recovery well where it is pumped to the surface and transferred to the recovery plant. In the plant, the uranium, present as a uranyl carbonate anionic complex, is recovered from the leach solution by ion exchange (IX). The IX resin acts like a sponge that adsorbs uranium. Once the IX resin is loaded to capacity, the extraction column is removed from service and the resin is taken to a central processing plant where the uranium is removed from the resin. Once the uranium is removed or "stripped" from the resin, the resin is taken back to the satellite plant and reused to remove uranium from the extraction solutions. A portion of the production fluid, approximately 1% of the total stream, is removed from the production fluid. Removing a portion of the production fluid creates a slightly negative balance between the production and the injection. The over pumping during the mining process creates a slight cone of depression in the active mine unit. The cone of depression is designed to keep the mining solutions contained in the mining zone and prevent excursions. The solution, re-fortified with dissolved oxygen and a carbonate precursor, is re-injected to extract additional uranium. Once all of the economical uranium has been extracted, generally when a well reaches 10 parts per million uranium concentration, groundwater restoration begins.

2.1.3 Groundwater Restoration

Groundwater restoration occurs after the mining process has ended. The mining area is treated using GWS, RO sweep, and reductant addition. The goal of the restoration process is to return the groundwater to baseline. If baseline conditions cannot be reached after the application of BPT, then the groundwater will have to meet secondary standards that meet ALARA and can be demonstrated to not pose a risk to human health or the environment. A considerable effort was expended on MU-B during the restoration process to meet the restoration goals set forth in the regulations. A more complete description of the restoration effort is included in Section 3.0 Corrective Action Assessment. The post-restoration condition of the formation and the groundwater is what the ACL License Amendment will analyze.

2.1.4 Constituents of Concern in Groundwater

COCs have been identified in groundwater based on the approved NRC License SUA 1548, WDEQ Permit 603, and Criterion 5B(2) of Appendix A to 10 CFR Part 40. COCs in groundwater at the Site were identified by comparing post-restoration data collected in 2011 to the calculated baseline UTLs and the MCVs presented in Criterion 5C. A constituent was considered a COC if any concentration from the post-restoration data in any MP well exceeded both the baseline UTL and the MCV. Arsenic, radium-226, uranium, and selenium concentrations were the constituents that exceeded both the UTL and MCV. Gross alpha, gross beta, and radium 228 were not included as a sampling requirement in the NRC License and the WDEQ permit to mine when MU-B was permitted and in operation at the SRH facility, and therefore data are not available for these constituents to be compared to regulatory standards and considered as potential COCs.

A hazard evaluation was completed for the COCs identified above to demonstrate that the proposed ACLs for the MU-B will not pose substantial risk to human health and the environment in the event exposure were to occur. A health risk-based concentration limiting the lifetime risk to 1×10^{-4} for groundwater consumption at a potential POE location was calculated for radium-226+228 and uranium. MCVs from Criterion 5 were used as the health-risk based values for arsenic and selenium. ACLs were selected from the 95% UTL on baseline groundwater concentrations or from the highest observed concentration in the MU-B production zone during the post-restoration monitoring sampling event in 2011, whichever is higher. In this case, the 2011 values were all higher and were selected for use as ACLs. ACLs at the POC wells are proposed to ensure that the health risk-based concentrations are maintained when constituents in groundwater have moved to the POE. Geochemical and hydrogeological modeling have shown (Table 6) that if ACLs for these constituents are met at the POC wells, the groundwater concentrations of each COC in the POE wells will be below the health risk-based concentrations presented in Section 2.3, and the constituent concentrations in the 30-Sand will not pose a substantial risk to human health or the environment.

The hazard evaluation from exposure to the COCs in groundwater was performed using risk coefficients and MCVs from the following:

- EPA's Federal Guidance Report (FGR) No. 13, Part 1 (EPA 402-R-97-014), "Health Risks from Low-Level Environmental Exposure to Radionuclides" (EPA, 1998).
- Appendix A to 10 CFR Part 40.

2.1.5 Distribution of Constituents and Attenuation Properties

Analytical data from field sampling in the fourth quarter of 2011 were joined with spatial data in ArcGIS and plotted on a basemap. The recent data program was designed to review wells that, at the end of restoration, had higher constituent concentrations and would be closest to the point of exposure. The most recent data available were used in the perimeter ring to provide adequate control points for interpolation of values. Baseline data were not used when POE well data from 2011 were available. The values for each COC were interpolated using the Natural Neighbor method (Figures 22-25). The Natural Neighbor method generates a localized interpolation, using only sample points that surround a query point, guaranteeing that the interpolated values will always be within the range of the interpolated points. In general, concentrations were higher in the POC wells (MP Wells) and lower in the POE wells (M Wells). Only field parameters (water level, temp, conductivity, dissolved oxygen, pH, and ORP) were measured in-situ at the injection wells (I-Wells). The redox data suggest that heavy metals concentrations may be lower in the injection wells. Most constituents were concentrated in two general areas. A group of wells on the northern side of the wellfield consisting of MP-31, MP-30, MP-19, MP-16, MP-14, and MP-12 generally contained higher concentrations of constituents, while MP-26 and MP-27 had higher concentrations on the southern side of the wellfield. Detailed distributions of ACL constituents are easily interpreted in spatial format (Figures 22-25).

2.1.5.1 Attenuation Properties of Arsenic

Arsenic is a redox-sensitive element. As a result, arsenic may be present in a variety of redox states. Arsenate (arsenic V) and arsenite (arsenic III) are the two forms of arsenic commonly found in groundwater (Masscheleyn et al., 1991). Arsenate generally predominates under oxidizing conditions. Arsenite predominates when conditions become sufficiently reducing. Under the pH conditions of most groundwater, arsenate is present as the negatively charged oxyanions $H_2AsO_4^-$ or $HAsO_4^{2-}$, whereas arsenite is present as the uncharged species $H_3AsO_3^0$ (Hem, 1985). Groundwater samples from Wells MP-14, MP-21, and MP-22 (production area wells with the highest arsenic concentrations) were analyzed at an offsite laboratory (Energy Laboratories, Inc.), and the arsenic in solution was determined to be primarily in the + 3 valence state (Table 4). This indicates that arsenic can form relatively insoluble sulfide minerals, which include orpiment and realgar. When these minerals are formed, the arsenic concentration in solution will decrease.

Table 4
Arsenic Speciation Data

Sample Date	Well ID	Arsenic-III (mg/L)	Arsenic-V (mg/L)
03/23/2005	MP-14	0.13	0.0068
03/23/2005	MP-21	0.4	0.01
03/23/2005	MP-22	0.27	0.014

Arsenate and arsenite adsorb to surfaces of a variety of aquifer materials, including iron oxides, aluminum oxides, and clay minerals. Adsorption and desorption reactions between arsenate and iron-oxide surfaces are particularly important controlling reactions because iron oxides are widespread in the hydrogeologic environment as coatings on other solids, and because arsenate adsorbs strongly to iron-oxide surfaces in acidic and near-neutral-pH water (Dzombak and Morel, 1990; Waychunas et al., 1993). Iron-oxide surfaces also adsorb arsenite, and both arsenate and arsenite adsorb to aluminum oxides and clay-mineral surfaces. However, these adsorption reactions generally appear to be weaker than is the case for arsenate adsorption to iron-oxide surfaces under typical environmental pH conditions (Manning and Goldberg, 1997). Nevertheless, pH-dependent adsorption and desorption reactions other than those between arsenate and iron-oxide surfaces may be important controls over arsenic mobility in some settings. The current distribution of arsenic in MU-B is shown in Figure 22.

2.1.5.2 Attenuation Properties of Selenium

Like arsenic, selenium is a redox-sensitive element. As a solid phase, selenium is commonly present as Se (native selenium), $FeSe_2$, and FeSe, commonly in association with sulfur-containing minerals. In natural aqueous environments, selenium may be present in -2, +4, and +6 valence states (Brookins, 1988). Selenium occurs in natural waters most commonly as selenite Se (IV) and selenate Se (VI). Under reducing conditions, selenium tends to be immobile. Selenium tends to be strongly partitioned to sulfide minerals, metal oxide minerals, and organic matter. Maximum adsorption of selenate and selenite occurs primarily through specific adsorption in the acidic pH range on geologic materials enriched in hydrous oxides of Al and Fe or amorphous aluminosilicates. Sulfate is reported to compete for Se adsorption sites. Se (VI) is only weakly adsorbed by oxides and clays at near-neutral pH. Hence, oxidation of Se (IV) to Se (VI) enhances selenium mobility and persistence in natural waters (Rai and Zachara, 1984).

2.1.5.3 Attenuation Properties of Radium-226

Radium-226 and radium-228 are products of the uranium-238 and thorium-232 decay chains, respectively. However, once in solution, these isotopes display the same geochemical behavior as all other radium ions. Radium, present in solution almost exclusively as Ra^{2+} ion, is soluble only under acid conditions and is generally immobile in natural waters due to the extreme insolubility of radium sulfate (Brookins, 1988). Radium-226 typically comprises more than 90% of total radium. Figure 24 shows the radium-226 distribution in the 30-Sand, with radium-226 present above 5 picocuries per liter (pCi/L) in some areas. However, radium-226 was present above 5 pCi/L in many of these areas during the baseline monitoring period, especially nearer to the ore body. Additionally, radium is commonly attenuated via co-precipitation with barium sulfate (barite) (SKB, 2008).

2.1.5.4 Attenuation Properties of Uranium

Uranium occurs in +4, +5, and +6 oxidation states. Most important in nature are the uranous [U(IV)] and uranyl [U(VI)] oxidation states. U(IV), more common in waters with a low Eh and pH, tends to be strongly partitioned to solid phase U(IV) minerals such as uraninite and coffinite under most natural conditions. U(VI), found in more oxidizing waters with a pH greater than 5, tends to be much more mobile than U(IV) due largely to the high solubility and stability of U(VI) carbonate complexes. The most important U(VI) complexes are carbonate complexes, although U(VI) complexes with fluoride, phosphate, and sulfate can also affect uranium transport behavior (Langmuir, 1997).

Adsorption-desorption reactions are an important consideration for uranium behavior in natural environments. For most environmental conditions, dissolved uranium and other trace elements will always partition themselves between the water and the surfaces of contacting solids in soils, sediments, and rocks. In most groundwater systems (pH>5) more than 99% of individual trace elements will be associated with solid surfaces and less than 1% dissolved. Because of their common occurrence in soils and sediments and strong sorptive behavior toward U(VI), the Fe(III) oxyhydroxides are generally the most important potential sorbents for uranium, with organic matter (peat, for example) second in importance (Langmuir, 1997). Once U(VI) has been adsorbed, it can be reduced to U(IV) in uraninite or coffinite by mobile reductants (such as Fe^{2+}), or the adsorbent itself if it is organic matter. If reduction does not follow adsorption, the uranium can be desorbed by an increase of alkalinity at constant pH or by raising the pH. Such changes increase the extent of uranyl carbonate complexing, which are poorly adsorbed, causing desorption and remobilization of uranyl species.

Recent studies show that the presence of dissolved calcium can significantly alter the transport properties of uranium by inducing the formation of ternary uranyl-calcium-carbonato complexes (Stewart, 2008). The speciation of dissolved U(VI) is skewed significantly towards these ternary complexes under most environmental conditions in the presence of dissolved calcium. Results indicate that there will be some reduction in the attenuation of dissolved complexed U(VI).

However, experimental data for these species are not as available as those for uranyl carbonate complexes. The behavior of uranyl-calcium-carbonato complexes is not included in this model.

2.2 Transport Assessment

2.2.1 Geochemical Assessment

2.2.1.1 Geology, Mineralogy, and Paleo-Geochemistry

The stratigraphic units of interest within the SRH licensed area are the Tertiary-age deposits of the Wasatch and Fort Union formations. The Fort Union Formation in the Powder River Basin is lithologically similar to the Wasatch Formation. Throughout the SRH area, the formations include interbedded silty claystones, sandy siltstones, relatively clean sandstones, and claystones with a few thin coal seams occurring locally. The degree of lithification is quite variable, ranging from virtually uncemented sands to moderately well-cemented siltstones and sandstones. The Wasatch Formation is known to be about 500 feet thick in the central and east-central portions of the permit area, while it is not present in the southwestern portion of the permit area. The total thickness of the Fort Union in the area is approximately 3,000 feet. Figure 18 shows a regional cross section of the geology in the permit area.

After deposition, the sediments in the Wasatch and Fort Union formations were reduced by the organic materials that were deposited along with the Wasatch and Fort Union formations. As meteoric water percolated down into the basin through overlying sediments, the reduced sediments were oxidized. As sediments were oxidized, a regional oxidation front was created (Figure 26), with oxidized sediments nearer to the incoming meteoric water and reduced sediments farther into the basin. When conditions in the aquifer changed from reduced to oxidized, redox-sensitive elements, including uranium, were released into solution. However, as the dissolved elements were carried along the flowpath towards un-oxidized portions of the formation, they were once again deposited as solid minerals. The geologic processes that established the original ore body continue to the present day. In some areas, the concentrations of uranium and other elements at the oxidation boundary were high enough to be economically recovered. Figure 27 shows a schematic representation of one of these oxidation boundaries (roll-front deposits). The regional and site-specific geology for MU-B is described in more detail in Section 1.2.3 of this document and in Sections 1.2 and 1.3, respectively, of Appendix A.

2.2.1.2 Alterations Due to ISR of Uranium

The roll-front deposits at MU-B were recovered from the 30-Sand using ISR techniques, therefore, the 30-Sand could potentially be affected by transport of COCs due to ISR of uranium. Because the 20-Sand is hydraulically connected to the 30-Sand in the northwestern portion of

MU-B (Section 2.2.2), it is possible that some small amounts of COCs may be transported within the 20-Sand due to activity in the 30-Sand. However, previous work by Lewis (2001) has shown that significant attenuation will take place in the 20-Sand as groundwater moves toward the POE. ISR consists of installing several patterns of groundwater wells. Generally, each pattern is a "five spot pattern," consisting of one production well surrounded by four injection wells (Figure 26). During the ISR process, groundwater is pumped from the formation, and oxygen, carbon dioxide, or sodium bicarbonate is added to the native groundwater. The injected water travels through the aquifer from the potentiometric high at the injection well to the potentiometric low at the central production well. As the oxidizing solution moves through the aquifer, it acts on the reduced minerals in the roll-front deposits, releasing uranium and other constituents into solution. The soluble uranium is complexed by the carbonate that was added to the water, keeping the uranium in solution during the ISR process. The water is then pumped to the surface and the uranium is removed from the solution using (IX) resin, which adsorbs the uranium from the solution. Once the uranium is removed from the groundwater, the water is fortified with oxygen, carbon dioxide, and/or sodium bicarbonate and returned to the wellfield where it is reinjected into the formation except for the removal of a bleed stream (typically 1% of the total flow) to provide hydraulic control of the mining solutions. This process repeats until the mine unit ceases production.

After ISR operation ceased, the groundwater restoration for MU-B began. The first step in the restoration process was to sample the MP wells using the approved constituent list from NRC License SUA-1548 and WDEQ permit No. 603 to establish post-ISR groundwater quality. Following post-ISR groundwater sampling, restoration began with GWS, which consisted of pumping the production wells without injection. GWS is designed to pull the water that has been affected by ISR into the center ISR patterns, which began reducing the TDS in the mine unit. Typically the GWS consists of removing at least one PV. The next phase of the restoration process, called RO sweep, consisted of pumping the water from the mine unit and treating the groundwater with an RO filter. The RO removes almost all of the TDS, metals, and other constituents from a large portion of the water that is fed to the filter. The clean water that is produced is called permeate and contains very little TDS. The TDS, metal salts, and other constituents are concentrated in a small percentage of the feed stream called "concentrate" that is disposed of using a deep disposal well. The clean RO permeate is injected back into the wellfield to further reduce the TDS and other constituents in the mining formation. The final restoration step is reductant addition, which is designed to introduce reducing conditions to the formation and stop the ISR process. MU-B had two methods of reductant addition employed during the restoration process. Part of the mine unit received sodium sulfide, a powerful chemical reductant, and the whole mine unit received biological amendments. In general, the restoration efforts served to re-establish reducing conditions in the MU-B production zone. A reduced environment can help redox-sensitive metals such as uranium to precipitate from solution if sufficient concentrations of other dissolved solids are present to form a solid-phase mineral. A more detailed summary of restoration efforts is detailed in Cameco (2009) (ML091831100).

2.2.1.3 *Current Geochemical Conditions*

Oxidation reduction potential conditions were measured at several monitoring and injection wells during the last quarter of 2011. Plotting of the data showed two distinct groupings of redox conditions (Figure 28). The differences in redox conditions may be attributed to differences in groundwater conditions and/or differences in measurement methods that were employed on each well type. The injection wells contain no pumps and were characterized with in-situ equipment by placing a multi parameter probe in the screened section of the well and recording measurements. Parameters in the production wells were measured by pumping the water from the wells through a flow-through cell at ground level, which contained a multi-parameter probe. It is notable that the lowest redox potentials occur in injection wells, which suggests that injected biological nutrient sources may have preferentially reduced the areas around the injection wells. Although the measurement methods were different for the two types of wells, both methods are recognized as best practices and should produce comparable results.

The distribution of the COCs is discussed in Section 2.1.5, and can be seen in Figures 22-25.

2.2.1.4 *Geochemical Model*

This section summarizes the methods and results of the geochemical assessment, which is included in this Application as Appendix A.

Conceptual Model

The model simulates lower-TDS water from upgradient of MU-B flushing through the higher-TDS ISR area. Chemistry data from an upgradient POE well is used for the incoming solution, while a mineralized zone POC well is used for the ISR area solution. A downgradient POE well is used along with location-based mineralogy to simulate the reduced portions of the aquifer and conditions downgradient of the mineralized (production) zone. Simulations are projected to the downgradient POE, although a particle of water may travel a significant distance past the POE before being discharged from the groundwater system (Figure 29). A more detailed description of the conceptual model and data used for the model is included in Appendix A. Several particle track paths were generated using the steady-state future prediction for the 30-Sand aquifer from the Aqui-Ver (2011) model. The track paths simulate the path of a particle of water as it moves from upgradient, through the ISR zone (POC wells), past the downgradient POE well, and ultimately to its discharge location. Geochemical modeling is conducted in the space between the upgradient POE well and the downgradient POE well.

Modeled Attenuation Processes

Advection and Dispersion

The model utilizes the TRANSPORT module of PHREEQC code to simulate the effects of physical processes such as advection, dispersion, and diffusion in concert with chemical processes such as dissolution, precipitation, ion-exchange equilibria, solution mixing, and surface complexation reactions. To match the conceptual model, boundary conditions were chosen to be constant (unlimited upgradient input) on the upgradient side of the simulation, and flux (conservation of mass) on the downgradient end of the simulation. Groundwater velocities for the model were obtained from the Aqui-Ver (2011) model, while longitudinal dispersivities were calculated using the formula from Xu and Eckstein (1995).

Reactive Minerals

In order to simulate the subsurface mineralogy along the particle track paths present at MU-B, the track paths were overlayed with a facies map in ArcGIS (Hunter, 1999). Each 50-m cell in the transport model is adjusted to contain the minerals most like those that would be present at its location along the track path (Figure 26). The facies shown on Figure 26 in map view correspond in a general sense to the mineral assemblages shown in cross-section in Figure 27, with the roll-front (the interface of reduced and oxidized zones) being located near the downgradient (east) edge of the alteration zone in Figure 26. Mineralogical studies from Mine Unit K (Appendix E) were also used as a guide for developing mineral assemblages. Three general sets of mineral assemblages were used to simulate mineralogical conditions: oxidized areas, transition areas, and reduced areas. All three mineral assemblages include quartz, k-feldspar, and k-montmorillonite. The transition zone assemblage also includes uraninite, coffinite, siderite, and goethite. Goethite is an important sorption surface for many of the constituents considered at the site, as described under sorption surfaces below. The reduced zone mineralogy contains quartz, k-feldspar, and pyrite, while the following mineral phases are allowed to precipitate if they become oversaturated: uraninite, coffinite, calcite, ferroselite, siderite, gypsum, and native selenium. The amount of these minerals present initially is consistent with the abundance in the aquifer matrix, the amount of mineral surface available for reaction, and their solubility in water. Pyrite was included in the reactive minerals because it occurs throughout the mineralized area and plays such a vital role in redox processes. The amounts of minerals present in each cell, along with all other model inputs, can be viewed in the PHREEQC input files (Appendix A).

Ion Exchange

Ion exchange surfaces are calculated based on mineralogical data that were collected from the A-Wellfield (MU-A). Cation exchange capacity (CEC) was measured in a milliequivalents per 100 grams (meq/100g) aquifer matrix for a core that was collected from the M-7 well in MU-A, and then converted to a milliequivalent per liter (meq/L) solution. Cation exchange values were converted from meq/100g soil to meq/L of porewater solution for input to PHREEQC to arrive at a value of 0.7 meq/L of solution. Due to the lack of available data, and in order to provide conservative modeling results, the exchange constant for barium was used for the radium ion exchange processes.

Sorption Surfaces

The sorption mechanism involves protonation/deprotonation and complexation reactions on surface sites. Goethite was assumed to have properties similar to those of hydrous ferric oxide (HFO), and is considered to be more realistic than HFO for natural systems. Sorption of arsenic, radium, and iron were modeled. In addition, the major cations calcium and magnesium and the sulfate anion were modeled to provide a realistic representation of the competition for surface sites on goethite. Surface-complexation constants for arsenate sorption on "weak" sites were obtained from Dzombak and Morel (1990), while the constants for radium and calcium were taken from Bassot et al. (2001). The surface area of goethite per liter of porewater was related to the mass of goethite using a specific surface area of 600 m^2 g^{-1} (5.33e4 m2 mol-1). The concentrations of weak and strong sites were assumed to be 0.2 and 0.005 mol per mol of goethite, respectively. The mass of goethite, like that of any other mineral phase in the model, is subject to change by dissolution and precipitation with changing conditions.

Co-Precipitation of Barite and $RaSO_4$

Most source-term calculations for Ra (II) pessimistically assume that its solubility is controlled by the individual solubility of $RaSO_4$(s), the most insoluble phase under near field conditions, while abundant information from early radiochemical research, natural system studies, and anthropogenic systems would indicate that Ra (II) behavior is largely determined by $BaSO_4$(s) precipitation (SKB, 2008). Modeling the removal of Ra (II) from solution by precipitation of (Ra, Ba) SO_4 will allow for removal of far more Ra (II) than by precipitation of pure $RaSO_4$.

In order to model the removal of Ra (II) from solution by co-precipitation with barite, the Solid Solutions module in the geochemical code PHREEQC (Parkhurst and Appelo, 1999) was used. Because Ra (II) has very similar size and charge to Ba (II), the crystal size and structure of pure $RaSO_4$ is nearly identical to that of pure $BaSO_4$; therefore, the behavior of the co-precipitated solid is nearly ideal (Zhu, 2004). Ideal behavior of the (Ra, Ba) SO_4 solid solution is assumed in this model.

2.2.2 Hydrogeology Assessment

2.2.2.1 Groundwater Flow

As discussed by Aqui-Ver (2011), with the termination of active restoration in June 2004, groundwater flow conditions in MU-B have been influenced largely by the recovery of MU-B, Highland pit lake, and the Exxon underground mine. The current rate of water level recovery is about 0.5 to 1 foot/year (Aqui-Ver, 2011). The groundwater elevation data for the 30-Sand and 20-Sand were collected by Cameco personnel in December 2010. In both the 30-Sand and 20-Sand aquifers, the aquifer potentiometric surfaces are about 5,050 to 5,060 feet above mean sea level. In general, groundwater in the 30-Sand flows steeply toward the southwest and the recovering Highland pit lake in the southern portion of MU-B; however, in the northern portion of MU-B, groundwater flows toward the underground mine (Figure 19). Groundwater flow in the 20-Sand has a similar pattern as that in the 30-Sand, but it has a flatter hydraulic gradient (Aqui-Ver, 2011). Groundwater flow in the 20-Sand flows generally toward the south in the southern and central portions of MU-B, but toward the underground mine in the northern portion of MU-B (Figure 20). In both aquifers, a groundwater flow divide is present in the central portion (30-Sand) or northern portion (20-Sand) of MU-B. Aqui-Ver (2011) estimated that the groundwater velocity is approximately 20 to 60 feet/year in the 30-Sand and 5 to 20 feet/year in the 20-Sand across the mine unit.

2.2.2.2 Flow System Characteristics

Estimates of hydraulic conductivity for the 20-Sand and 30-Sand are obtained from the results of aquifer test data collected prior to the start-up of uranium recovery in MU-A and MU-B (Lewis Water Consultants, 2001). Hydraulic conductivities of the 20-Sand and 30-Sand are both relatively uniform, with a range of 0.6 to 2.8 feet/day for the 20-Sand, and 1.6 to 2.7 feet/day for the 30-Sand (Lewis Water Consultants, 2001). The vertical hydraulic conductivity of the in-between aquitard was assigned an initial value of 3×10^{-5} feet/day in the Lewis Water Consultants model based on results of aquifer test leakance calculations (1987 20-Sand pump test) and laboratory testing of aquitard materials (Lewis Water Consultants, 2001). The groundwater model (Lewis Water Consultants, 2001) developed for MU-A and MU-B was calibrated with a hydraulic conductivity of 2.2 feet/day for the 30-Sand and 0.7 feet/day for the 20-Sand, and a vertical hydraulic conductivity of 2×10^{-4} feet/day for the in-between aquitard in the MU-B area. Based on the lithology of the alluvium, porosity is estimated to range from 0.15 to 0.25 (Fetter, 1989). In this study, a value of 0.2 is used to represent the porosity.

2.2.2.3 Surface Water

The permit area is located in the southern part of the Powder River Basin in the Sage Creek drainage of the North Platte River drainage system, and the Box Creek, Duck Creek, Willow

Creek, and Brown Springs Creek drainages of the Cheyenne River drainage system. All streams are ephemeral and flow only in response to snow melt and heavy thunderstorms. There are no gauging stations within the drainages; therefore, quantities are not measured. A considerable portion of the area encompassed by the project site is internally drained to playas. The project site receives approximately 12 inches of precipitation annually (see Section 3.6 of the Environmental Report (ER) (NRC, 2012) and WDEQ Appendix D4 (Appendix E in this Application) for additional climate information). Stock ponds constructed in many of the ephemeral streams draining the area collect some runoff for watering livestock; however, these ponds are dry much of the time. Additionally, there are numerous playas present which hold runoff water during times of abundant precipitation. Tables D6-1 and D6-2 in WDEQ Appendix D6 (Appendix E in this Application), which contain USGS stream flow records for Box Creek downstream of the SRH license area (drainage area = 109 mi^2), show the lack of runoff and stream flow in the area and the ephemeral nature of the stream system.

Sage Creek runs through the southwest portion of the license area. The USGS maintained a stream gage near Orpha, Wyoming, approximately 1.6 mi southeast of the southeast corner of the license boundary (USGS Gage No. 06648780). Peak streamflow values were recorded from 1965-1984 (WDEQ Table D6-1, Appendix E of this Application). The data indicate that Sage Creek is highly variable as annual peak flow rates range from 0 to 229 cubic feet per second. Sage Creek is also ephemeral, as 5 out of 19 years were dry. Surface waters in the area are used for stock watering and by wildlife.

In summary, the average annual runoff from the SRH license area is approximately 0.3 to 0.5 inches per year, with the majority of runoff occurring in response to thunderstorm events (Hodson et al., 1973). Snowmelt conditions occasionally contribute to surface water flow, but typically in an intermittent fashion.

2.2.2.4 Groundwater Modeling

Groundwater in MU-B has been affected by the dewatering and recovery of the ExxonMobil Highland open-pit and underground mine workings in the past 40 years. Different modeling efforts have been performed to investigate the groundwater flow conditions and fate transport within the aquifers (e.g., the 20-Sand, the 30-Sand, or the 40-Sand) in the area (Lewis Water Consultants, 2001; Aqui-Ver, 2011). The Aqui-Ver (2011) future steady-state model is adopted to determine the directions and velocities of groundwater flow in the aquifers. The calibrated hydraulic parameters from the Lewis Water Consultants (2001) model are used in the study. Also, the Aqui-Ver (2011) model extends the Lewis Water Consultants (2001) model to a larger area, including the Highland pit lake, and to more layers, including the 40-Sand and the 50-Sand.

The Aqui-Ver (2011) model includes six layers (Appendix B); however, layers 1 and 2 are considered inactive layers, with the other four layers representing the 50-Sand, 40-Sand, 30-Sand, and 20-Sand in the MU-B, respectively. In each layer, the model is discretized into 100 rows and 139 columns. There are a total of 83,400 cells with 54,279 of them being active. A uniform grid spacing of 200 feet is applied to the whole model area.

Constant head boundaries are used in the aquifers to represent the discharge locations (outcrops) or the regional formation dip. General head boundaries are used at model edges to incorporate the estimated pre-ISR regional groundwater flow direction (southeast/east) toward modeled discharge locations in the drainage of Box Creek. General head boundary conductance was assigned based on the hydraulic conductivity of aquifer materials and the estimated elevation and distance to known recharge and discharge areas. In addition, groundwater recharge was applied to the top active layer (50-Sand). The recharge rate was assigned with a value of 0.0044 inches/year. Also, an evaporation rate of 16.2 inches/year was assigned at the Highland pit lake.

