AZIMUTH

Technical Memorandum

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To: **Denis Gourde, Eric Lamontagne, Sebastian Tolgyesi, Ryan Vanengen, Sylvain Doire, Gaston Blanchette**

Cc: **Larry Connell**

From: **Gary Mann, Ryan Hill and Randy Baker**

RE: **Effects Assessment Strategy for Elevated TSS in Second Portage Lake**

Introduction

The purpose of this memorandum is to:

- Provide an update on the suspended sediments situation[1] in Second Portage Lake
- Discuss the nature of effects associated with elevated total suspended solids (TSS) based on literature studies
- Outline our recommended strategy for assessing potential ecological effects in Second Portage Lake

Situation Update

TSS concentrations in Second Portage Lake have been dropping consistently over the past two weeks (see **Figures 1 to 3**). However, while TSS concentrations are below the 15 mg/L over much of the lake, many of the routine monitoring stations are still exceeding the 7-day average trigger value (15 mg/L) and all the high value stations are exceeding the 6mg/L 7-day average trigger (this trigger is effective as of September 1)[2]. Some key aspects of the situation include:

- Deep turbid zones - Significantly elevated turbidity (i.e., > 2000 NTU) was measured in mid August at depths greater than 8 m in the lake depressions east of monitoring stations SE3 and NE1. While these areas are limited in size by local bathymetry, the extent and magnitude of turbidity in these zones was variable. We have not detected these zones recently, which suggests that this pool of very turbid water was mixed into the water column during a prolonged wind event and contributed to the very high turbidity readings in the lake east of the dike.

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[1] Routine field monitoring relies on direct measurements of turbidity. TSS concentrations are estimated using a linear regression relationship derived from our site-specific data set of paired measurements (i.e., field turbidity and laboratory TSS).

[2] The following terminology conventions are used to describe local geography: "upstream" relative to the East Dike refers to the final configuration rather than present gradients (i.e., the SE portion of the lake is the "upstream" area. The "impoundment" side, by extension, is the "downstream" NW arm of the lake. The work zone refers to the portion of the impoundment or upstream sides that are enclosed by the turbidity barriers.

- Southeast surface plume – Despite work on the dike moving progressively northward and away from this area, a notable plume was observed in surface waters adjacent to the SE turbidity barrier (i.e., SE3 and HVH3). TSS concentrations in the upper water column (i.e., top 2 to 5 m) in this zone were often twice as high as surface waters to the north. One likely contributor to this feature was the Western Channel, which input on the order of 46,000 m^3/day[3] up-gradient of the work zone, essentially displacing this same volume from the work area into the upstream side. A temporary dam was placed in the Western Channel on August 23 as a mitigation measure to curtail this discharge; monitoring results since then have shown conditions improve greatly, with surface waters now being fairly similar between NE and SE stations.

- Prevailing conditions – Vertical and horizontal mixing due to wind-driven waves and currents has transported suspended sediments over much of Second Portage Lake. Broad surveys conducted on August 18th and 22nd (i.e., before and after a major wind event; see **Figures 2 and 3** for the extent and magnitude of TSS in the top 5 m of the water column), clearly show the extent of mixing, with TSS concentrations over most of Second Portage Lake on the order of 15 to 20 mg/L at that time. TSS-laden water from Second Portage Lake have also been discharging to Tehek Lake at a rate of approximately 190,000 m^3/day[3] (**Figure 4**). In general, there is a gradient in TSS concentrations from the routine stations through SE Second Portage Lake and into Tehek. The latter was surveyed in late August (**Figure 5**), with only a small portion of the lake having concentrations higher than the 6-mg/L trigger for high value habitats. Turbidity surveys of Tehek Lake will continue on a routine basis (every 1 to 2 weeks) while there is helicopter availability at site.

Figure 4. Sediment plume in Tehek Lake observed on August 23.

Potential Effects

The input of sediments into Second Portage Lake could lead to chemical and physical effects to the ecosystem. Water samples collected near the upstream turbidity barrier are currently being analysed for nutrients (blast residue), metals (particulate or dissolved) and a suite of other parameters. The

[3] AMEC (2005) *Meadowbank Gold Project Mine Pit Dewatering Analysis of Effects* reports approximately 0.53 cms for the Western Channel and 2.21 cms for Second Portage Lake outflow in August.

results will be used to evaluate the potential for contaminant-related effects; this strategy would be modified to address contaminant-related effects. The physical effects of introduced sediment are described below.

The *Meadowbank Gold Project Water Quality Monitoring and Management Plan for Dike Construction and Dewatering* (July 2008) contained a review of the potential effects of total suspended solids (TSS) and turbidity on fish and fish habitat. These include smothering (e.g., of fish eggs or benthic invertebrates), decreased productivity (i.e., due to reduced light), reduced feeding (i.e., due to limited visibility), and gill clogging/abrasion. Effects are influenced by exposure and duration, as well as the size and shape of suspended particles. Overall, the most sensitive group appears to be salmonids (e.g., lake trout, Arctic char and whitefish), with their early life stages the most at risk. Consequently, management triggers were developed to address exposure duration (i.e., 24-hr average to cover exposures less than a day, and 7-day average to cover exposures ranging >1 day to <30 days) and seasonal sensitivity (i.e., higher triggers for less sensitive habitats and/or periods).

