Nechako White Sturgeon Habitat Restoration Plan 2021-22 Workshop and Planning Exercise

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Project Contact:
André Zimmermann, PhD, PGeo
Principal Geomorphologist

Prepared by:

Ministry of Environment and Climate Change Strategy
2202 Main Mall
Vancouver, BC V6T 1Z4

Ministry Project Contact:
Steve McAdam, PhD, RPBio
Hydro Impacts/Sturgeon Specialist

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Report prepared by:

Simon Gauthier-Fauteux, MSc
Geomorphologist
Northwest Hydraulic Consultants Ltd.

Steve McAdam, PhD
Hydro Impacts/Sturgeon Specialist
Ministry of Environment and Climate Change Strategy

Angie Coulter, MSc
Biologist
Ministry of Environment and Climate Change Strategy

A. E. ZIMMERMANN
34226
June 15, 2022

Report reviewed by:

Louise Porto

Louise Porto, MSc, RPBio
Associate Fisheries Biologist
Wood Canada Ltd.

André Zimmermann, PhD, PGeo
Principal Geomorphologist
Northwest Hydraulic Consultants Ltd.

BM Chilibeck

Barry Chilibeck, MASc, PEng (BC, YK)
Principal
Northwest Hydraulic Consultants Ltd.

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Steve McAdam	Contract Lead, Ministry of Environment and Climate Change Strategy
Angie Coulter	Biologist, Ministry of Environment and Climate Change Strategy

The following NHC personnel participated in the study:

Simon Gauthier-Fauteux	Project Geomorphologist, NHC
André Zimmermann	Principal Geomorphologist, NHC
Barry Chilibeck	Principal Engineer, NHC

NHC partnered with Wood Canada Ltd. for the planning and reporting components of the study:

Louise Porto	Associate Fisheries Biologist, Wood Canada Ltd.

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EXECUTIVE SUMMARY

The Nechako White Sturgeon Initiative (NWSRI) is seeking to develop habitat restoration strategies to restore natural recruitment of Nechako White Sturgeon. This project was commissioned by the Ministry of Environment and Climate Change Strategy as part of the NWSRI to:

- Review the current state of understanding regarding White Sturgeon habitat and biology in the Nechako River.
- Evaluate and rank potential restoration measures based on a high-level assessment of feasibility, effectiveness, and risk.
- Identify information needs required to implement the potential restoration measures.
- Outline a study plan to address these information needs over the next five years.

As part of this project, an interdisciplinary workshop was held amongst a range of subject-matter experts to discuss potential habitat restoration scenarios and identify knowledge gaps which must be addressed prior to implementation. Feedback from the workshop participants has been incorporated into the results of this study and forms part of the rationale for the recommended study plan.

This report has been prepared by NHC in collaboration with the Ministry of Environment and Climate Change Strategy. This report documents the outcomes of the workshop, evaluates and ranks potential restoration measures based on qualitative assessment of project feasibility, potential effectiveness, risk/cost, and potential outcomes, and prioritizes remaining information needs required to implement effective restoration designs. Addressing the information needs for the highest ranked restoration options forms the basis for the recommended study plan to be implemented over the next five years.

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1 INTRODUCTION

The Nechako River White Sturgeon (*Acipenser transmontanus*) population has been undergoing almost complete recruitment failure since about 1967. There is a pressing need to implement restoration strategies that promote natural recruitment due to the limited number of remaining wild adult sturgeon (< 500 fish). While hatchery inputs provide a stopgap measure against extirpation, the goal of the Nechako White Sturgeon Recovery Initiative (NWSRI) is a naturally recruiting population.

This project was commissioned by the Ministry of Environment and Climate Change Strategy as part of the NWSRI. The objectives of this project are to 1) review the current state of understanding regarding White Sturgeon habitat and biology in the Nechako River, 2) evaluate and rank potential restoration measures based on a high-level assessment of feasibility, effectiveness, and risk, 3) identify information needs required to implement the potential restoration measures, and 4) outline a study plan to address these information needs over the next five years.

As part of this project, an interdisciplinary workshop was held on March 21, 2022 to discuss potential habitat restoration scenarios and to identify knowledge gaps which must be addressed prior to implementation. Participants included a range of subject-matter experts, including members of Canadian and American government agencies, academic researchers, private consultants, and existing members of the NWSRI. Feedback from the workshop participants has been incorporated into the results of this study and forms part of the rationale for the recommended study plan.

This report documents the outcomes of the workshop, including participant feedback and discussion related to potential restoration options (Section 3). The potential restoration options discussed during the workshop are subsequently ranked into three groups (“Highly Ranked”, “Moderately Ranked”, and “Lowest Ranked”) based on qualitative assessment of project feasibility, potential effectiveness, risk/cost, and potential outcomes (Section 4). Addressing the information needs for the highest ranked restoration options forms the basis for the recommended study plan to be implemented over the next five years (Section 5). Supplemental biological and geomorphological background information supporting the development of the proposed restoration options and the identification of remaining knowledge gaps is provided in Appendix A.

1.1 Key Authors

This document was produced jointly between NHC, Steve McAdam (Contract Lead and Hydro Impacts/Sturgeon Specialist, Ministry of Environment and Climate Change Strategy) and Angie Coulter (Biologist, Ministry of Environment and Climate Change Strategy). Louise Porto (Associate Fisheries

Biologist, Wood Canada Ltd.) provided valuable feedback both as a critical external reviewer and as an experienced member of sturgeon recovery programs.