Figures 30 and 31 show the hydraulic heads and groundwater flow directions in the 30-Sand and 20-Sand aquifers based on the future steady-state groundwater flow model. The interval of the contours is 2 feet. For the whole model area, groundwater generally flows from west to east, and two apparent discharge locations are the Highland pit lake and Box Creek. The elevation of the Highland pit lake is about 5,060 feet.

In terms of the MU-B area, the aquitard separating the 20-Sand and 30-Sand is thin or missing in the northern and central portion of MU-B, thereby resulting in areas of hydraulic connection between the two aquifers. Results suggest that the general pattern of groundwater flow in the 20-Sand and 30-Sand is predicted to be similar, with groundwater flow toward the south and southeast across the MU-B area, and the large majority of MU-B groundwater flow ultimately captured by the Highland pit lake. A groundwater flow divide is predicted to exist along the northern boundary of MU-B in both the 30-Sand and 20-Sand aquifers. Although there appears to be no actual discharge from MU-B to Box Creek, the model predicts that the regional groundwater flow north of the divide discharges into the Box Creek drainage, whereas the flow south of the divide discharges into the Highland pit lake.

MODPATH is used to calculate the groundwater velocities for the five particles which are placed at the upgradient POE wells in the 30-Sand aquifer within the MU-B. Results indicate that the average groundwater velocity ranges from 5.21 to 10.66 feet/year for the five particles along their pathlines. A more detailed description of the Hydrogeologic assessment can be found in Appendix B.

2.2.3 Conclusions of Transport Assessment

Geochemical modeling indicates that there will be a reduction in constituent concentrations in groundwater over time and over distance from the POC (source) area. Based on the findings of the transport assessment (Section 2.2), the concentrations of dissolved constituents at the modeled POE are predicted to remain below the site-specific, health risk-based standard of 31 pCi/L for radium-226+228 and 0.09 mg/L for uranium, and the regulatory-based guidelines of 0.05 mg/L and 0.01 mg/L for arsenic and selenium, respectively (Appendix A to 10 CFR 40.5C, 2012). The concentrations are predicted to remain under these health risk-based values for the duration of the 1,000-year modeling period.

2.3 Exposure Assessment

In accordance with applicable criteria in Appendix A to 10 CFR Part 40 and in NUREG-1620, this exposure assessment provides the following:

- Transport and pathway assessment.
- Identification of existing and potential future uses of water resources (potentially complete exposure pathways to groundwater) that may be affected by the MU-B.
- Evaluation of potential human and environmental exposures to hazardous constituents at the proposed POE.
- Site-specific maximum permissible levels of constituents, applicable at the identified POE, that are considered protective of human health and the environment.
- A demonstration that the proposed ACLs do not pose any threat or potential future hazards to human health or the environment.

ACLs are being proposed for the following parameters: arsenic, selenium, natural uranium, and radium-226. For the human health hazard evaluation, potential exposures to these parameters are assessed quantitatively by comparing site-specific risk-based concentrations and regulatory-based MCLs/MCVs with the modeled values at the proposed POEs.

2.3.1 Pathway Assessment

The four major components of an exposure pathway are as follows:

- A source and mechanism of constituent release to the environment.
- An environmental transport medium for the released constituents (e.g., air, water, soil).
- A point of potential human contact with the affected medium (the exposure point).
- A human exposure route (e.g., inhalation, ingestion, or dermal contact) and receptor at the exposure point.

The absence of even one of these elements renders an exposure pathway incomplete. Without exposure, there is no potential risk; therefore, the exposure assessment is a critical component of a risk assessment.

The groundwater at the POE is the boundary of the aquifer exemption. Groundwater flow paths from most of MU-B flow through another exempted aquifer and toward the Exxon open-pit mine. The Exxon Highland pit is the ultimate destination of the bulk of MU-B groundwater. Because of the nature of this Site, and because of the groundwater classification, which is discussed in further detail below, a complete pathway between humans and groundwater at this site does not exist. It is extremely unlikely that future use for the area would be residential. In addition, it is even more unlikely that a resident would drill a well into the aquifer and use that water for drinking. Residential drinking water was used as the exposure scenario due to the extremely conservative and protective, albeit unlikely, nature of that scenario.

2.3.2 Resource Classification and Water Uses

Based on a determination by WQD and LQD staff personnel, in correspondence dated November 25, 2003, Mr. Richard Chancellor, Administrator, LQD, declared that the groundwater in MU-A at the HUP met the standards for Class IV (A). The baseline water quality for MU-B was Class IV (A) based on the radium content (approximately 288 pCi/l baseline average). However, during ISR, the groundwater was classified as Class V (Mineral Commercial) (WDEQ).

The ISR zone groundwater in MU-A and MU-B was classified as IV (A) based on the following four criteria:

- There were no average concentrations of trace metals that exceeded Class 1 Domestic Use standards.
- The average baseline uranium concentration value was less than the Class I standard of 5 mg/L.
- The average TDS concentration was less than 10,000 mg/L.
- The average radium-226 concentration was 316 pCi/L, which exceeded the Class I standard of 5 pCi/L.

In accordance with the WDEQ's groundwater classification program, this last criterion establishes the pre-ISR groundwater as Class IV (Appendix C).

2.3.2.1 Existing and Potential Future Uses of Water Resources

The Powder River Basin is primarily rural in nature with abundant reserves of natural resources. Development of these natural resources, including coal, oil, gas, coal bed methane, wind energy, and uranium, drive the economic growth of the region now and presumably in the near future. Along with the energy industry, agriculture, manufacturing, and tourism also contribute to the economy of this part of Wyoming.

Converse County is a rural county that comprises approximately 2.74 million acres of land. The urban areas of Douglas and Glenrock constitute less than 2% of the total, while transportation systems account for approximately 4.5%. Historically, the area was homesteaded and dry-land farmed. Today the area remains remote and contains a low population density primarily dominated by agricultural pursuits. The majority of people living in the area reside on dispersed ranches. Sheep and cattle grazing comprise the major past and present land use in the area and at the project site. The Vollman Ranch is the only inhabited residence located within the current permit area.

From the 1970s to the early 1980s, uranium was extensively recovered from areas within and adjacent to the SRH licensed area. Both surface and underground recovery methods were employed, with the majority of uranium ore being recovered by surface recovery methods. Within the project site boundaries, there is limited disturbance from both underground and surface recovery activities. Detailed regional existing land use conditions within 50 mi of the site and the evaluation of land use within 5 mi from the center of the site are provided in Section 3.1 of the ER (NRC, 2012).

Streams within the project area are all ephemeral, and many areas drain internally to small playas. Small stock ponds have been constructed on some of the ephemeral streams. Surface waters in the area are currently used for stock watering and by wildlife. The future use for surface water in the area is not expected to change.

There are more than 3,000 groundwater rights within the license area and a 3-mi area of the license boundary. The vast majority of these groundwater rights are for wells installed for hydrologic monitoring or dewatering purposes at decommissioned conventional uranium recovery operations, and ISR activities at SRH. A small number of the groundwater rights are associated with wells installed for livestock water and irrigation purposes. Three groundwater rights are for wells used intermittently for domestic supply. Detailed discussion of water usage in the vicinity of SRH is presented in Section 3.4 of the ER (NRC, 2012).

Pre-ISR groundwater at the site was determined to be of poor quality, and was classified as Class IV and Class V. The area within the monitoring well ring is an exempted aquifer, and the water can never be used for drinking water (WDEQ, 1987). The area to the south of the mine unit is an exempted aquifer because of the presence of the first Exxon Pilot and uranium mineralization that was being considered for production (Figure 21). These factors are not expected to change in the future, making this an extremely unlikely source of drinking water.

2.3.3 Evaluation of Human Health Hazards

This section documents the assumptions, equations, and input parameters used to develop health risk-based concentrations assuming use of groundwater at the POE as a potable water source. Potential human exposure pathways to groundwater are currently non-existent, and that is not expected to change in the future. While ingestion of impacted groundwater is not currently occurring nor is it expected to occur, in an effort to be conservative, this exposure pathway was evaluated as if it was complete.

The evaluation of potential hazards involves the identification of health risk-based concentrations in groundwater for the anticipated complete exposure scenario. Next, the calculated concentrations are compared to modeled values at the proposed POE wells to assess the potential hazard should groundwater in the vicinity of the POE wells be used as a potable source.

2.3.3.1 Health Risk-Based Concentrations

Proposed health risk-based concentrations for the COCs in groundwater will be MCVs for Groundwater Protection as established in Criterion 5C of Appendix A to 10 CFR Part 40, when available and applicable, or calculated values assuming a 1×10^{-4} target risk. MCVs protective of humans using water as a drinking source have been used because there is no control of groundwater directly downgradient of the POE. This scenario is unlikely due to the current and future land use in the region. The application of MCVs or values calculated assuming household use of the groundwater at the POE is therefore a conservative and health-protective approach.

Health Risk-Based Concentrations for Arsenic

An MCV for Groundwater Protection for arsenic of 0.05 mg/L has been established in Criterion 5C of Appendix A to 10 CFR Part 40. Maximum concentrations are generally health-based concentrations that may have been adjusted to account for technological limitations. Non-cancer effects of ingestion of arsenic can include thickening and discoloration of the skin, stomach pain, nausea, vomiting, diarrhea, numbness in hands and feet, partial paralysis, and blindness. Arsenic has been linked to cancer of the bladder, lungs, skin, kidney, nasal passages, liver, and prostate.

Health Risk-Based Concentrations for Selenium

An MCV for Groundwater Protection for selenium of 0.01 mg/L has been established in Criterion 5C of Appendix A to 10 CFR Part 40. Maximum concentrations are generally health-based concentrations that may have been adjusted to account for technological limitations. Non-cancer effects of ingestion of selenium can include liver dysfunction (i.e., prolongation of clotting time and serum glutathione titer), excess selenium excretion in the breath and urine, thickened and brittle nails, hair and nail loss, lowered hemoglobin levels, mottled teeth, skin lesions, and central nervous system abnormalities (peripheral anesthesia, acroparesthesia, and pain in the extremities).

Calculated Health Risk-Based Concentrations

Health risk-based concentrations that will limit the lifetime risk to 1×10^{-4}, assuming groundwater consumption at the POE location, are necessary for natural uranium and radium-226+228.

The health risk-based concentrations which limit the lifetime cancer mortality risk associated with ingestion of a radionuclide in water to less than 1×10^{-4} are determined using an EPA (1998) risk coefficient. The lifetime acceptable radionuclide intake, I(Bq), is calculated as:

$$I\ (Bq) = R/r$$

Where

R = acceptable lifetime risk of 1×10^{-4}

r = EPA (1998) risk coefficient expressed as a probability of radiogenic cancer mortality rate per unit (Bequerel [Bq]) intake of a particular radionuclide in tap water averaged over all ages and genders

Next, the acceptable intake is used in the following equation to calculate the health risk-based concentration (C_{hb}) targeted to achieve a lifetime risk of 1×10^{-4}:

$$C_{hb} = [(I)(CF)]/[(y)(d)(Q)]$$

Where

I = lifetime radionuclide intake

CF = unit conversion factor of 27 pCi/Bq

y = exposure duration for groundwater of 30 years

d = exposure frequency of 365 days per year (EPA, 2000)

Q = 1.11 liters per day lifetime combined average intake of tap water (EPA, 1998)

Using a 30-year exposure duration to calculate the health risk-based concentration is considered very conservative because of the very low probability of use of this aquifer as a primary potable water source for 30 years.

Health Risk-Based Concentration for Natural Uranium

The toxicology of uranium has been extensively studied in both humans and animal models, and the results of these studies have been summarized in journals, government documents, and meeting proceedings. Ingestion of natural uranium can cause kidney damage. The chemotoxic effects of uranium have been observed in humans exposed under both accidental and experimental conditions, and have been quantified using animal models. Soluble uranium oxide ions complex with serum proteins and bicarbonate. The bicarbonate complex is filterable at the renal glomerulus. The uranium oxide ion dissociates within the tibular filtrate and recombines with cell surface ligands (Durbin, 1984). At low doses, it appears that renal injury is indicated by urinary biochemical changes rather than overt illness; the association between the biochemical indicators and clinically observable injury is not well defined.

Natural uranium has not been demonstrated to be a human carcinogen. There is no direct evidence that ingestion of uranium induces cancer in humans (Mays et al., 1985), and EPA (1985) reports that ingestion of natural uranium has not been shown to cause cancer or bone marrow damage in laboratory animals. High specific-activity uranium isotopes, U-232 and U-233, have induced bone sarcomas in mice (National Research Council, 1988). The designation of natural uranium as a Class A carcinogen appears to be based on the qualitative and quantitative similarity in the results of animal studies involving U-232/U-233 and Ra-226, in combination with the fact that EPA considers all radionuclides to be Class A carcinogens.

The NRC effluent limit for natural uranium in water specified in Appendix B of 10 CFR 20 to control dose to an individual member of the general public is 300 pCi/L. This effluent limit is based on identifying a concentration in drinking water that will limit radiation dose to the NTC's 0.1 rem/year acceptable dose limit for individual members of the general public. The health risk-based concentration for radiotoxicity associated with natural uranium for this petition was developed using risk coefficients from FGR 13 (EPA, 1998) for ingestion of tap water.

FGR 13 identifies risk coefficients for ingestion of uranium isotopes in tap water that are expressed as the probability of radiogenic cancer mortality per unit intake where the intake is averaged over all ages and genders. However, while FGR 13 does not specify a risk coefficient for natural uranium, the mortality risk coefficients for U-232, U-235, and U-238 are 1.24E-09 Bq^{-1}, 1.21E-09 Bq-1, and 1.13E-09 Bq^{-1}, respectively. A risk coefficient for natural uranium of 3.29E-09 Bq-1 was calculated based on activity ratios of U-234, U-235, and U-238 in natural uranium at 0.4889, 0.02218, and 0.4998, respectively. Then the risk coefficient for Th-234, a short-lived decay product of U-238, was added to the U-238 risk coefficient because Th-234 activity will build into equilibrium within a few months. The final risk coefficient for natural uranium used to develop the health risk-based concentration was 3.46E-09 Bq^{-1}.

Using the calculated risk coefficient, the health risk-based concentration for natural uranium was calculated as follows:

$I(Bq) = R/r$

Where: $R=1E-04$

$r = 3.46E-09Bq^{-1}$

$I = 1E-04/3.46E-09 = 2.89E+04$ Bq

The health risk-based concentration for natural uranium, calculated using the parameters identified above, that will limit the lifetime risk associated with exposure in tap water to 1 x 10^{-4} is:

$Chb = I/(ED)(EF)(IW)$

Chb = [(2.89E+04 bq)(27 pCi/Bq)]/[(30 yr)(350 day/year) (1.11 L/day)] = 67 pCi/L

Thus, 67 pCi/L is the limiting activity-based concentration due to radiotoxicity calculated for this ACL application, which is equivalent to a mass-based concentration of 0.09 mg/L for natural uranium. The WDEQ and Criterion 5C of Appendix A to Part 40 CFR do not provide drinking water protection values for uranium. This value is not more restrictive than EPA's MCL of 0.03 mg/L, however uranium concentrations have been demonstrated to be at a maximum concentration of 0.0001 mg/L by the time groundwater reaches the POE. The 0.09 mg/L value is more protective than NRC's 300 pCi/L effluent limit for licensed facilities. This groundwater concentration, 67 pCi/L (0.09 mg/L), at the POE well would be protective of human health and the environment, and would ensure a lifetime risk below the 10^{-4} target level.

Health Risk-Based Concentration for Radium-226+228

There are currently three standards for Ra-226+228 in groundwater. The EPA has identified 5 pCi/L as the MCL for Ra-226+228. The NRC uses an MCV of 5 pCi/L (10 CFR 40 Appendix A) for Ra-226 and Ra-228 combined, and the WDEQ standard is also 5 pCi/L for the combined value.

The radiological characteristics of Ra-226 and Ra-228 indicate that a combined value for the two isotopes may not be the best approach to developing a protective value. Ra-226 is an alpha emitter, while Ra-228 is a beta emitter. In addition, data collected from MU-B groundwater at the site only contains values for Ra-226. The approved water analysis list for the baseline characterization of SRH did not include Ra-228, gross alpha, or gross beta, therefore these constituents have not been analyzed for and no data are available.

Although there are no Ra-228 data for groundwater in the MU-B, data from Mine Unit 4 (MU-4) and Mine Unit K (MU-K) MP wells are available, although MU-4 and MU-K are a considerable distance from MU-B, 10.7 and 8.1 mi, respectively. All of the uranium production at the SRH property is from the Fort Union Formation and are in the same depositional environment. The data from MU-4 and MU-K have been reviewed to estimate a likely percentage of Ra-228 in the total radium in the MU-B in order to calculate a health risk-based standard for Ra-226+228. Available data from MU-4 include baseline and post-mining data, collected in 1998 and 2010, respectively. MU-4 baseline Ra-226 values range from 901.4 to 1012 pCi/L, with the average being 951.9 pCi/L. Ra-228 values range from 0.5 to 6.5 pCi/L, with the average being 3.9 pCi/L. Using these baseline averages, Ra-228 is approximately 0.4% of the total baseline average Ra-226+228 value of 955.8 pCi/L. The MU-4 post-mining Ra-226 and Ra-228 values are 2,920 and 15.9 pCi/L, respectively. Using these baseline values, Ra-228 is approximately 0.5% of the total post-mining Ra 226+228 value of 2935.9 pCi/L. Available data from MU-K are from baseline samples collected in 2010. MU-K average baseline Ra-226 and Ra-228 values are 92.5 and 3.4 pCi/L, respectively, with Ra-228 being approximately 3.8% of the total average Ra226+228 value of 95.9 pCi/L.

The highest percentage of Ra-228 in total radium comes from the baseline average in MU-K of 3.8%. We can safely assume, and this will only make our health risk-based concentration more conservative, that the percentage of Ra-228 in total radium will increase post-mining in a similar manner to the MU-4 (0.1%). In order to be conservative, post-mining percentages of Ra-228 in total radium for MU-K have been estimated not at 3.9%, but at 6%.

Neither the EPA MCL nor the NRC MCV (both combine Ra-226 and Ra-228) are proposed for use as the health risk-based concentration for this assessment. Instead, a health risk-based concentration will be calculated for each radium isotope using risk coefficients presented in FGR 13. After a risk-based concentration has been calculated for each radium isotope, a combined health risk-based concentration that ensures a lifetime risk of mortality due to ingestion of Ra-226+228 in groundwater of 1 x 10^{-4} will be developed. The combined value will be based on the conservatively estimated fractions of Ra-226 and Ra-228 in the MU-B as established by reviewing available data from MU-4 and MU-K. The resulting combined value will be proposed as the ACL.

As discussed in Section 2.1.5.3, Ra-226 typically comprises more than 90% of total radium and is generally immobile in groundwater (Brookins, 1988). Based on the risk coefficients, Ra-228 poses a 3.8 times higher cancer mortality risk per unit intake than Ra-226. The health risk-based concentration for Ra-226 was calculated using the 7.17E-09 mortality risk coefficient specified in FGR 13 for ingestion of tap water containing Ra-226. The health risk-based concentration was targeted to achieve a 10^{-4} risk as follows:

I = (1.0E-04)/(7.17E-09 Bq-1)= 1.4E+04 Bq

C_{hb} = [(1.4E+04 Bq)(27 pCi/Bq)]/[(30 years)(365 days/year)(1.11 l/day)= 31 pCi/L

The health risk-based concentration for Ra-228 was calculated using the 2.0E-08 mortality risk coefficient specified in FGR 13 for ingestion of tap water containing Ra-228. The health risk-based concentration was targeted as follows to achieve a 10^{-4} risk:

I = (1.0E-04)/(2.0E-08 Bq_{-1})= 5.0E+03 Bq

C_{hb} = [(5.0E+03 Bq)(27 pCi/Bq)]/[(30 years)(350 days/year)(1.11 l/day) = 12 pCi/L

As shown above, the health risk-based concentrations for Ra-226 and Ra-228 in groundwater were calculated to be 31 pCi/L and 12 pCi/L, respectively. Separate health risk-based concentrations were developed to account for the different radiological characteristics; specifically, Ra-226 is an alpha emitter while Ra-228 is a beta-emitter. Evaluation of the groundwater data collected from other mine units in the area indicate that the radium composition varies from 99.6% to 96.2% Ra-226 and only 0.4% to 3.8% Ra-228. The source does not contain significant concentrations of Ra-228, probably because Ra-228 is a thorium series (Th-232) radionuclide. The low concentration of Ra-228 in MU-B groundwater suggests that Th-232 concentrations are low in SRH uranium ore bodies. Ra-228 is not part of either of these decay series. Toxicological data indicate that Ra-228 presents a higher cancer risk per unit intake than Ra-226. It was conservatively assumed that the post-mining average Ra-228 was 6% of the total radium.

Considering the individual health risk-based concentrations of 31 pCi/L for Ra-226 and 12 pCi/L for Ra-228 calculated above, and the conservative assumption that the groundwater contains 94% Ra-226 and 6% Ra-228, the combined health risk-based concentration designed to limit the lifetime mortality risk to 1 x 10^{-4} was calculated as follows:

$[C_{Ra\text{-}228}/C_{hb\ Ra\text{-}228}] + [C_{Ra\text{-}226}/C_{hb\ Ra\text{-}226}] = 1.0$

Where: $C_{Ra\text{-}228}$ = limiting Ra-228 concentration in pCi/L (6% or 0.06 of the Ra-226 limiting concentration based on fraction in the source)

$C_{hb\ Ra\text{-}228}$ = Ra-228 health risk-based concentration of 12 pCi/L

$C_{Ra\text{-}226}$ = limiting Ra-226 concentration in pCi/L

$C_{hb\ Ra\text{-}226}$ = Ra-226 health risk-based concentration of 31 pCi/L

$[(C_{Ra\text{-}226}*0.06)/12] + [C_{Ra\text{-}226}/31] = 1.0$

$C_{Ra226} = 29$ pCi/L

$C_{Ra\text{-}228} = 0.06*22$ pCi/L

$C_{Ra\text{-}228} = 1.74$ pCi/L

Using these data, the combined Ra-226 and Ra-228 health risk-based concentration that limits the lifetime cancer risk to 10^{-4} was calculated as follows:

$= C_{Ra226} + C_{Ra\text{-}228} = C_{hb\ Ra\text{-}226+228}$

29 pCi/L + 1.74 pCi/L = 31 pCi/L.

Comparison of Health Risk-Based Concentrations to Other Potentially Applicable Standards and Modeled Values at the Proposed POE

The health risk-based concentrations for water in the 30-Sand were compared to the WDEQ Chapter 8 (WDEQ, 2005) groundwater standards to ensure that the proposed risk-based concentrations were protective. The risk-based concentrations were compared to available WDEQ standards for domestic water supply. The health risk-based concentrations were also compared to Appendix A to Part 40 CFR and to relevant EPA MCLs. This comparison is presented in Table 5 below.

Table 5

Health Risk-Based Concentrations and Regulatory Standards for Constituents of Concern

Constituent	Health Risk-Based Concentration	WDEQ Domestic Water Supply	Appendix A to Part 40 CFR (MCVs)	EPA MCLs
Arsenic	0.05 mg/L	0.05 mg/L	0.05 mg/L	0.01 mg/L
Radium-226+228	31 pCi/L*	5 pCi/L	5 pCi/L	5 pCi/L
Uranium	0.09 mg/L	NA	NA	0.03 mg/L
Selenium	0.01 mg/L	0.05 mg/L	0.01 mg/L	0.05 mg/L

*Health risk-based concentration for Ra-226+228 include an estimated value for Ra-228 based on available data from other mine units.

Geochemical modeling was performed to estimate concentrations of constituents in groundwater at the proposed POE. See Section 2.2 and Appendix A for a detailed discussion of the geochemical model. Table 6 compares health risk-based concentrations of constituents in groundwater to modeled concentrations at the proposed POE. In all cases, modeled concentrations are below the health risk-based concentrations.

Table 6
Comparison of Health Risk-Based Concentrations to Modeled Values at the Proposed POE Wells

			Maximum Predicted POE Concentrations[a]			
Upgradient Well	**POC Well**	**POE Well**	**Selenium (mg/L)**	**Uranium (mg/L)**	**Arsenic (mg/L)**	**Radium-226+228**[b] **(pCi/L)**
M-56	MP-12	M-24	$4.0x10^{-5}$	$1x10^{-4}$	0.00157	9.57
M-55	MP-16	M-24	$1.2x10^{-5}$	$1x10^{-4}$	0.00211	9.89
M-63	MP-21	M-36	$1.1x10^{-5}$	$1x10^{-4}$	0.016	5.43
M-45	MP-27	M-38	$1.4x10^{-5}$	$1x10^{-4}$	0.00476	15.12
M-44	MP-26	M-37	$1.4x10^{-5}$	$1x10^{-4}$	0.00145	1.78
Health Risk-Based Value			0.01	0.09	0.05	31

Notes:

[a] Based on post-restoration monitoring data collected in 2011

[b] Simulations were conducted to estimate for the incremental activity increase due to Ra-228. These calculations are detailed in Appendix E.

2.3.3.2 *Human Health Hazard Assessment Summary*

Modeled groundwater concentrations at the POE for COCs are below the human health risk-based concentrations. This indicates that the proposed ACLs do not pose any present or potential future hazards to human health.

2.3.4 Environmental Hazard Assessment

The potential for environmental exposures to groundwater in the vicinity of the facility is expected to be limited to non-existent due to the lack of accessible permanent surface water bodies. No significant environmental or agricultural impacts can be postulated associated with exposure to groundwater containing constituents at the concentrations proposed in this ACL application because the impacted aquifer does not discharge to an accessible surface water source in the vicinity of the facility. The Highland pit lake is part of the proposed U.S. Department of Energy (DOE) withdrawal area for the Exxon Tailings. While the water from MU-B may eventually reach the Exxon pit, it is going to travel through a reduced ore body and should precipitate COCs before reaching the pit lake. Therefore, this environmental hazard evaluation is semi-qualitative in nature. The health risk-based concentrations protective of human health should be adequate to ensure that the health of livestock and indigenous wildlife is sufficiently protected. Therefore, the proposed health risk-based concentrations were compared to benchmark concentrations expected to cause minimal effects on wildlife populations.

2.3.4.1 Ecological Benchmark Concentrations for Inorganic Constituents

The toxicological benchmarks for inorganic constituents are based on no observed adverse effects levels (NOAELs) for representative mammalian and avian wildlife species assuming the animal receives 100% of its water from one source. The NOAELs, presumed to be non-hazardous to the surrounding biota, were derived for the DOE's Oak Ridge facility and presented by Sample et al. (1996). The collection of benchmark values indicated that white-tailed deer are the most sensitive species for which data are available. The benchmark water concentrations protective of white-tailed deer are:

Arsenic	0.292 mg/L
Selenium	0.857 mg/L

The proposed human health risk-based concentrations for arsenic (0.05 mg/L) and selenium (0.01 mg/L) are below the NOAEL-based toxicological benchmark values listed above. Therefore, the proposed human health risk-based concentrations for groundwater are considered protective of the environment for these constituents.

2.3.4.2 Ecological Benchmark Concentrations for Radionuclide Parameters

The health risk-based concentrations were compared to benchmarks for radionuclides established for the Rocky Flats Environmental Technology Site (Higley, 1995). The water concentrations are based on a maximum radiation dose to wildlife of 100 mrad per day. This dose rate represents a NOAEL for chronic radiation exposure to terrestrial and aquatic animals. Per Higley (1995), this maximum dose rate was derived based on the findings of an International Atomic Energy Agency technical report. The report stated that "There is no convincing evidence from the scientific literature that chronic radiation dose rates of 1 mGy/day or 100 mrad/day will harm animal or plant populations." The benchmark radionuclide concentrations used here were calculated considering the allowable dose rate, daily intake, fraction of the nuclide assimilated, and the body mass of the animal. The benchmark concentrations for water for terrestrial species are as follows:

Natural uranium	7 mg/L
Ra-226	250 pCi/L

The calculated health risk-based concentrations for natural uranium (0.09 mg/L) and Ra-226+228 (31 pCi/L) are below the ecological benchmarks presented above, indicating that the health risk-based concentrations are protective of the environment as well as human health.

2.3.4.3 Environmental Hazard Assessment Summary

The health risk-based concentrations calculated for the constituents of interest are all below the environmental benchmarks protective of wildlife. This demonstrates that the proposed health risk-based concentrations do not pose any present or potential future hazards to the environment. NRC guidelines (1996) for ACL applications specify that the persistence and permanence of adverse effects must be considered in the environmental hazard evaluation. Because there is not a complete pathway between the groundwater source and potential ecological receptors, and because the human health risk-based concentrations of COCs are demonstrated to be below the environmental benchmarks for wildlife, no adverse environmental impacts are anticipated.

