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4.9 Surface Waters

A surface water baseline investigation was conducted for the Project by Golder, and includes the area bounded by the Vorotan River valley to the east, the Arpa River to the west, the Kechut Reservoir to the north and Spandaryan Reservoir to the south. The study focused particularly on the Vorotan valley catchment to the east of Amulsar, the Arpa catchment to the west of Amulsar and the Darb catchment (a tributary of the Arpa) to the southwest of Amulsar.

Baseline data sets were compiled from various sources:

- Readily available (public) technical reports and data;
- Information provided by Lydian from environmental monitoring between 2007 and 2015; and
- Results of site visits in August 2011, November 2012, March 2013 and March 2014 by Golder technical staff.

For the purposes of this chapter, the Project area is defined as encompassing those parts of Amulsar and surrounds where project facilities or infrastructure are to be constructed. The surface water baseline study area extends beyond this to include those areas which lie downstream of the Project area in each catchment as well as some points upstream of the potentially influenced watercourses. Areas covered by water quantity (flow and stage) and water quality monitoring are identified in Section 4.9.6 and 4.9.7 of this chapter.

4.9.1 National Surface Water Regime and Regional Setting

There are 14 major river basins in Armenia, including the Arpa and Vorotan basins which the Project area straddles. Figure 4.9.1 shows the major river basins, as well as the country's largest river, the Araks (also called Arax and Aras), which forms the border between Armenia and Turkey and flows south-east along the Iranian border to the Caspian Sea. The major tributaries of the Araks are the Akhurian, Kasagh, Hrazdan, Azat, Arpa, Vorotan and Voghdji rivers. The Araks River flows towards the south and east, discharging to the Caspian Sea. The Republic of Armenia (RA) has prepared a set of ecological norms for each of the 14 major river basins (see Chapter 2).

Lake Sevan lies in the Caucasus Region and is the largest lake in Armenia, with its basin making up one sixth of the total territory of Armenia. During the Soviet era, outflows from the lake were artificially increased, leading to a dramatic fall in lake surface area and a decline in biodiversity and water quality. Measures to restore the quality and size of the lake have been on-going since the late 1960s and include a flow-augmentation tunnel connection with the Arpa River system in 1981 (Sevan – Kechut Reservoir tunnel). The Kechut Reservoir on the Arpa River is also linked to the Spandaryan Reservoir on the Vorotan River by the Spandaryan-Kechut tunnel, although this tunnel has never operated. Lake Sevan remains a nationally important resource for water supply, electricity, fishing, and recreation. Lake Sevan is protected by Armenian law, and has a specific Law governing its protection, as discussed in Chapter 2. The Law includes the Lake Sevan catchment basin, its ecosystems and zone of economic activity, and states that no activity may be permitted which may negatively impact on the Lake and its ecosystem. Article 10 of the Law prohibits ore processing in the central zone and the immediate impact zone of the lake. The proposed HLF and ADR plant and Passive Water Treatment (PWT) facility will be located within a tributary catchment draining to the Arpa River, downstream of the Kechut Reservoir and therefore any discharges from these facilities will not be within the portions of the Vorotan and Arpa river basins that fall within the ’immediate impact zone’ of Lake Sevan (see Chapter 2 for a discussion on the legal situation relating to the Lake Sevan).

The Project area related to the BRSF, which is located adjacent to the Darb and Vorotan catchment, naturally drains to the catchment of the Arpa river basin, upstream of the Kechut Reservoir (see Figure 4.9.2). The BRSF lies within the ‘immediate impact zone’ of Lake Sevan.

Figure 4.9.1: Rivers of the Republic of Armenia (UN Cartographic Section, 2013)

4.9.2 National Surface Water Quality Guidelines

The Government of Armenia has developed a methodology based on use of the Water Quality Canadian Index for designation of surface water quality. The water quality of a water body may be classified from Category I to Category V, reflecting a range from excellent, good, moderate, and poor to very poor[1].

The methodology provides an opportunity to present large-volume measurements of various water quality indicators by index values. These index values mathematically combine all the water quality measurements and provide for a simple description of water quality. European Union Water Framework Directive water management plans require water bodies to meet

[1] Model Guidelines for River Basin Management Planning in Armenia' (USAID, 2008)

biological, chemical/physical and hydrological objectives, which in combination, reflect a desired “good water status.” The Government of Armenia has focussed for now primarily on chemical/physical and hydrologic objectives, because Armenia has limited data available on biological conditions.

4.9.3 Regional Surface Water Regime

The major watercourses within and surrounding the Project area are shown in Figure 4.9.2. The Project area is bisected approximately north-south by a catchment divide, with the Arpa basin (shown in magenta/red for upstream and downstream of the Kechut Reservoir respectively) to the west and the Vorotan catchment (shown in green) to the east.

On a regional scale, the Arpa and Vorotan catchments are of similar size, as summarised in Table 4.9.1. These data relate to the greater Arpa and Vorotan basins at their outfall to the Araks/Arax and not just those catchments related to the Project area. As these catchments include lowland areas, their hydrological characteristics may not be wholly representative of conditions within the largely upland study area. In particular, higher evaporation would be expected in the warmer lowlands and the snow pack-melt cycle does not have as immediate an effect on runoff.

Table 4.9.1: **Relevant Regional Catchments (FAO, 2009)**

Catchment characteristics*	Arpa	Vorotan
Area (km^2)	2306	2476
Precipitation over total area ($Mm^{3)}$	1643	1828
Calculated Annual Precipitation (mm)	712	738
Evaporation (Mm^3)	768	811
Calculated Annual Evaporation (mm)	333	327
Total Annual Flow (Mm^3)	764	725
Total Annual Flow as Precipitation (mm)	331	293
Average flow at maximum extent (m^3/sec)	24.2	22.9

Notes:
** Refers to catchment areas within Armenia only.*

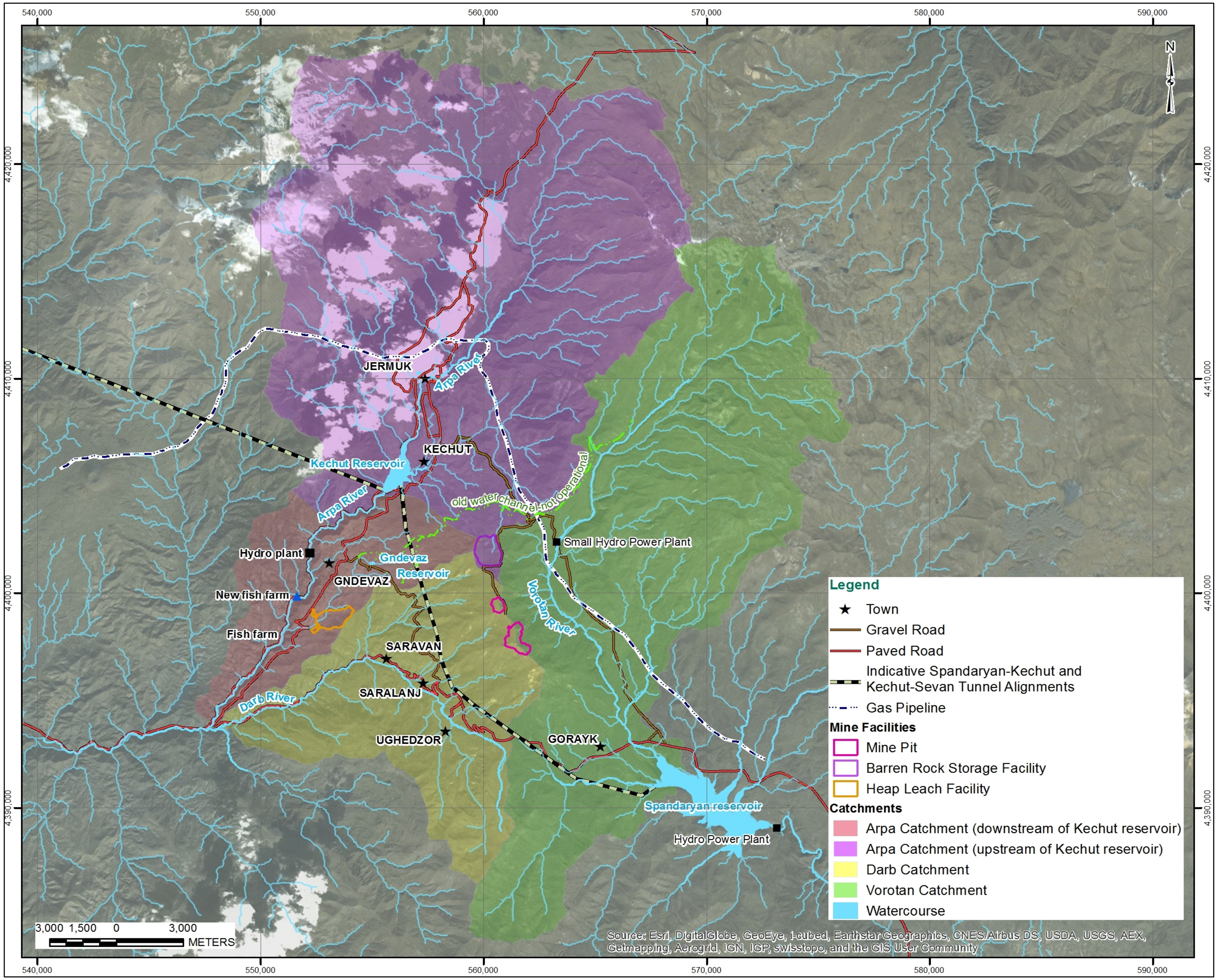

Figure 4.9.2: Project Location and Major Surface Water Features

Arpa and Darb Catchment

Amulsar forms the watershed (hydrologic divide) between the Vorotan and Arpa river catchments. The Arpa River flows northeast to southwest, passing northwest of Amulsar and is approximately 0.6 km from the mine infrastructure at its nearest point. The Darb River flows initially northwest along the south-western flank of Amulsar before turning southwest to join the Arpa River 14 km downstream of the Kechut Reservoir.

Kechut Reservoir is situated on the Arpa River north-west of Amulsar and lies approximately 4.5 km at its nearest point from the mine infrastructure. The Kechut Reservoir is artificially linked to Lake Sevan by two tunnels with a combined total length of approximately 48 km. This scheme of interconnected tunnels between reservoirs/river basins is part of the RA's national water supply strategy. The outfall from the Kechut Reservoir to the Sevan tunnel system is located at the southwest corner of the reservoir. In addition, discharges from the reservoir are used at a hydroelectric plant near Gndevaz and for water supply.

The Jermuk Hydrothermal Springs lie upstream of the Kechut Reservoir around the town of Jermuk. Chemical analysis of water from these springs in comparison to groundwater within the Project area shows them to be chemically distinct and thus of different origin than groundwater within the Amulsar Project area. This is discussed in more detail in the groundwater baseline (Section 4.8.8).

The Gndevaz Reservoir (Figure 4.9.2) is located within the Arpa catchment, to the east of Gndevaz village and to the northeast of the HLF. The reservoir was originally designed to be supplied by a man-made channel diversion known as the Gndevaz Channel but is currently supplied by snow melt and drainage from above the reservoir. A land drain diversion flowing northwards does however direct natural flow from a small area of the adjacent valley to the south into the Gndevaz Reservoir, discharging to the reservoir via a piped outflow (see Figure 4.9.5, adjacent to Site 14 Gauge).

The reservoir does not provide a potable supply to Gndevaz village. The area supplied by the reservoir is restricted to the fields below where it provides a source of water for livestock during the summer months, when the surrounding grasslands are used by herders. The reservoir discharges immediately below the dam wall into a stream channel which runs through a gorge (see Appendix 4.9.5).

The Gndevaz Channel is located to the north and west of Amulsar, sourced from the Vorotan River and running westwards towards Gndevaz village, approximately 1km north of the BRSF. A second arm of the channel branches off and runs south-westwards towards the Gndevaz Reservoir. The channel was an open, concrete-lined structure originally designed to supply irrigation water to Gndevaz from Arkhashan to the north of Amulsar. The channel, which reportedly has not been used for many years, has sections observed to be either infilled with soil or absent. Currently, any water found in the channel is thought to be derived from snow melt and local runoff which is diverted through short sections of the channel. The channel is currently being reinstated and is planned to be servicible by mid-2016. A water supply pipeline for Gndevaz, sourced from the Arkashan springs in the upper reach of the Vorotan, runs along part of the channel route.