2 NECHAKO HABITAT RESTORATION WORKSHOP

2.1 Objectives

The Nechako Habitat Restoration workshop was held virtually on March 21, 2022 and facilitated by Steve McAdam (Contract Lead and Hydro Impacts/Sturgeon Specialist, Ministry of Environment and Climate Change Strategy). The half-day workshop was intended to support the development of a habitat restoration plan for the Nechako White Sturgeon population. The primary goals of the interdisciplinary workshop were to discuss potential habitat restoration scenarios, assess their feasibility from a biological and geomorphic perspective, and identify information needs and research studies that would be required to support the various restoration measures. Additional (indirect) goals for the workshop were to foster collaboration between potential research partners and to encourage exchange of ideas between a range of subject-matter experts, including members of the Kootenai and Upper Columbia White Sturgeon Recovery Initiatives.

2.2 Format

The workshop began with a presentation (delivered by Steve McAdam) regarding the biology of White Sturgeon as it relates to recruitment failure in the Nechako River. Subsequently, NHC presented a summary of geomorphological findings to date and discussed how the fluvial geomorphology of the Nechako River may influence the quality of interstitial habitat within the spawning reach (Figure 2.1). Workshop participants were then led through an exercise to identify information needs for various potential habitat restoration scenarios, as described in greater detail below.

The purpose of the exercise was to consider various potential restoration scenarios and identify what information may be required to implement them successfully. To achieve this, the facilitator would present a potential restoration scenario to the participants and highlight important factors to be considered based on existing knowledge and experience related to the Nechako system (e.g., pros, cons, risks, and uncertainties). A general discussion would ensue related to that scenario, where participants were encouraged to provide critical feedback, highlight unidentified knowledge gaps, and share relevant experiences (e.g., “lessons learned”, how similar challenges are being addressed by other working groups, etc.). Participants were also encouraged to raise alternative restoration options which had not been considered to date.

Potential restoration scenarios were addressed in two groups; Group 1 (Section 3.1) includes options that directly address substrate remediation, such as substrate addition and physical cleaning, while Group 2 (Section 3.2) includes restoration that indirectly affects substrate, such as altered discharge or river channel modification. A total of 12 potential restoration options were discussed during the workshop. Each of the 12 options are presented in detail in Section 3, along with the information needs, risks/limitations, and additional discussion points raised during the workshop.

Figure 2.1 Overview map of the critical White Sturgeon spawning reach on the Nechako River depicting key location references.

2.3 Participants

A wide range of participants attended the workshop given the interdisciplinary nature of both recruitment failure mechanisms and potential restoration. The workshop included members of federal and provincial levels of the Canadian government, United States government agencies, academic institutions, private consulting companies, and existing members of the NWSRI Technical Working Group (TWG) and Community Working Group (CWG). As previously mentioned, certain participants also had involvement in the Upper Columbia and Kootenai White Sturgeon recovery programs, as a secondary objective of the workshop was to foster collaboration between groups who are striving to achieve similar goals. All participants, along with their primary affiliations, are listed below (Table 2.1).

Table 2.1 List of participants at the 2022 Nechako Habitat Restoration workshop.

Participant	Primary affiliation
Steve McAdam	Ministry of Environment and Climate Change Strategy
Angie Coulter	Ministry of Environment and Climate Change Strategy
Nikolaus Gantner	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Sarah Stephenson	Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Participant	Primary affiliation
Jeffrey Beardsall	Nechako White Sturgeon Recovery Initiative
Wayne Salewski	Nechako White Sturgeon Recovery Initiative
Erin Gertzen	Fisheries and Oceans Canada
Riley Wall	Fisheries and Oceans Canada
James Crossman	BC Hydro
André Zimmermann	Northwest Hydraulic Consultants
Barry Chilibeck	Northwest Hydraulic Consultants
Simon Gauthier-Fauteux	Northwest Hydraulic Consultants
Pascale Biron	Concordia University
Brett Eaton	University of British Columbia
Sean Wilson	Idaho Fish and Game
Ryan Hardy	Idaho Fish and Game
Ryan Fosness	United States Geological Survey
Charles Lauzon	Sea to Sky Energy Solutions

2.4 Outcomes

Participant feedback from the workshop has been incorporated into the results of this study as a series of summary tables describing each potential restoration option (Section 3). Additional discussion items that were highlighted during the workshop are also presented for each scenario (if applicable). Information needs identified during the workshop were subsequently used to inform the development of a strategic study plan to address highest priority data gaps over the next five years (Section 5). This information is intended to provide the foundation for the implementation of effective restoration actions.

3 RESTORATION SCENARIOS

3.1 Group 1 – Direct substrate modification

3.1.1 Scenario 1 - Repeated substrate addition, assume current spawning location (near Burrard Ave. Bridge)

3.1.1.1 Summary Description

Repeatedly adding spawning substrate is a potential way to restore the biological functionality of infilled and/or embedded substrates. This approach provides a relatively direct and effective way to restore recruitment assuming that substrate condition in early rearing habitats is the factor limiting survival. The biological effectiveness of the treatment may, however, be limited due to ongoing sedimentation.

Substrate has been previously added in two areas within the spawning reach in 2011 (i.e., the Lower Patch and Middle Patch), and there are indications that the experimental substrate placement could have increased recruitment in 2011. However, subsequent infilling of the Lower Patch demonstrates the need for ongoing remediation to support future (sustained) recruitment.

