Anvil Range Mine Site
Oxide Fines Management Plan

Deloitte and Touch Inc.

Interim Receiver of Anvil Range Mining Corporation

SRK Consulting (Canada) Inc.
Suite 800, 1066 West Hastings Street
Vancouver, B.C. V6E 3X2

Tel: 604.681.4196 Fax: 604.687.5532
E-mail: vancouver@srk.com Web site: www.srk.com

SRK Project Number 1CD003.44.100

July 2004

Authors
J. Chapman, P.Eng

Reviewed by
D. Hockley, P.Eng

Table of Contents

List of Tables

List of Figures

List of Appendices

1 Introduction

1.1 Terms of Reference

As part of the 2002/03 waste characterization program for the Anvil Range site, a number of seepage samples emanating from the oxide fines were collected and analyzed. The highest zinc concentrations were measured in seepage samples from the Oxide Fines Stockpile (1,230 to 10, 900 mg/L), the Medium Grade Stockpile (6,130 to 7,840 mg/L), and the mill area (1,110 to 2,260 mg/L). These results indicate that interim remedial activities targeted at these sources should be effective in reducing current metal loadings.

The immediate benefit that may be gained from the mitigation of the oxide fines is recognized in the 2004 water licence, Licence Number: QZ03-059. Condition 57 of the license requires that an oxide fines management plan be prepared for submission by mid-2004. Specifically, Condition 57 of the water licence states:

> *Plan for the Management of Oxide Fines*
>
> *57. A long term plan for the management of oxide fines shall be prepared and submitted to the Board by July 30, 2004 or no later than 90 days prior to the proposed implementation date, whichever comes first.*

1.2 Background

A number of methods for mitigating the metal loadings from the oxide fines and low grade ore are available, including:

- Collecting and treating seepage;
- Compacting the surface of the oxide fines stockpiles to reduce infiltration and thus reduce the metal loadings;
- Covering the oxide fines in place with a low permeability cover to limit infiltration and reduce loadings;
- Consolidating the various piles to a single location to reduce the footprint and thus the volume of seepage released from the oxide fines;
- Consolidating the piles and amending the oxide fines with lime to neutralize acidity and limit short-term contaminant release;
- Consolidating the piles and amending the oxide fines with limestone to neutralize acidity and provide excess neutralization capacity to neutralize future acid generation, thereby limiting long-term contaminant release;
- Relocating the oxide fines to a contained location such as within the confines of the Main Pit above the water table where seepage can be collected and treated;

- Relocating the oxide fines to below the water level in the Main Pit;
- Amending the oxide fines with lime to neutralize acidity and relocating the neutralized material below the water table in the Main Pit to prevent future acid generation.

A similar series of options are also available for the oxide fines at the Vangorda Pit.

This report presents results of investigations directed towards assessing the above options, recommends preferred options, and describes additional investigations that will be required to verify the performance and costs associated with the recommended strategy.

In addition to the oxide fines, low grade ore was placed in stockpiles at the site. The low grade ore is characterized by elevated zinc and sulphide minerals that are or will be generating acidic drainage with elevated zinc concentrations similar to those observed for the oxide fines. Also, like the oxide fines, the low grade ore has been placed in discrete and well-defined stockpiles that can easily be distinguished from the surrounding waste rock. Finally, the low grade ore could be mitigated by the same methods that apply to the oxide fines. Therefore, the low grade ore has been included in the investigations and option evaluation described herein.

2 Characterization of the Oxide Fines

2.1 Introduction

The field investigation of the oxide fines (and low grade ore) commenced in June of 2004 and at the time of writing the laboratory program had been initiated but not yet completed. The results from the laboratory investigation will be incorporated into the final oxide fines management plan. The results from the field investigations, together with any available results from the site-wide geochemical studies carried out in 2002 and 2003, are presented in the following sections.

2.2 Results from 2002/03 Investigations

Acid base accounting results are available for two samples from the Faro Crusher Stockpile and one sample from the Vangorda Baritic Fines. The results are provided in Table 2.1 and show that the samples have a high potential for acid generation, with little or no residual neutralization capacity.

Table 2.1
Acid Base Account Test Results from 2002/03

Sample Description	Paste pH	S(T) %	$S(SO_4)$ %	AP	NP	Net NP	NP/AP	TIC %	CO_3 NP
Faro Crusher Stockpile	6.9	6.71	0.10	207	24.8	-182	0.1	1.13	94.2
Faro Crusher Stockpile	5.7	18.6	0.40	569	7.8	-562	<0.1	0.67	55.8
Vangorda Baritic Fines	4.5	20.2	0.68	610	-2.7	-613	<0.1	0.19	15.8

These three samples together with one sample from each of the Faro Low Grade Ore Stockpile, Faro Oxide Fines, and the Faro Medium Grade Stockpile were analyzed for metals and sulphur species. These results are presented in Table 2.2. As shown, the samples are characterized by elevated zinc (0.5 % to 5.38 %) and lead contents (> 1 %).

The acid base accounting properties were also inferred from the inorganic carbon and sulphide sulphur contents. As shown at the bottom of Table 2.2, all samples are acid generating, with net acid production potentials in the range of about 112 to 1,099 kg$CaCO_3$ eq/tonne.

Leach extraction tests, utilizing a ratio of three parts distilled water to one part sample (weight ratio), were also completed on four of these samples. The results are summarised in Table 2.3. Three of the four samples were acidic and leached metals at elevated concentrations, including zinc, copper and cadmium. Total acidities (titrated to a pH of 8.5) ranged from 1,200 to 4,000 mg$CaCO_3$eq/L, which is equivalent to a lime demand of 3.7 to 12.2 kg per tonne (as CaO). Zinc leached at a concentration of 32.8 mg/L from the Faro Crusher Stockpile sample, even though it had a neutral pH.

