Golder Associates

TECHNICAL MEMORANDUM

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AMULSAR PROJECT - BRSF RISK ASSESSMENT OF HYDROLOGIC IMPACTS

1.0 BACKGROUND

The Barren Rock Storage Facility (BRSF) will be situated in the northern part of the Project Area and will be a valley-fill rock storage facility, with an open face on the east.

The BRSF design capacity is approximately 160 Mt. The BRSF will contain 130 Mt of barren rock from the Tigranes and Artavazdes deposits, and about 30 Mt from the Erato deposit. Development of the BRSF will take place in phases, with stacking beginning on the southern side of the BRSF footprint and developing the footprint towards the north as stacked benches are increased in height. The final footprint of the BRSF is expected to be approximately 140 hectares.

The objective of this technical memorandum is to conduct a risk assessment of the BRSF in order to establish the potential risk to water receptors as a consequence of leakage from the base of the BRSF. This assessment will support the groundwater impact assessment of the Amulsar Gold Project, being undertaken by Golder Associates UK (Golder) as part of the Environmental and Social Impact Assessment (ESIA) for the Project. The conceptual model that forms the basis for the BRSF risk assessment is based on the Groundwater Baseline, Chapter 4.8 of the ESIA, the BRSF design assessment (GRE, 2014) and the groundwater flow model (Golder 2014a).

2.0 SITE SETTING

The BRSF site occupies a valley which steepens northward between North Erato and the peak of a basalt scoria cone which forms the north-west valley flank. At its northeastern extent, the BRSF laps onto a ridge forming the margin of a second valley basin opening to the east. The southern portion of the BRSF site is a relatively flat slope with thicker soil deposits, which narrows to form the main, relatively steep-sided valley, which drains from south to north through the northern part of the site.

2.1 Geology

The geological site setting is based on information presented in the Groundwater Baseline, and data from geotechnical investigations (Golder, 2014b) and illustrated in Figure 1.

The BRSF footprint is underlain by colluvium comprising clay with varying amounts of silt, gravel, sand, and cobbles. The total thickness of colluvium ranges from less than 1 m along the sides of the scoria cone to greater than 10 m in the valley. In some geotechnical boreholes (e.g. in the south-east of BRSF), the clayey soils that are logged are likely to be unconsolidated superficial deposits/colluvium and the underlying argillic andesite.

The bedrock underlying the colluvium beneath the south-eastern portion of the BRSF comprises saprolitic argillically altered andesite of the Lower Volcanics. The bedrock underlying the colluvium beneath the north-western portion of the BRSF comprises Cenozoic Basalts. A basalt scoria cone is also present on the northwest side of BRSF.

The majority of the andesite has been both weathered and hydrothermally altered to the extent that it behaves similar to clay. This argillically altered andesite has a saprolitic texture, in that the structure of the original rock is clearly visible but many of the minerals have weathered to clays.

The geotechnical investigations did not determine the full thickness of the Cenozoic Basalt Flow. The basalts thicken to the northwest and are at least 90 m in thickness on the western margin of BRSF and 100 m in thickness in borehole DDAW013, located within the basalts immediately north of the BRSF. Clayey material was encountered at 98 m to 100 m at the base of DDAW013 which may represent either a sedimentary interbed in the basalt sequence, or the contact between the basalts and the underlying volcanics. In other parts of the Project Area, the basalt sequence is about 100 m thick. Within the basalt, there are lenses of scoria material and some areas where thicker scoria deposits exist.

To the south, the BRSF footprint follows the outcrop of the contact between the Upper (silicified) and Lower (argillic) Volcanics (LV). The contact dips southeast at this location, and silicified rocks occur to the southeast. The argillic Lower Volcanics occur outcropping along the mountain flank to the southwest of the BRSF. The Lydian geological model identifies this contact as the base of the interleaved silicified and argillic sequence, such that the in the southeastern portion of the BRSF is anticipated to be underlain by argillically altered porphyritic andesite to a depth of at least 150 m.

