Engineering Strategies to Improve Environmental and Economic Outcomes from In-Stream Construction-Induced Suspended Sediment

About Me

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PhD Candidate, UBCO
Water Resources Engineer

MSc. Research:

Design and evaluation of fish habitat compensation projects for Diavik Diamond Mines, Inc.

Consulting Work:

2013 Southern Alberta floods – mitigation and restoration projects and studies on the Bow River, Sheep River, Highwood River, and several other smaller tributaries

PhD Research:

Management of in-stream construction-induced suspended sediment in riverine ecosystems

Development Around Rivers

$200-300 million spent annually in AB

Development Around Rivers

10-20% of budget spent on sediment control and care of water

On the absence of sediment control research…

"

*…[it is] remarkable given that sediment-control devices are **often a requirement of regulators**…*

*…yet **the evidence to support the effectiveness** of the primary mitigative strategies **is weak**.*

Chapman et al. (2014). Clear as mud: a meta-analysis on the effects of sedimentation on freshwater fish and the effectiveness of sediment-control measures.

An overview of the issue

What and why?

What is in-stream construction-induced suspended sediment, its importance, and why do we need to manage it?

Current state of affairs.

What is the current framework that we work under and common management practices.

Engineering Implications

Challenges, an ethical dilemma, and the engineering-ecosystem management disconnect.

Strategies to improve our practice.

The case for a duration-based SS management framework.

1.

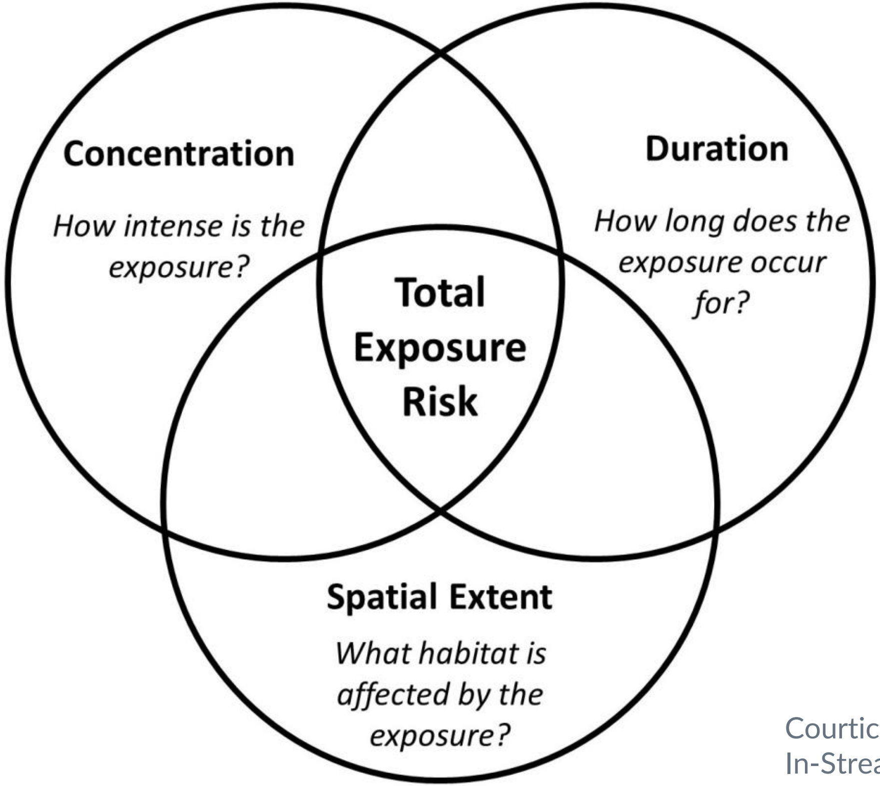
In-Stream Construction-Induced Suspended Sediment (ICISS)

What is it and why do we manage it?

In-stream Construction-Induced Suspended Sediment

Suspended sediment resulting from construction activities occurring in the wetted perimeter of a river

Suspended Sediment Exposure Risk Mechanisms in Riverine Ecosystems



Courtice and Naser (2019)
In-Stream Construction-Induced Suspended Sediment in Riverine Ecosystems.

ICISS Characteristics

Legend:

ICISS = In-stream construction-induced suspended sediment

ER = Exposure risk

SSC = Suspended sediment concentration (mg/L)

t = Activity duration (hours)

O = Reference site for turbidity monitoring at (x_r , y_r)

Sediment Control Measures

- Hydraulic and/or sediment isolation structure surrounding activity
- Increases in-stream scope of work
- Reduces SSC but increases duration
- Under what circumstances is this appropriate?