Table 2.2
Summary of Elemental Analysis and Sulphur Speciation

Parameter / Units		Analysis					
		Faro Low Grade Ore Stockpile 'A'	Faro Oxide Fines Stockpile	Faro Medium Grade Stockpile	Faro Crusher Stockpile	Faro Crusher Stockpile	Vangorda Baritic Fines Stockpile
Ag	ppm	11.4	47.2	24.0	18.0	38.6	27.2
Al	%	0.07	0.27	0.30	0.25	0.31	0.55
As	ppm	415	110	2,420	1,170	1,740	1,705
Co	ppm	48	39	27	25	39	129
Cr	ppm	50	76	94	106	103	115
Cu	ppm	681	731	1175	392	935	5714
Fe	%	>15.00	13.70	9.32	8.47	14.17	>15.00
Mn	ppm	65	120	180	705	570	1170
Mo	ppm	<2	6	16	6	-2	2
Ni	ppm	14	10	28	55	58	27
Pb	ppm	>10,000	>10,000	>10,000	12,400	29,300	20,900
Pb	%	1.84	3.72	2.19	1.24	2.93	2.09
Sb	ppm	20	55	95	60	95	65
Zn	ppm	6496	4571	>10,000	22,100	53,800	20,500
Zn	%	-	-	1.78	2.21	5.38	2.05
S(T)	%	36.2	11.9	10.3	6.7	18.6	20.2
$S(SO_4)$	%	1.03	2.16	1.10	0.10	0.40	0.68
TIC	%	<0.01	<0.01	0.01	1.13	0.67	0.19
AP		1099	304	288	207	569	610
CO_3NP		<1	<1	1	94	56	16
NNP		-1099	-304	-288	-112	-513	-594

Table 2.3
Summary of Leach Extraction Test Results

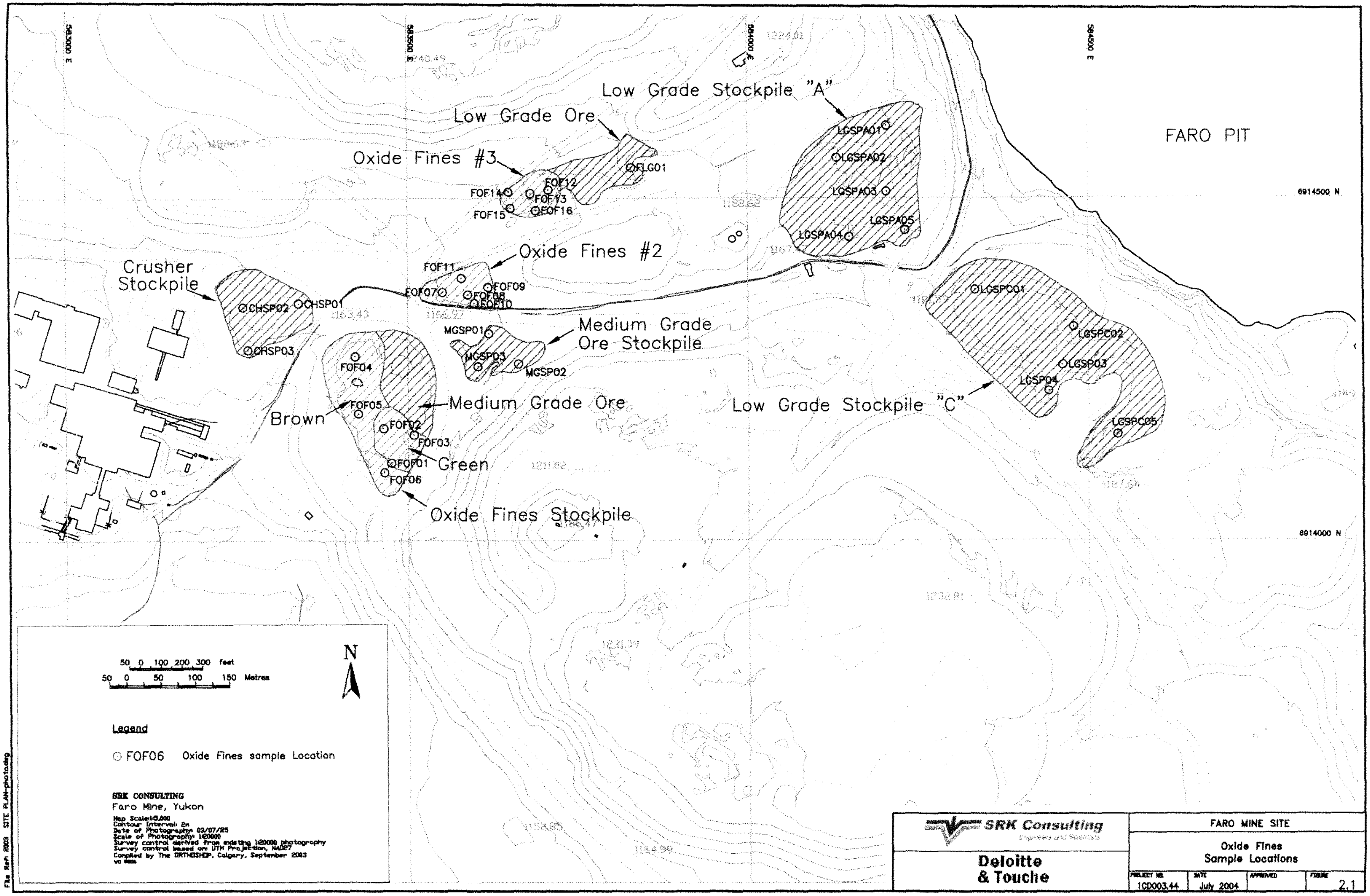
Parameter / Units			Vangorda Baritic Fines Stockpile	Faro Low Grade Ore Stockpile 'A'	Faro Medium Grade Stockpile	Faro Crusher Stockpile
pH			3.73	2.52	3.26	7.04
Redox.		(mV)	413	449	440	333
Conductivity		(uS/cm)	2530	4800	4880	950
Alkalinity		(mg CaCO3/L)	0.0	0.0	0.0	9.5
Acidity		(pH 4.5) (mg $CaCO_3$/L)	20	350	130	0
Acidity		(pH 8.3) (mg $CaCO_3$/L)	1240	2500	4060	31
Sulphate		(mg/L)	2540	3220	6100	651
Dissolved Metals						
Aluminum	Al	(mg/L)	18	14	68	<0.2
Arsenic	As	(mg/L)	<1	<1	<3	<0.2
Cadmium	Cd	(mg/L)	4.40	1.24	5.30	0.06
Calcium	Ca	(mg/L)	202	209	166	204
Cobalt	Co	(mg/L)	4.04	0.33	1.9	0.08
Copper	Cu	(mg/L)	73.0	21.9	34.3	<0.01
Iron	Fe	(mg/L)	20.2	464	39.2	<0.03
Lead	Pb	(mg/L)	1.7	1.7	<0.8	0.5
Magnesium	Mg	(mg/L)	92.2	15.5	91	27.8
Manganese	Mn	(mg/L)	124	11.9	42.9	0.952
Nickel	Ni	(mg/L)	1.4	0.4	1.8	0.1
Zinc	Zn	(mg/L)	803	922	2570	32.8