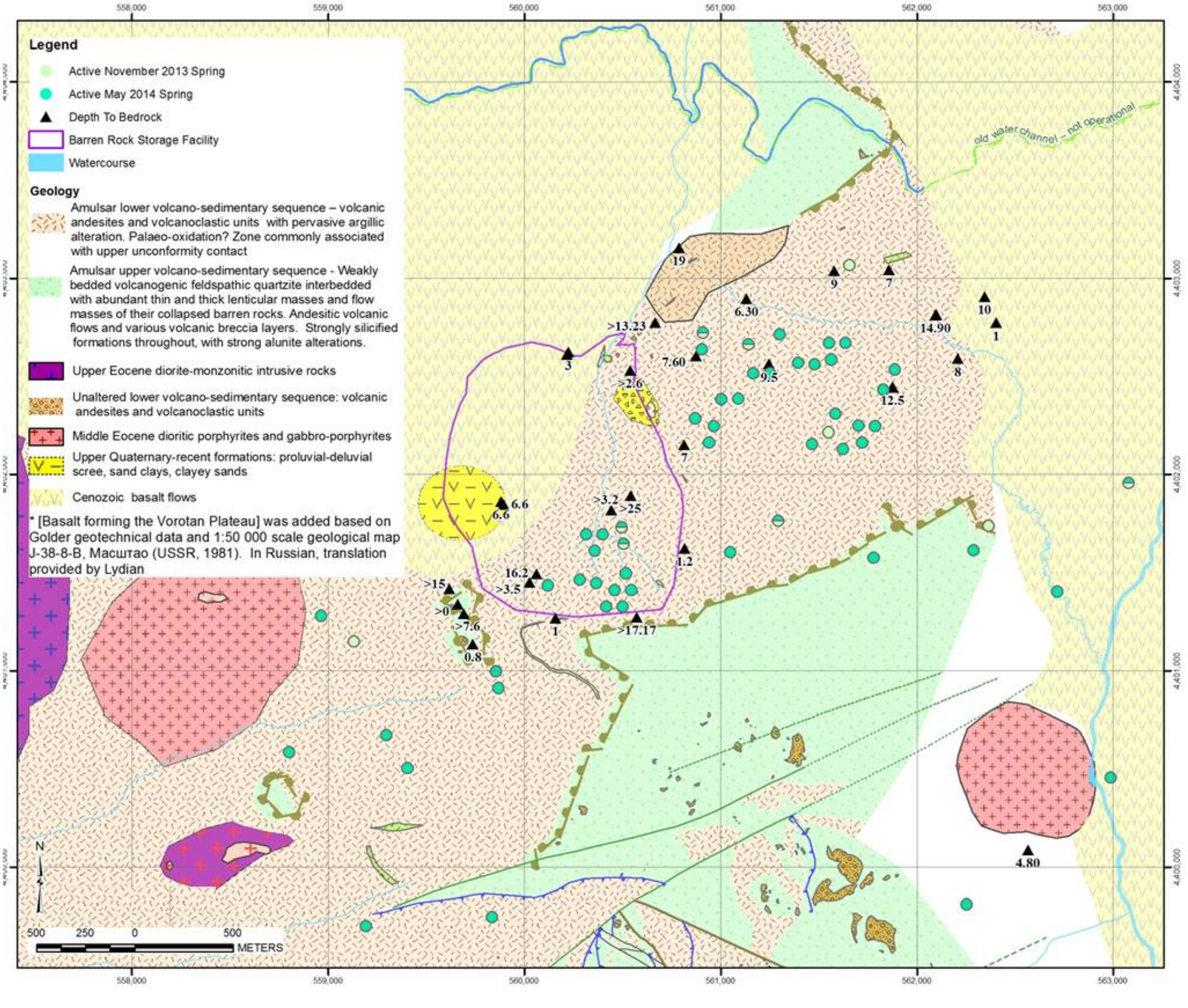

Figure 1: BRSF Geological Setting

2.2 Hydrogeology

2.2.1 Groundwater Recharge

Groundwater levels in the Amulsar area rise rapidly in the Spring and early Summer indicating recharge from snowmelt. In general, a more muted groundwater level response is observed at lower elevations (for example the BRSF area) which may in part be due to the locations of the monitoring wells near groundwater discharge locations.

Following the Spring snowmelt, groundwater levels decline rapidly following early Summer, and continue to decline more steadily through the dry Summer and Autumn months. At elevations where temperatures remain above freezing in October, limited recharge from rainfall or early season snowmelt may occur. Groundwater levels continue to decline over the Winter in response to the lack of recharge. The lowest groundwater elevations are recorded just prior to the onset of the Spring snowmelt.

Groundwater recharge rates are a function of precipitation (snowfall) (which is related to elevation), topography/aspect, geology and soils. The highest recharge occurs associated with higher elevation areas where snowfall accumulates and then melts slowly in the Spring. Recharge is least in open windswept areas where there is limited accumulation of snow.

Groundwater recharge rates also differ depending on the properties of the bedrock:

- In areas underlain by the argillic LV andesite, much of the recharge is rapidly discharged via shallow flow systems to nearby springs and streams (such as the spring systems in the southern part of the BRSF and adjacent valley, and to the west of the Amulsar ridge);
- Groundwater recharge occurs to the unaltered LV since this unit is more permeable than the argillic LV, but likely at lower rates since this unit is found at lower elevations where precipitation is less. Groundwater discharge from the unaltered LV sustains baseflow at lower elevations on Amulsar and where in hydraulic contact with the major rivers; and
- The basalt outcrop areas are typically devoid of surface water because of the greater infiltration potential of the soils and underlying bedrock. As a result, recharge over the Cenozoic Flow Basalts is interpreted to be greater than the other regional bedrock types. Groundwater in the basalt discharges at seepage faces where the basal contact of the basalt is exposed in incised valleys (Golder, 2014c) and discharges as baseflow to the incised valleys of the major rivers (Vorotan, Arpa, etc.).

2.2.2 Groundwater Elevation

The regional elevation of groundwater based on the existing monitoring locations is predominantly topographically controlled. Groundwater flows radially away from the Amulsar ridge toward the Arpa River to the north and west, toward the Vorotan River to the east and toward the Darb River to the southwest.

The BRSF is located at the north end of the Amulsar Ridge as shown on Figure 2. Based on the groundwater contours groundwater flow beneath the BRSF is towards the northwest. The area south of the BRSF forms an upgradient catchment to the facility. A number of springs are present within the footprint of the facility; it is interpreted that that these springs discharge upgradient recharge from the argillic LV andesite. It is assumed that due to the presence of these springs there is little if any underflow of upgradient groundwater and hence immediately downgradient groundwater flow and quality will reflect the flow and quality of local recharge and or leakage from the base of the BRSF.

