Mary River Project 2015 - 2016 Lake Sedimentation Monitoring Report

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Lake Sedimentation
Monitoring Report

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TABLE OF CONTENTS

LIST OF FIGURES

After Page …

LIST OF TABLES

After Page …

1.0 INTRODUCTION

1.1 Background

The Mary River Project, owned and operated by Baffinland Iron Mines Corporation (Baffinland), is a high-grade iron ore mining operation located in the Qikiqtani Region of northern Baffin Island, Nunavut (Figure 1.1). Construction of mine infrastructure for the initial mining stages at the Mary River Project, referred to as the Early Revenue Phase (ERP), commenced in mid-2013 and is on-going. Surface mining for the ERP commenced in mid-September 2014, and has since included pit bench development, ore haulage and stockpiling, and the crushing and screening of high-grade iron ore at the mine site. The Mary River Project has the potential to result in increased sediment deposition in mine area water bodies through fugitive dust deposition, surface runoff/erosion from the mine site and/or increased biological productivity (i.e., eutrophication due to treated sewage discharge). In aquatic environments, these deposits could lead to physical habitat alteration (e.g., changes in substrate composition) and/or chemical alteration (e.g., changes in metal and/or nutrient concentrations, organic content) that, in turn, could alter biotic assemblages and lead to adverse ecological effects (e.g., physical smothering, direct chemical response).

In order to better understand rates of sediment deposition potentially associated with the Mary River Project operation and the potential implications of this sediment deposition on aquatic biota, Lake Sedimentation Monitoring was included as a special investigation component of the mine Aquatic Effects Monitoring Program (AEMP; Baffinland 2014; NSC 2014a). The primary issue of concern regarding any increased sedimentation due to Mary River Project operation is the potential effects to Arctic charr (*Salvelinus alpinus*) populations at mine area lakes, which can possibly be affected by:

- Changes in benthic invertebrate community structure and/or density due to habitat alteration that, in turn, alter the Arctic charr food base;
- Loss of Arctic charr spawning habitat resulting from entrapment of fine material and greater embeddedness of substrate used for spawning; and,
- Limiting the amount of oxygen available in Arctic charr spawning beds during the overwinter incubation period, resulting in reduced egg hatching success and/or reduced larvae survival following hatch (Berry et al. 2003).

The Mary River Project Lake Sedimentation Monitoring study is a year-round sampling program that was designed to track total dry weight sediment deposition at Sheardown Lake NW separately over ice-cover and open-water periods (Baffinland 2014; NSC 2014a,b, 2015). Sheardown Lake NW is expected to receive the highest inputs of sediment inputs through dust

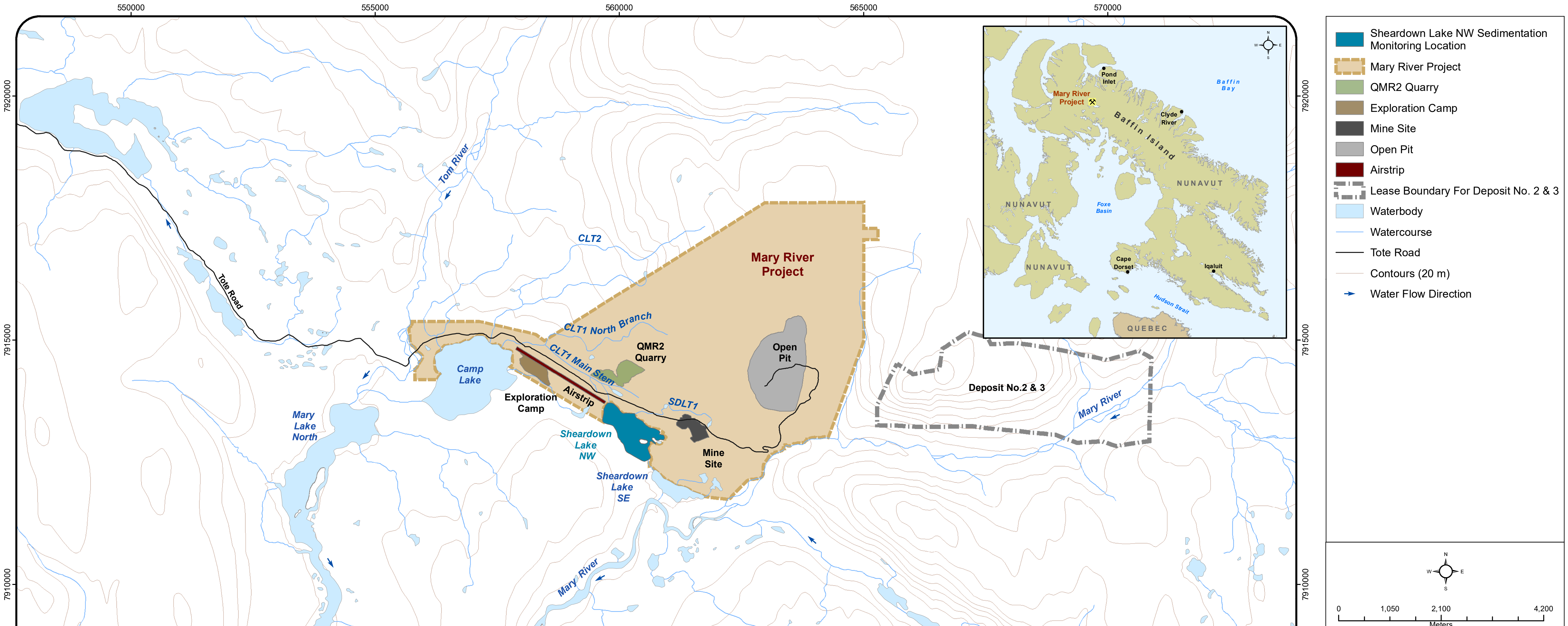

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Figure 1.1 : Mary River Project and Sheardown Lake NW Sedimentation Monitoring Locations.