2.3 2004 Field Investigation

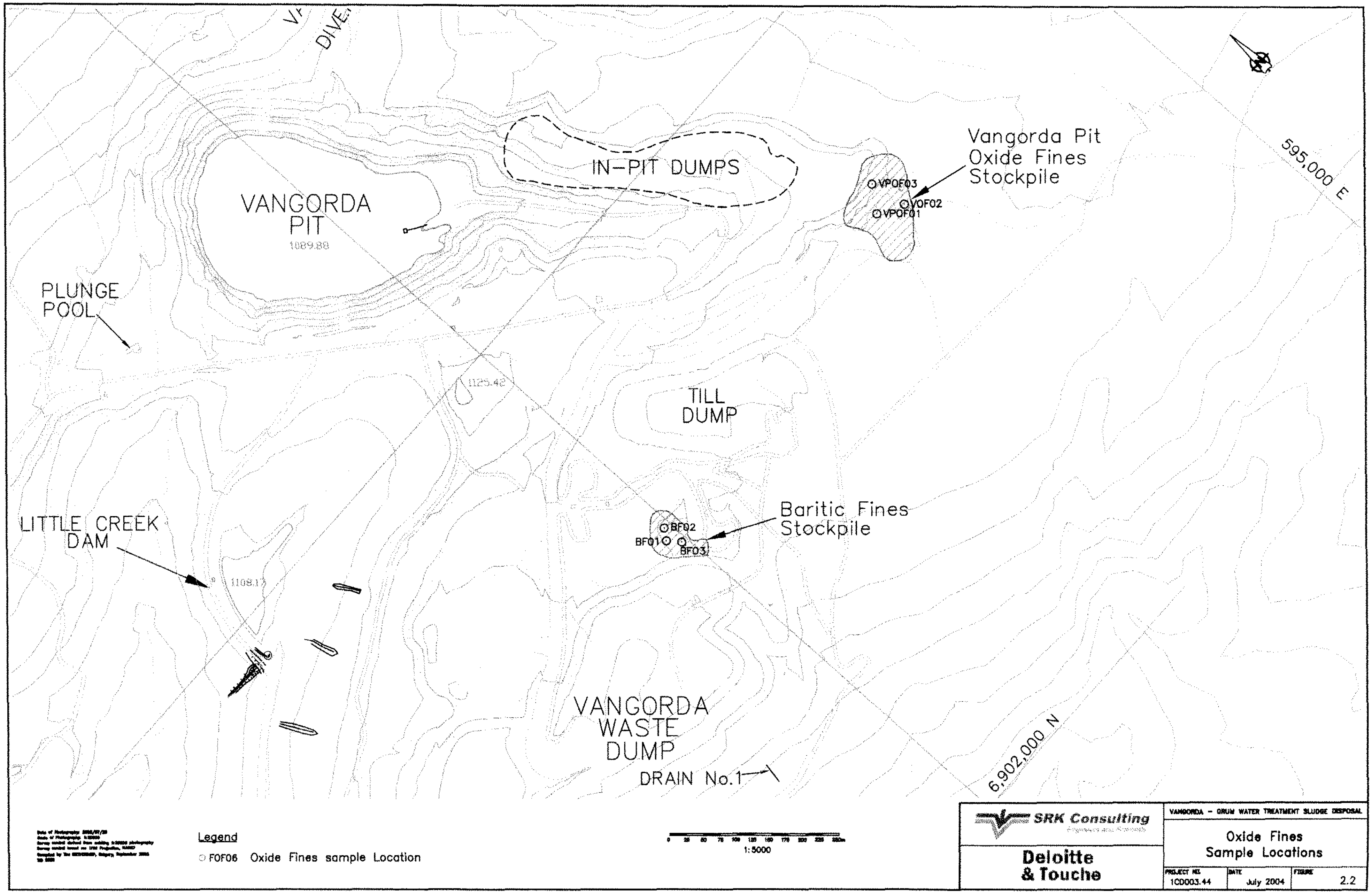
2.3.1 Mapping

The parts of the site known to contain oxide fines or low grade ore were traversed on foot to delineate each area. Figure 2.1 shows the oxide fines and low grade ore stockpiles areas at the Faro site, and Figure 2.2 shows the areas at the Vangorda Site.

There may be smaller areas outside of those identified that may contain oxide fines; however, these areas are expected to the relatively small. For example, there are small areas within the confines of the Faro Main Waste Rock Dump, adjacent the haul road to Vangorda/Grum that appear to be oxide fines. However, that deposit of oxides fines is integral to the Main Dump, and it would be very difficult to remediate it separately from the Main Dump. It was therefore not sampled within this program. There may also be other smaller areas of oxide fines that may be accessible and could be independently remediated. These areas could be addressed as part of the broader oxide fines management plan.



583000 E
583500 E
584000 E
584500 E
6914500 N
6914000 N
FARO PIT
Low Grade Stockpile "A"
LGSPA01
LGSPA02
LGSPA03
LGSPA04
LGSPA05
Low Grade Ore
FLG01
Oxide Fines #3
FOF12
FOF13
FOF14
FOF15
FOF16
Oxide Fines #2
FOF07
FOF08
FOF09
FOF10
FOF11
Crusher Stockpile
CHSP01
CHSP02
CHSP03
Medium Grade Ore Stockpile
MGSP01
MGSP02
MGSP03
Medium Grade Ore
Brown
Green
FOF01
FOF02
FOF03
FOF04
FOF05
FOF06
Oxide Fines Stockpile
Low Grade Stockpile "C"
LGSPC01
LGSPC02
LGSP03
LGSP04
LGSPC05
50 0 100 200 300 feet
50 0 50 100 150 Metres
N
Legend
FOF06 Oxide Fines sample Location
SRK CONSULTING
Faro Mine, Yukon
Map Scale 1:5,000
Contour Interval: 2m
Date of Photography 03/07/25
Scale of Photography 1:20000
Survey control derived from existing 1:20000 photography
Survey control based on UTM Projection, NAD27
Compiled by The ORTHOSHOP, Calgary, September 2003
SRK Consulting
Deloitte & Touche
FARO MINE SITE
Oxide Fines Sample Locations
PROJECT NO. 1CD003.44
DATE July 2004
APPROVED
FIGURE 2.1



