Introduction

Effluent water quality has been modeled as part of the on-going discussions with Federal and Provincial Regulators regarding the Proposed Star-Orion South Project (the Project). End of pipe water quality is relevant within Environment Canada's current legal understanding of the Fisheries Act, while potential changes in water quality within the receiving environment are relevant in analysis of potential effects to fish, fish habitat and other aquatic organisms.

Detailed assessment of potential effects of the Project of aquatic biota was conducted as part of the Revised EIS submitted to regulators in 2012. This assessment concluded that impacts were not significant with the implementation of a Fish Habitat Compensation Plan to offset direct losses of fish habitat. The updated 2013 water quality modeling is based on changes to site water management as a result of interaction with Federal regulators, and shows that water quality is improved as compared to the 2012 assessment; therefore the conclusion of no significant impacts remains valid.

Much of this report parallels Appendix 6.2.8-E of the revised EIS prepared by AMEC Environment and Infrastructure (AMEC 2012) and should be considered to update information presented in Appendix 6.2.8-E.

Regulatory Context

As described in AMEC (2012) Saskatchewan has developed water quality objectives that specify a value below which is considered to protective of aquatic life. Federally, the Canadian Council of Ministers of the Environment (CCME) has developed similar national water quality guidelines These objectives are applicable within the receiving environment, and are intended to be a default value, below which no further analysis is needed to conclude that there would be no impact on the aquatic environment. The following water quality objectives are applicable:

- Saskatchewan Water Quality Objectives (SWQOs) (Saskatchewan Environment, 2006)
- CCME Chloride Water Quality Guidelines (WQG) (CCME, 2011)

In contrast to the objectives above, Provincial and Federal legislation authorizes maximum discharge concentrations for approved mining activities. The two regulations are:

- Mineral Industry Environmental Protection Regulations (MIEPR) (SERM, 1996)
- Metals Mining Effluent Regulation (MMER)(DFO, 2002)

Note that the MMER and the Provincial Mineral Industry Environment Regulation (MIEPR) contain the same discharge limits with the exception of the inclusion of uranium in the MIEPR.

Shore Gold has been informed by Environment Canada that the Metal Mining Effluent Regulations do not currently apply to diamond mining, however a process is underway to examine the potential to extend these regulations to diamonds. Within this context, any substance, that is considered deleterious as defined in the Fisheries Act, cannot be released without a regulation authorizing its release. Detailed discussion regarding the interpretations of the Fisheries Act can be found in Section 3.5.1 of the EIS.

Comparison of Modeling Results to regulatory standards

Modeling described by AMEC 2013 is summarized in Table 1 below, and is compared to the Saskatchewan SWQO, the CCME objectives, and the MMER limits, as well as to background water quality in the Saskatchewan River. Bolded numbers show exceedances of one or more guideline or limit, and are discussed in more detail below.

Table 1. Predicted Water Quality

Parameter	**Units**	**Sask. SWQO (2006)**	**MMER**	**CCME (2012)**	**Saskatchewan River**	**PKCF Decant Water / Seepage Water**		**2013 End of Pipe (to diffuser)**	
		Guideline	**Discharge limit**	**Guideline**	**Background**	**Mean**	**Maximum**	**Mean**	**Maximum**
Conventional Parameters									
Specific conductivity	µS/cm				443	842	995	4232	4419
Total alkalinity	mg/L				159	183	190	314	321
Total dissolved solids	mg/L				262	492	*589*	*2688*	*2809*
Total hardness	mg/L				188	214	223	408	418
Major Ions									
Bicarbonate	mg/L				187	210	218	378	387
Calcium	mg/L				48	54	57	105	108
Carbonate	mg/L				4	3	3	1.3	1.4