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deposits and site runoff compared to other local waterbodies, and therefore this lake serves as the focus for the monitoring of lake sedimentation (Figure 1.1; NSC 2014b). Sedimentation monitoring was initiated at Sheardown Lake NW in 2013, with data collected from fall 2013 to fall 2014 serving as baseline for one full ice-cover and one full open-water period for the evaluation of potential effects of active Mary River Project operations on lake sedimentation. In June 2016, Environment and Climate Change Canada (ECCC) and Indigenous and Northern Affairs Canada (INAC) issued a *Fisheries Act* Direction (FAD) and a Letter of Non-Compliance (LNC), respectively, to Baffinland in response to unauthorized sediment releases to waterbodies associated with the Mary River Project (Baffinland 2016). Specifically, the FAD and LNC were issued as a result of aqueous Total Suspended Solids (TSS) concentrations above applicable discharge criteria at a number of watercourses on or adjacent to the mine property, Milne Port Tote Road and the mine haul road. Sheardown Lake NW receives discharge from one of the watercourses affected by the unauthorized sediment releases (i.e., Sheardown Lake Tributary 1 [SDLT1]). This report presents the results of the 2015 – 2016 Lake Sedimentation Monitoring study, including the evaluation of potential Mary River Project-related influences on sedimentation at Sheardown Lake NW in the second year following the onset of commercial mine operation in 2014. In consideration of the 2016 FAD and LNC, additional attention towards the evaluation of sedimentation-related effects at the area located nearest the SDLT1 outlet in Sheardown Lake NW was conducted for the 2016 assessment.

1.2 Report Organization

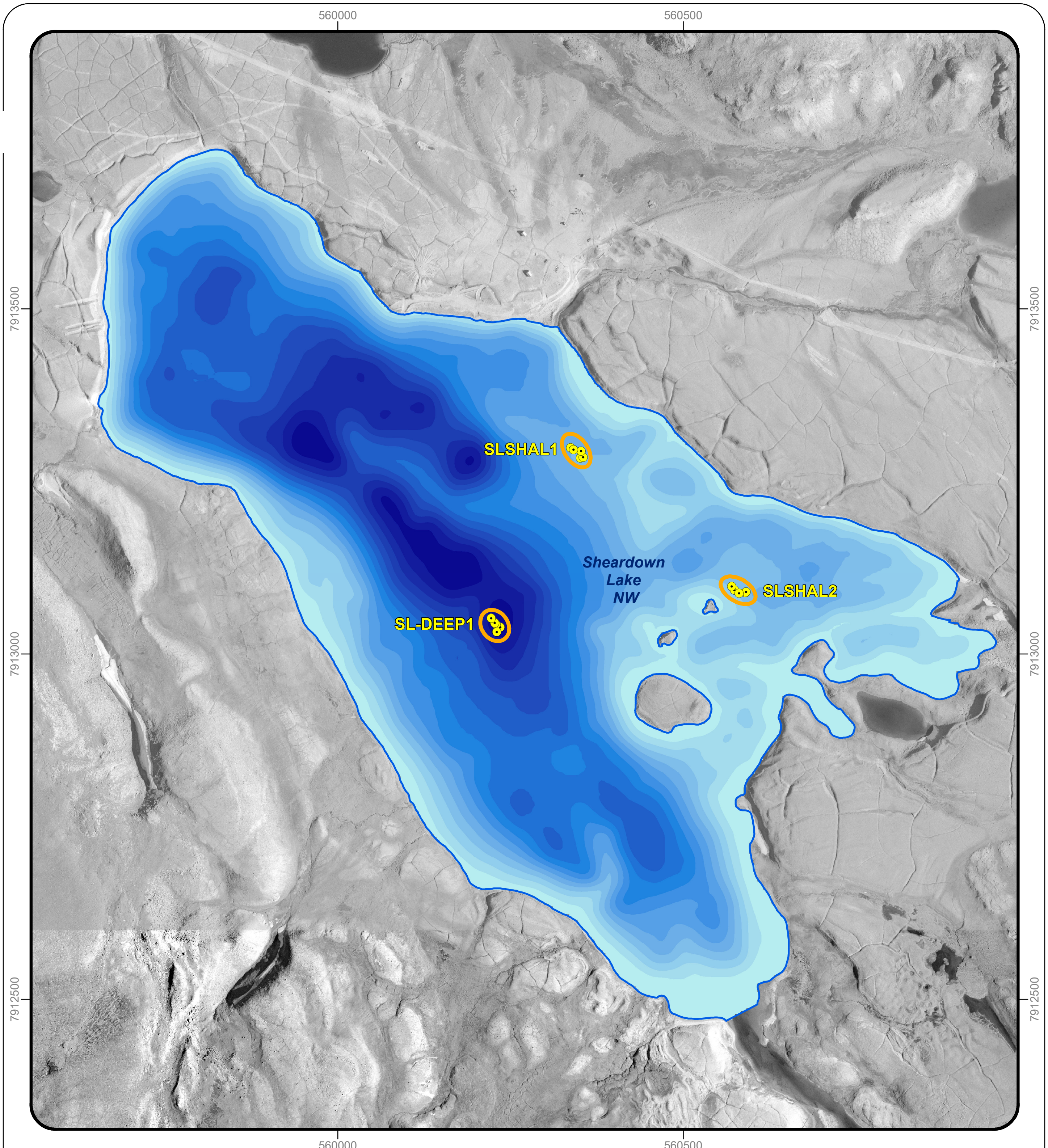
The content of this report reflects the approach outlined in the Lake Sedimentation Monitoring study design (Baffinland 2014; NSC 2014a,b) together with additional interpretive analysis conducted as part of the 2015 lake sedimentation report (Minnow 2016). A description of the study areas that serve as the focus for the Lake Sedimentation Monitoring study, as well as detailed methods used for the field sample collection, sample processing, sedimentation rate calculation and data analysis, are provided in Section 2.0. The lake sedimentation results are presented in Section 3.0, and conclusions of the 2015 – 2016 Lake Sedimentation Monitoring study are provided in Section 4.0. Finally, all references cited within this document are listed in Section 5.0.