VANGORDA PIT
1089.88
IN-PIT DUMPS
Vangorda Pit Oxide Fines Stockpile
VPOF03
VOF02
VPOF01
595,000 E
PLUNGE POOL
1125.42
TILL DUMP
Baritic Fines Stockpile
BF02
BF01
BF03
LITTLE CREEK DAM
1108.17
VANGORDA WASTE DUMP
DRAIN No.1
6,902,000 N
Legend
FOF06 Oxide Fines sample Location
1:5000
SRK Consulting
Deloitte & Touche
VANGORDA - GRUM WATER TREATMENT SLUDGE DISPOSAL
Oxide Fines Sample Locations
1CD003.44
July 2004
2.2

At the Vangorda site, the fill area identified at the southeast end of the pit was included because: i) in appearance the material is a greenish colour similar to that observed for oxide fines at the Faro Site, ii) it is fine grained and high in sulphide mineral content, and iii) the 2004 seepage monitoring indicated that flow from this area is acidic and contains in excess of 1,500 mg/L zinc.

The surface areas have been determined and the volumes of the material contained in each location have been estimated. The results are summarised in Table 2.4. Since it was not possible within the scope of the preliminary field investigation to determine the vertical extent of each of the stockpiles, two volume estimates are presented in the table. The first estimate represents the volume of material to the visible or best judgement base of the pile. The second estimate makes the conservative assumption that the pile extends to the pre-mining topography. Where the extent of the pile is clear, only a single volume estimate is presented.

Table 2.4
Summary of Planimetric Surface Areas and Estimated Volumes

Description	Planimetric Area (m^2)	Estimated Volume (m^3)	
		To Current Base of Pile	To Pre-mining Topography
Faro			
Oxide fines- green	5,000	21,000	-
Oxide fines- brown	14,000	38,000	-
Oxide fines- medium grade	9,000	50,000	-
Crusher stockpile	12,000	42,000	95,000
Medium grade stockpile	6,000	10,000	138,000
Oxide fines #2	5,000	10,000	67,000
Oxide fines #3	5,000	-	39,000
Low grade ore	7,000	-	44,000
Low grade stockpile A	36,000	71,000	555,000
Low grade stockpile C	51,000	333,000	723,000
Total	**150,000**	**658,000 to 1,770,000**	
Vangorda			
Vangorda Pit Oxide Fines	11,000	22,000	0
Baritic Fines Stockpile	4,000	3,000	38,000
Total	**15,000**	**25,000 to 60,000**	

2.3.2 Sampling

A total of 33 samples were obtained during the reconnaissance of the oxide fines and low grade ore stockpiles. The 27 Faro site sample locations are shown in Figure 2.1, and the 6 Vangorda site sample locations are shown in Figure 2.2. The samples were obtained by excavating shallow test pits (0.3 to 0.6 m) and obtaining a representative sample of the entire depth of the test pit. The samples were screened in the field to less than 10 mm, and field paste pH and conductivity measurements were completed.

The paste parameters are shown in Table 2.5. The oxide fines and the low grade ore stockpiles have on average a paste pH of between 2.0 and 2.5, with average conductivities ranging from 3,000 to

6,000 uS/cm. The Medium Grade Ore Stockpile and the Vangorda Baritic Fines Stockpile have average paste pH values of 3.7 and 3.0 respectively, with corresponding average conductivities of about 2,200 and 5,300 uS/cm. The oxide fines and low grade ore are clearly in an advanced state of oxidation and acid generation with high levels of stored acidity. The Faro Crusher Stockpile, likely represents the 'freshest' material sampled, with an average paste pH of about 5.6 and an average conductivity of about 2,200 uS/cm. However, the material has been shown to have a high potential to generate acid and it is recommended that it be incorporated in the oxide fines management plan.

2.3.3 Lime Demand Testing

The objectives of the lime demand tests were (i) to assess the amount of lime that would be required to neutralize a sample of acidic oxide fines or low grade ore to an endpoint pH of about 9.5 (to remove most of the zinc from solution) and (ii) to determine if the lime demand can easily and accurately be related to field parameters, which would enable field control of lime addition if it is selected as a management option.

A rapid test procedure was developed appropriate to conditions and state of oxidation of the Anvil Range samples. In precursor tests, aspects relating to the contact time before and after lime amendment were investigated to ensure that the results would accurately reflect the total lime demand of the samples. It should be recognized that these tests were completed under field conditions, and will require verification under more controlled laboratory conditions at a later date. However, for the purposes of this evaluation, these results are considered adequate.

The test procedure entailed contacting 200 g of the rock sample (screened to less than 10 mm) with 400 mL of site water for a period of one hour during which the sample was thoroughly stirred twice. The water pH and conductivity were then measured, and based on the results, the sample was titrated with milk of lime slurry (10 g/L or 100 g/L depending on initial pH and conductivity) to an endpoint pH between 9.5 and 10. The neutralized slurry was then stirred thoroughly twice over a period of one hour. The pH was measured and again adjusted to above 9.5 with milk of lime if it had decreased to below this value. The total volume of lime slurry added to the test was recorded and used to calculate the lime demand.

The results from the lime demand tests for the Faro site samples are summarised in Table 2.6 and those for the Vangorda site are summarised in Table 2.7. Detailed results are provided in Appendix A.

Table 2.5
Field Paste pH and Conductivity

Site	Description	Sample	Paste pH	Conductivity (uS/cm)
Faro	Crusher Stockpile	CHSP01	5.55	1612
		CHSP02	5.30	2340
		CHSP03	5.80	2560
	Average		**5.55**	**2171**
	Low Grade Ore	FLG01	2.15	5140
	Oxide Fines Stockpiles	FOF01	2.03	9950
		FOF02	2.24	8550
		FOF03	2.31	7040
		FOF04	1.96	8340
		FOF05	2.04	8180
		FOF06	2.16	8510
		FOF07	2.34	4090
		FOF08	2.04	6300
		FOF09	2.07	5530
		FOF10	2.14	4740
		FOF11	2.08	4680
		FOF12	2.21	4680
		FOF13	2.23	5360
		FOF14	2.13	6040
		FOF15	2.02	6060
		FOF16	1.96	5130
	Average		**2.12**	**6449**
	Low Grade Ore Stockpile A	LGSPA01	2.15	5010
		LGSPA02	2.25	4360
		LGSPA03	2.36	5560
		LGSPA04	2.37	2250
		LGSPA05	2.23	3930
	Average		**2.27**	**4222**
	Low Grade Ore Stockpile C	LGSPC01	2.94	2120
		LGSPC02	2.05	4880
		LGSPC03	2.35	3080
		LGSPC04	2.60	2460
		LGSPC05	2.42	4740
	Average		**2.47**	**3456**
	Medium Grade Ore Stockpile	MGSP01	2.77	1940
		MGSP02	5.25	2120
		MGSP03	3.10	2680
	Average		**3.71**	**2247**
Vangorda	Baritic Fines Stockpile	BF01	3.47	5250
		BF02	2.38	6210
		BF03	3.17	4690
	Average		**3.01**	**5383**
	Pit Oxide Fines	VPOF01	2.60	5800
		VPOF02	2.38	5760
		VPOF03	2.33	5370
	Average		**2.44**	**5643**