Given the extended duration of elevated TSS concentrations in Second Portage Lake (see *Situation Update* above), this discussion will focus on long-term exposures only and include both less-sensitive and sensitive salmonid life history stages. Appendix A of the aforementioned management plan contains a detailed analysis of the data used to derive the Meadowbank TSS triggers. The underlying data set, comprised of more than 300 data sets, was compiled from Caux et al. (1997) and was the basis for deriving the CCME TSS guidelines. Relevant results for chronic (i.e., long-term) exposures are discussed below. Response is estimated using a scale of 0 to 14 to indicate the "severity of ill effects" (SIE). SIE scores of 1 to 3 are behavioural responses such as alarm reaction, abandonment of cover or avoidance response. SIE scores from 4 to 8/9 indicate increasingly severe sub-lethal effects. SIE scores of 10 to 14 indicate mortality, ranging from 0 to 20% (for SIE score =10) to >80% (SIE score = 14).

Less-sensitive Life History Stages (non-spawning habitat; spawning habitat prior to September)

After excluding data for short exposures, high TSS (>100 mg/L) and those specific to eggs or larvae, 28 data points remained (**Figure 5**). There are limited data at low TSS concentrations, with the first five shown in **Table 1**.

Table 1. Effects of chronic exposure to less sensitive life history stages from chronic exposure to low TSS concentrations.

Species	Life Stage	TSS (mg/L)	Exposure Duration (days)	SIE Score	Response
Smelt	Adult	4	7	7	Increased vulnerability to predation
Lake Trout	Adult	4	7	3	Fish avoided turbid areas
Brook Trout	Adult	5	7	3	Fish more active and less dependent on cover
Chinook Salmon	Juv	6	60	9	Growth rate reduced
Brook Trout	Fry	12	245	9	Growth rates declined

None of the measured responses indicate mortality. At slightly higher TSS concentrations (18 mg/L) reduced abundance has been observed (SIE = 10, 30 day exposure for adult brown trout and rainbow trout). Mortality is first observed at 22 mg/L, but that data point involved a full year (365 days) of exposure and applies to a warmwater fish species. Beyond that, the next study showing mortality occurs at a TSS concentration of 90 mg/L (<20% mortality of rainbow trout under-yearlings exposed for 19 days). These data suggest that direct mortality may be quite unlikely at TSS concentrations < 20 mg/L. Nevertheless, reduced growth, which is observed at lower TSS concentrations, can be a significant sub-lethal effect.

A key consideration in the potential for adverse effects is whether juveniles and adults would be able to swim to avoid turbid waters. When deriving the trigger values we had not envisioned any suspended sediment plumes impacting the majority of the lake. Given the current situation, the only major refuge area left would be the arm that receives the outflow from Drilltrail Lake, where the constant inflow of clear water into a constricted arm is maintaining clear water. Apart from this area, fish would have experienced TSS concentrations in the range of 10 to 20 mg/L TSS concentrations for the last several weeks.

Without empirical data indicating otherwise, a conservative assumption would be that exposure durations would be on the order of at least several months. Sublethal effects of some degree should be considered probable and mortality unlikely for SE Second Portage Lake. The latter is supported by the fact that despite extensive monitoring coverage, no dead fish have been encountered in Second Portage Lake. Unless the plume expands/intensifies significantly, sublethal effects should be considered improbable in Tehek Lake.

Sensitive Life History Stages (spawning habitat starting in September)

The data set from above was expanded to include those points associated with early life history stages, resulting in the 38 cases shown in **Figure 6**. It is important to note that the concentration-response curve in this case appears to be quite flat except at very low TSS concentrations – the mean SIE score for the data points shown in **Figure 6** is 9.4, while the mean SIE score for the remaining data points (>100 mg/L TSS) is only slightly higher at 10.1. However, the SIE scale is not really linear, because direct measures of mortality apply only to SIE scores of 10 to 14.

Clearly there are variable, sometimes significant effects (e.g., mortality, SIE = 10 or more) that result from long-term exposure to TSS concentrations above around 15 mg/L. However, effects at concentrations of 12 mg/L or lower warrant a more detailed analysis. There are six data points where TSS concentrations are equal to or less than 12 mg/L; five were reported in **Table 1**, and one case targeting egg mortality that is presented in **Table 2**.

Table 2. Potential effects to sensitive life stages during chronic exposure to low TSS concentrations.

