APPENDIX E

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APPENDIX E1

Rock storage facility runoff water quality assessment

Olympic Dam Expansion Project RSF Runoff Water Quality Assessment

Report prepared by

SRK Consulting

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Project Code: BHP051

Olympic Dam Expansion Project
RSF Runoff Water Quality Assessment
BHP051

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1. Introduction

The proposed Olympic Dam Expansion would include construction of a Rock Storage Facility (RSF) to hold approximately 11.8 billion tonnes of rock that has no economic mineralization. In addition, a Low Grade Ore stockpile (LGS) would be constructed to store sub-economic or marginally economic ore during the operational period. The low grade ore contained in the LGS may or may not be processed during the operational period.

Both the RSF and the LGS would constitute significant new topographic features with the potential to have effects on the surrounding environment. Wrapping around the south, east and north sides of the proposed pit, the proposed RSF would be almost 14 km in total length and have an average width of about 4 km. The maximum height would be approximately 150 m above the regional area. The LGS would contain up to 709 million tonnes of low grade ore, and it would extend about 4 km in length and 3 km in width, with a maximum height of 150 m.

At the end of their operational life, the outer surfaces of both the RSF and the LGS would comprise cover sequence materials (i.e. all potentially reactive rocks from the basement sequence would be covered by the non-reactive cover sequence rocks).

Because of its size, runoff flows from the RSF may be significant and in responses to submissions received on the Draft EIS, detailed assessment of the potential quality of the runoff was undertaken.

This report provides an assessment of surface runoff and water quality that may occur from the RSF and the LGS. The assessment first reviews the physical processes that are expected to affect runoff and water quality, and then presents estimates of the runoff water quality that may occur during and after operations. The assessment draws on the outcomes of an evaluation of infiltration to the RSF, which are presented in a separate report (SRK 2010, Appendix F7 of the Supplementary EIS). Information relevant to the runoff water quality assessment are summarised herein. The runoff estimates together with the waste rock production schedule and solute release rates obtained from the geochemical characterisation program are then used to estimate solute concentrations in runoff for various rainfall events.

2. Approach

2.1 Runoff

Runoff from a soil surface occurs when the capacity of the soils to take up water is exceeded. The rate at which a soil can take in water is dependent on its properties, including grain size distribution, permeability and matric suction. A full treatment of those properties and the physical processes controlling infiltration requires a model that is quite complex. Such a model is presented by SRK in Appendix F7 of the Supplementary EIS and used to estimate long-term rates of infiltration into the RSF. As discussed therein, the accuracy of such estimates is highly dependent on the assumed material properties, which in the case of the RSF are not well characterized.

When the main interest is in runoff, a simpler form of infiltration modelling is normally adopted. The Green-Ampt method is one such simplification that was developed nearly 100 years ago and remains in wide usage for runoff calculations. It provides an explicit consideration of key soil properties and their effects on infiltration rates, without requiring numerical solution. This method was therefore adopted and is described in Section 3.

2.2 Water Quality

The quality of the runoff that would be generated from the RSF and the LGS would depend on a number of factors. Key factors include the following:

- **Type and area of rock exposed.** The various lithological units that would be stored in the RSF and the LGS differ in their geochemical make-up and the rate at which they react with meteoric waters. Therefore the total rates of solute release would depend on the types of rock that are exposed at surface, and the total area exposed to runoff water.
- **Evaporation.** The effects of evaporation are discussed in more detail in Appendix F7 of the Supplementary EIS, which identifies three phases of evaporation. In the RSF Phase 2 evaporation is likely to cause a reversal in water flows to the surface which would lead to the net transport of salts to the soil surface. The depth of Phase 2 evaporation that may contribute salt transport (or salt wicking) to the surface is dependant the soil properties of the materials but is typically about 1 metre.
- **Rate of weathering and solute release**. The rate of solute release would determine the amount of solutes that may accumulate on the surface between consecutive events that generate runoff.
- **Duration of exposure**. The time that the waste rock could be exposed for before it is covered by the next layer of material would indicate the maximum amount of solute that may be generated.
- **Period of accumulation**. The duration over which solutes are accumulated would depend on a number of factors including: i) the period between consecutive rainfall events that generate runoff, and, ii) the period between rainfall events where infiltration results in percolation. The second effect results in the removal of salts from the zone of evaporation (within which a net upward transport of solutes to the surface could occur) due to transport in percolating water to below the depth of influence of this zone.

Clearly the factors that may impact the solute release, transport to the surface and then release to runoff are complex.

As discussed later (Section 3), when rainfall occurs there is an initial short-term infiltration that occurs before ponding and run-off occurs. One approach to estimate the net solute release to the surface runoff would be to allow the initial infiltrating water to dissolve and remove salts from the surface of the RSF. The infiltrated water would remove the dissolved salts from contact with the subsequent runoff that may occur. This approach would be appropriate for salts that dissolve and reach equilibrium conditions rapidly (i.e. within the short timeframe that the initial abstraction would occur). Dissolution of only the most soluble salts, such as sodium chloride, could be expected to occur within the initial timeframe. Most salts would be expected to dissolve slowly, and may not even reach equilibrium conditions for the period that the water ponds on the surface before it is removed as runoff.

For the purpose of this assessment, the following simplified approach was adopted:

1. The schedule of placement was used to estimate i) the total area of exposure for each lithological unit, and ii) the maximum exposure time (before the surface is covered by a subsequent lift of material). These estimates (in units of years) were then used to calculate the area-weighted average maximum exposure times for each lithological unit for each year of operation.

2. The area of exposure was multiplied by the assumed depth of influence of the Phase 2 evaporation and multiplied with the bulk density to calculate the total mass of rock that could contribute to the salt loading at the surface through the salt wicking process. (The assumption is conservative as it does not allow for any salt transport out of the zone due to percolation. This also assumes that the salts are available at the surface instantaneously at the time the event occurs; in reality the wicking process would be slow and would depend on the frequency and intensity of rainfall events prior to the event that results in runoff.)

3. The solute release rates (in g/tonne/year) were corrected for the difference between the surface area of the samples as tested and the expected surface area of the run-of-mine rock.

4. The corrected solute production rates were then multiplied by the total mass of rock (in tonnes) that might contribute to the salt loading (step 2) and by the time weighted exposure (step 1) to determine the maximum possible solute release that could occur from each exposed lithological unit.

5. The total solute loading (estimated above) was then divided by the total volume of water that results from the rainfall event that could result in run-off.

The outcome of this approach would yield the maximum possible, or upper bound, estimate of concentrations that may occur in runoff from the RSF or the LGS.

The next section summarises the information that was used to support these calculations. The predicted runoff and water quality are presented and discussed in Section 4 of this report.

3. Input Data

3.1 Production Schedule

BHPBilliton generated a 'life-of-mine' waste rock production schedule showing the quantities of waste rock that would be produced from each lithological unit identified within the ultimate pit shell. Waste rock will be produced from the overburden or cover sequence and from the basement rocks. The major units that were included in the schedule are summarised in Table 3.1.

Table 3.1 Summary of Major Lithological Units Scheduled

ROCK UNIT	CODE
Overburden	
Andamooka Limestone	ZAL
Arcoona Quartzite Red	ZWAR
Arcoona Quartzite White	ZWAW
Corraberra Sandstone	ZWC
Tregolana Shale	ZWT
Basement	
Granite > 90%, Hematite < 10%	GRNB
Granite < 10%, Hematite > 90%	HEM
Volcanic components > hematite	VHEM
Hematite > 90% + quartz +or- Barite? no sulfide present	HEMQ

A summary of the production schedule is shown in Table 3.2. BHPBilliton then used that schedule to generate a three dimensional model of the RSF on a year by year basis, which allowed the estimation of the:

i) outer surface area of the RSF at any given time,

ii) proportion and area of exposure of each of the lithological units on the outer surface of the RSF at any given time; and,

iii) approximate time of exposure of the waste rock before it would be covered by a subsequent lift or layer.

The estimated schedule of exposure of each unit is summarised in Table 3.3. Detailed schedules of exposure and duration of exposure are provided in Appendix A.

A similar assessment was carried out for the low grade ore stockpile (LGS). The corresponding schedules for the LGS are summarised in Table 3.4 and Table 3.5 and the detailed results are provided in Appendix A.

These areas of exposure and duration of exposure were used to estimate the operational and post closure runoff water quality as described in Section 4.

Table 3.2 Summary of Rock Production Schedule

Production Year	Cover Units						Basement Units			
	Andamooka Limestone	Arcoona Quartzite (Red)	Arcoona Quartzite (White)	Corraberra Sandstone	Corraberra / Tregolana Transition	Tregolana Shale	Granite >90%, Hematite >10%	Granite <10%, Hematite >90%	Volcanic Rock > Hematite	Hematite>90%
	ZAL	ZWAR	ZWAW	ZWC	ZWC_ZWT	ZWT	GRNB	HEM	VHEM	HEMQ
1	51,560	-	-	-	-	-	-	-	-	-
2	82,810	2,710	-	-	-	-	-	-	-	-
3	154,370	19,930	-	-	-	-	-	-	-	-
4	102,650	280,090	-	-	-	-	-	-	-	-
5	1,120	371,010	42,080	30	-	-	-	-	-	-
6	186,210	41,980	41,130	52,720	94,140	26,440	-	-	-	-
7	81,390	95,140	-	-	12,470	166,940	9,620	810	13,310	2,540
8	8,320	198,500	64,670	30,330	67,610	14,970	2,390	380	4,930	780
9	130	161,500	12,020	150	13,140	123,970	35,420	110	11,700	15,410
10	-	186,530	111,170	28,660	39,430	710	570	50	3,040	1,130
11	-	-	470	5,520	57,380	135,460	55,160	1,620	15,880	22,170
12	-	-	16,290	27,830	15,170	62,350	109,580	1,830	3,100	5,580
13	-	-	4,870	11,660	85,430	79,560	82,300	14,010	-	960
14	113,760	17,790	-	-	-	108,140	21,690	640	9,110	69,830
15	6,930	77,520	-	-	-	1,450	32,250	2,120	33,010	102,800
16	-	69,070	-	-	-	-	36,240	2,700	38,210	81,890
17	-	125,970	4,350	-	-	-	24,970	2,320	34,480	62,100
18	136,160	132,980	6,260	-	-	-	6,840	1,200	12,800	29,300
19	1,220	95,700	34,670	34,230	95,530	73,450	2,510	610	4,240	20,480
20	-	64,270	9,670	-	-	141,760	57,040	1,570	700	8,220
21	-	27,430	47,350	37,140	77,090	14,190	47,280	110	1,320	-
22	102,260	-	-	-	13,500	146,020	23,600	1,480	3,540	13,710
23	81,410	3,080	-	-	-	2,150	56,780	6,140	19,340	95,320
24	52,340	150,570	-	-	-	-	24,700	2,160	12,710	72,390
25	-	232,380	340	-	-	-	18,080	11,930	22,210	70,890
26	-	92,440	96,280	53,430	22,180	10	18,890	9,040	18,420	27,090
27	-	-	-	2,330	141,020	213,570	10,750	1,660	6,870	9,300
28	48,780	-	-	-	-	109,040	76,130	3,930	3,950	16,510
29	68,590	90	-	-	-	-	76,830	11,430	15,110	30,100
30	137,390	370	-	-	-	-	42,890	12,510	7,690	57,040
31	840	205,820	-	-	-	-	24,800	9,450	1,180	57,720
32	35,570	190,920	-	-	-	-	19,300	11,580	2,260	43,830
33	-	129,410	106,580	40,680	23,490	-	8,000	12,690	3,140	20,170
34	65,650	-	-	15,210	149,760	110,410	7,470	9,460	7,620	6,890
35	-	-	-	-	-	249,300	43,370	11,970	7,030	4,280
36	39,330	31,210	-	-	-	9,900	105,330	9,590	1,160	290
37	-	85,530	16,350	6,610	70	-	85,590	8,900	750	1,920
38	-	50	12,700	20,280	61,050	51,130	50,860	12,240	700	4,770
39	-	-	-	-	-	99,220	123,220	11,350	740	4,310
40	52,130	-	-	-	-	-	124,810	10,610	520	3,150

Table 3.3 Summary of Estimated Schedule of Lithological Surface Exposure on the RSF

	Area of Rock Unit Exposed (Ha)										
Year	**ZAL**	**ZWAR**	**ZWAW**	**ZWC**	**ZWC_ZWT**	**ZWT**	**GRNB**	**HEM**	**VHEM**	**HEMQ**	**Total**
1	83	0	0	0	0	0	0	0	0	0	83
2	216	4	0	0	0	0	0	0	0	0	220
3	463	36	0	0	0	0	0	0	0	0	499
4	628	480	0	0	0	0	0	0	0	0	1108
5	444	1064	68	0	0	0	0	0	0	0	1576
6	451	1075	134	88	147	40	0	0	0	0	1934
7	508	1006	134	88	167	291	14	1	18	2	2229
8	445	1092	230	139	272	313	18	1	25	3	2538
9	443	1129	189	139	293	500	71	1	41	17	2822
10	434	1078	361	169	337	501	71	1	45	18	3016
11	304	1058	342	151	347	695	154	3	67	38	3158
12	214	1028	338	164	340	759	317	4	71	43	3279
13	144	967	336	174	434	827	425	16	53	42	3419
14	226	925	336	174	434	840	457	17	65	105	3580
15	203	1003	312	163	409	777	501	19	103	198	3689
16	194	1013	282	123	400	770	555	21	156	273	3787
17	194	1083	239	123	346	770	593	23	203	329	3902
18	412	1157	230	123	308	717	550	24	204	342	4068
19	414	1078	267	164	447	693	553	25	206	359	4206
20	414	1075	152	132	396	906	638	26	207	367	4313
21	414	969	199	194	516	927	634	25	187	347	4412
22	578	969	198	185	448	943	639	24	187	354	4526
23	709	974	179	161	430	893	583	30	214	441	4612
24	793	1212	164	119	390	793	497	19	231	506	4724
25	750	1553	165	119	291	695	492	29	249	507	4850
26	610	1699	319	208	325	570	489	36	247	473	4977
27	599	1530	319	212	546	889	434	35	186	372	5122
28	678	1395	312	212	546	1053	510	36	145	330	5217
29	780	1256	302	212	546	1053	614	46	148	331	5288
30	861	1128	302	212	546	1053	678	57	158	383	5378
31	789	1352	282	190	501	1025	711	65	154	417	5486
32	846	1556	247	155	419	943	740	75	157	457	5596
33	846	1664	402	223	433	780	667	86	161	467	5728
34	951	1594	326	187	594	874	607	94	169	474	5871
35	858	1594	326	187	526	1116	637	104	174	465	5986
36	850	1644	326	187	526	1045	778	107	159	439	6060
37	765	1774	352	198	526	1041	837	115	150	381	6138
38	687	1736	373	231	621	1118	875	124	134	319	6218
39	636	1536	373	231	621	1268	1059	123	135	323	6304
40	1006	1733	658	518	907	1554	0	0	0	0	6376