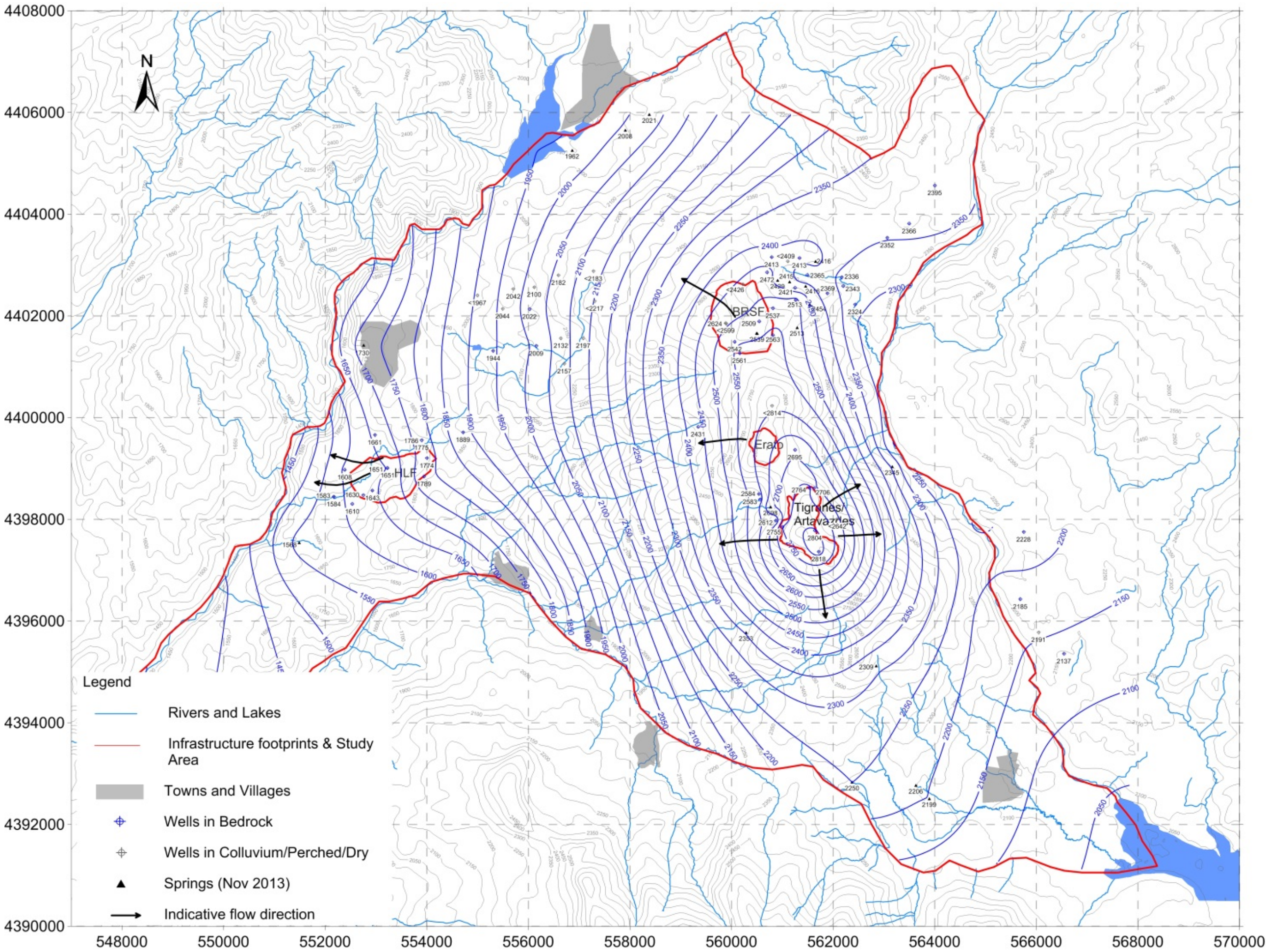

Figure 2: Interpreted Groundwater Elevation Contours

The Spandaryan-Kechut tunnel is located downgradient of the BRSF (Figure 3), between the facility and the Arpa River. The tunnel connects the Spandaryan Reservoir in the south and the Kechut reservoir in the north. Under current conditions, sluice gates in the Spandaryan Reservoir are closed and there is reportedly no surface water inflow to this tunnel, but discharge is observed which is interpreted to be groundwater (Golder, 2013). The tunnel therefore has the potential to capture a component of groundwater flow migrating westward from the BRSF and then divert this water to the Kechut Reservoir. The results of the groundwater modelling (Golder, 2014a) indicate that the tunnel is below the water table elevation and thus groundwater flows into the tunnel where the lining is damaged.

The Study Area groundwater flow model (Golder, 2014a) indicates that groundwater flow paths originating from the BRSF area pass beneath the Spandaryan-Kechut tunnel. Given the high sensitivity assigned to the water in the Spandaryan-Kechut tunnel (see Chapter 6.9 of the ESIA), and the potential limited field data to calibrate the modelled groundwater elevations in the vicinity of the tunnel, it is assumed for the purposes of this assessment that groundwater originating in the BRSF area may reach the tunnel.

3.0 BRSF DESIGN

The design of the BRSF incorporates measures to ensure the protection of surface water and groundwater that comes into contact with Potentially Acid Generating (PAG) barren rock by collecting and conveying this water to the BRSF toe pond. During mine operations, this water will be pumped to the HLF for use in the leaching process. At closure, drainage water from the BRSF will be collected and treated using a passive treatment system and then infiltrated locally (GRE, 2014).

The BRSF will be constructed to prevent PAG barren rock from coming into contact with water as much as possible, and using Non Acid Generating (NAG) barren rock to serve as a contact buffer between PAG material and the natural environment.

The BRSF will be constructed as follows:

- Prior to construction, topsoil from within the footprint of the BRSF will be removed and stored in a stockpile where it will be maintained until it is needed for concurrent final reclamation;
- Diversion channels will be constructed to ensure the natural run off from Amulsar Mountains routed around the BRSF to maintain this as natural (non-contact) surface water that naturally drains away from the BRSF;
- The existing subsoil in the footprint of the BRSF will be compacted in place to act as a low-permeability soil liner. This soil liner will direct any water that comes into contact with the barren rock to the toe of the BRSF via a 25 m wide NAG waste drainage layer, where the outflow will be collected for reuse (during operations) or treatment and infiltration (closure);
- In the absence of suitable subsoil to form a low-permeability soil liner, a liner will be formed using soil materials from within the BRSF footprint;
- The subsoil will not be compacted around springs within the BRSF footprint to allow them to continue to flow. Natural groundwater from these springs will be prevented from coming into contact with PAG barren rock by placing NAG waste over the compacted soil liner. Any water percolating through the basal drainage layer of the BRSF (from potential seeps and springs) will flow to the toe of the facility for collection. Because this underdrain is created from geochemically-inert NAG waste, the quality of the water should not be significantly affected;
- PAG waste will be placed in engineered cells that will be surrounded by NAG waste on all sides. As a result, the PAG waste will be in contact with neither the bottom soil liner nor the atmosphere. Amulsar PAG waste consists of argillized rock and contains a significant clay fraction. This clay fraction makes the PAG a low-permeability material. As a result, any water entering the body of the BRSF will flow preferentially through NAG barren rock that will be placed around the PAG cells; and
- At closure, the BRSF will be covered with an engineered evapotranspiration (E/T) cover specifically designed for the conditions found at the site. The components of the cover from the surface include:
  - Topsoil to provide a vegetative growth medium;
  - A layer of naturally-compacted clay that will act as a sponge that absorbs the influx of water into the cover system; and
  - A layer of gravel that will act as a capillary break between the cover soil and the barren rock in the facility. and
- A groundwater and surface water monitoring plan will be implemented during operations and closure. The purpose of the monitoring will be to evaluate the operational performance of the BRSF and identify any adverse trends in the discharge to the toe pond or changes in downgradient groundwater or surface water quality (potential leakage) that would require the implementation of modifications to the barren rock management system or additional mitigation measures.

4.0 CONCEPTUAL MODEL

The BRSF risk assessment was conducted by identifying the source-pathway-receptor linkages.

4.1 Source

The source comprises the leakage of fluids from the base of the BRSF that contains a loading of dissolved constituents from the rock. GRE has conducted geochemical modelling of the composition of the post-closure leakage of fluids from the BRSF (GRE, 2014). The results of the geochemical modelling are presented in Table 1.

Concentration of nitrogen in the BRSF as a result of transport of explosives residues in barren rock has been evaluated in Golder (2014e). This assessment is highly conservative as it neglects chemical and biologically mediated reactions which may act to reduce nitrate concentrations. However, it is considered appropriate to incorporate this in the impact assessment.