The Darb River is the largest tributary of the Arpa within the study area. Due to its significance to the Project, the Darb catchment is shown (yellow) in Figure 4.9.2, lying southwest of the Project area. Part of the footprint of the proposed open pits fall within the Darb catchment. The Darb catchment is not subject to the Lake Sevan Law as it joins the Arpa downstream of Kechut Reservoir.

A small cirque lake referred to as 'Benik's Pond' (Figure 4.9.5) is located in a topographic depression on the western side of Amulsar, within the Darb catchment. This pond is approximately 1 ha in area and has been used as a water supply for the exploration programme at Amulsar. The pond is underlain by superficial deposits and is fed by surface water runoff and a number of springs on the western side of the peak. 'Benik's Pond' is noteworthy for its naturally low pH (reportedly as low as 3). It has an average depth of 8 m.

Of the main infrastructure associated with the Project, only a portion of the open pits will be located within the Darb sub-basin of the Arpa catchment. The BRSF is located in the Arpa catchment, discharging to the Arpa upstream of Kechut reservoir; the HLF, ADR and PWT facilities will be situated wholly within the Arpa catchment, draining downstream of the Kechut Reservoir. The crusher is situated in the Arpa catchment and straddles the water divide between the catchment discharging upstream of the Kechut reservoir and that draining to downstream of the reservoir.

Vorotan Catchment

The Vorotan River flows south past the eastern flank of Amulsar, and in the vicinity of the Project area is up to approximately 10 m wide and 0.3 m to 0.8 m deep. The river flows through a grassed incised valley typically 30 m to 80 m below the surrounding plateau. This valley is more steeply incised to the north of the Project area. The underlying basalt bedrock is observed to outcrop in the river bed in the area adjacent to Amulsar.

Flowing south through the Project area, the Vorotan discharges to the Spandaryan Reservoir approximately 6.3 km south-east of the proposed Tigranes-Artavazdes open pit and south-east of Gorayk (Figure 4.9.2). The Spandaryan Reservoir is connected to the Kechut Reservoir on the Arpa River by the Spandaryan-Kechut tunnel. It is reported that no water transfers take place through the tunnel at the present time. Those parts of the Vorotan and Arpa rivers downstream of the Spandaryan and Kechut reservoirs respectively are not subject to the Lake Sevan law.

The Spandaryan-Kechut tunnel is approximately 22 km-long and runs approximately 3 km to the west of the footprint of the open pits and the BRSF and approximately 3 km east of the HLF footprint. Although tunnel construction was completed in 2003, the intake from the Spandaryan Reservoir is closed and the tunnel is not operational. The observed flow from the tunnel (Figure 4.8.26 in Groundwater section) is a result of groundwater infiltration into the tunnel, rather than direct flow from the Spandaryan Reservoir. This conclusion is supported by an environmental isotope analysis study (Golder 2013a, Appendix 4.9.1) and by results of chemical analysis of samples collected at the outfall to the reservoir (Section 4.8.1). The approximate tunnel alignment is shown on Figure 4.9.3.

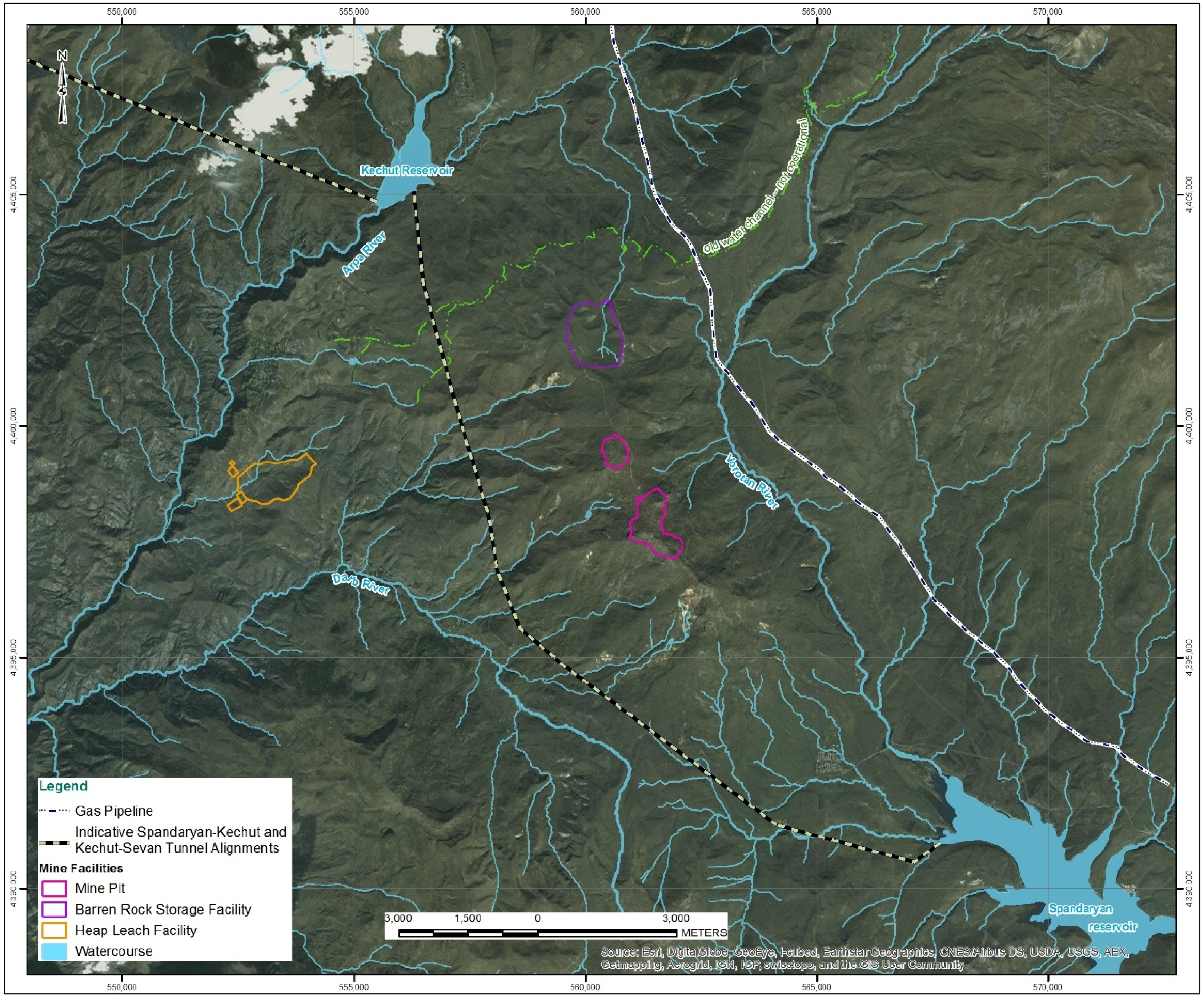

Figure 4.9.3: Spandaryan-Kechut Tunnel Location (approximate alignment)

Several reservoirs located within the Vorotan River basin, including the Spandaryan Reservoir, Angeghakot, Tolors, and Shamb have primarily been constructed to support hydropower plants; all but Spandaryan are outside of the study area. The Spandaryan Hydro Power Plant is located at the reservoir's downstream (southern) end (Figure 4.9.2).

4.9.4 Long Term Flow Data

There are limited available public long term data to characterise the flow regimes of the main rivers draining the Project area. Some historical data have been obtained for the Vorotan River upstream of the Spandaryan catchment as described below. No data or records have been found regarding the operation of the Kechut Reservoir spillway, HEP discharge and Lake Sevan transfer (aside from some anecdotal evidence, see below). The Darb catchment is significantly smaller than the Arpa and Vorotan and it does not appear that there is any long term gauging or flow monitoring on this river.

Vorotan Catchment

The annual average flow of the Vorotan River, in common with all rivers in Armenia, fluctuates considerably year to year. During dry years, the river flow decreases to reportedly very low levels. The maximum flow is observed in spring months during the annual snow melt and the co-incident wettest period of the year. At other times of the year, the flow is sustained by groundwater baseflow, from precipitation including storms during the summer months, and frontal rainfall during the autumn period.

A small hydro-power project (SHPP), the "MANE" project is currently being developed on the Vorotan River due east of the BRSF. Flow analysis has been carried out for that project (ERA, 2011) based on a set of historic flow data for the Vorotan. The historic Vorotan-Borisovka gauge (previously located within the footprint of the Spandaryan Reservoir) recorded Vorotan River flow measurements for the 45-year period from 1943 – 1987; this corresponds to a 507 km^2 catchment. When the Spandaryan Reservoir was commissioned, the gauging station was relocated to Gorayk, which significantly reduced the catchment size (to 268 km^2 – 26,800 ha) reporting to the new gauge location, called Vorotan-Gorayk. Historical data from the Vorotan-Gorayk gauging station (1987 – 2006) were combined with scaled flow data for the Borisovka gauge to produce a more complete dataset for the smaller Gorayk gauge catchment area, which encompasses the Vorotan valley upstream of Spandaryan Reservoir as shown on Figure 4.9.2.

Table 4.9.2: Total Annual Vorotan Flow vs Concurrent Precipitation (1962-1987)				
Statistic	**Annual Precipitation (mm)**	**Total Annual Volume (m^3/yr)**	**Implied Runoff (Yield) (mm/yr)**	**Yield/Precipitation (%)**
Mean	737.1	122,716,895	458	62%
5%	570.7	63,020,104	235	41%
25%	666.8	91,668,560	342	51%
50%	739.3	119,732,936	447	60%
75%	798.7	148,791,570	555	70%
95%	925.4	195,483,780	729	79%

Notes:
Percentiles based on total monthly precipitation (Vorotan Pass) and average monthly flow rate (Vorotan Gorayk Gauge) both for the 1962-1987 concurrent flow/precipitation record. Gauge catchment is 268 km^2 as per Figure 4.9.5.

Table 4.9.2 compares the catchment runoff (yield) for a range of percentile flows based on the Gorayk Gauge catchment from 1962-1987. This is compared to the percentile annual precipitation for the concurrent period of record at the Vorotan Pass station. The table shows the percentage yield (i.e. fraction of surface water runoff) increases in response to increasing precipitation. This response is a result of rainfall intensity exceeding the infiltration rate, be it very intense storms or antecedent soil moisture.

Based on the same dataset, Figure 4.9.4 compares percentile monthly flows to percentile monthly precipitation presented on an annual water year basis. The annual snow melt is often augmented by concurrent peak rainfall in May/June. Notably, relatively high monthly total rainfall for the 95th percentile of monthly rainfall totals (low probability of occurrence) in October-January are not reflected in the flow figures for the same months. When considered on a monthly time frame, relatively low groundwater levels, baseflow and high soil moisture deficit (following the dry summer months) would tend to attenuate the effects of a wet month on flow in the major watercourses. As the winter advances, precipitation falls as snow, largely stored until the spring snow melt.