Since 2011, biological monitoring programs have produced valuable information regarding spawning locations; most notable is that the majority of spawning in recent years has occurred in the vicinity (both upstream and downstream) of the Burrard Ave. Bridge. Understanding the spatial extent and frequency of substrate addition required to stimulate recruitment is one area that needs further evaluation. The proximity to Vanderhoof also emphasizes the need to evaluate flooding risk associated with repeated substrate addition.

3.1.1.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.1 Information needs identified for Scenario 1.

Information Needs	Notes
Baseline substrate condition	• Substrate monitoring programs would be needed to document baseline (pre-project) substrate conditions and monitor post-project changes in substrate composition. • Previous studies have evaluated existing substrate conditions within the downstream portion of the spawning reach, although studies were primarily focused upstream of the bridge until recently. Additional studies may be needed downstream of the bridge. • Previous studies have evaluated habitat suitability using underwater imagery, although freeze cores were also collected in certain locations. Additional studies may be warranted to evaluate baseline habitat suitability due to the potential discordance between surficial substrate characteristics and interstitial habitat suitability (i.e., immediately below the surficial grains).
Substrate addition methods	• Several potential methods have been considered. These include: 1) placing substrate using an excavator and barge (as was done in 2011), 2) placing the substrate on ice over the winter and letting it deposit/disperse during the spring thaw, 3) adding substrate from the bank using a rock slinger, and 4) adding substrate from the bridge and letting it disperse downstream. Additional feasibility studies would be required to determine the optimal placement method. • Biological studies have shown that small gravel (12-19 mm) is suitable for larval hiding; additional studies should investigate the biological and geomorphological implications of placing small gravel versus larger

Information Needs	Notes
	gravel-cobble substrates. The size and composition of the placed material may impact the effectiveness and longevity of the treatment, flooding risk, and may in part determine the optimal placement method (e.g., placing material in a certain location and letting it disperse downstream naturally).
Substrate movement rate	• Additional studies would be required to determine the rates and locations of sediment entrainment and deposition. This may include numerical modelling, *in-situ* monitoring and/or physical studies (e.g., tracers). • Entrainment and deposition of restored (coarser) material may affect required replenishment/maintenance and flooding risk, while transport and deposition of fine bedload (sand) may limit the effectiveness and longevity of the treatment.
Substrate infilling rate	• Previous studies have identified primary sediment transport pathways through the area and have documented the effects of sand bedload infilling restored substrates. • Current studies are attempting to monitor infilling rates *in-situ*; if successful, the results may provide information regarding when and under what hydraulic conditions infilling and winnowing occur. Future studies may use this monitoring system to evaluate infilling rates in other locations (e.g., to test the longevity of proposed restoration works), and/or to assess when remediation of recently placed substrates is needed. • Additional studies may be needed to evaluate techniques to delay infilling and/or to promote winnowing.
Restoration location and area	• Additional studies would be needed to determine the optimal location(s) to restore (e.g., trade-off between fish use, infilling rates, required maintenance, flood risk, etc.). • Additional information is needed to determine the optimal size of restored habitat to support biological functions while considering flood risk, repeatability, maintenance, costs, etc. • The limited number of fish produced by small areas of restored habitat may limit evaluation of success; a large area may be required to have the statistical power to prove that restoration was effective. This is even more so the case given that metrics for monitoring success may be easily confounded by uncontrolled variables (e.g., discharge, ice, etc.).
Environmental factors affecting spawning site selection	• Spawning site selection occurs at a variety of scales. Restoration must consider both large-scale (e.g., upstream or downstream of the bridge) and small-scale (e.g., spawn a few meters away from restored substrates) site selection. • Site selection may also change in the future; current studies are investigating the effects of environmental variables on spawning location (as detected by egg captures).

Information Needs	Notes
	• Lake Sturgeon (*Acipenser* fulvescens) have been found to spawn in different locations under similar environmental conditions; high variability in choice makes it very difficult to determine which combination of factors caused spawning to occur at a certain location. • Additional studies are needed to better understand downstream displacement patterns of eggs from initial spawning locations. This information may inform where to restore substrates in relation to selected spawning sites.
Biological goals for substrate condition	• Studies have shown that small gravel substrates with clean interstitial spaces support egg and larval hiding. However, no information is available regarding the suitability of substrates with an intermediate degree of infilling (which is typical of substrates in a natural setting). • Additional studies are needed to determine the optimal size, shape, and composition of restored substrates. • Additional studies are needed to evaluate the survival of eggs and larvae for different sizes and depths of substrate exposed to near-bed flow conditions that typically occur at the spawning locations.
Downstream geomorphological impacts	• Any addition or removal of material must consider downstream geomorphological impacts. • Smaller gravel is likely to have less of an impact as it can more easily be mobilized and it needs to be determined what is the smallest gravel that is good for egg survival.
Conceptual model of how discharge affects substrate	• While previous studies have made progress on understanding reach-scale hydraulics and sediment transport, there is an incomplete understanding of how discharge influences habitat characteristics (i.e., substrate). • Additional studies are needed to develop a conceptual (albeit evidence-based) model of how discharge, sediment transport and habitat quality are interrelated. • The existing gravel downstream of the bridge is relatively fine and may be selectively winnowed. The flow conditions that optimize the winnowing of the existing gravel need to be evaluated.
Flood risk	• Any addition of material must consider flooding risk.

3.1.1.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Ongoing sedimentation may decrease biological effectiveness shortly after placement.
- Potential number of repeated treatments may be limited by increases in flood risk.

- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Future changes in spawning location.