Table 2.6
Summary of Estimated Lime Demand for Faro Oxide Fines and Low Grade Ore Stockpiles

Location	Lime demand (kg CaO/tonne)			
	Sample	**Stage 1**	**Stage 2**	**Overall**
Crusher Stockpile	CHSP01	0.63	0.00	0.63
	CHSP02	0.70	0.00	0.70
	CHSP03	0.33	0.00	0.33
Average		**0.55**	**0.00**	**0.55**
Low Grade Ore	FLG01	6.65	0.00	6.65
Average		**6.65**	**0.00**	**6.65**
Oxide Fines Stockpiles	FOF01	13.00	0.00	13.00
Area 1 – Green/Brown	FOF02	15.50	1.95	17.45
	FOF03	11.75	3.35	15.10
	FOF04	17.50	2.30	19.80
	FOF05	23.75	1.20	24.95
	FOF06	17.65	0.00	17.65
Average		**16.53**	**1.47**	**17.99**
Area 2 – Oxide Fines #2	FOF07	13.50	1.00	14.50
	FOF08	15.00	0.00	15.00
	FOF09	14.50	1.90	16.40
	FOF10	7.50	0.00	7.50
	FOF11	9.35	0.00	9.35
Average		**11.97**	**0.58**	**12.55**
Area 3 – Oxide Fines #3	FOF12	7.55	2.00	9.55
	FOF13	7.20	0.75	7.95
	FOF14	8.00	0.50	8.50
	FOF15	9.25	1.00	10.25
	FOF16	8.50	0.80	9.30
Average		**8.10**	**1.01**	**9.11**
Low Grade Ore Stockpile A	LGSPA01	9.65	0.00	9.65
	LGSPA02	5.15	0.00	5.15
	LGSPA03	8.90	0.35	9.25
	LGSPA04	3.80	0.00	3.80
	LGSPA05	8.85	0.00	8.85
Average		**7.27**	**0.07**	**7.34**
Low Grade Ore Stockpile C	LGSPC01	1.95	0.00	1.95
	LGSPC02	6.75	0.70	7.45
	LGSPC03	2.40	0.50	2.90
	LGSPC04	3.95	0.00	3.95
	LGSPC05	4.00	0.85	4.85
Average		**3.81**	**0.41**	**4.22**
Medium Grade Ore Stockpile	MGSP01	3.00	0.00	3.00
	MGSP02	1.08	0.00	1.08
	MGSP03	2.75	0.00	2.75
Average		**2.28**	**0.00**	**2.28**

Table 2.7
Summary of Estimated Lime Demand for Vangorda Oxide Fines and Baritic Fines Stockpiles

Location	Lime demand (kg CaO/tonne)			
	Sample	**Stage 1**	**Stage 2**	**Overall**
Baritic Fines Stockpile	BF01	7.00	1.50	8.50
	BF02	7.80	2.00	9.80
	BF03	4.60	0.25	4.85
Average		**6.47**	**1.25**	**7.72**
Pit Oxide Fines	VPOF01	8.15	0.80	8.95
	VPOF02	7.55	0.80	8.35
	VPOF03	8.00	2.00	10.00
Average		**7.90**	**1.20**	**9.10**

The results indicate that there is some variability even within the more oxidized oxide fines and low grade ore stockpile material. Consequently, as shown in Table 2.6 and 2.7, the results for the oxide fines have further been subdivided according to the areas where the samples were obtained (see Figure 2.1), and averages were calculated for each of these areas. Generally, the average lime demand ranges from about 2.3 kg CaO per tonne for the medium grade ore stockpile, to about 18 kg CaO per tonne for the more oxidized oxide fines. Clearly, the Crusher Stockpile material is relatively un-oxidized (high pH, low paste conductivity) and the estimated current lime demand is about 0.55 kg CaO per tonne. These results suggest that material handling and amendment strategies may need to be varied from one area to another to accommodate these differences.

The lime demand can be used to estimate the costs that would be associated with neutralizing the contained acidity in the oxide fines and the low grade ore stockpiles. The estimated unit costs are shown in Table 2.8, and can be combined with the volume estimates to estimate overall costs should lime neutralization be considered. These costs do not include neutralization of acidity that may be generated in the future.

Table 2.8
Summary of Estimated Lime Amendment Costs to Neutralize Contained Acidity

Location		Lime Demand (kg/tonne)	Lime Cost ($/tonne)
Crusher Stockpile		0.55	0.18
Low Grade Ore		6.65	2.13
Oxide Fines Stockpiles	Area 1	17.99	5.76
	Area 2	12.55	4.02
	Area 3	9.11	2.92
Low Grade Ore Stockpile A		7.34	2.35
Low Grade Ore Stockpile C		4.22	1.35
Medium Grade Ore Stockpile		2.28	0.73
Baritic Fines Stockpile		7.72	2.47
Pit Oxide Fines		9.10	2.91

3 Preliminary Options Evaluation

3.1 Objectives

The objectives that were considered for evaluating the oxide fines management options are as follows:

- The option should achieve a significant reduction of metal loadings within a short time frame.
- The option should be effective in the short and medium term, with the potential for upgrading as part of the overall site rehabilitation program.
- The option should be cost effective and implementable using site resources where possible.
- The option should not impede or impact on measures that may be considered in the final closure and reclamation plan.

3.2 Preliminary Options Evaluation – Faro Site

Table 3.1 summarizes the preliminary evaluation of options for management of the oxide fines at the Faro site. The table identifies and provides brief descriptions of seven primary options, with variants for a number of them. The advantages and disadvantages are identified, and an indication as to whether an option is feasible within the context of the site considerations, potential future activities, and any other applicable considerations. The best options are discussed further in the following bullets.

