AMARA Mining Plc

ESIA Report
Yaoure Gold Project, Côte d'Ivoire

Appendix 6
Surface Water Baseline Study

Report No. A169-15-R2343
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Revision	Date	Description	Prepared	Reviewed	Approved		
					Study Manager	Sign-off	Client
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Table of Contents

List of Tables

List of Figures

1. HYDROLOGY INTRODUCTION

1.1 LOCAL AND REGIONAL CONTEXT

The project site is mainly drained by perennial and non-perennial tributaries of the Bandama River. Many stream courses are ephemeral, only flowing during one of the wet seasons.

Drainage from the major part of the area of the proposed open pits flows northwards into Kossou Lake. The extreme southern edge of the open pit may drain southwards into a separate tributary catchment which flows into the Bandama (Blanc) River south of Kossou Dam. Figure 1.1 shows the surface drainage system for the wider area encompassing the project site, and Figure 1.2 shows the project area within the Inner Exploration Licence in more detail, together with the current surface water and groundwater monitoring sites.

Therefore, the whole of the project site, including the TMF and other infrastructure, lie within the same sub-catchment whose waters all flow into either Kossou Lake or the Bandama (Blanc) River south of Kossou Dam, north of Toumbokro. This sub-catchment boundary also encloses the Inner Exploration Licence area and runs south from Kossou Lake to N'da Koffo Yobouékro, southwest to Lotanzia, and then ESE to the Bandama north of Toumbokro.

1.2 BANDAMA RIVER

There was no existing flow monitoring data for any of the Bandama tributary watercourses prior to the commencement of the baseline study for this current project. There is however daily data (with some gaps) from a gauging station for the Bandama River at Marabadiassa, which is just north of the northern extent of Kossou Lake. This record runs from 1962 to 1997 and therefore brackets the construction of the Kossou Dam and formation of Kossou Lake in 1972, but is independent of the managed discharges from Kossou Lake since that time. The Bandama River is the longest in Côte d'Ivoire at 800 km, flowing almost north-south through the centre of the country to discharge into the Tagba Lagoon and the Gulf of Guinea.

Table 1.1 summarises the daily flow data for the Bandama at Marabadiassa into monthly averages.

Figure 1.1
Topography and Drainage of the Project and Surrounding Area

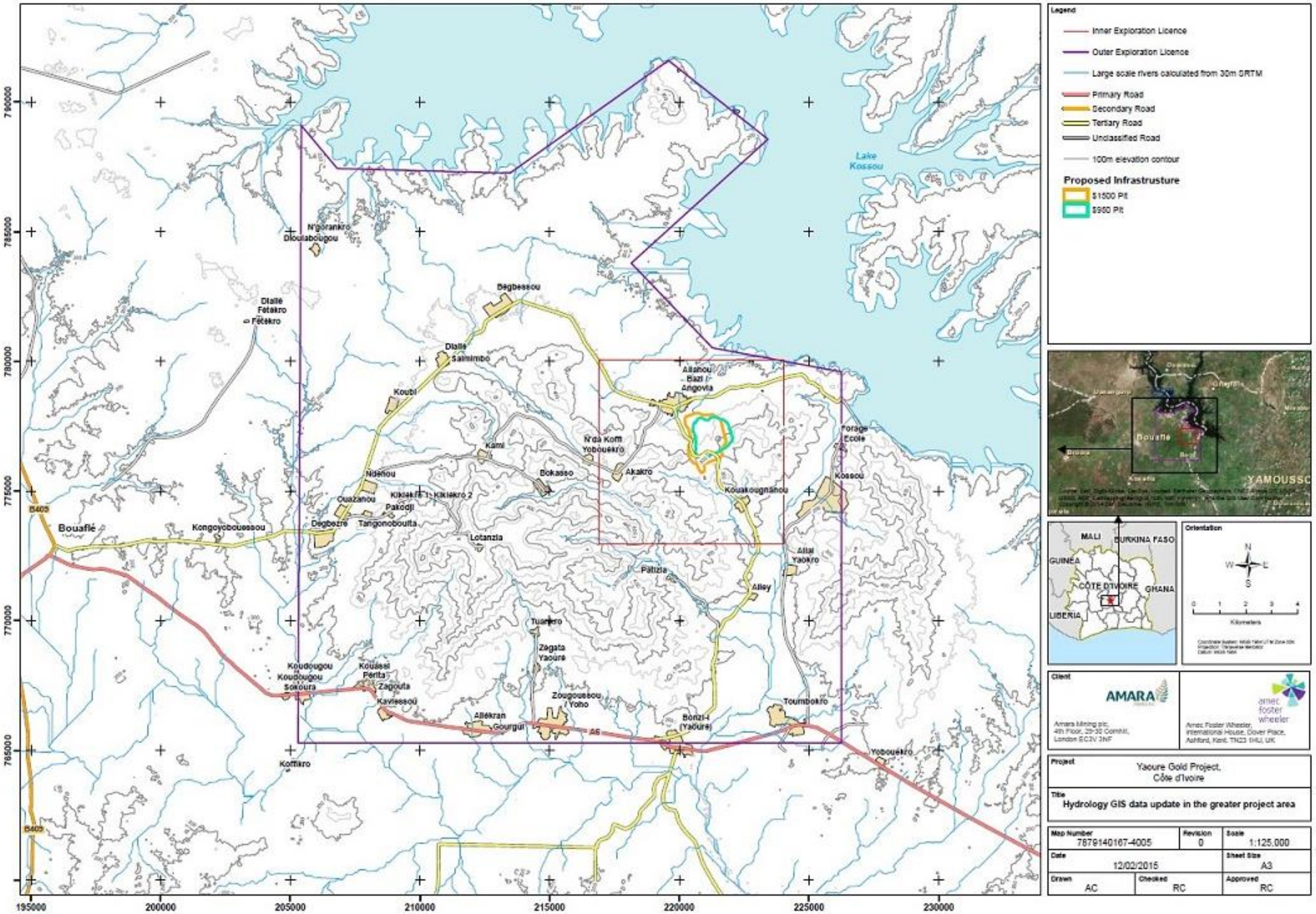


Figure 1.2
Topography and Drainage of the Project Locality and Current Monitoring Locations