2.0 STATION LOCATIONS AND STUDY METHODS

2.1 Station Locations

Increased sedimentation has the potential to affect Arctic charr populations by altering the benthic invertebrate food base (e.g., reduced invertebrate density and/or altering invertebrate community structure), reducing the quantity and/or quality of spawning habitat, and reducing egg hatching success (NSC 2014a,b). Three sedimentation monitoring stations were established to evaluate the amount of sedimentation in Sheardown Lake NW. The selection of station locations took into account dominant benthic habitat types present in the lake as well as habitat considered important for supporting the resident Arctic charr population. Accordingly, lake sediment deposition was assessed using sediment traps deployed at each of the three stations (Figure 2.1; Table 2.1) as follows:

1. Shallow Depositional Station (SL-SHAL1): Silt-loam represents the dominant substrate type in Sheardown Lake NW, and therefore increased sedimentation on habitat characterized by this substrate has the greatest potential to affect overall lake benthic invertebrate density and/or community structure. In turn, any benthic invertebrate community changes in habitat of this type has a high potential to affect the Arctic charr population. Silt substrate in the lake littoral zone (i.e., 2 – 12 m depth) was targeted for placement of this station to represent a potentially high sediment deposition habitat. Because this station is located near the outlet from Sheardown Lake Tributary 1, information acquired from this station also served to evaluate the extent to which unauthorized sediment releases affected sedimentation at Sheardown Lake NW in 2016.
2. Shallow Hard-Bottom Station (SL-SHAL2): Increased sedimentation at hard-bottom areas could reduce the amount of available spawning habitat and/or reduce egg hatching/reproductive success. Therefore, this station was established on coarse substrate (i.e., gravel, cobble) in the lake littoral zone at an area considered to provide suitable spawning habitat for Arctic charr.
3. Deep Profundal Station (SL-DEEP1): Because the main basin is the ultimate depositional zone for the lake, the highest sediment deposition rate is expected at this area that, in turn, provides an estimate of 'maximum' sedimentation. This station was established on silt substrate at the main lake basin in the lake profundal zone (30 m deep; Figure 2.1).



Sedimentation Monitoring Station

Bathymetry (m)

0- 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 14
14 - 16
16 - 18
18 - 20
20 - 22
22 - 24
24 - 26
26 - 28
28 - 30

N
W E
S

0 100 200 400
Meters

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Figure 2.1 : Sheardown Lake NW Lake Sedimentation Monitoring Locations, Mary River Project, 2014 - 2015.

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Table 2.1: Sediment trap replicate station coordinates, habitat information and deployment and retrieval information, Sheardown Lake NW Sedimentation Monitoring Study, 2015 - 2016.

Station	Station Replicate	Location (UTM; Zone 17W)		Station Depth (m)	Substrate	Ice - Cover Period (2015 - 2016)			Open-Water Period (2016)		
		Easting	Northing			Date Deployed	Date Retrieved	Set Duration (days)	Date Deployed	Date Retrieved	Set Duration (days)
Shallow 1 (SL SHAL1)	SL-SHAL-1A	560346	7913299	9.1	cobble	7-Sep-15	13-Jul-16	310	-	-	-
	SL-SHAL-1B	560348	7913291	9.1	cobble	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-1C	560349	7913289	8.9	cobble	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-1D	560351	7913268	8.8	cobble	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-1E	560340	7913279	8.8	cobble	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
Shallow 2 (SL SHAL2)	SL-SHAL-2A	560540	7913090	6	silt	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-2B	560544	7913093	5.9	silt	7-Sep-15	13-Jul-16	310	-	-	-
	SL-SHAL-2C	560548	7913097	6.2	silt	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-2D	560552	7913098	6.2	silt	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
	SL-SHAL-2E	560570	7913097	6.3	silt	7-Sep-15	13-Jul-16	310	14-Jul-16	8-Sep-16	56
Deep 1 (SL DEEP1)	SL-DEEP-1A	560235	7913039	29.5	silt	7-Sep-15	27-Jul-16	324	28-Jul-16	8-Sep-16	42
	SL-DEEP-1B	560229	7913043	29.4	silt	7-Sep-15	27-Jul-16	324	28-Jul-16	8-Sep-16	42
	SL-DEEP-1C	560227	7913045	29.5	silt	7-Sep-15	14-Jul-16	311	28-Jul-16	8-Sep-16	42
	SL-DEEP-1D	560230	7913032	29.6	silt	7-Sep-15	14-Jul-16	311	28-Jul-16	8-Sep-16	42
	SL-DEEP-1E	560222	7913052	29.5	silt	7-Sep-15	N/A	-	28-Jul-16	8-Sep-16	42

2.2 Field and Laboratory Methods

Five replicate sediment traps were originally deployed at each station in 2013 to monitor lake sedimentation. The sediment traps were constructed of three 50 cm long, 5 cm inside diameter polyvinyl chloride (PVC) pipes (i.e., 58.9 cm^2 surface area) sealed at the bottom and clamped together to create a single trap ‘unit’. The sediment traps were designed to provide an aspect ratio of approximately 10:1, which meets the ≥ 5:1 aspect ratio generally recommended for cylindrical sediment traps to effectively monitor sediment deposition (Mudroch and MacKnight 1994). The sediment trap unit was secured to a float-anchor system designed to maintain the trap in an upright position for the duration of deployment. Under this system, the mouth of the sediment trap unit was situated approximately 1 m above the substrate.

Sedimentation was assessed separately for applicable ice-cover and open-water periods at Sheardown Lake NW. The seasonal timing of the ice breakup and freeze-up period at Sheardown Lake NW generally corresponds to early July and mid-September, respectively. For the 2015 – 2016 study, ice-cover period sediment traps were deployed 07 September 2015 and retrieved 13 – 27 July 2016 (310 – 324 day duration), and open-water period sediment traps were deployed 14 – 28 July 2016 and retrieved 08 September 2016 (42 – 56 day duration; Table 2.1). For the ice-cover period, each sediment trap was secured to a marker buoy deployed such that the marker buoy was submerged approximately 2 m below the water surface to avoid entrapment of the buoy by ice during winter, and a grappling tool was then required to secure the marker buoy and retrieve the sediment trap in the spring. For the open-water period, a surface marker buoy was attached to each sediment trap line to aid with trap location during retrieval. Supporting information recorded at each station during sediment trap deployment included water depth and Global Positioning System (GPS) coordinates.

One sediment trap was unable to be located at Station SL-SHAL2 following the ice-cover period in 2015, and therefore sedimentation data was acquired from the four remaining sediment traps at this study station for the 2015-2016 period. In 2016, one sediment trap was unable to be located at Station SL-DEEP1 following the ice-cover period, and therefore sedimentation data for this period was based on data from only four sediment traps. The irretrievable trap was found later in the season (August), but because a substantial amount of the open-water period had passed, sedimentation information from this trap was not included in the 2015 – 2016 analysis. The inability to locate sediment traps following the ice-cover period in 2015 and 2016 was due to the likely entrapment of the marker buoy by ice and subsequent relocation of the sediment trap. Also in 2016, single sediment traps from each of Stations SL-SHAL1 and SL-SHAL2 were unable to be located in September at the end of the open-water study period, resulting in the acquisition of sedimentation data from only four sediment traps for this study period. Strong winds and steeply contoured bathymetric features near the location of sediment trap deployment at these stations was believed to result in relocation of these sediment traps to deeper waters and, as a result of the submergence of the marker buoys, precluded the subsequent locating and retrieving of these traps later in the season. An additional sediment trap was deployed at each of Station SL-SHAL1 and Station SL-SHAL2 at the end of the open-water season to provide a full complement of sediment traps (i.e., 5) at each station.