3.1.1.4 Additional Discussion

Additional items discussed during the workshop included the following:

An interesting question was posed as to whether sedimentation (as detected by the specific gauge analysis) has progressed from upstream to downstream, or from downstream to upstream? The former would suggest a change in upstream conditions causing the increased sedimentation, while the latter would suggest a potential change in downstream conditions. These two alternatives may support different approaches towards restoration (e.g., sediment trap upstream versus hydraulic controls downstream).

Participants also highlighted the importance and challenges of having clear biological criteria to evaluate project success. Biological monitoring programs have had limited success in capturing larvae (both on the Nechako and on other systems), so there is a data/knowledge gap between the egg and juvenile stages. The inability to capture larvae makes it difficult to determine the effectiveness of existing or restored substrates to promote survival from the egg to drifting larvae stage and adds a 2-3 year time lag between when restoration occurs and when a potential biological response can be detected through juvenile sampling. Despite these limitations in larval sampling, ongoing biological monitoring is implicit for all scenarios.

One clear risk of repeated substrate addition is increasing the flooding risk within the community of Vanderhoof. Adding gravels and cobbles may create a confining layer of large aggregate without having the flows capable of mobilizing the material downstream. This would likely 1) limit biological effectiveness due to infilling, 2) increase the flooding risk, and 3) limit the replicability of the treatment. Alternatives may include adding smaller material (e.g., small gravels) which can be periodically entrained by the flow; however, this approach would still need to consider rates and areas of entrainment and deposition.

Engineered features may also be included in the design to promote substrate cleaning, reduce the amount of material that has to be repeatedly added, and/or to attract fish; however, additional information is needed to design these effectively. The features may include rock spurs, engineered logjams, and boulder clusters. Boulder clusters on the Kootenai River system have been effective in creating and maintaining pools (i.e., scours out fine sediment), and appear to attract spawners.

Farmland within the Murray Creek system has been acquired as part of ongoing watershed restoration initiatives. Cattle will be removed from land this year to reduce sediment inputs, which could reduce the incoming sediment load immediately upstream of the Lower Patch. Additional funding has been secured for stream restoration on the acquired land (culvert removal for salmon). Additional areas for salmonid habitat restoration may include Stoney Creek and the bar on the south riverbank downstream of the Burrard Ave. Bridge.

3.1.2 Scenario 2 - Repeated substrate remediation, assume current spawning location (near Burrard Ave. Bridge)

3.1.2.1 Summary Description

Methods to sort or "clean" existing substrates may also be used to improve the biological functionality of degraded habitats. These methods may be used to remediate previously restored habitat which has since been infilled (e.g., Lower Patch), or may be applied to native substrates where the riverbed is composed of a pre-existing sandy gravel mix that could provide suitable early rearing habitat if effectively "cleaned". Thus, substrate remediation techniques provide the opportunity to 1) maintain the quality of existing habitats over time and 2) increase the number and/or area of suitable rearing locations without the need to place additional substrate.

A key benefit of substrate cleaning versus repeated substrate addition is that it should not lead to increased flood risk, which is an important consideration within the Vanderhoof reach. Understanding the spatial extent, frequency, and intensity of substrate cleaning that is required to stimulate a sufficient level of recruitment to support population recovery needs further evaluation.

3.1.2.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.2 Information needs identified for Scenario 2.

Information Needs	Notes
Baseline substrate condition	• Additional information is needed on whether there is enough ambient coarse substrate to clean (particularly downstream of the bridge). • Further studies may be warranted to assess gravel input rates and determine whether input rates are sufficient to continuously employ this method without substrate addition. • See Scenario 1.
Substrate cleaning methods	• Several cleaning methods have been used in the past with varying levels of success; these include mechanical raking, hydraulic jetting, and suction dredging. All methods tried to date have been limited by water depth/velocity and are very labour/time-intensive (i.e., not feasible for cleaning large areas). • Additional feasibility studies would be needed to identify alternative methods for cleaning larger areas.

Information Needs	Notes
	- Underwater video from April 2022 shows that the existing gravel can be mobilized at relatively low flows, but the degree to which the fines can be winnowed during these conditions remains uncertain.
Effectiveness of substrate cleaning	- Cleaning methods used to date (mechanical raking, hydraulic jetting, and suction dredging) have had varying degrees of effectiveness. In general, the most effective techniques tend to be limited to small areas. - Evaluating the effectiveness of various techniques is also challenging due to high turbidity during spring freshet. Current studies are evaluating alternative *in-situ* monitoring methods, although additional studies may be warranted to develop and test alternative methods (e.g., air-lift sampler). - Biological requirements for substrates also need to be refined to assess the suitability of resulting habitat.
Substrate movement rate	- (see Scenario 1)
Substrate infilling rate	- (see Scenario 1)
Restoration location and area	- (see Scenario 1)
Environmental factors affecting spawning site selection	- (see Scenario 1)
Biological goals for substrate condition	- (see Scenario 1)
Conceptual model of how discharge affects substrate	- (see Scenario 1)

3.1.2.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Future changes in spawning location.

3.1.2.4 Additional Discussion

Additional items discussed during the workshop included the following:

While the overarching goal is to implement feasible, effective restoration measures that support natural recruitment over the long-term, this approach may also be considered as an interim measure to gain “proof-of-concept” that substrate remediation produces natural recruitment. There are indications that the experimental substrate placement in 2011 could have resulted in a recruitment pulse, but additional studies may help solidify that link. Once interim measures have been proven to be effective, the approach may be refined to lower required costs, maintenance, disturbance, etc. This may include using engineered structures (e.g., rock spurs, boulder clusters, engineered logjams, etc.) to do the scouring as opposed to direct manipulation.