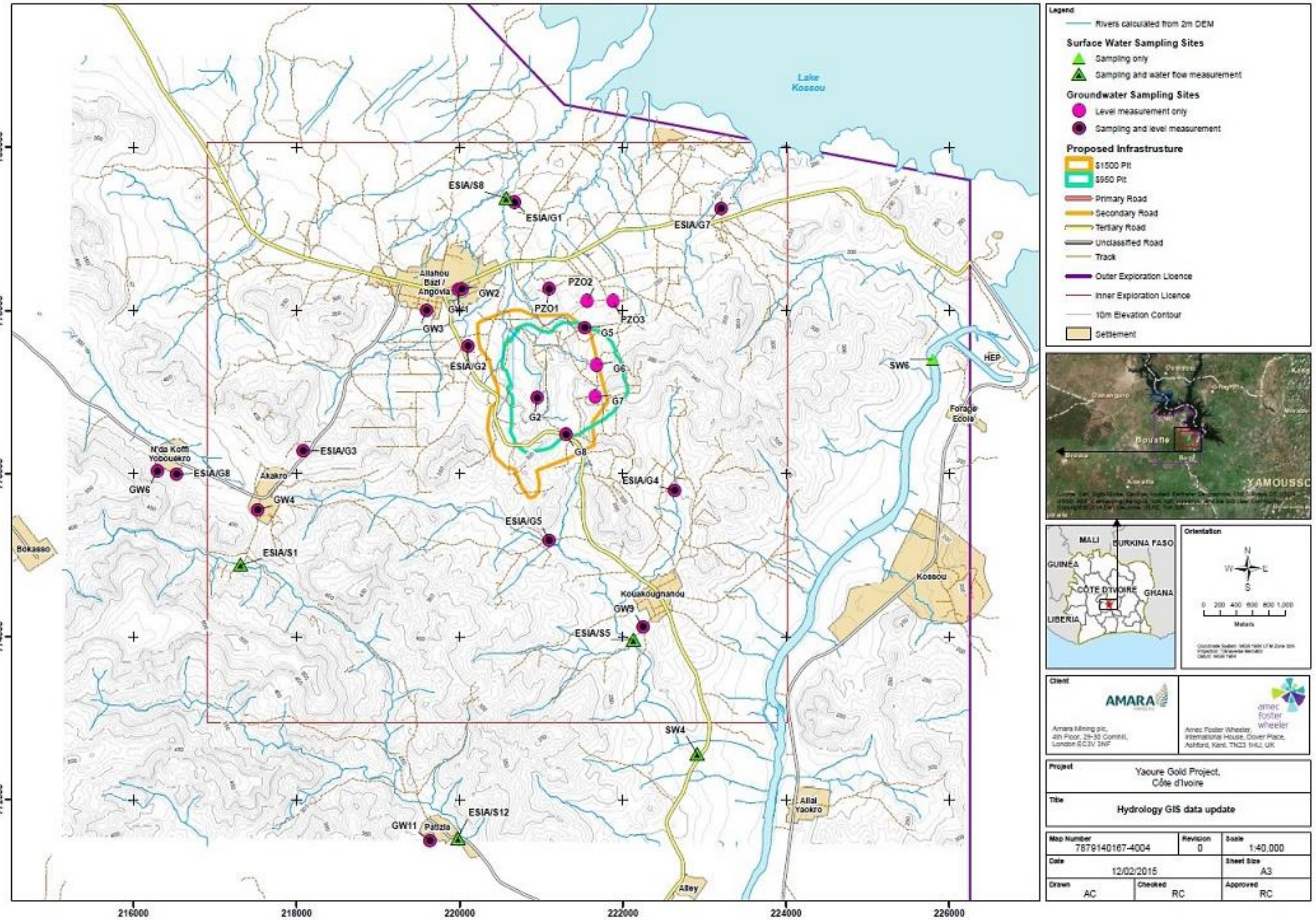


Table 1.1
Bandama River Flows at Marabadiassa, 1962-1997 (data provided by Amara)

Monthly Mean Stream Flows (m^3/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1962					4.9	8.1	21.5	114.0	538.0	419.0	130.0	49.4
1963	18.5	11.3	9.5	3.9	11.3	35.2	112.0	286.0	617.0	590.0	274.0	60.8
1964	26.7	11.9	5.1	6.0	17.3	37.0	47.0	435.0	1010.0	655.0	175.0	128.0
1965	68.6	35.7	16.7	13.6	11.0	58.8	223.0	443.0	663.0	619.0	154.0	55.1
1966	27.0	13.3	8.4	16.2	16.3	30.4	35.6	231.0	455.0	450.0	163.0	58.5
1967	22.7	15.2	11.8	7.8	14.0	14.5			592.0	425.0	94.4	36.6
1968	15.7	13.0	6.9	7.8	22.4	28.9	122.0	327.0	530.0	464.0	153.0	52.4
1969		29.0	11.1	6.3	3.3	4.0	89.3	222.0	402.0	377.0	335.0	73.1
1970	28.9	14.1	6.9	5.6	6.4	10.0	31.4	375.0	787.0	429.0	80.2	33.0
1971	15.6	7.7	6.7				9.9	185.0	445.0	278.0	48.4	25.9
1972		3.9	1.8	5.0	13.7	86.4	49.0	117.0	140.0	85.9	35.2	10.0
1973	6.6	1.8	0.4	1.8	5.2	3.1	100.0	296.0	333.0	155.0	49.7	10.3
1974	3.0	0.7	0.1	0.5	3.6	4.0	11.7	211.0	442.0	302.0	83.4	12.7
1975	7.8	3.2	1.2	1.0	6.3	7.6	24.4	200.0	526.0	200.0	40.4	16.8
1976	6.7	3.2	2.5	1.9	2.3	6.7	23.0	9.3	6.4	82.0	103.0	16.0
1977	5.8	2.0	0.3									
1978	0.8	0.1	0.0	1.8	8.7							
1979	1.2	0.1	0.0	0.0	4.7	27.9	150.0	344.0	797.0			
1980					10.2	20.5	43.1	181.0	567.0			
1981							56.0	250.0	234.0	120.0		
1982			1.5	9.2	6.9	5.8	17.6	37.6	117.0	55.7	36.0	6.6
1983	1.3	0.6	0.9	1.4	3.3	3.5	6.9	9.7	26.9	16.1	1.6	1.0
1984	0.0	0.0	0.4	0.1	7.2	10.9	23.9	57.4	147.0	83.9	21.7	5.5
1985	2.0	0.3	2.0	7.5	4.9	6.5	52.0	469.0	547.0	139.0	33.7	6.4
1986	3.0	1.7	0.9	3.4	3.3	8.0	11.7	83.7	263.0	115.0	50.4	10.7
1987	3.6	2.7	1.5	1.8	0.8	12.6	14.1	63.9	262.0	143.0	38.5	10.6
1988	3.3	0.7	0.3	0.0		2.9	49.3	172.0	466.0	272.0	29.4	7.8
1989	1.8	0.9	1.4	3.6	3.5	6.4	34.2	284.0	568.0	190.0	56.2	28.1
1990	15.8							139.0	104.0	74.0		
1991	1.4	0.1	0.0	0.0	5.6	14.6	66.8	183.0	359.0	135.0	35.1	7.0
1992	1.7	0.8	0.0	0.2	11.6	20.2	42.0	113.0	162.0	93.1	33.8	8.4
1993	3.4	0.5	0.8	0.3	11.1	15.3	16.4	22.9	125.0	83.3	27.0	5.8
1994	0.7	0.0	0.2	1.5	3.3	12.7	19.6	130.0	267.0	456.0	208.0	20.8
1995	4.9	1.3	0.2	1.0	13.5	7.5	19.5	144.0	327.0	227.0	64.9	14.1
1996	6.3	1.1	0.6	4.8	7.6	16.7	23.6	93.0	427.0	256.0	38.1	12.6
1997	6.7	2.8	0.4	7.2	7.0	26.9	43.8	177.0	320.0	279.0		12.9
Average	10.4	5.8	3.1	4.0	8.1	17.9	49.7	194.1	399.2	258.4	89.4	26.6
Maximum	68.6	35.7	16.7	16.2	22.4	86.4	223.0	469.0	1010.0	655.0	335.0	128.0
Minimum	0.0	0.0	0.0	0.0	0.8	2.9	6.9	9.3	6.4	16.1	1.6	1.0

1.3 DATABASE USED IN PREVIOUS ESIA FOR ANGOVIA MINE

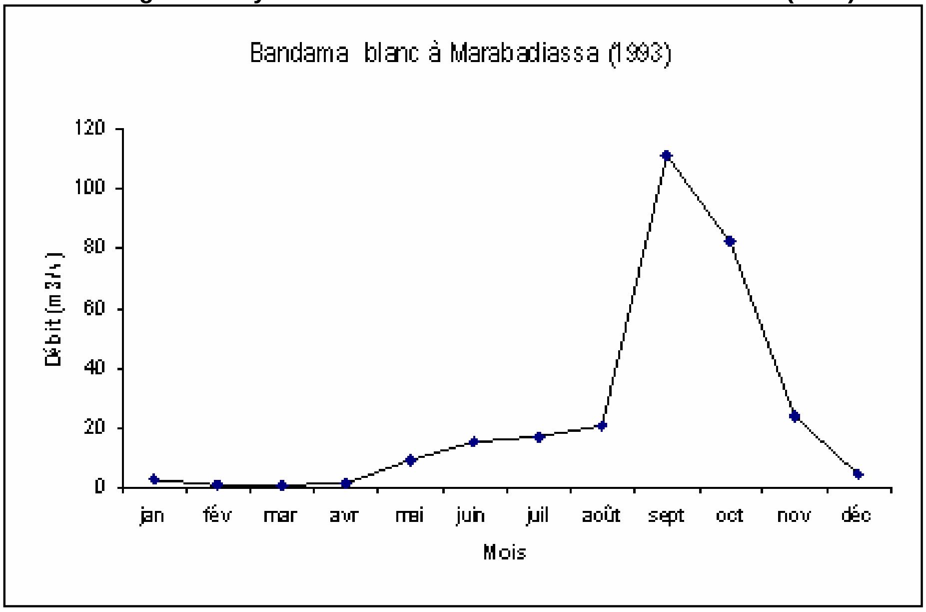
SGS (2007) provided hydrographs for the Bandama River upstream of Kossou Lake. The original data for this is not available, however some general characteristics for 1993 (after construction of the dam) are shown in Table 1.2 and Figure 1.3 below.