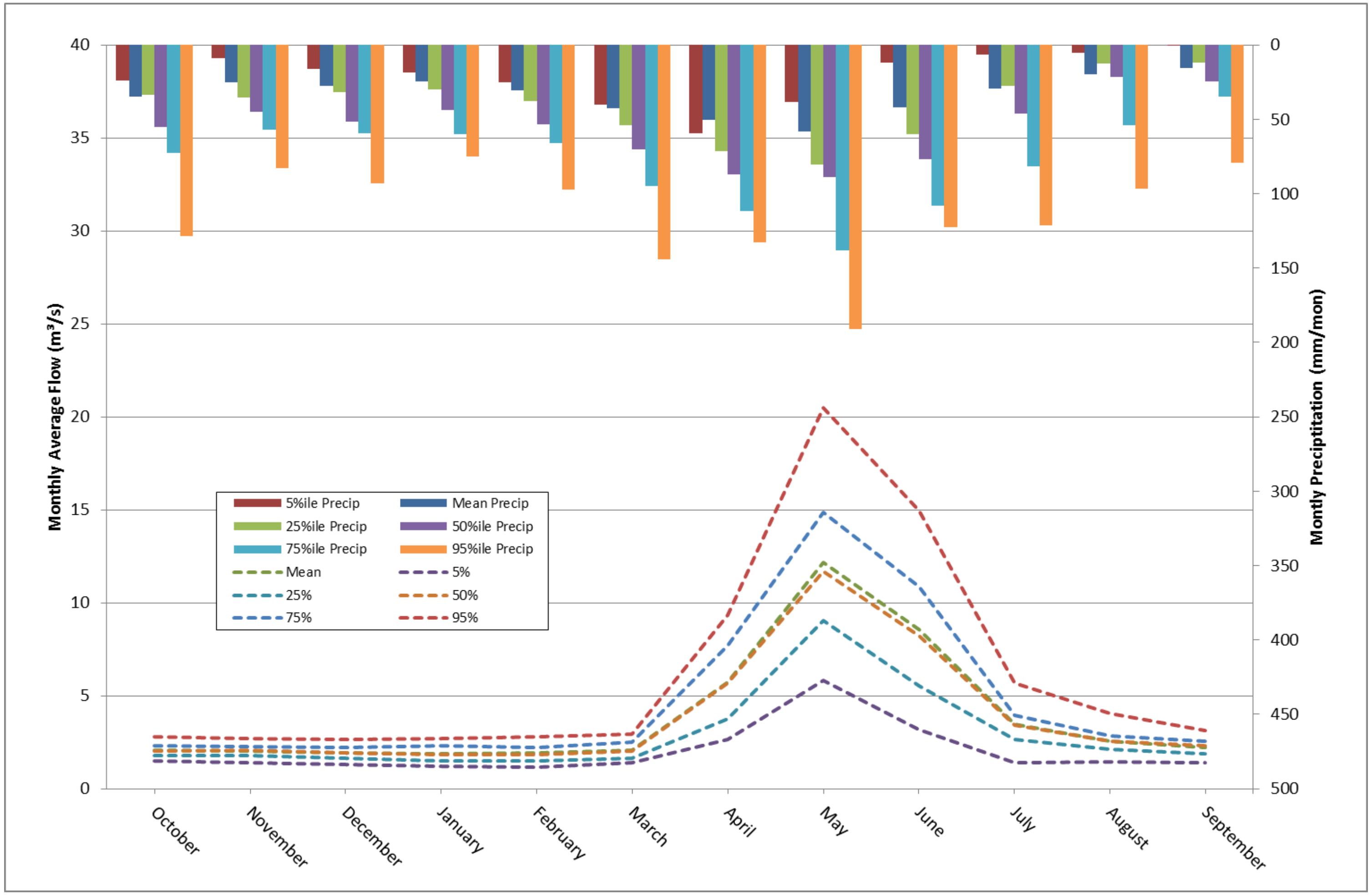

Figure 4.9.4: Comparison of Percentile Average Monthly Flows at Gorayk Gauge against Percentile Total Monthly "Vorotan Pass" Precipitation (1962-1987 Concurrent Record)

Arpa and Darb Catchment

Historical flow records for the Arpa and Darb rivers are not available and no historic gauging stations have been identified on the reach of the Arpa adjacent to the Project area, upstream or downstream of the Kechut Reservoir. The reach downstream of the Kechut Reservoir is a regulated waterway whose flow regime does not reflect the natural channel flow patterns. Data regarding the regulation of the spillway at the Kechut Reservoir are not available.

Possibly due to its relatively small size, no long term flow data are available for the Darb.

The hydropower plant west of Gndevaz may divert additional flow directly from the Kechut Reservoir to its discharge point, potentially increasing flows in the Arpa downstream of that location during low flow periods. Two fish farms, which are located downstream of the hydropower plant, are not consumptive water users of the Arpa. The hydropower plant and fish farms are presented in Figure 4.9.5 and also discussed in Section 4.9.7.

4.9.5 Surface Water Flow Monitoring

Spot Flow Measurements

Flow measurements taken on the three main rivers and on several tributaries within the study area in 2008, 2010 and 2011 are available in Geoteam Monitor Pro Database (Lydian, 2008-2011) (see also Appendix 4.9.2). Monthly average flows for late summer and early autumn are provided in the reports.

In parallel to and in support of continuous monitoring during the winter-spring seasons of 2012-2013 and 2013-2014, spot flow measurements were collected at stations throughout catchment (both at gauged and ungauged points and available in the Geoteam Monitor Pro Database). The locations of both the 2008-2011 phase of flow monitoring and the 2012-2015 continuous and spot flow monitoring are shown on Figure 4.9.5.

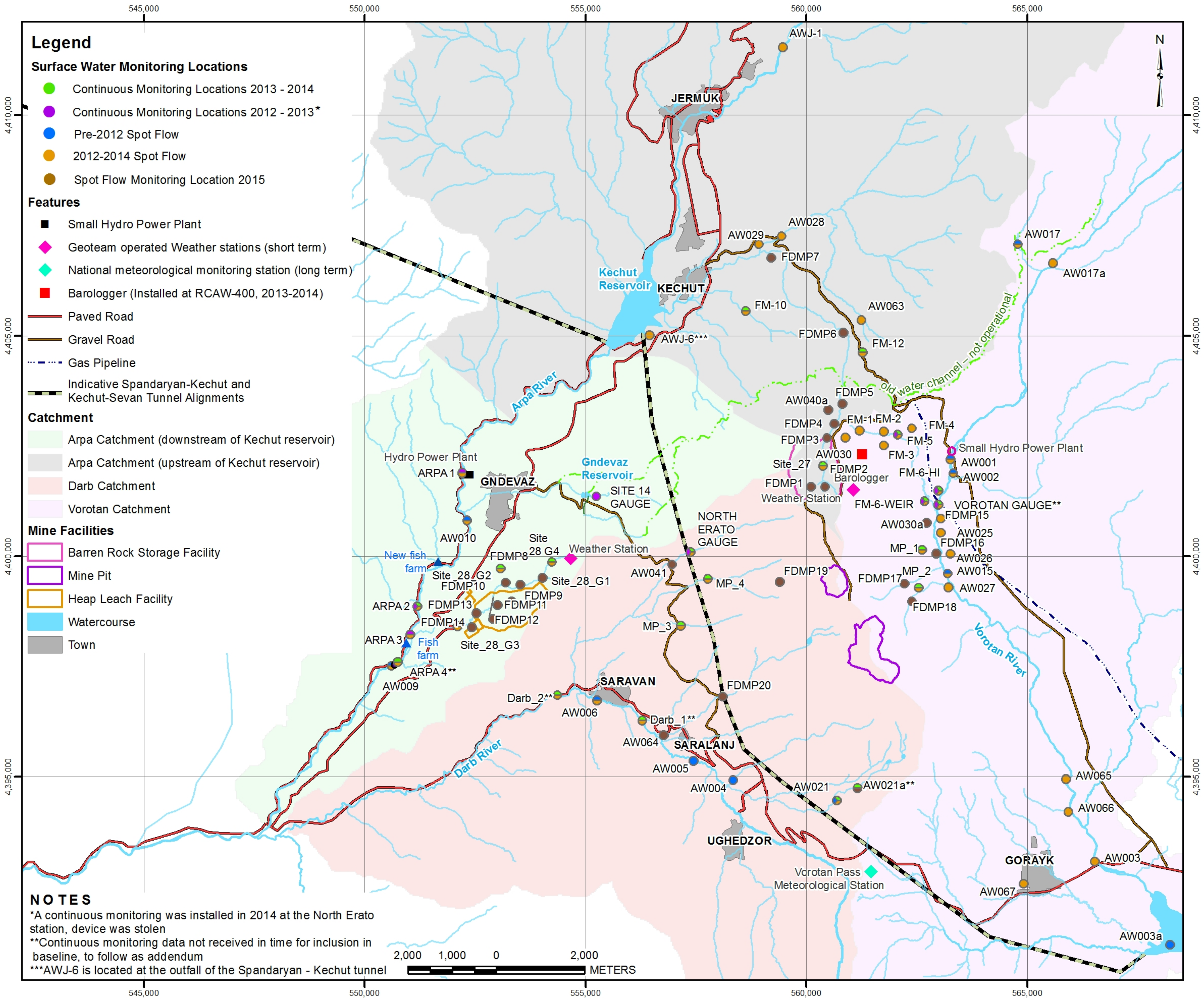

Figure 4.9.5: Surface Water Stage/Flow Monitoring Locations

Table 4.9.3 describes the seasonal flow patterns and Table 4.9.4 presents average flow measurements over the monitoring period on a quarterly basis.

Table 4.9.3: Seasonal Hydrologic Patterns		
Quarter	**Months**	**Flow and Hydrological Pattern**
Q1	January - March	High elevation sites may freeze, low flow in main rivers, some precipitation driven events at lower elevation
Q2	April – June	Spring snow melt period generally commences April-May, peak flows in June/July dependent on elevation
Q3	July – September	July may include latter parts of spring snow melt. Low flow in smaller watercourses experienced during August-September, lowest precipitation months.
Q4	October - December	Frontal rainfall and lowering temperatures lead to increased runoff driven flow in smaller catchments; snowpack accumulation commences, high elevation sites may freeze.

Table 4.9.4 indicates the number of spot flow measurements collected at each location and also the number of flow readings in each quarter at all locations. Flow data from smaller watercourses during the low flow periods in Q3 are limited to 2010 and 2011 at a select number of sites. The main rivers have a more complete spot flow monitoring record.

The spot flow measurements for the 2012-2015 monitoring period are included in Appendix 4.9.2 along with monthly average measurements from Lydian annual monitoring reports.

Table 4.9.4: Average Seasonal Flow Monitoring Summary 2008-2015. Flows in m^3/s

	Year	2008	2010				2011				2012				2013				2014				2015				Data Count Per
Location	Quarter	??	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	Location
Arpa (downstream of Kechut Reservoir)	Arpa 1														3.140												1
	Arpa 2														2.670			2.605	3.212	4.411				4.573	3.617		6
	Arpa 3														2.960												1
	Arpa 4																		3.772	4.502				4.661	4.152		4
	AW009			3.060	2.823	2.740		2.910	2.600							7.679								5.283	3.872		12
	AW010			3.045	2.857	2.750		3.000	2.800							3.937											10
Arpa (upstream of Kechut reservoir)	AWJ1														1.065	3.009											2
Arpa Tributary (downstream of Kechut Reservoir)	FDMP10																							0.000	0.000		8
	FDMP11																							0.000	0.000		8
	FDMP12																							0.000	0.000		8
	FDMP13																							0.000	0.000		8
	FDMP14																							0.001	0.000		8
	FDMP8																							0.000	0.000		4
	FDMP9																							0.001	0.000		8
	Site 28 G1																		0.000	0.000				0.001	0.000		10
	Site 28 G2																	0.000	0.000	0.000				0.000	0.000		11
	Site 28 G3																	0.000	0.000	0.000				0.002	0.001		11
	Site 28 G4																							0.001	0.000		8
Arpa Tributary (upstream of Kechut Reservoir)	AW028												0.082		0.048												2
	AW029												0.069											0.431	0.071		3
	AW063																			0.022							1
	FDMP1																							0.183	0.000		4
	FDMP2																							0.000	0.000		4
	FDMP3																							0.060	0.000		5
	FDMP4																							0.001	0.000		5
	FDMP5																							0.003	0.000		4
	FDMP6																							0.000	0.000		4
	FDMP7																							0.008			2
	FM10																	0.006	0.003	0.015				0.071			4
	FM12																	0.004	0.001	0.022							3
	Site 27																	0.006		0.059				0.002	0.000		5
Darb	AW005	0.000		0.205	0.207	0.220		0.200	0.205															1.318	0.188		13
	AW006	0.006		0.965	0.887	0.780		1.080	0.900				0.230											1.107	0.189		13
	Darb1																		0.432	0.408				1.760			3
	Darb2																		0.828	1.193				1.873			3
Darb Tributary	AW004	0.005		0.165	0.160	0.180		0.200	0.175																		10