2.3.5 Hazard Assessment Summary

An aquifer exemption prohibits using groundwater at the site as drinking water by humans now and in the future. This exemption renders the pathway between humans and groundwater incomplete and no exposure or risk is possible. Ecological receptors also do not have a complete pathway to this groundwater source, however the aquifer exemption does not apply to irrigation or livestock watering. Therefore, the environmental assessment was performed to comply with Appendix A 10 CFR Part 20 and estimate potential risk to ecological receptors from ingesting groundwater from the site. This ACL demonstration presents health risk-based concentrations for groundwater based on an acceptable cancer risk of 1×10^{-4} and/or a hazard quotient of 1 for non-carcinogenic constituents considering the protection of human health at present and in the foreseeable future POE. The health risk-based concentrations are not intended to be drinking water standards for the general public, but are site-specific values shown to present no substantial health risk. The risk-based concentrations take into account the very low probability of exposure to groundwater, the limited population that could potentially be exposed, and reasonable estimates of health risk. The poor quality of local, ambient background groundwater, as well as the surrounding aquifer exemptions, further reduces the possibility that groundwater will be used as a potable water source. The human health risk-based concentrations were compared to available ecological benchmarks considered protective of wildlife. The human health risk-based concentrations calculated for the constituents are more restrictive than concentrations that might be of concern for ecological receptors, and are therefore also considered protective of the environment. The concentrations modeled for all constituents of interest in groundwater at the POE are below the human health risk-based concentrations, indicating that the risk-based concentrations do not pose any present or potential future hazards to human health.

3.0 CORRECTIVE ACTION ASSESSMENT

3.1 Description of Corrective Action Program

The Corrective Action Program (CAP) for MU-B was carried out in accordance with the general directions of the Reclamation Plan contained in Permit No. 603 and the requirements of Chapter 11 of WDEQ's LQD Rules and Regulations (Non Coal – In-Situ Mining). To accomplish groundwater restoration, Cameco employed BPT by using a combination of recognized techniques, including GWS, RO treatment, and the addition of chemical and biological reductants. Although restoration techniques and results are summarized in the text below and in Table 7, more detailed versions of these descriptions, as well as reasoning for some of the techniques, can be found in the Mine Unit B Groundwater Restoration Completion Report (ML091831100).

3.1.1 Groundwater Sweep

The GWS phase of MU-B restoration began in July 1991 with the cessation of active ISR. GWS consists of significantly over producing from the affected ISR zone so that a steep cone of depression is created within the sandstone formation. Producing a steep cone of depression causes the influx of any ISR solutions that may have flared beyond the ISR zone during production. Initially in MU-B, the GWS phase of restoration consisted of pumping from the ISR zone without re-injection. This continued until the first RO unit was brought on line in MU-B in July 1997. GWS continued, however, throughout the groundwater treatment and re-injection phase by taking an average wellfield bleed of 23% through both RO rejection rates and through the pumping of selected production wells without re-injection. A cumulative water volume of approximately 2.9 PVs was withdrawn from the 30-Sand during the GWS phase of restoration with additional GWS used for hydraulic control during the groundwater treatment phase of restoration.

3.1.2 Groundwater Treatment and Re-Injection

The main objective of this phase of restoration was to remove TDS from the groundwater by pumping the groundwater to an RO unit and then re-injecting the clean water (permeate). The first operational RO unit in MU-B was RO 2, which began trial operations on July 1, 1997. This RO unit treated the southern portion of MU-B. Shortly thereafter, RO 1 was brought on line to treat the northern portion of MU-B. A de-carbonator unit was associated with RO 1 and was used to remove residual carbon dioxide from the RO permeate prior to re-injection. Finally, RO 3 was used to treat the western MU-B area. The treatment phase of restoration ended on June 30, 2004, when the last RO unit was shut down. A total of 13.5 PVs were treated by RO. An additional 2.3 PVs of groundwater were withdrawn from the 30-Sand via the bleed stream from each of the on line RO units, bringing the total cumulative bleed from the MU-B pattern areas during the GWS and groundwater treatment and re-injection phases of the restoration to 5.2 PVs.

There are four reasons for the large number of PVs treated during this phase of restoration, which will not be encountered in future restoration operations. First, the B 13/14 area was flushed with permeate and then re-circulated with the reductant sodium sulfide. The procedure was successful in decreasing selenium concentrations, but caused a significant increase in TDS. Therefore, this area was flushed again with permeate following the reductant addition.

The second reason for the increased RO treatment PVs was the time taken to develop a suitable procedure for adding a reductant to the formation. Although hydrogen sulfide was used during the restoration of MU-A, Cameco determined that the risk to its employees was too great to continue using it as a reducing agent. Sodium sulfide was the reductant chosen as a replacement for hydrogen sulfide. Following the B 13/14 re-circulation test, Cameco tested the use of sodium sulfide by adding it to the RO permeate injection stream. These tests extended the amount of time that some patterns remained on line that otherwise would have been shut in following the completion of permeate flush.

The third reason for increased RO treatment is that the injection of RO permeate proved to be the most effective way to add the nutrients used during the bioremediation procedure. Therefore, a significant number of patterns that had been previously permeate-flushed were retreated by RO to enhance the bioremediation process.

The fourth reason for increased RO treatment is that much of the infrastructure (i.e., header houses) had been removed from MU-B prior to the start of restoration activities. Many patterns that had been cleaned by permeate flush continued to operate longer than would normally be required while new infrastructure was being installed. In future restoration operations, the infrastructure will be in place, which will make restoration operations much more efficient.

3.1.3 Reductant Addition

RO treatment is an effective method for removing TDS from groundwater; however, it is not the preferred method for decreasing the concentration of oxidized metals such as selenium. The oxidation state of the formation must be returned to reducing conditions to achieve this goal. In 1999, Cameco began experimenting with adding the reductant sodium sulfide to the permeate injected from RO 1. The addition of this reductant to the injection stream caused injection well plugging problems and was only moderately successful in decreasing selenium concentrations. A total of 1.09 PVs were treated with sodium sulfide, primarily in the northern portion of MU-B. An additional 0.3 PVs were treated through re-circulation in the B 13/14 header house area.

In August 2001, Cameco began experimenting with bioremediation technology as a reducing agent. This method proved to be more effective than sodium sulfide in creating reducing conditions within the formation and was eventually applied to the entire MU-B wellfield area. Bioremediation was first applied in the western portion of MU-B on December 1, 2003, and ended in the northern portion of MU-B on June 29, 2004. Bioremediation was also applied to portions of the southern MU-B area in the spring of 2004. A total of 0.88 PVs were treated using this method.

3.1.4 Re-Circulation Patterns

The "Re-circ" heading listed in Table 7 includes the total gallons of groundwater that were circulated during three different operations. Between July 31, 1999, and June 30, 2000, groundwater was re-circulated in a closed loop in header house B 13/14 to test the effectiveness of sodium sulfide as a reductant. Between August 31, 2001, and September 30, 2002, groundwater was re-circulated in a closed loop in header house B 16E during the initial bioremediation test. During the final time period between August 31, 2003, and June 30, 2004, additional production wells were brought on line to speed up the reduction process. The groundwater flow from these additional production wells bypassed the RO units, but the groundwater re-injected to these wells contained either nutrients for the bioremediation process or sodium sulfide.

Table 7
MU-B Annual Water Volumes

DATE	GWS	RO Feed	Re-circ	Total	Bioremediation	Sodium Sulfide	Bleed
	(gallons)						
12/31/91	13,082,020	0	0	13,082,020	0	0	13,082,020
12/31/92	32,226,033	0	0	32,226,033	0	0	32,226,033
12/31/93	22,536,659	0	0	22,536,659	0	0	22,536,659
12/31/94	20,082,555	0	0	20,082,555	0	0	20,082,555
12/31/95	24,782,943	0	0	24,782,943	0	0	24,782,943
12/31/96	15,859,395	0	0	15,859,395	0	0	15,859,395
12/31/97	8,067,492	30,934,260	0	39,001,752	0	0	14,077,637
12/31/98	4,457,736	77,501,768	0	81,959,504	0	0	16,033,170
12/31/99	7,247,930	98,345,921	12,089,326	117,683,177	0	12,089,326	24,618,956
12/31/00	11,355,002	123,097,965	6,684,660	141,137,627	0	6,684,660	33,127,985
12/31/01	5,915,682	124,668,657	3,940,612	134,524,951	0	0	30,424,835
12/31/02	3,476,960	183,123,445	4,703,121	191,303,526	0	0	34,114,762
12/31/03	8,590,442	146,019,678	6,586,153	161,196,273	4,623,646	33,953,179	29,259,734
6/30/04	2,538,556	45,208,427	22,391,088	70,138,071	49,302,402	14,492,248	10,823,771
Totals	**180,219,405**	**828,900,121**	**56,394,960**	**1,065,514,486**	**53,926,048**	**67,219,413**	**321,050,455**
DATE	**GWS**	**RO Feed**	**Re-circ**	**Total**	**Bioremediation**	**Sodium Sulfide**	**Bleed**
	(pore volumes)						
12/31/91	0.21	0.00	'0.00	0.21	0.00	0.00	0.21
12/31192	0.52	0.00	0.00	0.52	0.00	0.00	0.52
12/31/93	0.37	0.00	0.00	0.37	0.00	0.00	0.37
12/31/94	0.33	0.00	0.00	0.33	0.00	0.00	0.33
12/31/95	0.40	0.00	0.00	0.40	0.00	0.00	0.40
12/31196	0.26	0.00	0.00	0.26	0.00	0.00	0.26
12/31/97	0.13	0.50	0.00	0.63	0.00	0.00	0.23
12/31198	0.07	1.26	0.00	1.33	0.00	0.00	0.26
12/31/99	0.12	1.60	0.20	1.91	0.00	0.20	0.40
12/31100	0.18	2.00	0.11	2.29	0.00	0.11	0.54
12/31/01	0.10	2.03	0.06	2.19	0.00	0.00	0.49
12/31/02	0.06	2.98	0.08	3.11	0.00	0.00	0.55
12/31/03	0.14	2.37	0.11	2.62	0.08	0.55	0.48
6/30/04	0.04	0.73	0.36	1.14	0.80	0.24	0.18
Totals	**2.93**	**13.47**	**0.92**	**17.32**	**0.88**	**1.09**	**5.22**

3.2 Results of the Groundwater CAP

3.2.1 Post-Restoration Sampling

Post-restoration sampling was performed in accordance with WDEQ Permit No. 603 permit requirements and WDEQ, LQD Guideline 4 for In-Situ Mining. The groundwater restoration success is based on the average groundwater quality at MP wells used to determine baseline. Beginning on June 28, 2004, the MU-B MP wells and five perimeter monitoring wells were sampled, and the samples were sent to Energy Laboratories in Casper, Wyoming, for full Guideline No. 8 analysis. The five perimeter monitoring wells were sampled because they had been on excursion status either during production or during restoration (Appendix C). During the six-month stability period, MU-B was sampled four times per the WDEQ permit and the restoration plan. Two of the samples were the agreed short constituent list and the other two were full constituent Guideline No. 8 samples. Additionally the M, MO, and MU wells were sampled once every two months as required by the WDEQ Permit to Mine. Additional selective post-restoration samples were collected to answer questions about specific monitoring wells and wells that had elevated arsenic concentrations. A final round of uranium samples were collected at the request of the LQD on January 2007. Additional sampling was conducted in 2011 to collect current information on the COCs for the ACL geochemical model.

3.2.2 Constituent Concentration Trends

The average concentrations for radium-226, uranium, arsenic, and selenium at MP wells from 1987–2011 at MU-B were plotted to better understand any trends in groundwater concentrations. These concentration trend plots are shown in Figures 32 and 33. Average concentration plots were similar for radium-226, selenium, and uranium, exhibiting a sharp increase in concentration between the 1987 (baseline) period and the 1991 (end of ISR) period. The initial rise is followed by a fairly sharp decrease between the 1991 and 2004 (end of restoration) period to levels that are near baseline concentrations. Finally, concentrations during the stability monitoring period (2004) were slightly elevated from those at the end of restoration for uranium, selenium, and radium-226. It should be noted that concentrations may vary between sampling events, and that the rise between the stability monitoring period and post stability samples may be related to aquifer conditions that are still attempting to reach equilibrium. Arsenic has exhibited a distinctly different trend than uranium and radium-226. Beginning in 1987, concentrations slowly rose to 2004 levels. When samples were taken again in 2011, the levels of arsenic in the groundwater had begun to decrease as shown in Figure 33.

3.2.3 Post-Restoration Groundwater Quality

Sampling in 2004 revealed that the overall restoration effort resulted in the following:

- 34 parameters were analyzed in 20 MP wells to evaluate the restoration effort. Eleven parameters exceeded the baseline plus one standard deviation (Ca, Mg, HCO_3, TDS, Cond, Alk, Fe, Mn, U, Se, and As).
- Radium did not meet the Wyoming Class I standards at the end of stability.
- The Class I uranium standard when the mine unit was put into production was 5 mg/L. The LQD evaluated the restoration effort for MU-B against the standards that were in place at the time that the permit was issued. (Wyoming currently does not have a Class I standard for uranium).
- Selenium concentrations were above baseline levels, but met Class I standards.
- Arsenic was above the Class I standard at the end of stability, but the concentration declined during post-stability monitoring and met the Class I standard of .05 mg/L.

The State of Wyoming approved Cameco's restoration effort on March 31, 2008, stating that MU-B had been restored to "Class of Use" using BPT.

3.3 Feasibility of Alternate Groundwater Corrective Actions for MU-B

3.3.1 Continuation of Previous Corrective Actions

Cameco believes that continuing active restoration in an effort to return constituent concentrations to baseline in MU-B would be an excessive use of limited groundwater resources for a potentially very limited benefit to protect the health and safety of the general public and the environment. Aquifer exemptions prohibit the use of groundwater at the site for drinking water now and in the future. Modeled groundwater concentrations at the POE for COCs are below the human health risk-based concentrations. The following sections of this document provide the reasoning behind the statement that the continuation of corrective actions to restore groundwater quality to baseline concentrations in MU-B is neither practicable nor reasonably achievable.

3.4 Corrective Action Costs

3.4.1 Cost of Current CAP for MU-B

The MU-B restoration costs were based on the following information and assumptions:

- Actual MU-B restoration costs for the years 2002–2011.
- Estimated restoration costs the years 1997–2001.
- Estimated GWS costs for the years 1991–1997.

A brief discussion of the assumptions used to report or calculate the costs is included in the following sections. Costs are tabulated in Tables 8-11.

3.4.1.1 Actual Restoration Costs 2002–2011

Actual restoration costs for the years 2002 through 2011 were captured from Cameco's accounting system (Table 8). Costs for prior years were not available. The costs for the time period include MU-A; however, the MU-A costs for the time period were minimal because the active restoration of MU-A was completed in 1999, and the only ongoing restoration activities from 1999 until the acceptance of restoration by WDEQ in November 2003 were groundwater sampling activities. Groundwater sampling represented minor costs in the MU-A – MU-B area because of the small size of MU-A. MU-A costs were removed where they could easily be accounted for in the historical information.

Table 8
Cameco Resources - Smith Ranch Highland Operation
MU-B Restoration Costs for the Years 2002-2011

Year	7702 - Restoration MU-B	7772 - Plug and Abandon MU-B	7781 - Reclamation MU-B	Total by Year MU-B
2011	21,276.22	-	69,846.35	91,122.57
2010	6,105.31	-	3,117.15	9,222.46
2009	337.72	1,540.71	18,426.74	20,305.17
2008	117.86	3,250.43	12,023.32	15,391.61
2007	-	555.78	27,158.28	27,714.06
2006	1,518.70	277.86	43,846.17	45,642.73
2005	146,406.47	92,100.79	-	238,507.26
2004	476,560.39	-	-	476,560.39
2003	712,449.63	-	-	712,449.63
2002	282,754.96	-	-	282,754.96
Total	**1,647,527.26**	**97,725.57**	**174,418.01**	**1,919,670.84**

3.4.1.2 Estimated Restoration Costs for the Years 1997–2001

Actual restoration costs for the years 1997–2001 are not available; therefore, restoration costs have been estimated using the actual operating data from the years 2002–2004 (Table 9). The time period selected for the estimate consists of the last years of active restoration on MU-B. The actual costs were divided by the total number of gallons treated during the year. The total treated water cost was averaged over the three years to provide a total cost of handling RO operation and GWS and disposal. The average restoration cost was applied to the volume of water handled from 1997–2001, which was predominantly RO sweep with lesser amounts of GWS applied. The estimate was applied only to the volume of water from the MU-B restoration effort.

Table 9
MU-B Annual Water Volumes

Date	Reverse Osmosis Feed	Estimated Fully Loaded Restoration Costs
12/31/1997	30934260	$129,924
12/31/1998	77501768	$325,507
12/31/1999	98345921	$413,053
12/31/2000	123097965	$517,011
12/31/2001	124668657	$523,608
	Total	**$1,909,104**

Note: Restoration Costs are Based on the Average Cost of Restoration for the Years 2002-2004:

Year	Annual Restoration Cost	Annual Restoration Gallons	Cost Per Gallon
2002	$282,755	191303526	0.0015
2003	$712,450	161196273	0.0044
2004	$476,560	70138071	0.0068
		Average cost per gallon handled:	**0.0042**

3.4.1.3 Estimated Restoration Costs for the Years 1991–1996

The restoration activities for the years 1991–1996 consisted predominantly of GWS in MU-B. The cost for this period was estimated using the pumping cost of GWS (Table 10). The cost of labor to run the GWS is difficult to capture from existing records. The pumping and disposal costs are a calculation of the power required to move the water from the ground to disposal. The cost estimate for this period is very conservative because it does not include any labor or materials used.

Table 10
Estimated GWS Cost for MU-B Restoration

	GWS					Land Application						
Date	GWS (gal)	Submersible (gpm)	Submersible (hp)	Submersible (kW-h)	Pumping Cost	Land Application Pumping (gal)	Land Application Capacity (gpm)	Land Application Run Time (hrs)	Land Application Pumping (hp)	Land Application Pumping (kW-h)	Pumping Cost	GWS and Land Application Power Costs
12/31/1991	13,082,020	25	7	45744.72	$1,830	13,082,020	130	1,677	35	43791	$1,752	$3,581
12/31/1992	32,226,033	61	18	117629.28	$4,705	32,226,033	130	4,132	35	107875	$4,315	$9,020
12/31/1993	22,536,659	43	13	84954.48	$3,398	22,536,659	130	2,889	35	75440	$3,018	$6,416
12/31/1994	20,082,555	38	11	71884.56	$2,875	20,082,555	130	2,575	35	67225	$2,689	$5,564
12/31/1995	24,782,943	47	14	91489.44	$3,660	24,782,943	130	3,177	35	82959	$3,318	$6,978
12/31/1996	15,859,395	30	9	58814.64	$2,353	15,859,395	130	2,033	35	53088	$2,124	$4,476
Total			1991-1996 Total		$18,821						$17,216	$36,035

Notes:

GWS occurred 365 days per year.
All submersible pumps were 10 gpm, 3 hp.
Pipeline system to PSR 2 installed for 2001.
gal = gallon
gpm = gallons per minute
hp = horsepower
hrs = hours
kW-h = kilowatt hour

3.4.1.4 *Total Costs of Restoration Effort with Calculated Inflation*

Finally, the costs of restoration for the years of 1991 – 2011 were combined and calculated with inflation, and are presented below in Table 11.

Table 11
MU-B Restoration Costs by Year, 1991 – 2011

Year	Total Cost Dollars	Note	Total Cost with Inflation Dollars
1991	$3,581		$5,986
1992	$9,020		$14,637
1993	$6,416		$10,109
1994	$5,564		$8,547
1995	$6,978		$10,424
1996	$4,476	1	$6,495
1997	$129,924		$184,292
1998	$325,507		$454,637
1999	$413,053		$564,447
2000	$517,011		$683,532
2001	$523,608	2	$673,101
2002	$282,755		$357,826
2003	$712,450		$881,514
2004	$476,560	3	$574,352
2005	$238,507		$278,030
2006	$45,643		$51,544
2007	$27,714		$30,430
2008	$15,392		$16,276
2009	$20,305		$21,547
2010	$9,222		$9,628
2011	$91,123	4, 5	$92,226
Total	**$3,865,000**		$4,929,580
Total (1991-2004)			$4,429,899

Notes:

1. Actual restoration costs are not available. Restoration costs for the years 1991–1996 only account for the electrical costs for GWS.
2. Actual restoration costs are not available. Restoration costs were estimated by using the average operating costs from the years 2002–2004, the years of greatest restoration activity.
3. Active restoration was completed 6/30/2004.
4. Restoration costs for 2005–2011 include well abandonment, site maintenance, regulatory compliance, and regulatory reporting costs.
5. Total pounds of uranium produced from MU-A/B was 1.67 million pounds.

3.4.2 Cost for Continuation of Previous Corrective Actions

The restoration of MU-B resulted in the pumping, treatment, and handling of over one billion gallons of water. The mitigation plan to further lower the COCs identified in this ACL application would require minimum initial expenditures of nearly $10 million, as detailed below:

- $750,000 for a new 500-gpm RO and refurbishment of Sat. 1 at HUP to return to operation.
- $2,000,000 to refurbish the mine unit infrastructure, which would include main pipeline inspection and repair, replacement of down hole pumps, refurbishment of header houses, and re-establishment of power to the mine unit.
- $7,200,000 estimated total cost for installation of two disposal wells to provide additional disposal capacity near Mine Unit 1 to prevent impacts to current restoration efforts in Mine Units C, D, and E, which would affect future restoration efforts for Mine Units H, I, F, J, and K.

A 500-gpm RO system would treat an estimated three PVs per year at MU-B, with annual operating costs estimated at $415,000:

- $115,000 for equipment expenses
- $300,000 for staffing expenses

3.5 Corrective Action Benefits

3.5.1 Benefits of Current CAP for MU-B

Although the results of the current CAP are described in detail in Section 3.2, a brief summary of the benefits of the current CAP are discussed in this section. The current CAP has improved the overall quality of the groundwater from that of post-ISR water quality, and has returned the groundwater in MU-B to "Class of Use" (Cameco, 2009) (ML091831100). In fact, all of the constituents except for radium and arsenic met the Wyoming Class I, II, or III standards at the end of stability. The mine unit average for arsenic did not meet Class I standards at the end of the stabilization period, but trended down during post-stability monitoring to meet the Class I standards. Wyoming currently does not have a Class I standard for uranium. However, despite the extensive remediation efforts employing BPT that have been proven effective and recognized by WDEQ (Section 3.1), the CAP has not succeeded in returning the groundwater quality to baseline conditions. The current CAP has reduced concentrations of COCs at the POC such that future concentrations at the POE will be protective of human health and the environment as demonstrated in Section 2 Hazard Assessment.

3.5.2 Benefits of Continuation of Previous Corrective Actions

Uncertainties associated with the corrective actions make determination of benefits a difficult task. The concentrations of COCs during the corrective action process typically follow an exponential pattern of decrease. During the initial phases of corrective action, constituent concentrations rapidly decrease until they reach a site-specific threshold level, at which point the constituent trends will go asymptotic. At this stage, the concentrations will remain relatively stable or decrease at a very slow rate if corrective action continues. Accordingly, it is difficult to accurately determine a time period for additional corrective action that will result in compliance with specific baseline concentrations. However, Cameco estimates that the continuation of corrective action in MU-B would cost $415,000 per year for those uncertain results.

Since MU-B can never be used as a drinking water source per the aquifer exemption, and the Section 2 Hazard Assessment has shown that the potential risk to humans and the environment from MU-B are below potential risk levels recognized as substantial, continuation of the restoration effort would not further decrease the potential risk to humans and the environment without exceeding NRC ALARA guidance (see Section 3.6.2, below). Furthermore, continuing with restoration in MU-B would be a costly and excessive use of substantial volumes of groundwater and would compete with other mine units that are in more urgent need of corrective action. Therefore, it is Cameco's position that the continuation of corrective actions to restore groundwater quality to baseline concentrations in MU-B is neither practicable nor reasonably achievable.

3.6 As Low As Reasonably Achievable Demonstration

3.6.1 ALARA Requirements

Radiation protection regulations mandate that doses be "as low as is reasonably achievable" (ALARA), taking into account the following factors:

- The state of technology.
- The economics of improvement in relation to benefits to public health and safety.
- Various societal and socioeconomic considerations.
- The utilization of atomic energy in the public interest.

License termination, or termination of a CAP, requires that the licensee demonstrate that the applicable dose/risk criteria for COCs have been satisfied and that doses/risk are ALARA. Restoration of groundwater potentially impacted by licensed activities requires that COC limits be met at a specified POC. These concentration limits are background concentrations, drinking water concentration limits, or site-specific ACLs which, if met, will not result in an unacceptable risk to humans or the environment at the nearest downgradient proposed POE.

The ALARA analysis determines whether the proposed ACL values that are protective of human health and the environment are in fact ALARA "after considering practicable corrective actions" (NRC, 1996). Appendix D of NUREG-1727, "NMSS Decommissioning Standard Review Plan," describes the methodology for demonstrating compliance with the radiological criteria license termination, and assumes a value of $2,000 for one person-rem averted (NRC, 2000). The ALARA compares the total dose averted by specific CAPs and the economic value of averting that dose. If the cost per person-rem averted is greater than $2,000, ACLs are considered to be ALARA (NRC, 2000).

3.6.2 ALARA Demonstration for MU-B

As detailed in the preceding sections, Cameco believes that ALARA criteria have been met for the MU-B restoration, which has been approved by the WDEQ as having met "Class of Use" standards. As explained in Section 3.2, past corrective actions at MU-B have reduced the concentrations of the COCs significantly since the end of ISR in 1991. Continuation of corrective action at MU-B would result in very few public health and safety, societal, or socioeconomic benefits, while unnecessarily consuming limited groundwater and energy resources.

As discussed earlier, groundwater modeling indicates that constituent concentrations at the POE are decreasing to levels that are protective of human health and the environment via natural attenuation processes within the aquifer. In addition, the water within MU-B (POC) is exempted from future use as a potable drinking water source, so will represent no harm to human health or the environment. Further corrective actions will do little, if anything, to diminish concentrations at the POC wells, will be wasteful of limited natural resources, and will delay the restoration of other mine units at the facility.

Nevertheless, Table 12 summarizes the costs and benefits of a hypothetical CAP compared with no further corrective action. Benefits are summarized in terms of the hypothetical 50% reduction in uranium, arsenic, selenium, and radium-226 concentrations at the POC. The estimated cost of each alternative corrective action and the cost per unit U-nat concentration reduction at the POC are used as a measure of the cost effectiveness of the alternative.

It is uncertain how much the COC concentrations in groundwater might be reduced at the POC in MU-B as a result of continuation of the current CAP. An estimated 50% reduction in the COC concentrations at the POC in MU-B was considered the most optimistic reduction that could possibly be expected. A 50% reduction was assumed for purposes of performing an ALARA demonstration.

Table 12
Cost Benefit Analysis of Continuation of the CAP

Parameter	Units	Baseline (Oct/Nov 1987)*	End ISR (July 1991)*	End of Restoration (2004)*	Difference after 13 Years of Restoration	Units Dropped Within 1 Year	Cost (Present Value 2012 $)	50% Reduction in Concentration	Estimated Cost for 50% Reduction in Concentration
Ra-226	pCi/l	316	1478	437	1041	80.08	$4.4 Million	218.5	$10 Million
As	mg/l	<.001	0.008	0.058	-0.05	-0.004		0.029	
U-nat	mg/l	0.062	22.3	1.79	20.51	1.58		0.895	
Selenium	mg/l	<.001	0.806	.012	.794	0.06		.006	

Note:
* = Values obtained from Table 2 in Section 1 of the ACL report.

As shown in Section 3.3, the alternative corrective actions considered would not significantly reduce constituent concentrations in MU-B groundwater. An analysis was performed to determine potential dose averted by the alternative corrective actions for ALARA evaluation consistent with Appendix D of NUREG-1727, "NMSS Decommissioning Standard Review Plan." The collective averted dose that would result for the alternative corrective action for each of the constituents was determined using the method described below. The intake of hazardous constituents averted from consumption of groundwater containing reduced levels of constituents and used as drinking water for a lifetime was calculated as follows:

$$Idw = (Cgw)((IW)(EF)(ED))$$

Where:

Idw = Intake from groundwater, μCi

Cgw = Groundwater concentration reduced by alternative corrective action, μCi/L

IW = Average daily water intake of 1.11 liters per day (Schleien, 1992)

EF = Exposure frequency of 350 days/year (EPA, 1998)

ED = Exposure duration of 30 years

The annual intake in pCi per year was converted to μCi per lifetime by multiplying the annual intake in pCi by 1 x 10^{-6} (μCi/pCi).

The total annual intake of hazardous constituents averted from other food sources potentially impacted by groundwater at reduced constituent concentrations was not considered for the following reasons: (1) the water from POC wells in MU-B is not expected to be used for irrigation or livestock watering in the future due to its "Class of Use" and overall poor quality, and (2) the contribution from other food sources is expected to be insignificant in comparison to the contribution assumed from using groundwater as a drinking water source.

