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TECHNICAL MEMORANDUM

Date 13 December 2018

TO: Ed Surbrugg, TetraTech
Todd Johnson, Sandfire America
Jerry Zieg, Sandfire America

CC: Craig Jones, MT DEQ
Wayne Jepson, MT DEQ

FROM: Lisa Bithell Kirk, Ph.D., P.Geo., Principal Biogeochemist

RE: Correction of Transcription Error for MW1B Sb values, 2011-2012 data used in groundwater models

Enviromin has investigated and resolved an error in predicted antimony values for the underground workings of the proposed BBC Mine. This error resulted from an unrecognized transcription error for 5 antimony measurements made in samples of water from monitoring well MW1B collected in 2011-2012. These are samples TSC-1108-201, BBC-1111-202, BBC1203-202, BBC 1205-204, and BBC-1208-201. An incorrect detection limit of 0.03 mg/L was inadvertently copied in placed of the correct 0.003 mg/L value for these five samples. Propagation of this error into calculated average antimony values for the YnlA rock unit resulted in overprediction of antimony in groundwater quality predictions for the underground workings at Year 6 of Operations and Post Closure. This error was inadvertently reported in

- Table 4-4 (page 36) and Table 4-5 (page 37) of Enviromin's 2017 Water Quality Modeling Report (provided as Appendix N of the BBC MOP)
- Table 4-11 of the 2017 BBC MOP, 2017 and
- Table 2 of Sandfire's memorandum evaluating the Agency Modified Alternative, dated 10.16.18.

The detection limits for these samples have been corrected, allowing adjustment of the predicted YnlA groundwater quality. The predicted antimony value dropped significantly for the YnlA, from 0.003 to 0.0012 mg/L, and thus corrected the predicted water quality in the underground workings, during operations at Year 6 and post-closure. Each of the above identified tables has been replaced in the subject documents and replacement pages have been provided. These corrections do not modify the conclusions of these documents, which correctly stated that antimony will not exceed the Montana DEQ non-degradation criteria under post-closure conditions.

Please contact me with any questions you have regarding this correction.

Table 4-4. Model Predictions for Underground Water Quality at Year 6 of Operations

		Mixed Groundwater with No Mine Influence	Underground model predictions at yr 6, after PhreeqC									Groundwater Standards (MT DEQ-7)
			BASECASE (HCT wk1-4, 1 m max rind, Fracture density 10% in UZ and 2% in LZ, Oxid. Rate = 6 kg/m2/yr)	Fracture density one half basecase	Fracture density twice basecase	All HCT data of wall rock	Oxid. Rate = 40 kg/m2/y	2 m fracture zone thickness	15 m reactive zone	Paste backfill surface area doubled	Combined High Reactive Mass Parameters (Oxid Rate 40, 2-meter rind, fracture density x2, backfill SAx2)	
pH	s.u.	7.09	6.67	6.68	6.65	4.87	6.55	6.65	6.64	6.51	6.39	na*
Al	mg/L	0.014	0.012	0.011	0.017	0.229	0.013	0.017	0.018	0.017	0.082	na
Alkalinity	mg/L $CaCO_3$	218	183	180	188	182	183	188	188	183	207	na*
As	mg/L	0.051	0.004	0.002	0.010	0.068	0.004	0.010	0.010	0.005	0.101	0.01
Ba	mg/L	0.049	0.00122	0.00167	0.00075	0.00896	0.00167	0.00075	0.00076	0.00160	0.00034	1
Be	mg/L	0.0008	0.0006	0.0005	0.0008	0.0011	0.0007	0.0008	0.0008	0.0007	0.0020	0.0040
Ca	mg/L	76	89	83	100	89	103	100	103	89	141	na
Cd	mg/L	0.000045	0.000045	0.000045	0.000045	0.000045	0.000045	0.000045	0.000045	0.000045	0.000045	0.005000
Cl	mg/L	1.29	1.38	1.35	1.44	1.43	1.64	1.44	1.45	1.40	1.86	na*
Cr	mg/L	0.007	0.00066	0.00064	0.00070	0.01044	0.00089	0.00070	0.00072	0.00097	0.00147	0.1
Cu	mg/L	0.0019	0.0007	0.0006	0.0009	0.3693	0.0011	0.0009	0.0009	0.0009	0.0068	1.3
F	mg/L	0.64	1.14	0.90	1.60	0.83	1.16	1.60	1.67	1.14	2.63	4
Fe	mg/L	1.81	0.0024	0.0023	0.0025	0.0057	0.0031	0.0025	0.0025	0.0034	0.0024	na**
Hg	mg/L	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.000006	0.002000
K	mg/L	3.4	11	8	17	10	12	17	18	11	37	na
Mg	mg/L	47	60	54	72	54	75	72	75	60	112	na
Mn	mg/L	0.146	0.165	0.162	0.172	0.186	0.313	0.172	0.173	0.166	0.334	na**
NO_3	ppm as N	0.02	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	1
Na	mg/L	11	14.7	13.1	17.8	14.7	15.0	17.8	18.4	14.7	27.9	na
Ni	mg/L	0.004	0.007	0.005	0.009	0.049	0.010	0.009	0.009	0.007	0.017	0.1
P	mg/L	0.011	0.003	0.002	0.005	0.012	0.003	0.005	0.005	0.003	0.021	na
Pb	mg/L	0.001	0.00002	0.00002	0.00004	0.00112	0.00002	0.00004	0.00004	0.00002	0.00255	0.015
SO_4	mg/L	205	304	262	388	284	398	388	405	305	672	na**
Sb^	mg/L	0.0011	0.0028	0.0021	0.0042	0.0014	0.0029	0.0042	0.0043	0.0028	0.0085	0.006
Se	mg/L	0.0005	0.0039	0.0024	0.0069	0.0017	0.0042	0.0069	0.0073	0.0039	0.0151	0.05
Si	mg/L	8.78	1.55	1.55	1.55	1.54	1.55	1.55	1.55	1.55	1.54	na
Sr	mg/L	10.5	10.5	10.4	10.8	10.4	11.4	10.8	10.8	10.5	12.1	4
Tl	mg/L	0.001	0.002	0.002	0.002	0.002	0.005	0.002	0.002	0.002	0.006	0.002
U	mg/L	0.005	0.037	0.021	0.069	0.028	0.038	0.069	0.069	0.037	0.133	0.03
Zn	mg/L	0.029	0.030	0.029	0.032	0.040	0.031	0.032	0.033	0.031	0.041	2