- Option 3 – Cover in place. Covering in place would require that the oxide fines be contoured to appropriate side-slopes to meet the requirements for the cover under consideration. Three cover options have been identified, with increasing efficiency. A cost-benefit analysis will be required to identify the most effective cover.
- Option 4 – Consolidate and cover. The benefit of consolidating the oxide fines and low grade ore stockpiles is that the overall footprint is reduced. This also means that the area of the cover would be reduced. Consolidating all the sources to one location has obvious advantages. Ultimately, however, there will be a trade-off between the reduction in cost associated with the cover (from cover in place to a smaller cover for the consolidated piles) against the increase in cost associated with re-handling.
- Option 7 – Relocate to the Faro Pit. Of this option, only the third variant, amending with lime to neutralize acidity and deposition below the water level, will adequately meet the objectives for the oxide fines management plan. To prevent the immediate release of zinc into the pit water, it will be necessary to neutralize the oxide fines to a minimum pH of 9.5 before the material is dumped in the pit lake. However, the oxide fines tend to be clayey and are relatively moist. This material will be very difficult to neutralize effectively on a dry basis as it would tend to 'ball' when mixed resulting in incomplete neutralization. Therefore a 'wet' neutralization step would need to be tested. Long-term release of zinc, through dissolution of the neutralized

acidity, is also a potential concern and may represent a significant risk to the water quality in the Faro Pit.

With respect to Option 7, consideration may also be given to relocating the Faro oxide fines to the Vangorda Pit, should backfilling be identified as the preferred option for the Vangorda Pit. Due to their reactivity, the oxide fines would likely be placed at the bottom of the pit; neutralization would still be required to protect groundwater quality. This option would increase the overall costs, however, any potential constraints on closure options for the Faro Pit would be removed.

Table 3.1
Summary Description of Oxide Fines Management Options

Item	Option	Option Description	Advantages	Disadvantages	Recommendations/ Information requirements
1	Seepage collection and treatment	Collection ditches would be installed to intercept seepage	› Immediate reduction of loadings; › Treatment plant already in place; › Reductions will be effective for as long as the mill treatment plant is operational; › Low cost capital cost; › Most flexible option and least likely to impact potential options for the rest of the site.	› Disseminated piles will complicate seepage collection; › Infiltration to sub-soils will not be captured; › High operating costs	Need to assess the feasibility of collecting seepage at X23 and adjacent to the stockpiles
		a) Treat directly in treatment plant	› Treat high concentration stream more effectively; › Lower volumes	› Requires treatment plant to be operated from spring thaw to winter freeze-up › Would require surge capacity i.e. it would be necessary to construct an impoundment at or below X23 to contain and store high flow conditions) › New construction will increase project footprint	Will require an assessment of required surge capacity, feasibility of new impoundment and implications with respect to water treatment.
		b) Pump to and store in Faro Pit	› Provides surge/storage capacity	› Will increase contaminant levels in pit lake; › May preclude in pit treatment system	Need to assess impacts on pit lake water quality and assess implications to final closure
2	Compact Surfaces	Surface of stockpiles would be regraded and compacted to reduce permeability of the surface layer and to minimize infiltration	› Low cost; › Easy to implement.	› Surface runoff will remain contaminated at previous levels; › Compacted layer will be disrupted by freeze-thaw action leading to a loss of low permeability; › Disturbance could lead to increased short-term loadings	Not recommended. (Will not meet minimum performance requirements)

Table 3.1 (cont.)

Item	Option	Option Description	Advantages	Disadvantages	Recommendations/ Information requirements
3	Cover in Place	Slopes would be regraded to enable cover placement. Three cover options available as follows:	› Limits disturbance and reduces risk of short-term releases		Can provide effective control. Will require complete cover design cost-benefit analysis to select appropriate design. Preliminary indications suggest that the HDPE cover would be most cost effective
		a) soil cover (compacted till, uncompacted layer to support vegetation, total thickness of 2 m)	› Expected to reduce infiltration volumes	› Long haul distances for appropriate soils; › Susceptible to frost action	
		b) Geosynthetic (GCL) composite cover with about 1.5 m frost protection (till)	› Better performance expected than for soil cover – expect up to 95 % reduction in infiltration volumes	› GCL need cover layer to provide confinement and protect it from freezing conditions	
		c) Synthetic (HDPE) overlain by 0.5 m soil	› Excludes water completely and limits oxygen effectively;	› Reduced slope (4:1) will increase footprint; › May be impossible in some areas due to limited available area for increased footprint; › Difficult to place in winter	

Table 3.1 (cont.)

Item	Option	Option Description	Advantages	Disadvantages	Recommendations/ Information requirements
4	Consolidate and cover	The stockpiles would be consolidated to a single location and covered. Cover options would be as for Item 3 above. Relocation options as follows:	› Reduces overall footprint and thus volume of infiltration; › Provides for controlling seepage	› High cost for relocation; › Disturbance may lead to significant short-term releases	Requires cost benefit assessment. ("Trade-off" between reduced cover area and volumes relocated)
		a) Relocate to a lined facility	› Effective control of seepage (collect and treat); › Direct measure of infiltration and cover performance	› High costs; › Requires a stable, flat location for construction of a lined facility	Not recommended (Incremental foot print and additional costs are not likely to justify the benefits.)
		b) Relocate to the Main Dump and place above the sulphide cell	› Sulphide cell also covered when cover placed	› Seepage from oxide fines may accelerate depletion of neutralization capacity of the Main Dump	Not recommended (Due to potential impacts and implications to overall closure plan, potential for accelerating acidification of main dump, and overall costs to move entire volume of oxide fines and low grade ore stockpiles)
		c) Consolidate at Stockpile "C"	› Would not need to relocate Stockpile "C" which represents about half of the volume	› Seepage likely to enter the Faro Pit	Recommend for further investigation. Need to verify that oxide fines and low grade ore stockpiles can be accommodated in the Stockpile "C" location
5	Amend with lime, consolidate and cover	During the relocation, lime would be blended in with the oxide fines to neutralize acidity; cover options as described above in Item 3.	› Will affect immediate reduction in loadings and control short-term release effectively.	› High cost (could add between $2 million and $6 million to cost of relocation and cover); › Low lime efficiency expected due to clayey nature of oxide fines and blinding from high acidity › Will need 'wet' mixing system	Not recommended. (Lime amendment will provide short-term benefits only if covered with conventional soil covers, and little benefit if covered with HDPE cover and is not likely to be a feasible option due to cost implications.)
6	Amend with limestone to limit future acid generation, consolidate and cover	During the relocation, limestone would be blended in with the oxide fines to neutralize acidity and provide excess neutralization potential for future acid generation	› Long-term control on acid generation and metal leaching	› High limestone requirements (between 100 to 1000 kg/tonne) which will increase the volume of material significantly; › Cost will be very hihgh	Not feasible. Not recommended

Table 3.1 (cont.)