Table 1.2
Bandama General Characteristics for 1993

Parameters	Bandama at Marabadiassa	Total Bandama
Catchment (km^2)	22,293	97,000
Average annual flow (m^3/s)	24	171
Specific annual discharge ($l/s.km^2$)	1.08	0.0017
Rainfall (mm)	1060	
Low flow (m^3/s) (date)	0.328 (26 Apr)	
Peak flow (m^3/s) (date)	181 (15 Sep)	
Months of highest flow	Sep/Oct	
Months of lowest flow	Dec-Apr	

(SGS, 2007 after Direction de l'Eau, 1993; JICA, 2001)

Figure 1.3
Average Monthly Flow of the Bandama Blanc at Marabadiassa (1993)



Upstream of Kossou Lake, Marabadiassa reflects the northern Ivorian climate with one peak period in September.

SGS (2007) divided the subcatchment in which the project resides into five components (Figure 1.4) and carried out calculations on extreme flows based on analysis of flow records for the Bandama Blanc at Marabadiassa and the Marahoué at Bouaflé. The raw flow records have not been available for this study but the results of the calculations are shown in Table 1.3.

Figure 1.4
Project Subcatchments Determined by SGS (2007)

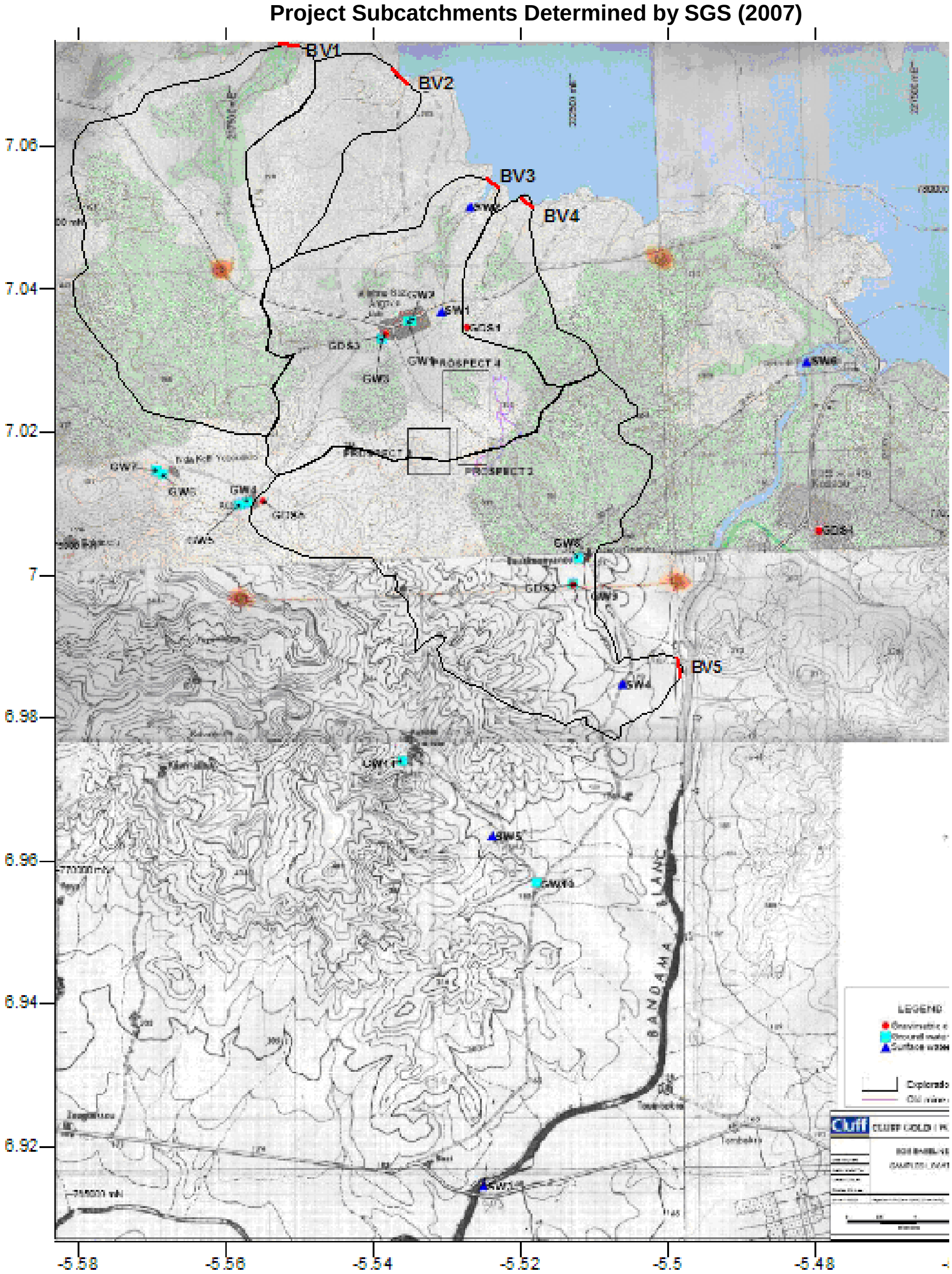


Table 1.3
Calculated Extreme Flows in the Project Sub-catchments (Source: SGS, 2007)

Catchment	Catchment Area (km^2)	Average annual flow (m^3/s)	1 in 10 years flood flow (m^3/s)	1 in 20 years flood flow (m^3/s)	1 in 50 years flood flow (m^3/s)	1 in 100 years flood flow (m^3/s)
Bandama Blanc at Marabadiassa	22,293	24	829	987	1190	1343
Marahoué at Bouaflé	19,800	22	842	993	1189	1336
BV1	14.34	-	41.4	-	-	-
BV2	4.02		15		-	-
BV3	12.42	-	45	-	-	-
BV4	2.93	-	14.8	-	-	-
BV5	17.56	-	41.2	-	-	-

1.4 PREVIOUS SURFACE WATER QUALITY

The previous heap leach activities at Angovia/Yaoure were investigated and audited as part of that operation's closure monitoring.

In 2005 it was reported that *"Detoxification of the spent heaps seems to have been successful as no residual cyanide (free, WAD and total) were found in downstream drainages or in some of the sediments collected at the base of the heaps. However, it is preferable to confirm this assertion and collect some additional water samples during the next rainy season (June/July 2005)"* (SGS, 2005).

It was also reported by SGS that *"Rehabilitation of the process solution ponds area was either interrupted or rushed. Site observations and the presence of cyanides in standing water pools confirm that the area is a potential source of long-term contamination to both surface and ground waters. It is highly recommended to rehabilitate this site to an appropriate standard so it does not pose any further threat to the environment"* (SGS, 2005). A similar situation was described by AMEC (2005).

A real and potential surface water pollution issue concerns the activities of artisanal miners ('*orpailleurs*'). SGS (2005) *"did not identify any major impact on air quality and water quality (with the exception of regular pollution of waters by suspended solids and a potential for cyanide contamination from the process solution ponds area), potential for acid mine drainage or pollution by solid or liquid waste. Within the close proximity of the former AGM active areas, two major "orpailleurs" sites were identified. These are the N'gbonlobounou site in the valley of the Wintin-wintin stream and the northern portion of Pit North. In addition, signs of their persistent activities were found within almost all the AGM former operational areas (Pits, heaps, processing, ROM pad). The "orpailleurs" at Angovia do not use mercury or other chemicals to collect gold. Therefore, the main resulting environmental impacts of their digging and panning activities are a degradation of soils, surface water quality through an increase in suspended solids, landscape and vegetation".*

A baseline surface water monitoring programme was proposed to the then Cluff Gold in 2006 (SGS, 2006). This included the monitoring sites shown in Table 1.4 Monitoring was done intermittently between 2006 and 2012.