Uncertainty in Our Impacts

- We cannot directly measure our impacts to the fish or the aquatic ecosystem
- Must choose acceptable SS exposure limits to be confident we don't cause harm
- Ongoing research will help to inform these limits

If we can't directly measure our impact, how do we quantify our risk or harm?

2.

The Current State of Affairs

Current suspended sediment management framework and its challenges

Common observations about the current management framework…

“

This doesn’t make sense

We are wasting time and money

Frustrating

These measures don’t seem to do much

Current Regulatory Framework

- Canadian Council of Ministers of the Environment (CCME)
  - Water quality guidelines for the protection of aquatic life
  - **25 mg/L over 24 hours** or **5 mg/L over 30 days**

- Duration is commonly dropped
  - 25 mg/L above background levels

Focus on concentration targets → install sediment control measures

Current Regulatory Framework

- Compliance Protocols: exceedances
  - When measured concentrations above background exceed prescribed limit (i.e. 25 mg/L)
  - Must halt construction and report exceedance to regulatory spill hotline
  - Revised sediment control measures are then developed to prevent future exceedances
  - Contractor on stand-by until concentration falls below threshold (or returns to background levels)

3.
Engineering Implications

Challenges, an ethical dilemma, and the engineering-ecosystem management disconnect.

Once "everything possible" has been implemented to prevent exceedances, how do we manage activities that continue to create exceedances?

Exceedance

$\neq$

Unacceptable Environmental Risk

A regulatory exceedance only considers half of the equation…

Let's take a step back…

- *CCME guidelines cite Newcombe and Jensen (1996) and the Severity of Ill-Effects (SEV) Scale*

- *Meta-analysis of SS dose-response studies*

TABLE 1.—Scale of the severity (SEV) of ill effects associated with excess suspended sediment.

SEV	Description of effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0–20% mortality; increased predation; moderate to severe habitat degradation
11	>20–40% mortality
12	>40–60% mortality
13	>60–80% mortality
14	>80–100% mortality

Let's take a step back…

$$SEV = 1.1 + 0.61\ln(Dur) + 0.74\ln(SSC)$$

- *Adult and juvenile salmonids*
- *25 mg/L over 24 hours corresponds to SEV=5.4*
- *"Minor physiological stress"*
- *i.e. rapid recovery upon elimination of the exposure*

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Engineering Implications of Newcombe and Jensen's Work

$$SEV = 1.1 + 0.61\ln(Dur) + 0.74\ln(SSC)$$

- *Natural logarithms imply "order of magnitude" relationship with increase risk and effects, given SS concentration and duration*

- *Greatest rate of change in effect occurs at low concentrations and durations*

"Concentration alone is a poor predictor of SS effects"

Engineering Implications of Newcombe and Jensen's Work

$$SEV = 1.1 + 0.61 \ln(Dur) + 0.74 \ln(SSC)$$

- *Contradictions with engineering theory*
- *More efficient mixing of SS release may result in higher exposure risk (Courtice and Naser, 2019)*
- *Unique engineering considerations required to reduce SS exposure risk*

Engineering Implications of Newcombe and Jensen's Work

$$SEV = 1.1 + 0.61\ln(Dur) + 0.74\ln(SSC)$$

- *Given model uncertainty, duration and concentration are of comparable importance*
  - *Reducing duration may be just as important as reducing concentration*

- *Mathematically, if duration and concentration are comparable in their risk of adverse effects, we can use their product as a parameter for engineering risk management*

Engineering Implications of Newcombe and Jensen's Work

$$SEV \propto \ln(Dur) + \ln(SSC)$$

$$SEV \propto \ln(Dur\ x\ SSC)$$

$$SEV \propto \ln(Dose)$$

- *Product of duration and concentration is dose (mgh/L)*
- *If we reduce dose, we reduce SEV and SS exposure risk*

Engineering Implications of Newcombe and Jensen's Work

$$SEV \propto \ln(Dur) + \ln(SSC)$$

$$SEV \propto \ln(Dur\ x\ SSC)$$

$$SEV \propto \ln(Dose)$$

- *Dose has units of time x mass x volume^{-1}*
- *(time x mass x volume^{-1}) x (volume/time) = mass*