Table 4.9.4: Average Seasonal Flow Monitoring Summary 2008-2015. Flows in m³/s

Location	Year	2008	2010				2011				2012				2013				2014				2015				Data Count Per Location
	Quarter	??	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
	AW021																	0.002	0.004	0.028							3
	AW021a																							0.019			1
	AW041																							0.205	0.023		4
	AW064																							0.278	0.000		3
	FDMP19																							0.006	0.000		4
	FDMP20																							0.300	0.000		3
	MP3																	0.002	0.000	0.005							3
	MP4																	0.005	0.051	0.070							4
	North Erato															0.063		0.004	0.022	0.028				0.012	0.002		7
Vorotan	AW001	0.003		3.480	0.677	0.700		1.700	0.800				2.591		2.095									3.604	2.742		14
	AW003	0.001		6.995	1.347	1.540		4.700	1.500						3.776	6.018			6.054					6.708	3.246		17
	AW007	0.009																									1
	AW008	0.005																									1
	AW015			5.305	1.127	1.180		4.300	1.300				2.934							2.803					4.109		12
	AW017a														1.786	4.069											2
	AW065																			0.016							1
	Vorotan														2.550	5.954		2.498						3.903	2.007		5
Vorotan Tributary	AW002	0.000											0.189														2
	AW017			0.095	0.087	0.080		0.100	0.080				0.012							0.237							11
	AW025												0.019		0.015	0.077											3
	AW026												0.024		0.008	0.102											3
	AW027														0.002	0.109											2
	AW030														0.013					0.001				0.001			6
	AW030a																0.061								0.005		2
	AW040a																							0.081	0.000		4
	AW066																			0.006							1
	AW067																		0.151	0.318							5
	FDMP15																							0.002	0.000		2
	FDMP16																							0.000	0.000		2
	FDMP17																							0.008	0.002		2
	FDMP18																							0.006	0.002		2
	FM1											0.070		0.062													4
	FM2											0.091		0.138													4
	FM3											0.031		0.031													4
	FM4											0.001		0.001													4
	FM5											0.136		0.182			0.049	0.004	0.003	0.060							8
	FM6											0.199		0.196				0.006									5

Table 4.9.4: Average Seasonal Flow Monitoring Summary 2008-2015. Flows in m³/s

Location	**Year**	**2008**	**2010**				**2011**				**2012**				**2013**				**2014**				**2015**				**Data Count Per Location**
	Quarter	**??**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	
	FM6WEIR																			0.280							1
	MP1																	0.004		0.114				0.084			4
	MP2																	0.009		0.147				0.164			3
Data Count Per Quarter		8		18	27	9		9	18			18	9	6	13	10	2	15	22	26				136	39		

Continuous Monitoring

Continuous flow monitoring has been undertaken at selected locations on watercourses within the Vorotan, Arpa and Darb catchments in the Project area from November 2012 to May 2013 and December 2013 to May 2014 (available at Geoteam Monitor Pro Database).

Continuous monitoring sites are shown on Figure 4.9.5, which indicates monitoring year and identifies spot flow monitoring locations. Figure 4.9.6 and Figure 4.9.7 identify the main river and mine area stream catchments which have been continuously monitored.

Table 4.9.5 provides details of the station type and characteristics (catchment area, channel slope, station elevation) as well as some catchment characteristics (average catchment elevation, slope and aspect) and monitoring year.

Two types of flow monitoring station were installed: weir stations and open channel monitoring stations. Stations included pressure transducer devices with built-in data loggers, which were installed in weirs or in sections of conduit buried in the banks of the stream. Gauge boards were also installed to enable manual measurement of water level ("stage") and calibration of the transducer records.

On the smaller streams, rectangular notch weirs stations were constructed on site using local materials. These weirs were sized based on the physical channel dimensions, spot flow measurements and with reference to British Standard ISO 1438 (BS, 2008) and field measurement references (WMO, 2010).

The larger watercourses and selected smaller tributaries were monitored with open channel stations, and field data and topographic surveys of the monitoring reach were used to develop cross-sectional profiles. The continuous stage record for these stations was converted into a flow estimate as described below.

Golder staff installed the stations included in the 2012/2013 monitoring period with the assistance of Geoteam field staff. The stations installed for the 2013/2014 monitoring period were installed by Geoteam staff based on instructions and method statements provided by Golder. These method statements and the proposed monitoring plan are detailed in the Environmental Monitoring Plan (see Appendix 8.12).

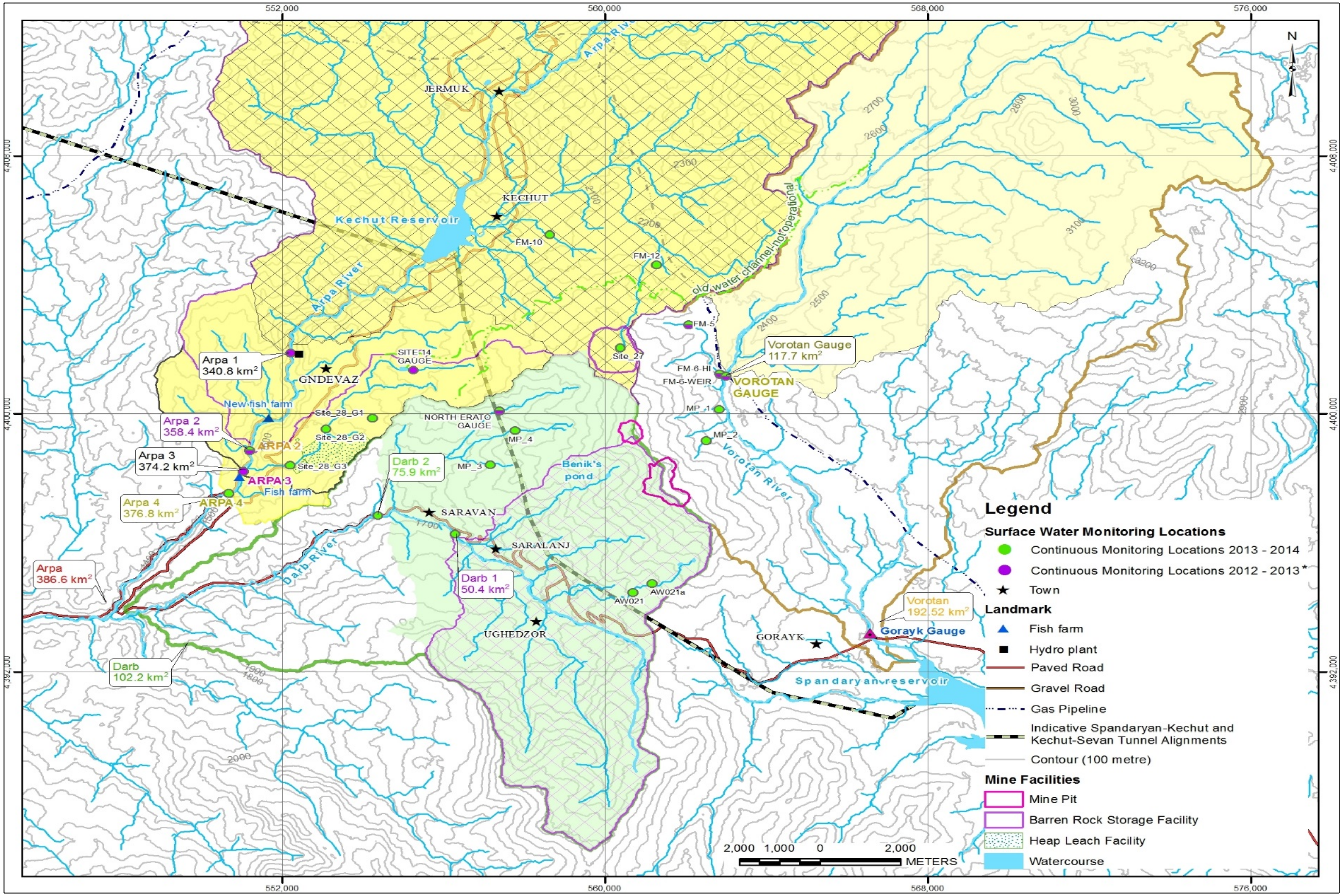

Figure 4.9.6: Continuously Monitored Gauged Catchment Extents on Major Watercourses in the Project Area

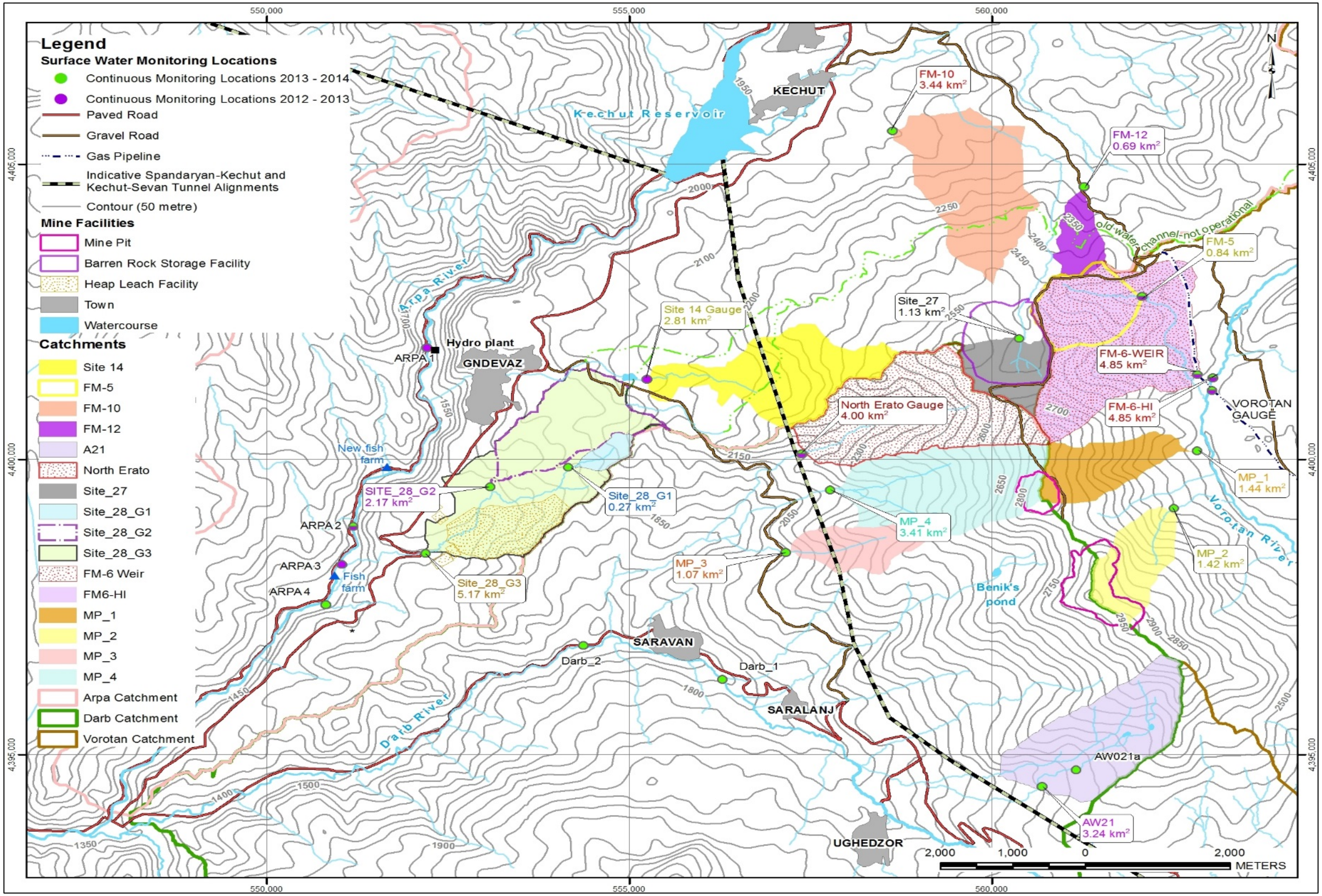

Figure 4.9.7: Continuously Monitored Gauged Catchment Extents on Smaller Mine Area Watercourses

Table 4.9.5: Summary of Continuous Monitoring stations and gauged catchment characteristics