Parameter	Units	Sask. SWQO (2006)	MMER	CCME (2012)	Saskatchewan River	PKCF Decant Water / Seepage Water		2013 End of Pipe (to diffuser)	
		Guideline	Discharge limit	Guideline	Background	Mean	Maximum	Mean	Maximum
Chloride	mg/L			120 long term, 640 short term	7	110	***155***	***1120***	***1176***
Fluoride	mg/L				0.1	*0.3*	*0.3*	*1.7*	*1.8*
Hydroxide	mg/L				1	0.7	0.8	0.6	0.6
Magnesium	mg/L				17	19	19	35	36
Potassium	mg/L				3	7	8	38	40
Sodium	mg/L				20	94	125	*809*	*849*
Sulfate	mg/L				67	107	124	*509*	*531*
Nutrients									
Ammonia as nitrogen	mg/L			0.02-190	0.05	0.2	0.3	1.3	1.4
Nitrate	mg/L			2.9	0.4	0.4	0.4	0.2	0.2
Total Phosphorus	mg/L			Depends on receiving environment	0.1	0.1	0.1	0.06	0.06

Parameter	Units	Sask. SWQO (2006)	MMER	CCME (2012)	Saskatchewan River	PKCF Decant Water / Seepage Water		2013 End of Pipe (to diffuser)	
		Guideline	Discharge limit	Guideline	Background	Mean	Maximu m	Mean	Maximum
Metals									
Aluminum	mg/L	0.1		0.1 (Depends on receiving environment)	**0.4**	**0.4**	**0.4**	**0.2**	**0.2**
Antimony	mg/L				0.0004	0.0002	0.0002	0.0001	0.0001
Arsenic	mg/L	0.005	0.5	0.005	0.0007	0.0008	0.0008	0.0004	0.0004
Barium	mg/L				0.1	0.1	0.1	0.0	0.0
Beryllium	mg/L				0.0002	0.0001	0.0001	0.0001	0.0001
Boron	mg/L			1.5	0.03	0.1	0.2	1.3	1.3
Cadmium	mg/L	**0.0001**		**0.000064 (based on 214mg/l hardness)**	**0.00008**	**0.00008**	**0.00009**	0.00004	0.00004
Chromium	mg/L	**0.001 (hexavalent)**		**0.001 (hexavalent)** **0.009 (trivalent)**	**0.002**	**0.002**	**0.002**	0.0007	0.0008
Cobalt	mg/L				0.0005	0.0006	0.0006	0.0003	0.0003
Copper	mg/L	0.004	0.3	**Depends on hardness**	0.002	0.003	0.003	0.002	0.002
Iron	mg/L	**0.3**			**0.6**	**0.8**	**0.8**	**0.4**	**0.5**
Lead	mg/L	0.007	0.2	**Depends on hardness**	0.0006	0.0008	0.0009	0.0005	0.0005
Manganese	mg/L				*0.05*	*1.9*	*2.0*	*0.7*	*0.8*
Molybdenum	mg/L			0.073	0.001	0.001	0.001	0.0005	0.0005
Nickel	mg/L	0.15	0.5	**Depends on hardness**	0.002	0.002	0.003	0.001	0.001

Parameter	Units	Sask. SWQO (2006)	MMER	CCME (2012)	Saskatchewan River	PKCF Decant Water / Seepage Water		2013 End of Pipe (to diffuser)	
		Guideline	Discharge limit	Guideline	Background	Mean	Maximum	Mean	Maximum
Selenium	mg/L	0.001		0.001	0.0004	0.0004	0.0004	0.0003	0.0003
Silver	mg/L	**0.0001**		**0.0001**	**0.0002**	**0.0001**	**0.0001**	0.00005	0.00005
Strontium	mg/L				0.4	0.5	0.5	1.8	1.8
Thallium	mg/L			0.0008	0.00009	0.00009	0.00009	0.0001	0.0001
Tin	mg/L				0.0002	0.0003	0.0003	0.0001	0.0002
Titanium	mg/L				0.008	0.008	0.009	0.003	0.003
Vanadium	mg/L				0.002	0.002	0.002	0.001	0.001
Zinc	mg/L	0.03	0.5	0.03	0.01	0.02	0.02	0.01	0.01

Identification of parameters of potential concern

Within the predicted water quality model for seepage from the PKCF into local ravines and end of pipe effluent discharge, 5 parameters exceed one or more water quality objective or discharge limit. These parameters are discussed below to analysis if the predicted discharge has the potential to cause an environmental effect.