The averted dose was calculated as follows:

AD = (I)(CF)(P)

Where:

AD = Averted effective dose equivalent in person-rem

I = Intake of a constituent by an individual

CF = Intake to dose conversion factor in mrem/µCi

P = Number of persons exposed (4). A hypothetical family of four was assumed for the unlikely scenario of consuming groundwater for domestic purposes at the potential POE.

The averted dose in mrem was converted to person-rem by dividing by 1000. The averted dose due to a potential reduction in groundwater concentrations caused by implementation of alternative corrective actions was calculated for each COC using the above method. The results are summarized below in Table 13.

Using the estimated present value of the continuation of the current CAP, the cost of one person rem averted would be approximately $18,600. This would far exceed the NRC's ALARA guidance of $2,000 per person-rem as specified in NRC's Appendix D of NUREG-1727. Furthermore, the $18,600 that would be spent averting the one per person-rem is very near to the $20,000 per person-rem for demonstration of "Prohibitively expensive" criteria as specified in Section 4.0 of Appendix D of NUREG-1727. Per Appendix D of NUREG-1727, if the cost per person-rem averted is greater than $2,000, ACLs are considered to be ALARA. Therefore, the groundwater concentrations at the facility are ALARA.

Table 13
Averted Dose Summary

Constituent	Concentration Reduced (CGW) (pCi/L)	Averted Intake from ingestion of GW (µCi)	Intake Dose Conversion Factor (mrem/µCi)	Averted Collective Dose (person-rem)
U-nat	0.895 mg/L or 599.65 pCi/L	6.98	268.9	7.51
Ra-226	218.5	2.55	1324.6	13.51

Notes:

CGW = groundwater concentration reduced by alternative corrective action
GW = groundwater
µCi = microcuries
mrem/µCi = millirem per microcurie
pCi/L = picocuries per liter

4.0 PROPOSED ALTERNATE CONCENTRATION LIMITS AND IMPLEMENTATION MEASURES

4.1 Proposed Alternate Concentration Limits

The proposed ACLs are protective of human health and the environment as demonstrated in Section 2.3 and by the geochemical modeling (Appendix A). As demonstrated in Section 3.6, the proposed ACLs are ALARA. The portion of the aquifer contained within the POE boundary is an EPA exempted aquifer, and as such cannot now or again in the future be considered as a source of drinking water. The hazard assessment (Section 2.0) demonstrates that geochemical conditions result in the attenuation of constituent concentrations prior to reaching the POE boundary via the natural attenuation mechanisms that formed the ore deposit in the first place. Geochemical modeling indicates that the attenuation capacity of the 30-Sand is such that any residual constituents derived from ISR operations will be mitigated well before they reach the proposed POE. The proposed POE is the EPA aquifer exemption boundary (Figure 21). Groundwater flow paths from most of MU-B flow through another exempted aquifer and toward the Exxon open-pit mine. The Exxon pit is the ultimate destination of the bulk of MU-B groundwater. Because of the nature of this site and the fact that the groundwater classification is not drinking water, a complete pathway between humans and groundwater at this site does not exist in nature. It is extremely unlikely that future use for the area will be residential, and it is even more unlikely that a resident will drill a well into the aquifer as a source of drinking water. The corrective actions already implemented at the facility have been effective, although the ability to remove constituents from the 30-Sand are diminishing, and reclamation efforts continue. Continued corrective actions will have little or no effect on improving the water quality of the 30-Sand.

Cameco is requesting ACLs for the following constituents for which Groundwater Protection Standards (GPS) are listed in NRC License SUA-1548: arsenic, uranium, selenium, and radium-226. The proposed ACL values are presented in Table 3 and were selected based on the highest post-restoration concentrations.

Data indicate that the 30-Sand contains sufficient attenuation capacity to ensure that the ACL values listed in Table 3 are below the risk-based thresholds before reaching the proposed POE. Cameco considers groundwater quality in the downgradient POE wells to be representative of the flow regime. The potential hazards associated with an exposure at the proposed POE have been evaluated (Section 2.3), resulting in COC concentrations at the POE that are protective of human health and the environment.

The approach presented herein, proposing the elimination of the CAP and acceptance of ACLs, is consistent with NRC approval of ACLs at conventional mining and milling facilities. Should groundwater migrate past the POE boundary, geochemical modeling has shown that ACL constituents in the 30-Sand groundwater will be attenuated to levels that are protective of human health and the environment via natural attenuation processes in the 30-Sand aquifer.

4.2 Proposed Implementation Measures

Cameco is proposing ACLs as the GPS for the 30-Sand because these values are ALARA and are below risk-based thresholds before reaching the proposed POE location.

Assuming the ACLs are approved and the CAP is eliminated, Cameco proposes to develop a monitoring plan to accomplish the following objectives:

- Ensure that, as groundwater moves from the POC to the POE and outside of the exempted aquifer, groundwater concentrations of COCs are protective of human health and the environment.
- Monitor the quality of incoming upgradient water, especially in the area near the Exxon underground mine.
- Verify that the groundwater levels are stabilizing in a manner consistent with that predicted by the hydrogeologic model.
- Collect additional data in order to re-evaluate the ACLs.

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FIGURES

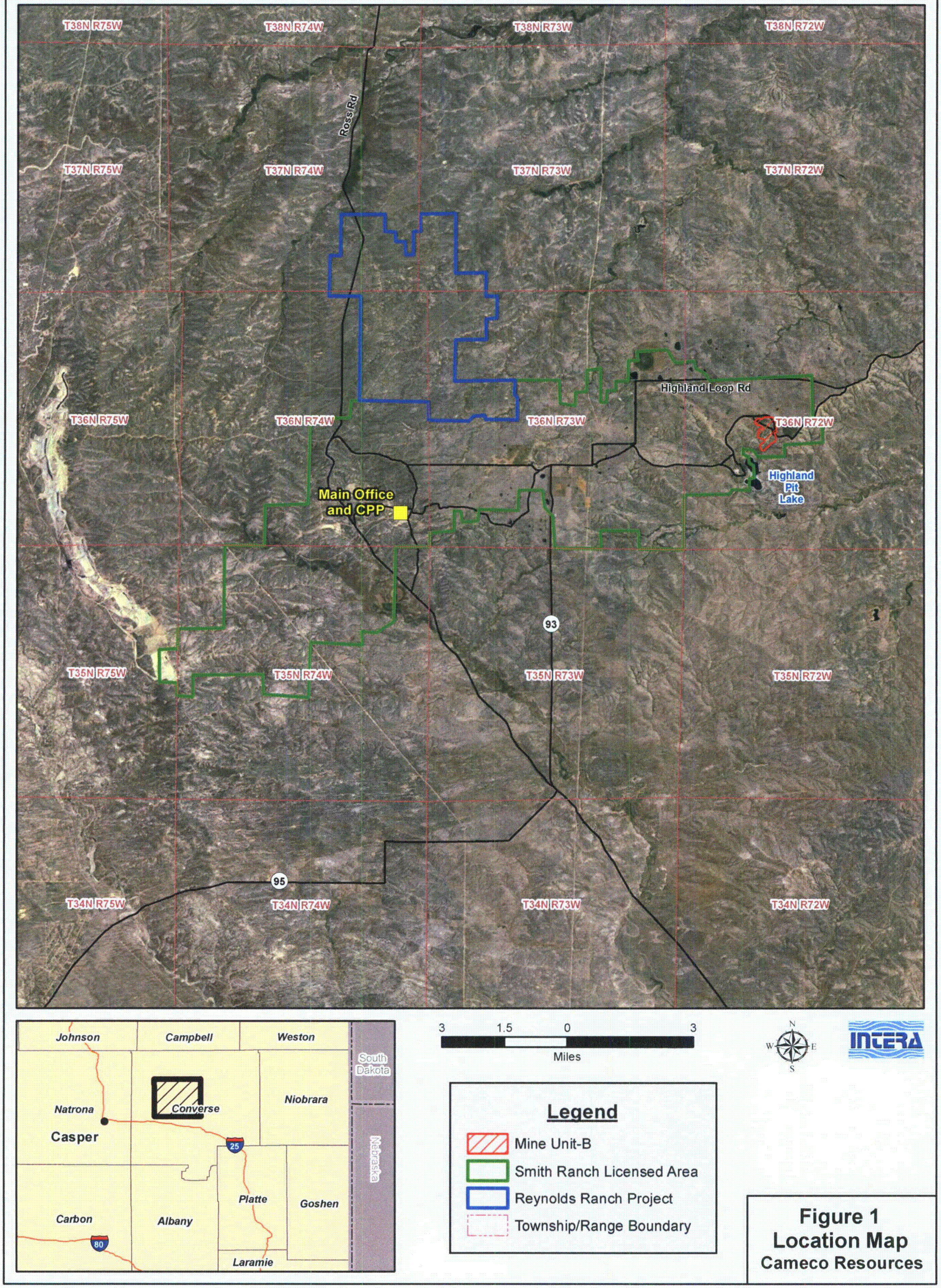

Figure 1
Location Map
Cameco Resources

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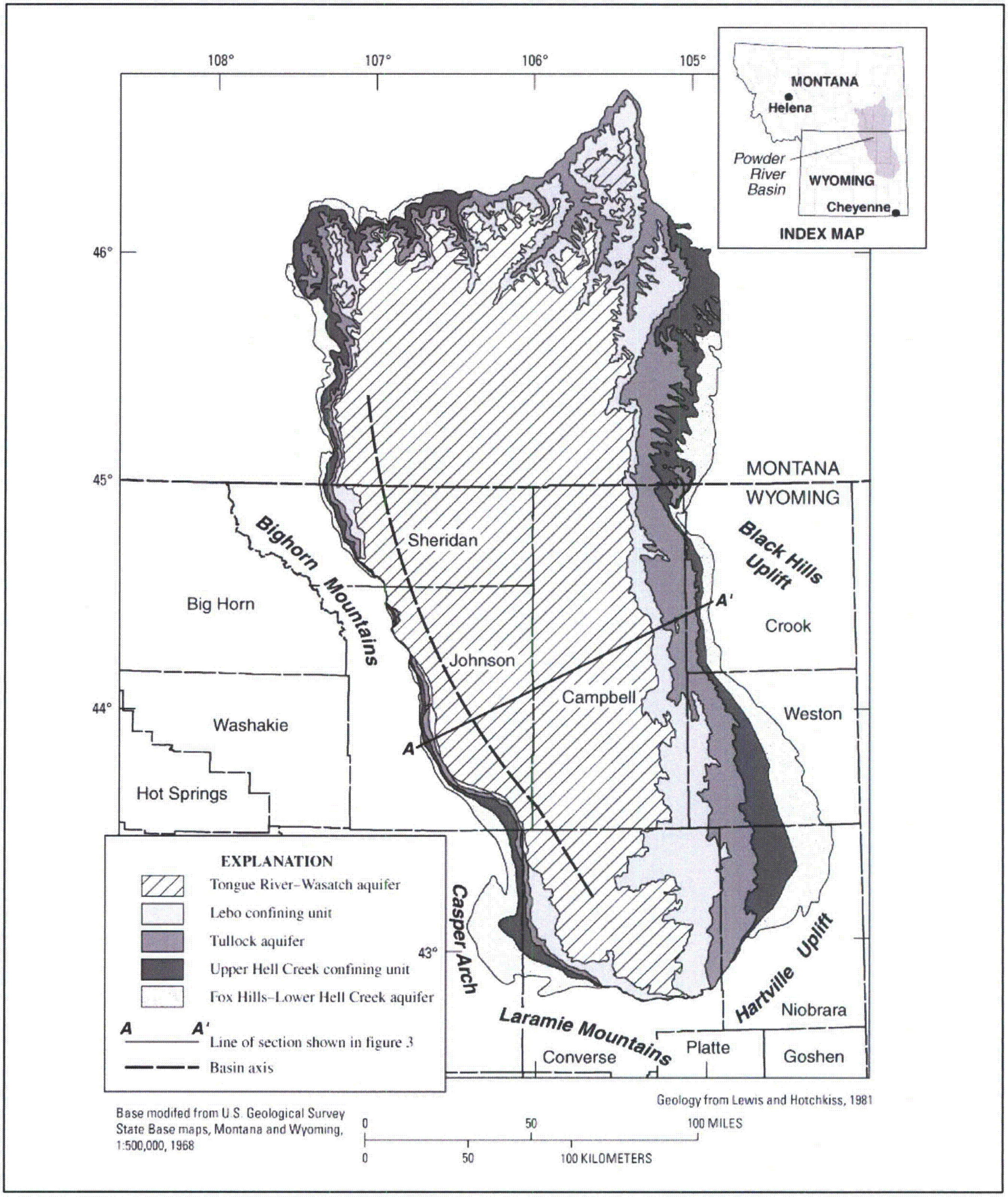
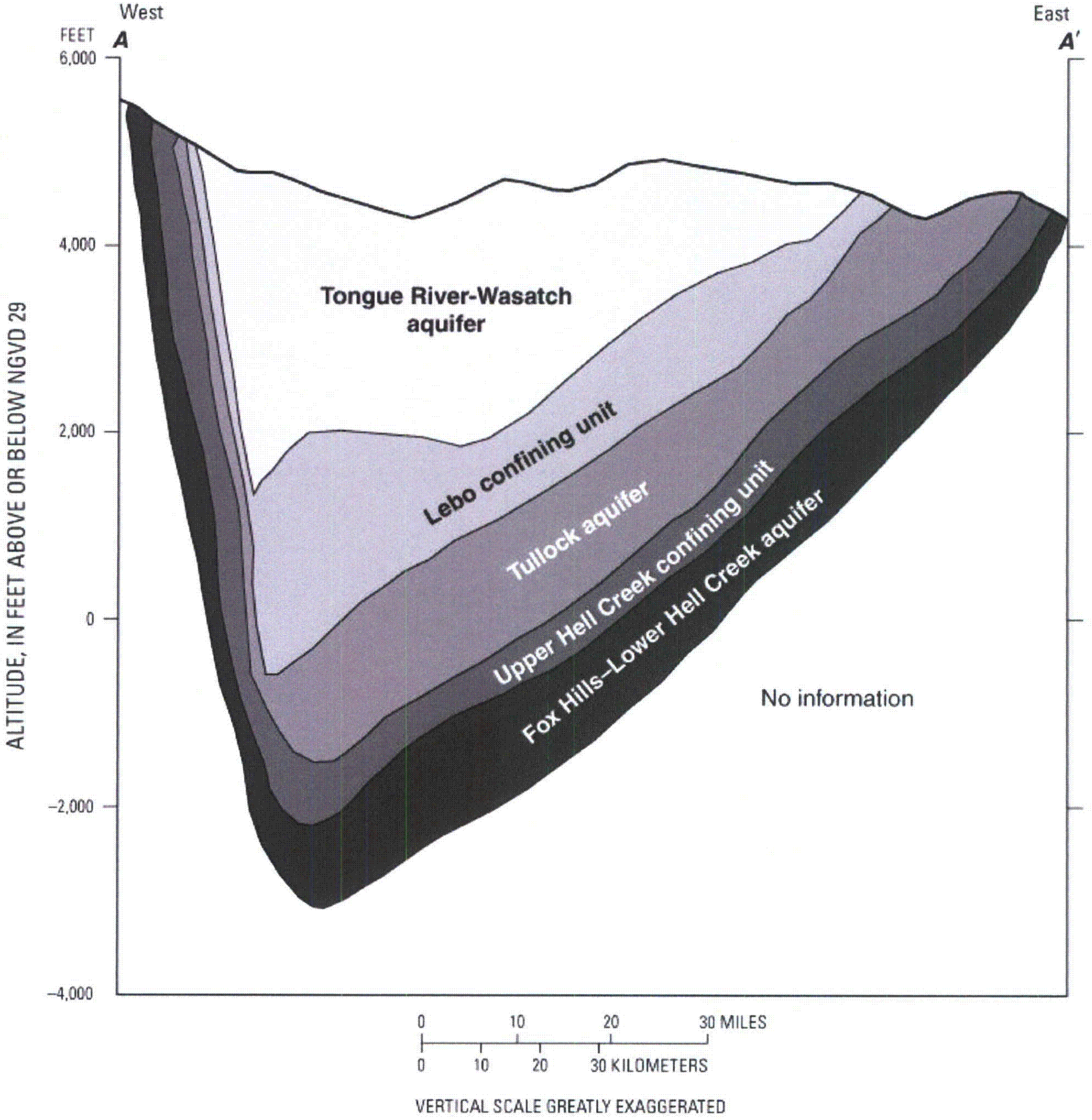


Source: Hinaman, 2005.

Figure 2
Geomorphology of the Powder River Basin
Cameco Resources



Source: Hinaman, 2005.

Figure 3
Basin Scale Cross Section of the Powder River Basin
Cameco Resources

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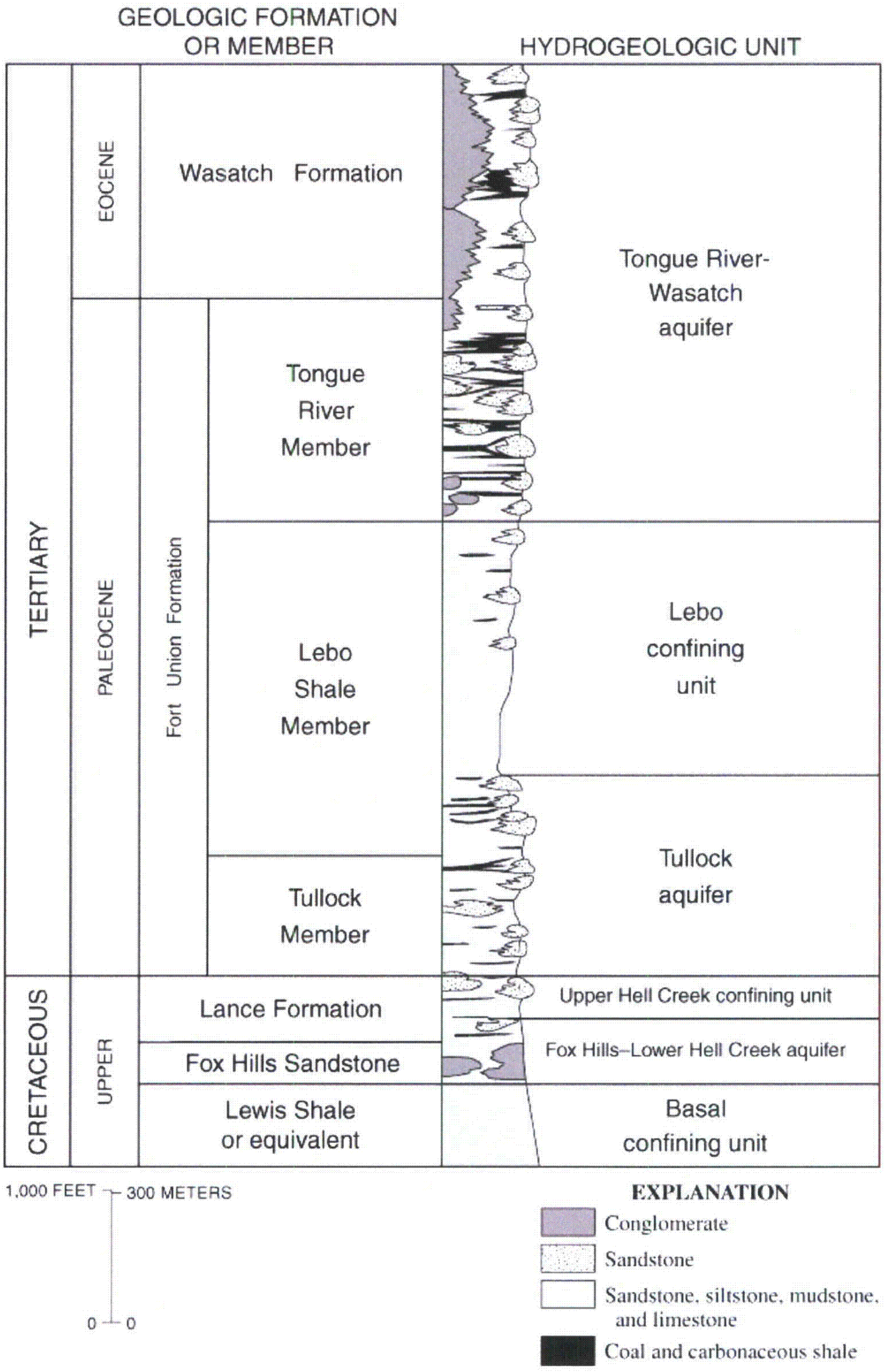
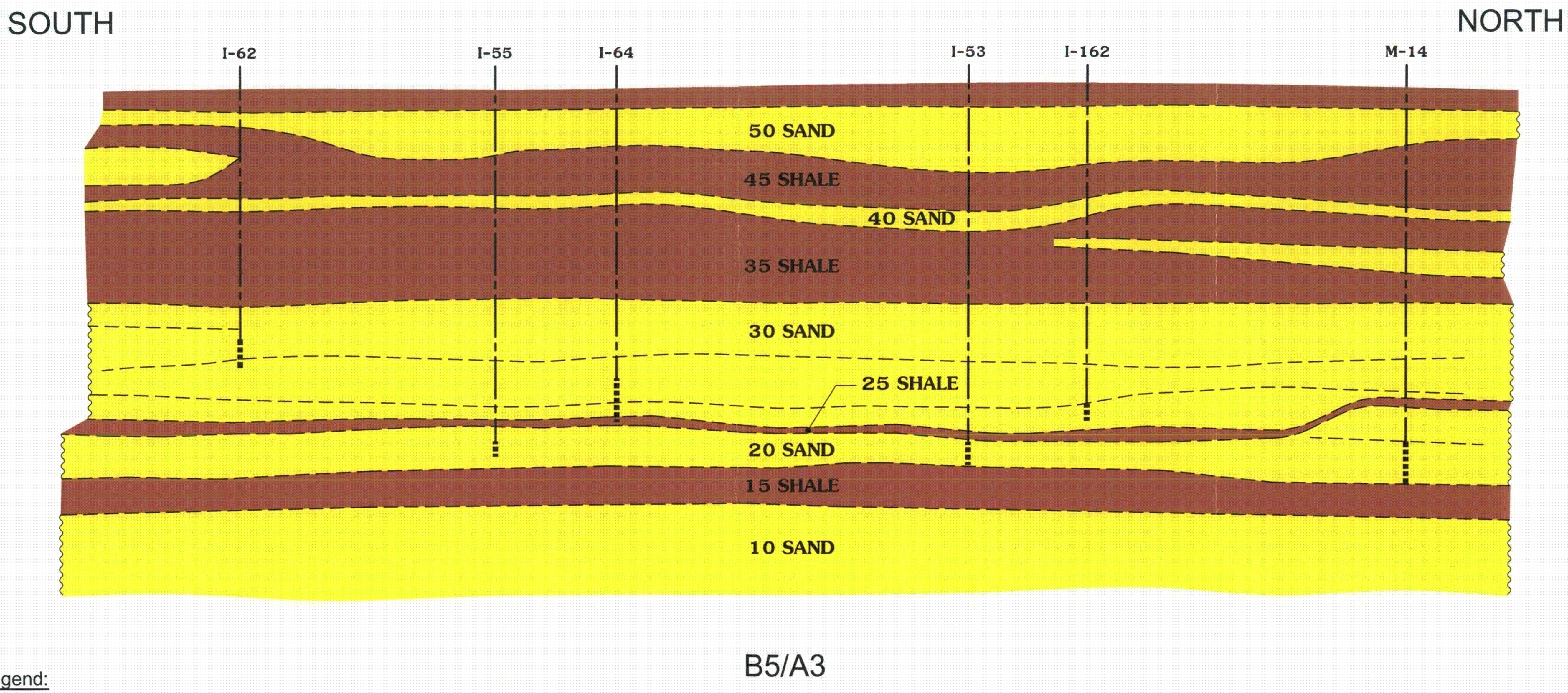


Source: Hinaman, 2005.

Figure 4
Stratigraphic and Hydrogeologic Correlation Chart for the Powder River Basin
Cameco Resources



Legend:

SAND	🟨
SHALE	🟫
WATER WELL	— - — - —
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	- - - - - - -
GROUPING	〰〰〰

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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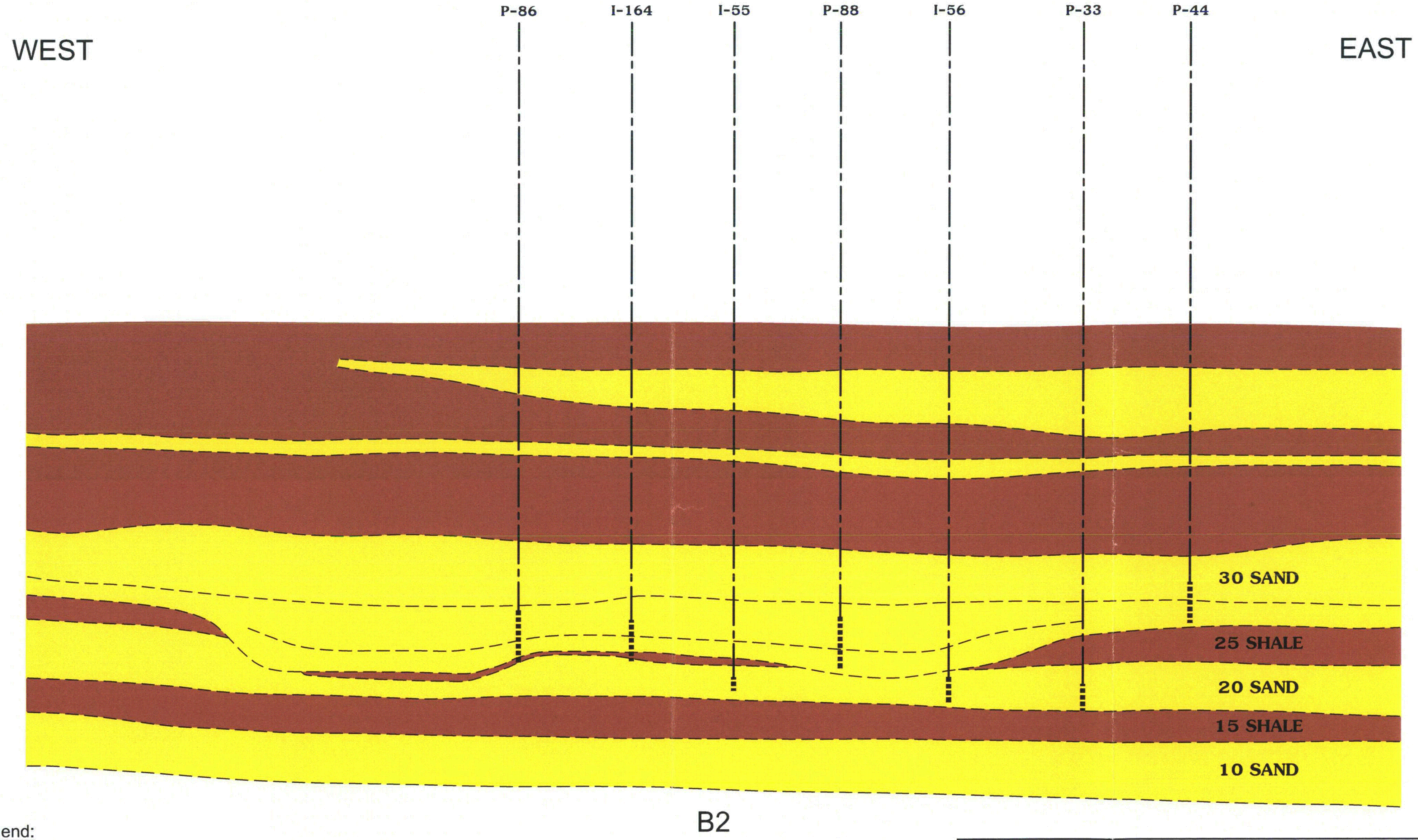
Figure 5
Mine Unit B ACL Application
Cross Section from
I-62 to M-14
Cameco Resources



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WATER WELL	—·—·—
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	– – – – – –
GROUPING	∿∿∿∿∿∿