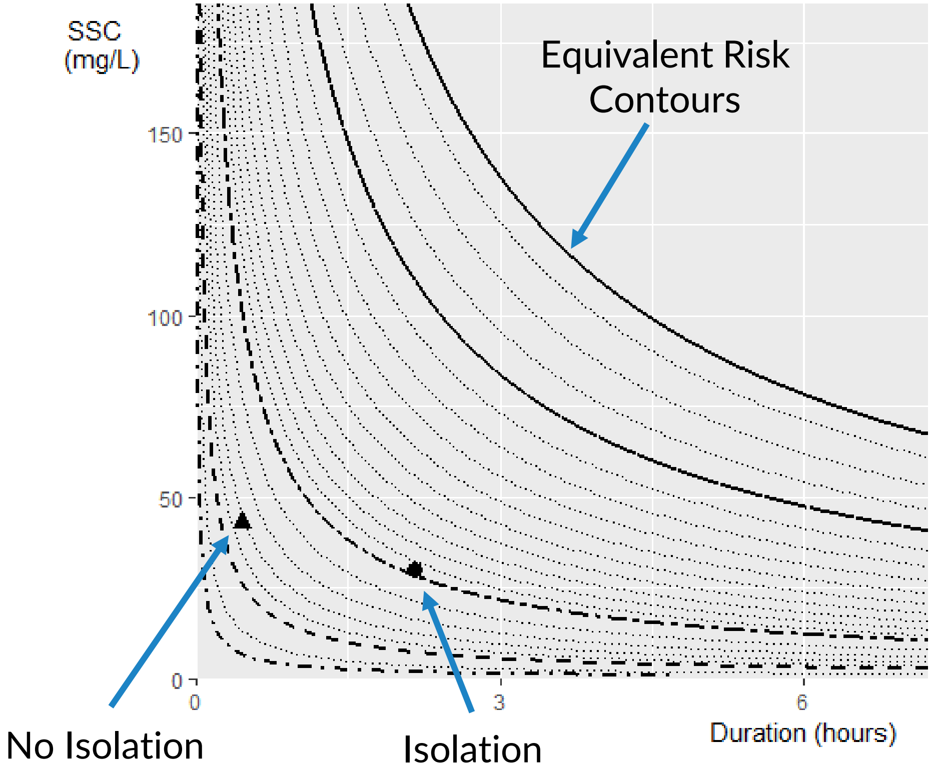
Mass ∝ Dose ∝ Exposure Risk

Engineering design should minimize total mass of sediment released

Engineering Challenges with Current Framework

- *Current framework does not incentivize reductions in total SS mass*
- *Limiting concentration may come at a cost of increasing duration through the installation of sediment control measures*
- *Pilot study was undertaken for demonstration of this issue*

Engineering Challenges with Current Framework



An ethical dilemma…

- *Prevalent concentration-based framework, no consideration for duration, e.g. exceedances above 25 mg/L likely on many projects*
- *We are aware projects commonly do not achieve targets*
- *Clients expect projects to move forward*

Without an alternative, we are forced to undertake projects with the knowledge that we may be faced with violating conditions of regulatory permitting, without any reliable mitigative measures

An ethical dilemma…

Unmitigated liability

- *Limited precedent for regulatory enforcement*
- *Currently relying on "good faith decisions" from practitioners and regulators*
- *Future changes could substantially impact management paradigm in unpredictable ways that directly affect project feasibility*

An ethical dilemma...

Optics for the profession

- *A large and growing database of projects that have been documented to exceed permitted SS releases is open to scrutiny*
- *Regardless of complexity of the issue, an engineer is signing off on these projects*

This does not imply negligence or improper decisions have been made, rather the framework we work under is not conducive to making optimum economic or environmental decisions

The Engineering-Ecosystem Disconnect

Risk Management	Design Understanding	Mitigation
We don't feel in control of managing environmental risk. Rely on qualified aquatics professionals	Aquatics professionals don't understand the design.	Mitigation measures may not fit the design or are otherwise overly burdensome *"We weren't expecting this in the original budget..."*

4.

Strategies to Improve our Practice

The case for a duration-based SS management framework

The case for a duration-based SS management framework

Let's consider a simple example, constructing a new gravel bed channel

Assumptions (for simplicity):

- *Unavoidable release of SS when channel is opened*
- *Flow is not sufficient to cause erosion of the channel*


PC: Airborne Engineering Corp.