The predicted concentrations of constituents are compared to the Republic of Armenia (RA) Category II Maximum Acceptable Concentrations (MAC) for the Arpa Basin in order to identify the potential for leakage from the facility to impact surface water quality.

Post-closure leakage rates calculated by GRE (2014) have been used in this risk assessment. The average leakage rate is 15 m^3/day or 5,475 m^3/year.

Table 1: Modelled Composition of BRSF Leakage (Post Closure)

Constituent	Units	Arpa MAC (Category II)	Estimated Post Closure Concentration
Al	µg/l	144	164,399
As	µg/l	20	104.9
Ba	µg/l	28	9.2
Be	µg/l	0.038	12.2
B	µg/l	450	55.5
Cd	µg/l	1.014	2.2
Ca	mg/l	100	42.7
Cl-	mg/l	6.88	1.3
Cr+3	µg/l	11	0.1
Co	µg/l	0.36	622.9
Fe(3)	mg/l	0.072	0.5
Pb	µg/l	10.14	244.3
Li	µg/l	3	53.2
Mg	mg/l	50	20.3
Mn	µg/l	12	281.2
Ni	µg/l	10.34	373.8
Nitrate	mg N/l	2.5	365*
K	mg/l	3.12	35.0
Se	µg/l	20	52.8
Sulphate	mg/l	16.04	412.3
P	mg/l	0.2	5.2
V	µg/l	10	14.3
Zn	µg/l	100	2264.1

**Based on the average total nitrogen loading reported in Golder, 2014e*

4.2 Pathways

The hydrogeological characterisation indicates that the BRSF site is situated at the headwaters of the groundwater flow system originating from the northern end of the Amulsar ridge. As a result of the geological conditions, groundwater recharge to the area underlain by the argilized volcanics is locally discharged as springs with some baseflow to local surface water. In the north-western part of the BRSF, the topographical and geological conditions suggest that there is little if any upgradient groundwater flow entering the BRSF footprint and that groundwater flow in the Cenozoic basalt is currently driven by local recharge.

As discussed in Section 2.2.1 there is evidence that surface run off in the BRSF area underlain by basalt is limited and thus there is potentially greater recharge to the groundwater system.

Recharge is estimated to be about 200 mm/yr in the valley east of the BRSF, with a slightly higher recharge rate of 250 mm/yr in the BRSF and adjacent basins where the restricted entrance to both valleys promotes snow capture and restricts runoff. Water quality and flow monitoring indicates that recharge to the argilized volcanics and overlying colluvial sediments that underlie the southeastern part of the BRSF is primarily rapidly discharged to springs or to surface water as baseflow.

The groundwater flow model predicts that recharge entering the groundwater system within the Cenozoic basalts will migrate in a northwesterly direction towards the Kechut Reservoir and Arpa River. Some groundwater may also reach the Spandaryan-Kechut tunnel (Figure 3). The travel time (for an un-retarded constituent) from the BRSF site to the Spandaryan-Kechut tunnel ranges between 64 and 120 years, with an average of 94 years, whereas the travel time from the BRSF to the Arpa River ranges between 94 and 150 years, with an average of 126 years. Groundwater travel time calculations presented in Section 5.2.3 are based on an effective porosity of 2%.

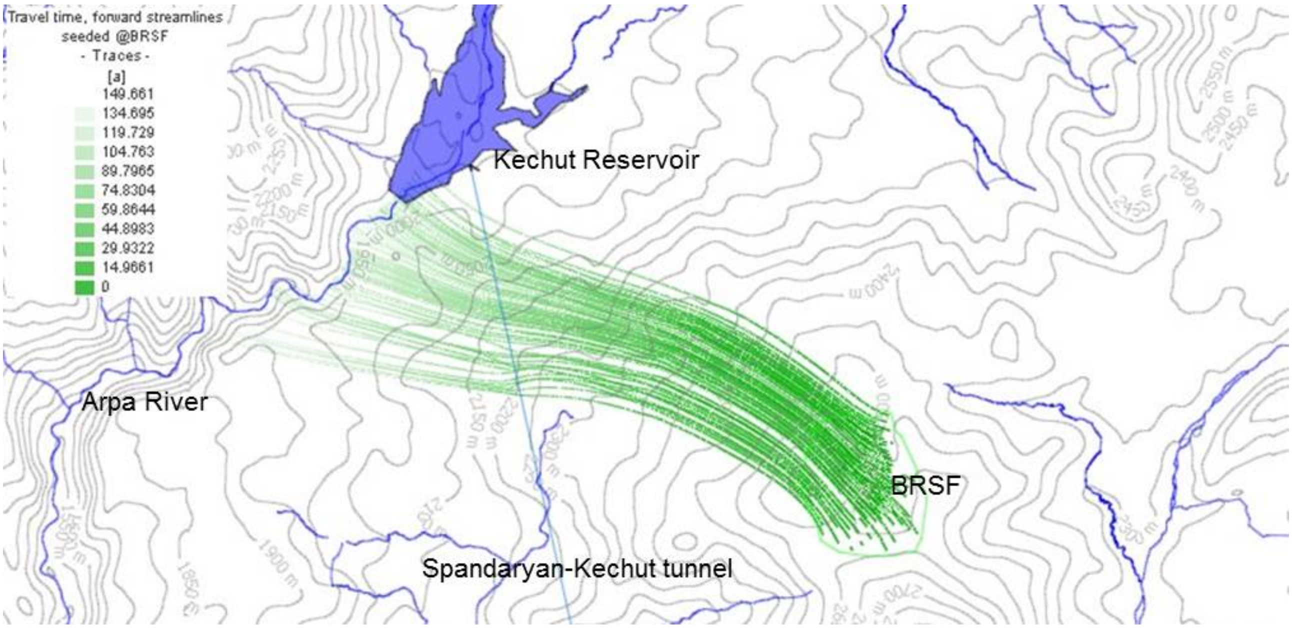

Figure 3: Modelled Groundwater Flow Pathlines, Post Closure Scenario

4.2.1 Geochemical Processes

Solute transport in groundwater is a function of the geological and geochemical conditions along the groundwater pathway. Physical, chemical and biological processes influence groundwater flow and solute concentrations. The overall effect of these processes is to retard the migration of certain constituents, particularly metals in groundwater flow. In modelling, a retardation factor is used to calculate the groundwater travel time for retarded constituents.