Table 1.4
Proposed Surface Water Monitoring Sites (SGS, 2006)

Code	Name	Description	GPS Coordinates (UTM)	
			North	East
SW1	Wintin-wintin Stream I	Upstream of Wintin-wintin before Allahou Bazi Village	778394	220478
SW2	Wintin-wintin Stream II	Downstream of Wintin-wintin upstream of Bandama River confluence	779991	220960
SW3	Bandama River I	Downstream of Bandama River at Clement Bambakro Village	764899	220575
SW4	N'Zué blé Stream	N'Zué blé Stream upstream of Patizia II Village	772564	222909
SW5	Palé Stream	Palé Stream downstream of Patizia I Village	770294	220916
SW6	Bandama River II	Upstream of Bandama River below the dam wall	777398	225794

Samples were analysed for the following:

Physical Chemical Parameters: pH, Dissolved Oxygen, Conductivity, Total Dissolved Solids, Apparent Colour, True Colour, Turbidity, Alkalinity and Hardness ($CaCO_3$).

Nutrient and Other Chemical Parameters: Sodium (Na), Potassium (K), Sulphate, Chloride, Nitrate, Nitrate, Calcium, Magnesium (Mg), COD and BOD.

Metals (Total and then Dissolved alternatively): Fe, Mn, Zn, Pb, Hg, Cr, Ni, As, Cd, Al, Bi, Sb, Cd, Co and Se.

Cyanide: Free and total Cyanide.

In general the waters were all close to neutral in pH, can show elevated concentrations of iron and there were cases of detectable arsenic in SW1 and SW2, of total cyanide (barely at the limit of detection) in SW2, SW3 and SW4, and total coliforms, staphylococcus and streptococcus in all the locations. The bacterial contamination will be due to sanitation conditions in the villages upstream of the sample points. Otherwise quality appears to be acceptable.

A further set of samples was taken and analysed for a reduced set of parameters by Lapisen in November 2013. Results were generally similar, but included some detectable total cyanide (0.22 mg/L) in SW2.

2. PEAK FLOW ESTIMATION FOR THE PROPOSED AMARA PROJECT

Peak flows/discharges were determined at five locations downstream of the proposed mine infrastructure using the Rational Method, as discussed below.

2.1 METHODOLOGY

The Rational Method was selected for peak flow estimation for the following reasons:

- It is a well-established method that can be applied to a wide range of catchments, including those at the site;
- The required input parameters can be obtained/estimated from the data available for the site; and
- Initial estimates for peak flows can be obtained using limited available data - these can subsequently be worked up into more detail as required as a project progresses and/or more data become available.

2.1.1 Rational Method

The Rational Method formula is given as:

$$Q_p = 2.78CiA$$

where:

Qp = design peak runoff (l/s);

C = runoff coefficient (dimensionless), which is dependent on the catchment characteristics;

i = rainfall intensity for the design return period (in mm/hr) and for the critical storm duration for the catchment; and

A = total catchment area being drained (ha).

2.1.2 Walkover surveys in July 2014 and January 2015

Anecdotal information obtained during the walkover surveys helped to inform the determination of parameters for input into the Rational Method, and provided context for the results. It is understood that:

- The current monitoring plan (see Section 3 below) includes the collection of spot flow values on a daily or weekly basis along watercourses in the vicinity of the site, as documented in the site monitoring plan, however with the exception of a perennial watercourse located to the south of the TMF valley, these were dry at the time of the January 2015 walkover survey;
- Many of the ephemeral watercourses in the vicinity of the site are poorly defined and were barely discernible at the time of the walkover surveys;
- Infiltration, at least during the dry season, appears to be rapid;

- There is only little primary rainforest left in the area. Land use varies between secondary forest, savannah, areas cleared for small scale agriculture, bare earth and developed area (villages and former mining development); and
- It is understood that the heap leach pads associated with previous mining operations are now 'barren' of leachable material and that runoff from the historic leach pads is routed to the natural drainage system.

2.1.3 Catchment Areas

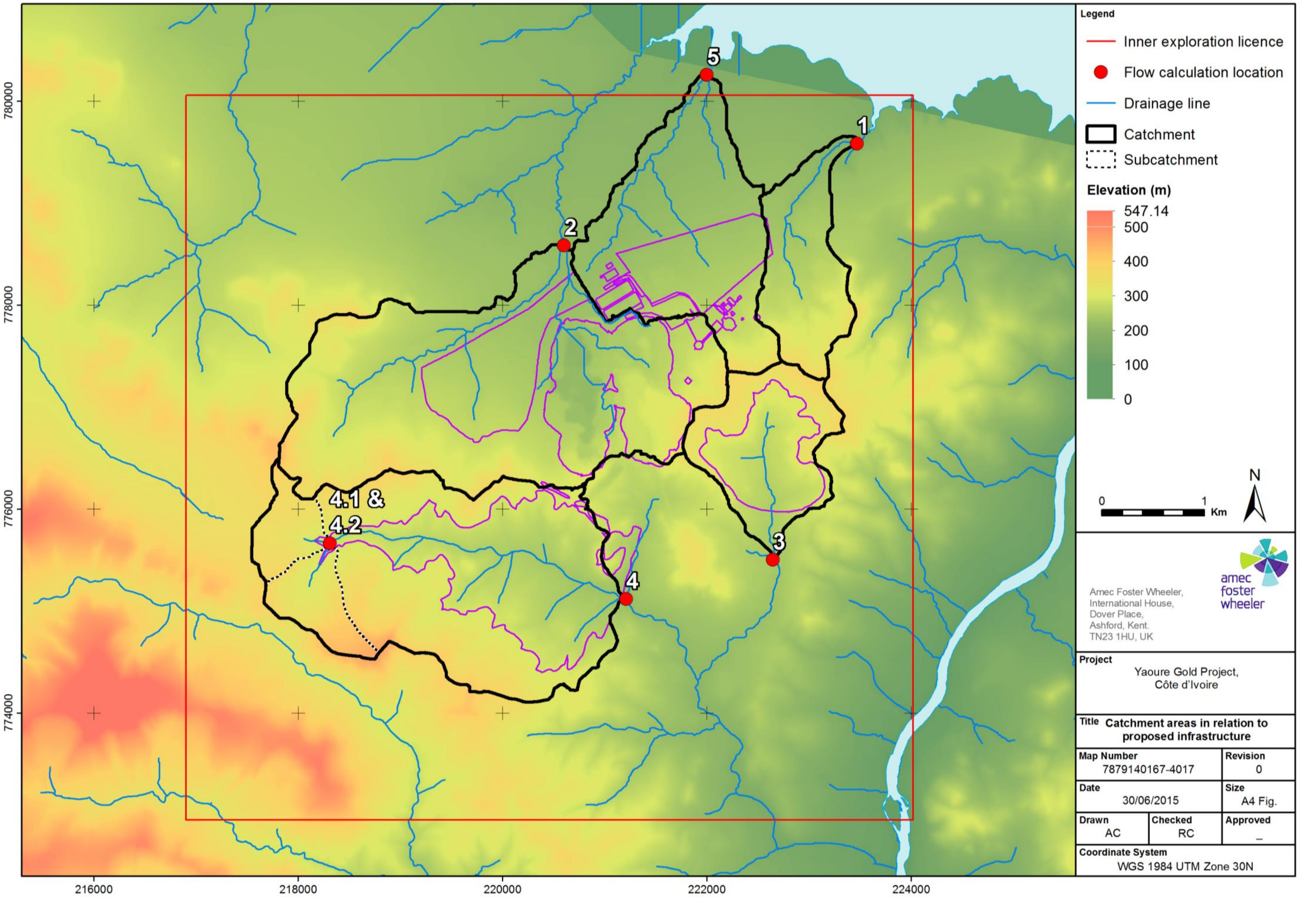
Watersheds and drainage catchments were delineated in GIS using ArcHydro software. Once the watersheds had been delineated, the locations at which peak flows would be calculated were determined. The locations were selected so as to ensure that all rain falling on or upstream of the proposed mine infrastructure would be covered. Catchment and flow location selection considerations, including the infrastructure within each catchment, are presented in Table 2.1 below. Catchments, flow locations, provisional infrastructure locations and drainage routes are presented in Figure 2.1 below.