Table 3.4 Summary of Low Grade Ore Production Schedule

Year	Production (Tonnes per annum)			
	GRNB	HEM	VHEM	HEMQ
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	2,454,015	1,016,571	3,898,790	1,769,976
7	1,291,090	433,970	2,988,502	1,417,928
8	4,473,648	446,182	2,412,996	2,138,661
9	2,142,521	624,479	2,231,131	1,867,220
10	8,474,550	1,969,427	3,870,808	3,635,266
11	16,155,796	2,496,733	4,572,345	7,394,544
12	13,736,256	258,229	-	206,002
13	4,261,442	642,755	628,032	1,540,235
14	7,520,857	1,384,858	4,668,175	3,787,816
15	10,027,013	1,229,943	6,025,329	7,861,873
16	11,840,317	1,402,703	7,505,881	4,831,237
17	4,029,998	1,553,057	3,352,895	3,177,885
18	3,469,048	888,567	648,790	2,616,388
19	28,416,970	1,422,118	-	1,508,933
20	42,176,223	801,002	387,474	-
21	16,308,122	780,420	2,331,387	14,690
22	14,935,236	3,056,031	3,726,335	3,034,706
23	16,498,217	902,878	1,197,207	6,639,810
24	11,737,659	3,144,934	2,114,314	5,402,064
25	11,327,767	3,445,500	3,249,298	1,581,906
26	8,186,247	1,333,438	2,857,776	2,771,751
27	13,117,834	4,732,887	1,829,999	5,189,563
28	16,751,728	5,022,005	1,430,012	5,462,451
29	11,584,877	5,143,183	371,986	4,321,276
30	7,333,632	6,592,031	79,417	7,752,663
31	8,610,640	7,226,014	324,150	7,822,686
32	7,598,539	5,819,840	750,926	7,368,594
33	8,968,675	7,757,363	1,945,115	4,865,812
34	13,515,560	4,446,172	1,298,829	2,708,298
35	20,586,869	3,541,644	96,822	1,397,325
36	20,395,896	3,035,250	89,432	2,423,594
37	17,578,334	3,713,074	241,925	3,842,766
38	14,583,712	2,505,175	182,991	3,244,622
39	13,452,261	2,569,776	131,641	3,147,359
40	8,999,283	2,591,489	316,535	2,344,045

Table 3.5 Summary of Estimated Schedule of Lithological Surface Exposure on the LGS

Year	Surface Area (Ha)			
	GRNB	HEM	VHEM	HEMQ
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	36,519	9,245	53,184	16,096
8	55,732	13,191	93,951	28,991
9	122,305	17,249	126,867	48,440
10	154,189	22,928	157,302	65,421
11	280,301	40,838	210,104	98,480
12	520,719	63,544	272,476	165,727
13	725,131	65,892	272,476	167,600
14	788,547	71,737	281,043	181,608
15	900,467	84,331	344,722	216,054
16	1,049,681	95,517	426,915	287,551
17	1,225,880	108,273	529,303	331,487
18	1,285,851	122,397	575,041	360,387
19	1,337,475	130,477	583,891	384,180
20	1,760,355	143,410	583,891	397,903
21	2,387,989	150,695	589,177	397,903
22	2,630,675	157,792	620,979	398,036
23	2,852,930	185,584	671,811	425,634
24	3,042,712	180,603	624,191	457,026
25	3,160,809	205,146	590,117	486,704
26	3,271,385	212,890	604,006	484,109
27	3,381,207	225,017	590,187	476,256
28	3,478,416	268,058	587,778	492,204
29	3,642,285	291,023	572,285	505,880
30	1,760,355	143,410	583,891	397,903
31	3,674,403	395,396	578,443	613,808
32	3,692,540	455,265	574,298	675,941
33	3,730,281	495,597	570,862	723,505
34	3,798,746	566,143	547,396	747,755
35	3,930,659	595,392	532,921	740,888
36	4,152,018	627,600	484,242	713,596
37	4,364,335	642,446	433,073	711,700
38	4,530,923	676,213	386,373	726,647
39	4,700,975	684,872	343,132	727,254
40	Cover materials 6,584,859			

3.2 Rock Geochemistry

A geochemical characterisation program was completed by ENSR/AECOM in 2008, as summarised by SRK in Appendix K5 of the Draft EIS, on the samples of rock representative of waste rock that would be produced from the proposed Olympic Dam open pit mine.

The selection of the samples considered the rock classification and production schedule. An objective of that assessment was to determine the potential for the waste rock to leach and release contaminants. Therefore, the assessment included a series of small scale weathering tests to determine solute release rates from each rock type. The tests were continued for a period of 174 weeks and the leachate properties were used to estimate average solute release rates from each lithological type.

In general the kinetic leach tests indicated that:

- None of the cover materials are potentially acid generating.
- None of the samples tested became acidic within the more than three years testing period.
- Release rates of major ions (predominantly sodium chloride) initially were elevated, potentially due in part to saline porewater contained in the samples. The release rates generally decreased rapidly within the first five or six cycles of testing to low values indicating wash-out of contained salts with little or no ongoing production. It should be noted that the tests completed on the cover or overburden sequence of materials were terminated after about 6 cycles and the production rates calculated for these materials are therefore skewed toward the early flushing rather than the longer term production rates.
- Some parameters, including sulphate, were elevated due to pre-existing minerals (e.g. gypsum) and weathering products that accumulated prior to testing. For these parameters the production rates would tend to over estimate the actual rates of production from primary mineral weathering.
- Release rates of trace elements generally tended to decrease over time.
- Leachates from overburden materials generally do not contain elevated concentrations of solutes, apart from initial release of salinity from either saline porewater and/or drilling fluids that contacted the samples.
- Leachates from granitic material contain detectable concentrations of copper, molybdenum and uranium.
- Leachates from hematitically altered materials contain detectable concentrations of arsenic, and molybdenum.
- Volcanic and epiclastic materials produce leachates with higher sulphate, aluminium, arsenic, copper, iron, manganese and zinc relative to other materials tested.

The estimated average solute release rates are summarised in Table 3.6.

Table 3.6 Solute Release Rates Estimated for Kinetic Leach Tests (Average for 172 weeks)

Parameter	**Average Solute Release Rate (g/t/year)**								
	ZAL	**ZWAR**	**ZWAW**	**ZWC**	**ZWC_ZWT**	**ZWT**	**GRNB**	**HEM**	**HEMQ**
Total Alkalinity as CaCO3	170	89	24	52	112	112	86	38	63
Sulphate	45	138	59	216	84	84	62	24	25
Chloride	87	51	29	644	256	256	21	120	60
Fluoride	0.7	1.2	0.4	0.5	0.5	0.5	9.7	1.4	3.1
Calcium	12	7	2	29	16	16	12	14	13
Magnesium	7	3	2	27	15	15	8	4	5
Sodium	101	117	62	545	167	167	33	83	45
Potassium	2	11	2	7	8	8	19	8	5
Iron	0.043	4.134	1.405	0.655	8.571	8.571	0.480	0.364	0.307
Aluminium	0.238	4.292	1.858	0.490	7.838	7.838	0.806	0.363	0.209
Antimony	0.002	0.002	0.003	0.002	0.002	0.002	0.006	0.016	0.033
Arsenic	0.002	0.003	0.005	0.002	0.065	0.065	0.092	0.344	0.572
Barium	0.120	0.538	0.870	0.308	0.803	0.803	1.068	2.709	2.646
Cerium	0.002	0.013	0.041	0.006	0.017	0.017	0.010	0.024	0.029
Cobalt	0.002	0.003	0.002	0.002	0.005	0.005	0.012	0.005	0.008
Copper	0.006	0.030	0.026	0.004	0.076	0.076	0.105	0.024	0.052
Lanthanum	0.002	0.006	0.022	0.002	0.007	0.007	0.007	0.014	0.016
Lead	0.002	0.017	0.005	0.009	0.026	0.026	0.021	0.005	0.007
Manganese	0.008	0.256	0.208	0.047	0.386	0.386	0.158	0.034	0.062
Molybdenum	0.009	0.003	0.007	0.002	0.004	0.004	0.361	0.169	0.274
Nickel	0.002	0.008	0.002	0.002	0.010	0.010	0.018	0.028	0.020
Silicon	1.0	4.9	3.5	0.9	5.2	5.2	2.1	1.1	1.2
Strontium	0.093	0.103	0.041	0.514	0.269	0.269	0.112	0.508	0.196
Thorium	0.002	0.002	0.002	0.002	0.002	0.002	0.006	0.004	0.004
Uranium	0.002	0.018	0.002	0.002	0.003	0.003	0.038	0.004	0.004
Yttrium	0.002	0.015	0.002	0.006	0.003	0.003	0.010	0.015	0.007
Zinc	0.009	0.104	0.075	0.025	0.065	0.065	0.089	0.047	0.087

Source: AECOM, 2010 – presented as Appendix F6 of Supplementary EIS

4. Runoff Predictions

4.1 Runoff Frequency and Volume Estimates

4.1.1 Method

The proportion of a storm's precipitation that becomes runoff is a function of the precipitation intensity and duration, and the properties of the ground surface. When the rate of precipitation exceeds the ability of the ground surface to take in water, ponding occurs. Once the ponds or puddles become inter-connected, runoff is possible. If the precipitation continues at sufficient intensity for a sufficiently long duration, runoff can be substantial.

The Green-Ampt method, developed nearly 100 years ago and remaining in wide usage, was adopted for estimating runoff. It provides an explicit consideration of key soil properties and their effects on infiltration rates, without requiring numerical solution.

The Green-Ampt method assumes that rainfall produces a front of water moving into the soil. Above the water front, the soil is assumed to be saturated; and below it is assumed to be unsaturated at a constant water content. The driving forces for the downward movement of the wetting front are gravity, the head imposed by surface ponding, and the matric suction extorted by the soil just below the wetting front. Putting those assumptions into Darcy's law allows solutions to be derived for many different parameters of interest. The common formulation for infiltration estimates is:

$$I = \frac{\lfloor(\theta_s - \theta_i)\psi_f\rfloor}{[(p/K_s - 1)]}$$

Where:

I is the total amount of water infiltrated (cm),
p is the rainfall rate (cm/s),
K_s is the saturated hydraulic conductivity (cm/s),
Ψ_f is the matric suction at wetting front,
θ_i is the initial moisture content (dimensionless) and
θ_s is the saturated moisture content (dimensionless).

Similar to the more complex model used in Appendix F7 of the Supplementary EIS, the Green-Ampt formulation also includes material properties (K_s and θ_s) and parameters dependent on material properties (Ψ_f and θ_i) that, in the case of the RSF, are not well characterised. As discussed further below, that limitation restricts the accuracy of any of the estimates presented herein.

Estimating infiltration is only part of the runoff calculation. The complete sequence of calculations was as follows, for precipitation events of various intensity and duration:

- Estimate the precipitation intensity (p) and the total precipitation (P);
- Estimate the amount "lost" to infiltration (I) by the Green-Ampt method; and
- Assume the remainder is available for runoff (R=P-I).

4.1.2 Precipitation Inputs

Precipitation intensities for various storm durations were estimated from the project's design rainfall intensity chart. The selected values are shown in Table 4.1. The total precipitation associated with each event was estimated by multiplying precipitation intensity by duration. Results are shown in Table 4.2.

Table 4.1 Precipitation intensities (mm/hr) for various storm durations and return periods

Return Period (yrs)	Storm duration (hours)							
	0.083	**1**	**2**	**6**	**12**	**24**	**48**	**72**
1	42.2	12	7.2	3	1.8	1.1	0.6	0.42
2	56	17	10	4.2	2.5	1.5	0.9	0.6
5	74	25	15	7.5	3.3	2.4	1.3	0.9
10	95	30	20	8.2	4.4	2.8	1.6	1.1
20	122	38	24	11	5.8	3.6	2.0	1.5
50	172	50	31	14	8.3	4.8	2.7	1.80
100	204	60	37	17	10.1	6.0	3.1	2.16
500	395	110	65	32	22.7	9.0	5.0	3.34

Table 4.2 Total precipitation (mm) for various storm durations and return periods

Return Period (yrs)	Storm duration (hours)							
	0.083	**1**	**2**	**6**	**12**	**24**	**48**	**72**
1	3.5	12.0	14.4	18.0	21.6	26.4	28.8	30.2
2	4.7	17.0	20.0	25.2	30.0	36.0	40.8	43.2
5	6.2	25.0	30.0	45.0	40.1	57.6	62.4	64.8
10	7.9	30.0	40.0	49.2	52.9	67.2	76.8	79.2
20	10.1	38.0	48.0	66.0	69.8	86.4	96.0	108.0
50	14.3	50.0	62.0	84.0	100.1	115.2	129.6	129.6
100	17.0	60.0	74.0	102.0	121.2	144.0	148.8	155.5
500	32.9	110.0	130.0	192.0	272.4	216.0	240.0	240.5

4.1.3 Assumed Material Properties

Appendix F7 of the Supplementary EIS describes the many factors that could influence the physical properties of the RSF surface and the associated difficulty in a priori selection of model parameters. That report adopts four sets of physical properties selected from literature to represent the range of possible RSF surface materials:

- Material 1 is one of the coarsest soils in a recent collection of material properties for well-characterized soils (Perkins and Nimmo, 2009). It is a clean sandy gravel with very low fines content, and is expected to be representative of durable waste rock that undergoes little abrasion or weathering.
- Material 2 is a gravel-sand-silt mixture obtained from the sandstone waste pile at the Cluff Lake Mine in northern Canada, which has been the subject of extensive research by two Canadian universities. It is expected to be representative of brittle sedimentary rock subjected to abrasion and traffic compaction.
- Material 3 is a gap graded sand with minor gravel and minor fines. It was selected from the Perkins and Nimmo (2009) data set to represent rapidly weathering sedimentary materials, such as some of the shales expected to be placed in the RSF.
- Material 4 is a silty sand selected from the Perkins and Nimmo (2009) data set to represent a blend of the dune sand and clay pan materials covering the surface of the project area.