Item	Option	Option Description	Advantages	Disadvantages	Recommendations/ Information requirements
7	Relocate to the Faro Pit	The stockpiles would be consolidated to a single location within the Faro Main pit. The following options are available:			
		a) Locate within the catchment of the pit above the water level	› Seepage contained within the catchment of an existing water treatment system	› Does not affect future acid generation; likely to exacerbate short-term releases due to disturbance; › Will significantly increase metal concentrations in the pit lake	Not recommended. (Metal loading to the pit lake will increase and will impact water quality significantly)
		b) Place below water	› Will prevent future oxidation and acid generation; will release contained acidity to the confines of the existing water treatment system	› Will significantly impact water quality in Faro Pit	Not recommended. (This could increase the acidity in the pit lake by as much as 450 to 1200 mg $CaCO_3$ eq/L)
		c) Amend with lime to neutralize contained acidity and place below water	› Neutralization of contained acidity will reduce impacts on pit lake water quality; will prevent future acid generation	› High cost (could add between $2 million and $6 million to cost of relocation and cover); › Low lime efficiency expected due to clayey nature of oxide fines and blinding from high acidity › Will need 'wet' mixing system › Neutralized acidity could dissolve over the long term, releasing zinc	Offers the best long term control on future acid generation and may address short-term releases effectively.

3.3 Preliminary Options Evaluation – Vangorda Site

The evaluation for the Vangorda Site is somewhat simpler since the volumes of materials involved are significantly smaller. Following an evaluation process similar to that above, it can be concluded that the favourable options include:

- Consolidating and covering;
- Neutralizing and placing below water in the Vangorda pit; and,
- Consolidating with the Faro oxide fines.

Consolidating the Baritic Fines with the Vangorda Pit Oxides fines, within the confines of the Vangorda pit would have the advantage that any seepage would report to an existing water treatment collection point. However, this option would adversely affect the pit lake water in the long term.

Placing the Baritic and Oxide fines below water in the Vangorda pit would require complete neutralization of contained acidity to a pH in excess of 9.5 prior to deposition. Long-term porewater quality would need to be assessed.

Consolidating the Baritic Fines and Oxide fines with those at the Faro site is an attractive option since it would completely remove the oxide fines from the Vangorda site. This option would be considered if consolidate and cover is selected as the primary option at the Faro site, but could also be considered in the event that neutralization and underwater disposal is selected. The latter case offers the advantage that the potential for contaminant release would be restricted to only one pit lake.

4 Recommendations

4.1 Faro Oxide Fines

As discussed in the previous section, Option 7, neutralizing the oxide fines with lime and relocating them to below the water level in the Faro pit, would provide the maximum control on metal release and acid generation in the future. However, there are a number of questions associated with this option including the ability to blend lime with the fines and the effects on long-term water quality in the pit lake.

Covering of the oxide fines (Option 3), with or without consolidation (Option 4), would also provide effective control on metal and acid release. Consolidation will reduce the footprint of the oxide fines materials, and infiltration would further be reduced by a suitable cover system. There are several options available, and an optimum combination of consolidating and covering needs to be determined.

For both options, there is insufficient information to estimate costs. However, it is clear that costs for lime amendment and relocation to the Faro Pit will far exceed that of consolidation and covering. On the other hand, the 'consolidate and cover' options will have ongoing care and maintenance costs.

To develop reliable performance and cost estimates for the remaining options, it is recommended that the following steps be undertaken.

Option 3 / 4 – Consolidate and Cover

i) Verify the size of oxide fines stockpiles by completing test pit excavations where possible to verify the base or extent of the stockpile areas, and compute overall volumes;

ii) Evaluate available 'storage capacity' at Stockpile "C" from current topography and final slope requirements for cover placement and optimize the volume that might be consolidated and/or covered in place;

iii) Estimate potential implications / constraints on final rehabilitation strategies that may be considered for the adjacent areas, including the Faro Pit.

iv) Select a preferred cover based on performance criteria and cost implications;

v) Assess overall performance for the option, estimate capital and care and maintenance costs.

Option 7 Amend and Place Below Water in Faro Pit

i) Identify methods and assess feasibility of 'wet' and 'dry' lime amendment;

ii) Complete 'wet' and 'dry' field scale tests, for example using a cement mixer, at site to determine mixing requirement, effects of moisture content on acidity neutralization and lime utilization, and any other parameters that may affect neutralization;

iii) Assess settling rates and solute release when neutralized material is 'dumped' into a column of water using large scale column tests;

iv) Determine potential changes in pore water quality under anoxic conditions by complete saturated anoxic column tests;

v) Assess impacts on the pit lake; and,

vi) Estimate overall implementation costs.

As noted before, placement in the Vangorda Pit may also be considered should backfilling of that pit be selected as the preferred closure option. In that case, haulage costs would need to be considered in the final analysis.

Once the above steps have been completed, the options can be compared and a preferred option selected. A final design would then be completed and implemented.

4.2 Vangorda Pyritic and Oxide Fines

While the volumes of oxide fines at the Vangorda site are small in comparison to those at the Faro site, a similar evaluation process is recommended. In this case, consideration should also be given to the relocation and consolidation or co-disposal of the Vangorda material with the Faro oxide fines. This latter consideration will require only that the relocation costs be estimated and added to the other option costs.