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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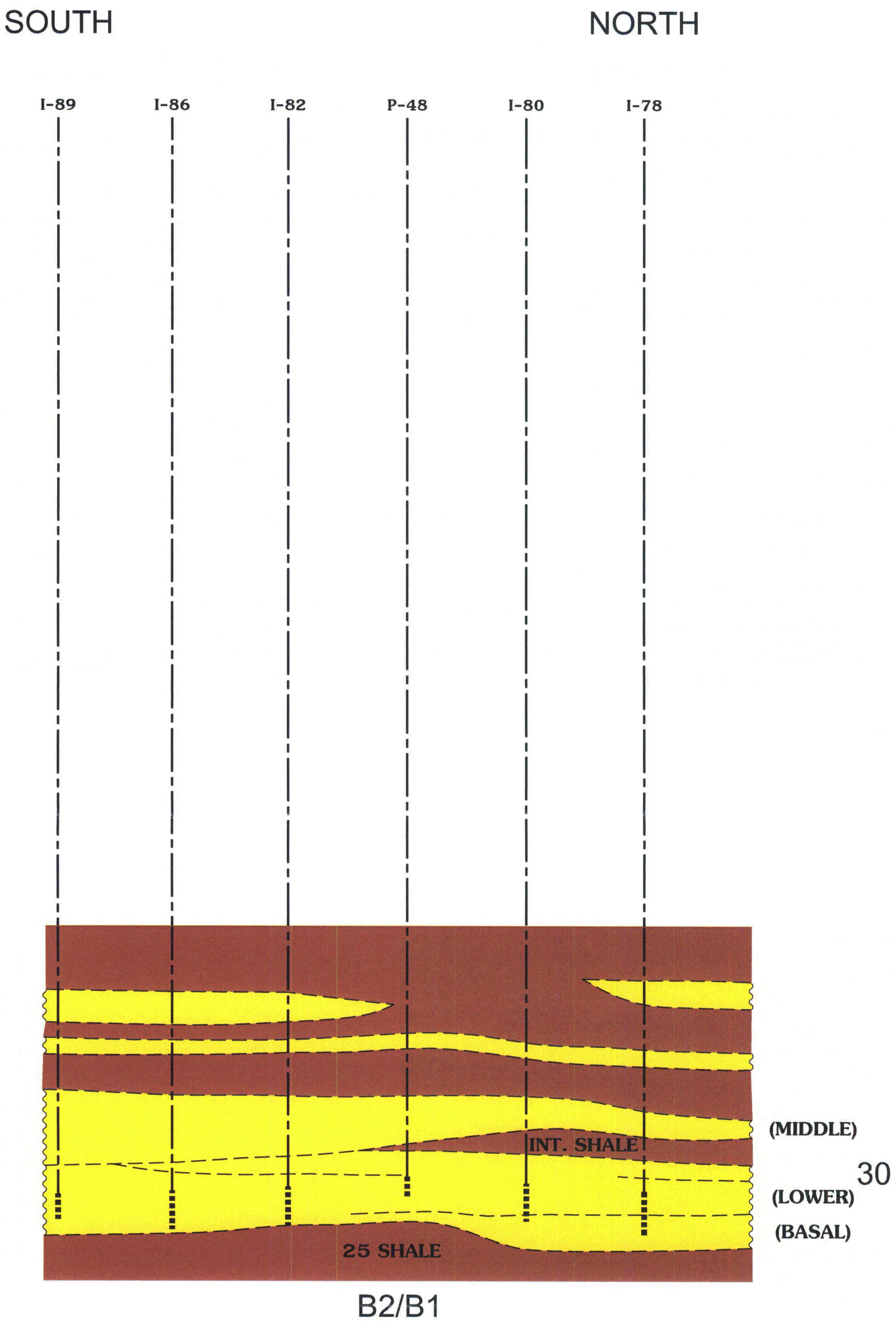
Figure 6
Mine Unit B ACL Application
Cross Section from
P-86 to P-44
Cameco Resources



Legend:

SAND	🟨
SHALE	🟫
WATER WELL	—·—·—
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	– – – – – –
GROUPING	〰〰〰

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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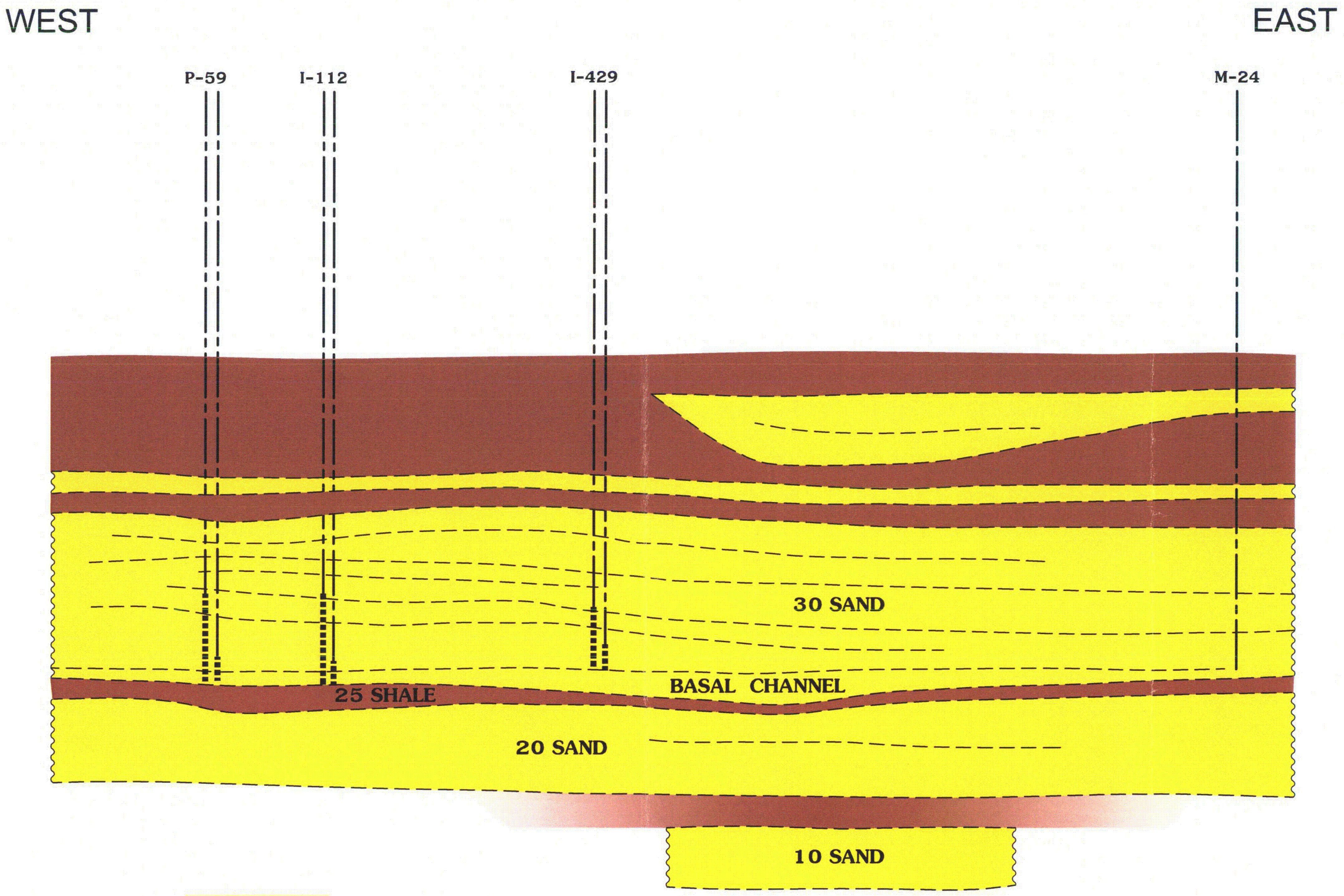
Figure 7
Mine Unit B ACL Application
Cross Section from
I-89 to I-78
Cameco Resources



B2

Legend:

SAND	🟨
SHALE	🟫
WATER WELL	—·—·—
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	– – – – – –
GROUPING	~~~~~~

Note:
Additional control points from exploration boreholes
(not shown) were used for creating cross sections.

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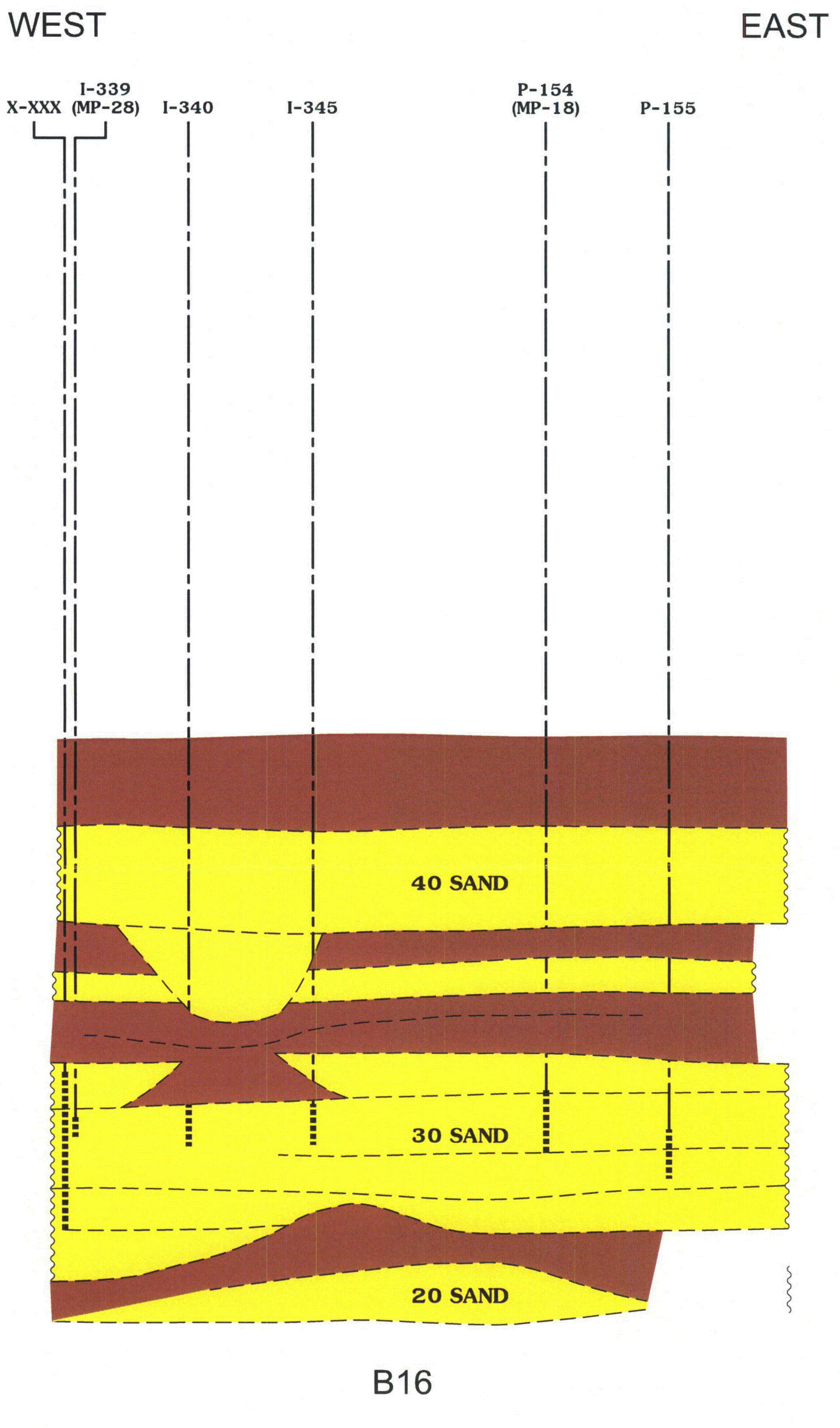
Figure 8
Mine Unit B ACL Application
Cross Section from
P-59 to M-24
Cameco Resources



Legend:

SAND	🟨
SHALE	🟫
WATER WELL	— - — - —
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	– – – – – –
GROUPING	~~~~~~~~~~

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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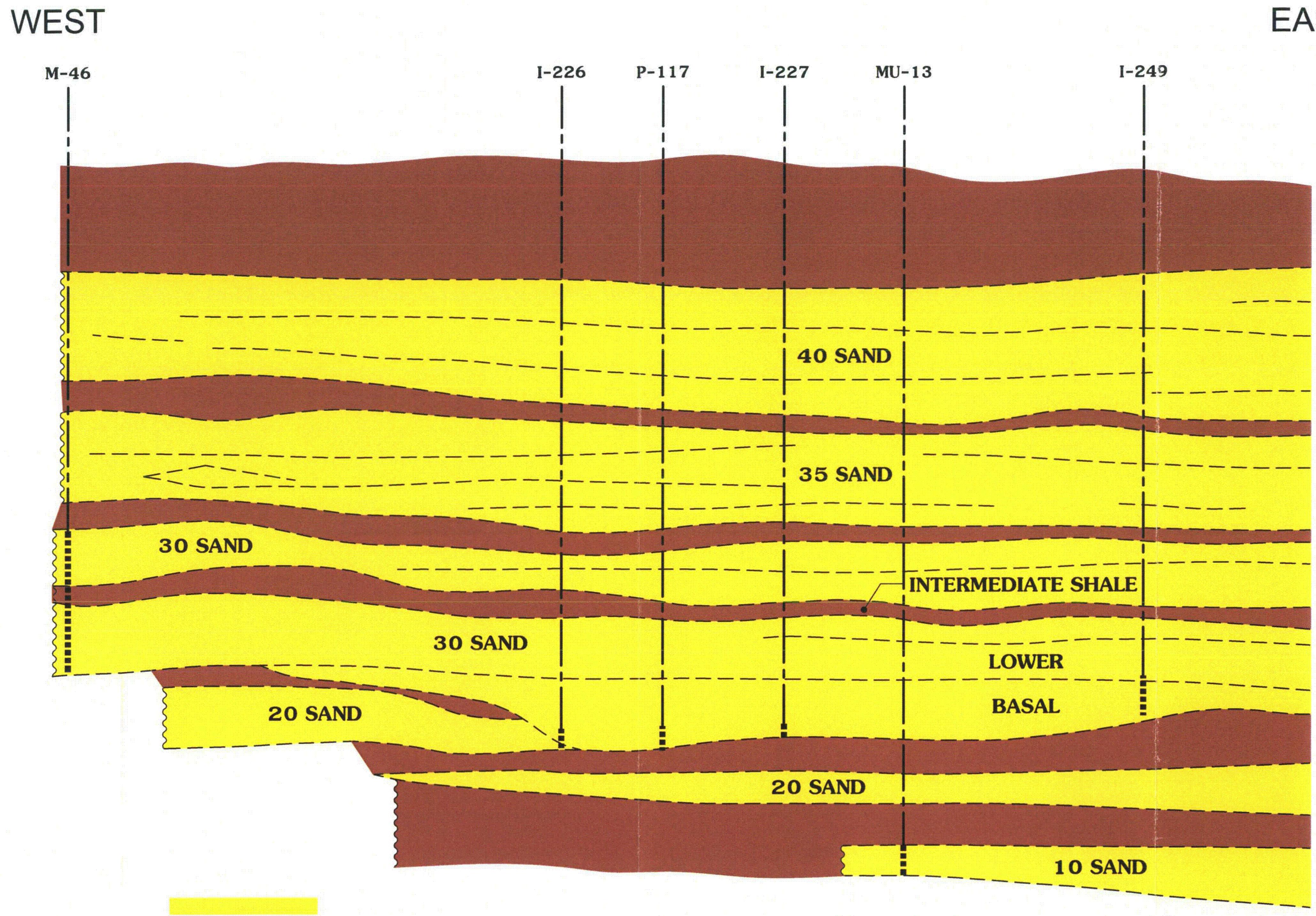
Figure 9
Mine Unit B ACL Application
Cross Section from
MP-28 to P-155
Cameco Resources



Legend:

SAND 🟨
SHALE 🟫
WATER WELL — - — - —
SCREEN SECTION OF WELL ▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE – – – – – –
GROUPING ∿∿∿∿∿∿∿

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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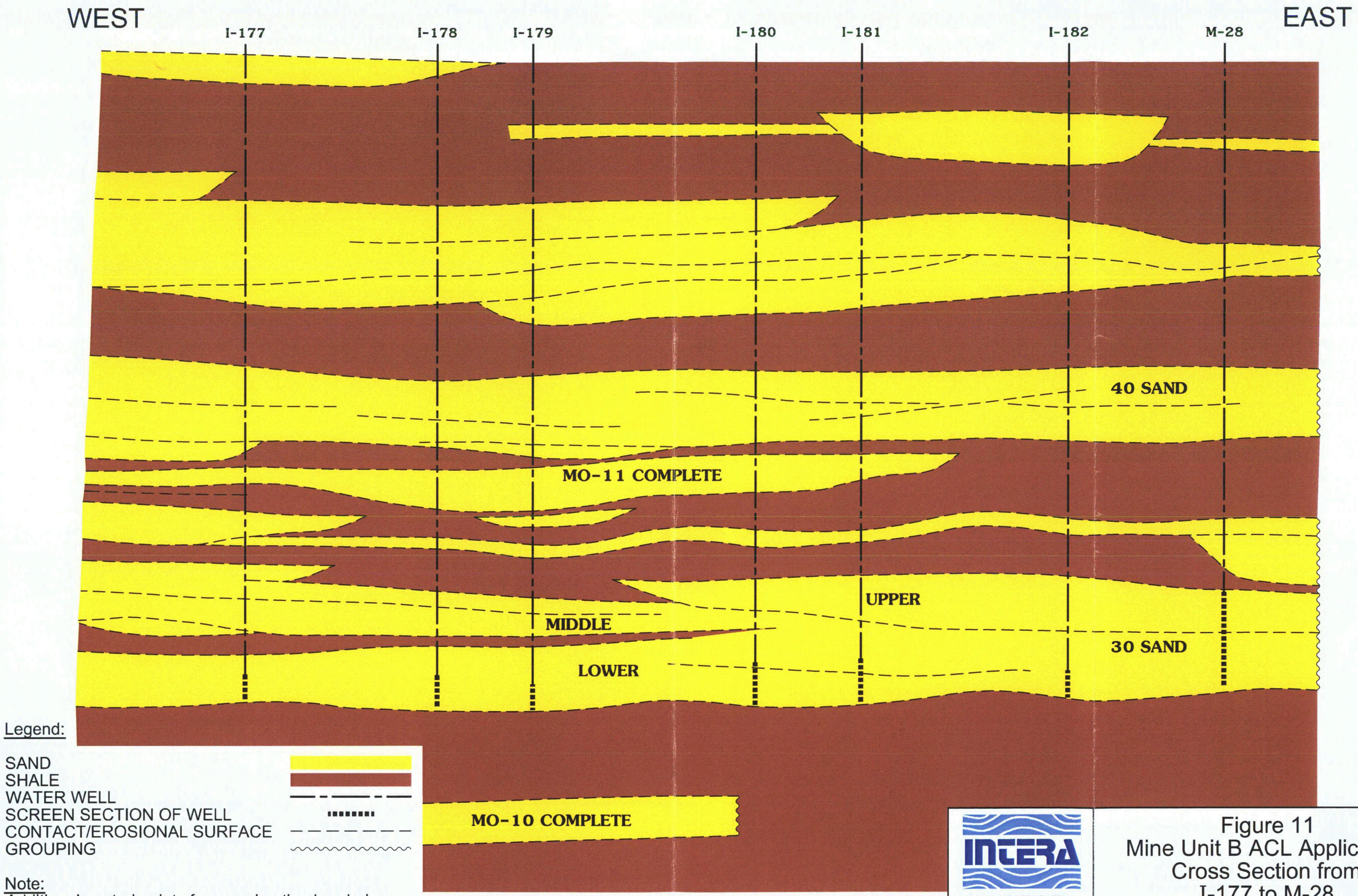
Figure 10
Mine Unit B ACL Application
Cross Section from
M-46 to I-249
Cameco Resources



Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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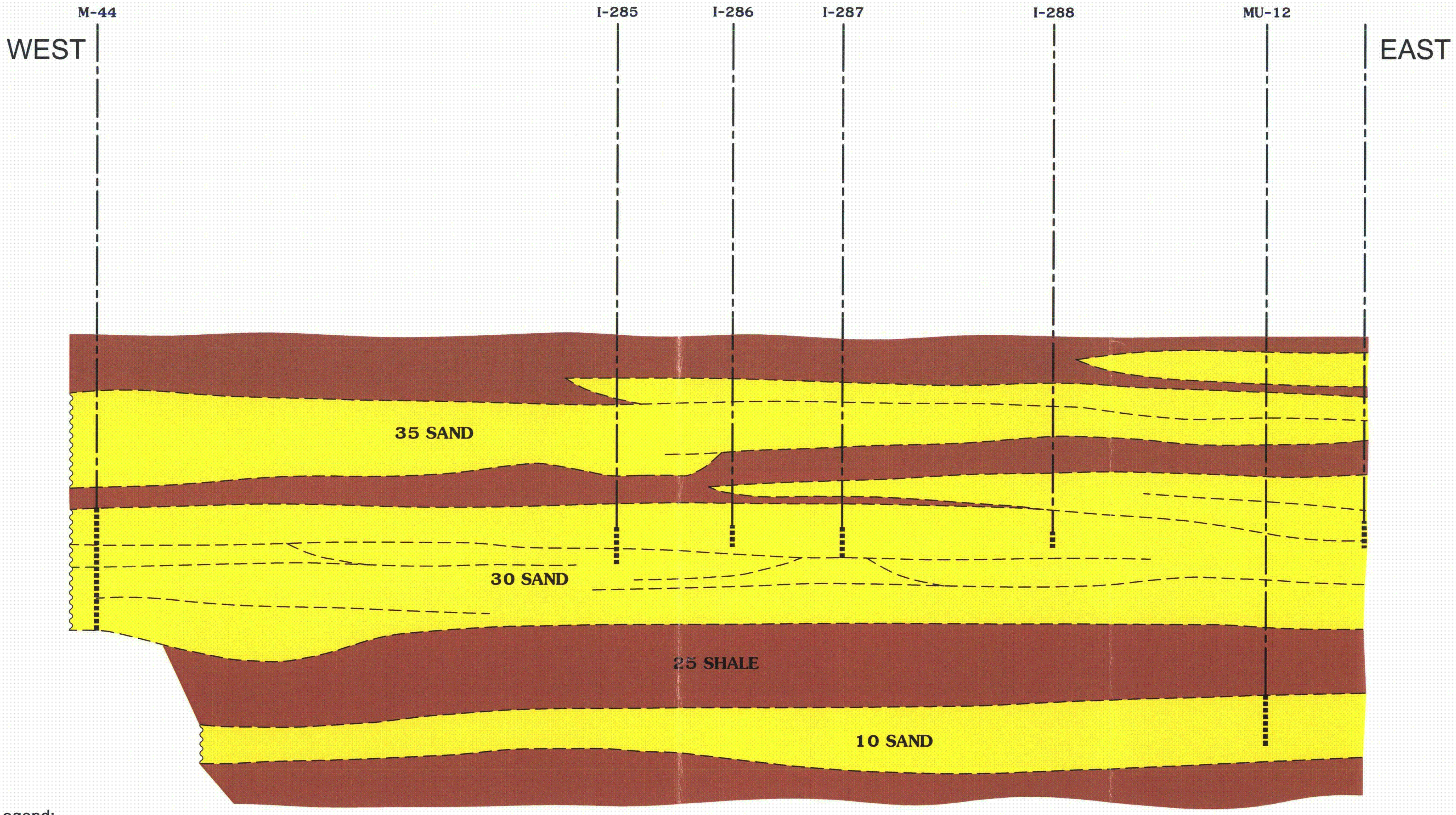
Figure 11
Mine Unit B ACL Application
Cross Section from
I-177 to M-28
Cameco Resources



Legend:

SAND	🟨
SHALE	🟫
WATER WELL	— - — - —
SCREEN SECTION OF WELL	▪▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE	- - - - - - -
GROUPING	~~~~~~~~~~

B11

Note:
Additional control points from exploration boreholes (not shown) were used for creating cross sections.

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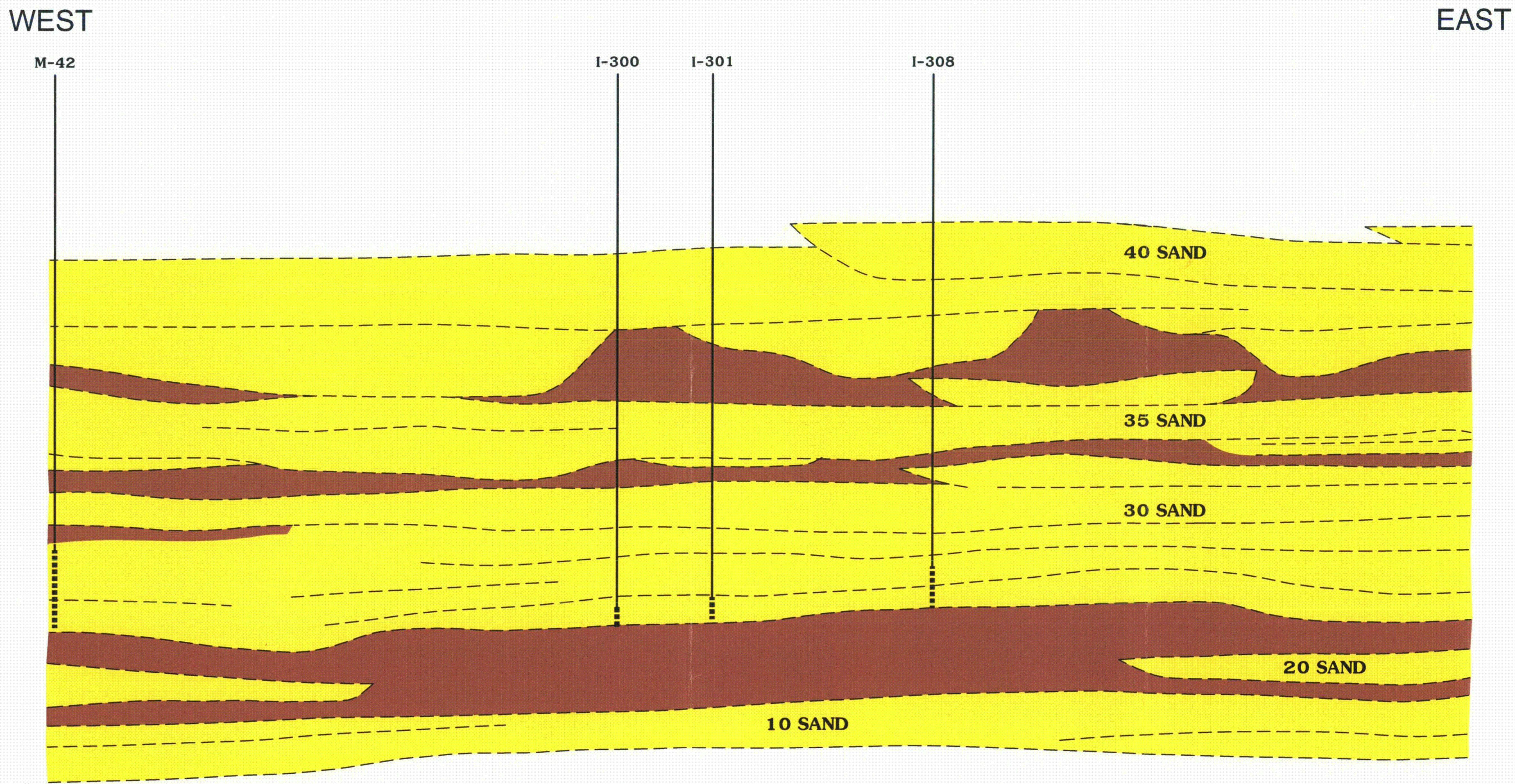
Figure 12
Mine Unit B ACL Application
Cross Section from
M-44 to MU-12
Cameco Resources



B12

Legend:

SAND 🟨
SHALE 🟫
WATER WELL — - — - —
SCREEN SECTION OF WELL ▪▪▪▪▪▪▪▪
CONTACT/EROSIONAL SURFACE – – – – – –
GROUPING 〰〰〰

Note:
Additional control points from exploration boreholes
(not shown) were used for creating cross sections.