The parameters used to represent each material in the Green-Ampt calculations are shown in Table 3. Other properties are summarized in Appendix F7 of the Supplementary EIS.

The values of matric suction at the wetting front shown in Table 4.3 are not fundamental parameters. In many applications, users of the Green-Ampt method select these parameters from tables of values fitted to field data. However, those tables have been developed for agricultural or urban runoff applications and do not include materials as coarse as is expected to be on the RSF surface. The matric suction values shown in Table 4.3 were therefore obtained from each material's soil-water characteristic curve. They correspond to the upper inflection points on the soil water characteristic curves, which are sometimes referred to as "air entry values". The soil water characteristic curves are also presented in Appendix F7 of the Supplementary EIS.

Table 4.3 Parameters used to characterize RSF surface materials in Green-Ampt calculations

Property		Material 1	Material 2	Material 3	Material 4
		Sandy Gravel	Gravel-Sand-Silt Mixture	Poorly Graded Gravel with Sand	Sandy Silt
Saturated hydraulic conductivity K_s	m/d	0.4752	2.3	1.42	5.25E-03
	cm/s	5.50E-04	2.66E-03	1.64E-03	6.08E-06
	mm/hr	19.8	95.8	59.2	0.22
Matric suction at wetting front ψ_f	kPa	0.3	1.5	1.5	8
	cm	3.1	15.3	15.3	81.6
	mm	30.6	153.0	153.0	815.8
Saturated moisture content θ_S		0.39	0.24	0.31	0.35
Eff. Saturation before storm S_i		0.25	0.5	0.17	0.5
Moisture content before storm θ_i		0.0975	0.12	0.0527	0.175
Available storage (θ_S - θ_i)		0.2925	0.12	0.2573	0.175

4.1.4 Results

Table 4.4 to Table 4.7 present the results from the runoff calculations. Each table shows the potential runoff for one material type subjected to the range of precipitation durations and intensities shown in Table 4.1. The first column shows the average return intervals for each set of storm durations and intensities. "NP" in the tables indicate that the material is able to take in water at a rate that exceeds the storm intensity, meaning that "no ponding" is expected, and therefore no runoff.

The patterns in the results can be best understood by starting with Table 4.5 and Table 4.6, showing results for Materials 2 and 3, respectively. Materials 2 and 3 both have very high hydraulic conductivity, and are therefore not expected to produce runoff except in extremely intense storms. Such storms would be of limited duration, five minutes (0.083 hr)to one hour, and would occur only very infrequently, once every 500 years.

Table 4.4, on the other hand, shows runoff predicted more frequently and in storms of longer duration. The lower hydraulic conductivity of Material 1 is the main reason for the difference. Table 4.4 shows a potential for minor runoff even in 1-in-10-year storms, and significant runoff potential for storms of 1-2 hours duration and 20-100 year return periods. More extreme events are also expected to generate runoff. Notably though, even the 500-year 24-hour event is expected to be taken in by the soil surface and produce no runoff.

Material 4 is representative of some of the dune sand and clay plan materials that would be stripped from the pit surface. As Table 4.7 shows, its lower hydraulic conductivity would lead to a significant potential for runoff even in storms with return periods of 10 years or less.

Table 4.4 Runoff estimates (mm) for Material 1, sandy gravel with little or no fines

Return	Storm duration (hours)							
Period (yrs)	**0.083**	**1**	**2**	**6**	**12**	**24**	**48**	**72**
1	NP	NP	NP	NP	NP	NP	NP	NP
2	NP	NP	NP	NP	NP	NP	NP	NP
5	2.9	NP	NP	NP	NP	NP	NP	NP
10	5.6	12.6	NP	NP	NP	NP	NP	NP
20	8.4	28.3	5.8	NP	NP	NP	NP	NP
50	13.2	44.1	46.2	NP	NP	NP	NP	NP
100	16.0	55.6	63.7	NP	NP	NP	NP	NP
500	32.4	108.0	126.1	177.5	211.3	NP	NP	NP

Note: NP = no ponding

Table 4.5 Runoff estimates (mm) for Material 2, gravel-sand-silt mixture

Return	Storm duration (hours)							
Period (yrs)	**0.083**	**1**	**2**	**6**	**12**	**24**	**48**	**72**
1	NP	NP	NP	NP	NP	NP	NP	NP
2	NP	NP	NP	NP	NP	NP	NP	NP
5	NP	NP	NP	NP	NP	NP	NP	NP
10	NP	NP	NP	NP	NP	NP	NP	NP
20	NP	NP	NP	NP	NP	NP	NP	NP
50	NP	NP	NP	NP	NP	NP	NP	NP
100	0.7	NP	NP	NP	NP	NP	NP	NP
500	27.0	NP	NP	NP	NP	NP	NP	NP

Note: NP = no ponding

Table 4.6 Runoff estimates (mm) for Material 3, poorly graded sand with gravel

Return	Storm duration (hours)							
Period (yrs)	**0.083**	**1**	**2**	**6**	**12**	**24**	**48**	**72**
1	NP	NP	NP	NP	NP	NP	NP	NP
2	NP	NP	NP	NP	NP	NP	NP	NP
5	NP	NP	NP	NP	NP	NP	NP	NP
10	NP	NP	NP	NP	NP	NP	NP	NP
20	NP	NP	NP	NP	NP	NP	NP	NP
50	NP	NP	NP	NP	NP	NP	NP	NP
100	0.9	NP	NP	NP	NP	NP	NP	NP
500	26.0	64.2	NP	NP	NP	NP	NP	NP

Note: NP = no ponding

Table 4.7 Runoff estimates (mm) for Material 4, silty sand

Return	Storm duration (hours)							
Period (yrs)	0.083	1	2	6	12	24	48	72
1	2.8	9.3	9.9	6.8	1.9	NP	NP	NP
2	4.1	15.1	16.8	17.4	16.3	11.6	NP	NP
5	5.8	23.7	27.9	40.7	30.1	43.3	33.5	19.0
10	7.6	29.0	38.4	45.3	45.4	55.1	54.2	43.8
20	9.9	37.2	46.7	63.1	64.2	77.2	78.5	83.6
50	14.2	49.4	61.0	81.7	96.2	108.4	117.0	109.9
100	16.8	59.5	73.2	100.1	118.0	138.6	138.0	139.4
500	32.8	109.7	129.5	191.0	271.0	212.4	233.5	230.5

Note: NP = no ponding

4.1.5 Discussion

SRK points out, in Appendix F7 of the Supplementary EIS, the difficulty in estimating the surface properties of the RSF, but suggests that as a “best current estimate”, it would be reasonable to assume that about 50% of the RSF surface material would behave similarly to Material 2 or 3, and the other half similarly to Material 1.

Under that assumption, there would be no runoff from the half of the RSF surface with properties similar to Materials 2 or 3, except in very brief and very intense storms with return periods of 500 years or more. Even then, the runoff amounts would be small enough (25-65 mm) that they could be controlled by minor texturing of the RSF surface.

Runoff would occur more frequently from the portion of the RSF surface with properties similar to Material 1. In events up to a 100-year return period, runoff amounts would be small enough (15-65 mm) to be largely controlled by surface texturing. Larger events would either need to be stored in swales created on the RSF surface or would flow into the dune catchments along the RSF toe.

For assessing the potential impacts of runoff contamination on the surrounding catchments, it would be reasonable to consider the 20-year 1-hour or 50-year 2-hour storms. Those storms are estimated to produce runoff amounts that, in the absence of control measures, would be sufficient to find their way to the catchments along the RSF toe. Those storms are also frequent enough to be reasonably foreseeable within the mine life, but rare enough to allow for considerable build-up of evaporate salts in the intervening periods.

Material 4 is representative of sand dune and clay pan material that would only end up on the RSF surface if it were mined and placed with the underlying soils and the Andamooka limestone (i.e. as part of the overburden sequence) in the waste rock dump, or if it were stockpiled after being stripped from the pit area, and then spread as a cover on completed portions of the RSF. The material’s propensity to generate runoff would need to be taken into account before it is considered for use as a cover. However, any runoff generated from Material 4 should be clean.

It should be noted that the soils and weathered overburden above the Andamooka Limestone formation is not accounted for as a separate unit or material type within the resource and mine waste block model for the project. In the infiltration modelling (in Appendix F7 of the Supplementary EIS), this material type (Material 4) was excluded as a surface material on the RSF to ensure a conservative approach. However, from a runoff volume perspective, the presence of these materials could result in much higher runoff and exclusion of this material type may not necessarily lead to a conservative assessment of runoff volumes. Therefore, as described in the next section two approaches were adopted to estimate runoff water quality. The first approach (Case 1) is consistent with the assumptions adopted for the infiltration modelling whereas the second (Case 2) considers the potential effects of higher runoff that may result from the presence of the overburden soils and sediments within the ZAL unit.

4.2 Production Period Runoff Water Quality Estimates

4.2.1 Constraints and Assumptions

A spreadsheet model was developed to estimate the potential water quality that may result for various runoff conditions, based on the approach described in the previous chapter. The input variables include the following:

- Storm return period
- Storm duration
- Accumulation time for solutes (i.e. period preceding the event over which solutes accumulated)
- Depth of salt movement to surface

As noted before, the different material types would not all yield equal amounts of runoff. The material type selections to represent the various lithological units for the two approaches are shown in Table 4.8.

Table 4.8 Summary Material Type Assignments

Category	Code	Lithology	
		Case 1 – Low Runoff	Case 2 – High Runoff
Cover Sequence			
Material Type 4	ZAL	-	Sand and Andamooka Limestone (1, 2)
Material Type 3	ZWT	Tregolana Shale (7, 8) Sand and Andamooka Limestone (1, 2)	Tregolana Shale (7, 8)
Material Type 2	ZWC	Corraberra Sandstone (5)	Corraberra Sandstone (5)
	ZWC_ZWT	Sandstone	Sandstone
Basement Sequence			
Material Type 1	ZWAR	Arcoona Quartzite Red (3)	Arcoona Quartzite Red (3)
	ZWAW	Arcoona Quartzite White (4)	Arcoona Quartzite White (4)
	GRNB	Granite Breccia (9)	Granite Breccia (9)
	HEM	Hematite Breccia (10)	Hematite Breccia (10)
	VHEM	Volcanic Breccias (11, 12, 14, 15, 16, 17, 18)	Volcanic Breccias (11, 12, 14, 15, 16, 17, 18)
	HEMQ	Silicic Hematite Breccia (13)	Silicic Hematite Breccia (13)

(Numbers in brackets indicate kinetic test identification number used to derive solute production rates)

In general, the initial calculations indicated that for fixed terms of solute accumulation and fixed depths of contribution, generally the higher the return period the lower the solute concentrations for any given material type that generates runoff. The calculations also show that the deeper the zone of accumulation contributing to solute release, the higher the resultant concentrations.

The depth of leaching (i.e. the depth of rock for which upward water flux could occur) that could contribute to the salt loading to the surface would depend on the period during which no precipitation occurs. During this period, evaporation near the surface would ‘draw’ water from lower down which would then carry salts from lower down. The longest period in the rainfall record without precipitation is about 353 days. The infiltration model (see Appendix F7 of the Supplementary EIS) indicated that during that period, the evaporation would have been about 50 mm (the range for the four material types is 48-53 mm).

Using the field moisture capacity estimates for the material types, the minimum depth to supply 50 mm of evaporation would be as follows:

- Material 1: 0.6 m
- Material 2 : 0.6 m

- Material 3 : 1.6 m
- Material 4 : 0.3 m

The material types that best represent the rock types that would be placed in the RSF are Material types 1, 2 and 3, with the majority represented by types 1 and 2. Therefore, as a simplifying assumption for the purpose of this assessment an average depth of influence of 1 m was adopted.

The high salinity production rates estimated for the cover sequence materials generally result in very high concentration estimates that cannot be sustained by the solids content of the materials in the longer term (i.e. for example Na release could exceed the initial solids content of the materials). As noted before, the kinetic tests for the cover sequence materials were terminated early and as a result, the production rates are unduly influenced by the initial flush and the actual longer term release rates would be expected to be much lower. The kinetic tests completed on the cover sequence materials were run for six flush cycles, which equates to about 24 weeks of testing. The results for the longer term tests carried out on the basement sequence materials generally indicate that the salinity is flushed from the materials within about 20 cycles of flushing, or the equivalent of 40 weeks of testing. These results indicate that even under the high rates of flushing of the test conditions not all of the salinity is available for instantaneous mobilisation, and that multiple flush events were required to mobilise the salinity. Therefore, single rainfall events would be unlikely to mobilise all of the salinity that may be present in the material.