Prepared by

John Chapman

Reviewed by

Darryl Hockley

Appendix A

Lime Demand Test Results

Appendix A - Lime Demand Test Results

Description	Sample ID	Paste Parameters pH	Paste Parameters Cond. (mS/cm)	Initial pH	Initial Cond. (mS/cm)	After 60 min pH	After 60 min Cond. (mS/cm)	Stage 1 Lime (mL) 10 g/L	Stage 1 Lime (mL) 100 g/L	Immediate pH	Immediate Cond. (mS/cm)	At 60 min. pH	Stage 2 Lime 10 g/L	End Pt. pH	Lime demand Stage 1	Lime demand Stage 2	Lime demand Overall
FARO								10	100				10				
Crusher Stockpile	CHSP01	5.6	1.61	-	-	5.9	2.02	12.5	-	9.5	-	-	0		0.63	0.00	0.63
	CHSP02	5.3	2.34	6.1	1.68	5.5	2.01	14	-	9.7	-	9.6	0	-	0.70	0.00	0.70
	CHSP03	5.8	2.56	-	-	6.0	2.63	6.5	-	9.6	-	9.6	0		0.33	0.00	0.33
Average		**5.6**	2.17												**0.55**	**0.00**	**0.55**
Low Grade Ore	FLG01	2.2	5.14	-	-	2.3	4.62	8	12.5	9.5	-	-	0		6.65	0.00	6.65
															6.65	**0.00**	**6.65**
Oxide Fines Stockpiles	FOF01	2.0	9.95	-	-	2.2	7.07	-	26	9.7	-	-	0		13.00	0.00	13.00
	FOF02	2.2	8.55	2.3	7.06	2.5	6.35	-	31	9.5	4.06	8.1	39	9.6	15.50	1.95	17.45
	FOF03	2.3	7.04	-	-	2.5	5.50	5	23	9.7	-	-	67	9.6	11.75	3.35	15.10
	FOF04	2.0	8.34	2.2	8.44	2.2	6.68	-	35	9.8	4.70	7.6	46	9.5	17.50	2.30	19.80
	FOF05	2.0	8.18	2.0	9.29	2.2	6.92	475	-	9.5	5.29	8.5	24	9.5	23.75	1.20	24.95
	FOF06	2.2	8.51			2.3	7.66	3	35	9.5	-	-	0		17.65	0.00	17.65
Average															**16.53**	**1.47**	**17.99**
	FOF07	2.3	4.09	-	-	2.4	6.65	-	27	9.7	-	-	20	9.5	13.50	1.00	14.50
	FOF08	2.0	6.30	2.1	6.84	2.2	5.93	-	30	11.6	7.06	9.9	0	-	15.00	0.00	15.00
	FOF09	2.1	5.53	2.1	7.05	2.1	6.04	-	29	9.7	5.11	7.9	38	9.4	14.50	1.90	16.40
	FOF10	2.1	4.74	-	-	2.4	5.77	-	15	9.9	-	-	0		7.50	0.00	7.50
	FOF11	2.1	4.68	-	-	2.3	6.18	7	18	9.7	-	-	0		9.35	0.00	9.35
Average															**11.97**	**0.58**	**12.55**
	FOF12	2.2	4.68	-	-	2.3	4.06	11	14	9.5	-	-	40	9.5	7.55	2.00	9.55
	FOF13	2.2	5.36	-	-	2.3	4.23	4	14	9.6	-	-	15	9.6	7.20	0.75	7.95
	FOF14	2.1	6.04	-	-	2.1	4.99	-	16	9.9	-	-	10	9.6	8.00	0.50	8.50
	FOF15	2.0	6.06	-	-	2.2	4.94	5	18	9.6	-	-	20	9.6	9.25	1.00	10.25
	FOF16	2.0	5.13	-	-	2.0	5.11	-	17	9.5	-	-	16	9.5	8.50	0.80	9.30
Average		**2.1**	6.45												**8.10**	**1.01**	**9.11**
Low Grade Ore Stockpile A	LGSPA01	2.2	5.01	-	-	2.3	5.75	3	19	9.5	-	-	0		9.65	0.00	9.65
	LGSPA02	2.3	4.36	-	-	2.3	4.01	3	10	9.6	-	-	0		5.15	0.00	5.15
	LGSPA03	2.4	5.56	2.4	4.95	2.5	4.48	178	-	9.5	-	8.8	7	9.4	8.90	0.35	9.25
	LGSPA04	2.4	2.25	-	-	2.6	2.62	21	5.5	9.5	-	-	0		3.80	0.00	3.80
	LGSPA05	2.2	3.93	-	-	2.4	4.69	17	16	9.5	-	-	0		8.85	0.00	8.85
Average		**2.3**	4.22												**7.27**	**0.07**	**7.34**
Low Grade Ore Stockpile C	LGSPC01	2.9	2.12	-	-	3.3	1.94	39	-	9.5	-	-	0		1.95	0.00	1.95
	LGSPC02	2.1	4.88	2.2	5.55	2.1	4.28	135	-	9.6	3.76	8.9	14	9.6	6.75	0.70	7.45
	LGSPC03	2.4	3.08	2.6	2.17	2.7	1.98	48	-	9.9	1.85	8.0	10	9.8	2.40	0.50	2.90
	LGSPC04	2.6	2.46	-	-	2.9	1.78	79	-	9.5	-	9.5	0		3.95	0.00	3.95
	LGSPC05	2.4	4.74	-	-	2.6	3.45	-	8	9.8	-	-	17	9.5	4.00	0.85	4.85
Average		**2.5**	3.46												**3.81**	**0.41**	**4.22**
Medium Grade Ore Stockpile	MGSP01	2.8	1.94	-	-	3.1	2.17	-	6	9.9	-	9.6	0		3.00	0.00	3.00
	MGSP02	5.3	2.12	-	-	5.8	2.18	21.5	-	9.6	-	9.7	0		1.08	0.00	1.08
	MGSP03	3.1	2.68	3.6	2.28	3.9	1.96	55	-	9.8	-	9.6	0		2.75	0.00	2.75
Average		**3.7**	2.25												**2.28**	**0.00**	**2.28**
VANGORDA																	
Baritic Fines Stockpile	BF01	3.5	5.25	-	-	3.7	5.99	-	14	9.6	-	-	30	9.5	7.00	1.50	8.50
	BF02	2.4	6.21	2.6	5.38	2.6	4.27	156	-	9.9	4.31	-	40	9.7	7.80	2.00	9.80
	BF03	3.2	4.69	-	-	3.5	3.86	2	9	9.6	-	-	5	9.5	4.60	0.25	4.85
Average		**3.0**	5.38												**6.47**	**1.25**	**7.72**
Pit Oxide Fines	VPOF01	2.6	5.80	-	-	2.8	5.66	3	16	9.6	-	-	16	9.5	8.15	0.80	8.95
	VPOF02	2.4	5.76	2.4	5.38	2.6	4.31	151	-	9.6	4.32	-	16	9.5	7.55	0.80	8.35
	VPOF03	2.3	5.37	-	-	2.6	4.91	-	16	9.8	-	-	40	9.5	8.00	2.00	10.00
Average		**2.4**	5.64												**7.90**	**1.20**	**9.10**