The retardation factor for a constituent is dependent on the density of the geological medium, the partition coefficient of that particular constituent between liquid and solid (Kd (l/kg)) and the effective porosity of the geological medium.

4.3 Receptors

Results of groundwater flow modelling (Golder, 2014a) indicate that any leakage from the BRSF is most likely to flow to the downstream shore of the Kechut Reservoir and to the Arpa River downstream of the Kechut Reservoir. The groundwater model indicates that groundwater pathways from the BRSF may pass beneath the Spandaryan-Kechut tunnel. However, given the high significance of the tunnel in terms of water management in the Project Area and uncertainty with respect to actual groundwater flow paths, this assessment also considers that BRSF leakage may potentially reach the tunnel and ultimately the Kechut Reservoir.

The Kechut Reservoir is used as a potable water supply and hence is a primary receptor for water quality. Water quality of the Arpa River at the inflow to the Kechut Reservoir is monitored; the average composition is presented in Table 2. Water quality has also been monitored in the Arpa River downstream of the Kechut reservoir, average composition at this location is also presented in Table 2.

The background water quality of the Arpa River at the inflow to the Kechut Reservoir is presented for all constituents considered in the initial screening in Table 2. Substances exceed the Category II MAC for the Arpa for iron, lithium and manganese at all locations and for cobalt at AW010. These substances are shown in bold in Table 2. The laboratory detection limits for beryllium at all locations and for cobalt at AWJ5 and AWJ6 exceeded the Category II MAC. No above detection results were reported, such that baseline concentrations may be below the water quality standard.

The Spandaryan-Kechut tunnel is used as a conduit for drinking water, though it is not directly used as a drinking water source. Water quality in the tunnel outfall is monitored at AWJ6, and the average composition is presented in Table 2.

Table 2: Existing Composition of Water in the Spandaryan Kechut Tunnel and Water Entering the Kechut Reservoir from the Arpa River

Constituent	Units	Arpa MAC (Category II)	Average Quality in Kechut Reservoir inflow (AWJ5)	Average Quality in Arpa River d/s of Kechut Reservoir (AW010)	Average Quality in Spandaryan-Kechut tunnel discharge (AWJ6)
Al	µg/l	144	64.9	36.6	72
As	µg/l	20	4.55	4.95	6.76
Ba	µg/l	28	13.1	13.4	20.4
Be	µg/l	0.038	**0.2**	0.2	**0.2**
B	µg/l	450	0.0328	0.0503	0.0542
Cd	µg/l	1.014	0.5	0.612	0.5
Ca	mg/l	100	9.97	13.8	63.9
Cl-	mg/l	6.88	2.44	4.44	3.07
Cr+3	µg/l	11	5	3.32	5
Co	µg/l	0.36	**0.5**	**0.369***	**0.505**
Fe(3)	mg/l	0.072	**0.132**	**0.11**	**0.404**
Pb	µg/l	10.14	1	2.03	1.99
Li	µg/l	3	**8.44**	**10.7**	**4.27**
Mg	mg/l	50	3.01	5.85	9.35
Mn	µg/l	12	**26.3**	**15.1**	**39.1**
Ni	µg/l	10.34	3	1.82	3
Nitrate	mg N/l	2.5	0.508	**3.21**	0.5
K	mg/l	3.12	1.9	2.14	3.12
Se	µg/l	20	5	5.45	5
Sulphate	mg/l	16.04	9.92	12.1	**126**
Zn	µg/l	100	3.97	1.79	3.78

**Average concentration between 2009 and 2011, analysis in subsequent years reported below detection results but a higher detection limit (0.5 µg/L) was applied.*

5.0 BRSF RISK ASSESSMENT

5.1 Framework for Assessment of Risk to Receiving Waters

The approach for this risk assessment is as follows:

- Step 1 – A screening level assessment of travel time in groundwater to identified receptors is conducted to identify constituents which may potentially be released to receiving waters within 1000 years; and
- Step 2 – For parameters which will arrive at identified receptors within 1000 years, predicted maximum concentrations in surface water have been calculated utilizing reasonable maximum parameters.

Two pathways are considered:

- Groundwater flowing from the BRSF, into the Spandaryan-Kechut tunnel and subsequently to Kechut Reservoir (Section 5.1.1); and
- Groundwater flowing from the BRSF, passing beneath the Spandaryan-Kechut tunnel and discharging to the Arpa River downstream of Kechut Reservoir (Section 5.1.2).

For this analysis, the BRSF is treated as a constant source, such that once solutes transported from the facility arrive at the point of discharge, concentrations are not considered likely to significantly decrease with time. There is no consideration of the time for leakage in the unsaturated zone below the BRSF to reach groundwater or any constituent attenuation processes in the unsaturated zone. Attenuation in the unsaturated zone will result in a lower source concentration upon reaching groundwater. In addition, the potential infiltration of post-closure discharge water from the BRSF after being treated using the passive treatment system is not considered, as this may not occur within the affected catchment.

5.1.1 Calculation of Travel Times in Groundwater to Points of Discharge

Table 3 presents example retardation factors and calculated minimum groundwater travel time for constituents with elevated concentrations in the BRSF leakage to travel to the Spandaryan-Kechut Tunnel and the Arpa River downstream of the Kechut Reservoir, respectively. A basalt density of 2.35 g/cm^3 and an effective porosity of 0.02 (2%) is assumed. Average unretarded travel times of 94 years to the Spandaryan-Kechut tunnel and 126 years to the Arpa River based on particle pathline simulations in the groundwater flow model (Golder, 2014a) have been applied in calculations.

Table 3: Estimated Retardation Factors and Retarded Groundwater Travel Times for Selected Constituents

Constituent	Kd (l/kg)	Reference	Retardation Factor	Estimated Travel Time to Spandaryan-Kechut Tunnel (years)	Estimated Travel Time to Arpa River (years)	Distance travelled in 1000 years (assuming a typical unretarded flow distance of 45 m per year)
Aluminium	261	SKB (2011), Sandy till	30669	>10,000	>10,000	1 m
Arsenic	9	Mid-value of range, USEPA 1994	1059	>10,000	>10,000	43 m
Barium	1.4	USEPA 1994, pH 6.8	166	>10,000	>10,000	272 m
Beryllium	790	USEPA 1994, pH 6.8	92826	>10,000	>10,000	0 m
Boron	0.0068	SKB (2011), Sandy till	2	115	170	Spandaryan-Kechut Tunnel and/or Arpa River
Cadmium	2.7	USEPA, 2005. Mean value for soil/soil water partitioning	318	>10,000	>10,000	141 m
Calcium	0.28	SKB (2011),	34	2200	3200	1327 m