Species	Life Stage	TSS (mg/L)	Exposure Duration (days)	SIE Score	Response
Rainbow Trout	Egg	7	48	11	Mortality rate 40%

Among the cases in **Tables 1 and 2**, the most significant study and one that drives existing federal guidance, is the study showing 40% mortality of rainbow trout eggs at a TSS concentration of 7 mg/L. We used this study to set the chronic (7-day) trigger for the management plan. While the lack of multiple studies corroborating this particular dose-response point increases the uncertainty, the magnitude of response alone warrants taking it seriously.

Monitoring Strategy

Given that suspended sediments can directly or indirectly affect the entire range of organisms in the aquatic environment, the strategy needs to address a broad array of concerns. Details of the strategy are presented in **Table 3**; sampling locations shown in **Figure 7**; the following is an overview:

- *Water Quality and Limnology* – The most obvious effect of sediment inputs into clear lakes is a noticeable reduction in water clarity and reduced light penetration. There are other possible effects, however, which can be equally significant. These include introduction of metals and nutrients, or other changes to normal conditions (e.g., oxygen reductions). The program detailed in **Table 3** includes a comprehensive list of components to quantify these issues.

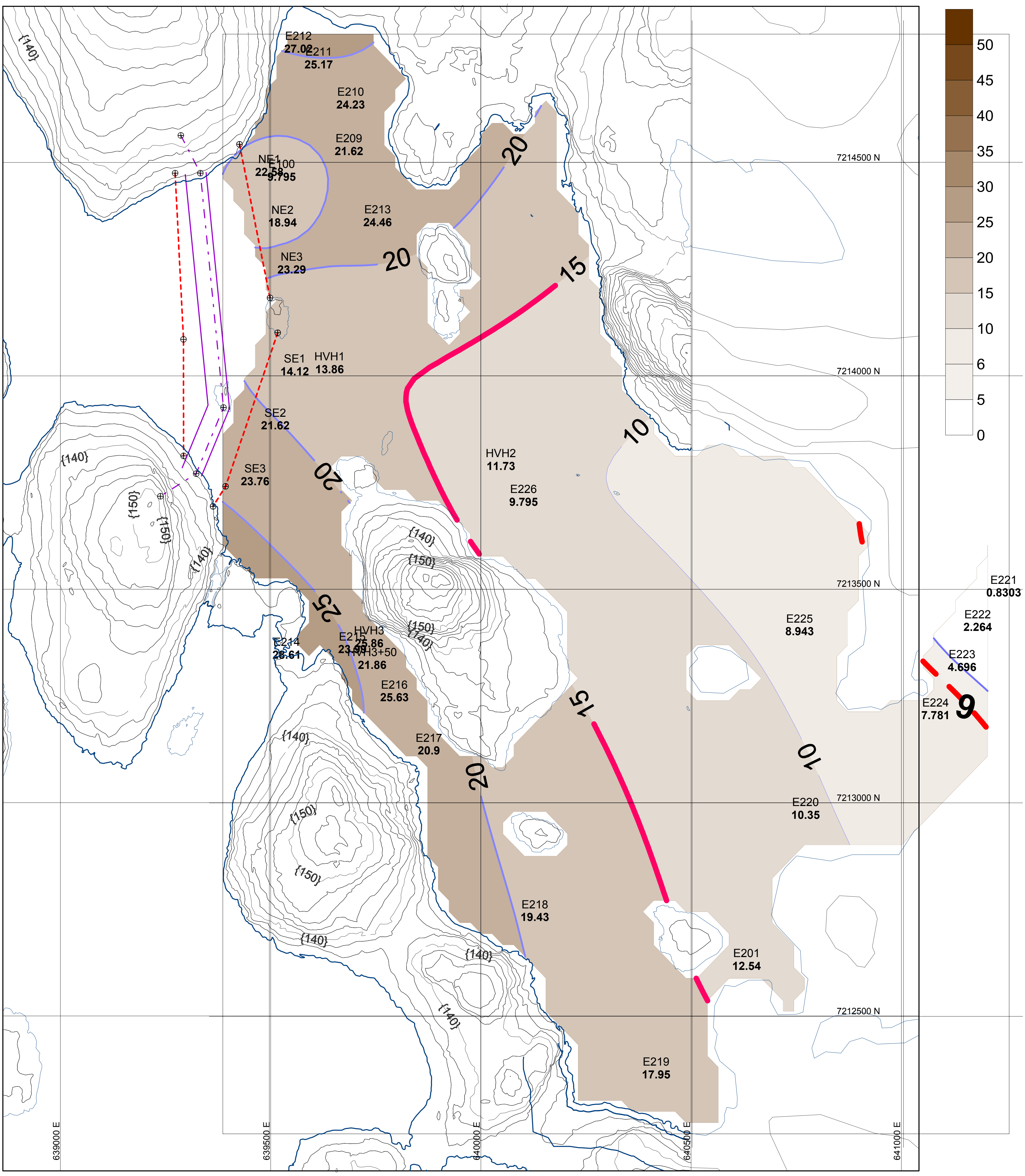
- *Field Effects Measurements* – Directly measuring key aspects of target aquatic receptors in the field is the best approach to determining the ecological significance of elevated TSS in Second Portage Lake. The components detailed in **Table 3** range from the base of the food chain to fish. Water-clarity related changes in productivity would be seen in the phytoplankton and likely zooplankton. Sediment deposition onto high-value habitat areas will be explored with sediment traps (placed in advance of dike construction) and follow-up video surveys in 2009. Direct assessment of fish populations (through CPUE comparisons between years) will not be conducted in 2009 unless the laboratory effects testing shows adverse results for fish. Stable isotope analysis (SIA) will be used to empirically document the predominant energy flow paths in Second Portage Lake. This technique works on the principle “you are what you eat”, with isotopic ratios of carbon and nitrogen in fish reflective of their predominant diets. This information will be useful to determine the relative importance of any reduced productivity observed in the water column (pelagic) or bottom (benthic) food chains.