Supersaturated phases in basecase: Alunite, $Ba_3(AsO_4)_2$, Cr_2O_3, ferrihydrite, quartz

empirical prediction of endpoint, not based on modeling

See discussion of sensitivity scenarios in Section 4.1.

*narrative standards may exist **secondary standard

^Sb predictions revised 12/2018 to correct MW1B detection limit error affecting GW contribution

Results include the mass load from the seven lithological units, precipitation of supersaturated phases and sorption on ferrihydrite, based on PHREEQC models.

Table 4-5. Model Predictions for Underground Water Quality after closure

		Underground model predictions at closure, after PhreeqC			Groundwater Standards (MT DEQ-7)	Estimated Groundwater Non-degradation Criteria
		BASECASE	Paste backfill surface area doubled	Detection limits = 0		
pH	s.u.	6.81	6.77	6.81	na*	6.0-7.8
Al	mg/L	0.015	0.016	0.015	na	0.058
Alkalinity	mg/L $CaCO_3$	144	147	144	na*	na
As	mg/L	0.0000	0.0000	0.0000	0.01	0.064
Ba	mg/L	0.0169	0.0159	0.0169	1	0.1928
Be	mg/L	*0.0002*	*0.0003*	*0.0001*	0.004	0.00095
Ca	mg/L	64	71	64	na	na
Cd	mg/L	0.000042	0.000042	0.000042	0.005000	0.0008
Cl	mg/L	1.7	2.0	1.7	na*	na
Cr	mg/L	0.00048	0.00052	0.00048	0.1	0.025
Cu	mg/L	*0.0002*	*0.0003*	*0.0001*	1.3	0.1970
F	mg/L	*0.36*	*0.40*	*0.33*	4	1.2
Fe	mg/L	0.00	0.00	0.00	na**	na
Hg	mg/L	0.000006	0.000006	0.000006	0.002	0.000010
K	mg/L	2.9	3.8	2.9	na	na
Mg	mg/L	22.1	20.9	22.1	na	na
Mn	mg/L	0.053	0.054	0.051	na**	na
NO_3	ppm as N	3.30	3.30	3.30	1	7.5
Na	mg/L	4.8	5.3	4.8	na	na
Ni	mg/L	*0.0049*	*0.0057*	*0.0042*	0.1	0.025
P	mg/L	0.001	0.001	0.001	na	na
Pb	mg/L	0.00001	0.00001	0.00001	0.015	0.0028
SO_4	mg/L	115	124	115	na**	250**
Sb^	mg/L	0.0016	0.0021	0.0008	0.006	0.002
Se	mg/L	*0.0009*	*0.0012*	*0.0005*	0.05	0.0085
Si	mg/L	1.55	1.55	1.55	na	na
Sr	mg/L	2.1	2.2	2.1	4	6.48
Tl	mg/L	0.0037	0.0038	0.0037	0.002	0.0039
U	mg/L	0.00504	0.00511	0.00497	0.03	0.008
Zn	mg/L	*0.018*	*0.021*	*0.015*	2	0.317