Sediment trap retrieval involved pulling the entire unit to the surface very slowly to prevent sediment re-suspension in, and/or sediment loss from, each sediment trap. The entire contents of the trap, including all water and deposited sediment, was transferred into a 20 L plastic container pre-labelled with station identification and collection date information. Ambient water was used to rinse all sediment from each sediment trap, applied as a pressurized spray where appropriate. Upon complete removal of all material within the sediment trap, the sediment traps were redeployed at approximately the same locations of retrieval. Following collection of all sediment from individual traps, the sample containers were sealed and stored upright in the dark until submission to the analytical laboratory. The lake sedimentation samples were shipped to ALS Canada Ltd. (ALS; Waterloo, ON) for analysis of sediment total dry weight. At the laboratory, the sedimentation samples were filtered through a pre-weighed 0.70 µm glass fibre filter. The filter apparatus and container were rinsed three times to ensure complete removal of all sediment. The filter and residual sample material was dried at 105°C for two hours, allowed to cool for one hour, and then weighed to the nearest milligram using an appropriate balance with draft shield. As in previous studies, low sample volumes were encountered for each sediment trap replicate, and each station, for both of the 2015 – 2016 ice-cover and open-water period samples, precluding any additional analysis of the sedimentation material (e.g., sediment metal concentrations, dry bulk density).

2.3 Data Analysis

Sedimentation (deposition) rate was calculated for each replicate sediment trap using the equation (Kemp et al. 1974):

$$\textit{Sedimentation rate}\ (mg/cm^{-2}day^{-1}) = \frac{\textit{dry weight}\ (mg)}{\textit{total area}\ (cm^2)} \div \textit{deployment time period (day)}$$

The sedimentation data were evaluated statistically as follows: 1) spatial comparisons among the three stations for separate ice-cover and open-water periods; 2) comparisons between the ice-cover and open-water periods at each station; and, 3) temporal comparisons at each station among baseline (i.e., 2013 – 2014), 2014 - 2015 and 2015 - 2016 data sets separately for ice-cover and open-water periods. For the statistical analysis, raw data were assessed for normality and homogeneity of variance and log-transformed as necessary to meet test assumptions prior to conducting Analysis-of-Variance (ANOVA) and *post-hoc* tests, where appropriate. In instances where normality could not be achieved through data transformation, non-parametric Mann-Whitney U-test statistics were used to validate pair-wise statistical results, and Kruskal-Wallis H-tests were used to validate multiple station/year statistical results from the ANOVA using log-transformed data. Similarly, in instances in which normal data exhibited unequal variance despite log transformation, Student's t-tests were used assuming unequal variance to validate the statistical findings of the ANOVA tests for two-group comparisons. For multiple station or year comparisons, Tukey's Honestly Significant Difference (HSD) or Tamhane's *post-hoc* tests were conducted in cases in which normal data with equal and unequal variance, respectively, were encountered. All statistical comparisons were conducted using SPSS Version 12.0 software (SPSS Inc., Chicago, IL).

In addition to the analysis of sedimentation rates, an estimate of the uncompacted thickness (i.e., mm) of sediment accumulation was also calculated separately for each of the ice-cover and open-water periods using the equation (Kemp et al. 1974):

$$\textit{Accumulation thickness}\ (mm \cdot yr^{-1}) = \frac{\textit{Sedimentation rate}\ (mg \cdot cm^{-2} yr^{-1})}{\textit{Dry bulk density}\ (mg \cdot cm^{-3})}$$

In lieu of sufficient sample volumes to determine bulk density of sedimentation material, bulk density information from similar sedimentation studies conducted by Minnow Environmental Inc. (Minnow; unpublished data) at Canadian Shield lakes in northern Ontario was used as a surrogate for the calculation of sediment accumulation. Because these Minnow data were collected over the summer open-water period at temperate latitudes where aquatic biological productivity can be expected to be higher than at polar latitudes, the calculation of annual accumulation thickness using the Minnow bulk density information is likely to overestimate actual accumulation thickness for Sheardown Lake NW. Therefore, the derived accumulation thicknesses for the Mary River Project using these methods were considered conservative estimates of actual values. Adverse effects on fish egg survival have been documented for a sediment accumulation thickness exceeding approximately 1 mm during the egg incubation period (Morgan et al. 1983; Fudge and Bodaly 1984). Therefore, an accumulation thickness of 1 mm was used as a threshold for potential effects to Arctic charr egg incubation associated with sediment deposits at the Mary River Project. On Baffin Island, Arctic charr spawning occurs in autumn (September-October) and although egg hatch occurs in early April, larval emergence generally does not occur until ice breakup in mid-July (Scott and Crossman 1998). Because this period essentially mirrors the ice-cover period used in this study, accumulation thickness for the ice-cover period was used to evaluate potential effects of depositing sediment on Arctic charr egg survival at Sheardown Lake NW.

3.0 RESULTS

3.1 Sedimentation Rates

3.1.1 2015–2016 Season

Spatially within Sheardown Lake NW, sedimentation rates were lower at the shallow littoral stations (i.e., SL-SHAL1 and SL-SHAL2) than at the deep profundal station (i.e., main basin Station SL-DEEP1) during both the 2015-2016 ice-cover and 2016 open-water periods (Figure 3.1; Appendix Tables A.1 and A.2). The occurrence of highest sedimentation rate at the deepest area of Sheardown Lake NW was consistent with normal lake deposition patterns (see Wetzel 2001). Notably, the sedimentation rate nearest the SDLT1 tributary outlet (i.e., Station SL-SHAL1) was significantly lower than at stations SL-SHAL2 and SL-DEEP1 for the ice-cover period, and compared to the main basin (Station SL-DEEP1) for the open-water period (Appendix Table A.4). This suggested that sediment deposition in 2016 was relatively low at shallow, silt-bottomed littoral areas of Sheardown Lake NW that provide key habitat for benthic invertebrates that serve as the food base for resident Arctic charr. The 2015 - 2016 sedimentation rate at Station SL-SHAL2, which represents shallow, rocky littoral areas that potentially provide spawning habitat for Arctic charr in Sheardown Lake NW, were intermediate to or lower than the rates at the shallow and deep depositional stations for ice-cover and open-water periods, respectively (Figure 3.1).