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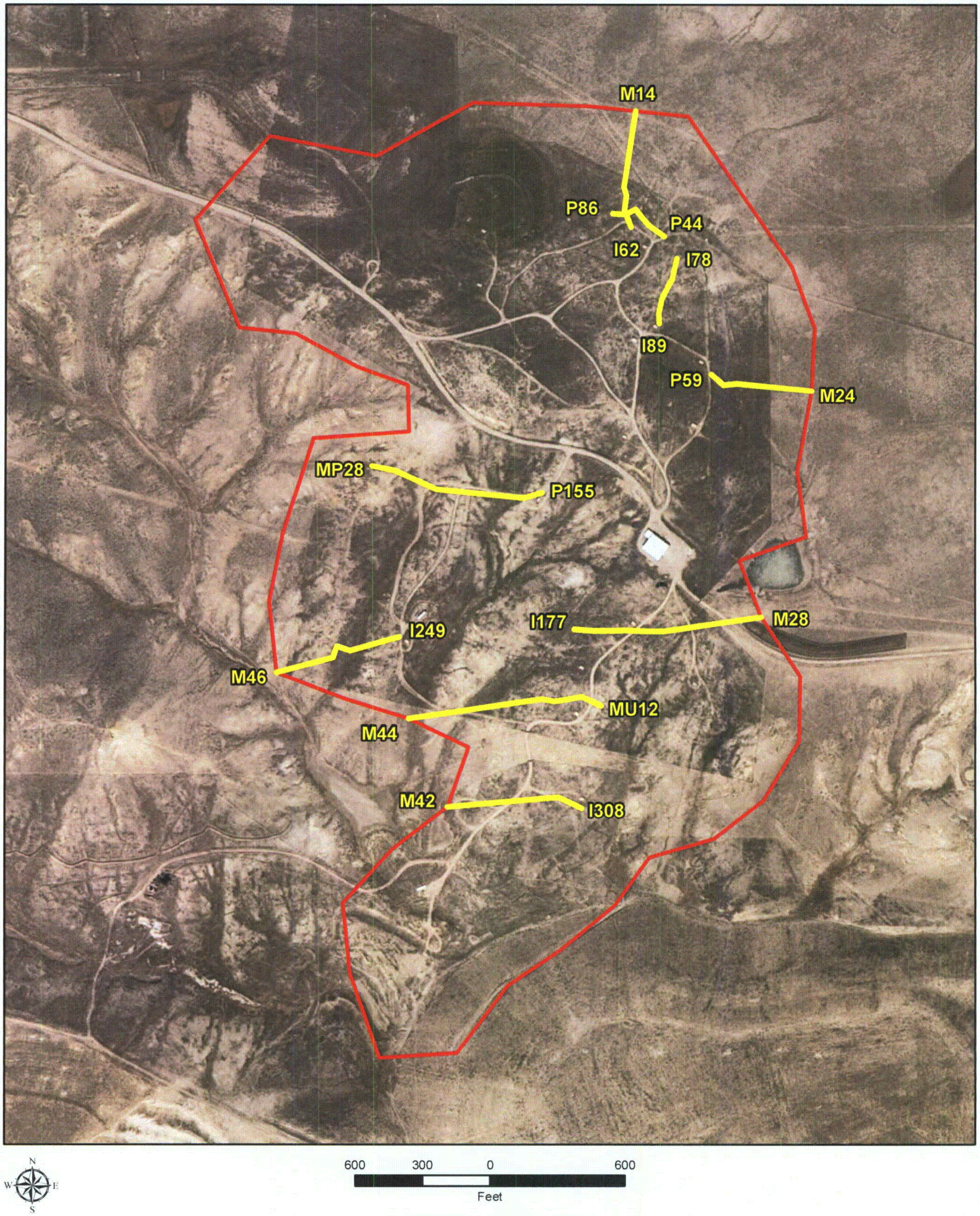
Figure 13
Mine Unit B ACL Application
Cross Section from
M-42 to I-308
Cameco Resources



Legend

🟨 Cross Section

🟥 Mine Unit-B

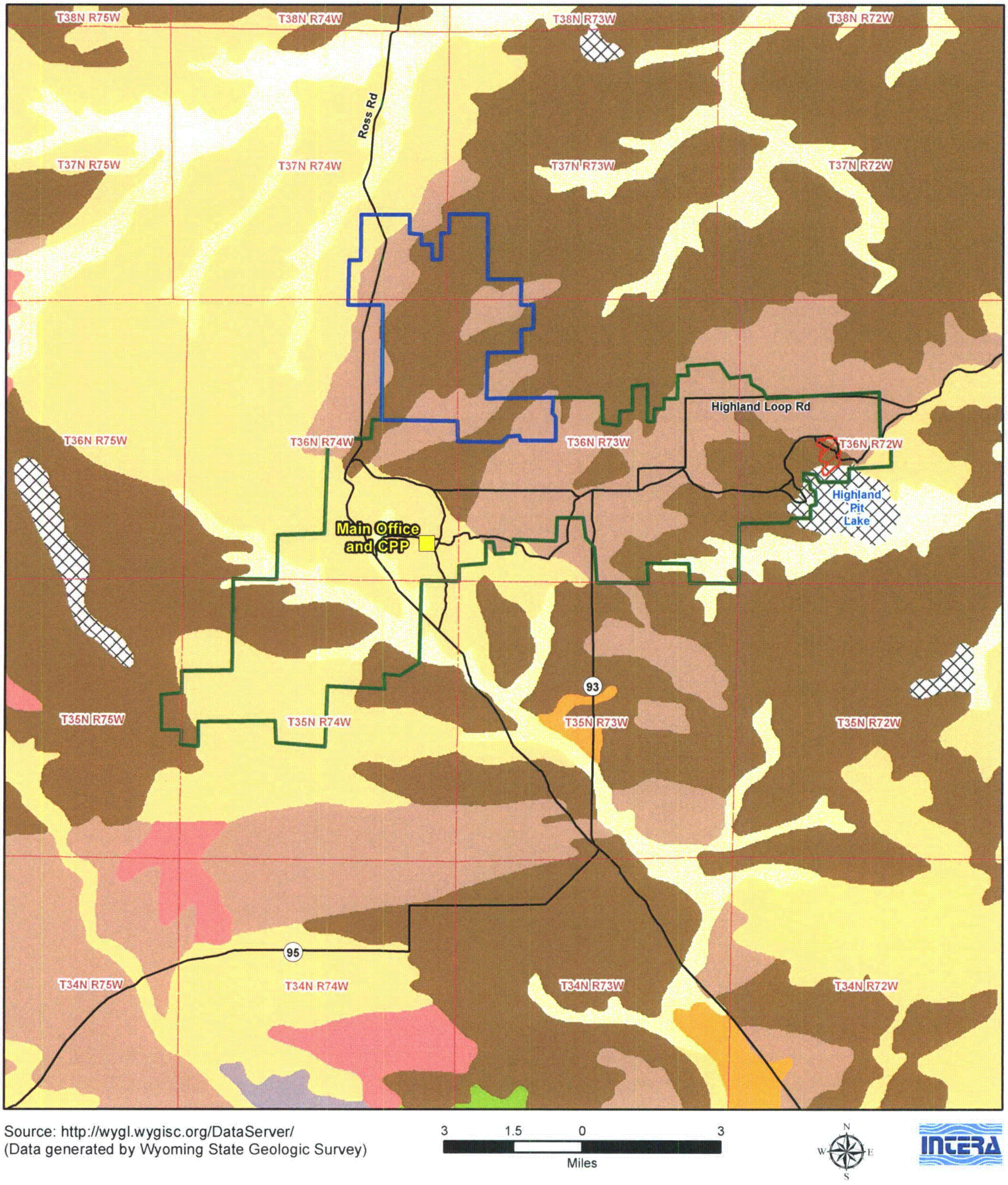
INTERA

Source: Hunter, 1999.

Figure 14
Basemap for Mine Unit-B Cross Sections

Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull14_CrossSectsMine_Rev0.mxd 9/20/2012



Source: http://wygl.wygisc.org/DataServer/
(Data generated by Wyoming State Geologic Survey)

Surface Geology

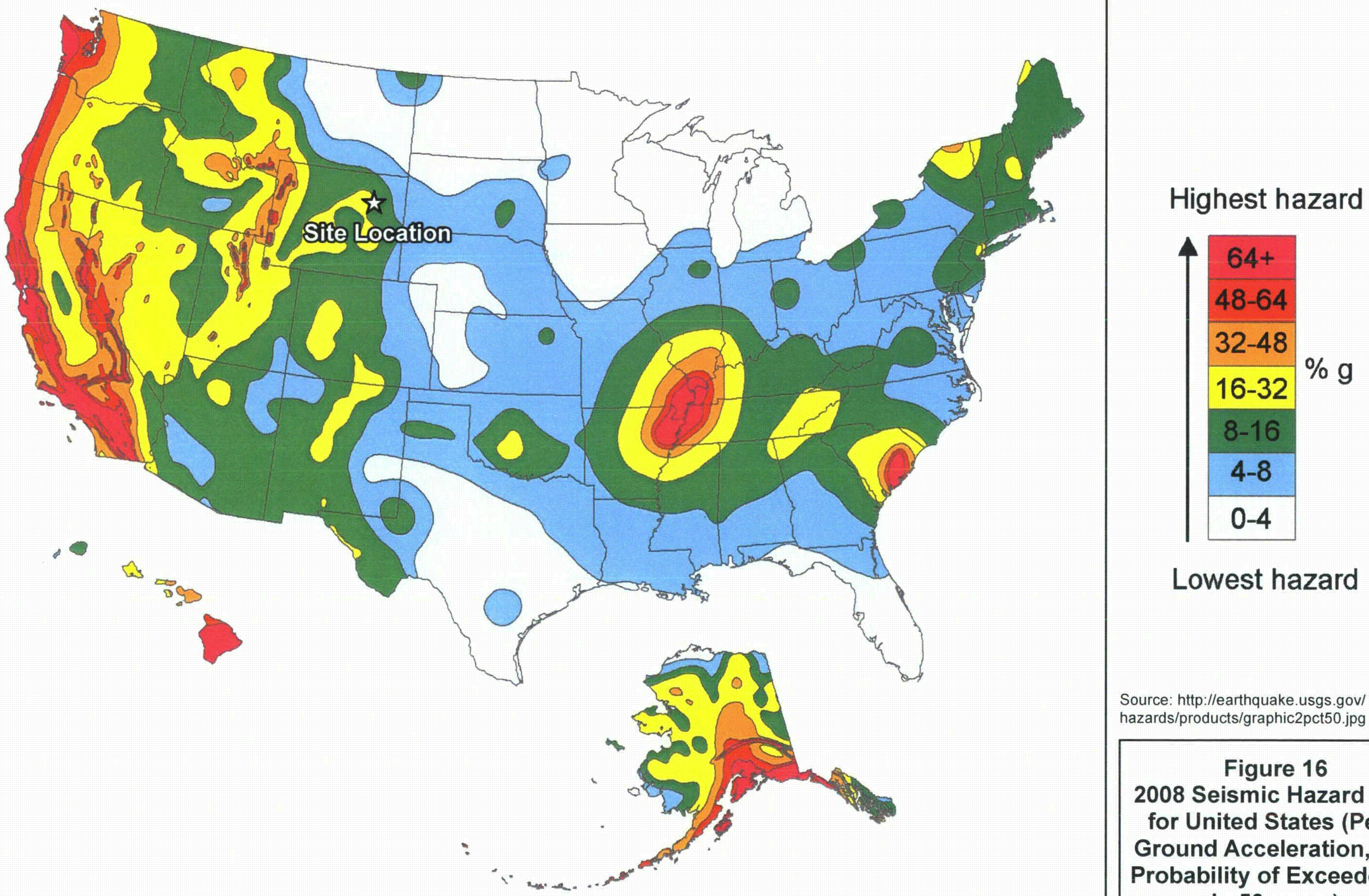
Alluvium	▨ Mined Areas
🟥 Bedrock	🟫 Residuum
🟩 Dissected Bench	🟨 Slopewash
🟪 Dissected Terrace	🟧 Terrace
🟫 Eolian Mixed	

Legend

- ▨ Mine Unit-B
- 🟩 Smith Ranch Licensed Area
- 🟦 Reynolds Ranch Project
- ⬚ Township/Range Boundary

Figure 15
Surficial Geology Map for the Smith Ranch Area
Cameco Resources

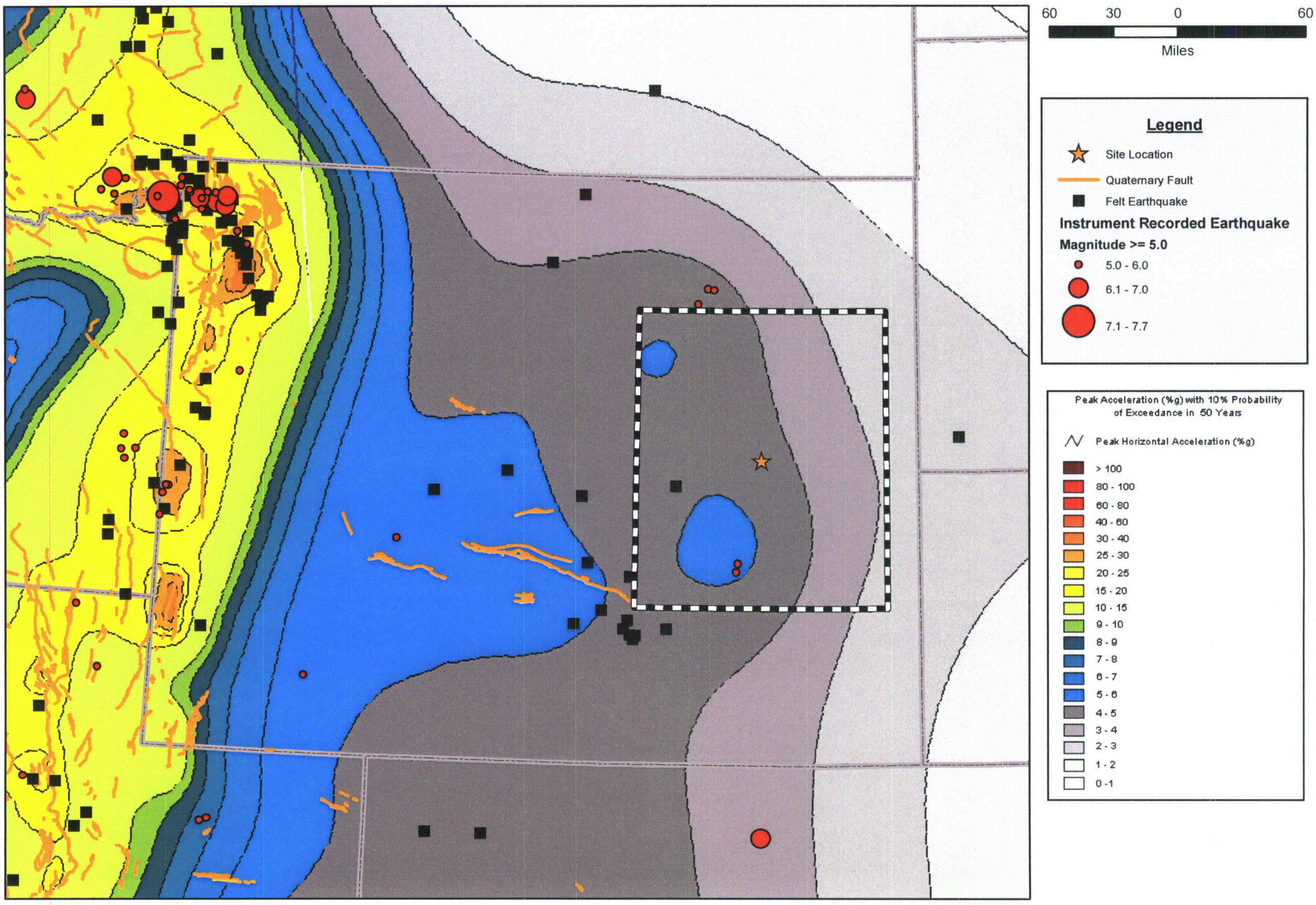
File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull15_GeologicOutcrop_Rev1.mxd 1/28/2013



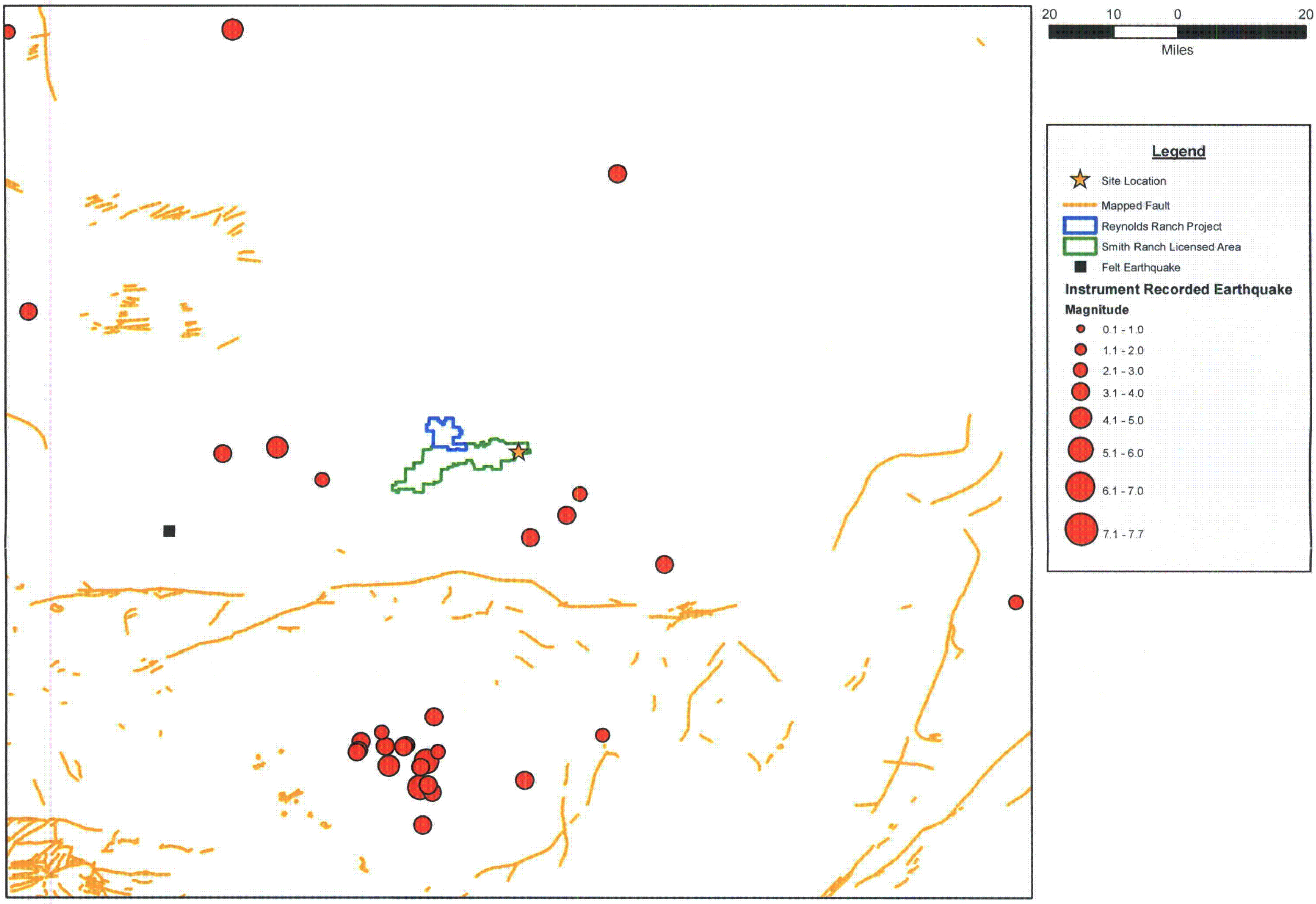
Source: http://earthquake.usgs.gov/
hazards/products/graphic2pct50.jpg

Figure 16
2008 Seismic Hazard Map for United States (Peak Ground Acceleration, 2% Probability of Exceedence in 50 years)
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull16_EarthquakeHazardUS.mxd 3/23/2012



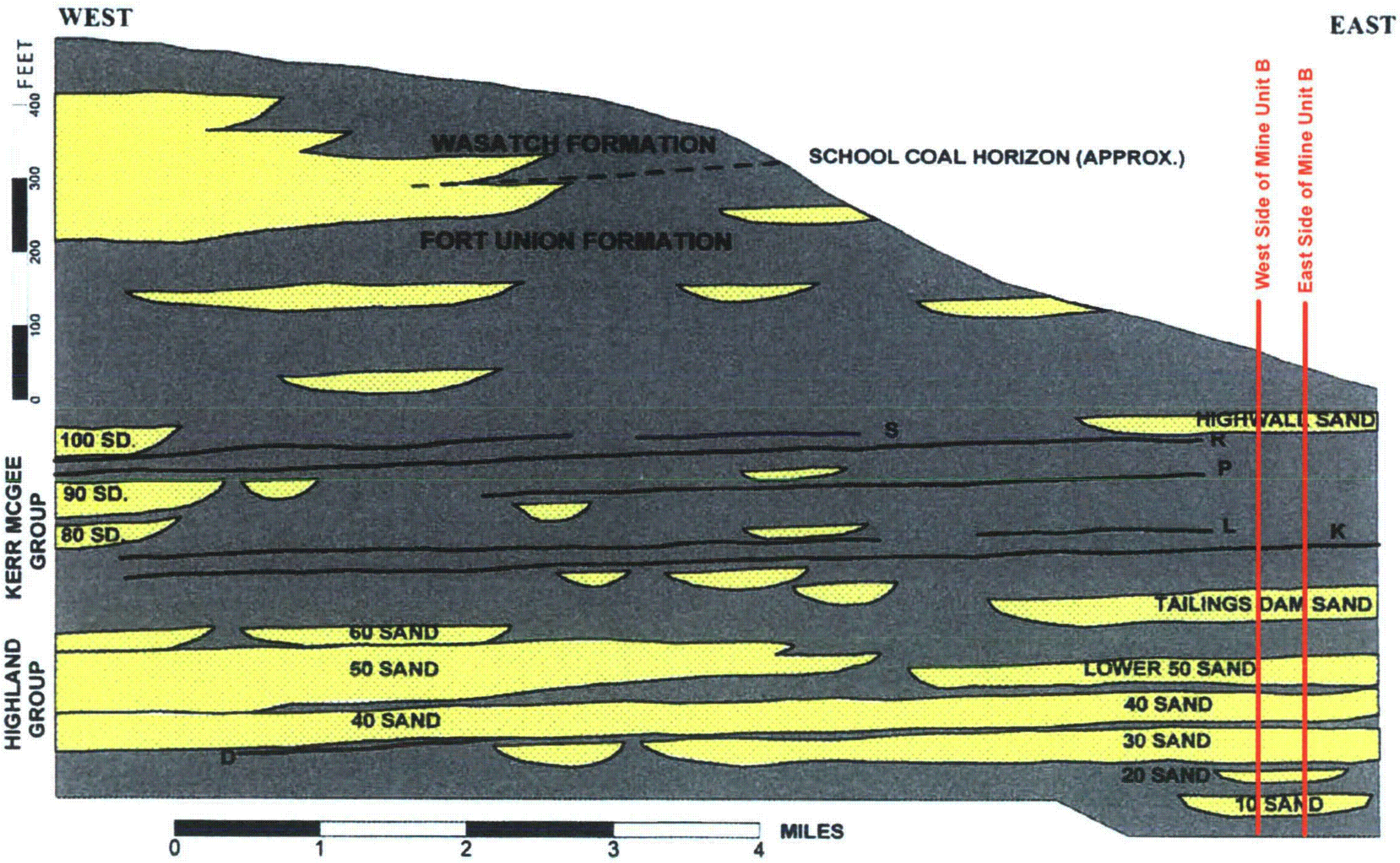
Peak Ground Acceleration, 10% Probability of Exceedence in 50 Years with Earthquakes and Quaternary Faults

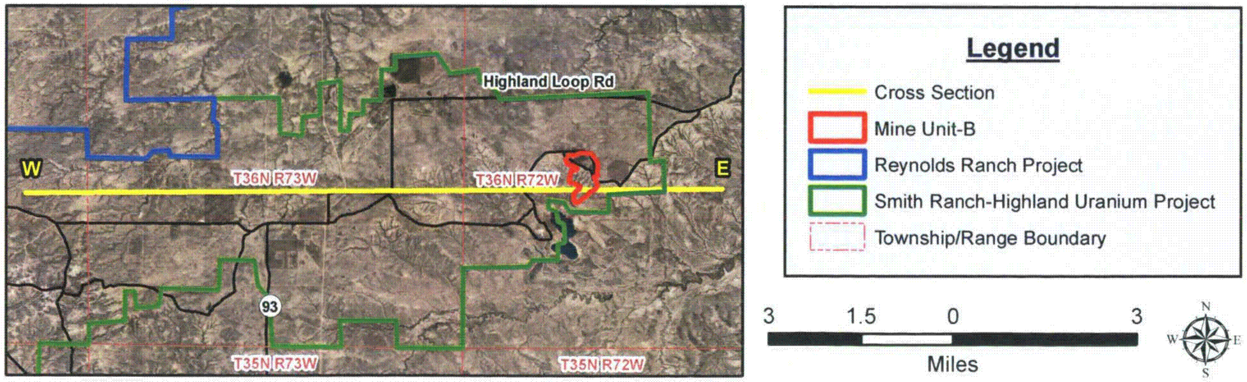


Faults and Historic Earthquakes within the Immediate Vicinity of the Site

Source(s):
Earthquakes - http://earthquake.usgs.gov/earthquakes/eqarchives/epic/
Mapped Faults - http://wygl.wygisc.org/wygeolib/catalog/main/home.page
Quarternary Faults - http://earthquake.usgs.gov/hazards/qfaults/
Peak Ground Acceleration - http://earthquake.usgs.gov/hazards/products/graphic10pct50.jpg

Figure 17
2008 Seismic Hazard Map for Wyoming Area
Cameco Resources



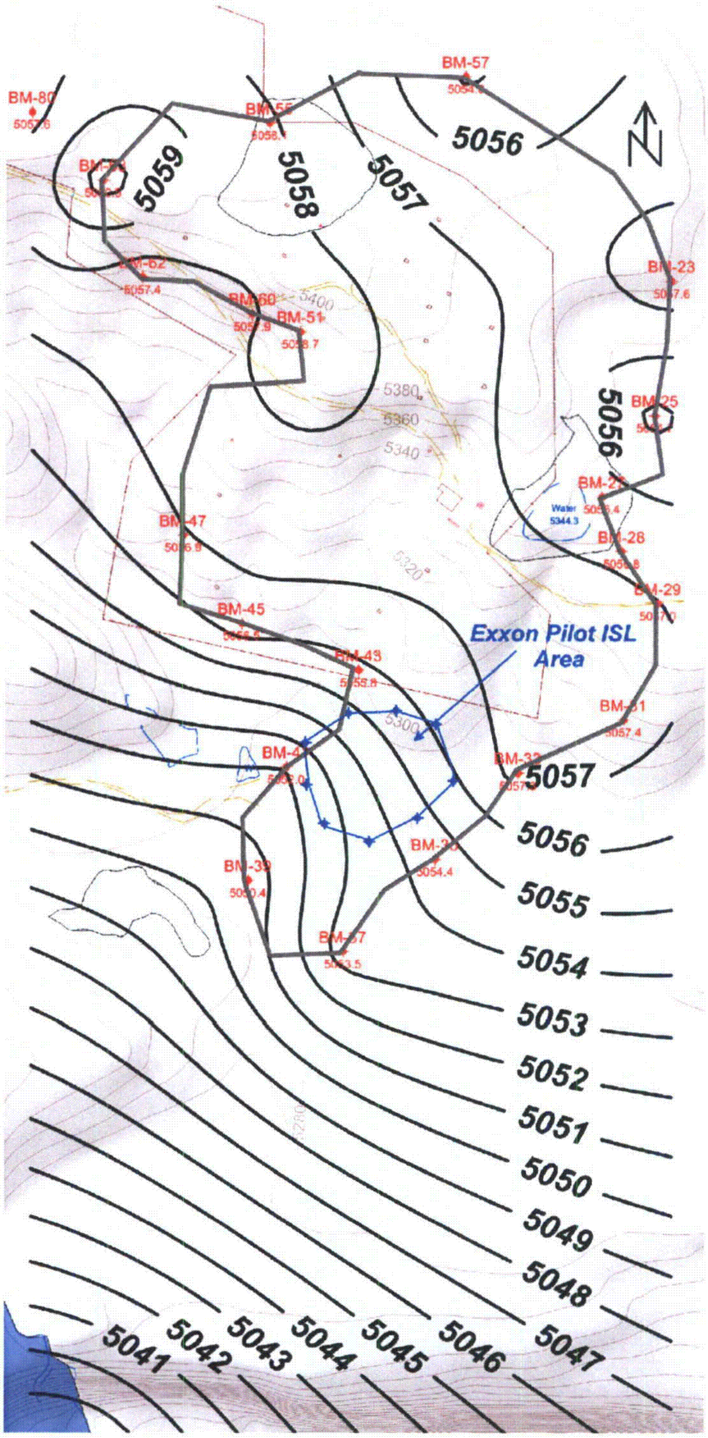


Source: Hunter, 1999.