Chloride

Within the PKCF seepage, maximum predicted chloride concentrations (155 mg/l), as well as the 95% percentile value of 149 mg/l (reported in AMEC 2013) marginally exceed the long term CCME chloride guideline of 120 mg/l, but are below the short term value of 640 mg/l. Since these exceedances are for extreme events, which are by definition, shorter term, it is unlikely that these exceedances will result in an environmental effect. The mean seepage concentration (110 mg/l) is below the long term CCME guideline. As a result, chloride within the PKCF seepage is not considered a parameter of potential concern.

Within the end of pipe effluent, mean (1120 mg/l) and maximum (1176 mg/l) chloride concentrations exceed both the short term and long term CCME objectives. In addition, these values are above the background concentrations in the Saskatchewan River (7 mg/l).

As a result, chloride within the effluent has the potential to change water chemistry in the receiving environment and is carried forward as a parameter of potential concern.

Cadmium

Cadmium concentrations exceed the CCME hardness adjusted guideline of 0.000064 mg/l in the PKCF seepage for the mean and maximum cases. However, background concentrations are equal to those predicted in the seepage, and as such, cadmium releases do not have the potential to reduce water quality, and is not considered a parameter of potential concern.

Chromium

Similar to cadmium, total chromium concentrations in the PKCF seepage exceed the hexavalent chromium guidelines (but not the CCME trivalent chromium guideline). However, background chromium concentrations are equal to the seepage concentrations and do not have the potential to reduce water quality. The value for hexavalent chromium was selected as a screening value since it is more conservative, despite the fact that it is very unlikely that all chromium measured (i.e., total chromium) would be in the hexavalent state. Chromium is not considered a parameter of potential concern as there is no potential for the proposed discharge to change water chemistry in the receiving environment, and thus is unlikely to have an environmental effect.

Iron

Iron concentrations exceed the Saskatchewan SWQO naturally in the Saskatchewan River, and in modeled mean and maximum values for the seepage and end of pipe discharge. Saskatchewan River concentrations (0.6 mg/l) are higher that the modeled end of pipe discharge (mean and maximum 0.4 mg/l) but slightly lower that PKCF seepage values (0.8 mg/l). Therefore, PKCF seepage water has the potential to change water quality and iron is considered a parameter of potential concern in the seepage, but not in the end-of-pipe discharge.

Silver

Silver concentrations are equal to the Saskatchewan SWQO (0.0001 mg/l) in the PKCF seepage, and naturally exceed the SWQO in the Saskatchewan River (0.0002 mg/l). As the modeled discharge has lower concentrations than background, discharge does into have the potential to reduce water quality and is not considered a parameter of potential concern.

Aluminum

Aluminum concentrations exceed the Saskatchewan SWQO naturally in the Saskatchewan River, and in modeled mean and maximum values for the seepage and end of pipe discharge. Saskatchewan River concentrations (0.4 mg/l) are equal to or higher than the modeled results, therefore discharge does not have the potential to reduce water quality. Aluminum is therefore not considered a parameter of potential concern.

Parameters of Potential Concern

Parameters of potential concern are summarized in Table 2.