- *Laboratory Effects Measurements* – Taking site water into the laboratory provides a unique opportunity to conduct a suite of tests on sensitive life history stages under controlled conditions. These tests will provide insights into how turbid water and/or settled sediment may affect zooplankton and fish survival, feeding and growth. The fish tests will target key developmental stages and will be modified from standard methods to increase realism. For example, the trout embryo test will be conducted two ways: with renewal of overlying water as per the protocol and with no renewal (to minimize disruption of particle settlement). The trout swim-up larvae test will be conducted using zooplankton for feeding, rather than the standard “trout chow”. As per their value to quantify the toxicity of contaminants, these tests will provide valuable information on the physical effects of suspended sediments. All the tests will be run across a series of dilutions (field sampling for water will target the highest areas of turbidity outside the turbidity barriers), allowing the results to be extrapolated to a range of TSS concentrations. The second sampling event will not occur unless conditions worsen significantly over the next few weeks.

Together, these study components should provide a good weight-of-evidence regarding the potential for the elevated TSS concentrations to cause significant ecological effects in Second Portage Lake.

Figure 1. TSS Concentrations in Second Portage Lake, 1 Sept 2008

(Note: TSS concentrations in mg/L shown in grey-shaded boxes; values are the maximums taken from vertical profiles, or 24-hour averages for routine stations that have been sampled more than once in 24hrs)



Legend
Monitoring Location
W*n*, NE*n*, SE*n* = Routine Stations HVH*n* = High Value Habitat Stations
see Station HVH2 for data legend n/a = data do not cover full duration blank = no data available

TSS Trigger Values (mg/L)

Station	24-hr Ave	7-d Ave
Routine	50	15
HVH_a	50	15
HVH_b	25	6

a = prior to Sept 1
b = after Sept 1

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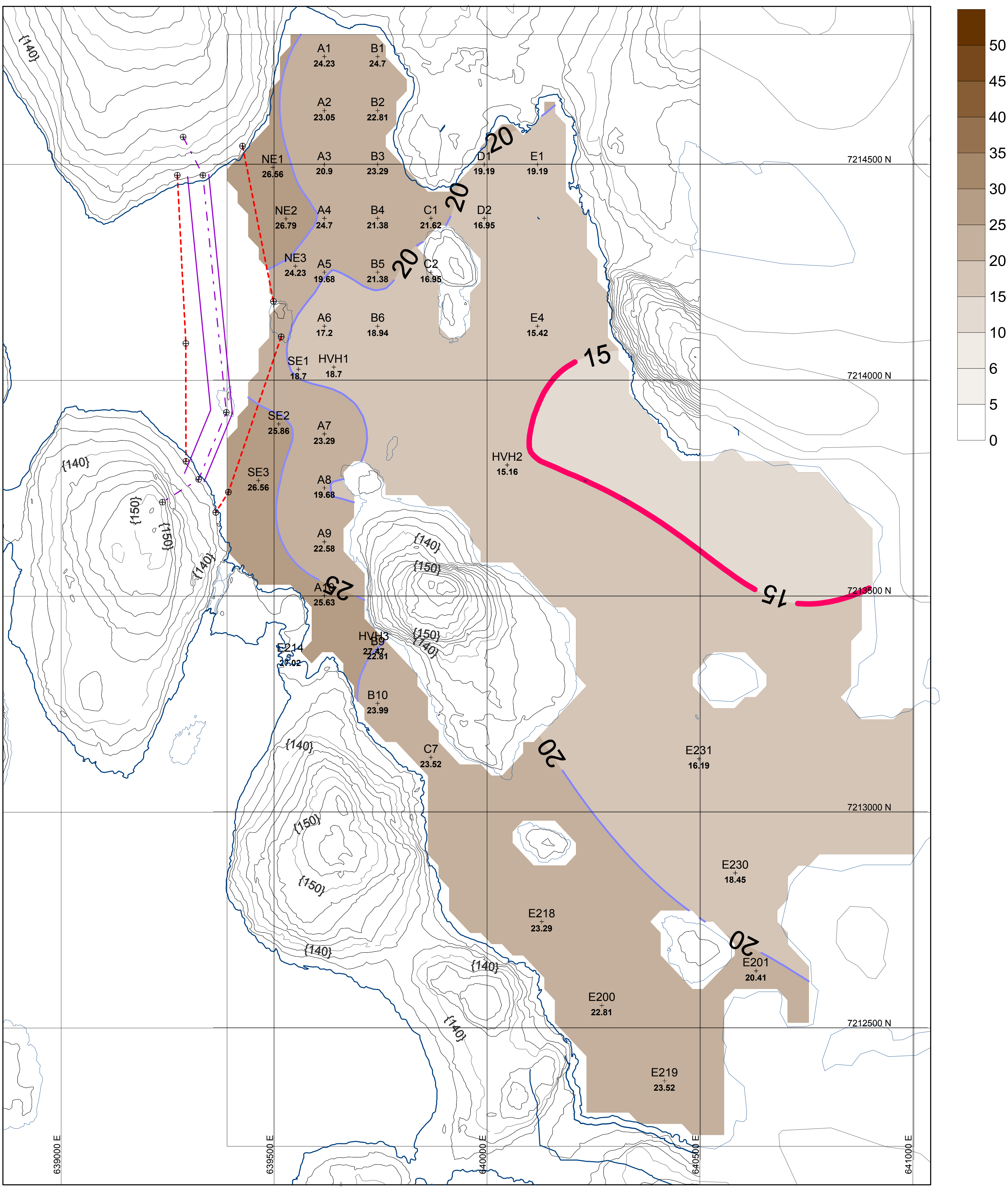
MEADOWBANK GOLD PROJECT - EAST DIKE CONSTRUCTION