As per the delineation of the sub-catchments, the drainage routes indicated in Figure 2.1 were also determined using ArcHydro software in ArcGIS. These indicate potential drainage routes, which may be associated with overland flow paths, rills, gullies and/or channels, depending upon the upstream catchment characteristics, such as catchment size, ground cover and slope.

Table 2.1
Catchment and Flow Location Selection Considerations

Catchment No.	Infrastructure within catchment	Flow location considerations
1	• (Some of) Waste Rock Dump B	Located sufficiently downstream so as to capture all run-off from Waste Rock Dump B, but upstream of a small confluence from which flows are not of interest.
2	• Open pit • Angovia Waste Dump • Some of the proposed plant site • Some of the former heap leach area	Located at the bridge crossing for the existing road between the Angovia settlement and the Kossou Dam. Located just downstream of a sub-catchment confluence so as to capture flows from both the Angovia Waste dump and the proposed pits.
3	• Waste Dump (C)	Located upstream of a confluence with a small tributary from which flows are not of interest. The small portion of Waste Dump C which appears to be outside of the catchment (to the south east) does actually drain to this same watercourse, but does so just downstream of the confluence, hence appearing to be outside of catchment 3.
4	• TMF	Located upstream of a nearby tributary that will not be contributing flow to the TMF.
5	• Proposed plant site • Low grade stockpile • Waste Rock Dump B • Existing Office Buildings and water ponds • Former heap leach and ponds	Located downstream of the site so as to capture several smaller flow paths originating from the site in one catchment.

Figure 2.1
Catchments, Flow Locations, Provisional Infrastructure Locations and Drainage Routes



Source: Based upon LiDAR data and a provisional infrastructure plan provided by Amara/Tetratech

2.2 RUNOFF COEFFICIENT C

The dimensionless runoff coefficient C in the Rational Method is dependent on the catchment characteristics, such as ground cover, soil type, relief, and antecedent conditions. For this study, C was determined using professional judgement based upon visual inspection of aerial photography and 'Landsat' data obtained from the United States Geological Survey (USGS) on Normalized Difference Vegetation Index (NDVI) (for ground cover type and vegetation coverage), combined with general consideration of the soil type (not too heavy, but also not highly permeable) and knowledge of the relatively low relief in the area of interest (from LiDAR digital elevation model data). This was further supported by information obtained during the site visit, and judgement on the antecedent conditions likely to be present following the peak of the wet season, when the peak flows are likely to occur.

Estimated runoff coefficients are presented in Table 2.2 below.

Table 2.2
Run-off Coefficients for use in the Rational Method

Parameter	Catchment ID				
	1	2	3	4	5
Runoff coefficient C (initial estimate) (dimensionless)	0.25	0.3	0.25	0.3 (peak)[1] 0.2 (WBM)[2]	0.4

[1] Runoff coefficient of 0.3 recommended for the TMF catchment for use in the Rational Method to calculate peak flow.

[2] Runoff coefficient of 0.2 recommended for the TMF catchment for use in water balance modelling of the TMF.

As indicated in the notes of Table 2.2, while a runoff coefficient of 0.3 has been used for assessment of peak flow at the TMF catchment outlet, this is considered conservative since the TMF catchment is the most densely vegetated (according to the aerial photography and Landsat NDVI imagery). This is considered appropriate for peak runoff calculations. However, for water balance calculations, which need to consider the resource element to inform make-up water requirements (assuming TMF catchment runoff drains to the TMF and will not be intercepted) a runoff coefficient of 0.2 is recommended.

2.2.1 Rainfall Intensity

Rainfall intensity was determined from IDF curves generated using rainfall data from the Bouaflé weather station and the formula of Sherman (1931), as discussed in the accompanying Climate Baseline Study (Amec Foster Wheeler, 2015). The IDF data used in this study and corresponding curves are presented below in Table 2.3.

Table 2.3
IDF Results (Rainfall Intensity in mm/hr)

Return Period (years)	Rainfall intensity (mm/hr)								
	Duration (mins)								
	5	10	20	30	60	120	180	720	1440
100	191.5	172.7	157.4	124.8	89.1	57.5	42.9	13.9	9.2
1,000	249.4	224.8	204.9	162.5	116.0	74.9	55.9	18.1	9.9

2.2.2 Critical Storm Duration

The peak flow for a catchment occurs when the entire catchment is contributing flow from rainfall. The duration of the storm for which the peak flow rate will occur is known as the critical storm duration, which is generally considered equal to the 'time of concentration'.

The time of concentration (T_c) for a catchment is defined as:

a. the time taken for water to flow from the most remote point on the catchment to the point of interest; or
b. the time taken from the start of a rainfall event until all of the catchment is simultaneously contributing to flow at the point of interest.

Time of concentration can be estimated using a number of methods. For this study, the Bransby-Williams method was used, which is a commonly used method and considered to be suitable in this instance. Times of concentration were cross-checked against values obtained using other methods, including a simple areal-velocity calculation and the Kerby and Kirpich methods. All of the T_c values were found to be comparable.

The Bransby Williams method is as:

$$T_c = \frac{58.5L}{A^{0.1}S^{0.2}}$$

Where:

L is the network length (km);

A is the catchment area (km2); and

S is the slope (m/km).

L is determined by the longest flow path in the catchment, which was determined using ArcHydro software in GIS. A is the area contributing to runoff along the flow path. S is given by the difference in elevation along the longest flow path.

The input parameters for the Bransby-Williams method are presented in Table 2.4 below.

Table 2.4
Input Parameters for the Calculation of the Time of Concentration for the Bransby-Williams Method

Parameter	Catchment ID				
	1	2	3	4	5
Catchment area (m^2)	1,426,348	6,926,244	1,757,128	5,959,332	3,240,352
Longest flow path/network length (km)	3.02	4.50	2.32	4.96	4.47
Elevation at the top of the longest flow path (m ASL)	388.12	377.66	382.93	463.77	274.36
Elevation at the bottom of the longest flow path (m ASL)	188.87	212.36	238.71	224.58	188.17
Slope (m/m)	0.07	0.04	0.06	0.05	0.02
Slope (m/km)	65.9	36.8	62.3	48.3	19.3

T_c values calculated using the Bransby-Williams method are presented in Table 2.5 below, together with T_c calculated using the various other methods highlighted above, ranging from simple calculations of drainage length with assumed velocities, to variations on the Kerby and Kirpich methods. The additional methods, although less suitable at the site, provide confidence in the values obtained using the Bransby-Williams method.

Table 2.5
Calculated Time of Concentrations

Calculation method	Catchment ID				
	1	**2**	**3**	**4**	**5**
Direct length assumed velocity (of 0.5m/s) (minutes)[1]	78	120	64	123	99
Detailed length assumed velocity of 0.5m/s (minutes)[2]	101	150	77	165	149
Bransby-Williams (minutes)	**74**	**105**	**56**	**112**	**129**
Kerby-Kirpich (minutes)[3]	Location at which flow becomes channelised required- not known at this stage				
Kerby only (all overland) (minutes)[4]	75	104	81	123	105
Kirpich only (all overland) (minutes)[5]	56	96	47	93	122
Kirpich only (all channel flow) (minutes)[6]	28	48	23	47	61
Time of concentration used (Bransby-Williams) (minutes)	**74**	**105**	**56**	**112**	**129**

[1] For the direct length assumed velocity method, the time of concentration is simply estimated by dividing the direct 'as the crow flies' distance between the top and bottom of the catchment by an assumed velocity of flow. This gives a 'ball park' estimate of likely time of concentration.