Location	Point ID	Continuous Stage Monitoring		Station Characteristics				Catchment Characteristics (Average)			Mine Facility
		2013 - 2014	2012 - 2013	Station Type	Station Elevation (m AOD)	Local Channel Slope (m/m)	Upstream Catchment (Km²)	Aspect (8 point)	Upstream Slope (m/m)	Elevation (m AOD)	
Arpa	Arpa 1	N	Y	Open	1525	0.015	340.8	S	0.071	2760	Wider Site Area
	Arpa 2	Y	Y	Open	2300	0.011	358.4	S	0.077	2716	Wider Site Area
	Arpa 3	N	Y	Open	2075	0.017	374.2	S	0.075	2685	Wider Site Area
	Arpa 4	-	N	Open	1950	N/A	376.8	S	0.075	2668	Wider Site Area
Arpa Tributary	FM-10	-	N	Weir	2050	0.065	3.44	NW	0.089	2267	Wider Site Area
	FM-12	Y	N	Weir	2227	0.023	2.88	NE	0.082	2514	Wider Site Area
	Site 14*	N	Y	Open	2029	0.051	2.81	W	0.091	2293	Wider Site Area
	Site_27	Y	N	Weir	2529	0.016	1.13	N	0.067	2618	BRSF / Crusher
	Site_28_G1	Y	N	Open	1850	0.064	0.27	W	0.065	1943	Valley Leach Facility
	Site_28_G2	Y	N	Weir	1675	0.011	2.17	SW	0.067	1908	Valley Leach Facility
	Site_28_G3	Y	N	Weir	1600	0.035	5.17	NW	0.086	1849	Valley Leach Facility
Darb	Darb_1	-	N	Open	1750	0.016	50.4	S	0.078	2571	Artavazdes / Tigranes Open Pit
	Darb_2	-	N	Open	1600	0.029	75.9	S	0.081	2501	Artavazdes / Tigranes Open Pit
Darb Tributary	AW021_A / AW021	-	N	Weir	2310	0.030	3.24	S	0.053	2577	Artavazdes / Tigranes Open Pit
	MP_3	Y	N	Open	2000	0.123	1.07	NW	0.050	2282	Erato Open Pit
	MP_4	Y	N	Weir	2125	0.057	3.41	W	0.050	2538	Erato Open Pit
	North Erato	N	Y	Open	2150	0.060	4.00	NW	0.059	2515	BRSF / Crusher
Vorotan	Vorotan	-	Y	Open	2275	0.005	117.7	NE	0.102	2964	Wider Site Area
Vorotan Tributary	FM-5	Y	Y	Weir	2350		0.84	NE	0.083	2472	Wider Site Area
	FM-6-HI	Y	Y	Open	2275	0.015	4.86	NE	0.076	2499	Wider Site Area
	FM-6-WEIR	Y	Y	Weir	2275		4.85	NE	0.076	2500	Wider Site Area
	MP_1	Y	N	Open	2268	0.071	1.45	E	0.044	2617	Erato Open Pit
	MP_2	Y	N	Open	2375	0.137	1.42	NE	0.041	2747	Artavazdes / Tigranes Open Pit

Y = Continuous monitoring carried out
- = Contuous Monitoring carried out, data not available for 2014 baseline presentation
N = Continuous Monitoring not carried out

As identified in Table 4.9.5, some of the stations at which monitoring was carried out during the 2013-2014 period could not be reported in this baseline document generally due to access issues in obtaining the transducer records. Data for these remaining stations will be included in addenda to the ESIA. A summary of continuous monitoring records is presented in Table 4.9.6

Table 4.9.6: Summary of Continuous Monitoring records		
Monitoring Period:	**2013/2014**	**2012/2013**
Available station records	13	9
Total number of station records:	19	9
Available station records covering both periods:	4	
Number of stations covering both periods:	5	

The stage dataset is presented graphically as instantaneous and daily average hydrographs in Appendix 4.9.2. Approximate discharge and flow velocity for each monitoring location were calculated by applying Manning's calculation (Shaw, 1994) or using empirical weir equations (BS, 2008) applied to the stage dataset. The record of estimated flow is also presented graphically in Appendix 4.9.2.

Table 4.9.7 and Table 4.9.8 present flow and unit area runoff (yield) for each monitored catchment over the 2012 and 2013 monitoring periods respectively. Maximum and average flows for the monitored period have been calculated for each location, allowing estimation of catchment yield based on the gauged catchment size. Average flows were used to estimate the yield on a monthly basis. Stage/flow data for high elevation stations on tributaries within the mine area generally present a poor record during the winter period as freezing conditions result in the gaps for those months.

Table 4.9.7: Flow Statistics and Catchment Yield, 2012-2013 Monitoring Period

Location	Point ID	Gauged Area (km²)	Maximum Flow (m³/s)	Average Flow (m³/s)	Average Unit Discharge (mm/month)	Monthly Unit Discharge (mm/month) November	December	January	February	March	April	May
Arpa	Arpa 1	340.8	7.625	3.417	26	N/A	25	25	22	28	27	32
	Arpa 2	358.4	9.180	3.535	26	N/A	25	24	21	28	26	33
	Arpa 3	374.2	6.731	2.959	20	N/A	22	21	18	22	19	24
Arpa Tributary	Site 14	2.813	0.703	0.079	73	N/A	N/A	N/A	N/A	12	90	26
Darb Tributary	North Erato	4.005	1.139	0.053	34	13	11	14	15	26	58	87
Vorotan	Vorotan	117.7	4.511	2.083	46	34	37	33	28	36	62	84
Vorotan Tributary	FM-6-HI	4.856	0.541	0.092	49	10	19	17	12	32	127	153
	FM-6-WEIR	4.852	0.841	0.193	103	6	8	12	14	47	214	253

Notes:
1) Average Unit Discharge for a nominal 30 day month, length of valid monitoring data record varies from site to site.
2) Limited calibration data was available for the 2012-2013 monitoring period at the Arpa river stations. Discrepancies in upstream/downstream measurements may arise from this source or may relate to operation of the Kechut HPP adjacent to Arpa 1.

Table 4.9.8: Flow Statistics and Catchment Yield, 2013-2014 Monitoring Period

Location	Point ID	Gauged Area (km²)	Maximum Flow (m³/s)	Average Flow (m³/s)	Average Unit Discharge (mm/month)	Monthly Unit Discharge (mm/month) November	December	January	February	March	April	May
Arpa*	Arpa 2	358.4	19.399	3.656	26	19	24	23	21	21	30	67
Arpa Tributary	Site_27	1.133	0.630	0.023	53	32	67	18	16	23	144	N/A
	Site_28_G1	0.274	0.021	0.001	9	N/A	25	N/A	0	4	11	31
Darb Tributary	MP_3	1.069	0.051	0.007	17	11	8	12	N/A	4	29	38
Vorotan Tributary	FM-6-HI	4.856	0.589	0.091	48	7	10	5	7	31	139	110
	FM-6-WEIR	4.852	0.718	0.090	48	9	14	13	13	33	142	44
	MP_1	1.445	0.205	0.056	101	69	59	49	45	79	166	178
	MP_2	1.424	0.493	0.045	82	16	19	16	15	16	197	460

Notes:
N/A - Data not available/monitoring station not yet installed
1) Average Unit Discharge for a nominal 30 day month, length of valid monitoring data record varies from site to site.
2) Data was collected but not available for presentation in the baseline for sites: Vorotan, FM-10, Darb 1, Darb 2, AW021 and Arpa 4.
3) Data collected for Sites 28 G2 and Site 28 G3 was of insufficient quality for presentation. Site 28 G2 appeared dry for the monitoring period
4) North Erato gauge was installed but the device was removed/stolen
5) Unit discharge for the Arpa is based on total upstream catchment; this may not be meaningful due to the presence of the Kechut reservoir. On receipt of the Arpa 4 data, a comparison between these sites may allow the yield for the area of catchment between the locations to be calculated.

Interpretation of the Baseline Data

The 2012-13 monitoring data demonstrates that the FM-6 tributary to the Vorotan River and the Vorotan station have a relatively steady flow during the winter months, which increases rapidly during the spring snow melt. The Arpa, in comparison to the Vorotan, appears to have a steadier flow in the 2012-2013 snow melt months, reflecting the artificial control at the Kechut Reservoir. Low flows are reached in these rivers late in the winter, recorded at approximately 2.5 m^3/s at the Arpa stations for both years and at approximately 1.4 m^3/s for the corresponding period at the Vorotan gauging station. No data are available for the Darb during the 2013/2014 monitoring period. Data for the 2014/15 monitoring period are generaly consistent with previous years.

There are no surface watercourses or springs within the footprints of the proposed open pits. Watercourses and springs are present within the footprints of the BRSF and the HLF.

Numerous minor perennial tributaries feed the Darb and Vorotan rivers originating on the slopes of Amulsar and the plateau to the east of the Vorotan. Perennial tributary FM-6 drains the valley to the east of the BRSF, Tributary Site 27 drains the BRSF location and Tributary Site 28 G1 and G2 drain two tributaries upstream of the HLF site.

Downstream of stations Site 28 G1 and G2, Site 28 G3 (a weir station) was damaged and failed to record usable data during the monitoring period. It appears that Site 28 G1 catchment feeds the majority of flow arising downstream at Site 28 G3 (Table 4.9.8), however water abstraction for irrigation of nearby orchards may account for the lack of flow at Site 28 G2. Despite the relatively small of the catchment to Site 28 G1, in comparison to Site 28 G2 catchment, observed flows suggest the stream is sustained by groundwater during low flows. Springs in this catchment were not monitored during 2013, 2014 or 2015.

Tributaries to the Vorotan MP-1 and MP-2 on the slopes below the proposed Erato and Tigranes Artavazdes pits show a relatively constant flow throughout the winter period indicative of groundwater discharge.

During the spring snow melt these tributaries are fed by ephemeral streams which are dry in the late winter period. The gauge at Site 14 shows a marked increase in flows during the spring melt, being a dry channel for the remainder of the year. Site 28 also on the west of the mountains was largely dry during the monitoring period; however the northern extent of Site 28 may be influenced by local water users.

Low Flow and Environmental Flow Conditions

In temperate or continental climates (such as Armenia), the 95th percentile of minimum average daily flows (Q_{95}) is used to describe low flow. A Q_{95} value of 0.4 m^3/s has been identified[2] for the SHPP (estimated catchment area, 85.2 km^2) on the Vorotan east of the BRSF based on frequency analysis of available data for the Vorotan Borisovka (estimated catchment area, 507 km^2) and Vorotan Gorayk gauging stations (268 km^2), adapted through catchment area-scaling.

The environmental flow (or ecological flow) differs from the low flow, and is the minimum level of river flows required to maintain the proper functions of river network ecosystem[1]. This approach specifies the ecological flow as 75% of the average flow of 10 consecutive days with minimum flow in the winter period (normally the lowest flow of the year in Armenia). For the proposed hydropower project (ERA, 2011), a minimum environmental flow of 0.3 m^3/s for the Vorotan has been set.

In the absence of long term flow data, the equivalent low flow value for the Arpa at location Arpa 4 (catchment area of 376.8 km^2) was determined using baseline flow data from the Arpa and historical data from the Vorotan. A synthetic flow time series for the Arpa was created by scaling the Vorotan-Borisovka (1943-1987) gauge data based on relative catchment size. The "Q_{95}" for the synthetic daily time series data is 1.85 m^3/s. However the estimate of low flow in the Arpa is subject to error using this method because the Arpa is regulated at the outlet from the Kechut Reservoir.

The point flow data recorded in 2008-2011 and the continuous monitoring data collected from 2012-2014 have been analysed and low flows identified. Analysis of the field data suggests low flows in the range of 2 to 2.5 m^3/s for the period of record. This is comparable to the low flow derived from the synthetic time series described above.

In reference to low flows, water levels in the rivers of southern Armenia were reported to have been reduced by 40-50% below normal levels during the 2000-2001 droughts[3].

2 ERA Ltd., 2011 MANE SHPP Design Document - Yerevan, Armenia

3 World Bank, November 2001. Technical Paper "Armenia - Towards Integrated Water Resources Management" Environmentally and Socially Sustainable Department, Europe and Central Region

Flood Risk

The spring snowmelt and associated high flows typically last for three months and do not result in major human impacts, as flows tend to build slowly and decrease rapidly, with major floods confined to the base of the deeply incised river valleys.

The maximum monthly average flow recorded at the Vorotan-Borisovka gauge (estimated catchment 507 km^2) downstream of Spandaryan Reservoir from the 45-year period from 1943 – 1987, was 43.93 m^3/s; the average monthly flow at this location for the month of May was 23.3 m^3/s. As a point of comparison, the minimum monthly average flow occurred each January, averaging 3.7 m^3/s.