Sedimentation rates were significantly higher during the open-water period compared to the ice-cover period at all three Sheardown Lake NW sedimentation monitoring stations (Appendix Table A.5). On average, sedimentation rates ranged from 1.5 – 3.0 times greater during the open-water period compared to the ice-cover period, potentially reflecting a combination of greater sources of sediment generated by the mine during the summer (e.g., fugitive dust) and/or naturally greater organic (e.g., phytoplankton) productivity during the open-water period. Nevertheless, approximately 70 – 79% of the total sediment deposited at the Sheardown Lake NW stations in 2015-2016 occurred over the ice-cover period (Appendix Table A.7), reflecting the much longer period of ice-cover compared to open-water through a typical year in the arctic.

Annual sedimentation extrapolated from the 2015-2016 Sheardown Lake NW data indicated approximately 27.1 and 31.3 mg/cm^2/year of sediment deposition at the SL-SHAL1 and SL-SHAL2 littoral stations, respectively, and 39.6 mg/cm^2/year of sediment deposition at the SL-DEEP1 profundal station. These annual rates were within the range of those observed at other Canadian arctic lakes (e.g., 7 – 50 mg/cm^2/year; Lockhart et al. 1998) and much lower than at proglacial lakes in south-east Greenland (e.g., mean of 790 mg/cm^2/year; Hasholt et al. 2000).

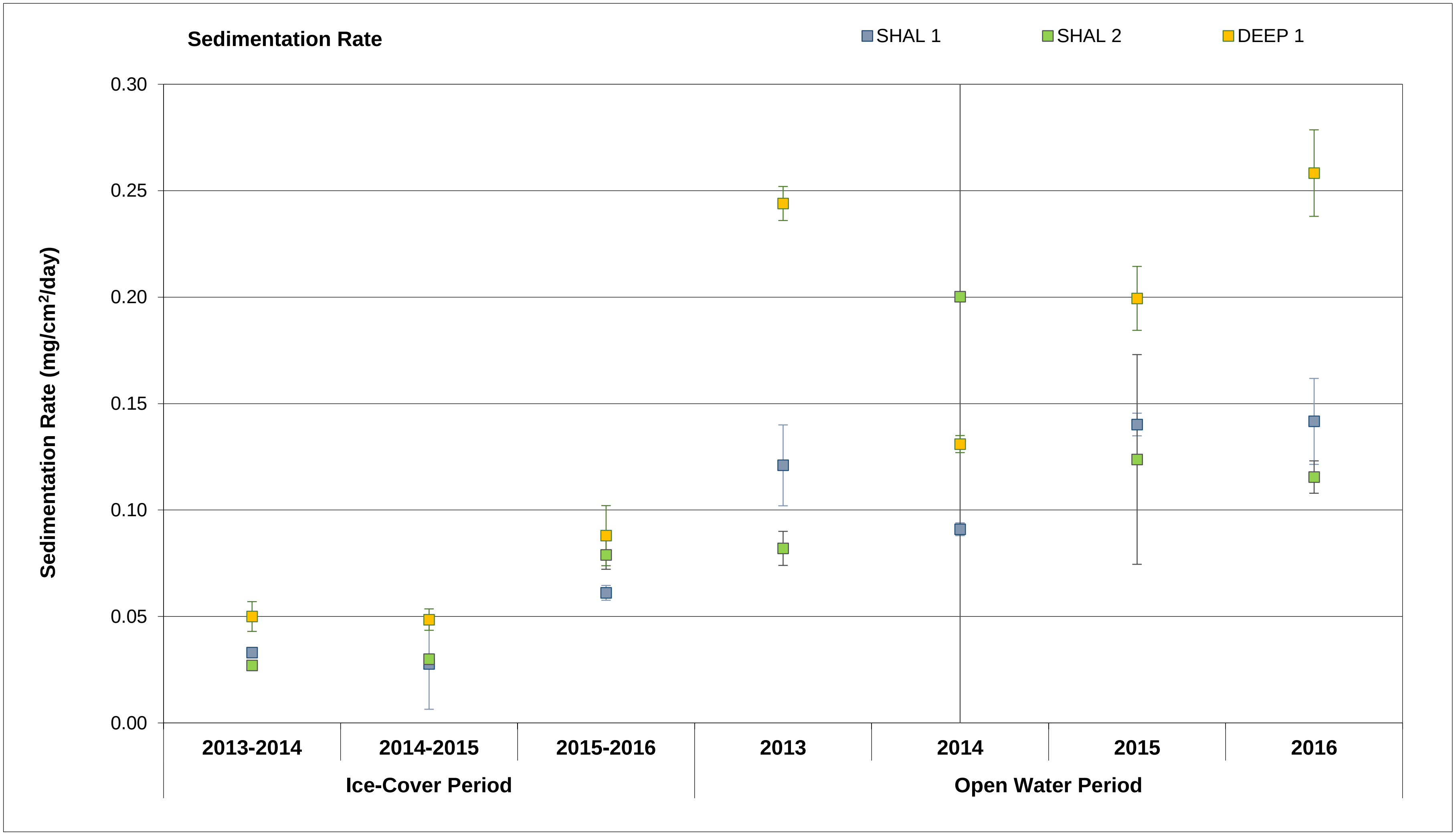

Figure 3.1: Sedimentation rates during ice-cover and open-water periods at Sheardown Lake NW over mine baseline (2013 - 2014) and operational (2015 - 2016) phases, Mary River Project Lake Sedimentation Monitoring Study.

Therefore, the annual sedimentation rate at Sheardown Lake NW in 2016 was within ranges typical for Arctic lakes.