Participants further highlighted that there are two general, yet not mutually exclusive approaches towards substrate remediation: direct manipulation (i.e., producing the desired substrate manually) and indirect manipulation (i.e., using/altering local hydraulics to produce the desired result). Additional studies are needed to investigate how local hydraulics may be used to maintain suitable spawning substrate. It was suggested that numerical models may be better suited for this application than physical models, yet both approaches have limitations. Careful consideration of unintended geomorphological impacts is also required as the riverbanks within and downstream of the spawning reach are typically composed of readily erodible material.

Finally, it was noted that there may be some relatively good spawning habitat downstream from where fish typically spawn; this area was reported to have a large gravel bar and suitable depths and velocities for spawning. It is unknown why fish do not typically spawn at this location, but the site may be considered for future restoration work (e.g., if fish start to spawn there naturally, or if spawners can be attracted to that location by use of engineered structures, chemical attractants, etc.).

3.1.3 Scenario 3 - Combination of substrate addition and remediation, assume current spawning location (near Burrard Ave. Bridge)

3.1.3.1 Summary Description

This restoration scenario is intended to combine the beneficial aspects of substrate addition and cleaning. The addition of new substrates would provide a baseline habitat condition with a known substrate composition. Repeated cleaning of previously placed substrates could then restore habitat functionality which has been lost due to progressive infilling.

Such an approach would require an understanding of the spatial extent and composition of substrates required to restore a known baseline habitat condition (i.e., a sound understanding of how substrate characteristics relate to biological function and productivity). As with Scenario 2, further evaluation would also be needed to determine the frequency and intensity of substrate cleaning required to stimulate enough recruitment to support population recovery.

This scenario may provide greater certainty about habitat function than Scenario 2, as recently placed substrates would provide a baseline level of biological functionally (at least initially). Like Scenario 2, a key benefit of this option is that the overall increase in flood risk is at least partially mitigated by remediation of placed substrates, as opposed to relying solely on repeated substrate additions (Scenario 1).

3.1.3.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.3 Information needs identified for Scenario 3.

Information Needs	Notes
Baseline substrate condition	• (see Scenario 1 and 2)
Substrate addition methods	• (see Scenario 1)
Substrate cleaning methods	• (see Scenario 2)
Effectiveness of substrate cleaning	• (see Scenario 2)
Substrate movement rate	• (see Scenario 1)
Substrate infilling rate	• (see Scenario 1)
Restoration location and area	• (see Scenario 1)
Environmental factors affecting spawning site selection	• (see Scenario 1)
Biological goals for substrate condition	• (see Scenario 1)
Downstream geomorphological impacts	• (see Scenario 1)
Conceptual model of how discharge affects substrate	• (see Scenario 1)
Flood risk	• (see Scenario 1)

3.1.3.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Ongoing sedimentation may decrease biological effectiveness shortly after placement.
- Potential number of repeated (placement) treatments may be limited by increases in flood risk.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).

- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Future changes in spawning location.

3.1.3.4 Additional Discussion

No additional items were discussed during the workshop pertaining to this restoration scenario, other than those previously described for Scenarios 1 and 2.

3.1.4 Scenario 4 - Substrate addition/remediation to enlarge Middle Patch (upstream of secondary channels), natural spawning site selection

3.1.4.1 Summary Description

This scenario uses the combined approach of substrate addition and remediation described in Scenario 3 but applied to the Middle Patch only. The main rationale for this scenario is that placed substrates appear to infill less quickly at the Middle Patch than at the Lower Patch, allowing for the added substrate to provide longer-term habitat improvements while potentially requiring less frequent remediation.

The key limitation of this scenario is that spawning activity is much less frequent in this area than around the main spawning locations near the bridge. That said, occasional observations of pre-spawning behaviour just downstream of the Middle Patch suggest there may be additional benefit from habitat enhancement at this location. Further evaluation of past and present spawning site selection would be needed to properly evaluate the potential benefits of this scenario.

3.1.4.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.4 Information needs identified for Scenario 4.

Information Needs	Notes
Baseline substrate condition	• Although the substrate conditions at the Middle Patch have been periodically monitored since placement, most studies have been focused around the Lower Patch. Additional studies may be needed to evaluate existing substrate characteristics at the Middle Patch, as well as in areas adjacent to the placed substrate where little information is currently available. • Sediment transport rates through this area have only been monitored by a few studies, and most of the bedload sampling dataset is from a single high flow year. Additional sediment monitoring programs may be warranted to refine our understanding of sediment transport through the area.

Information Needs	Notes
	• As with previous scenarios, substrate monitoring programs would be needed to document baseline (pre-project) substrate conditions and monitor post-project changes in substrate composition.
Substrate addition methods	• (see Scenario 1)
Substrate cleaning methods	• (see Scenario 2)
Effectiveness of substrate cleaning	• (see Scenario 2)
Substrate movement rate	• (see Scenario 1)
Substrate infilling rate	• (see Scenario 1)
Restoration location and area	• Potential restoration options include expanding the Middle Patch downstream to where the secondary channels re-enter the mainstem; however, limited sediment transport data is currently available for this area. Additional sediment monitoring programs may be warranted to refine our understanding of sediment transport through the area. • Future restoration works need to consider interaction with any future bank protection work along Riverside Park. • (see Scenario 1)
Environmental factors affecting spawning site selection	• Prevalence of natural spawning at this location is currently low, introducing the risk that restored substrates will have a minimal effect on population recruitment. • (see Scenario 1)
Biological goals for substrate condition	• (see Scenario 1)
Downstream geomorphological impacts	• (see Scenario 1)
Conceptual model of how discharge affects substrate	• (see Scenario 1)
Flood risk	• (see Scenario 1)

3.1.4.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Minimal effect on population recruitment due to limited spawners at this location.
- Ongoing sedimentation may decrease biological effectiveness shortly after placement.