Italicized predictions affected by detection limit propogation in the model

prediction of endpont, not based on modeling

*narrative standards may exist

**secondary standard

^Sb predictions revised to correct MW1B detection limit error 12/2018

Supersaturated phases in basecase: $Ba_3(AsO_4)$, barite, Cr_2O_3, ferrihydrite, gibbsite, quartz

Results include precipitation of supersaturated phases and sorption to ferrihydrite and sulfide.

Diminished oxidation due to flooding, completion of backfilling, and reduced inflow of water from below the VVF produces the base case chemistry shown in **Table 4-5**. While the predicted pH and alkalinity are lower than background groundwater quality, and a bit lower than the quality predicted underground during operations, predicted pH is 6.81 with 144 mg/L alkalinity and a sulfate concentration of 115 mg/L. No parameters fail to meet MT groundwater standards or non-degradation criteria in post-closure groundwater. Our sensitivity analysis shows that propagation of detection limits for censored (less than detect) values results in overestimation of increased concentrations for Sb, Be, Cu, F, Ni and Zn.

Table 4-11. Predicted Water Quality for UG Workings Post-closure

		Underground model predictions at closure, after PhreeqC			Groundwater Standards (MT DEQ-7)	Estimated Groundwater Non-degradation Criteria
		BASECASE	Paste backfill surface area doubled	Detection limits = 0		
pH	s.u.	6.81	6.77	6.81	na*	6.0-7.8
Al	mg/L	0.015	0.016	0.015	na	0.058
Alkalinity	mg/L $CaCO_3$	144	147	144	na*	na
As	mg/L	0.0000	0.0000	0.0000	0.01	0.064
Ba	mg/L	0.0169	0.0159	0.0169	1	0.1928
Be	mg/L	*0.0002*	*0.0003*	*0.0001*	0.004	0.00095
Ca	mg/L	64	71	64	na	na
Cd	mg/L	0.000042	0.000042	0.000042	0.005000	0.0008
Cl	mg/L	1.7	2.0	1.7	na*	na
Cr	mg/L	0.00048	0.00052	0.00048	0.1	0.025
Cu	mg/L	*0.0002*	*0.0003*	*0.0001*	1.3	0.1970
F	mg/L	*0.36*	*0.40*	*0.33*	4	1.2
Fe	mg/L	0.00	0.00	0.00	na**	na
Hg	mg/L	0.000006	0.000006	0.000006	0.002	0.000010
K	mg/L	2.9	3.8	2.9	na	na
Mg	mg/L	22.1	20.9	22.1	na	na
Mn	mg/L	0.053	0.054	0.051	na**	na
NO_3	ppm as N	3.30	3.30	3.30	1	7.5
Na	mg/L	4.8	5.3	4.8	na	na
Ni	mg/L	*0.0049*	*0.0057*	*0.0042*	0.1	0.025
P	mg/L	0.001	0.001	0.001	na	na
Pb	mg/L	0.00001	0.00001	0.00001	0.015	0.0028
SO_4	mg/L	115	124	115	na**	250**
Sb^	mg/L	0.0016	0.0021	0.0008	0.006	0.002
Se	mg/L	*0.0009*	*0.0012*	*0.0005*	0.05	0.0085
Si	mg/L	1.55	1.55	1.55	na	na
Sr	mg/L	2.1	2.2	2.1	4	6.48
Tl	mg/L	0.0037	0.0038	0.0037	0.002	0.0039
U	mg/L	0.00504	0.00511	0.00497	0.03	0.008
Zn	mg/L	*0.018*	*0.021*	*0.015*	2	0.317

Italicized predictions affected by detection limit propogation in the model

prediction of endpont, not based on modeling

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^Sb predictions revised to correct MW1B detection limit error 12/2018

Supersaturated phases in basecase: $Ba_3(AsO_4)$, barite, Cr_2O_3, ferrihydrite, gibbsite, quartz