3.1.2 Temporal Comparisons

Sedimentation rates over the 2015-2016 ice-cover period were significantly greater than the rate determined for the mine baseline study (2013 – 2014) and previous year of mine operation (2014 – 2015) at all Sheardown Lake NW lake sedimentation monitoring stations (Figure 3.1; Appendix Table A.6). Ice-cover period sedimentation rates at all three Sheardown Lake NW stations were uniformly about 2 – 3 times higher in 2015-2016 compared to rates at each respective station in the two previous studies (Figure 3.1). A similar magnitude of difference in sedimentation rates occurred between 2015- 2016 and the two previous studies at all stations for the ice-cover period. Relatively uniform sedimentation rates among the three Sheardown Lake NW stations in 2015-2016 suggested a broad-scale source of sediment to the lake (e.g., deposits from fugitive dust, autochthonous organic matter) and/or wide-scale dispersal of sediment from a point source (or sources) potentially related to physical properties of the depositing sediment (e.g., particle size, shape and/or relative density). Open-water season sedimentation rates were significantly higher at stations SL-SHAL1 and SL-DEEP1 in 2016 compared to the 2014 study (Appendix Table A.6). However, mean sedimentation rates in the 2016 open-water season at all of the Sheardown Lake NW stations were comparable to those observed during the 2013 baseline study, suggesting that sediment deposition in the 2016 open-water season was within the natural range of baseline conditions (Figure 3.1).

Annualized sedimentation rates for 2015 - 2016 (i.e., 27.1 – 39.5 mg/cm^2/year) were higher than rates during the 2013 - 2014 baseline period (i.e., 14.3 – 21.2 mg/cm^2/year; from NSC 2014a) and the 2014 - 2015 study (i.e., 15.5 – 24.5 mg/cm^2/year), largely as a result of higher sedimentation during the 2015 – 2016 ice-cover period. Overall, greater sedimentation rates occurred at Sheardown Lake NW during the 2015 – 2016 ice-cover period than during either the 2013 – 2014 mine baseline or 2014 – 2015 mine operational periods, suggesting a mine-related influence during the 2015 - 2016 ice-cover period. However, mine-related influences on Sheardown Lake NW sedimentation did not extend into the 2016 open-water season as evidenced through comparable sedimentation rates among 2013, 2014, 2015 and 2016 open-water period monitoring.

3.2 Sediment Accumulation Estimate

Annual accumulation thickness of sediment calculated for Sheardown Lake NW ranged from 1.36 mm/year at shallow littoral Station SL-SHAL1 to 2.02 mm/year at the deep profundal Station SL-DEEP1. These sediment accumulation thicknesses were higher than those observed among seven arctic lakes in western Greenland, which ranged from 0.27 ± 0.12 to 1.2 ± 0.32 mm/year and averaged 0.54 mm/yr (Sobek et al. 2014). In addition, the annual accumulation thicknesses at Sheardown Lake NW were greater in 2016 than in 2015, the latter of which ranged from 0.79 mm/year at the shallow littoral stations to 1.25 mm/year at the deep profundal station of Sheardown Lake NW (Minnow 2016). Therefore, the 2016 results supported the findings of the sedimentation rate analysis, and suggested greater sedimentation at Sheardown Lake NW in 2016 compared to previous studies.

Adverse effects on fish egg survival have been documented for a sediment accumulation thickness exceeding approximately 1 mm during the egg incubation period (Morgan et al. 1983; Fudge and Bodaly 1984). The sediment accumulation thickness calculated for the Arctic charr egg incubation/larval pre-emergence period (i.e., approximately mid-September to mid-July; Scott and Crossman 1998) at Sheardown Lake NW varied from 0.96 ± 0.05 mm at the littoral hard-bottomed station (i.e., SL-SHAL1) to 1.24 ± 0.11 mm at the littoral silt-bottomed station (i.e., SL-SHAL2). The highest sediment accumulation thickness for Sheardown Lake NW over the anticipated Arctic charr egg incubation/larval pre-emergence period was predicted for the profundal soft-bottomed station at the main basin of the lake (1.42 ± 0.24 mm). Because the accumulation thickness was near or slightly greater than 1 mm over the duration of the anticipated Arctic charr egg incubation/larval pre-emergence period, Arctic charr hatch success was potentially affected as a result of relatively high sedimentation at Sheardown Lake NW in 2016.

Arctic charr population monitoring conducted as part of the Mary River Project CREMP indicated substantially higher relative abundance of young-of-the-year (YOY) along nearshore areas of Sheardown Lake NW than at a comparable reference lake in 2016 based on electrofishing catch-per-unit-effort (CPUE; 0.47 and 0.20 YOY per electrofishing minute, respectively; Minnow 2017). In addition, nearshore electrofishing CPUE for Arctic charr YOY at Sheardown Lake NW was greater in 2016 than in 2015 (i.e., 0.13 YOY per electrofishing minute). Arctic charr YOY from Sheardown Lake NW were also significantly heavier and longer, showed significantly faster growth, and did not differ significantly in condition (i.e., weight-at-length relationship) from those at the reference lake in 2016 (Minnow 2017). Collectively, these data indicated successful Arctic charr hatch, emergence, and subsequent YOY growth at Sheardown Lake NW in 2016. In turn, this suggested that sediment accumulation thicknesses calculated for the Arctic charr incubation period at Sheardown Lake NW there were based on bulk density information from northern Ontario lakes may have overestimated actual accumulation thicknesses at Sheardown Lake NW in 2016. Specifically, the data used to estimate sediment accumulation at Sheardown Lake NW were based on bulk density information collected at temperate latitudes over the summer period when aquatic biological productivity can be expected to be higher than at polar latitudes. Therefore, the derived accumulation thicknesses for Sheardown Lake NW can be considered conservative (over)estimates of actual values. This was supported by Arctic charr YOY catch and health data, which indicated relatively high abundance of healthy YOY and suggested no adverse influences of sedimentation on egg hatch success, larval emergence and early life stage growth of Arctic charr at Sheardown Lake in 2016.

4.0 CONCLUSIONS

Lake Sedimentation Monitoring is included as a special investigation component of the Mary River Project AEMP to track sedimentation and evaluate the potential for adverse influences on resident Arctic charr populations related to excessive sedimentation at a representative lake (Sheardown Lake NW) within the immediate area of mine influence (NSC 2014a,b, 2015). Sedimentation monitoring was initiated in 2013 – 2014 to provide information prior to the start-up of active mine operations. The principal conclusions of 2015 – 2016 lake sedimentation monitoring study are as follows:

- Annual sedimentation rate at Sheardown Lake NW in 2015 – 2016 was within the range observed among Canadian arctic lakes uninfluenced by anthropogenic activities.
- Sedimentation rates over the ice-cover period were significantly higher in 2015 - 2016 than during the mine baseline (2013 – 2014) and early operational (2014 - 2015) phases at Sheardown Lake NW. In addition, annualized sedimentation rates in 2015 - 2016 were higher than those during the 2013 - 2014 baseline and 2014 – 2015 mine operational phases. Therefore, the temporal data suggested higher sedimentation rates at Sheardown Lake NW during the 2015 – 2016 ice-cover period compared to previous studies.
- Annual accumulation thickness of sediment at Sheardown Lake NW in 2015 – 2016 was in the upper range of that documented at pristine Arctic lakes, suggesting that sedimentation at Sheardown Lake NW was relatively high. In addition, sediment accumulation thickness over the duration of the anticipated 2015 – 2016 Arctic charr egg incubation/larval pre-emergence period at Sheardown Lake NW was near a threshold effect level of 1 mm of sediment deposition for effects on salmonid egg hatch success. However, because a relatively high abundance of healthy Arctic charr YOY was observed at Sheardown Lake NW in 2016, derived accumulation thicknesses that were based on bulk density data from temperate latitudes likely overestimated actual sediment accumulations for Sheardown Lake NW.