Nevertheless, for the purpose of this assessment conservatively it was assumed that the maximum period of solute accumulation that could occur for the cover sequence materials at any given time during the operational period is 1 year (based on the rainfall records), and that all of this salinity will be available for dissolution during any given rainfall event. This is very conservative since it is likely not all of the salinity would be equally available for all surfaces at all times during the operational period due to the placement sequence.

The initial calculations also showed that the concentrations of some solutes (e.g. Fe, Ba, etc.) may exceed solubility limits. Therefore, solubility limits similar to those calculated for the RSF percolate were adopted and imposed as necessary. A summary of these is provided in Table 4.9 and were determined for atmospheric conditions. In addition, the calculations allowed for the formation of gypsum (and the removal of Ca and SO4) where its solubility was exceeded.

Table 4.9 Estimated Solubility Limits

Parameter	Maximum Concentration (mg/L)
Total Alkalinity as $CaCO_3$	160
Iron	0.20
Aluminium	0.20
Arsenic	0.060
Barium	0.010
Copper	0.12
Lead	0.010
Nickel	0.15
Thorium	0.001
Uranium	0.30
Total Phosphorus	0.033

As discussed in Section 4.1 runoff would not occur for all materials types under all conditions. For example, the Material Type 4 classed surfaces (e.g. comprising the sand and Andamooka Limestone (ZAL) materials) would be expected to generate runoff fairly readily, with runoff occurring for an event with a 1 year return period. The as a peak runoff would occur for the 2 hour duration event, whereas the highest concentrations would occur for a 0.083 hour (5 minute) event. Materials represented by Material Type 2 and Type 3 (Tregolana Shale; sandstone) on the other hand would be least likely to generate runoff and would require a 1:100 year event before any runoff could be generated.

Runoff flows and water quality estimates for the RSF for various events are presented and discussed in the next section.

4.2.2 RSF Runoff and Water Quality

4.2.2.1 Case 1: Low Runoff

The estimated runoff volumes that would be generated by 0.083 hour events for any given return period are illustrated in Figure 4.1and that for 2 hour events are shown in Figure 4.2. The figures represent the volume of water that would be generated as runoff for any given even within the given year and reflects the surface area exposure for the RSF at the time. The results indicate that for return periods of less than 1:5 years, no runoff would be expected to occur. However, for 1:5 and longer return periods runoff would be observed, and would occur primarily from the materials that are represented by Material Type 1.

As noted in the infiltration modelling it is possible that surface undulations would preclude runoff in many cases. Furthermore, flow from one are that would support runoff could be partially or totally lost within another area of material exposure that would not support runoff. These estimates represent upper bound flows and, consequently, the comparatively small volumes of runoff that would be generated by the short duration events (0.083 hour) may in fact not leave the surface of the RSF. The longer duration events would lead to significantly higher volumes of water, but as with the shorter duration events not all of the water would flow from the surface of the RSF.

The estimated water quality results for the low runoff case, which is consistent with the assumptions for the infiltration modelling, are summarised in Table 4.10 for short duration storm events (0.083 hours or 5 minutes) at various return periods. Note that the period of accumulation was set to 0.5 years (or 6 months) for the 1:1 and 1:2 year return periods as it is unlikely that for such a short return periods all of the solutes produced within 1 year would have migrated to surface. For the longer return periods a maximum period of accumulation of 1 year was adopted as the longest dry period (without rain) on record for the site is in the order of about 353 days.

As shown in Figure 4.3 the salinity release (as indicated by the chloride concentration) would decrease from year to year for the first few years, and then remain approximately constant for the remainder of the period. The peak concentration of other solutes related to oxidation reactions generally would peak later in about Year 24 as shown by the sulphate concentration profile given in Figure 4.4. These trends repeat for all the events with a return period greater than 1:5 years, albeit at lower peak concentrations.

It is important to note that these estimates assume that only one such event occurs in any given year and that all the solutes generated during that period report to the runoff. Multiple events would lead to correspondingly lower concentrations.

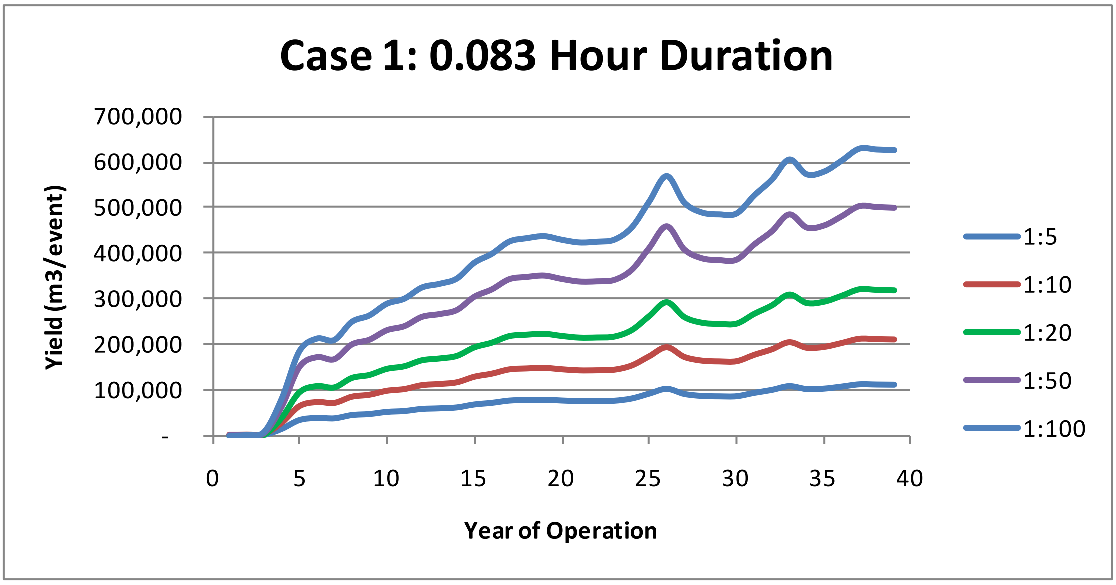

Figure 4.1 Estimated Runoff Volumes for Case 1 Storm Events of 0.083 Hour Duration

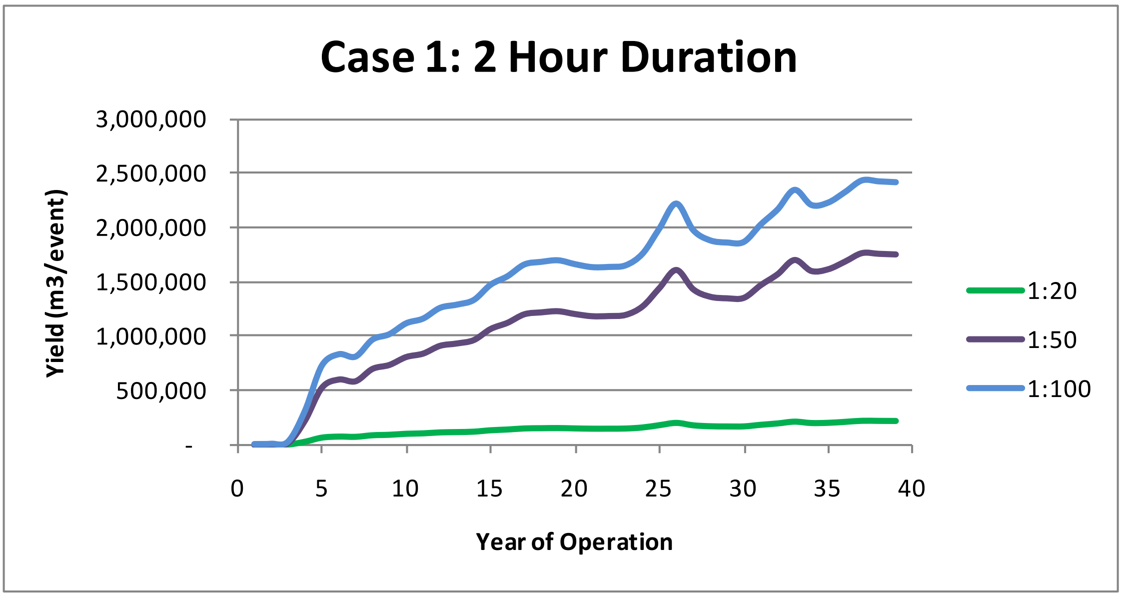

Figure 4.2 Estimated Runoff Volumes for Case 1 Storm Events of 2 Hour Duration

Table 4.10 Summary of Estimated Low Runoff Case RSF Water Quality During Operations for Events of 0.083 hour Duration

Input Variable	**Units**	**Value**						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence		1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentration**						
pH		n/r	n/r	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
Alkalinity as $CaCO_3$	(mg/L)	n/r	n/r	161	161	161	161	161
Sulphate	(mg/L)	n/r	n/r	8001	6511	5328	4081	3304
Chloride	(mg/L)	n/r	n/r	5445	4273	3342	2361	2097
Fluoride	(mg/L)	n/r	n/r	339	265.8	207.9	146.8	119.5
Silicon	(mg/L)	n/r	n/r	17.4	17.4	17.4	17.4	17.4
Calcium	(mg/L)	n/r	n/r	450	450	450	450	401
Magnesium	(mg/L)	n/r	n/r	475	373	292	206	180
Sodium	(mg/L)	n/r	n/r	8119	6372	4984	3520	2882
Potassium	(mg/L)	n/r	n/r	908	713	557	394	327
Iron	(mg/L)	n/r	n/r	0.200	0.200	0.200	0.200	0.200
Aluminium	(mg/L)	n/r	n/r	0.200	0.200	0.200	0.200	0.200
Antimony	(mg/L)	n/r	n/r	1.681	1.319	1.032	0.729	0.594
Arsenic	(mg/L)	n/r	n/r	0.060	0.060	0.060	0.060	0.060
Barium	(mg/L)	n/r	n/r	0.010	0.010	0.010	0.010	0.010
Cerium	(mg/L)	n/r	n/r	2.020	1.585	1.240	0.876	0.723
Cobalt	(mg/L)	n/r	n/r	3.218	2.525	1.975	1.395	1.137
Copper	(mg/L)	n/r	n/r	0.120	0.120	0.120	0.120	0.120
Lanthanum	(mg/L)	n/r	n/r	1.102	0.865	0.676	0.478	0.393
Lead	(mg/L)	n/r	n/r	0.010	0.010	0.010	0.010	0.010
Manganese	(mg/L)	n/r	n/r	17.6	13.8	10.8	7.67	6.10
Molybdenum	(mg/L)	n/r	n/r	18.1	14.2	11.1	7.84	6.36
Nickel	(mg/L)	n/r	n/r	0.150	0.150	0.150	0.150	0.150
Strontium	(mg/L)	n/r	n/r	4.800	4.800	4.800	4.800	4.800
Thorium	(mg/L)	n/r	n/r	0.001	0.001	0.001	0.001	0.001
Uranium	(mg/L)	n/r	n/r	0.300	0.300	0.300	0.300	0.300
Yttrium	(mg/L)	n/r	n/r	1.059	0.831	0.650	0.459	0.378
Zinc	(mg/L)	n/r	n/r	10.0	7.87	6.15	4.35	3.57
Total Phosphorus	(mg/L)	n/r	n/r	0.033	0.033	0.033	0.033	0.033

n/r – no runoff

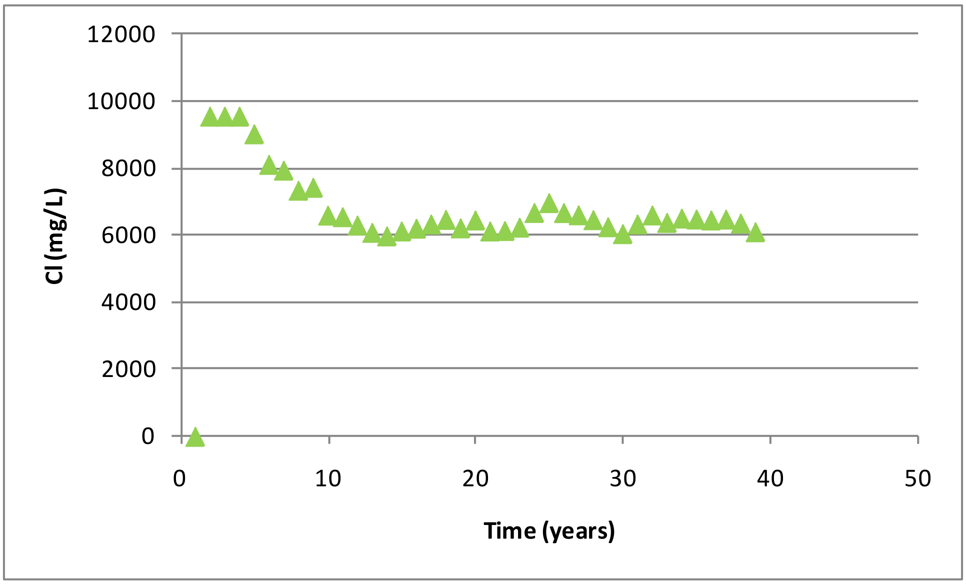

Figure 4.3 Chloride Concentrations in RSF Low Runoff for Annual Events of 1:5 Year Return Period of 0.083 h Duration

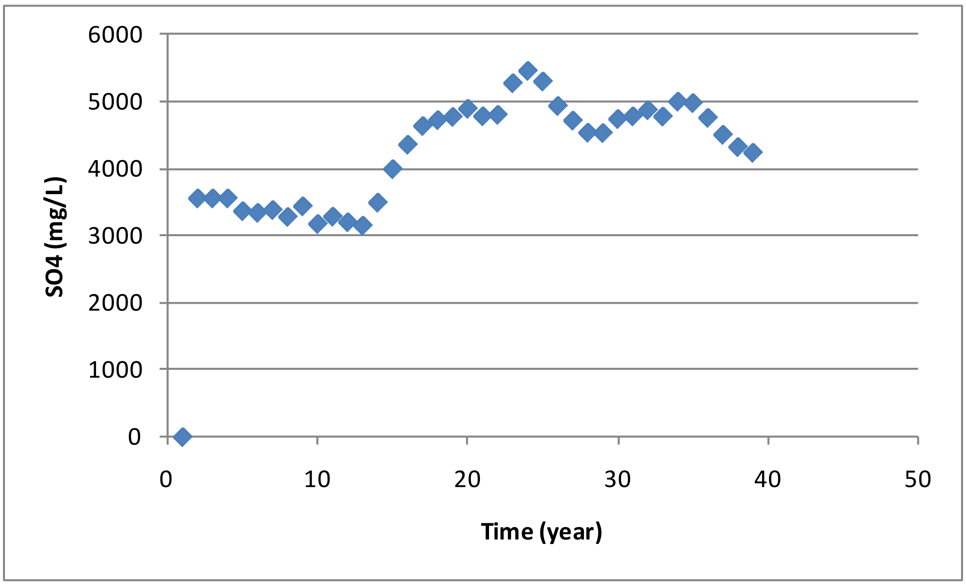

Figure 4.4 Sulphate Concentrations in RSF Low Runoff for Annual Events of 1:5 Year Return Period of 0.083 h Duration

The runoff water quality for corresponding events but of a longer duration (2 hrs) were also generated for comparison. The results are shown in Table 4.11. The longer duration – lower intensity events would not produce runoff for events of less than a 1:10 return period. For the events in excess of a 1:10 year return period, the concentration trends are similar to those calculated for the 0.083 hr return period events, except that the solute concentrations generally are lower.