Modeling Results

Table 2 describes the predicted groundwater chemistries for the *Revised Base Case with Cement Walls* and the *AMA* model, and compares them with the original *Base Case* and sensitivity analyses. In the *AMA*, *Revised Base Case with Cement Walls,* and original *Base Case*, we predict the potential precipitation of $Ba_3(AsO_4)_2$, barite, Cr_2O_3, ferrihydrite, gibbsite and quartz, based on PhreeqC predictions of supersaturation in the mixed water at closure. Metals sorb to both ferrihydrite and sulfide under closure conditions. Little significant difference is predicted by the model scenarios presented in Table 2. For the two new models evaluated in this memo, most constituents show a slight increase (if any), compared to the original *Base Case*. However, Mg and Ba show a slight decrease because of increased precipitation of ferrihydrite that can sorb these metals in the *AMA* model and the *Revised Base Case with Cement Walls*.

Table 2. Results of the water quality model the original Base Case and sensitivity analyses, Revised Base Case with Cement Walls, and Agency Modified Alternative.

		Underground model predictions at closure, after PhreeqC					**Groundwater Standards (MT DEQ-7)**	**Estimated Groundwater Non-degradation Criteria**
		Original BASECASE	**Revised BASECASE with cement walls**	**Agency Modified Alternative**	**Paste backfill surface area doubled**	**Detection limits = 0**		
pH	s.u.	6.81	6.79	6.80	6.77	6.81	na*	6.0-7.8
Al	mg/L	0.015	0.016	0.015	0.016	0.015	na	0.058
Alkalinity	mg/L $CaCO_3$	144	145	144	147	144	na*	na
As	mg/L	0.0000	0.0000	0.0000	0.0000	0.0000	0.01	0.064
Ba	mg/L	0.0169	0.0163	0.0168	0.0159	0.0169	1	0.1928
Be	mg/L	*0.0002*	*0.0003*	*0.0002*	*0.0003*	*0.0001*	0.004	0.00095
Ca	mg/L	64	68	65	71	64	na	na
Cd	mg/L	0.000042	0.000042	0.000042	0.000042	0.000042	0.005000	0.0008
Cl	mg/L	1.7	1.8	1.7	2.0	1.7	na*	na
Cr	mg/L	0.00048	0.00050	0.00049	0.00052	0.00048	0.1	0.025
Cu	mg/L	*0.0002*	*0.0002*	*0.0002*	*0.0003*	*0.0001*	1.3	0.1970
F	mg/L	*0.36*	*0.38*	*0.37*	*0.40*	*0.33*	4	1.2
Fe	mg/L	0.00	0.00	0.00	0.00	0.00	na**	na
Hg	mg/L	0.000006	0.000006	0.000006	0.000006	0.000006	0.002	0.000010
K	mg/L	2.9	3.4	3.0	3.8	2.9	na	na
Mg	mg/L	22.1	21.5	22.0	20.9	22.1	na	na
Mn	mg/L	0.053	0.054	0.053	0.054	0.051	na**	na
NO_3	ppm as N	3.30	3.30	3.30	3.30	3.30	10	7.5
Na	mg/L	4.8	5.0	4.8	5.3	4.8	na	na
Ni	mg/L	*0.0049*	*0.0053*	*0.0050*	*0.0057*	*0.0042*	0.1	0.025
P	mg/L	0.001	0.001	0.001	0.001	0.001	na	na
Pb	mg/L	0.00001	0.00001	0.00001	0.00001	0.00001	0.015	0.0028
SO_4	mg/L	115	120	115	124	115	na**	250**
Sb^	mg/L	0.0016	0.0019	0.0015	0.0021	0.0008	0.006	0.002
Se	mg/L	*0.0009*	*0.0010*	*0.0009*	*0.0012*	*0.0005*	0.05	0.0085
Si	mg/L	1.55	1.55	1.55	1.55	1.55	na	na
Sr	mg/L	2.1	2.2	2.1	2.2	2.1	4	6.48
Tl	mg/L	0.0037	0.0037	0.0037	0.0038	0.0037	0.002	0.0039
U	mg/L	0.00504	0.00507	0.00504	0.00511	0.00497	0.03	0.008
Zn	mg/L	*0.018*	*0.020*	*0.018*	*0.021*	*0.015*	2	0.317

Italicized predictions affected by detection limit propogation in the model

prediction of end point, not based on modeling

*narrative standards may exist

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^ Sb values revised to correct MW1B detection limit error 12/2018

Supersaturated phases are the same in the original base case and AMA: $Ba_3(AsO_4)$, barite, Cr_2O_3, ferrihydrite, gibbsite, quartz