[2] For the detailed length assumed velocity method, the time of concentration is simply estimated by dividing the 'detailed' longest flow path distance between the top and bottom of the catchment by an assumed velocity of flow. This gives an upper 'ball park' estimate of likely time of concentration.

[3] The Kerby-Kirpich method involves addition of the time of concentration calculated for overland flow using the Kerby method to the time of concentration calculated for channel flow using the Kirpich method. This method can be applied to catchments between 1.61 and 80km^2, main channel lengths between 1.6 and 80km and slopes between 0.002 and 0.02. However, the determination of a location at which overland flow becomes channel flow is required. This is currently unknown and therefore this method has not been applied.

[4] The Kerby method is meant for overland flow in small drainage basins only. The upper limit should be a flow length of about 305m. All catchments, flow lengths and slopes are too large and too steep to rely upon values determined by the Kerby method only. Values are presented here for indicative purposes only. The Kerby Method also requires the estimate of a dimensionless retardance co-efficient (N), which is based up on the ground cover (this should not be interpolated between tabulated values).

[5] The Kirpich method is meant for channel flow, but can also be used for overland flow or flow in a natural grass channel by applying an adjustment factor. The method can only be applied to catchments of certain sizes, channel lengths and channel slopes. All catchments are too large for the application of this method alone. Values are presented here for indicative purposes only.

[6] The Kirpich method yields very conservative or short times of concentration that result in high peak runoff rates, especially from the rational method. This method should only be used if the available data are limited to watershed length and slope, or the method is specified. All catchments are too large for the application of this method alone. Values are presented here for indicative purposes only.

2.3 RATIONAL METHOD RESULTS

The input parameters used in the Rational Method and the peak flow results for the 100 and 1,000 year return periods are presented in Table 2.6 below.

Table 2.6 Rational Method Input Parameters and Results for the 100 and 1000 Year Return Period Events					
Parameter	Catchment ID				
	1	2	3	4	5
Catchment Area (m^2)	1,426,348	6,926,244	1,757,128	5,959,332	3,240,352
Runoff coefficient C (initial estimate) (dimensionless)	0.25	0.3	0.25	0.3	0.4
Time of concentration/critical storm duration (minutes)	74	105	56	112	129
Rainfall intensity – 100 year return period (mm/hr)	82	65	94	62	55
Rainfall intensity – 1000 year return period (mm/hr)	106	85	122	81	75
Peak flow – 100 year return period (m^3/s)	8	38	11	31	20
Peak flow – 1000 year return period (m^3/s)	11	49	15	40	27

The results presented in Table 2.5 and Table 2.6 confirm that not-insignificant peak flows could occur from any of the catchments at the site, and further consideration will be required as the infrastructure plan for the mine is progressed. The flows presented in Table 2.6 do not include an allowance for climate change, or for the proposed development at the site (i.e. to reflect changes in landcover). Further analysis was undertaken, as discussed below, to take account of the most significant changes that would occur at the site, which will be associated with the pits in catchment 2 and the TMF in catchment 4.

2.4 DEVELOPED MINE SCENARIO

2.4.1 Introduction

For the developed mine scenario, there are a number of additional hydrological considerations which will need to be taken into account as the mine infrastructure proposals progress. The most significant of these, associated with the pits and the TMF, i.e. catchments 2 and 4 respectively, are discussed in the Section below.

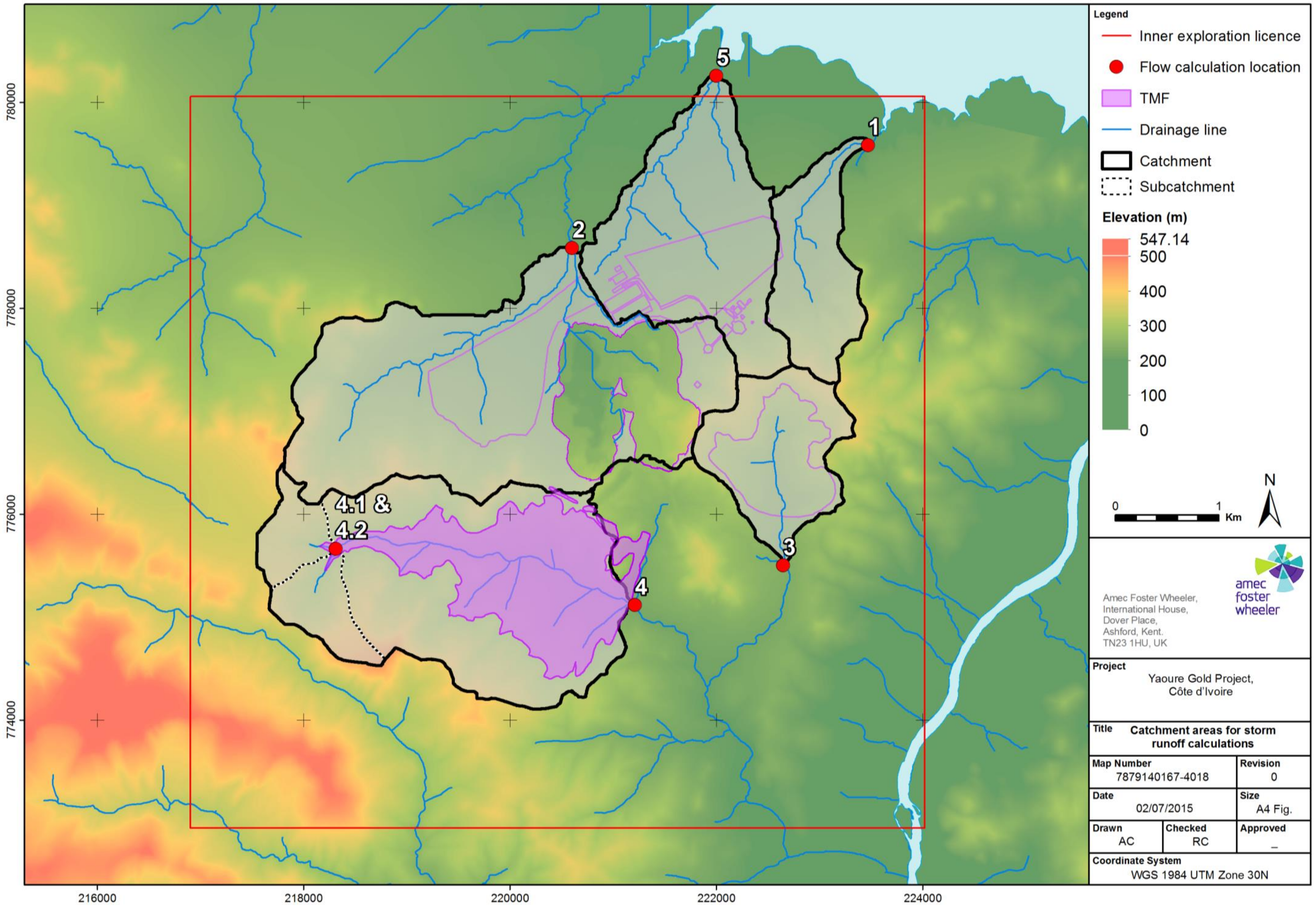
2.4.2 Changes to catchment characteristics and sub-catchments for TMF diversions

For the developed mine scenario, the area of catchment 2 will be reduced by the size of the pits (see Figure 2.1 and Figure 2.2), and catchment 4 will be reduced by the area of the TMF. The resulting catchments have been referred to as Catchments 2a and 4a respectively in this report.