Whilst the solute concentration estimates for the shorter duration events are significantly higher than those shown for the longer duration events, as noted before the runoff associated with the shorter duration events is not likely to leave the surface of the RSF and would be expected to be retained mostly on the surfaces of the RSF.

Table 4.11 Summary of Estimated Low Runoff Case RSF Water Quality During Operations for Events of 2 hour Duration

Input Variable	Units	Value						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	2	2	2	2	2	2	2
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence		1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentration**						
pH		n/r	n/r	n/r	n/r	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
Alkalinity as $CaCO_3$	(mg/L)	n/r	n/r	n/r	n/r	161	161	161
Sulphate	(mg/L)	n/r	n/r	n/r	n/r	1235	956	801
Chloride	(mg/L)	n/r	n/r	n/r	n/r	703	544	456
Fluoride	(mg/L)	n/r	n/r	n/r	n/r	43.7	33.9	28.4
Silicon	(mg/L)	n/r	n/r	n/r	n/r	17.4	17.4	17.4
Calcium	(mg/L)	n/r	n/r	n/r	n/r	142	110	92
Magnesium	(mg/L)	n/r	n/r	n/r	n/r	61	47	40
Sodium	(mg/L)	n/r	n/r	n/r	n/r	1049	812	680
Potassium	(mg/L)	n/r	n/r	n/r	n/r	117	91	76
Iron	(mg/L)	n/r	n/r	n/r	n/r	0.200	0.200	0.200
Aluminium	(mg/L)	n/r	n/r	n/r	n/r	0.200	0.200	0.200
Antimony	(mg/L)	n/r	n/r	n/r	n/r	0.217	0.168	0.141
Arsenic	(mg/L)	n/r	n/r	n/r	n/r	0.060	0.060	0.060
Barium	(mg/L)	n/r	n/r	n/r	n/r	0.010	0.010	0.010
Cerium	(mg/L)	n/r	n/r	n/r	n/r	0.261	0.202	0.169
Cobalt	(mg/L)	n/r	n/r	n/r	n/r	0.416	0.322	0.270
Copper	(mg/L)	n/r	n/r	n/r	n/r	0.120	0.120	0.120
Lanthanum	(mg/L)	n/r	n/r	n/r	n/r	0.142	0.110	0.092
Lead	(mg/L)	n/r	n/r	n/r	n/r	0.010	0.010	0.010
Manganese	(mg/L)	n/r	n/r	n/r	n/r	2.285	1.769	1.482
Molybdenum	(mg/L)	n/r	n/r	n/r	n/r	2.337	1.809	1.516
Nickel	(mg/L)	n/r	n/r	n/r	n/r	0.150	0.150	0.150
Strontium	(mg/L)	n/r	n/r	n/r	n/r	2.620	2.028	1.699
Thorium	(mg/L)	n/r	n/r	n/r	n/r	0.001	0.001	0.001
Uranium	(mg/L)	n/r	n/r	n/r	n/r	0.191	0.148	0.124
Yttrium	(mg/L)	n/r	n/r	n/r	n/r	0.137	0.106	0.089
Zinc	(mg/L)	n/r	n/r	n/r	n/r	1.294	1.002	0.840
Total Phosphorus	(mg/L)	n/r	n/r	n/r	n/r	0.033	0.033	0.033

n/r – no runoff

4.2.2.2 Case 2: High Runoff

The estimated volumes of runoff that could be generated for the Case 2 assessment are shown in Figure 4.5 and Figure 4.6 for the short and longer duration events respectively. When compared to the Case 1 assessment, the runoff estimates for the short duration events are shown to increase. However, the quantities still remain relatively small. The runoff equivalent would be about 16 mm for the 1:100 year event which, through local surface undulations, would likely be attenuated on the surface of the RSF.

The runoff estimates for the longer duration events show that for events with a return period of up to 1:20 years, the runoff volumes remain relatively low. For the 1:50 year and 1:100 year return period events there is a significant increase in runoff. This is because the materials that otherwise would not yield runoff at lower return periods start to contribute to the runoff at these more significant events. Under these circumstances it is likely that a significant quantity of runoff could leave the surfaces of the RSF.

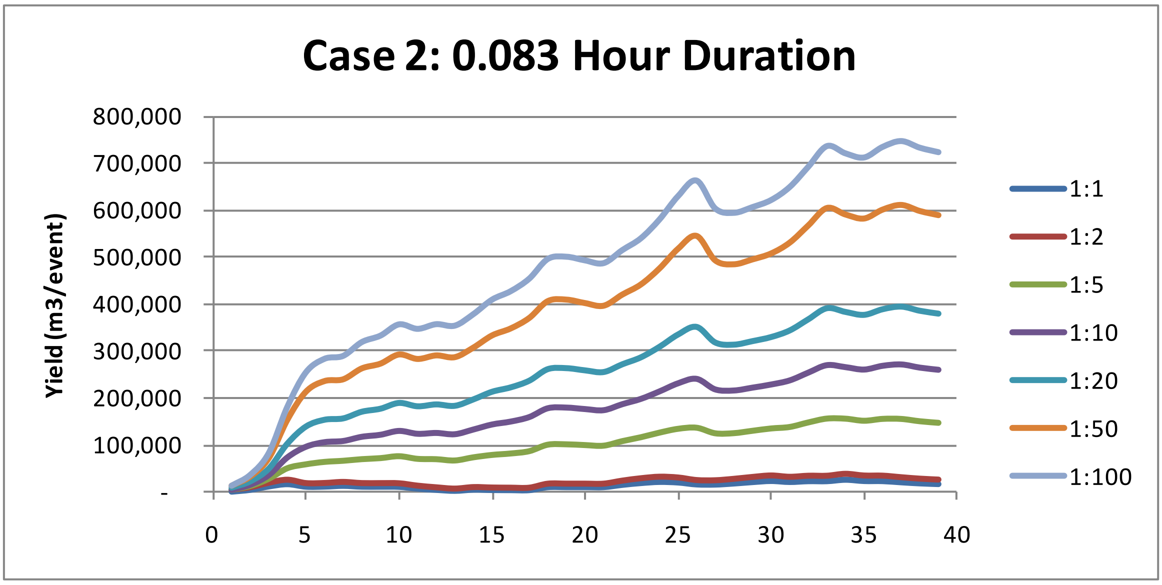

Figure 4.5 Estimated Case 2 RSF Runoff Yield for 0.083 Hour Duration Events

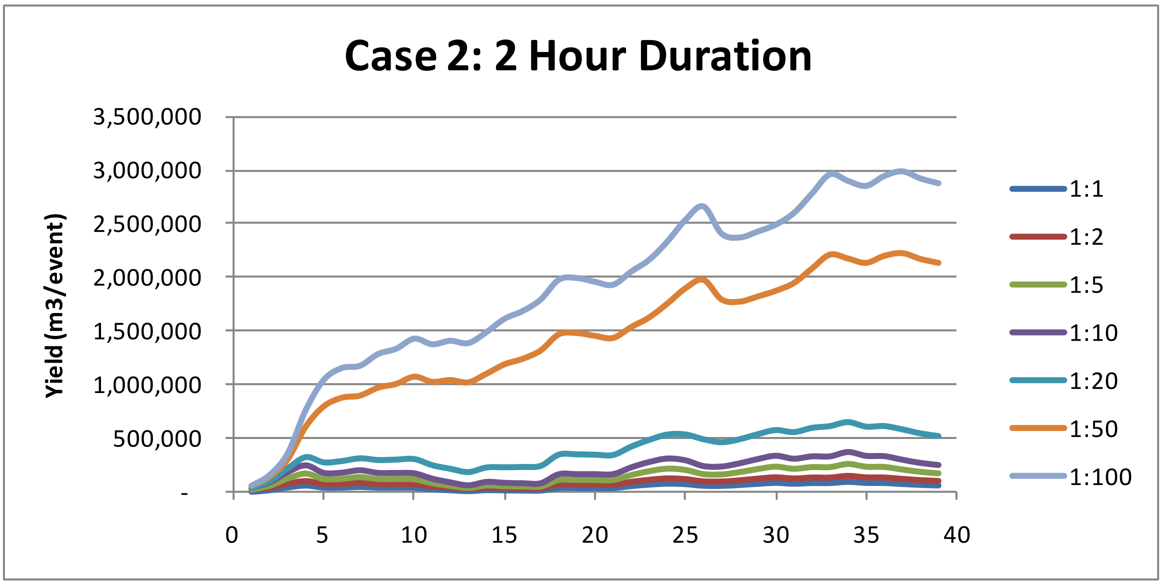

Figure 4.6 Estimated Case 2 RSF Runoff Yield for 2 Hour Duration Events

As noted above, the short duration events (generating low runoff volumes) generally would yield the highest concentrations, and therefore would represent the upper bound concentrations. The results are summarised in Table 4.12. The table shows the estimated concentrations in runoff for the 0.083 hr duration event for each of the return periods shown in the first row of the table and represent the maximum concentrations that would be encountered through the life of operations. (Note that the period of accumulation was set to 0.5 years (or 6 months) as it is unlikely that for such a short return period that all of the solutes produced within 1 year would have migrated to surface. For the longer return periods a maximum period of accumulation of 1 year was adopted as the longest dry period (with no rain) on record for the site is in the order of about 340 days.)

For the 1:1 year and 1:2 year return periods, the solute concentrations would be constant throughout the life of operations at the given concentrations since runoff would occur only from the very fine grained cover or overburden type materials. However, for longer return periods, other material types would start generating runoff which would then affect the water quality. As shown in Figure 4.7 the salinity release (as indicated by the chloride concentration) would increase from year to year for the first few years, and would peak in year 5; in subsequent years the concentrations would decrease or remain constant. The peak concentration of other solutes related to oxidation reactions generally would peak later in about Year 24 as shown by the sulphate concentration profile given in Figure 4.8. These trends repeat for all the events with a return period greater than 1:5 years, albeit at lower peak concentrations.

It is important to note that these estimates assume that only one such event occurs in any given year and that all the solutes generated during that period report to the runoff. Multiple events in a year would lead to correspondingly lower concentrations in subsequent events. For example, for the first of two consecutive 1:10 year events approximately six months apart, the runoff concentrations would reflect those shown in the table. However the concentrations in the runoff for the second event would only be about one quarter of that given in the table.

The runoff water quality estimates for longer duration (2 hrs) with corresponding return periods were also generated for comparison. The results are shown in Table 4.13. The trends are similar to those calculated for the 0.083 hr return period events, except that the concentrations would remain constant for return periods of less than 1:20 year return periods. The effects of other materials become apparent only for events with return periods at or above 1:20 years.