- Potential number of repeated (placement) treatments may be limited by increases in flood risk.
- Unintended geomorphological impacts (e.g., Riverside Park).
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Future changes in spawning location.

3.1.4.4 Additional Discussion

Additional items discussed during the workshop included the following:

It was noted that the District of Vanderhoof may seek to implement bank protection and/or flood mitigation works along Riverside Park. Restoration approaches may need to consider future works in the area, and it may be beneficial to integrate habitat components into the bank protection/flood mitigation designs; however, this remains speculative at this point as no permitting approvals have been granted for this work. Alternative options may be a setback dike, which would have less interaction with in-stream restoration works.

3.1.5 Scenario 5 - Substrate addition/remediation to enlarge Middle Patch (upstream of secondary channels), induce increased spawning near Middle Patch

3.1.5.1 Summary Description

This scenario is similar to Scenario 4, except that it includes an additional (and unknown) behavioral manipulation to increase the amount of spawning activity around the Middle Patch. This scenario therefore combines the greater longevity of restored habitats at the Middle Patch with an assumed increase in the prevalence of spawning.

One key limitation to this scenario is the assumed ability to shift spawning activity even a short distance upstream of their current spawning location near the bridge. The location of the Middle Patch was selected in part due to the detection of a high concentration of eggs at this location during the 2009 spawning period. While similar egg detections haven’t occurred since, that observation, combined with the anecdotal observation of spawning behaviour ~200 m downstream of the Middle Patch, suggests that fish occasionally select this area for spawning. Understanding the environmental conditions associated with habitat selection offers some promise regarding the potential to induce increased spawning at this site.

3.1.5.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.5 Information needs identified for Scenario 5.

Information Needs	Notes
Baseline substrate condition	• (see Scenario 4)
Substrate addition methods	• (see Scenario 1)
Substrate cleaning methods	• (see Scenario 2)
Effectiveness of substrate cleaning	• (see Scenario 2)
Substrate movement rate	• (see Scenario 1)
Substrate infilling rate	• (see Scenario 1)
Restoration location and area	• (see Scenario 1 and 4)
Environmental factors affecting spawning site selection	• Past experiments have shown that some fish may be attracted to certain areas using chemical attractants (pheromones from ovarian fluid); however, the ability to influence spawning site selection using artificial methods remains unproven. • (see Scenario 1)
Biological goals for substrate condition	• (see Scenario 1)
Downstream geomorphological impacts	• (see Scenario 1)
Conceptual model of how discharge affects substrate	• (see Scenario 1)
Flood risk	• (see Scenario 1)

3.1.5.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Minimal effect on population recruitment due to limited spawners at this location.
- Unproven ability to influence spawning site selection.
- Ongoing sedimentation may decrease biological effectiveness shortly after placement.
- Potential number of repeated (placement) treatments may be limited by increases in flood risk.
- Unintended geomorphological impacts (e.g., Riverside Park).
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).

- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Future changes in spawning location.

3.1.5.4 Additional Discussion

Additional items discussed during the workshop included the following:

Participants commented that it may be better to focus on several smaller sites as opposed to a single, larger site due to unpredictability in fish behavior and spawning site selection. Multiple sites may spread the risk and increase the chances of (at least partial) success.

3.1.6 Scenario 6 - Substrate trapping upstream of the Lower Patch, assume current spawning location (near Burrard Ave. Bridge)

3.1.6.1 Summary Description

The objective of this scenario would be to increase the quality of existing substrates within the primary spawning area by (at least temporarily) limiting the supply of fine bedload entering the area, as opposed to using direct manipulation (i.e., physical “cleaning”). Conceptually, a substrate trap could be as simple as a hole or trench that is maintained prior to and during the spawning period. A suitable location for a sediment trap remains uncertain, but the routing of fine bedload through the northern secondary channels of the Island Complex suggests a location within those channels might be possible. Another potential location may be at the downstream end of the Island Complex but still upstream of the Lower Patch, where the trap may be positioned to capture sediment inputs from Murray Creek as well as sand bedload being output from the secondary channels.

Given that this scenario would emulate a reduction in sediment supply, it would be important to develop a sound conceptual model of how a decrease in sediment supply would produce substrates capable of supporting egg/larval survival. Additional and ongoing studies on fine substrate deposition and removal (winnowing) are likely to provide useful information for evaluating the feasibility of this restoration scenario.

3.1.6.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.6 Information needs identified for Scenario 6.

Information Needs	Notes
Baseline substrate condition	• (see Scenario 1 and 2)