Table 2. Parameters of Potential Concern

Parameter	PKCF Seepage	Effluent Discharge
Chloride		X
Iron	X	

Chloride

Maximum and mean predicted chloride concentrations in the effluent discharge exceed both the short term (640mg/l) and the long term (120 mg/l) CCME water quality objectives. In Appendix 6.2.8-E of the Revised EIS, AMEC prepared a discussion of the CCME guidelines for chloride. This discussion is repeated below:

“Though a number of studies that showed that chloride toxicity is counteracted by elevated hardness, CCME concluded that there were insufficient data available to develop a hardness relationship for chronic toxicity. CCME further recognizes the importance of the ameliorating effects of hardness by encouraging jurisdictions (*e.g.* Provinces) to develop site-specific hardness adjusted water quality criteria if they so choose. (CCME, 2011).

In addition, the chloride guidelines are based on generic environmental fate and behaviour and toxicity data. The guidelines are conservative values below which all forms of aquatic life, during all life stages and in all Canadian aquatic systems, should be protected. Because the chloride guidelines are not corrected for any toxicity modifying factors (*e.g.* hardness), they are generic values that do not take into account any site-specific factors. Since the chloride guidelines are mostly based on toxicity tests using laboratory organisms, the guideline may not be relevant for areas with a naturally elevated concentration of chloride and associated adapted ecological community (CCME, 2011)."

Additional Literature Review

Subsequent to the submission of the Revised EIS, Shore conducted a literature review of recent studies conducted on chloride. These studies are summarized below, and are intended to supplement the information presented in Appendix 6.2.8-E.

Corsi et al (2010) looked at the effects of chloride from road salts on 12 sites in Wisconsin. Standard chronic toxicity testing was conducted on Ceriodaphnia Dubia and P. promelas. Corsi et al (2010) observed adverse responses in C. Dubia at chloride concentrations of 1610 mg/l and greater, and at 2940 mg/l for P. Promelas. From these results, they calculated an IC25 for C. Dubia of 1050 mg/l, and 1810 mg/l for P. promelas. In addition, long term tests (longer than 2 weeks) were conducted based on 37 samples from a salt affected watershed. In these long-term tests, initial toxic effects were observed between 600 and 1100 mg/l for C. Dubia, with no young produced over 1770 mg/l.

Williams et al (2000) looked at 23 springs in the greater Toronto Area to develop an index of salt tolerance (measured by chloride) of 34 different taxa of aquatic organisms. At 3,000 mg/l Cl-, none of the naturally occurring taxa in the springs exhibited obvious stress after 96 hours of exposure. At 4,500 mg/l, responses were more varied, and at 6,000 mg/l responses were sufficient to identify salt tolerant and salt intolerant taxa within the study. Additional long term (60 day) testing was conducted on a snail (Physa sp.) and an amphipod (G. pseudolimneous) at 1,000 mg/l and 2,000 mg/l Cl-. No differences were observed between treatment and control for either of the two tested species at either concentration.

Kang et al (2011) examined effluents with a wide range of chloride concentrations (greater than 10,000 mg/l) and their toxicity to D. Magna and T. japonicus. They calculated an EC50 of 3140 mg/l Cl- for D. magna, and suggested that test species should be selected based on receiving environment to best reflect potential for environmental effect.

Gillis (2011) examined the most sensitive life-stage (glochidia) of fresh water mussels to different chloride levels. From this study, EC50 was calculated for different species of glochidia. Calculated EC50s ranged from 113 to 1430 mg/l Cl-, depending on species, with most around 200 mg/l. Gillis (2011) noted that results varied significantly depending on the source water used in the testing. For example, Lampsillis fusciola were much less sensitive to chloride in natural water (EC50 1265-1559 mg/l Cl-) than in reconstituted water (EC50 285 mg/l Cl-). For another species (Lampsilis siliquoidea) the EC50 varied from 168 to 1430 mg/l Cl- when specimens for testing were collected from 2 different watersheds. This large variation highlights the importance of the receiving environment in interpretation of toxicity results.

Gillis (2011) also observed acute toxicity of glochidia at 1300 mg/l Cl-, and concluded that glochidia are very sensitive to chloride, but less sensitive when tested in hard water. The author also noted that there was no way to tell if the observed effects were due to Cl- or Na+.