Table 4.12 Summary of Estimated RSF Runoff Water Quality During Operations for Events of 0.083 hour Duration

Input Parameter	**Units**	**Value**						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence	(m)	1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentrations**						
pH		6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Total Alkalinity as $CaCO_3$	(mg/L)	161	161	161	161	161	161	161
Sulphate	(mg/L)	1752	1474	4910	4501	3866	3042	2571
Chloride	(mg/L)	3785	2819	5016	4014	3160	2240	1980
Fluoride	(mg/L)	30.3	22.6	274	223.1	176.4	125.4	104.1
Silicon	(mg/L)	17.4	17.4	17.4	17.4	17.4	17.4	17.4
Calcium	(mg/L)	450	406	450	450	450	427	363
Magnesium	(mg/L)	325	242	437	350	275	195	170
Sodium	(mg/L)	4395	3273	6485	5286	4187	2980	2512
Potassium	(mg/L)	108	80	771	628	496	352	296
Iron	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Aluminium	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Antimony	(mg/L)	0.076	0.056	1.097	0.967	0.784	0.565	0.472
Arsenic	(mg/L)	0.060	0.056	0.060	0.060	0.060	0.060	0.060
Barium	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cerium	(mg/L)	0.076	0.056	1.445	1.181	0.939	0.677	0.573
Cobalt	(mg/L)	0.076	0.056	2.584	2.114	1.673	1.190	0.988
Copper	(mg/L)	0.120	0.120	0.120	0.120	0.120	0.120	0.120
Lanthanum	(mg/L)	0.076	0.056	0.794	0.648	0.518	0.373	0.314
Lead	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	(mg/L)	0.353	0.263	13.582	11.111	8.795	6.255	5.399
Molybdenum	(mg/L)	0.383	0.285	13.262	10.848	8.623	6.173	5.117
Nickel	(mg/L)	0.076	0.056	0.150	0.150	0.150	0.150	0.150
Strontium	(mg/L)	4.054	3.019	4.800	4.800	4.800	4.800	4.800
Thorium	(mg/L)	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Uranium	(mg/L)	0.076	0.056	0.300	0.300	0.300	0.300	0.300
Yttrium	(mg/L)	0.076	0.056	0.851	0.694	0.549	0.390	0.325
Zinc	(mg/L)	0.379	0.282	7.79	6.36	5.04	3.58	3.00
Total Phosphorus	(mg/L)	0.033	0.033	0.033	0.033	0.033	0.033	0.033

Table 4.13 Summary of Estimated RSF Runoff Water Quality During Operations for Events of 2 hour Duration

Input Parameter	Units	Value						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	2	2	2	2	2	2	2
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence	(m)	1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentrations**						
pH		6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Total Alkalinity as $CaCO_3$	(mg/L)	161	161	161	161	161	161	161
Sulphate	(mg/L)	481	346	462	346	620	671	580
Chloride	(mg/L)	920	662	883	662	598	512	432
Fluoride	(mg/L)	7.4	5.3	7.1	5.3	26.6	28.5	24.1
Silicon	(mg/L)	10.6	7.6	10.1	7.6	17.4	17.4	17.4
Calcium	(mg/L)	132	95	127	95	106	97	82
Magnesium	(mg/L)	79	57	76	57	52	45	38
Sodium	(mg/L)	1068	769	1026	769	737	675	573
Potassium	(mg/L)	26	19	25	19	76	80	68
Iron	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Aluminium	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Antimony	(mg/L)	0.018	0.013	0.018	0.013	0.104	0.124	0.108
Arsenic	(mg/L)	0.018	0.013	0.018	0.013	0.060	0.060	0.060
Barium	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cerium	(mg/L)	0.018	0.013	0.018	0.013	0.137	0.151	0.129
Cobalt	(mg/L)	0.018	0.013	0.018	0.013	0.243	0.270	0.229
Copper	(mg/L)	0.064	0.046	0.061	0.046	0.120	0.120	0.120
Lanthanum	(mg/L)	0.018	0.013	0.018	0.013	0.077	0.083	0.071
Lead	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	(mg/L)	0.086	0.062	0.082	0.062	1.273	1.419	1.203
Molybdenum	(mg/L)	0.093	0.067	0.089	0.067	1.245	1.386	1.181
Nickel	(mg/L)	0.018	0.013	0.018	0.013	0.132	0.145	0.123
Strontium	(mg/L)	0.985	0.709	0.946	0.709	1.635	1.636	1.382
Thorium	(mg/L)	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Uranium	(mg/L)	0.018	0.013	0.018	0.013	0.118	0.130	0.110
Yttrium	(mg/L)	0.018	0.013	0.018	0.013	0.082	0.089	0.075
Zinc	(mg/L)	0.092	0.066	0.088	0.066	0.737	0.813	0.689
Total Phosphorus	(mg/L)	0.033	0.033	0.033	0.033	0.033	0.033	0.033

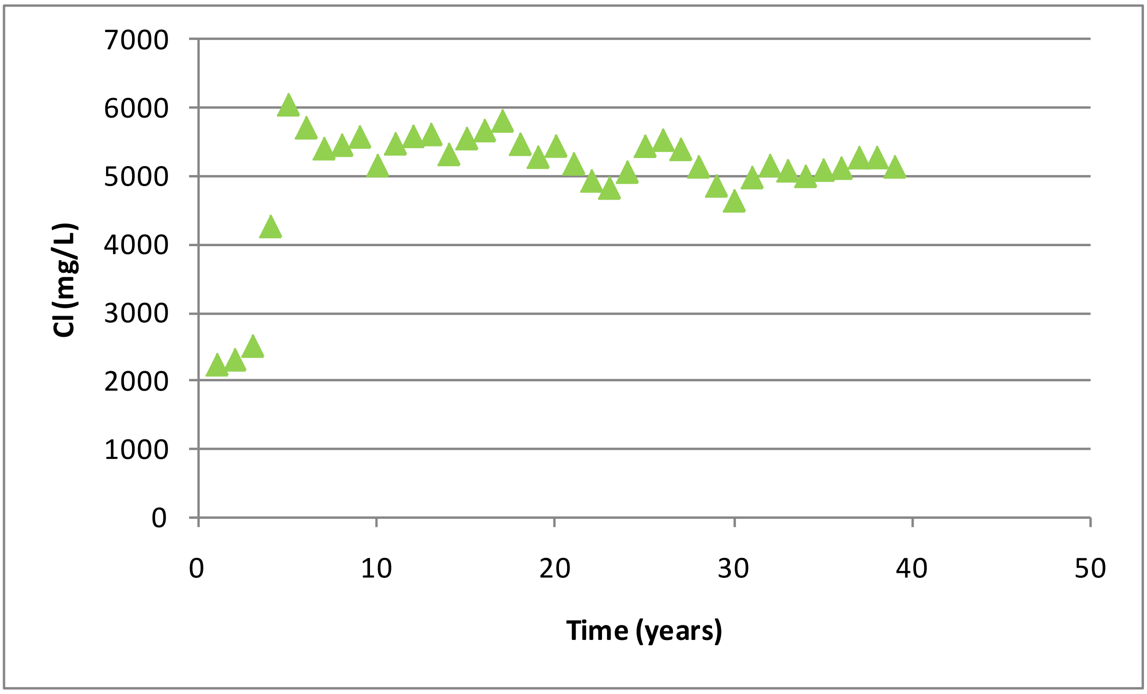

Figure 4.7 Chloride Concentrations in RSF Runoff for Annual Events of 1:5 Year Return Period of 0.083 h Duration

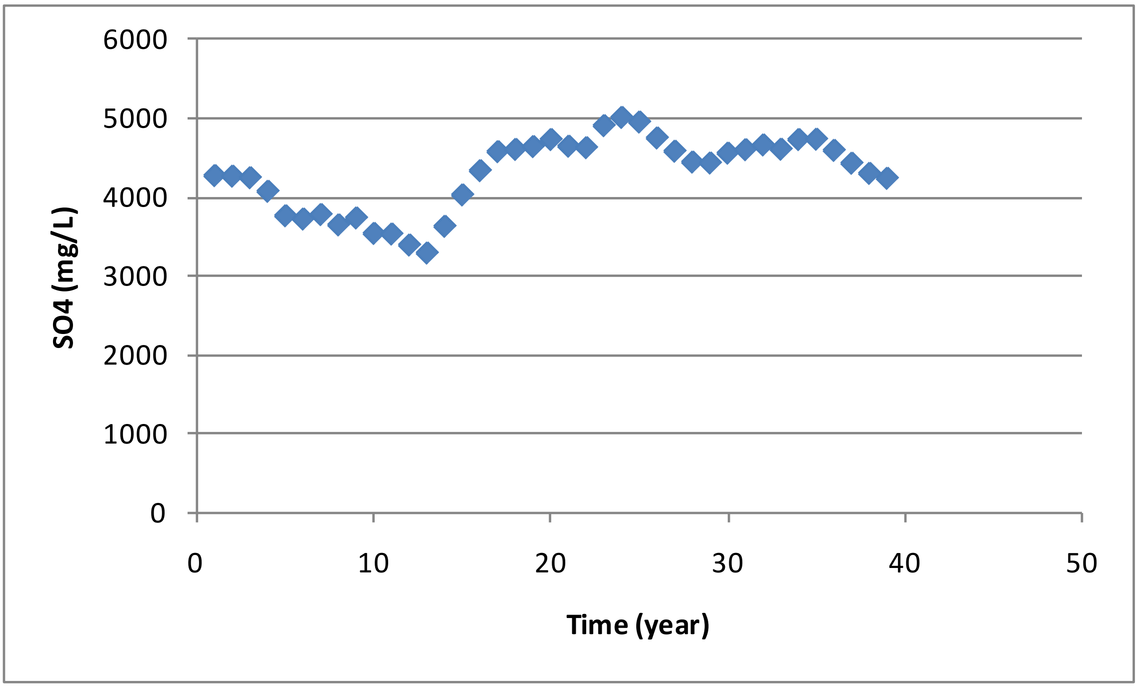

Figure 4.8 Sulphate Concentrations in RSF Runoff for Annual Events of 1:5 Year Return Period of 0.083 h Duration

4.2.3 LGS Runoff Water Quality

Unlike the RSF, no cover sequence materials would be placed in the LGS. Therefore material type selection does not vary and a low and high runoff case assessment was not undertaken. The estimated runoff volumes for the LGS are shown in Figure 4.9 and Figure 4.10 for the 0.083 hour duration and the 2 hour duration events respectively. As shown for the short duration events, the LGS would not yield runoff for events with a return period of less than 1:5 years. For the 2 hour duration events, runoff would occur only for events with a return period of 1:20 or more.

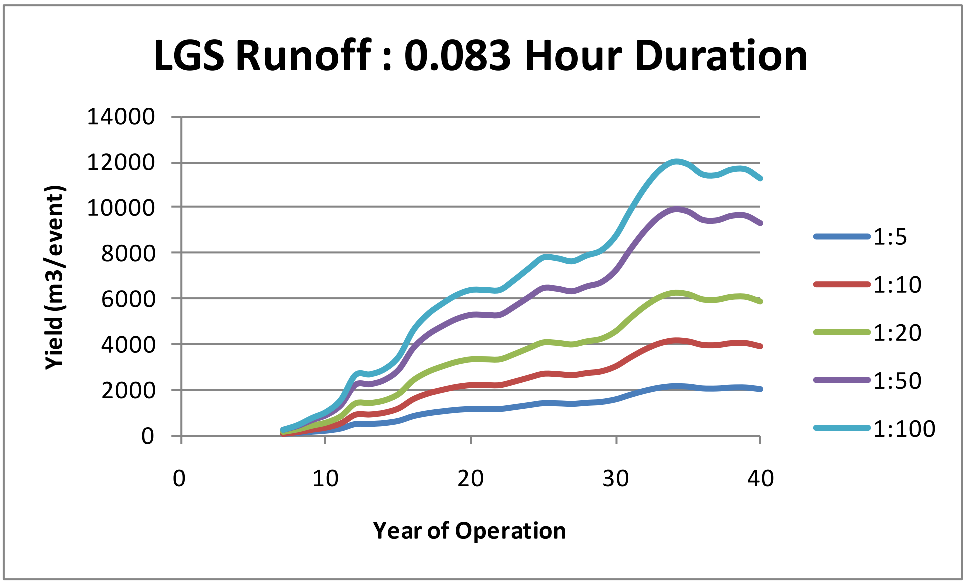

Figure 4.9 LGS Runoff Volume Estimates for Events of 0.083 Hour Duration

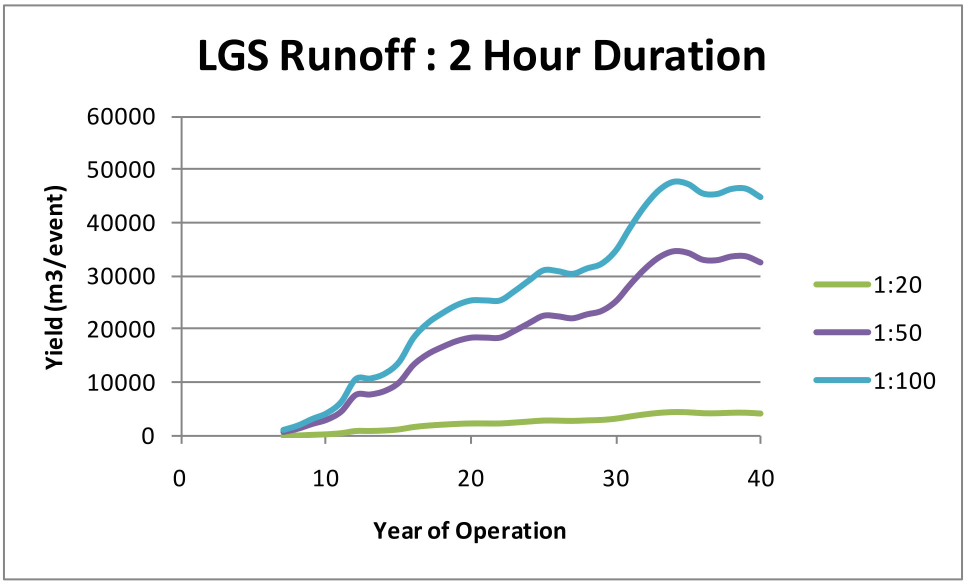

Figure 4.10 LGS Runoff Volume Estimates for Events of 2 Hour Duration

Even for the short duration events (0.083 hour), an event with a 1:20 year return period would yield the equivalent of about 8 mm which is likely to be attenuated within local surface undulations and runoff would be minimal. However, events with a return period in excess of 1:50 years and of 2 hour duration (yielding about 46 mm) would be expected to yield runoff from the LGS.

The estimated runoff water quality for the LGS under similar conditions as those adopted for the RSF are shown in Table 4.14 and Table 4.15 for the 0.083 hour duration and the 2 hour duration events respectively. As for the RSF, these estimates represent single events that occur only once in the given operational year. Multiple events would lead to lower concentrations as solutes would be removed with each event that would not be available in a subsequent event.

The corresponding chloride and sulphate concentrations are shown in Figure 4.11 and Figure 4.12 respectively. Unlike for the RSF that would be influenced by the cover sequence materials, the chloride concentrations tend to decrease over time as more materials with lower stored salinity would be exposed. The sulphate concentrations also would be expected to decrease over time as shown as materials with lower reactivity is exposed later in the life of the facility.