INTERA

Figure 18
Cross Section of Uranium Bearing Strata in the Smith Ranch Highland Area
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull18_Hunter99XSection_Rev0.mxd 9/20/2012

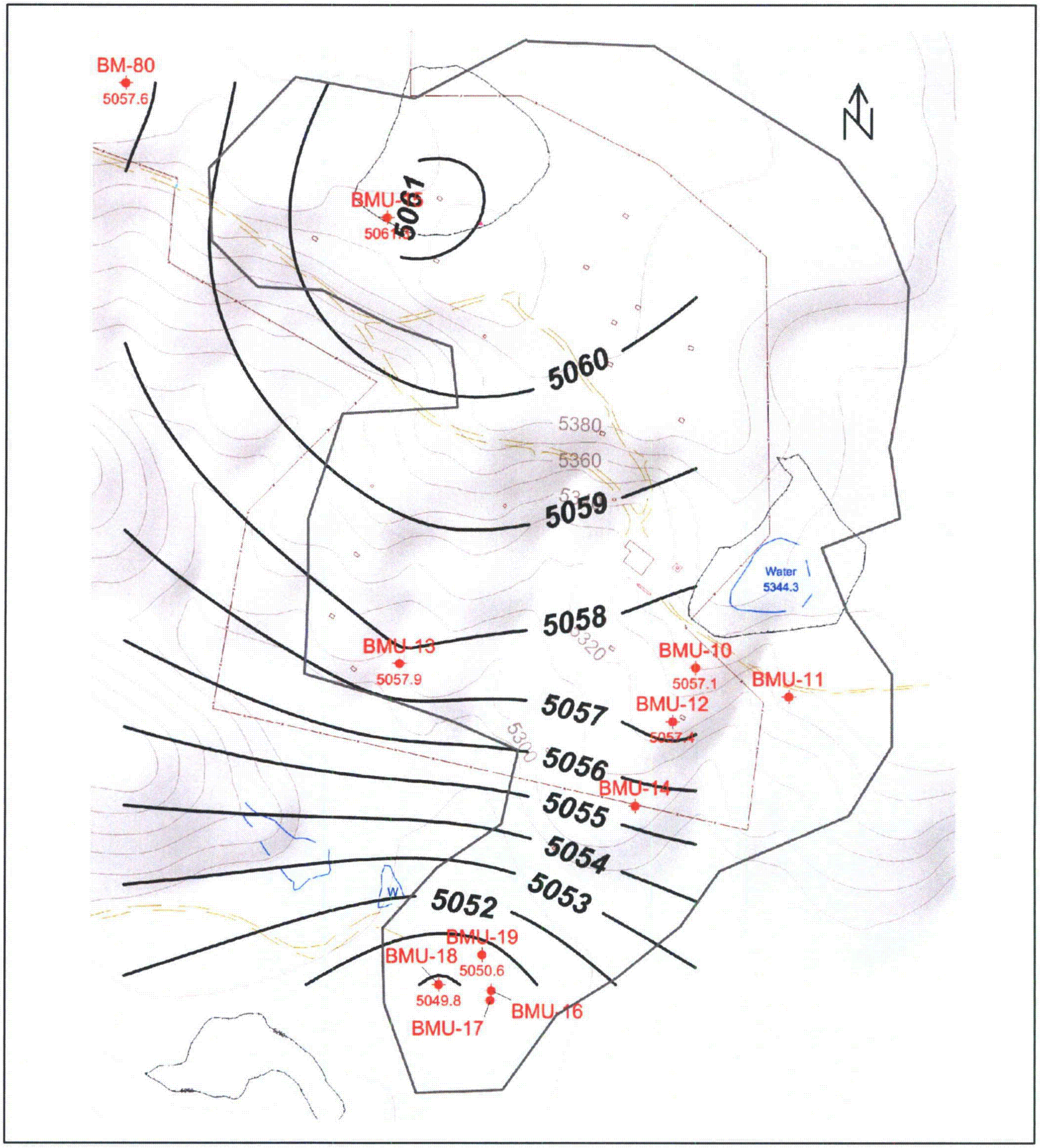


Source: Aqui-Ver, 2011.

INTERA

Figure 19
30-Sand Water Level Elevation, December 2010
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull19_30-Sand.mxd 3/20/2012



Source: Aqui-Ver, 2011.

Figure 20
20-Sand Water Level Elevation, December 2010
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull20_20-Sand.mxd 3/20/2012

INTERA

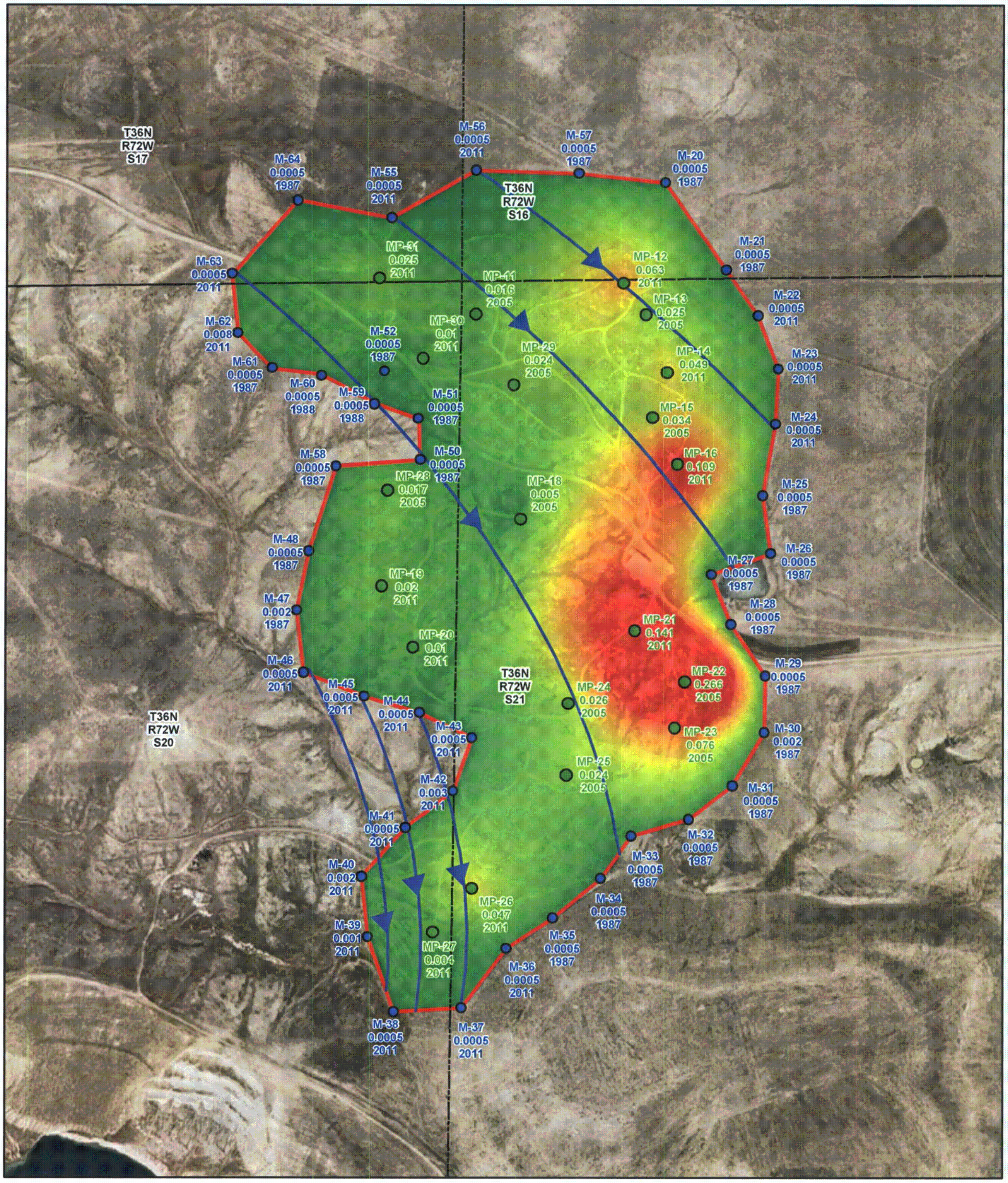
Legend

🟧	DOE Long-Term Care Boundary
⬚	Section Boundary
🟦	Aquifer Boundary (Estimated)

Source: Cameco.

Figure 21
Aquifer Classification Zones near Mine Unit-B
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2012_02\FigFull21_AquiferClass_Rev0.mxd 9/20/2012



Arsenic (mg/L)

High : 0.140926

Low : 0.0005

Legend

- ● Point of Exposure Well (Name/Result/Year)
- ● Point of Compliance Well (Name/Result/Year)
- — Particle Track Path
- ▭ Point of Exposure Ring

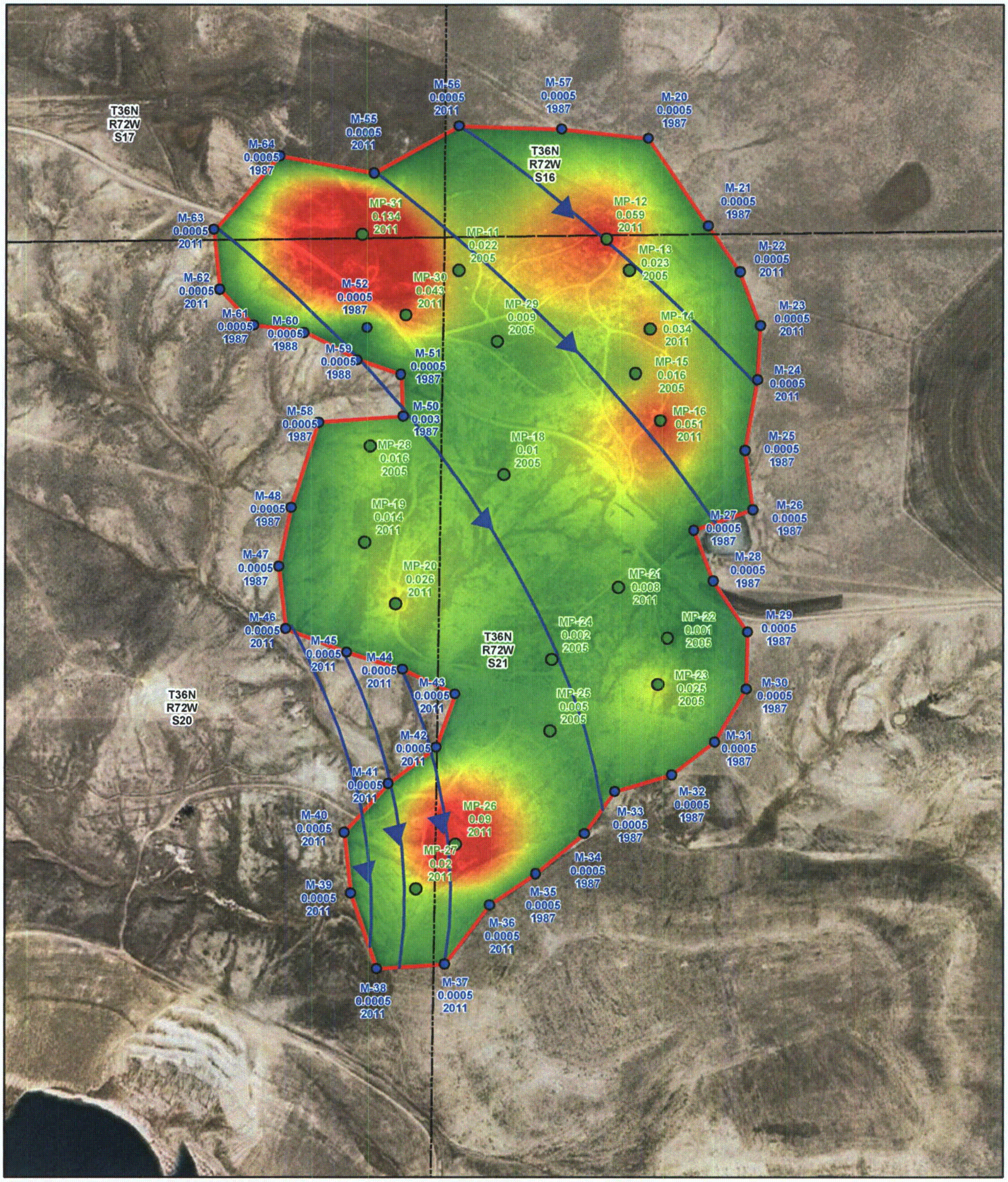
700 350 0 700

Feet

N W E S

Figure 22
Natural Neighbor Interpolation of Arsenic Groundwater Concentrations
Cameco Resources

INTERA



Selenium (mg/L)

High : 0.132532

Low : 1.50454e-005

Legend

- ● Point of Exposure Well (Name/Result/Year)
- ● Point of Compliance Well (Name/Result/Year)
- Particle Track Path
- ▭ Point of Exposure Ring

700 350 0 700

Feet

N W E S

Figure 23
Natural Neighbor Interpolation of Selenium Groundwater Concentrations
Cameco Resources

INTERA

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull23_SeleniumInterpolations_Rev0.mxd 2/4/2013

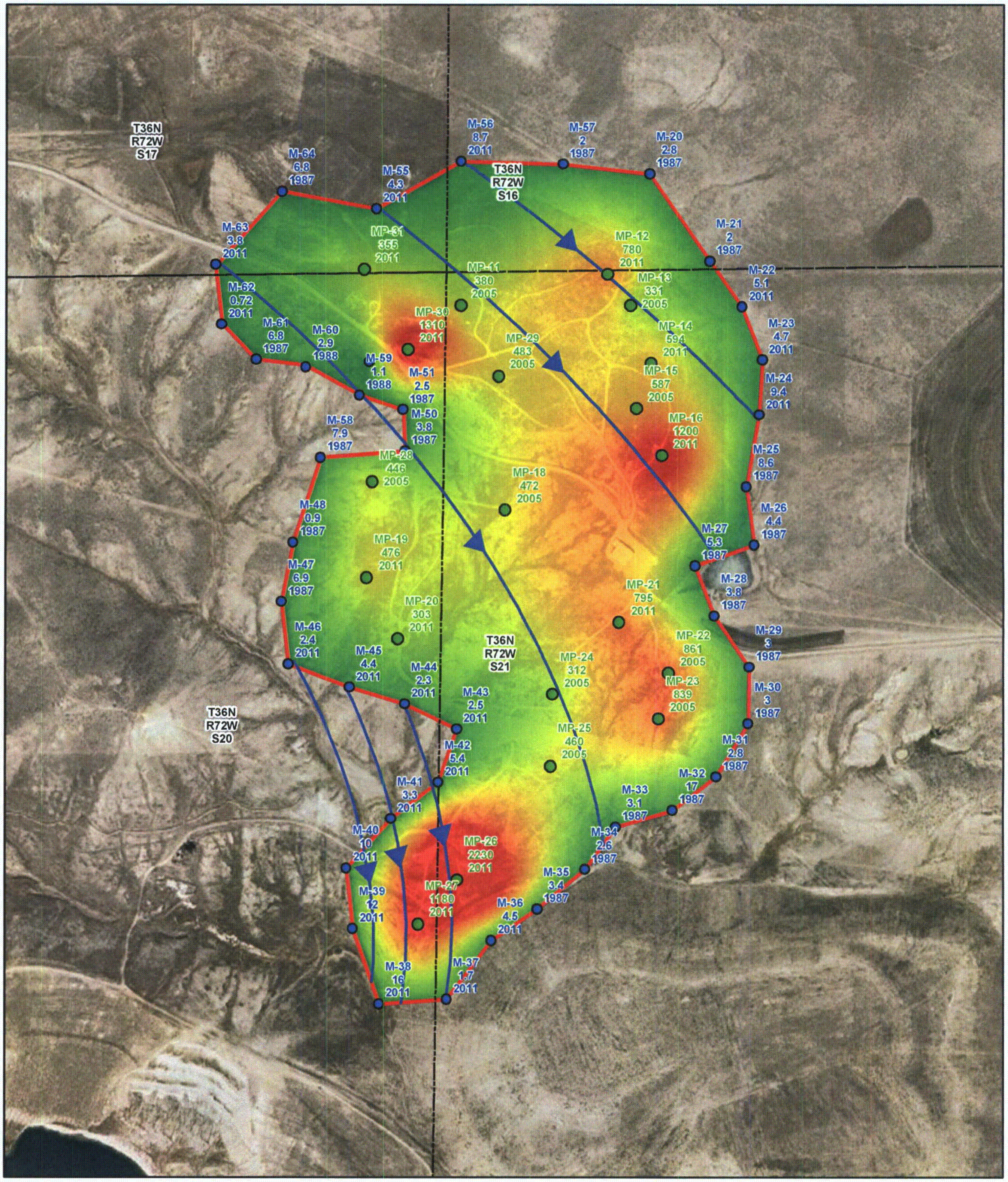
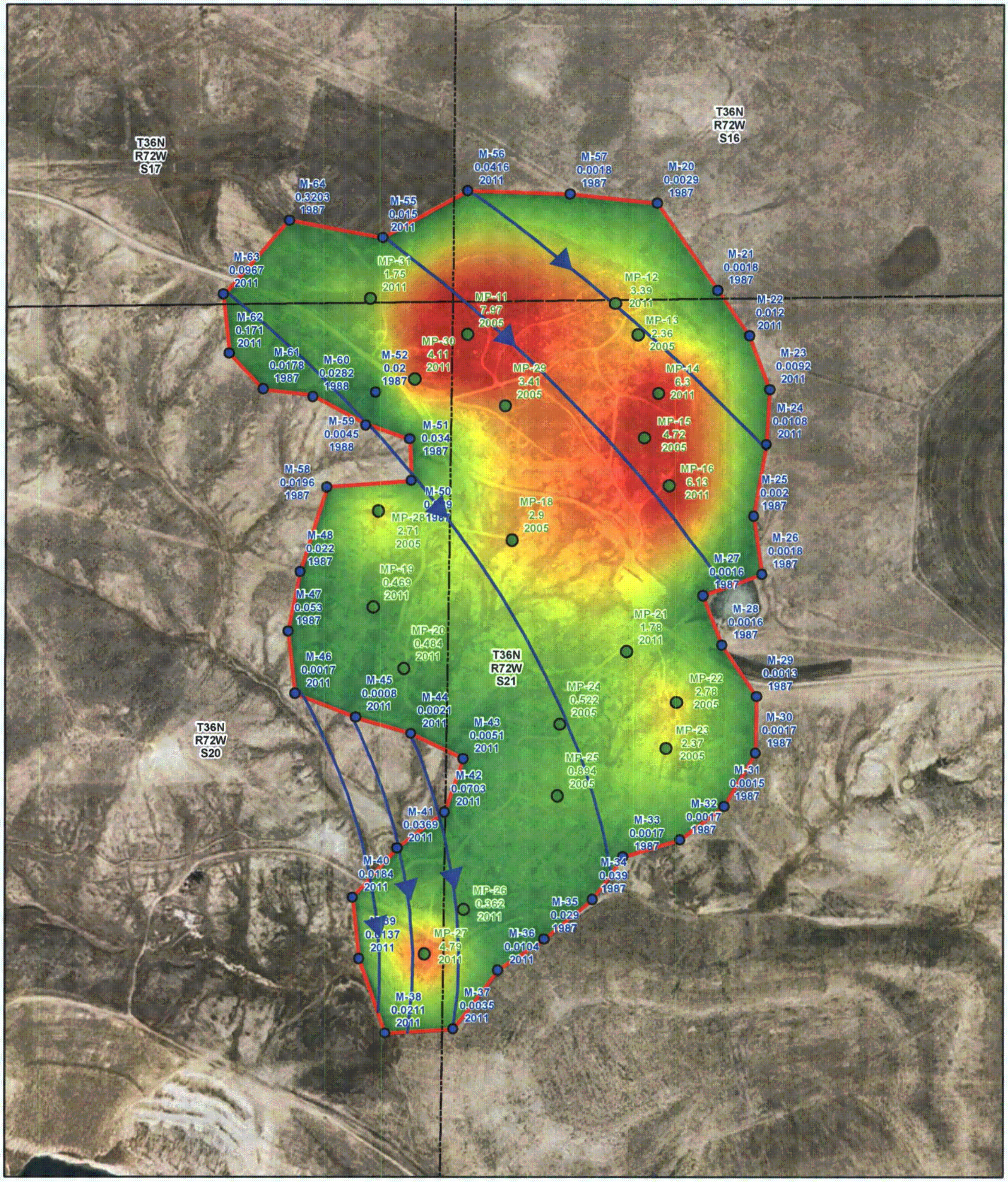


Figure 24
Natural Neighbor Interpolation of Radium 226 Groundwater Concentrations
Cameco Resources

INTERA

File: S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull24_Rad226Interpolations_Rev0.mxd 2/4/2013



Uranium (mg/L)

High : 7.9418

Low : 0.00172505

Legend

- ● Point of Exposure Well (Name/Result/Year)
- ● Point of Compliance Well (Name/Result/Year)
- — Particle Track Path
- ▭ Point of Exposure Ring

700 350 0 700

Feet

N
W E
S

Figure 25
Natural Neighbor Interpolation of Uranium Groundwater Concentrations
Cameco Resources

INTERA

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull25_UraniumInterpolations_Rev0.mxd 2/4/2013

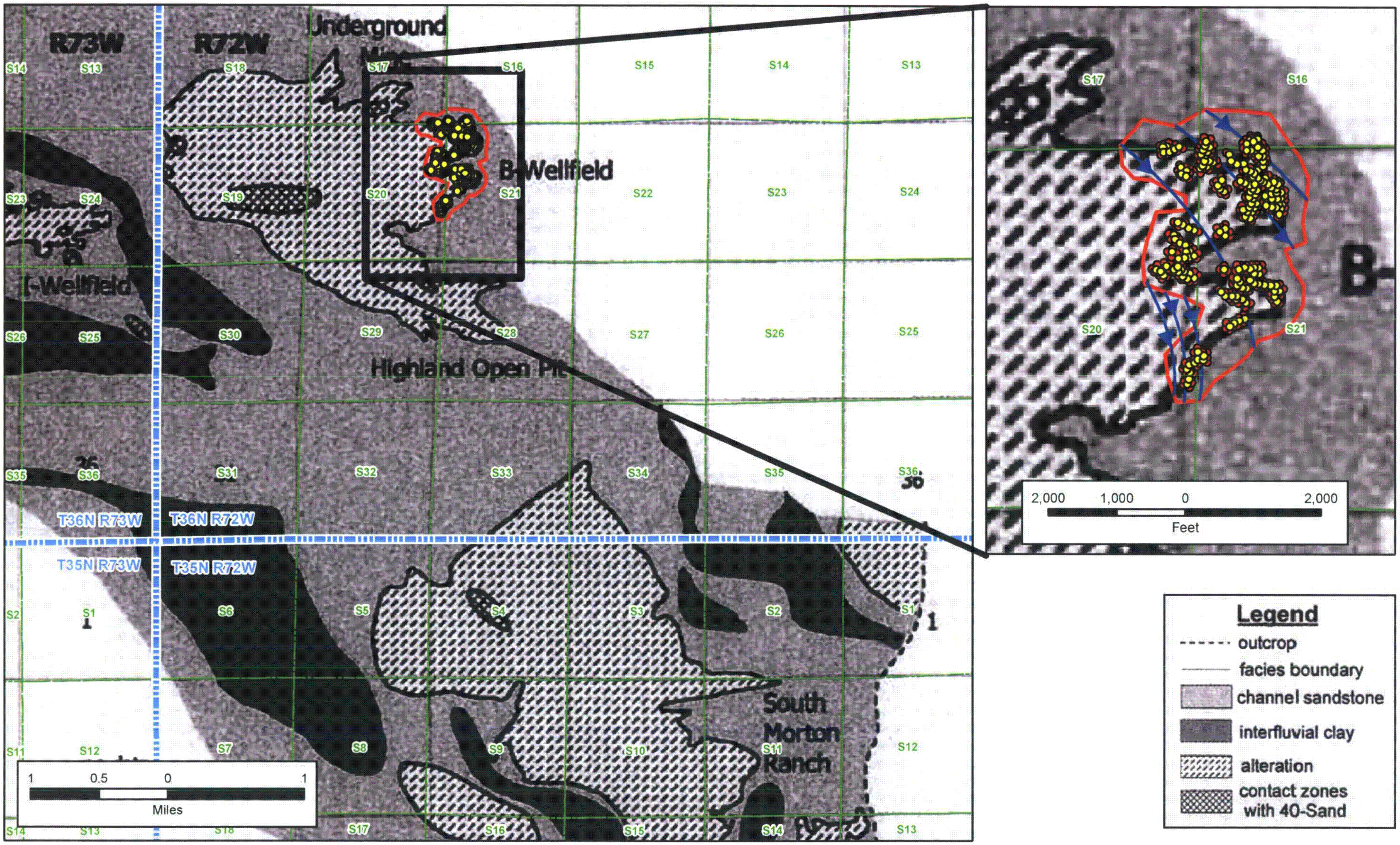
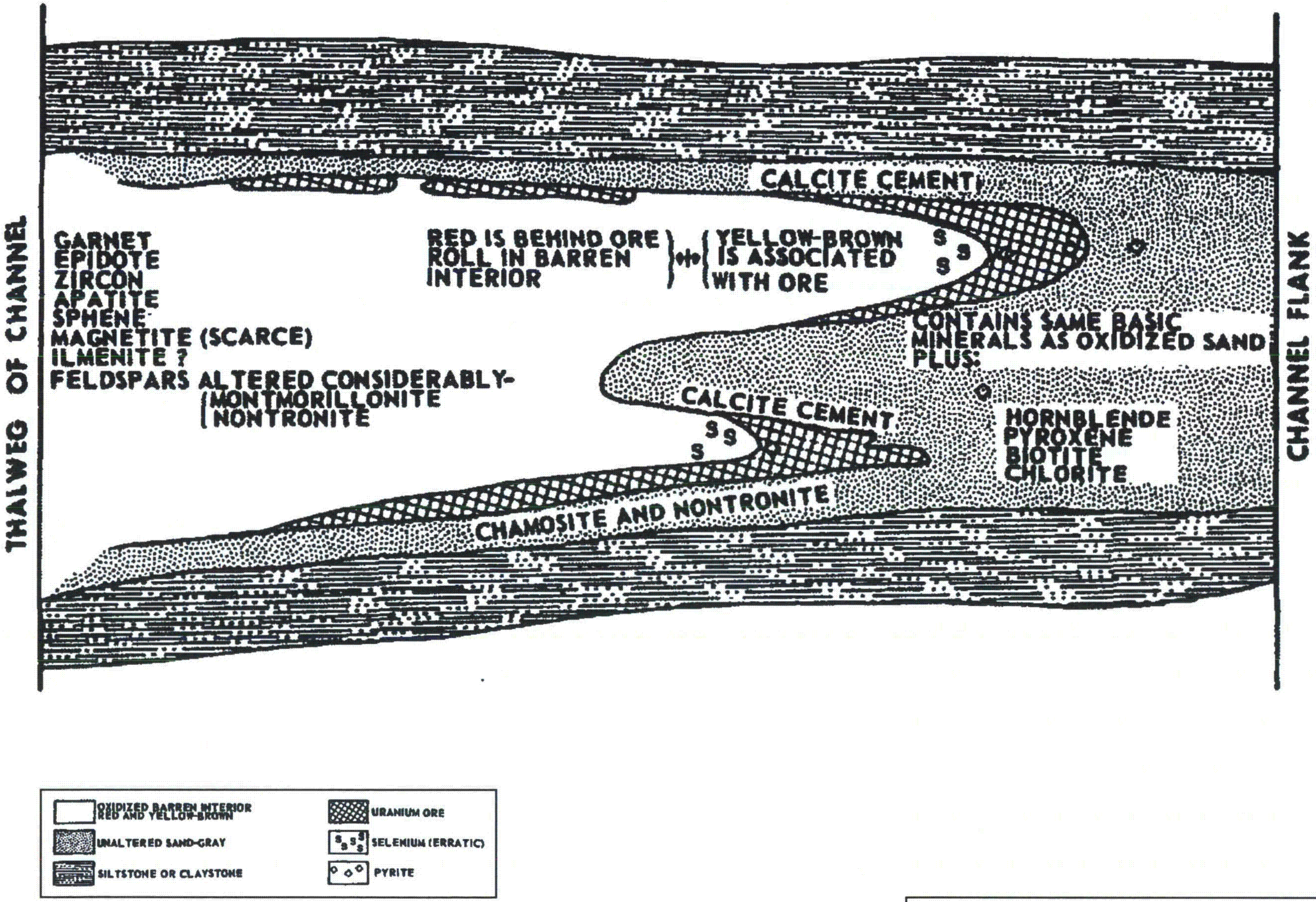


Figure 26
Mineralization Front for 30-Sand from Hunter, 1999

Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull26_30SandMinerals_Rev0.mxd 2/4/2013



Modified from Langden and Kidwell, 1973.