Iowa Department of Natural Resources (2009) concluded that chloride toxicity was dependant on hardness and sulfate content, and developed a formulae for site specific water quality objectives (i.e., in the receiving environment). Toxicity increased slightly with an increase in sulfate, and decreased strongly with an increase in hardness. Based on Iowa (2009) formulae, for the Saskatchewan River the short term Cl- objective would be 546.1 mg/l and the long term objective would be 349 mg/l based on the hardness and sulfate content in the Saskatchewan River. Iowa (2009) also recommended consideration of a mixing zone for effluent where the receiving environment could be shown to dilute discharges at all times, and that measurements (for comparison to the short and long term objectives) should be taken after an appropriate mixing zone for regulatory purposes. Iowa (2009) also reported that hardness had an impact on toxicity to C. dubia, and conducted a series of 48 hour tests at 7 different hardness levels. For a hardness of 400 mg/l (as compared to the hardness of the modeled discharge of 408 mg/l in Shore's proposed discharge) a mean LC50 was calculated to be 1589 mg/l Cl-. Note that some variability was seen between labs and between replicates; however, the authors concluded that the results were comparable.

Iowa (2009) also proposed sulfate criteria based on the receiving environment's chloride and hardness, with a low value of 500 mg/l sulfate for low chloride (Cl- < 5mg/l) and low hardness (H< 100 mg/l) and a high value of 2,000 mg/l sulfate for chloride between 5 and 500 mg/l and high hardness (H >500 mg/l). For Cl- and harness above these values, the authors recommend a standard determined on a case by case basis in conjunction with an applicable permitting process. The sulfate testing showed that sulfate alone had almost no long term effects; if an organism survived the initial shock of an increase in sulfate, then no further effects were observed over time.

Soucek and Kennedy (2005) collected data used to develop recommendations in Iowa (2009). C. Dubia responses to chloride were tested at various sulfate levels at a fixed hardness of 300 mg/l. At 400 mg/l sulfate, an LC50 was calculated of 1154 mg/l, while at 600 mg/l, an LC50 of 1192 mg/l was calculated. In addition to the data summarized above, Soucek and Kennedy (2005) demonstrated that hardness ameliorated sulfate toxicity in both H. azteca and C. Dubia.

Toxicity Testing

Shore conducted acute toxicity testing on Daphnia magna and Rainbow trout, chronic testing on fathead minnows and Ceriodaphnia dubia, and testing of C. dubia acclimatized to hardness for Mannville formation water as presented in Appendix 6.2.8-E. Testing showed that Mannville formation water had no acute effects on D. magna or rainbow trout and no chronic effect on fathead minnow. Chronic effects were observed for C. dubia on both the acclimatized and non-acclimatized test populations.

From the un-acclimatized C. dubia testing, a LC50 of 67% Mannville water and an IC25 of 24% Mannville water were calculated (page 50 of Appendix 6.2.8-E). If all complicating factors are ignored (i.e., effects of other constituants and hardness), 67% Mannville water corresponds to a chloride concentration of 1,139 mg/l and 24% Mannville water would have a chloride concentration of 408 mg/l.

Results of the acclimatized C. dubia testing are best examined on a total dissolved solids basis (Nautilus 2012) due to the acclimatization procedure, and as such, effects to to chloride alone cannot be isolated from the results. On a sum of ions basis, the population acclimatized to a 200 mg/l hardness had a IC25 of 1,253 mg/l, and the population acclimatized to 500 mg/l hardness had a IC25 of 1,889 mg/l. Nautilus (2012) also noted that it was difficult to maintain appropriate chemistry as $CaCO_3$ precipitated out during acclimatization and tests. It is unknown what effect this precipitation could have had on C. dubia.

Comparing the 500 mg/l hardness acclimatized IC25 to the pure Mannville water, the IC25 roughly corresponds to a dilution of 48% (TDS of modeled Mannville water 3950 mg/l). Assuming no other effects from other parameters, the chloride content at a 48% Mannville dilution is 816 mg/l.