Constituent	Kd (l/kg)	Reference	Retardation Factor	Estimated Travel Time to Spandaryan-Kechut Tunnel (years)	Estimated Travel Time to Arpa River (years)	Distance travelled in 1000 years (assuming a typical unretarded flow distance of 45 m per year)
		Sandy till				
Chloride	0	Not retarded	1	64	95	Spandaryan-Kechut Tunnel and/or Arpa River
Chromium	19	Mid-value of range, USEPA 1994	2234	>10,000	>10,000	20 m
Cobalt	126	USEPA, 2005	14806	>10,000	>10,000	3 m
Iron	142	SKB (2011), Sandy till	16686	>10,000	>10,000	3 m
Lead	16	SKB (2011), Sandy till	1881	>10,000	>10,000	24 m
Lithium	0	Not retarded	1	64	95	Spandaryan-Kechut Tunnel and/or Arpa River
Magnesium	0.1	SKB (2011), Sandy till	13	800	1200	Spandaryan-Kechut Tunnel and/or Arpa River
Manganese	0.68	SKB (2011), Sandy till	81	5200	7700	556 m
Nickel	65	USEPA 1994, pH 6.8	7639	>10,000	>10,000	6 m
Nitrate	0	Not retarded	1	64	95	Spandaryan-Kechut Tunnel and/or Arpa River
Potassium	0.036	SKB (2011), Sandy till	5	340	500	Spandaryan-Kechut Tunnel and/or Arpa River
Selenium	5	USEPA 1994, pH 6.8	589	>10,000	>10,000	76 m
Sulphate	0	Not retarded	1	64	95	Spandaryan-Kechut Tunnel and/or Arpa River
Zinc	3.7	SKB (2011), Sandy till	436	>10,000	>10,000	103 m

Based on the estimated retardation factors, aluminium, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, iron, lead, manganese, nickel, selenium and zinc would not be sufficiently mobile to travel within groundwater from the BRSF to either the Spandaryan-Kechut tunnel or Arpa River within a 1000 year period. These substances are thus considered to pose little if any risk to surface water. It is estimated that the remaining substances could arrive at the Spandaryan-Kechut tunnel or Arpa River within a period of 1000 years and hence will be considered further in this risk assessment.

5.1.2 Assessment of Impacts to Spandaryan-Kechut Tunnel and Kechut Reservoir

The following assumptions are made for the screening-level assessment:

- There is no upgradient groundwater flow beneath the BRSF facility;
- Leakage from the BRSF to the Cenozoic basalt is 5,475 m^3/yr and is constant;

- The BRSF leakage has a chemical quality as shown in Table 1 and is assumed to be constant;
- Recharge of 200 mm/yr occurs over the groundwater flowpath from the BRSF to the Kechut Reservoir;
- Groundwater flow paths from the BRSF reach the Spandaryan-Kechut tunnel and flow to the Kechut Reservoir;
- Background flow in the Spandaryan-Kechut tunnel is 0.19 m^3/s (originating from groundwater) with the quality shown in Table 3;
- Surface water inflow to the Kechut Reservoir is 2.0 m^3/s (under seasonal low flow conditions) with the quality shown in Table 3;
- The minimum groundwater travel time from the BRSF to the Kechut Reservoir is 64 years; and
- The groundwater flow pathway width from the BRSF entering the Kechut Reservoir is 1,500 m.

The analysis is based on the water balance defined in Section 5.1.1. The potential impact of geochemical processes on travel time and therefore time for impact in the receiving waters to occur is discussed further in Section 5.2.3

Table 4: Potential Increase in Concentration in Water in the Spandaryan-Kechut Tunnel after 1000 years

Constituent	Units	Arpa MAC Category II	Average Quality in Spandaryan-Kechut tunnel flow (AWJ6)	Estimated Increase in Concentration in Spandaryan-Kechut Tunnel	Estimated Peak Concentration in water in the Spandaryan-Kechut Tunnel	% Increase in concentration in water in the tunnel
Al	µg/l	144	72	N/A	N/A	0%
As	µg/l	20	6.76	N/A	N/A	0%
Ba	µg/l	28	20.4	N/A	N/A	0%
Be	µg/l	0.038	0.2	N/A	N/A	0%
B	µg/l	450	0.0542	0.1	0.1	94%
Cd	µg/l	1.014	0.5	N/A	N/A	0%
Ca	mg/l	100	63.9	N/A	N/A	0%
Cl-	mg/l	6.88	3.07	0.0	3.1	0%
Cr+3	µg/l	11	5	N/A	N/A	0%
Co	µg/l	0.36	0.505	N/A	N/A	0%
Fe(3)	mg/l	0.072	0.404	N/A	N/A	0%
Pb	µg/l	10.14	1.99	N/A	N/A	0%
Li	µg/l	3	4.27	0.0	4.3	1%
Mg	mg/l	50	9.35	0.0	9.4	0%
Mn	µg/l	12	39.1	N/A	N/A	0%
Ni	µg/l	10.34	3	N/A	N/A	0%
Nitrate	mg N/l	2.5	0.5	0.3	0.8	67%
K	mg/l	3.12	3.12	0.0	3.2	1%

Constituent	Units	Arpa MAC Category II	Average Quality in Spandaryan-Kechut tunnel flow (AWJ6)	Estimated Increase in Concentration in Spandaryan-Kechut Tunnel	Estimated Peak Concentration in water in the Spandaryan-Kechut Tunnel	% Increase in concentration in water in the tunnel
Se	µg/l	20	5	N/A	N/A	0%
Sulphate	mg/l	16.04	126	0.4	126.4	0%
Zn	µg/l	100	3.78	N/A	N/A	0%

N/A – constituent will not travel to the receptor within 1000 years.