These flow estimates are for a significantly larger catchment than that adjacent to the Project area at the Golder installed Vorotan gauging station. At that station (AW015), the highest flow recorded during the baseline period was approximately 6 m^3/s.

Physical infrastructure, both existing and proposed, is not threatened by natural flooding from the Vorotan River upstream of the Spandaryan Reservoir. Regular spring snow melt flood waters in the Vorotan valley are anecdotally reported to rise above the level of the bridge near the hydropower plant, inundating the road along the side of the valley.

Historical flow data are not available for the Arpa and Darb. An indication of typical spring high flows in these rivers based on the two years of point flow monitoring is presented in this section. In addition the Arpa River is a managed watercourse; hence natural flood risk has already been mitigated; the presence of the Kechut Reservoir upstream of the reach adjacent to the Project area means that natural flooding is buffered and managed.

As no major infrastructure or facilities associated with the Project are proposed within the natural flood plain of the Vorotan, Darb or Arpa rivers, a fluvial flood risk assessment for the main rivers is not required. The proposed mine facilities are all located several hundreds of metres above the adjacent Vorotan, Darb and Arpa rivers. Fluvial modelling of the Vorotan River on the reach east of the BRSF as presented in Appendix 4.9.3 and indicate flood levels for the 1 in 1000 year flood could reach an elevation of 2293 m asl on the main channel; the nearest proposed mine facilities are at an elevation of over 2400 m asl.

Perennial and ephemeral streams (many fed by springs) drain the areas proposed for the mine facilities. The mountain slopes and valleys where the proposed mine facilities will be located do not contain major surface watercourses.

4.9.6 Surface Water Quality

Water quality monitoring has been conducted since 2007 by Geoteam and the local Ministry of the Environment. Surface water quality samples were collected as shown in Table 4.10.1 and Table 4.10.2 While monitoring during the first quarter (of each year) is less frequent, there is a relatively good spread of data across the seasons (final column in table).

Surface water quality sampling locations are shown on Figure 4.10.1. The parameters analysed in each year are summarised in Table 4.10.1**.**

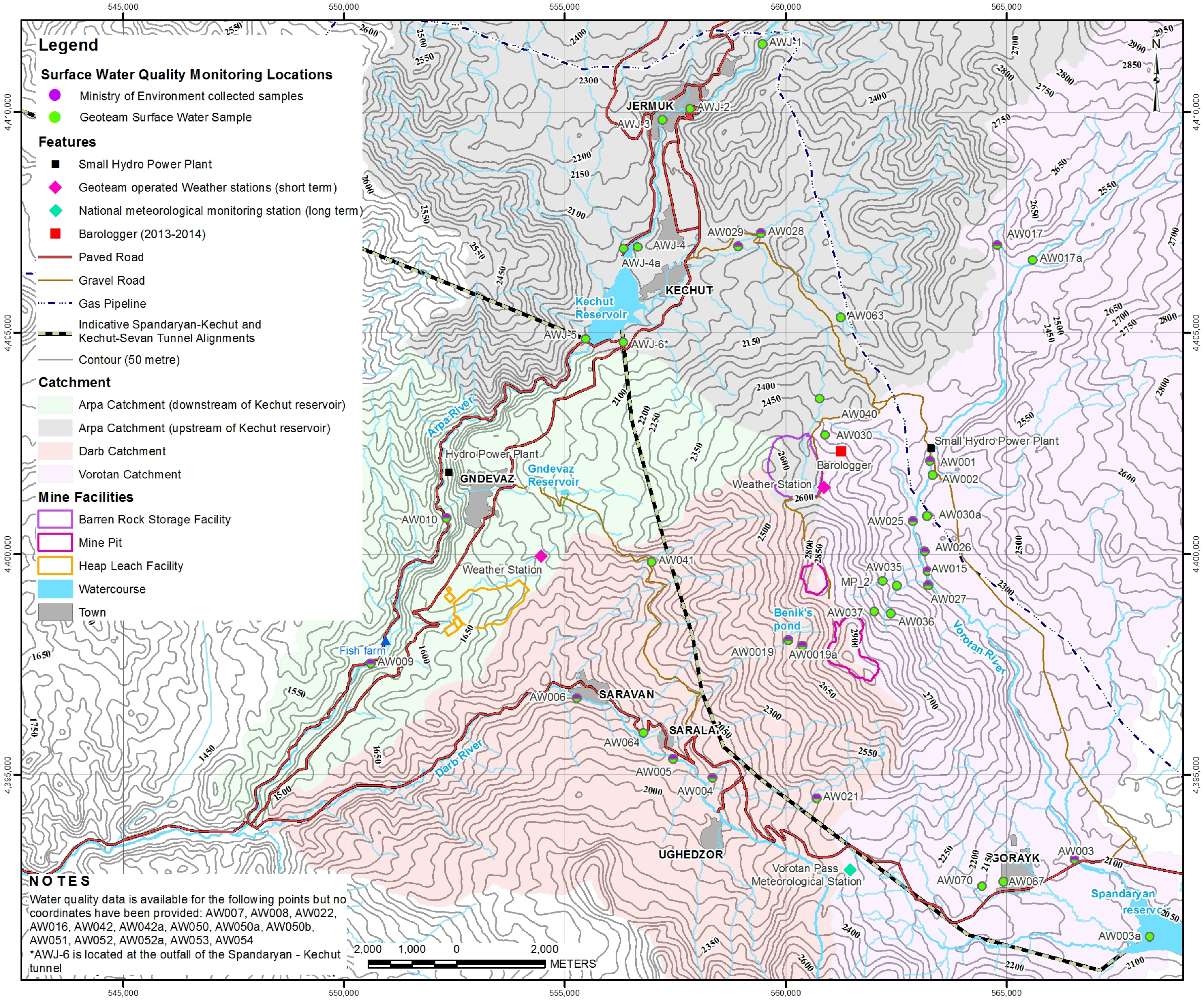

Figure 4.10.1: Surface Water Quality Sampling Locations

Table 4.10.1: Summary of Surface Water Quality Analysis Suites, 2007 to 2015

Parameter Analysed	2007	2008	2009	2010	2011	2012	2013	2014	2015 Q2	2015 Q3
Acid Neutralising Capacity (Alkalinity pH 4.5)							■	■	■	
Acid Neutralizing Capacity (Alkalinity pH 8.3)		■				■		■	■	
Actinium 227					■	■	■			
Aggressive CO2					■	■	■	■	■	■
Aluminium		■			■	■	■	■	■	■
Ammonia	■				■	■	■	■	■	
Ammonia and Ammonium ions	■	■	■	■	■	■	■	■	■	■
Ammonia as N					■	■	■	■	■	■
Antimony		■			■	■	■	■	■	■
Arsenic	■	■	■	■	■	■	■	■	■	■
Barium		■			■	■	■	■	■	■
Base Neutralising Capacity (Acidity pH 4.5)						■	■	■	■	
Base Neutralising Capacity (Acidity pH 8.3)						■		■	■	
Benzene		■								
Benzo(a)pyrene		■								
Beryllium		■			■	■	■	■	■	■
Bismuth		■			■		■	■	■	■
Boron		■			■		■	■	■	■
Bromide					■	■	■	■	■	
BTEX Sum		■								
BTEXS Sum		■								
Cadmium		■		■	■		■	■	■	■
Caesium 134					■					
Caesium 137					■	■				
Calcium	■	■	■	■	■	■	■	■	■	■
Calcium Hardness					■	■	■	■	■	■
Carbonates		■			■	■	■	■	■	■
Chloride	■	■	■	■	■	■	■	■	■	■
Chromium	■	■	■	■	■		■	■	■	■
Cobalt	■		■	■	■	■		■	■	■
Colour (True)										■
COD	■	■								■
Copper	■	■	■	■	■	■		■	■	■
Dissolved silicate as H_2SiO_3										■
Dissolved silicate as SiO_2										■
Dissolved silicate as SiO_3										■
Easily Released Cyanides		■			■	■	■	■		
Ethylbenzene		■								
Fluoride		■			■	■	■	■	■	
Free CO_2 as CO_2					■	■		■	■	■
Gross Alpha		■			■	■	■			

Table 4.10.1: Summary of Surface Water Quality Analysis Suites, 2007 to 2015

Parameter Analysed	2007	2008	2009	2010	2011	2012	2013	2014	2015 Q2	2015 Q3
Gross Beta		■			■	■	■			
Hardness	■	■	■	■	■	■	■	■	■	■
Hardness as CaCO3					■	■	■	■	■	■
Hexavalent Chromium		■			■	■		■	■	
Hexavalent Chromium - Soluble										■
Hydrogen Carbonates		■			■	■	■	■	■	■
Iodine 131					■	■	■			
Inorganic Nitrogen as N										■
Iron	■	■	■	■	■	■		■	■	■
Lead	■	■	■	■	■	■		■	■	■
Lead 210					■	■	■			
Lithium					■	■		■	■	■
m.p-Xylene		■								
Magnesium	■	■	■	■	■	■		■	■	■
Magnesium Hardness					■	■	■	■	■	■
Manganese	■	■	■	■	■	■		■	■	■
Mercury		■			■	■		■	■	■
Molybdenum	■	■	■	■	■	■		■	■	■
Nickel	■	■	■	■	■	■		■	■	■
Niobium					■	■		■	■	
Nitrate as N					■	■	■	■	■	■
Nitrates	■		■	■	■	■	■	■	■	■
Nitrite as N					■	■	■	■	■	■
Nitrites	■		■	■	■	■	■	■	■	■
Non Polar Aliphatics		■			■					
Orthophosphate										■
Orthophosphate as P										■
pH	■	■			■	■		■	■	■
Phosphorus										■
Potassium	■	■			■	■		■	■	■
Potassium 40					■	■	■			
Protactinium 231					■	■	■			
Radium 223					■	■	■			
Radium 226					■	■	■			
Radium 228					■	■	■			
Selenium		■			■	■		■	■	■
Silicon					■	■		■	■	
Silver		■			■	■		■	■	■
Sodium	■	■		■	■	■		■	■	■
Styrene		■								
Strontium										■

Table 4.10.1: Summary of Surface Water Quality Analysis Suites, 2007 to 2015

Parameter Analysed	2007	2008	2009	2010	2011	2012	2013	2014	2015 Q2	2015 Q3
Sulfide as S^{2-}					■	■	■	■	■	■
Sulfides as H_2S	■				■	■		■	■	■
Sulphate as SO_4^{2-}	■	■	■	■	■	■		■	■	■
Sum of Hydrocarbons					■					
Suspended solids dried at 105 °C										■
Tellurium					■	■		■	■	■
Thallium					■			■	■	■
Tin										■
Thorium 227					■	■	■			
Thorium 228					■	■	■			
Thorium 230					■	■	■			
Thorium 234					■	■	■			
Titanium					■	■		■	■	■
Toluene		■								
Total CO_2 as CO_2					■	■		■	■	■
Total Cyanide		■			■	■	■	■		
Total Extractable Aliphatics		■			■			■		
Total Extractable Aromatics		■			■	■		■		
Total Phosphorus as P										■
Tungsten		■			■	■		■	■	
Unpolar Aliphates						■		■		
Uranium					■	■		■	■	■
Uranium 235					■	■	■			
Vanadium										■
Xylenes		■								
Zinc	■	■	■	■	■	■		■	■	■

Statistical summaries for the water quality data are presented in Appendix 4.9.4 (the full data set is available from the Geoteam Monitor Pro database).

Elevated Water Quality Parameters – General Trends

The results of the water quality analyses for the period 2007-2014 (also available from the Geoteam Monitor Pro database) were compared with Maximum Allowable Concentrations (MAC) prescribed under Category II of the Republic of Armenia Decree N-75N (2011) for the Vorotan and Arpa Rivers with the exception of standards for cyanide, which are derived from the IFC EHS Guidelines for Mining (discharge standards). These project criteria are described in Chapter 2.