Once the TMF is fully developed, the TMF catchment (4a) will effectively comprise a number of smaller sub-catchments either reporting to the TMF, or a diversion channel around its edge. Peak flow calculations were therefore also carried out for two representative sub-catchments in the TMF catchment, to provide information as to the likely magnitude of flows for assessing diversion channel feasibility with respect to the likely capacity required. Sub-catchments at the upstream end of the TMF were selected, as two of the largest sub-catchments in the 4a catchment.

The amended catchments 2a and 4a are shown in Figure 2.2 below, together with the 4.1 and 4.2 sub-catchments, and the original catchment 1-5.

Figure 2.2
Amended Catchments 2a and 4a (greyed), and Sub-catchments 4.1 and 4.2



Source: Based upon LiDAR data provided by Amara on DATE and a provisional infrastructure plan provided by Amara on date (Feb/early March 2015)

The Rational Method input parameters and results for the 100 and 1,000 year return period events for catchments 2 and 4 are reproduced in Table 2.7 below, together with the values for the amended 2a catchments, and the 4.1 and 4.2 sub-catchments. A value for 4a has not been presented, owing to the fact that two diversion channels would likely be required, one to the north and the other to the south of the TMF.

Table 2.7
Rational Method Input Parameters and Results for the 100 and 1000 Year Return Period Events for the Amended Catchments and Sub-catchments of Catchments 2 and 4

Parameter	Catchment ID				
	2	2a	4	4.1	4.2
Catchment Area (m^2)	6,926,244	5,301,289	5,959,332	486,836	579,504
Longest flow path (total) (km)	4.50	4.50	4.96	1.19	1.57
Elevation at the top of the longest flow path	377.66	377.66	463.77	367.55	463.77
Elevation at the bottom of the longest flow path	212.36	212.36	224.58	284.76	284.76
Slope (m/m)	0.04	0.04	0.05	0.07	0.11
Runoff coefficient C (initial estimate) (dimensionless)	0.3	0.3	0.3	0.2	0.2
Time of concentration/critical storm duration (minutes)	105	108	112	32	38
Rainfall intensity – 100 year return period (mm/hr)	65	64	62	122	116
Rainfall intensity – 1000 year return period (mm/hr)	85	83	81	159	151
Peak flow – 100 year return period (m^3/s)	38	31	31	3	4
Peak flow – 1000 year return period (m^3/s)	49	37	40	4	5

The estimated peak flows in Table 2.7 indicate that, at any point in the lifetime of the pits, peak flows in Catchment 2 would be expected to be between the estimate for 2a (the smallest catchment footprint during the lifetime of the mine) and that for the existing catchment 2 (the largest catchment footprint during the lifetime of the mine), depending upon the stage of pit development, i.e. between 31 and 38 m^3/s for the 100 year event.

It can be seen that, even with the TMF at its full extent (covering a total area of approximately 2.14 km^2), a significant proportion of the upstream catchment will remain (approximately 3.65 km^2). This is approximately 60% of original area of catchment 4 (approximately 5.96 km^2), indicating that diversion along the margins of the TMF would likely be required in order to ensure that sufficient control on water volumes and management requirements within the TMF are facilitated.

Initial estimates for the required capacity of the diversion channel have been made based upon the characteristics of the upstream sub-catchments that would otherwise report to the TMF (catchments 4.1 and 4.2).

Sub-catchments 4.1 and 4.2, at the upstream end of the TMF have been estimated to produce peak flows in the region of 4 to 5 m^3/s, for both the 100 year and 1,000 year events. This indicates that a diversion channel with at least this capacity would likely be required.

2.5 RESULTS SUMMARY

Peak flows calculated using the rational method, for all catchments, amended catchments and sub-catchments considered in this report and for all return periods are provided in Table 2.8 below.

Table 2.8
Summary of Peak Flow Estimates for all Catchments, Amended Catchments and Sub-catchments, for all Return Periods

Peak flows (m^3/s)								
Return period (years)	**Catchment**							
	1	**2**	**3**	**4**	**5**	**2a**	**4.1**	**4.2**
100	8	38	11	31	20	28	3	4
1,000	11	49	15	40	26	37	4	5

3. CURRENT MONITORING

A monitoring programme for water quality, flow and levels was prepared and instigated by Amara in November 2014. This document is attached to this Baseline Study. Monitoring sites are shown on Figure 1.2.

3.1 FLOW DATA

Flow monitoring commenced in December 2014. Data collected through to April 2015 has coincided with the dry season and so many ephemeral streams have been dry or nearly so. Flows recorded have shown the following ranges (see Figure 1.2 for locations):

S1 0.001 – 0.107 m^3/s

S5 dry – 0.019 m^3/s

S8 dry – 0.314 m^3/s

S12 0.074 – 0.302 m^3/s

SW4 dry – 0.019 m^3/s

3.2 WATER QUALITY DATA (SURFACE AND GROUNDWATER)

A total of seventy groundwater samples and twenty two surface water samples have been collected to date for measurement of field parameters and laboratory analysis in four campaigns during December 2014, January 2015, February 2015 and March 2015. The samples were obtained from twenty seven different installed surface and groundwater monitoring sites within the Yaoure Project area (see Figure 1.2, Table 3.1 and Table 3.2). The programme is ongoing.

Water samples were taken according to the Water Baseline Field Instructions sampling procedure and schedule. Field parameters, including pH, electrical conductivity (EC), dissolved oxygen (DO) and temperature were measured at the same time as sampling. Water samples for laboratory analysis were either directly taken from surface water courses or removed by pumping or bailing from monitoring wells. For monitoring well sampling at least three times the borehole volume was discharged before sampling. Rest water levels were measured before sampling.

Sample bottles were provided by the laboratory and contained preservatives as necessary. Samples were taken for both Total Metal and Dissolved Metal analysis. Samples for dissolved metals analysis were filtered using disposable 45 µm cellulose filters prior to putting in the sample bottles. Quality assurance (QA) and quality control (QC) includes the use of blank and duplicate samples.

Table 3.1
Groundwater Monitoring Sites

Monitoring site	Easting	Northing
ESIA/G1	220670.4	779326
ESIA/G2	220101.4	777559.1
ESIA/G3	218080.2	776279.7
ESIA/G4	222632.2	775795.2
ESIA/G5	221094.5	775180.3
ESIA/G7	223201.6	779248.5
ESIA/G8	216529.3	775989.4
GW/1	219982	778257
GW/2	220025	778263
GW/3B	219593	778005
GW/4	217521	775559
GW/6	220769	778039
GW/9	222246	774119
GW/K	226240	774857
PZ01	221096	778268
PZ03	221878	778113
YRC 761	220950	776928
YRC 766	221524	777793

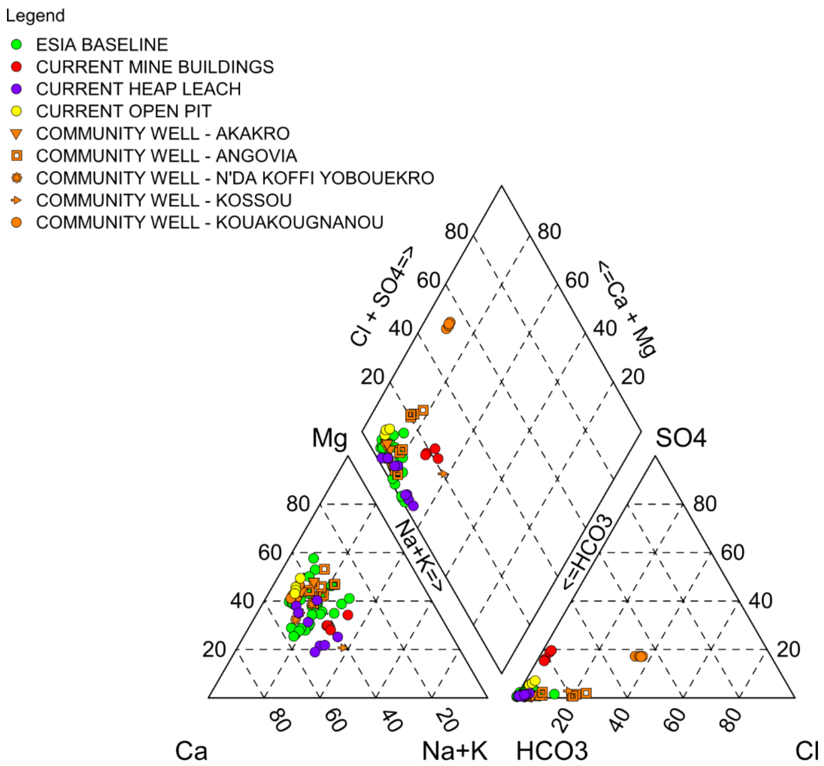
Table 3.2
Surface Water Monitoring Sites