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APPENDIX A

SEDIMENTATION INFORMATION

Table A.1: Sediment trap results for the 2014 - 2015 ice-cover period at Sheardown Lake NW, Lake Sedimentation Monitoring Study, 2014 - 2015.

Station	Station Replicate	Retrieval Location (UTM; Zone 17W)		Station Depth (m)	Date Deployed	Date Retrieved	Set Duration (days)	Total Dry Weight (g)	Sedimentation Rate (mg/cm^2/day)
		Easting	Northing						
Shallow 1 (SL SHAL1)	SL-SHAL-1A	560346	7913299	9.1	7-Sep-15	13-Jul-16	310	1.16	0.064
	SL-SHAL-1B	560348	7913291	9.1	7-Sep-15	13-Jul-16	310	1.13	0.062
	SL-SHAL-1C	560349	7913289	8.9	7-Sep-15	13-Jul-16	310	1.09	0.060
	SL-SHAL-1D	560351	7913268	8.8	7-Sep-15	13-Jul-16	310	1.02	0.056
	SL-SHAL-1E	560340	7913279	8.8	7-Sep-15	13-Jul-16	310	1.18	0.065
						Average	**310**	**1.116**	**0.061**
						Standard Deviation	**0.0**	**0.063**	**0.003**
Shallow 2 (SL SHAL2)	SL-SHAL-2A	560540	7913090	6.0	7-Sep-15	13-Jul-16	310	1.50	0.082
	SL-SHAL-2B	560544	7913093	5.9	7-Sep-15	13-Jul-16	310	1.34	0.073
	SL-SHAL-2C	560548	7913097	6.2	7-Sep-15	13-Jul-16	310	1.55	0.085
	SL-SHAL-2D	560552	7913098	6.2	7-Sep-15	13-Jul-16	310	1.28	0.070
	SL-SHAL-2E	560570	7913097	6.3	7-Sep-15	13-Jul-16	310	1.54	0.084
						Average	**310**	**1.442**	**0.079**
						Standard Deviation	**0.0**	**0.124**	**0.007**
Deep 1 (SL DEEP1)	SL-DEEP-1A	560235	7913039	29.5	7-Sep-15	27-Jul-16	324	2.08	0.109
	SL-DEEP-1B	560229	7913043	29.4	7-Sep-15	27-Jul-16	324	1.50	0.079
	SL-DEEP-1C	560227	7913045	29.5	7-Sep-15	14-Jul-16	311	1.51	0.082
	SL-DEEP-1D	560230	7913032	29.6	7-Sep-15	14-Jul-16	311	1.50	0.082
	SL-DEEP-1E	560222	7913052	29.5	7-Sep-15	N/A	-	-	-
						Average	**317.5**	**1.648**	**0.088**
						Standard Deviation	**7.5**	**0.288**	**0.014**

Table A.2: Sediment trap results for the 2016 open-water period at Sheardown Lake NW, Lake Sedimentation Monitoring Study, 2015 - 2016.

Station	Station Replicate	Retrieval Location (UTM; Zone 17W)		Station Depth (m)	Date Deployed	Date Retrieved	Set Duration (days)	Total Dry Weight (g)	Sedimentation Rate (mg/cm^2/day)
		Easting	Northing						
Shallow 1 (SL SHAL1)	SL-SHAL-1A	-	-	-	-	-	-	-	-
	SL-SHAL-1B	560378	7913304	9.1	14-Jul-16	8-Sep-16	56	0.48	0.146
	SL-SHAL-1C	560373	7913299	8.9	14-Jul-16	8-Sep-16	56	0.392	0.119
	SL-SHAL-1D	560375	7913308	8.8	14-Jul-16	8-Sep-16	56	0.551	0.167
	SL-SHAL-1E	560376	7913303	8.8	14-Jul-16	8-Sep-16	56	0.446	0.135
	Average						**56**	**0.467**	**0.142**
	Standard Deviation						**0.0**	**0.067**	**0.020**
Shallow 2 (SL SHAL2)	SL-SHAL-2A	560552	7913107	6	14-Jul-16	8-Sep-16	56	0.351	0.106
	SL-SHAL-2B	-	-	5.9	-	-	-	-	-
	SL-SHAL-2C	560552	7913106	6.2	14-Jul-16	8-Sep-16	56	0.37	0.112
	SL-SHAL-2D	560551	7913108	6.2	14-Jul-16	8-Sep-16	56	0.405	0.123
	SL-SHAL-2E	560551	7913106	6.3	14-Jul-16	8-Sep-16	56	0.398	0.121
	Average						**56.0**	**0.381**	**0.116**
	Standard Deviation						**0**	**0.025**	**0.008**
Deep 1 (SL DEEP1)	SL-DEEP-1A	560241	7913032	29.5	28-Jul-16	8-Sep-16	42	0.636	0.257
	SL-DEEP-1B	560236	7913043	29.4	28-Jul-16	8-Sep-16	42	0.638	0.258
	SL-DEEP-1C	560229	7913044	29.5	28-Jul-16	8-Sep-16	42	0.606	0.245
	SL-DEEP-1D	560234	7913034	29.6	28-Jul-16	8-Sep-16	42	0.722	0.292
	SL-DEEP-1E	560221	7913050	29.5	28-Jul-16	8-Sep-16	42	0.593	0.240
	Average						**42**	**0.639**	**0.258**
	Standard Deviation						**0**	**0.050**	**0.020**

Table A.3: Sedimentation (mg/cm^2/day) summary statistics for Sheardown Lake NW, Lake Sedimentation Monitoring Study, 2015 - 2016