Parameters recorded above MAC standards for the Vorotan and Arpa rivers in the surface water samples described above are summarised in Table 4.10.2

The laboratory detection limits for antimony, beryllium, cobalt and molybdenum typically exceed MACs; consequently there are a number of locations where 100% of the analyses exceed the MAC. Throughout much of the study area concentrations of aluminium, iron and manganese appear to be naturally elevated above the MACs. Elevated sulphate and barium concentrations are apparent in the Darb River, its tributaries and tributaries of the Vorotan. Elevated lithium concentrations are also apparent within each of the major catchments.

Time-history concentration graphs for selected parameters and locations are presented in Appendix 4.9.4. The graphs clearly indicate seasonal water quality patterns in the Vorotan and its tributaries, where the concentration for a number of parameters (aluminium, barium, copper, iron, lithium, manganese and sulphate) increase during the autumn and winter period, when flow in the catchment is dominated by baseflow. Concentrations decrease in spring due to the influx of snow melt. Seasonal trends are particularly noticeable in the smaller catchments that are in close proximity to seepage inflows (springs). Similar albeit less pronounced seasonal patterns for lithium and sulphate are also observed in the Arpa and tributaries. There is no clear seasonal pH pattern in the Arpa or Vorotan.

Table 4.10.2: Summary of Exceedances in Surface Water of MAC for Vorotan and Arpa Rivers – Geoteam Sampling

Location in Catchment	Monitoring Location	Aluminium	Ammonia as N	Ammonium ions	Antimony*	Arsenic	Barium	Beryllium*	Cadmium	Calcium	Chloride	Chromium	Cobalt*	Copper	Hardness	Hardness as CaCO3	Iron	Lead	Lithium	Manganese	Mercury	Molybdenum*	Nickel	Nitrate as N	Nitrates	Nitrite as N	Nitrites	Ortho-phosphate	pH	pH Value	Potassium	Sodium	Sulphate as SO4 2-	Tin*	Total Phosphorus	TSS	Vanadium	Zinc
Arpa MACs		144	0.4	0.51	0.28	20	28	0.038	1.014	100	6.88	11	0.36	21	10	10	0.072	10.14	3	12	0.3	0.82	10.34	2.5	11.1	0.06	0.2	0.1	6.5 - 9	6.5-9	3.12	10	16.04	0.08	0.2	6.8	0.01	100
Unit		µg/l	mgN/l	mgN/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mgN/l	mg/l	mgN/l	mg/l	mg/l			mg/l	mg/l	mg/l	µg/l	mg/l	mg/l	mg/l	µg/l
Arpa (downstream of Kechut reservoir)	AW009	2		2	24	1		24	1		11	1	29	9	51	21	35	1	20	27	2	36	1	1	1			1			1	22	12	1		6		
	AW010	1		2	13	1		13	1		6	1	18	9	39	10	26	1	10	19		24	1	1	1			1			1	12	6	1		6		
Arpa (upstream of Kechut reservoir)	AWJ1	2			7			7					7		7	7	6			4		7		1	1													
	AWJ2	2			7			7					7		6	6	4		2	1		7																
	AWJ3	1			3			3	1				3		3	3	3		1	1		3																
Arpa Tributary (upstream of Kechut reservoir)	AW028	4			20			20					20		20	20	19		2	19		20										2						
	AW029	3			18			18					18		18	18	18		8	18		18																
	AW040				6			6					6		5	5						6																
	AW063	2			3		1	3					3		2	2	3			2		3		1	1													
	AWJ4	2			7			7					7		6	6	6		3	5		6																
	AWJ4a	2			5			5					5		5	5	4			1		5																
	AWJ5	2	1		14			15					14		12	12	12		14	12		16				1	1							1				
	FDMP3	1			1			1					1				1					1																
	FM10	1			2			2					2				2					3						1						1		1		
Arpa (upstream of Kechut reservoir) Tunnel	AWJ6				16			16					15		13	13	16		14	14		17				1	1	1			7	16	14	1	1			
Darb	AW005	1		2	16	1	15	16	1		1	1	26	9	43	15	31	1		27	2	23	1						1		6	3	20			8		
	AW006	5		2	20	1	18	20	1		3	1	26	9	48	19	35	1		33	2	31	1			1	1				16	4	26			10		
Darb Tributary	AW0019				9		4	9					12	4	14	9	13			12		9											3			2		
	AW0019A	4			11		6	11					14	4	14	10	15			15		11											11			2		
	AW004	1		2	15	1	6	15	1			1	29	9	38	14	26	1		32	2	20	1						2	1		4	27			7		
	AW021	12		1	13		2	13				1	20	17	19	12	20	5	8	20		13	15						14	11			16			4		
	AW041	7			9			9					8		6	6	8			9		10							2	2			9	1				
	AW064	1			3		2	3		1			3		2	2	2			3		3										1	3					
Vorotan MACs		284	0.4	0.51	0.5	20	12	0.054	1.01	100	8	10.5	0.28	22	10	10	0.16	10.14	2	8	0.3	2	10.45	2.5	11.1	0.06	0.2	0.1 mg/l	6.5-9		4.46	8.46	17.02	0.16	0.2	5.5	0.016	100
Unit		µg/l	mgN/l	mgN/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	mg/l	µg/l	µg/l	µg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mgN/l	mg/l	mgN/l	mg/l	mg/l			mg/l	mg/l	mg/l	µg/l	mg/l	mg/l	mg/l	µg/l
Vorotan	AW001			2	19	1	1	19	1		1	1	23	8	38	16	5	2	2	14	2	2	1					1	1			1	1	1	1	5	1	
	AW003			2	25	1		25	1		1	1	28	9	46	22	15	2	6	26	1	2	1					1	1	1		1	3	1		8		
	AW015	1		2	12		1	12			1		17	9	33	12	7	1	2	17		2					1		1							7		
	AW017a				6			6					6		5	5																						
Vorotan Tributary	AW002				3			3					3		3	3			3	1																		
	AW003a	3			7		4	7					7		6	6	5		1	6				2	2	1	1		1	1								
	AW007				1	1	1	1	1		1				2		1	1		1	1		1						1									
	AW008				1	1	1	1	1		1				2			1		1	1		1						1			1	1					
	AW017			1	8		1	8				1	12	6	15	7	5	1		4			1	1	1				1	1						5		
	AW025	9	1	1	9		9	9					9	8	9	9	9		5	9									8	6			7					
	AW026	7	1	1	9		9	9					9		8	8	6		1	8									7	5			6					
	AW027	4			9		9	9					9		7	7	5		5	8									7	5			6					
	AW030	3			14		12	14					14		14	14	14			14		3							4	4	2	2	12					
	AW030a	1			8		5	8					8		7	7	8			8													4					
	AW035	5			5		5	5					5	5	5	5	5		4	5									4	3			5					1
	AW036	2			3		2	3					3	2	3	3				2									2	1			2					
	AW037				3		3	3					3		3	3	1			3																		
	AW067	3			3		3	3					3		2	2	3			3													1					
	MP2	1			3		3	3					3		2	2	2			2									1	1								
	AW070	1			2		1	2					2				1					1		1	1			1						1				

Data bar illustrates percentage of samples exceeding MAC and the value represents the number of exceedances.
* Laboratory detection limit typically exceeds MAC.

In addition to laboratory analysis, in-situ field measurements were also collected (which are available in the Geoteam Monitor Pro database) and presented in Appendix 4.9.4. The average pH at monitored locations based on field measurements taken between 2010 and 2014 is summarised in Table 4.10.3 with low pH locations identified on Figure 4.10.2. These low pH locations are indicative of naturally occurring acid rock drainage as described in groundwater Section 4.8.7.

Table 4.10.3: Surface Water pH, Summary of Field Measurements 2010 – 2015

	Monitoring Location	Average	Minimum	Maximum	Data Count
Arpa (downstream of Kechut reservoir)	Arpa 2	7.8	7.8	7.8	1
	Arpa 4	7.4	7.4	7.4	1
	AW009	7.5	6.0	9.5	49
	AW010	7.4	3.2	9.2	34
Arpa (upstream of Kechut reservoir)	AWJ1	7.4	6.7	8.0	7
	AWJ2	7.3	6.8	8.1	6
	AWJ3	7.4	7.1	7.9	3
Arpa (upstream of Kechut reservoir) Tributary	AW028	7.3	6.2	7.9	21
	AW029	7.3	6.4	8.3	20
	AW040	6.9	6.1	7.6	5
	AW040a	7.2	7.2	7.2	1
	AW063	7.4	7.4	7.4	1
	AWJ4	7.5	7.0	8.4	6
	AWJ4a	7.5	7.1	8.0	3
	AWJ5	7.9	7.1	10.6	12
	FDMP3	7.9	7.9	7.9	1
	FM10	7.9	7.7	8.2	3
	FM12	7.1	7.1	7.1	1
Arpa (upstream of Kechut reservoir) Tunnel	AWJ6	7.8	7.4	8.2	11
Darb	AW005	7.2	4.6	8.6	43
	AW006	7.3	5.1	9.7	53
	Darb 1	7.9	7.9	7.9	1
	Darb 2	7.7	7.7	7.7	1
Darb Tributary	AW0019	6.5	4.6	7.6	16
	AW0019A	6.3	4.6	7.4	16
	AW004	6.6	5.2	8.0	38
	AW021	3.8	2.9	9.6	23
	AW041	6.8	6.1	7.4	4
	AW064	7.0	7.0	7.0	1

Table 4.10.3: Surface Water pH, Summary of Field Measurements 2010 – 2015					
	Monitoring Location	**Average**	**Minimum**	**Maximum**	**Data Count**
	MP 3	7.7	7.7	7.7	1
	MP 4	7.8	7.8	7.8	1
	North Erato	7.2	7.2	7.2	1
Vorotan	AW001	7.0	4.9	8.7	38
	AW003	7.0	2.2	8.6	50
	AW015	7.3	5.5	9.3	28
	AW017a	7.1	7.1	7.2	2
Vorotan Tributary	AW002	8.1	7.5	8.5	3
	AW003a	6.7	6.1	7.3	6
	AW017	6.7	4.8	8.1	20
	AW025	4.1	3.5	5.2	12
	AW026	4.8	4.2	5.7	11
	AW027	6.4	4.8	7.4	11
	AW030	6.6	4.7	7.2	12
	AW030a	7.2	5.8	8.0	6
	AW035	3.6	3.5	3.7	3
	AW036	4.3	3.7	5.5	3
	AW037	5.8	5.0	6.6	3
	AW067	7.2	6.8	7.6	2
	AW070	7.6	7.6	7.6	2
	FM5	6.9	6.9	6.9	1
	FM6WEIR	7.0	7.0	7.0	1
	MP 1	6.6	6.6	6.6	1