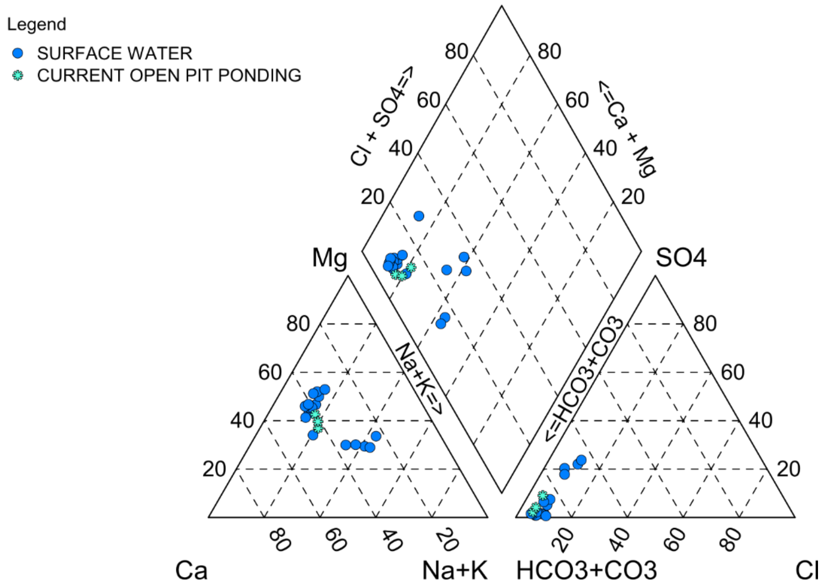
Monitoring site	Easting	Northing
ESIA/S1	217312	774878
ESIA/S12	219976	771533
ESIA/S5	222128	773965
ESIA/S8	220568	779374
SW/4	222909	772564
SW/6	225794	777398
YSP	220834	777088
YCP	220583	777209
YNP	220719	777535

Plotting the major cations Na+, K+, Ca2+, Mg2+ and major anions HCO3-, CO32-, SO42- and Cl- on a trilinear Piper diagram assists in classifying the hydrochemical facies of groundwater and surface water samples. The majority of groundwater samples plot as Ca-Mg-HCO3 water type and the majority of surface water samples plot as Mg-Ca-HCO3 water type (Figure 3.1).

Figure 3.1

Piper Diagrams for Groundwater and Surface Water Samples





Physical characteristics

pH

The samples from Yaoure Project area have pH values from field measurements ranging from 6.68 – 8.38, with a mean value of 7.71 signifying marginally alkaline waters.

Electrical conductance

Electrical conductivity values varied from 7.7 to 134.2 mS/m, averaging 43.2 mS/m.

Temperature

Field measurements from the December campaign show that the samples had temperatures ranging from 24.9°C to 28.6°C, with a mean value of 27.6°C.

Dissolved Oxygen

Field measurements only available from the December campaign show that the samples had dissolved oxygen values ranging 17.5 % to 113.9 %, with a mean value of 51.5 %.

Suspended solids at 103 -105°C

Total suspended solids at 103-105°C values for the sample vary from 1 to 10000 mg/L, averaging 191.8 mg/L.

Hardness

The calculated hardness values vary from 22 to 649 mg/L, with a mean value of 196 mg/L indicating very hard water. No health-based guideline value is proposed for hardness in drinking-water by WHO.

Turbidity

Turbidity for the samples ranges from 0.2 to 6900 NTU, with 61% of the samples giving values which exceed the World Health Organisation (WHO) Guideline Value for Drinking Water (2011) of 5 NTU.

Heavy metals and health significant chemicals

Arsenic

Over two thirds of the samples had detectable measurements of dissolved arsenic. One sample from GW/6 has a dissolved arsenic value of 0.028 mg/L which marginally exceeds the WHO Guideline Value of 0.02 mg/L. The remaining samples have values averaging 0.0025 mg/L.

Antimony

Dissolved antimony measurements for samples range from 0.0001 – 0.004 mg/L which is below the WHO Guideline Value of 0.01 mg/L.

Cadmium

Only one sample from ESIA/S8 had a detectable level of dissolved cadmium. Measuring 0.002 mg/L it is below the WHO Guideline Value for Drinking Water of 0.003 mg/L.

Chromium

Just over half the samples had measurable levels of dissolved chromium. One sample from GW/4 has a dissolved chromium value of 0.079 mg/L which exceeds the WHO Guideline Value of 0.05 mg/L. The remaining samples have average of 0.0048 mg/L.

Copper

Dissolved copper exists at measurable levels in eleven samples, ranging from 0.001 to 0.0029 mg/L. These values are far below the WHO Guideline Value of 2 mg/L.

Lead

A third of the samples have measureable levels of dissolved lead. Three samples from ESIA/G4, ESIA/G7 and YRC 766 have dissolved lead values of 0.25, 0.02 mg/L and 0.014 mg/L respectively, which marginally exceed the WHO Guideline Value for Drinking Water of 0.01 mg/L. The remaining samples have an average of 0.0023 mg/L.

Mercury

Dissolved mercury was not detected in any of the samples.

Barium

Dissolved barium measurements for the samples range from 0.001 to 0.082 mg/L which is well below the Who Guideline Value of 0.7 mg/L.

Boron

Only nine samples had measurable levels of dissolved boron, with the largest value of 0.21 mg/L being well below the WHO Guideline Value of 2.4 mg/L.

Fluoride

Only six samples had measurable levels of dissolved fluoride, ranging from 0.1 to 0.4 mg/L. These values are well below the WHO Guideline Value of 1.5 mg/L.

Zinc

Almost half of the samples had detectable levels of dissolved zinc, ranging from 0.005 to 1.6 mg/L.

Selenium

Dissolved selenium was not at detectable levels in any of the samples.

Nickel

Dissolved nickel exists at measurable levels in over three quarters of the samples, ranging 0.001-0.012 mg/L. These values are below the WHO Guideline Value of 0.07 mg/L.

Uranium

Dissolved uranium exists at measurable levels in twelve samples with values ranging from 0.001 – 0.002 mg/L which is well below the WHO Guideline Value of 0.03 mg/L.

Microbiology

No data was obtained on the microbial water quality.

Nutrients

Ammonia

Ammonia values for samples are all below 0.3 mg/L which has no direct relevance to health at these levels.

Nitrite

Nitrite exists at measurable levels in only eleven samples and these values are all below the Who Guideline Value for Drinking Water of 3 mg/L, averaging 0.26 mg/L.

Nitrate

Nitrate exists at measureable levels in almost two thirds of the samples. The four samples from borehole GW/9 have nitrate values between 220.3 and 348.4 mg/L which exceed the WHO Guideline Value for Drinking Water of 50 mg/L. The remaining samples have average Nitrate values of 4.6 mg/L.

Phosphate

Phosphate exists at measureable levels in just over half of the samples, but at low values ranging from 0.02 to 0.16 mg/L and averaging 0.07 mg/L.

Organic matter

Biochemical oxygen demand

Biochemical oxygen demand exists at measurable levels in over a quarter of the samples, ranging 05 – 13 mg/L and averaging 7.6 mg/L.

Chemical oxygen demand

Chemical oxygen demand exists at measureable levels in a third of samples, ranging 25 – 260 mg/L and averaging 48 mg/L/.

Organic contaminants

Phenol

Phenol was at measureable levels in only three samples ranging 0.1- 0.4 mg/L/

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