Information Needs	Notes
Substrate movement rate	- Additional analysis of existing sediment transport data would be needed to determine the size of the sediment trap based on annual sediment volumes. - Sediment sampling programs would be needed to measure pre- and post-project sediment transport rates downstream of the sediment trap. - May need to add substrate cleaning and/or flow manipulation to cause winnowing that would remove fines.
Substrate infilling rate	- (see Scenario 1)
Environmental factors affecting spawning site selection	- (see Scenario 1)
Biological goals for substrate condition	- (see Scenario 1)
Downstream geomorphological impacts	- Over the long term, channel degradation caused by the reduction in sediment supply may have unintended geomorphological impacts which must be assessed (e.g., increased bank erosion downstream of the trap). - (see Scenario 1)
Substrate trapping methods	- A feasibility study would be needed to determine how to implement this option (e.g., long-reach excavator operating from a removable bridge deck on fixed piles). - Additional substrate treatments may be used in conjunction with a sediment trap (e.g., S2SES system); information on sediment volumes would be required to design the system appropriately. - Obtaining permits for construction and maintenance may be challenging.
Effectiveness of altering downstream conditions	- Additional information is needed on whether suitable interstitial habitat can be created through winnowing of existing substrates (i.e., what substrate composition is necessary to make the pore sizes for larvae?). - Physical or laboratory experiments may be warranted to investigate whether eggs/larvae survive over winnowed substrates (e.g., flume experiments using samples of existing substrates found within the reach).
Sediment trap location	- Additional studies (e.g., numerical modelling) and/or sediment sampling programs would be needed to determine the optimal location for the sediment trap. - Siting the trap should consider Murray Creek sediment inputs and bedload transport rates within secondary channels versus the mainstem channel during average and low flow years (most of the existing dataset is from a single high flow year).
Conceptual model of how discharge affects substrate	- (see Scenario 1)

Information Needs	Notes
Reach-scale hydraulic/sediment transport model	• A (2D or 3D) reach-scale morpho-dynamic model may be needed to estimate sediment volumes and assess hydraulic and geomorphological impacts; however, it may be challenging to accurately simulate sediment transport processes (e.g., winnowing of sand from a gravel bed) due to modelling limitations and the influence of upstream sediment supply.

3.1.6.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Permitting required for construction and maintenance.
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Frequent maintenance requirements.
- Time/duration of flow required to produce desired habitat.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Future changes in spawning location.
- Unintended geomorphological impacts.
- Numerical modelling limitations.
- Influence of additional/changing sediment loads and pathways.
- Public safety/navigational hazard.

3.1.6.4 Additional Discussion

Additional items discussed during the workshop included the following:

Participants commented that investigating this option may be amenable to large-scale physical experiments. For example, a large flume may be used to replicate flow velocities that are consistent with those observed in the spawning reach. The flume may then be run for long durations with substrate samples taken directly from the spawning reach to see whether suitable habitat can be produced by winnowing of existing material. Eggs/larvae may then be introduced to the flume to determine the biological suitability of the resulting substrates; this may be especially informative given the limited amount of available information regarding larval behavior on natural substrates and under realistic flow conditions.

3.1.7 Scenario 7 - No substrate remediation, assume fish will (periodically) spawn or induce increased spawning at the upstream end of the spawning reach

3.1.7.1 Summary Description

This scenario would take advantage of the apparently suitable substrate and hydraulic conditions at the upstream end of the spawning reach. The key limitation to this scenario is that the prevalence of spawning activity in this area is currently low. Therefore, like Scenario 5, identifying a method to induce increased spawning at this location is arguably the critical assumption of this scenario.

No environmental factors have been identified to date which would explain annual shifts in spawning location within the Vanderhoof reach. For example, during a high freshet year such as 2015, all egg detections occurred near or downstream of the Burrard Ave. Bridge. However, monitoring on the Kootenai River shows that increased fish movement to the upstream end of the spawning reach occurs in response to elevated spring discharge. While these results from the Kootenai River show promise, this scenario essentially represents a "do-nothing" scenario for the Nechako system until methods are developed to manipulate spawning site selection (e.g., by altering environmental variables, using chemical attractants, etc.).

3.1.7.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.7 Information needs identified for Scenario 7.

Information Needs	Notes
Environmental factors affecting spawning site selection	• (see Scenario 1 and 5)
Biological goals for substrate condition	• Additional experiments (e.g., egg releases) may be warranted to determine whether existing substrates at the upstream end of the spawning reach support survival through early life stages.

3.1.7.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Minimal effect on population recruitment due to limited spawners at this location.
- Unproven ability to influence spawning site selection.

3.1.7.4 Additional Discussion

Additional items discussed during the workshop included the following:

This essentially represents a “do nothing” scenario. While it is being considered for completeness, ongoing recruitment failure under existing conditions clearly demonstrates the need to implement restoration measures to promote survival through early life stages.

3.1.8 Scenario 8 - Temporary placement of substrate substitute (e.g., retrievable substrate mats, “bioball” carpet, etc.), assume current spawning location (near Burrard Ave. Bridge)

3.1.8.1 Summary Description

This scenario would use a novel intervention to capture sufficient eggs and/or drifting yolksac larvae to support subsequent recruitment. Given the high mortality during early life stages, reliably increasing the survival of a small proportion of the total spawning output might be able to overcome recruitment failure. New techniques would likely be required for this approach, rather than simply increasing the intensity of current measures such as egg mat sampling. While such techniques have not been identified, artificial egg rearing substrates were discussed as an option during the early stages of the Nechako recovery program based on apparent use of this sort of technique in Russia. However, there has been no further information or follow up for this option since that time.

Techniques to increase survival of yolksac larvae would include the installation of artificial substrates on the riverbed. The use of “bioballs” as a surrogate for rocky interstitial habitat in captive rearing suggests the possibility that a “bioball mat” might provide a means to increase survival of yolksac larvae. However, large-scale application of these techniques within the spawning reach may be technically challenging to implement and the effectiveness of these measures remains unproven in natural environments.

3.1.8.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.8 Information needs identified for Scenario 8.

Information Needs	Notes
Substrate infilling rate	• (see Scenario 1)
Restoration location and area	• (see Scenario 1)
Environmental factors affecting spawning site selection	• This restoration option could target different life stages depending on placement location relative to spawning sites (i.e., placement at spawning sites targets eggs, while placement downstream of spawning sites targets larvae). • (see Scenario 1) • Needs to be placed just before spawning to limit sediment infilling.