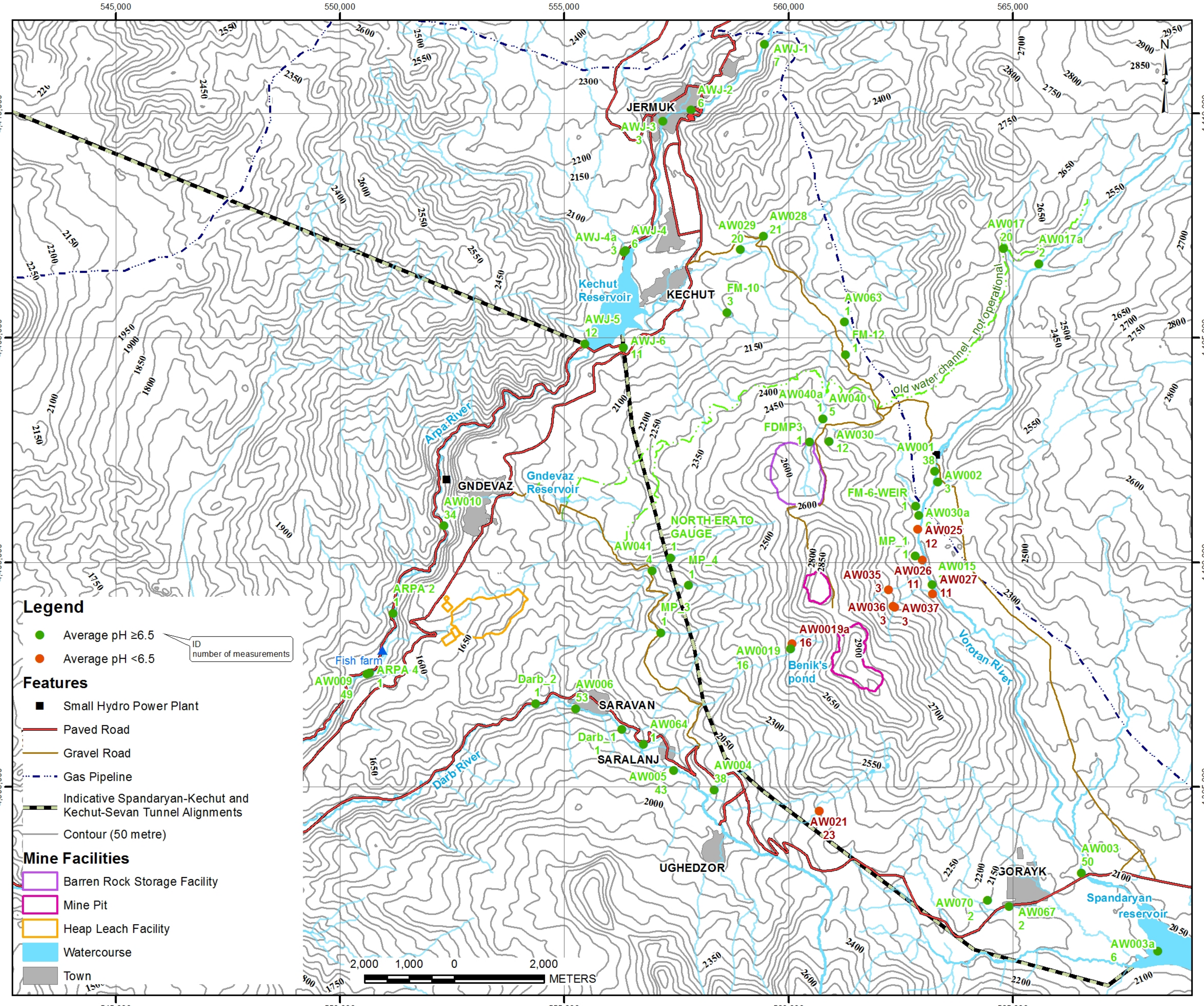

Figure 4.10.2: Surface Water Locations – Average pH

Surface water quality shows significant temporal and spatial variability. Figure 4.10.2 shows sampling locations where an average pH of less than 6.5 has been measured. The majority of these low pH sites are found on the flanks of Amulsar reflecting the geochemical influence of ore-bodies.

Analysis indicates low or undetectable levels of substances typically associated with agricultural or anthropogenic sources (e.g. ammoniacal nitrogen, nitrate, chloride and hydrocarbons). Cyanide was detected at concentrations below MACs in the Vorotan River (AW001, AW003 and AW015) in 2011; in Benik's Pond adjacent to Amulsar peak (AW019) in 2011; and in a stream feeding Benik's Pond (AW019a) in 2011. Cyanide was not detected at all locations in all other years. Although gross beta analysis indicated low but detectable activities, speciated analysis of radioactive substances has not identified any substances above specific laboratory detection limits. It is noted that the variations in water quality cannot be linked to activities (natural or anthropogenic) in the vicinity of Amulsar and may reflect changes in sampling and/or laboratory methodologies (including detection limits) and reporting, as well as environmental changes.

The key trends in water quality are outlined in the following sections.

Arpa River and Tributaries

All surface water monitored at stations along the Arpa River and Arpa tributaries have a near neutral pH. With the exception of AW040, all locations exhibit iron and manganese concentrations above MACs.

Water quality around Kechut Reservoir is generally similar for the various monitoring locations, with iron and manganese frequently above MACs. Lithium and aluminium concentrations also exceed MACs at most locations around Kechut Reservoir. Potassium, sodium and sulphate concentrations are elevated at AWJ6, exceeding MACs throughout most of the monitoring rounds.

Downstream of the Kechut Reservoir, water quality in the Arpa River at AW009 and AW010 is broadly consistent with upstream water quality. However, exceedances of MACs are also regularly observed for sodium and sulphate, and to a lesser extent chloride and copper.

Darb River and Tributaries

The two monitoring locations in the Darb River (AW005 and AW006) are reported to have near neutral pH over the monitoring period. The monitoring location on the main tributary (AW004), monitored further upstream, shows a slightly acidic pH below the MAC pH value; however, data indicate that low pH occurs more frequently in recent years of monitoring, and decreases through the summer months as flow declines. AW021 located in a separate tributary of the Darb on the south-west flank of Amulsar, indicates consistently acidic surface water, averaging pH 3.8 (field measurements). Laboratory analysis also indicates the pH at AW021 is consistently less than the MAC pH value.

Water quality is slightly poorer moving downstream along the main channel of the Darb, between stations AW005 and AW006, which may be attributed to villages located between the two monitoring locations. Exceedances of MACs include ammonium, cadmium, chromium, chloride, lead, nitrite, mercury, potassium and sodium. Water quality in a tributary of the Darb at AW021 frequently exceeds MACs for aluminium, lead, lithium, nickel, sulphate and copper. Exceedances also occur downstream at AW004, although less frequently.

Water quality in Benik's Pond (AW019) and in a stream draining to Benik's Pond (AW019a) below Erato Peak are characterised by slightly acidic pH. Laboratory analysis determined predominantly elevated concentrations of metals above MACs with respect to barium, copper, iron and manganese. Sulphate has frequently been recorded above MACs in AW019a and to a lesser degree at AW019.

Vorotan River and Tributaries

The pH of surface water in the Vorotan River is near neutral at all three monitored locations (AW001, AW003 and AW015) with slightly lower pH at upstream location AW001 and downstream location AW003 than in the area immediately adjacent to Amulsar (AW015). The pH at all three monitoring locations shows considerable variability between monthly monitoring rounds but no clear seasonal trend. In comparison, a number of monitored mountain streams and tributaries entering the Vorotan from the eastern flank of Amulsar are consistently acidic (pH less than 6.5).

Water quality is typically better in the Vorotan River than in its tributaries. There is no clear change in water quality between upstream location AW001 and downstream location AW003 (at the Spandaryan Reservoir). Water in the Vorotan River exceeded MACs consistently (in more than one year and at multiple locations) with respect to aluminium, barium, iron, lithium, manganese, and sulphate. The pH also falls below the lower limit of the MAC range for pH on at least one occasion at each location in most years.

Tributaries flowing into the Vorotan from the eastern flank of Amulsar (AW025, AW026, AW027, AW030, AW035, AW036 and AW037) exhibit low pH, typically containing concentrations of aluminium, barium, iron, lithium, manganese and sulphate above the MAC's.

4.9.7 Surface Water Users

National Water Supply

The Kechut Reservoir and Spandaryan Reservoir both form part of the Sevan scheme and thus their waters will indirectly be used to supply irrigation needs, municipal water supply and environmental maintenance of Lake Sevan. The Kechut-Sevan tunnel system is currently in operation while the Spandaryan-Kechut tunnel is not a functional system at present. No detailed records have been obtained to quantify the abstraction (water extraction/withdrawal) schedule employed under the Sevan scheme. However, a World Bank technical paper (World Bank, 2001) has identified a planned inter-basin transfer of 250-300 million m^3 of water annually from the Arpa River to Lake Sevan. The report states that the Spandaryan tunnel, when operational, will divert 165 million m^3/yr to Kechut.

Agriculture and Stock Watering

Within the study area, the Vorotan River's main channel and tributaries and the Darb River near Saravan, are used as a water source by herders as described in the Springs and Water Users Study (see Appendix 4.9.5). Table 4.8.22 in the Groundwater chapter describes the various locations of these water supplies (see Sections 4.8.9 & 4.8.10)

Numerous minor diversions of smaller watercourses are employed in the Vorotan, Darb and Arpa to supply water to agriculture and horticulture in the Project area. Many of these are ad-hoc and will vary from year to year, particularly those employed by the herders in the Vorotan valley to supply water to meadows for grazing cattle. This is in addition to more permanent arrangements in relation to the Gndevaz Reservoir to irrigate crops and horticulture in the adjacent foothills.

Aquaculture

Two fish farms, located approximately 6.5 km and 8 km downstream of the Kechut Reservoir, are adjacent to the Arpa River and within the study area. The fish farms are supplied with water directly from the Arpa via intakes on the adjacent channel. The fish farms are not consumptive water users of the Arpa; they simply circulate water through their facilities and discharge to a downstream location. Water quality at monitoring sites up and downstream of the fish farms (AW010 and AW009) are comparable, indicating no adverse water quality impacts. Water quality impacts typically associated with fish farm discharges, such as increased nutrient loading, lower dissolved oxygen, and increased TSS, may be discernable in the discharge mixing zone.

Ecosystem Services

Surface water and spring fed ecosystems are described in detail in Chapter 4.10. In general, the ecology baseline has not identified any Armenian Red Book or IUCN red list species present in the surface water courses within the Project area. Some plant species are regionally endemic but not directly dependant on surface water supply for their wellbeing. Habitat and land-use survey mapping has identified a number of alpine and montane meadow-type habitats in the upper parts of Amulsar (>1,900 m asl) with grazing meadows in these areas. Below this elevation, cultivation and hay cutting occur. Sub-alpine and alpine meadows in the upper slopes of the mountain are fed by snow melt; the lower montane meadows are supported by groundwater seepage, springs and watercourses.

Reservoirs

Arpa Catchment - Kechut Reservoir

Kechut Reservoir is used for water supply (Sevan scheme), fishing and as outlined previously, flow regulation and hydroelectric power production.

A hydroelectric power plant is located immediately west of Gndevaz village, and is reportedly supplied directly from the Kechut Reservoir and not directly from the Arpa itself. Discharge from the hydropower plant is approximately 2km upstream of the proposed water abstraction point for the Project. Further details of the operational regime of this hydropower plant are not available.

Arpa Catchment - Gndevaz Reservoir

The Gndevaz Reservoir was designed to be supplied by the defunct Gndevaz channel. At present, the reservoir is filled largely by natural runoff, through the diversion channel from the catchment immediately to the southeast and, on occasion, through the diversion channel from the north east which formerly connected the Gndevaz channel to the reservoir. The Gndevaz channel is currently being reinstated and is planned to be operational by mid-2016. The potable water supply pipeline from the Vorotan that runs along the Gndevaz channel and passes the reservoir to the north has a distribution point and periodically, when there is excess supply, water is redirected from this distribution point to the reservoir. The reservoir is reported to be used only for agricultural irrigation downstream of the dam. Irrigation is achieved by discharging from the reservoir to the natural channel in the gorge immediately downstream of the reservoir.

Vorotan River and Spandaryan Reservoir

Water from the Vorotan River and its tributaries is used for hydroelectric energy production, fisheries, stock watering and irrigation. There are a number of hydroelectric plants located along the Vorotan River ("The Vorotan Cascade"); the power generated from these plants constitutes approximately 25% of Armenia's total energy supply. The Spandaryan Reservoir's primary function is for this use (until the potential activation of the Spandaryan-Kechut tunnel), but it is also used for fishing, irrigation and watering of stock. A small run-of-river power plant is located upstream of the road crossing on the Vorotan River to the east of the BRSF.

Local Water Supply

It is understood that direct abstraction from surface water sources is not used to supply potable water to any of the municipalities in the vicinity of the mine. Section 4.8.10 describes the origin of these municipal supplies from spring and ground water sources.

Gndevaz Channel

As discussed in Section 4.9.3, the Gndevaz Channel (part of a soviet era inter-basin transfer scheme) is no longer serviceable and has not been used for many years, although works to re-instate the channel are scheduled for completion by mid-2016. Some minor flows accumulate along the channel where intact sections remain; these may be used as sources for irrigation and stock watering.

Arpa Gorge Irrigation Pipeline

The Arpa Gorge irrigation pipe supplies Gndevaz and eight other communities together with a hydroelectric plant with water from the Kechut Reservoir. The supply is reported to be unreliable and does not operate in winter. The pipe is controlled by a water user's cooperative and abstraction requires a permit from the Armenian Government.

Drinking Water Analysis

Potable water has been sampled from pipelines and spring and groundwater sources during the baseline period as presented in Section 4.8.10. The samples were screened against Project criteria as defined in Chapter 2.4. Screening is presented in Appendix 4.9.4 (the full dataset is available in the Geoteam Monitor Pro database).