Table 5: Potential Increase in Concentration in Kechut Reservoir after 1000 years

Constituent	Units	Arpa MAC Category II	Average Quality in Kechut Reservoir inflow (AWJ5)	Estimated Increase in Concentration Kechut Reservoir	Estimated Peak Concentration in water in the Kechut Reservoir	% Increase in concentration in water in the reservoir at low flows
Al	µg/l	144	64.9	N/A	N/A	0%
As	µg/l	20	4.55	N/A	N/A	0%
Ba	µg/l	28	13.1	N/A	N/A	0%
Be	µg/l	0.038	0.2	N/A	N/A	0%
B	µg/l	450	0.0328	0.004	0.037	13%
Cd	µg/l	1.014	0.5	N/A	N/A	0%
Ca	mg/l	100	9.97	N/A	N/A	0%
Cl-	mg/l	6.88	2.44	0.00	2.4	0%
Cr+3	µg/l	11	5	N/A	N/A	0%
Co	µg/l	0.36	0.5	N/A	N/A	0%
Fe(3)	mg/l	0.072	0.132	N/A	N/A	0%
Pb	µg/l	10.14	1	N/A	N/A	0%
Li	µg/l	3	8.44	0.00	8.4	0%
Mg	mg/l	50	3.01	0.00	3.0	0%
Mn	µg/l	12	26.3	N/A	N/A	0%
Ni	µg/l	10.34	3	N/A	N/A	0%
Nitrate	mg N/l	2.5	0.508	0.03	0.5	6%
K	mg/l	3.12	1.9	0.00	1.9	0%
Se	µg/l	20	5	N/A	N/A	0%
Sulphate	mg/l	16.04	9.92	0.03	10.0	0%
Zn	µg/l	100	3.97	N/A	N/A	0%

N/A – constituent will not travel to the receptor within 1000 years.

Based on this analysis no measurable change in water quality in the Kechut Reservoir is predicted to occur arising from BRSF leakage post-closure. Measureable change in concentrations of boron and nitrate may occur in water in the Spandaryan-Kechut tunnel at low flows, but these constituents will remain below the MAC in surface waters.

5.1.3 Assessment of Impacts to the Arpa River

The following assumptions are made for the screening level assessment:

- There is no upgradient groundwater flow beneath the BRSF facility;
- Leakage from the BRSF to the Cenozoic basalt is 5,475 m^3/yr and is constant;
- The BRSF leakage has a quality as shown in Table 1 and is assumed to be constant;
- Recharge of 200 mm/yr occurs over the groundwater flowpath from the BRSF to the Arpa River;
- Groundwater flow paths from the BRSF pass under the Spandaryan-Kechut tunnel and flow to the Arpa River downstream of the Kechut Reservoir;
- Flow rate of the Arpa River is 2.0 m^3/s (at low flows) plus a contribution from the Spandaryan-Kechut tunnel of 0.19 m^3/s (under low flow conditions) with the quality shown in Table 3;
- The minimum groundwater travel time from the BRSF to the Arpa River is 95 years; and
- The groundwater flow pathway width from the BRSF entering the Arpa River is 1,500m.

The analysis is based on the water balance defined in Section 5.2.1.

Table 6: Potential Increase in Concentration in Arpa River after 1000 years

Constituent	Units	Arpa MAC Category II	Average Quality in Arpa River Downstream of Kechut (AW010)	Estimated Increase in Concentration Arpa River	Estimated Peak Concentration in Arpa River	% Increase in concentration in Arpa River at Low Flows
Al	µg/l	144	36.6	N/A	N/A	0%
As	µg/l	20	4.95	N/A	N/A	0%
Ba	µg/l	28	13.4	N/A	N/A	0%
Be	µg/l	0.038	0.2	N/A	N/A	0%
B	µg/l	450	0.0503	0.004	0.051	9%
Cd	µg/l	1.014	0.612	N/A	N/A	0%
Ca	mg/l	100	13.8	N/A	N/A	0%
Cl-	mg/l	6.88	4.44	0.00	4.4	0%
Cr+3	µg/l	11	3.32	N/A	N/A	0%
Co	µg/l	0.36	0.369	N/A	N/A	0%
Fe(3)	mg/l	0.072	0.11	N/A	N/A	0%
Pb	µg/l	10.14	2.03	N/A	N/A	0%
Li	µg/l	3	10.7	0.00	10.7	0%
Mg	mg/l	50	5.85	0.00	5.9	0%
Mn	µg/l	12	15.1	N/A	N/A	0%
Ni	µg/l	10.34	1.82	N/A	N/A	0%
Nitrate	mg N/l	2.5	3.21	0.03	3.2	1%
K	mg/l	3.12	2.14	N/A	N/A	0%
Se	µg/l	20	5.45	N/A	N/A	0%
Sulphate	mg/l	16.04	12.1	0.03	12.1	0%
Zn	µg/l	100	1.79	N/A	N/A	0%

Based on this analysis, no measureable change in water quality in the Arpa River will occur as a result of leakage from the BRSF.

5.2 Assessment of Impacts on Groundwater

This section outlines the estimated impact on groundwater immediately upgradient to the Spandaryan-Kechut tunnel and the Arpa River, respectively. Table 8 summarises predicted peak change in concentration in groundwater at the point of discharge to receiving waters for constituents which are predicted to have travel times of less than 1000 years. All other constituents of potential concern in GRE (2014) are predicted to arrive at the point of discharge after more than 1000 years.

Table 7: Potential Increase in Groundwater Concentration from BRSF Leakage (Post Closure)

Constituent	Units	Average Quality in AWJ6 (Spandaryan-Kechut tunnel) (i.e. typical regional groundwater composition)	Estimated Concentration in GW before discharge to Spandaryan-Kechut tunnel (including background)	% Increase in GW concentration	Estimated Concentration in GW before discharge to Arpa River (including background)	% Increase in GW concentration
B	µg/l	0.0542	0.4	641%	0.3	437%
Cl-	mg/l	3.07	3.1	0%	3.1	0%
Li	µg/l	4.27	4.6	8%	4.5	5%
Mg	mg/l	9.35	9.5	1%	9.4	1%
Nitrate	mg N/l	0.5	2.8	457%	2.1	311%
K	mg/l	3.12	3.3	7%	3.3	5%
Sulphate	mg/l	126	128.6	2%	127.8	1%

A change in groundwater concentration of less than 10% is predicted for the constituents presented in Table 8, with the exception of boron and nitrate.

A more detailed assessment has been conducted for nitrate and boron, using an analytical advection dispersion model, in order to provide a better estimate for the concentration of these constituents in groundwater. The results of these assessments are shown in Figure 4. Similar to the screening analysis, this analysis does not consider any attenuation in the unsaturated zone below the BRSF. Attenuation in the unsaturated zone will result in a lower source concentration upon reaching groundwater. In addition, the infiltration of post-closure discharge water from the BRSF after being treated using the passive treatment system is not considered.

The spreadsheet model “Remedial Targets Worksheet Release 3.1” (Environment Agency, 2006a) has been used to calculate the travel time in groundwater to the point of discharge to area-wide groundwater receptors and the concentration of boron and nitrate. The methodology is described in “Remedial Targets Methodology” (Environment Agency, 2006b).