Study Period	Station	Sample Size	Mean	Standard Deviation	Standard Error	95% Confidence Interval		Minimum	Maximum
						Lower Bound	Upper Bound		
Ice-Cover 2015 - 2016	SL SHAL 1	5	0.061	0.003	0.002	0.057	0.065	0.056	0.065
	SL SHAL 2	5	0.079	0.007	0.003	0.071	0.087	0.070	0.085
	SL DEEP1	4	0.088	0.014	0.007	0.066	0.110	0.079	0.109
Open-Water 2016	SL SHAL 1	4	0.142	0.020	0.010	0.110	0.174	0.119	0.167
	SL SHAL 2	4	0.116	0.008	0.004	0.103	0.128	0.106	0.123
	SL DEEP1	5	0.258	0.020	0.009	0.233	0.284	0.240	0.292

Table A.4: Statistical comparison of sedimentation among Sheardown Lake NW stations for ice-cover and open-water periods, Lake Sedimentation Monitoring Study, 2015 - 2016.

Study Period	Overall 3-group Comparison			Pair-wise, post-hoc comparisons[a]				
	Significant Difference Among Areas?	p-value	Staistical Test[b]	(I) Area	(J) Area	Significant Difference Between 2 Areas?	p-value	Statistical Test
Ice-Cover 2015 - 2016	YES	0.00065	ANOVA[c]	SL SHAL1	SL SHAL2	YES	0.0055	Tukey's HSD[d]
				SL SHAL1	SL DEEP1	YES	0.0007	
				SL SHAL2	SL DEEP1	NO	0.3233	
Open-Water 2016	YES	0.00000	ANOVA[d]	SL SHAL1	SL SHAL2	NO	0.1355	Tukey's HSD[d]
				SL SHAL1	SL DEEP1	YES	0.0000	
				SL SHAL2	SL DEEP1	YES	0.0000	

[a] Post-hoc analysis of 1-way ANOVA among all areas protected for multiple comparisons.

[b] Statistical tests include Analysis of Variance (ANOVA) and Kruskal Wallis H-test (KW H-test).

[c] Data non-normal despite log-transformation. Therefore, multiple-group ANOVA results validated using Kruskal-Wallis H-test (KW test) performed on log-transformed data (KW test p = 0.0106) and pair-wise ANOVA results validated using Mann-Whitney U-tests performed on log-transformed data.

[d] Untransformed data were normally distributed and homogenous, and therefore no data transformation was used for the multiple-group comparison and post-hoc pair-wise comparisons.

Table A.5: Statistical comparison of sedimentation (mg/cm^2/day) between the 2015-2016 ice-cover and 2016 open-water periods at Sheardown Lake NW, Lake Sedimentation Monitoring Study, 2015 - 2016.

Station	Statistical Test Results			Summary Statistics						
	Significant Difference Between Areas?	*p*-value	Statistical Analysis[a]	Period	N	Mean	Standard Deviation	Standard Error	Minimum	Maximum
SL SHAL1	YES	0.000	β , γ	Ice-Cover 2015-2016	5	0.061	0.003	0.002	0.056	0.065
				Open-Water 2016	4	0.142	0.020	0.010	0.119	0.167
SL SHAL2	YES	0.000	α , γ	Ice-Cover 2015-2016	5	0.079	0.007	0.003	0.070	0.085
				Open-Water 2016	4	0.116	0.008	0.004	0.106	0.123
SL DEEP1	YES	0.000	β , δ	Ice-Cover 2015-2016	4	0.088	0.014	0.007	0.079	0.109
				Open-Water 2016	5	0.258	0.020	0.009	0.240	0.292

[a] Data analysis included: α - data untransformed; β - data log transformed; γ - single factor ANOVA test conducted; δ - single-factor ANOVA test results validated using Mann-Whitney U-test; and, ε - single-factor ANOVA test results validated using t-test assuming unequal variance.

Highlighted values indicate significant difference between study areas based on ANOVA p-value less than 0.10.

Table A.6: Statistical comparison of sedimentation rates between mine baseline (2013, 2014) and operational (2015, 2016) phases at Sheardown Lake NW during ice-cover and open-water periods, Lake Sedimentation Monitoring Study.

Station	Study Period	Overall 3-group Comparison: Significant Difference Among Areas?	Overall 3-group Comparison: p-value	Overall 3-group Comparison: Staistical Test[b]	Pair-wise, post-hoc comparisons[a]: (I) Area	(J) Area	Significant Difference Between 2 Areas?	p-value	Statistical Test
Shallow 1 (SHAL1)	Ice-Cover	YES	0.00552	ANOVA[b]	2013 - 2014	2014 - 2015	NO	0.3488	Tukey's HSD[b]
					2013 - 2014	2015 - 2016	YES	0.0785	
					2014 - 2015	2015 - 2016	YES	0.0044	
	Open-Water	YES	0.00029	ANOVA[c]	2014	2015	YES	0.0007	Tukey's HSD[c]
					2014	2016	YES	0.0009	
					2015	2016	NO	0.9916	
Shallow 2 (SHAL2)	Ice-Cover	YES	0.00000	ANOVA[c]	2013 - 2014	2014 - 2015	NO	0.3057	Tamhane's [c]
					2013 - 2014	2015 - 2016	YES	0.0001	
					2014 - 2015	2015 - 2016	YES	0.0001	
	Open-Water	NO	0.57662	ANOVA[c]	2014	2015	NO	0.8871	Tamhane's [c]
					2014	2016	NO	0.8513	
					2015	2016	NO	0.9863	
Deep 1 (DEEP1)	Ice-Cover	YES	0.00007	ANOVA[b]	2013 - 2014	2014 - 2015	NO	0.9242	Tukey's HSD[b]
					2013 - 2014	2015 - 2016	YES	0.0002	
					2014 - 2015	2015 - 2016	YES	0.0001	
	Open-Water	YES	0.00000	ANOVA[c]	2014	2015	YES	0.0000	Tukey's HSD[c]
					2014	2016	YES	0.0000	
					2015	2016	YES	0.0001	

[a] Post-hoc analysis of 1-way ANOVA among all areas protected for multiple comparisons.

[b] Untransformed data were non-normally distributed; log-transformation resulted in normally distributed data. and thus the log-transformed data were used for statistical tests.

[c] Untransformed data were normally distributed, and thus un-transformed data used for statistical tests.