Table 4.14 Summary of Estimated LGS Runoff Water Quality During Operations for Events of 0.083 hour Duration

Input Parameter	Units	Value						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence	(m)	1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentrations**						
pH		n/r	n/r	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Total Alkalinity as $CaCO_3$	(mg/L)	n/r	n/r	161	161	161	161	161
Sulphate	(mg/L)	n/r	n/r	3701	3059	2609	2151	1973
Chloride	(mg/L)	n/r	n/r	6964	5466	4275	3020	2540
Fluoride	(mg/L)	n/r	n/r	627	491.7	384.6	271.6	228.5
Silicon	(mg/L)	n/r	n/r	17.4	17.4	17.4	17.4	17.4
Calcium	(mg/L)	n/r	n/r	450	450	450	450	450
Magnesium	(mg/L)	n/r	n/r	668	524	410	290	244
Sodium	(mg/L)	n/r	n/r	5927	4651	3638	2570	2162
Potassium	(mg/L)	n/r	n/r	1283	1007	788	556	468
Iron	(mg/L)	n/r	n/r	0.200	0.200	0.200	0.200	0.200
Aluminium	(mg/L)	n/r	n/r	0.200	0.200	0.200	0.200	0.200
Antimony	(mg/L)	n/r	n/r	1.861	1.461	1.142	0.807	0.679
Arsenic	(mg/L)	n/r	n/r	0.060	0.060	0.060	0.060	0.060
Barium	(mg/L)	n/r	n/r	0.010	0.010	0.010	0.010	0.010
Cerium	(mg/L)	n/r	n/r	2.374	1.863	1.457	1.029	0.866
Cobalt	(mg/L)	n/r	n/r	15.7	12.3	9.6	6.8	5.7
Copper	(mg/L)	n/r	n/r	0.120	0.120	0.120	0.120	0.120
Lanthanum	(mg/L)	n/r	n/r	1.355	1.064	0.832	0.588	0.494
Lead	(mg/L)	n/r	n/r	0.010	0.010	0.010	0.010	0.010
Manganese	(mg/L)	n/r	n/r	26.9	21.1	16.5	11.6	9.8
Molybdenum	(mg/L)	n/r	n/r	29.3	23.0	18.0	12.7	10.7
Nickel	(mg/L)	n/r	n/r	0.150	0.150	0.150	0.150	0.150
Strontium	(mg/L)	n/r	n/r	4.800	4.800	4.800	4.800	4.800
Thorium	(mg/L)	n/r	n/r	0.001	0.001	0.001	0.001	0.001
Uranium	(mg/L)	n/r	n/r	0.300	0.300	0.300	0.300	0.300
Yttrium	(mg/L)	n/r	n/r	1.438	1.128	0.883	0.623	0.524
Zinc	(mg/L)	n/r	n/r	15.455	12.129	9.487	6.701	5.637
Total Phosphorus	(mg/L)	n/r	n/r	0.033	0.033	0.033	0.033	0.033

Table 4.15 Summary of Estimated LGS Runoff Water Quality During Operations for Events of 2 hour Duration

Input Parameter	Units	Value						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	2	2	2	2	2	2	2
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence	(m)	1	1	1	1	1	1	1
Duration of accumulation	(years)	0.5	0.5	1	1	1	1	1
Parameter		**Maximum Concentrations**						
pH		n/r	n/r	n/r	n/r	6.5-8.5	6.5-8.5	6.5-8.5
Total Alkalinity as $CaCO_3$	(mg/L)	n/r	n/r	n/r	n/r	161	161	161
Sulphate	(mg/L)	n/r	n/r	n/r	n/r	882	648	541
Chloride	(mg/L)	n/r	n/r	n/r	n/r	900	696	583
Fluoride	(mg/L)	n/r	n/r	n/r	n/r	80.9	62.7	52.5
Silicon	(mg/L)	n/r	n/r	n/r	n/r	17.4	17.4	17.4
Calcium	(mg/L)	n/r	n/r	n/r	n/r	214	165	139
Magnesium	(mg/L)	n/r	n/r	n/r	n/r	86	67	56
Sodium	(mg/L)	n/r	n/r	n/r	n/r	766	593	497
Potassium	(mg/L)	n/r	n/r	n/r	n/r	166	128	108
Iron	(mg/L)	n/r	n/r	n/r	n/r	0.200	0.200	0.200
Aluminium	(mg/L)	n/r	n/r	n/r	n/r	0.200	0.200	0.200
Antimony	(mg/L)	n/r	n/r	n/r	n/r	0.240	0.186	0.156
Arsenic	(mg/L)	n/r	n/r	n/r	n/r	0.060	0.060	0.060
Barium	(mg/L)	n/r	n/r	n/r	n/r	0.010	0.010	0.010
Cerium	(mg/L)	n/r	n/r	n/r	n/r	0.307	0.237	0.199
Cobalt	(mg/L)	n/r	n/r	n/r	n/r	2.024	1.567	1.313
Copper	(mg/L)	n/r	n/r	n/r	n/r	0.120	0.120	0.120
Lanthanum	(mg/L)	n/r	n/r	n/r	n/r	0.175	0.136	0.114
Lead	(mg/L)	n/r	n/r	n/r	n/r	0.010	0.010	0.010
Manganese	(mg/L)	n/r	n/r	n/r	n/r	3.469	2.685	2.250
Molybdenum	(mg/L)	n/r	n/r	n/r	n/r	3.779	2.926	2.452
Nickel	(mg/L)	n/r	n/r	n/r	n/r	0.150	0.150	0.150
Strontium	(mg/L)	n/r	n/r	n/r	n/r	4.800	4.800	4.246
Thorium	(mg/L)	n/r	n/r	n/r	n/r	0.001	0.001	0.001
Uranium	(mg/L)	n/r	n/r	n/r	n/r	0.300	0.233	0.195
Yttrium	(mg/L)	n/r	n/r	n/r	n/r	0.186	0.144	0.120
Zinc	(mg/L)	n/r	n/r	n/r	n/r	1.996	1.546	1.295
Total Phosphorus	(mg/L)	n/r	n/r	n/r	n/r	0.033	0.033	0.033

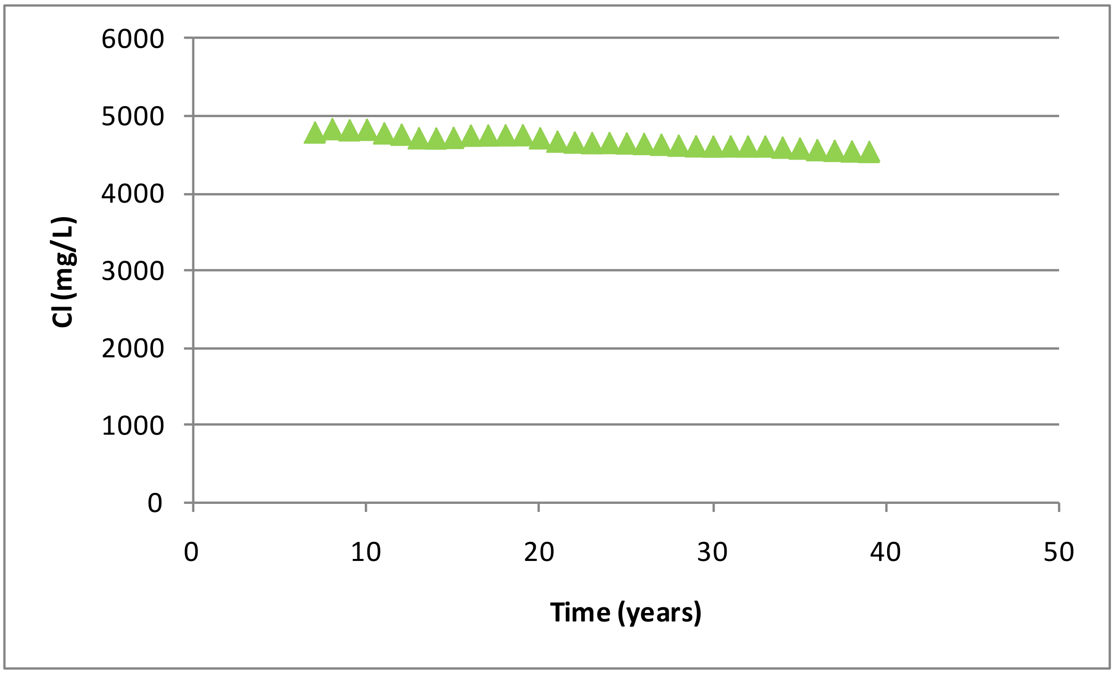

Figure 4.11 Chloride Concentrations in LGS Runoff for Annual Events of 1:5 Return Period of 0.083 Hour Duration

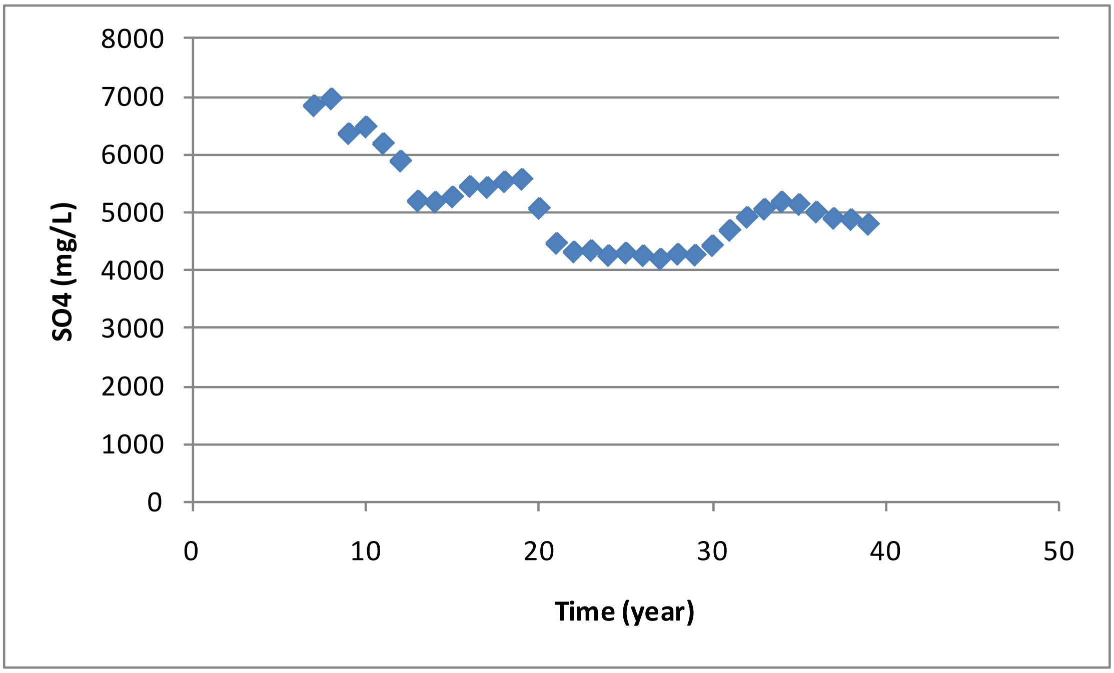

Figure 4.12 Sulphate Concentrations in LGS Runoff for Annual Events of 1:5 Return Period of 0.083 Hour Duration

4.3 Post Closure Water Quality

The proposed closure strategy for the RSF, and for the LGS if it remains in place, would be to fully cover the facility with overburden or cover sequence materials. For the purpose of this assessment, it was assumed that a minimum cover of 1 m would be placed (i.e. to coincide with the assumed depth of the evaporation related transport of salts).

A series of calculations was completed to estimate the maximum concentrations that may occur in runoff water quality from a covered facility. The results are summarised in Table 4.16 and may apply to both the RSF and the LGS. (Note that the final composition of exposed materials for the LGS is not known at present hence there could be some minor differences.)

The estimates presented in the table represent the maximum concentrations that would result for a single first event that could occur once after closure. Since that event would remove most of the available solutes, and since the cover sequence materials would not be expected to continue to generate solutes, the concentrations in all subsequent runoff events would decrease and continue to decrease until background surface water quality for the region would be reached. The rate of decrease would however depend on the magnitude and duration of preceding events. Some of the solutes that are limited by solubility constraints may continue to be released at their equilibrium concentration until the accumulated secondary mineral phases had been depleted, after which the concentrations would also decrease to background concentrations.

Table 4.16 Summary of Estimated Maximum Post Closure Single Event Runoff Water Quality for 0.083 Hour Duration Events

Input Parameter	**Units**	**Value**						
Return Period	(year)	1	2	5	10	20	50	100
Storm Duration	(hr)	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Total Precipitation	(mm)	3.5	4.7	6.2	7.9	10.1	14.3	17
Depth of influence	(m)	1	1	1	1	1	1	1
Duration of accumulation	(years)	1	1	1	1	1	1	1
Parameter		**Concentrations**						
pH		6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
Total Alkalinity as $CaCO_3$	(mg/L)	161	161	161	161	161	161	161
Sulphate	(mg/L)	3958	2948	4564	3858	3090	2214	1893
Chloride	(mg/L)	7571	5638	3594	2740	2122	1490	1442
Fluoride	(mg/L)	61	45	45	36	29	20	17
Silicon	(mg/L)	17.4	17.4	17.4	17.4	17.4	17.4	17.4
Calcium	(mg/L)	450	450	442	326	250	174	156
Magnesium	(mg/L)	650	484	252	184	140	98	93
Sodium	(mg/L)	8791	6546	5456	4340	3410	2415	2126
Potassium	(mg/L)	215	160	322	277	223	160	139
Iron	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Aluminium	(mg/L)	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Antimony	(mg/L)	0.152	0.113	0.082	0.064	0.050	0.035	0.031
Arsenic	(mg/L)	0.060	0.060	0.060	0.060	0.060	0.059	0.060
Barium	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Cerium	(mg/L)	0.152	0.113	0.433	0.381	0.309	0.223	0.198
Cobalt	(mg/L)	0.152	0.113	0.112	0.091	0.072	0.051	0.046
Copper	(mg/L)	0.120	0.120	0.120	0.120	0.120	0.120	0.120
Lanthanum	(mg/L)	0.152	0.113	0.207	0.177	0.142	0.102	0.090
Lead	(mg/L)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Manganese	(mg/L)	0.707	0.526	6.781	6.079	4.953	3.584	3.291
Molybdenum	(mg/L)	0.766	0.571	0.256	0.180	0.135	0.093	0.079
Nickel	(mg/L)	0.150	0.113	0.150	0.150	0.150	0.120	0.108
Strontium	(mg/L)	4.800	4.800	4.800	3.878	3.043	2.154	2.000
Thorium	(mg/L)	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Uranium	(mg/L)	0.152	0.113	0.300	0.300	0.300	0.249	0.208
Yttrium	(mg/L)	0.152	0.113	0.412	0.362	0.293	0.212	0.177
Zinc	(mg/L)	0.759	0.565	2.854	2.528	2.053	1.482	1.278
Total Phosphorus	(mg/L)	0.033	0.033	0.033	0.033	0.033	0.033	0.033

5. Discussion

5.1 Runoff

The hydraulic conductivity of the waste rock in the RSF will be determined by the grain size distributions which is difficult to predict accurately prior to the construction of the RSF. However, when conservative assumptions of surface grain size are applied, the infiltration modelling (Appendix F7 of Supplementary EIS) suggests that runoff will be unlikely to occur, except in high intensity rainfalls events.