Discussion

The effects of chloride have been demonstrated to be dependent on hardness (Environment Canada 2007) and sulfate concentrations (Iowa 2009). Is has also been shown that considerable variability is found when testing different populations of the same aquatic organisms (Gillis 2009) and when testing naturally occurring water as compared to lab reconstituted water. These differences highlight the importance of the receiving environment when interpreting toxicity data related to chloride, and even when selecting an appropriate species to test (Kang et al 2011). Consideration of an appropriate mixing zone is suggested by Iowa (2009), as well as development of site specific chloride targets in the receiving environment based on hardness and sulfate. Testing on rainbow trout, fathead minnow and Daphnia magna conducted by Shore show no toxic effects at 100% Mannville water (TDS 3950 mg/l and chloride 1,700 mg/l), therefore, the proposed discharge, which contains approximately two thirds the chloride concentration of the tested water will also be non-toxic to these three species.

For C. dubia, effects were observed in the acclimatized testing and within the un-acclimatized testing of 100% Mannville water. The proposed effluent discharge is of higher quality that the Mannville, with mean (1,120 mg/l) and maximum (1,176 mg/l) chloride concentrations close to the LC50 for C. dubia determined by Soucek and Kennedy (2005) for 300 mg/l hardness and variable sulfate concentrations and to that calculated from Shore's un-acclimatized chronic toxicity testing (1,139 mg/l). The predicted chloride content is below the hardness adjusted calculated LC50 of 1,589 mg/l presented in Iowa (2009).

Long term effects (chronic) on C. dubia from chloride range substantially, from an IC25 of 408 mg/l Cl^- for the un-acclimatized testing (note this value assumes no complicating effects of other substances), to a value of 816 mg/l Cl^- from the acclimatized testing, to

1,050 mg/l Cl- reported in literature (Corsi et al 2010). The mean and maximum chloride levels in the proposed discharge would be greater than these values. However, in order for this testing to be environmentally relevant to the impact assessment, C. dubia would need to make up a component of the fish habitat within the Saskatchewan River. As C. dubia are primarily still water invertebrates, their presence within the Saskatchewan River is unlikely. In addition, exposure time to concentrations above the LC25 needs to be sufficient such that chronic effects can occur. Exposure time would be extremely limited; chloride levels would decrease to approximately 19 mg/l above background within 40 m of the diffuser (Appendix 6.2.8-E).

When examining the entire range of aquatic invertebrates that occur in Canada, an even wider range of results are reported. For glochidia, Gillis (2011) reported effects as low as 113 mg/l chloride. Williams et al (2000) reported that chloride concentrations needed to be above 6,000 mg/l in order to differentiate between salt tolerant and intolerant species, and that no response was seen at 3,000 mg/l in 34 different aquatic organisms. This large variation in response indicates that biological processes, species variability and environmental variations within the aquatic system are important factors to consider when assessing chloride effects. It is important to note that C. dubia nor glochidia are present in the receiving environment.

Conclusion: Chloride

The proposed effluent will cause a negligible change in chloride concentrations in the receiving environment, and are not expected to have short term or long term effects on fish habitat in the receiving environment.

Iron

Iron concentrations in the Saskatchewan River and in the LSA are extremely variable, ranging from 0.05 to greater than 2.0 mg/l. Results presented in Appendix 5.2.8-A show, in general across sampling sites, a mean concentration of 0.6 mg/l iron with a standard deviation of 0.6 mg/l. The predicted concentration in the PKCF seepage is 0.8 mg/l, and although this value is more than the mean result, it falls within one standard deviation from the mean background results. It can then be considered within the natural variability of the River and Ravines, and therefore has a negligible effect on water quality.

Conclusion: Iron

Iron concentration in the PKCF seepage and discharge to Ravines will have a negligible effect on water quality.

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