SOUTHEAST SECOND PORTAGE LAKE
TURBIDITY-BASED TSS ESTIMATES (MEAN 0-5m) - AUGUST 18

FIGURE 2

SE 2PL TSS.GRF



Legend	TSS Trigger Values (mg/L)		
Monitoring Location	**Station**	**24-hr Ave**	**7-d Ave**
W*n*, NE*n*, SE*n* = Routine Stations	Routine	50	15
HVH*n* = High Value Habitat Stations	HVH_a	50	15
see Station HVH2 for data legend	HVH_b	25	6
n/a = data do not cover full duration	a = prior to Sept 1		
blank = no data available	b = after Sept 1		

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MEADOWBANK GOLD PROJECT - EAST DIKE CONSTRUCTION

SOUTHEAST SECOND PORTAGE LAKE
TURBIDITY-BASED TSS ESTIMATES (MEAN 0-5m) - AUGUST 22

FIGURE 3

SE 2PL TSS.GRF

Figure 5: Fish Concentration-Response Data for Long-Term (> 24hr) Exposure to TSS, Excluding Data Points for Eggs/Larvae (source: Caux et al. 1997; data for TSS concentrations > 100 mg/L not shown)

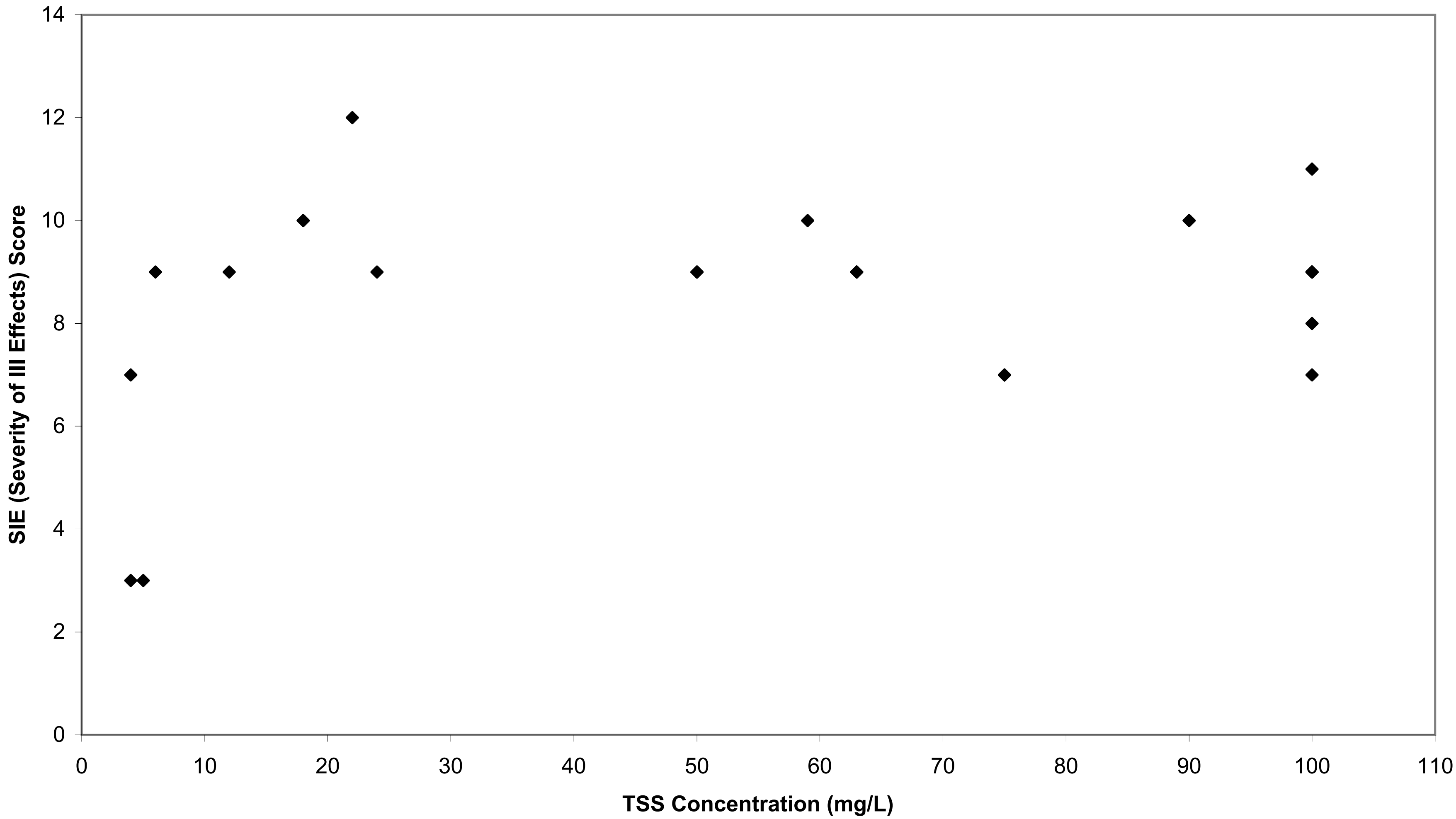
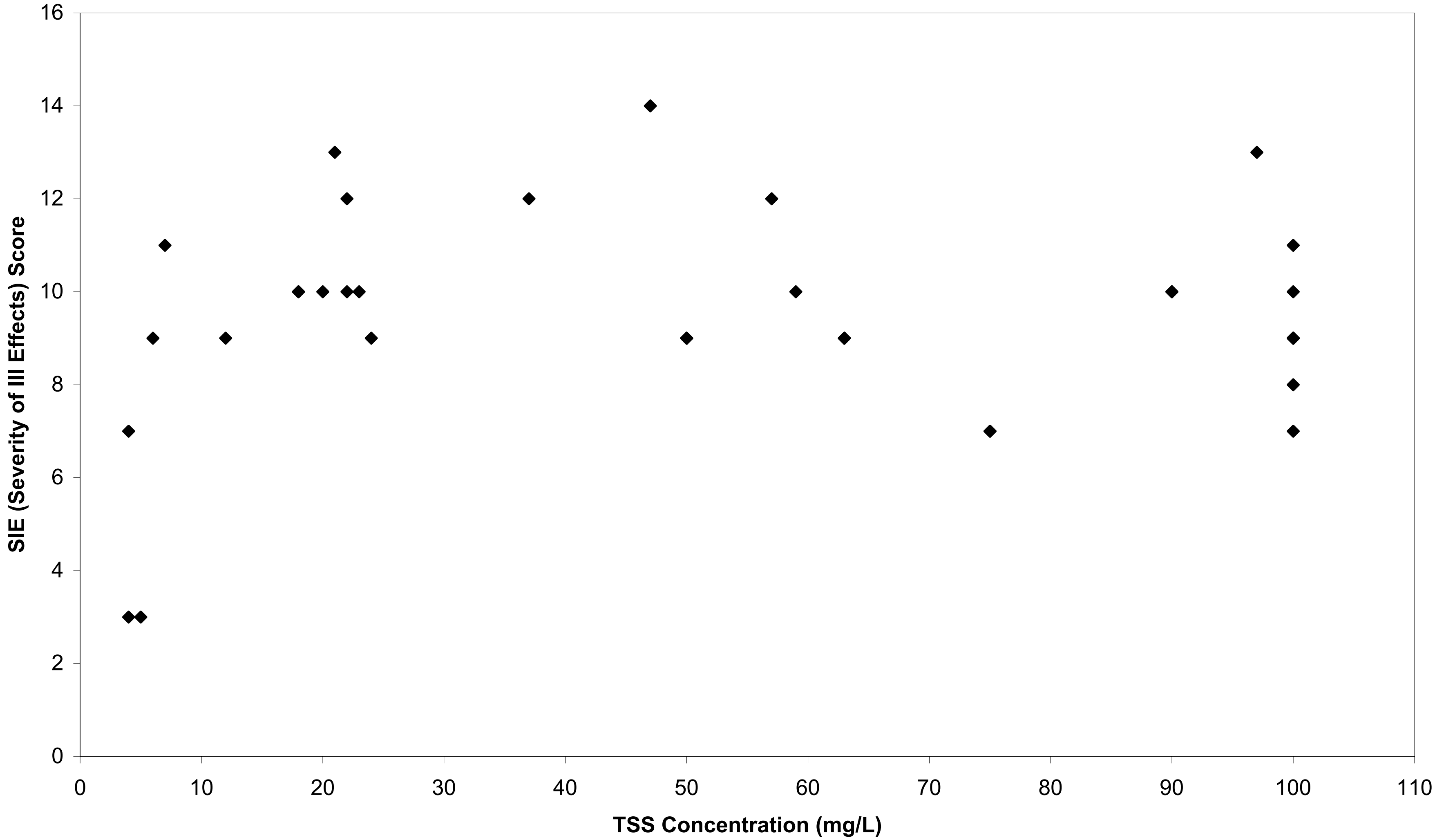
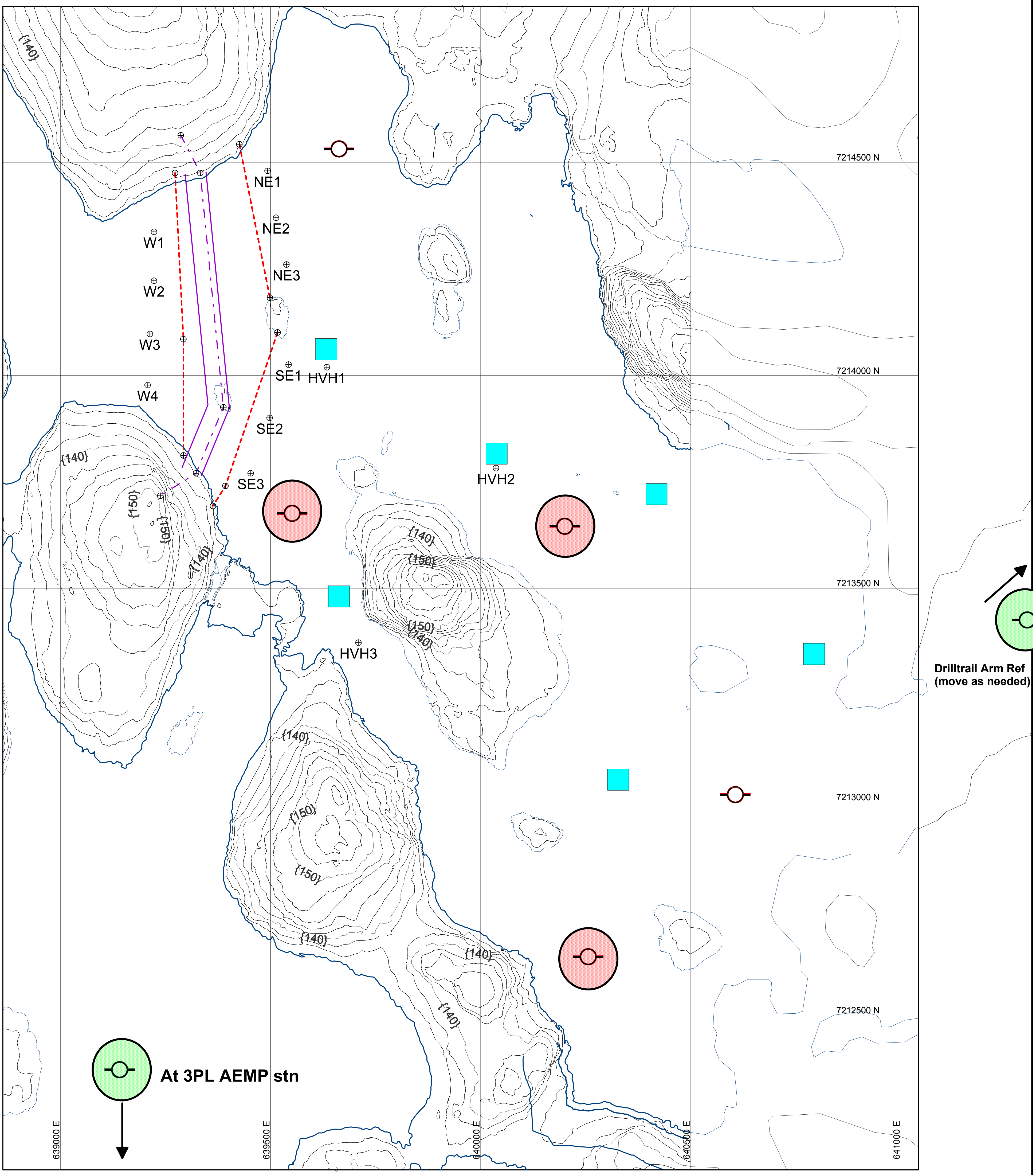