The sensitivity runs with and without ponding also suggest a possible mitigation measure, should runoff prove to be a problem. When the infiltration model was set to allow up to 25 mm of ponding before directing water to runoff, even the high runoff rates predicted for Material 4 were very significantly reduced (Appendix F7 of Supplementary EIS). The implication is that modification of the RSF surface to delay runoff, for example by locally flattening or scarifying the surface, would effectively control runoff and limit or even negate release to the adjacent natural terrain.

In summary, events that in general yield the equivalent of less than about 20 to 25 mm of runoff would not be expected to yield significant volumes of runoff that would be transported away from either the RSF or the LGS. This means that none of the short duration (0.083 hour) events with a return period of 1:100 or less would be expected to yield runoff. However, the Case 1 analysis shows that events of a 2 hour duration and a return period of 1:50 or more could generate runoff locally. The Case 2 analysis suggest that events as low as 1:5 or 1:10 year return periods could generate runoff; however the net yield from these events would be expected to be low. Therefore, events that could generate runoff that would be released from the RSF and the LGS during the operational period would have a relatively low probability of occurring.

5.2 Water Quality

Water quality estimates have been prepared for runoff events of both short duration and longer duration for a range of return periods. However, as discussed above, not all events would be expected to yield runoff from either the RSF or the LGS during the operational period. The water quality estimates were prepared for the event duration and return periods that would be expected to yield runoff from the RSF and the LSG. The water quality estimates showed that the solute concentrations would increase with increasing accumulation period. A maximum period of accumulation of 1 year was adopted (which equates to the longest period without rain) and conservatively it was assumed that all of the solutes that would accumulate during this period would be available for dissolution during a subsequent rainfall event. Column testing however showed that multiple flushing events are required over an extended period to mobilise all of the readily soluble salts present in the mine rock materials. Therefore, solute concentrations are likely to be lower than estimated.

The assessments herein considered both low and high runoff events.

The Case 1 (low runoff) analysis suggests that the water quality associated with events of 2 hour duration and return periods of 1:5 years or 1:10 years would provide conservative estimates of the potential water quality that may be released as runoff. The water quality associated with the 2-hour duration 1:20 or 1:50 return period events (Case 1 analysis for the RSF) would be considered more appropriate. The same would apply to the estimates for the LGS runoff. The Case 2 (high runoff) analysis generally yielded lower solute concentrations.

After closure, once the potentially reactive materials had been covered with a layer of cover sequence material of about 1 m or more, the water quality in the runoff would be expected to become progressively cleaner after the first flush had removed most of the soluble salt loadings.

6. References

AECOM, 2010. Olympic Dam Kinetic Testing Program, Appendix F6 of Supplementary EIS

Green, W.H., and G. Ampt, 1911. “Studies in soil physics. I. The flow of air and water through soils”. Journal of Agricultural Science, Vol. 4, pp. 1-24.

Perkins, K., and J. Nimmo, 2009. “High-quality unsaturated zone hydraulic property data for hydrologic applications”. Water Resources Research, Vol. 45, W07417.

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Appendices

Appendix A: Schedule of Rock Placement

Table A-1 Schedule of RSF Waste Rock Placement

Year	Mine Rock Production (1000 tonnes per annum)									
	ZAL	ZWAR	ZWAW	ZWC	ZWC / ZWT	ZWT	GRNB	HEM	VHEM	HEMQ
1	51,556	-	-	-	-	-	-	-	-	-
2	82,814	2,713	-	-	-	-	-	-	-	-
3	154,367	19,927	-	-	-	-	-	-	-	-
4	102,648	280,094	-	-	-	-	-	-	-	-
5	1,122	371,009	42,083	33	-	-	-	-	-	-
6	186,209	41,980	41,130	52,722	94,139	26,440	-	-	-	-
7	81,386	95,138	-	-	12,466	166,935	9,621	809	13,308	2,539
8	8,323	198,503	64,672	30,330	67,608	14,967	2,391	377	4,931	783
9	128	161,503	12,021	153	13,142	123,973	35,421	115	11,697	15,414
10	-	186,530	111,172	28,660	39,428	713	573	48	3,041	1,129
11	-	-	470	5,520	57,380	135,456	55,160	1,624	15,882	22,169
12	-	-	16,289	27,828	15,165	62,348	109,576	1,827	3,095	5,576
13	-	-	4,872	11,664	85,427	79,561	82,299	14,006	-	960
14	113,756	17,786	-	-	-	108,143	21,692	639	9,112	69,833
15	6,926	77,520	-	-	-	1,447	32,246	2,122	33,014	102,799
16	-	69,073	-	-	-	-	36,241	2,695	38,210	81,887
17	-	125,974	4,351	-	-	-	24,966	2,322	34,483	62,103
18	136,163	132,984	6,263	-	-	-	6,844	1,201	12,796	29,298
19	1,224	95,700	34,666	34,233	95,534	73,448	2,506	607	4,243	20,477
20	-	64,273	9,668	-	-	141,760	57,042	1,573	696	8,220
21	-	27,435	47,349	37,143	77,086	14,186	47,283	110	1,323	-
22	102,259	-	-	-	13,497	146,019	23,600	1,479	3,537	13,706
23	81,411	3,078	-	-	-	2,155	56,780	6,137	19,342	95,319
24	52,339	150,566	-	-	-	-	24,698	2,164	12,712	72,387
25	-	232,376	340	-	-	-	18,081	11,930	22,212	70,885
26	-	92,439	96,277	53,433	22,181	13	18,892	9,041	18,416	27,089
27	-	-	-	2,332	141,016	213,573	10,754	1,657	6,874	9,303
28	48,778	-	-	-	-	109,040	76,132	3,929	3,951	16,507
29	68,591	87	-	-	-	-	76,826	11,427	15,112	30,097
30	137,386	366	-	-	-	-	42,891	12,508	7,685	57,037
31	842	205,816	-	-	-	-	24,801	9,449	1,184	57,716
32	35,566	190,917	-	-	-	-	19,296	11,575	2,264	43,831
33	-	129,409	106,585	40,683	23,486	-	8,003	12,693	3,139	20,174
34	65,654	-	-	15,214	149,756	110,406	7,467	9,458	7,617	6,894
35	-	-	-	-	-	249,303	43,366	11,965	7,028	4,282
36	39,330	31,208	-	-	-	9,904	105,331	9,589	1,164	288
37	-	85,530	16,353	6,609	69	-	85,593	8,900	751	1,925
38	-	47	12,700	20,281	61,051	51,135	50,861	12,242	699	4,768
39	-	-	-	-	-	99,217	123,220	11,347	742	4,314
40	52,130	-	-	-	-	-	124,811	10,615	523	3,150
41	150,921	78,263	-	-	-	-	39,253	8,396	671	3,932

Table A-2 Schedule of Waste Rock Exposure on the RSF

Year	Mine Rock Exposed (Ha)									
	ZAL	**ZWAR**	**ZWAW**	**ZWC**	**ZWC / ZWT**	**ZWT**	**GRNB**	**HEM**	**VHEM**	**HEMQ**
1	149	0	0	0	0	0	0	0	0	0
2	388	8	0	0	0	0	0	0	0	0
3	834	65	0	0	0	0	0	0	0	0
4	1131	864	0	0	0	0	0	0	0	0
5	800	1916	122	0	0	0	0	0	0	0
6	811	1935	240	159	265	72	0	0	0	0
7	915	1811	240	159	300	524	26	1	33	4
8	800	1966	414	250	490	564	32	2	45	5
9	797	2031	340	250	527	900	127	2	74	31
10	782	1940	651	304	607	902	129	2	81	33
11	548	1904	616	271	624	1251	276	5	120	69
12	386	1850	609	296	613	1366	570	8	128	78
13	260	1740	605	313	782	1489	765	29	95	75
14	407	1665	605	313	782	1512	823	31	117	190
15	365	1806	562	294	736	1398	903	33	186	357
16	349	1823	508	222	720	1386	1000	38	280	491
17	349	1949	431	222	623	1386	1067	42	365	592
18	742	2083	414	222	555	1291	990	43	367	615
19	745	1941	481	296	805	1247	995	44	370	647
20	745	1935	273	238	713	1631	1148	47	372	660
21	745	1744	358	350	929	1669	1141	44	336	624
22	1041	1744	357	333	806	1698	1150	44	337	637
23	1276	1753	322	289	774	1607	1049	54	385	793
24	1427	2182	296	215	701	1427	894	34	416	910
25	1351	2795	296	215	523	1251	885	53	448	912
26	1099	3059	575	375	586	1026	880	64	445	851
27	1079	2754	575	382	982	1601	781	63	335	669
28	1220	2511	562	382	982	1896	918	65	261	595
29	1404	2261	544	382	982	1896	1105	82	266	596
30	1549	2030	544	382	982	1896	1220	102	285	689
31	1420	2433	507	342	903	1845	1280	117	278	750
32	1523	2802	444	279	755	1697	1331	136	283	822
33	1523	2995	724	402	780	1403	1200	154	289	841
34	1713	2870	587	336	1068	1574	1093	169	305	853
35	1545	2870	587	336	946	2009	1146	187	313	837
36	1531	2959	587	336	946	1881	1401	192	287	790
37	1377	3194	634	356	946	1875	1506	207	270	685
38	1236	3124	671	417	1118	2013	1576	223	241	574
39	1144	2764	671	417	1118	2282	1906	222	243	581
40	1810	3120	1185	932	1633	2797	0	0	0	0

Table A-3 Schedule of Low Grade Ore Placement in the LGS

	Production (1000 tonnes per annum)			
Year	**GRNB**	**HEM**	**VHEM**	**HEMQ**
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	2,454	1,017	3,899	1,770
7	1,291	434	2,989	1,418
8	4,474	446	2,413	2,139
9	2,143	624	2,231	1,867
10	8,475	1,969	3,871	3,635
11	16,156	2,497	4,572	7,395
12	13,736	258	-	206
13	4,261	643	628	1,540
14	7,521	1,385	4,668	3,788
15	10,027	1,230	6,025	7,862
16	11,840	1,403	7,506	4,831
17	4,030	1,553	3,353	3,178
18	3,469	889	649	2,616
19	28,417	1,422	-	1,509
20	42,176	801	387	-
21	16,308	780	2,331	15
22	14,935	3,056	3,726	3,035
23	16,498	903	1,197	6,640
24	11,738	3,145	2,114	5,402
25	11,328	3,446	3,249	1,582
26	8,186	1,333	2,858	2,772
27	13,118	4,733	1,830	5,190
28	16,752	5,022	1,430	5,462
29	11,585	5,143	372	4,321
30	7,334	6,592	79	7,753
31	8,611	7,226	324	7,823
32	7,599	5,820	751	7,369
33	8,969	7,757	1,945	4,866
34	13,516	4,446	1,299	2,708
35	20,587	3,542	97	1,397
36	20,396	3,035	89	2,424
37	17,578	3,713	242	3,843
38	14,584	2,505	183	3,245
39	13,452	2,570	132	3,147
40	8,999	2,591	317	2,344

Table A-4 Schedule of Low Grade Ore Exposure on the RSF

	Production (1000 tonnes per annum)			
Year	GRNB	HEM	VHEM	HEMQ
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
7	3.7	0.9	5.3	1.6
8	5.6	1.3	9.4	2.9
9	12.2	1.7	12.7	4.8
10	15.4	2.3	15.7	6.5
11	28.0	4.1	21.0	9.8
12	52.1	6.4	27.2	16.6
13	72.5	6.6	27.2	16.8
14	78.9	7.2	28.1	18.2
15	90.0	8.4	34.5	21.6
16	105.0	9.6	42.7	28.8
17	122.6	10.8	52.9	33.1
18	128.6	12.2	57.5	36.0
19	133.7	13.0	58.4	38.4
20	176.0	14.3	58.4	39.8
21	238.8	15.1	58.9	39.8
22	263.1	15.8	62.1	39.8
23	285.3	18.6	67.2	42.6
24	304.3	18.1	62.4	45.7
25	316.1	20.5	59.0	48.7
26	327.1	21.3	60.4	48.4
27	338.1	22.5	59.0	47.6
28	347.8	26.8	58.8	49.2
29	364.2	29.1	57.2	50.6
30	368.5	33.8	57.7	54.5
31	367.4	39.5	57.8	61.4
32	369.3	45.5	57.4	67.6
33	373.0	49.6	57.1	72.4
34	379.9	56.6	54.7	74.8
35	393.1	59.5	53.3	74.1
36	415.2	62.8	48.4	71.4
37	436.4	64.2	43.3	71.2
38	453.1	67.6	38.6	72.7
39	470.1	68.5	34.3	72.7
40	658.5	0.0	481.7	70.2