Figure 27
Schematic Diagram of Roll-Front Deposit
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull27_LangdenRollFront_Rev0.mxd 2/4/2013

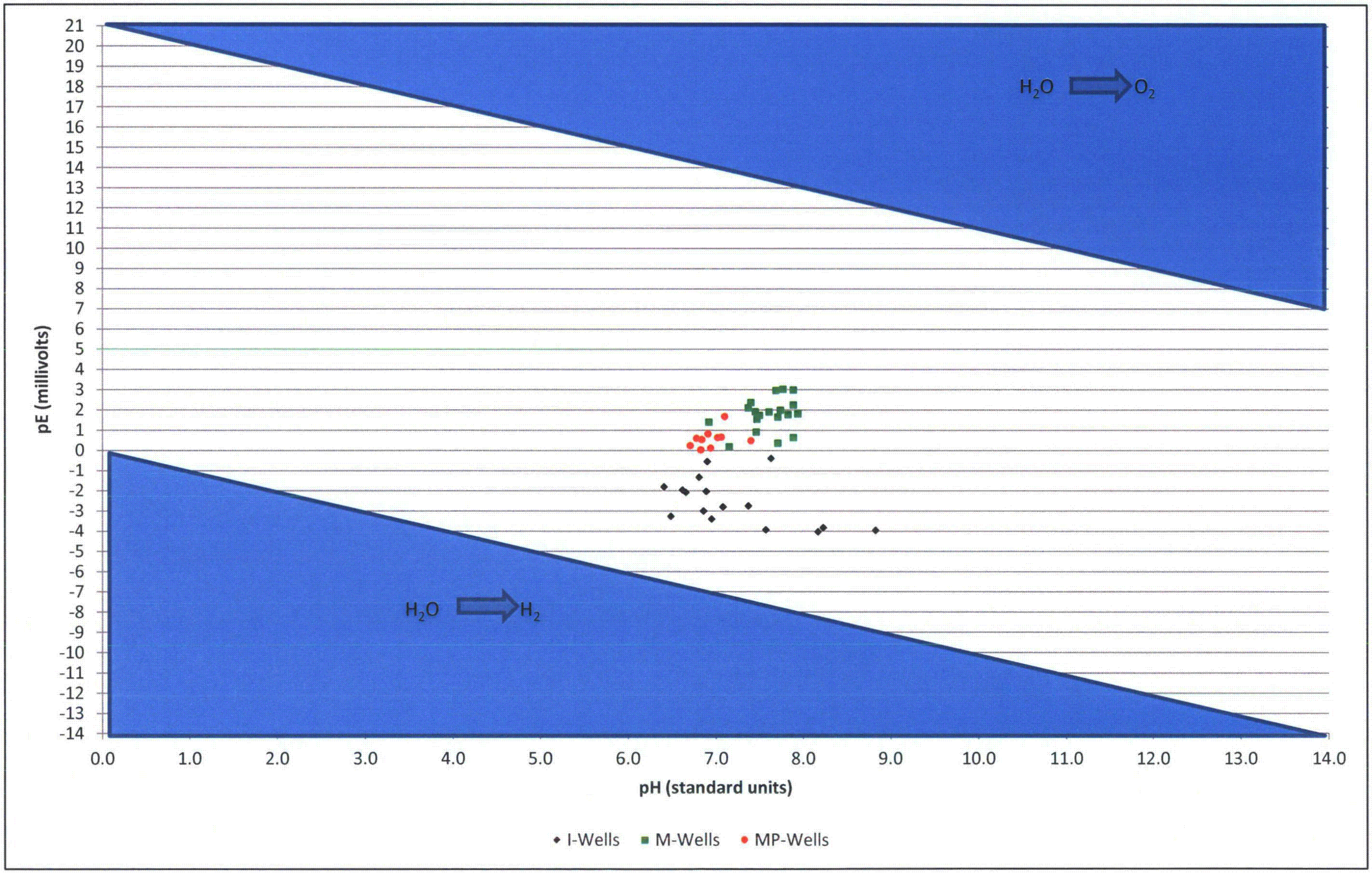


Figure 28
pH pE Plot
Cameco Resources

S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull28_pHpEPlot.xlsx\FigurePrintFormat 2/4/2013

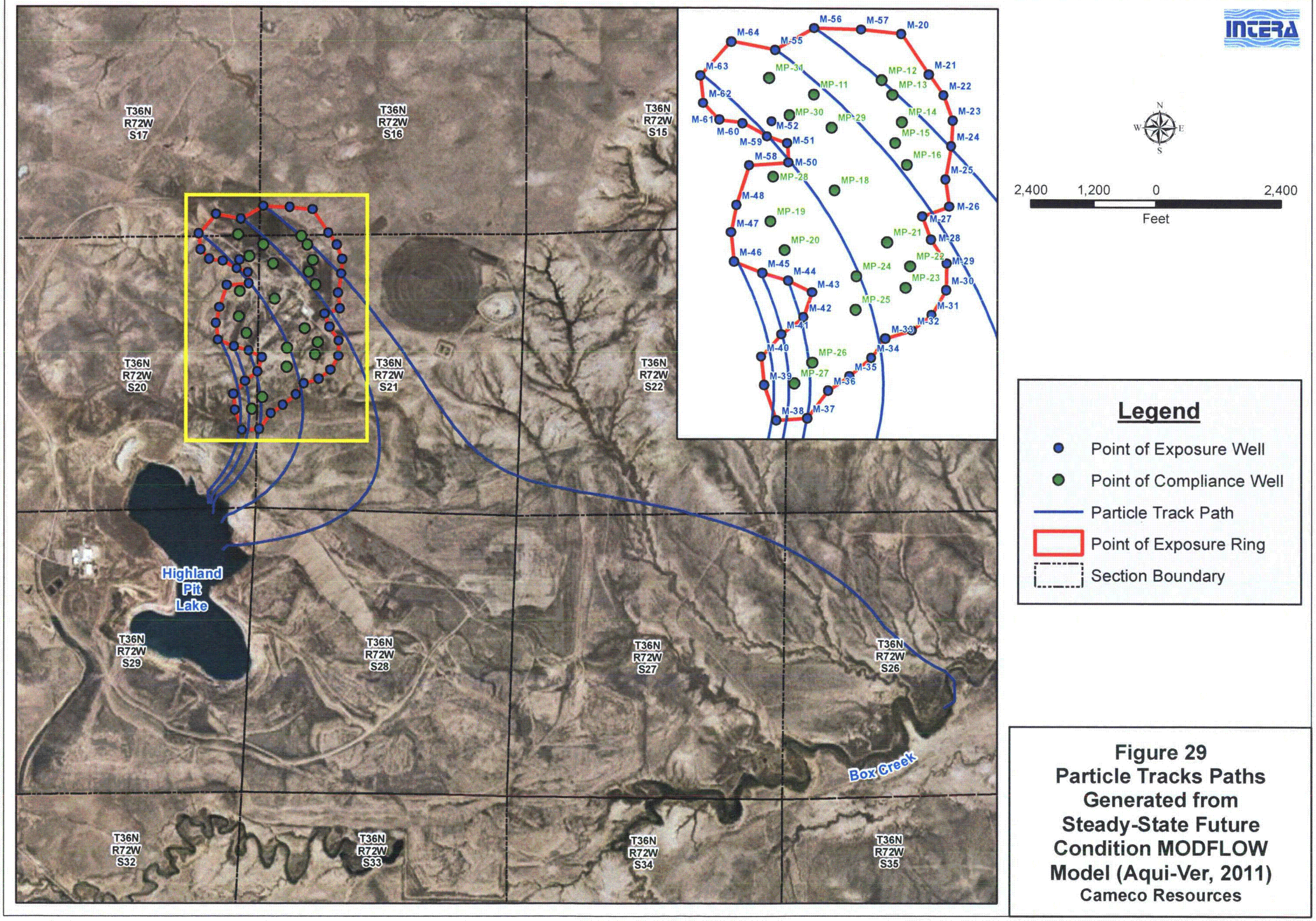


Figure 29
Particle Tracks Paths Generated from Steady-State Future Condition MODFLOW Model (Aqui-Ver, 2011)
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull29_ParticleTracks_Rev0.mxd 2/4/2013

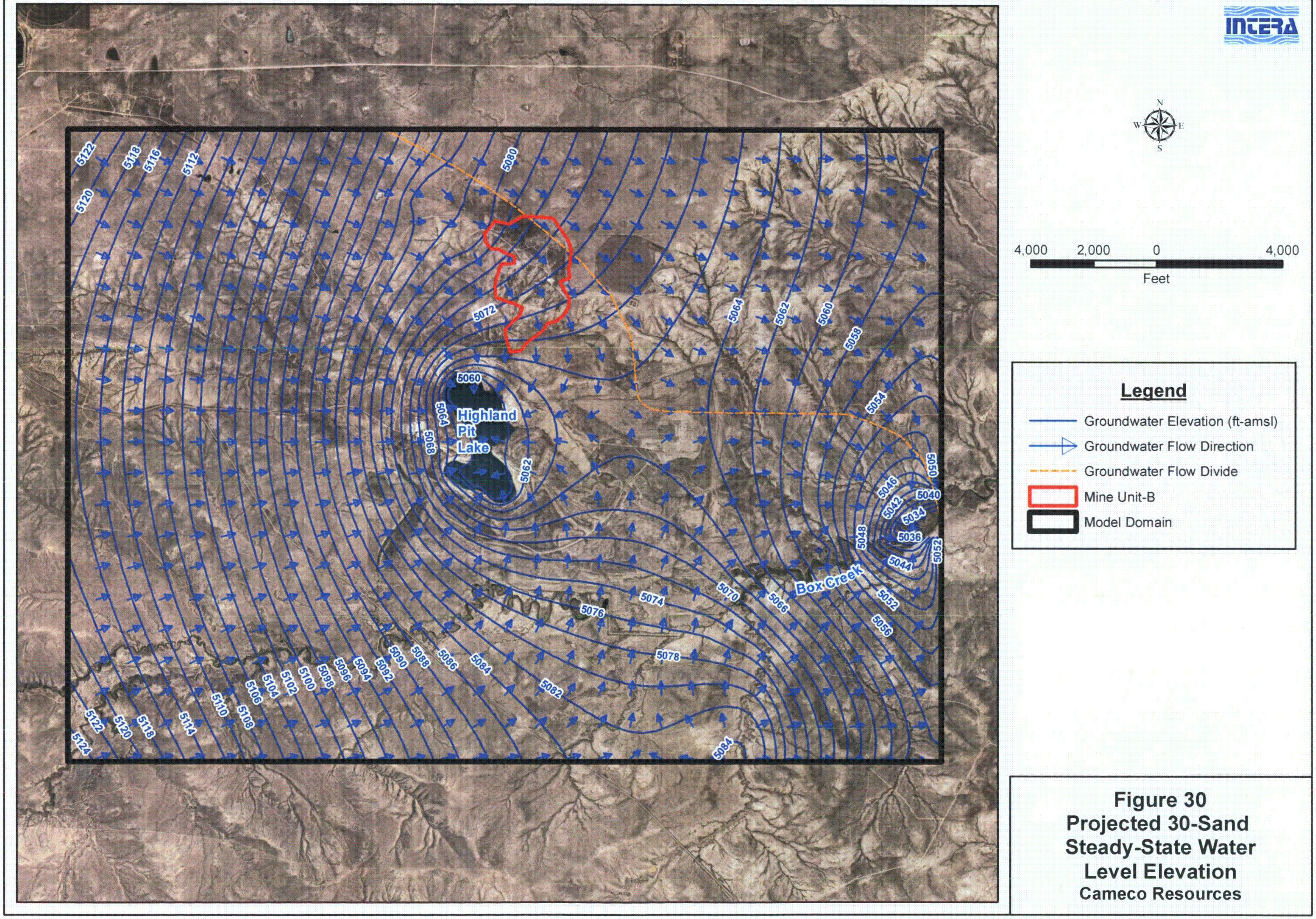


Figure 30
Projected 30-Sand Steady-State Water Level Elevation
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull30_GW_30Sand.mxd 2/4/2013

INTERA

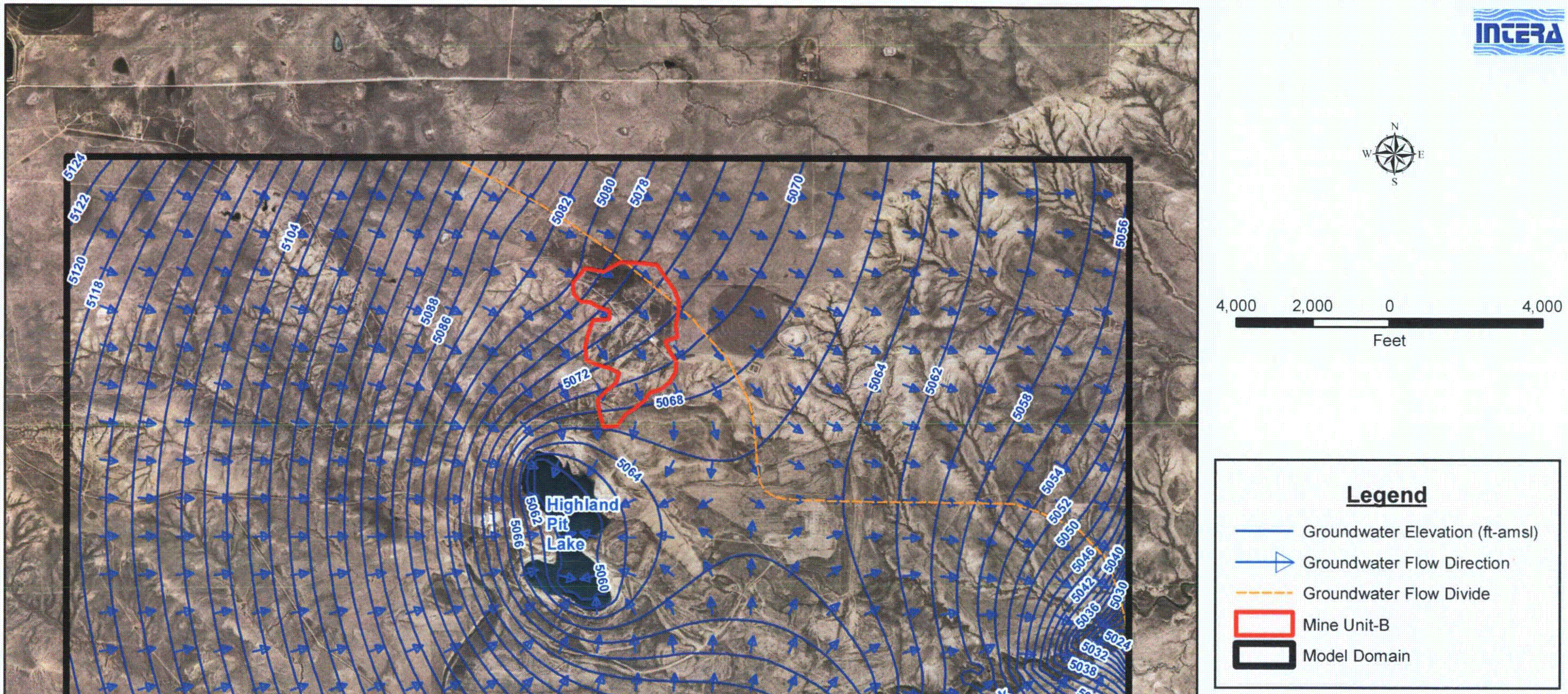
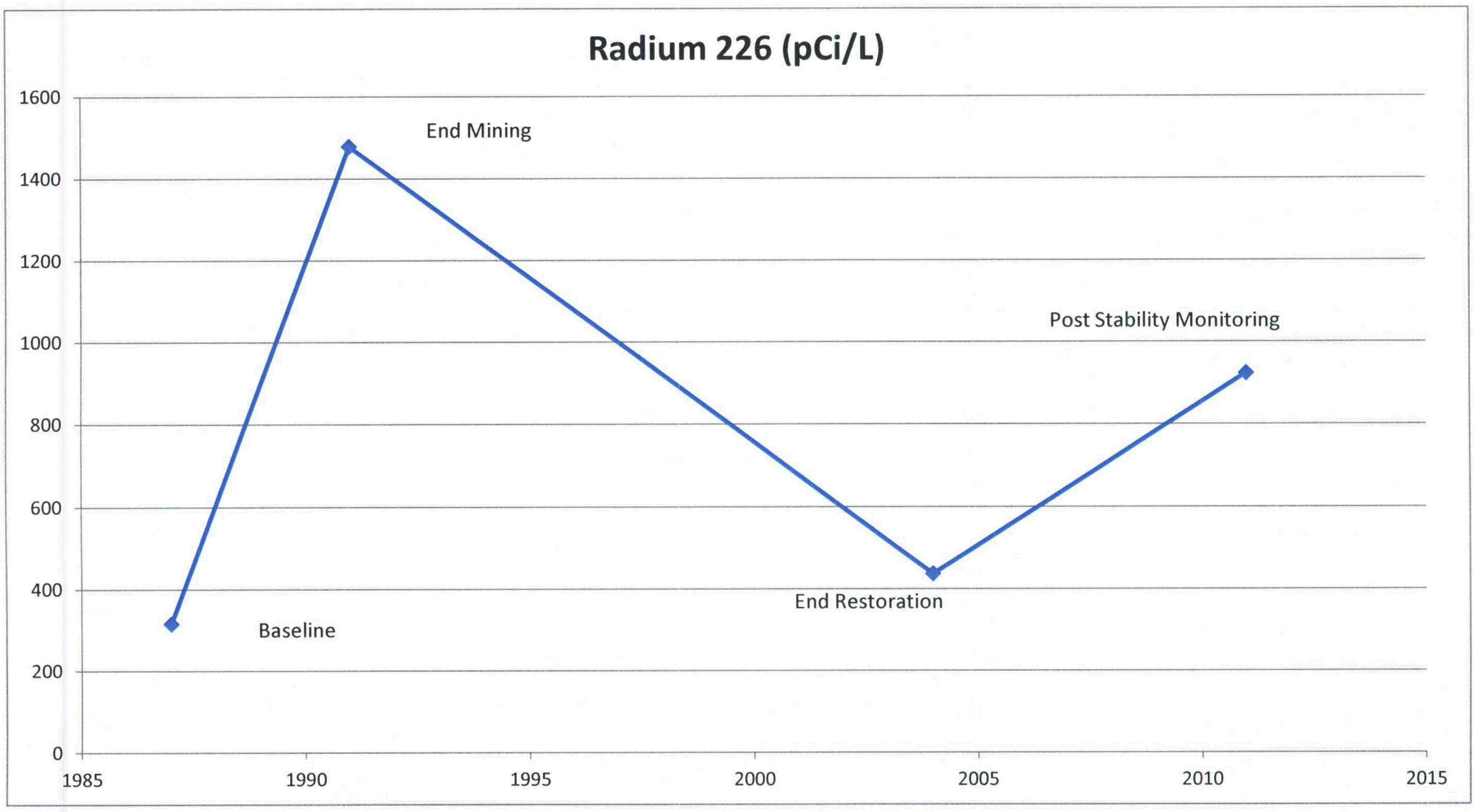


Figure 31
Projected 20-Sand Steady-State Water Level Elevation
Cameco Resources

File: S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull31_GW_20Sand.mxd 2/4/2013



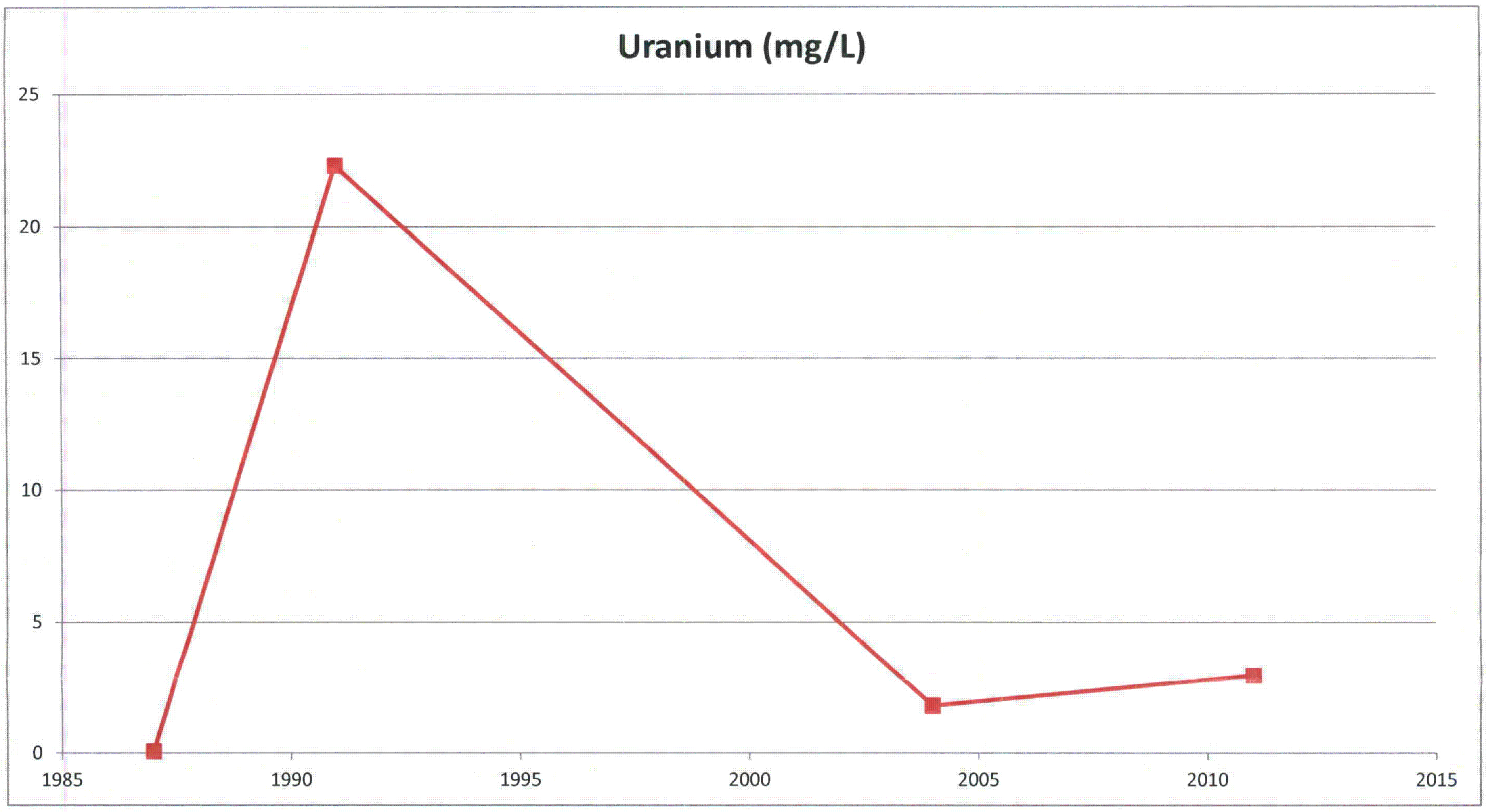
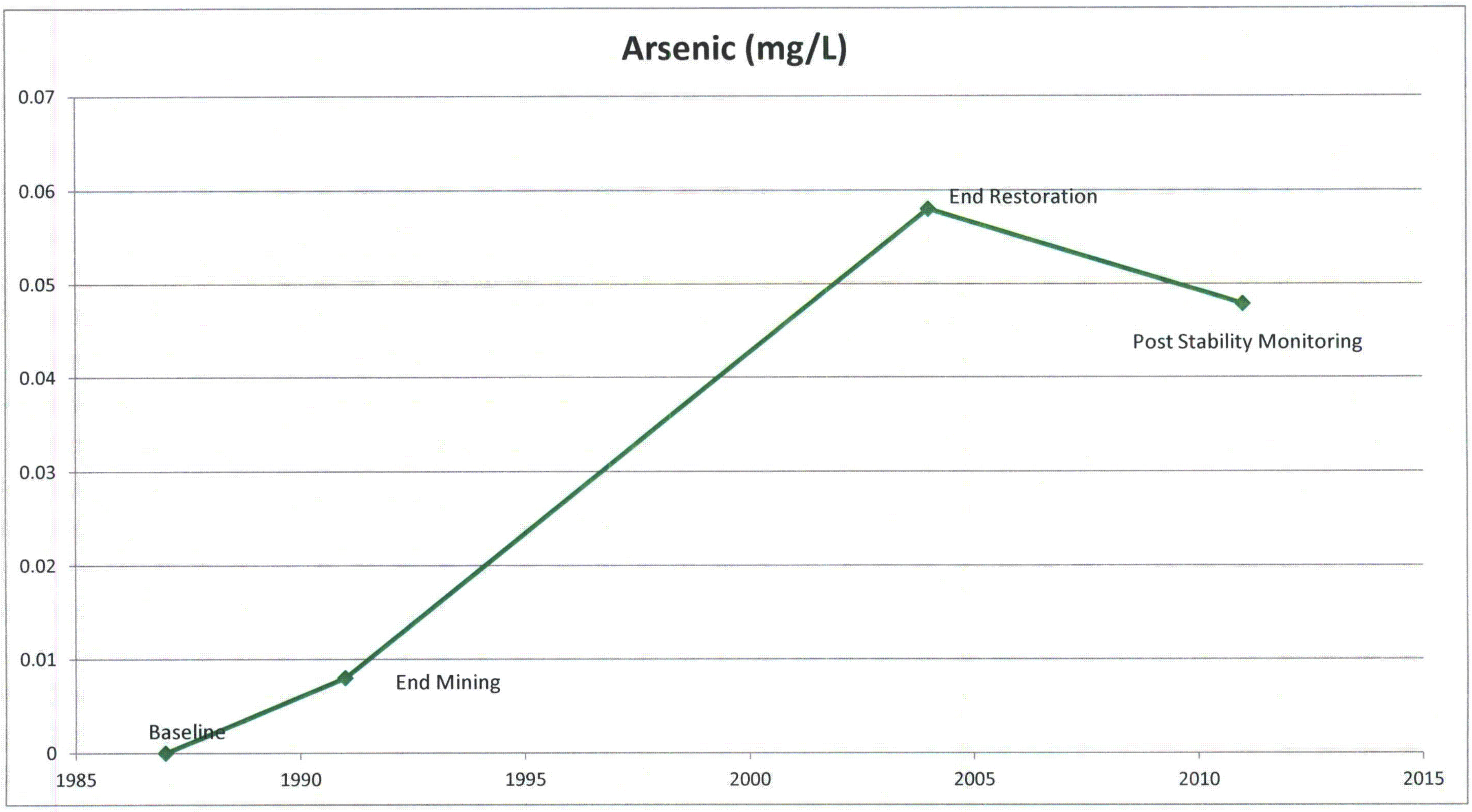


Figure 32
Groundwater Concentration Trends for Radium 226 and Uranium
Mine Unit B, Converse County Wyoming
Cameco Resources

S:\Projects\CAMEC-Cameco_Resources_ACL_ Applications_for_Areas_B&C\Graphics\MapDocuments\TaskB2MineUnitFullReport_2013_02\FigFull32-33_COCTrends.xls\Figure31 2/4/2013



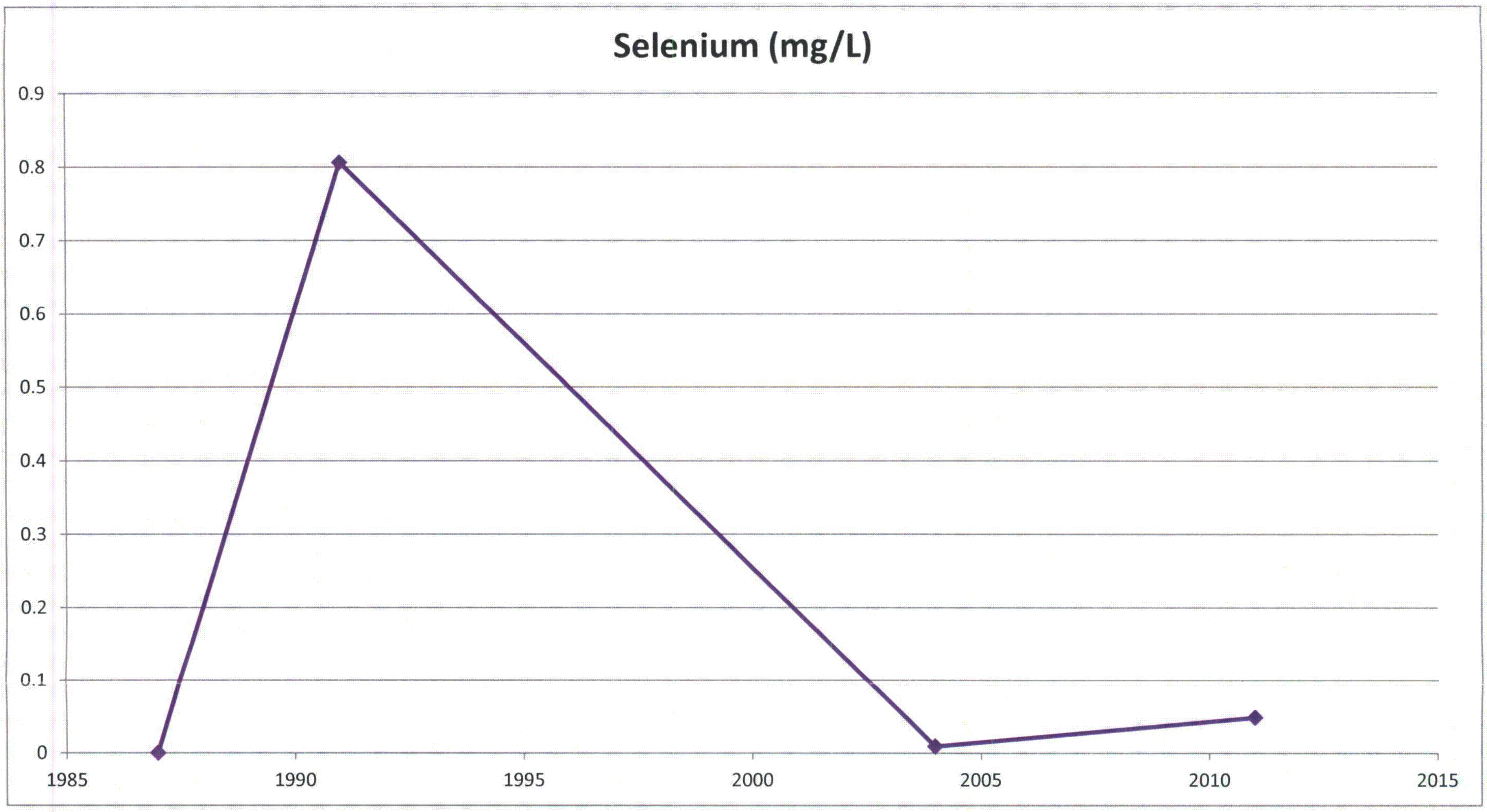


Figure 33
Groundwater Concentration Trends for Arsenic and Selenium
Mine Unit B, Converse County Wyoming
Cameco Resources