Figure 6: Fish Concentration-Response Data for Long-Term (> 24hr) Exposure to TSS (source: Caux et al. 1997; data for TSS concentrations > 100 mg/L not shown)





Water/Limnology Station

Field Effects Areas (5 reps/area) - Phytoplankton and Zooplankton.

Field Effects - High Value Habitat Sediment Traps

Legend

Monitoring Location

W*n*, NE*n*, SE*n* = Routine Stations
HVH*n* = High Value Habitat Stations

Green symbols = reference areas
Red symbols = target areas

TSS Trigger Values (mg/L)

Station	24-hr Ave	7-d Ave
Routine	50	15
HVH_a	50	15
HVH_b	25	6

a = prior to Sept 1
b = after Sept 1

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MEADOWBANK GOLD PROJECT - EAST DIKE CONSTRUCTION

SOUTHEAST SECOND PORTAGE LAKE
WATER QUALITY/LIMNOLOGY STATION AND FIELD EFFECTS AREAS

FIGURE 7

SE 2PL TSS.GRF

Table 3. Second Portage Lake TSS Effects Assessment - Program Details.

Component	Rationale	Sampling Design
Water Quality and Limnology		
TSS	Collect more data to ensure site-specific model with turbidity is representative.	Select stations to cover range of prevailing conditions (two events); Drilltrail Arm as reference area.
Metals (total/dissolved)	Assess whether metals are elevated and in bioavailable form.	As for TSS.
Nutrients and Conventionals	Assess whether nutrient levels are elevated from blasting residues and characterize basic water quality.	As for TSS.
Secchi Depth	Common indicator of water clarity.	As for TSS.
pH/Conductivity	Assess basic water quality.	As for TSS.
Dissolved oxygen	Assess oxygen levels in lake.	Depth profiles at key stations for broad coverage (two events).
Temperature	Assess mixing *vs* stratification.	As for dissolved oxygen.
Field Effects Measurements		
Component	**Rationale**	**Sampling Design**
Primary Production ● Chlorophyll-a ● Phytoplankton biomass/taxonomy	Turbid water can affect primary productivity by reducing the quantity and quality of light penetrating into the lake.	Three "impact" areas and two reference (Drilltrail Arm and Third Portage Lake) areas (each with 5 reps).
Secondary Production - Pelagic ● Zooplankton biomass/taxonomy	Reductions in primary productivity may affect zooplankton, which rely on phytoplankton for food.	As above, but 1 rep for taxonomy.
Secondary Production - Benthic ● Benthic community	Eventual deposition of suspended sediments may result in effects to the benthic community.	Monitoring will occur in **2009/10** and target deep turbid basins and reference areas (5 reps/area); latter would include Drilltrail Arm and Third Portage Lake areas too. Final locations pending temporal analysis of monitoring data to ice out.
Fish		
● Fish population (CPUE) - compare 2009 data with past years (likely 2002, but possibly 2008 fishout data) to determine any population-scale impacts.	Prolonged exposure to turbid water may affect fish. These components will provide insight into the long-term consequences of the elevated TSS in Second Portage Lake. The food chain component will show the relative importance of pelagic-based and benthic-based energy flow paths to help interpret the significance for fish of any effects to zooplankton or the benthic community.	Conducted only if laboratory studies show likely direct effects. Gillnetting in **2009** (short sets); compare to previous years.
● High value habitat (sedimentation) - sediment trap data (2008) and video habitat surveys (**2009**) surveys will be used to assess the status of key areas.		Analyze trap data in 2008; compare **2009** video survey results between areas with high and low TSS.
● Food chain (stable isotopes) - comparison of N and C isotopes in fish, zooplankton and benthic invertebrates provides insights into the relative importance of the pelagic and benthic food webs. This will help put any observed effects to zooplankton or the benthic community into perspective.		Characterize food webs by taking 30 fish/key species (use fishout fish), 10 each of zooplankton and benthos samples (5 in Second Portage and 5 in Third Portage).
Laboratory Effects Measurements		
Component	**Rationale**	**Sampling Design**
Secondary Production - Zooplankton ● Lethal - *Daphnia magna* 48-hr LC50 ● Sublethal - *Ceriodaphnia dubia* 7-day growth/survival/repro	While current conditions are unlikely to cause lethal responses in zooplankton, they might result in sublethal effects.	Samples will be collected targeting the highest TSS concentrations observed in the field; laboratory dilutions will be used to test a range of concentrations in order to broadly extrapolate the results to the lake in general. Only one round of sampling will occur unless conditions worsen over the next several weeks.
Fish ● Lethal - Rainbow trout 96-hr LC50 ● Sublethal - Rainbow trout embryo 7-day (w/out renewal) ● Sublethal - Rainbow trout embryo 7-day (with renewal) ● Sublethal - Rainbow trout swim-up larvae 7-day surv/growth	While current conditions are unlikely to cause lethal responses in trout, they might result in sublethal effects to sensitive life history stages. The 7-day larval test will be conducted using live zooplankton as food to take reduced visibility into consideration. The embryo development test will be conducted with/without renewal of overlying water to allow settlement to occur in the non-renewal test.	As above.