The case for a duration-based SS management framework

Do we open the channel slowly or quickly to reduce SS exposure risk?

Short answer:

- *Total mass of sediment released is likely similar, therefore the* ***exposure risk is likely to be similar***
- *Caveat: the existing literature doesn't lend well to the analysis of dynamic releases*
- *There is no evidence to support one approach having more or less risk than the other*

The case for a duration-based SS management framework

Do we open the channel slowly or quickly to reduce SS exposure risk?

Long (mathematical) answer

Total Mass = Concentration x Duration x Discharge

- *Total mass and discharge are constant between approaches*
- *Duration to wash out the channel is controlled by our decision on opening "slowly" or "quickly"*

The case for a duration-based SS management framework

Do we open the channel slowly or quickly to reduce SS exposure risk?

Long (mathematical) answer

$$\textit{Concentration} = \textit{Total Mass}/(\textit{Duration} \times \textit{Discharge})$$

- *Concentration becomes a **function of duration***

The case for a duration-based SS management framework

Do we open the channel slowly or quickly to reduce SS exposure risk?

Long (mathematical) answer

$$SEV = 1.1 + 0.61\ln(Dur) + 0.74\ln(SSC)$$

$$SEV = 1.1 + 0.61\ln(Dur) + 0.74\ln\left(\frac{Total\ Mass}{Dur\ x\ Discharge}\right)$$

<u>Exposure risk becomes a function of duration</u>

The case for a duration-based SS management framework

Generalizing this concept:

- *A "quick" or "slow" opening of the channel is representative of construction* ***production rate***
- *Production rate will impact the intensity of a release*

The case for a duration-based SS management framework

Generalizing this concept:

- ***Total mass*** *of entrained sediment and* ***production rate*** *of construction are considerations that we CAN manage*
- *SS concentration CANNOT be directly managed and is highly variable among project activities and site characteristics*

The case for a duration-based SS management framework

How do we minimize total mass?

- *More pragmatic design – minimization of construction footprint*
- *Balance expected scope and duration of construction with scope and duration required to install sediment control measures*
- *Large projects (e.g. Harvey Passage) are likely to benefit from extensive sediment control measures*
- *Small projects (e.g. minor bridge repair work) may benefit from prioritizing duration over concentration*
- *An area of ongoing research*

The case for a duration-based SS management framework

How do we manage production rate?

- *Duration-based compliance framework*
- *If we consider the CCME guidelines, SEV = 5.4, we can select concentration-duration pairs of equal exposure risk*

The case for a duration-based SS management framework

Duration-Based SS Exposure Compliance

- *SEV = 5.4 (adult and juvenile salmonids)*
- *Daily duration based on average concentration observed during construction*
- *E.g. if turbidity monitoring measures average 50 mg/L, construction can occur for 10 hours per day*

SSC (mg/L)	Duration (hours)
25	24
30	19
35	16
40	14
45	12
50	10
75	6
100	4
150	3
200	2
250	1

The case for a duration-based SS management framework

Duration-Based SS Exposure Compliance

- *Provides contractor with agency over their environmental risk management*
- *If release intense and daily duration limit low, construction methodology may be altered on-the-fly to reduce concentration and increase duration limit*
- *Intermittent "down time" for exceedances is not needed, reduces stand-by expenses*

SSC (mg/L)	Duration (hours)
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The case for a duration-based SS management framework

Duration-Based SS Exposure Compliance

- *Takes the focus away from reducing concentration and places it on SS dose*
- *Facilitates consideration for alternative mitigation measures that may not be as costly*
- *For highly sensitive ecosystems, shorter work days may be more appropriate than bulky sediment control measures, and less expensive*

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The case for a duration-based SS management framework

Duration-Based SS Exposure Compliance

- *Lower duration may correlate to **lower costs***
- *Reduced interactions with the aquatic environment may **lower environmental risk***

Managing duration more directly manages SS exposure risk, given unpredictable site conditions

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The case for a duration-based SS management framework

Duration-Based SS Exposure Compliance

- *AEP is currently considering this framework on a case-by-case basis*
- *More study needed to verify suitability on all projects*
- *Small scale projects are low-risk candidates and implementation of the framework is encouraged*

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Ongoing and Future Research Activities

- *Update existing exposure risk model to improve SS risk management*
- *Analyze turbidity data from numerous projects to characterize SS concentration, duration, and exposure risk for common activities*
- *Currently seeking more data to improve analysis*

Thank You

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