The methodology is based on tiered assessment methodology or which the Level 3 tier is applicable to the situation at Amulsar:

- Level 3 Groundwater: Calculation of concentration of constituents of potential concern in groundwater at an identified downgradient receptor as a result of migration of a continuous source of mining-influenced groundwater using the Ogata Banks (1961) solution. The analytical solutions are described in Appendix D of Environment Agency (2006b).

In addition to advection and dispersion of dissolved constituents, the model also simulates attenuation through the processes of retardation (sorption) and biodegradation. Retardation of sorbed metallic contaminants is calculated using a linear isotherm.

The calculations indicate that concentration of boron while exceeding baseline conditions approaches the background concentration at the locations evaluated. It is noted however that even though the Arpa MAC Standard II does not apply to groundwater, the concentration of boron is orders of magnitude less than this standard. The concentration of nitrate as nitrogen (assuming a continuous high concentration source with no change in concentration over this time – a very unlikely occurrence) also approaches the background concentration at the receptor. This scenario is unlikely and of low probability such that it should not be used for decision making or impact assessment. The concentration of nitrate is similar to the Arpa MAC Standard II at each respective location.

In the unlikely event that nitrate concentrations above those predicted by Golder (2014e) and evaluated in this assessment are identified during operations, mitigation measures can be implemented to control nitrogen release from explosives and to promote fixing of nitrates in barren rock storage areas.

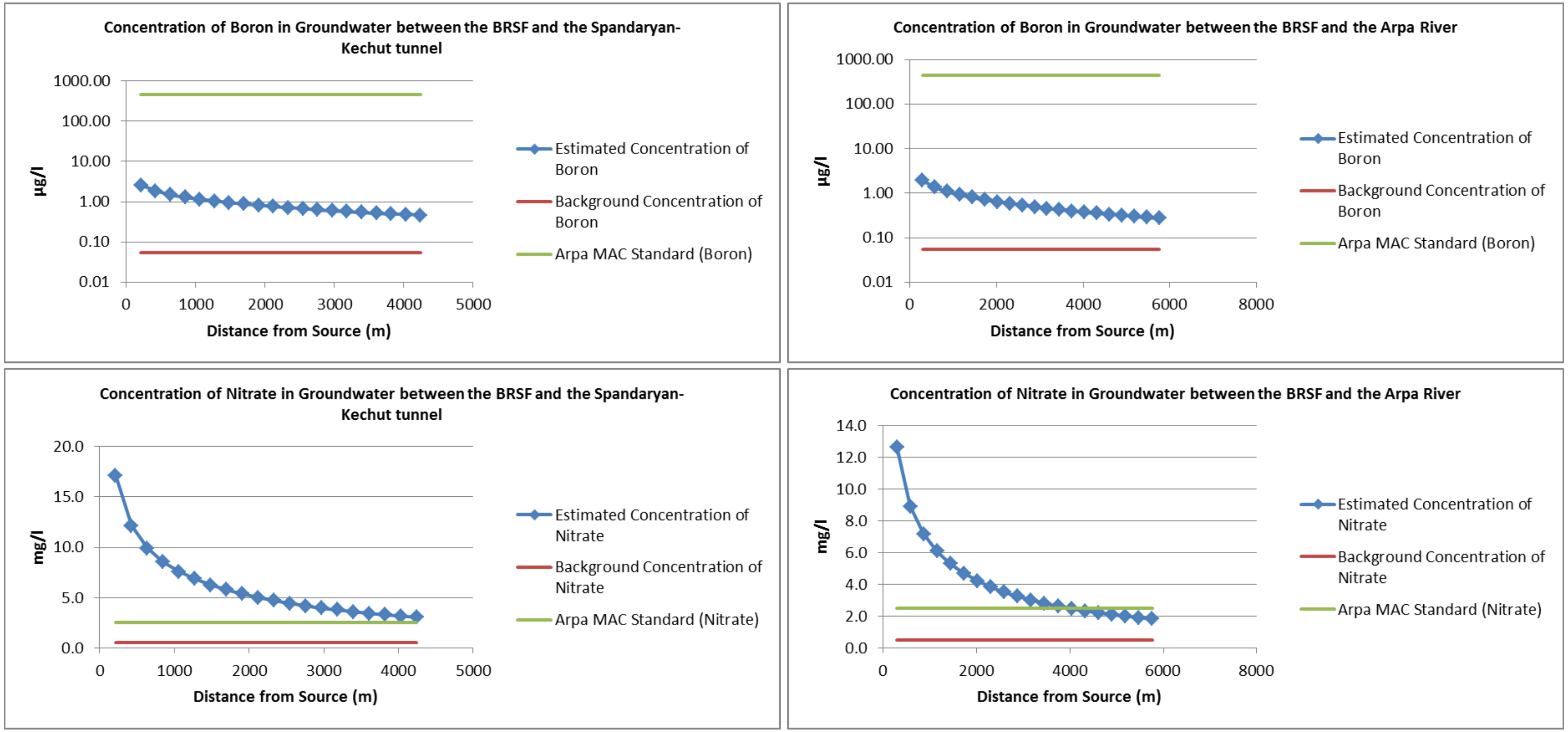

Figure 4: Results of Advection Dispersion Modelling for Boron and Nitrate,.

6.0 SENSITIVITY TO BRSF LEAKAGE RATE AND UNSATURATED FLOW

This assessment has been completed on the basis of the average post-closure leakage rate from the BRSF using unsaturated flow modelling of 15 m^3/day (GRE, 2014). Greater leakage rates may occur if the evaporative cover does not meet the expected reduction in long-term infiltration into the BRSF. Under these conditions, there would be a greater flux into the groundwater system, however the solute concentrations in the leakage would likely decrease commensurately and the solute mass would not increase because of the geochemical and hydraulic reactions occurring within the BRSF (GRE, 2014).

The assessment of BRSF groundwater impacts has evaluated solute migration in the saturated zone based on the current conceptual hydrogeological model, but has not incorporated a detailed assessment of unsaturated flow and transport processes. Further investigation may be completed as part of the final design process that may provide additional information concerning the shallow flow beneath the site. Evaluation of some of the uncertain physical/chemical processes such as unsaturated flow and vapor transport which will influence solute transport will be conducted as part of the final design process. Potential leakage rates and solute transport predictions will be updated. The monitoring program for the facility (locations, frequency, constituents and types of monitoring) will be updated if required following final design.

7.0 REFERENCES

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