Information Needs	Notes
Biological goals for substrate condition	• The effectiveness of different artificial substrates remains uncertain for egg versus larval trapping (e.g., a “bioball” carpet could capture drifting larvae, but may not be effective for eggs if they settle between the “bioballs” as opposed to within them). • Artificial substrate may provide a survival benefit over restored substrates (e.g., decreased predation). • This option may still require hatchery rearing if the artificial substrates effectively capture eggs but do not promote successful rearing.
Artificial substrate methods	• A feasibility study is needed to determine how to implement this option (e.g., deployment and anchoring of artificial substrates, material to use as artificial substrate, etc.).

3.1.8.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Subsequent sedimentation/debris accumulation could limit effectiveness.
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Hatchery rearing may still be required.
- Lack of examples and unproven biological effectiveness.
- Pollution caused by damage or degradation of plastics.
- Potential impacts on benthic invertebrates.

3.1.8.4 Additional Discussion

Additional items discussed during the workshop included the following:

This approach may also be considered as a monitoring tool to assess the effectiveness of restoration works. The inability to sample drifting larvae using nets is a current limitation of biological sampling. There may be potential to use artificial substrate mats (e.g., “bioball carpet”) as a method to capture eggs and larvae, although sampling effectiveness at different life stages would need to be investigated.

3.2 Group 2 – Indirect substrate modification

3.2.1 Scenario 9 - Manipulate discharge to maintain habitat quality (substrate) during spawning period, assume current spawning location (near Burrard Ave. Bridge)

3.2.1.1 Summary Description

Using discharge and/or hydrograph characteristics to produce substrate conditions capable of supporting natural recruitment clearly represents an attractive restoration strategy. The potential success of this approach is in part supported by the detection of occasional recruitment pulses in 1994/95, 2007 and 2011; however, the reason(s) why low-level recruitment occurred in those years remain uncertain[1]. 2015 was also a high flow year and has not produced a recruitment pulse.

Support for this restoration scenario will likely require the development of a conceptual model explaining the relation between discharge, substrate conditions and recruitment within the spawning reach. Subsequently, it will be critical to validate the conceptual model using physical models and/or field-based data to successfully implement this scenario.

It may also be important to note that this scenario differs from Scenario 11 in that it is not necessarily based on the restoration of “naturalized” discharge. Instead, this scenario is focussed on the functional outcome of achieving substrate improvements in the Nechako River by manipulating discharge, and this scenario could conceivably include a mixture of low and high discharge conditions. This approach may improve the quality of existing substrates if 1) the sediment supply can be cut off (Scenario 6) and 2) flows can be identified/implemented that effectively mobilize the surficial gravels.

3.2.1.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.9 Information needs identified for Scenario 9.

Information Needs	Notes
Baseline substrate condition	• (see Scenario 1)
Substrate movement rate	• Additional studies are needed to evaluate how sediment transport changes under different flow regimes (e.g., ramping rates). • Sediment sampling programs would be needed to measure pre- and post-implementation sediment transport rates.

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[1] Substrate change is the leading candidate mechanism to explain the recruitment pulse in 2011, as this year corresponds to when the Middle and Lower Patch spawning pads were placed. It is not currently known what produced the other recruitment pulses, although this remains the subject of ongoing research.

Information Needs	Notes
Substrate infilling rate	• Additional studies are needed to determine which hydraulic conditions promote infilling versus winnowing. • Higher flows may also entrain more sediment from upstream, highlighting the need to control sediment sources as well as promote sediment winnowing.
Environmental factors affecting spawning site selection	• (see Scenario 1)
Biological goals for substrate condition	• (see Scenario 1)
Effectiveness of altering downstream conditions	• (see Scenario 6)
Conceptual model of how discharge affects substrate	• A sound conceptual model of flow and sediment transport processes is needed to justify any recommended changes to the flow regime. • (see Scenario 1)
Flood risk	• Changes in the flow regime must consider flooding risk (e.g., effects on winter ice jams, etc.).
Reach-scale hydraulic/sediment transport model	• A (2D or 3D) reach-scale morpho-dynamic model may be needed to further investigate the relation between discharge and sediment transport within the spawning reach; however, it is not anticipated that a model alone will accurately simulate sediment transport processes (e.g., winnowing of sand from a gravel bed) due to modelling limitations and the influence of upstream sediment supply.

3.2.1.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Influence of additional/changing sediment loads and pathways.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Future changes in spawning location.
- Unintended geomorphological impacts.
- Numerical modelling limitations.
- Remaining uncertainties around discharge-substrate interactions.
- Inability to implement desired multi-year discharge regime (e.g., operational constraints).
- Potential increases in flooding risk (e.g., ice effects caused by changes in winter flows).

3.2.1.4 Additional Discussion

Additional items discussed during the workshop included the following:

While the overall magnitude of high flows is constrained by flooding concerns, it may be possible to manipulate the hydrograph characteristics (ramping rates, etc.) to produce desired substrate conditions within the spawning reach. For example, a long receding limb may promote increased sand transport out of the reach; however this would typically occur after the spawning period. Another component to this potential approach is whether altered flows and sediment transport processes can alter existing substrates in a way to support natural recruitment.

It was also noted that it may take a long time (e.g., decades) to prove and implement a hydrograph-based restoration strategy. This is due to the significant duration of geomorphologically-effective flows which may be required to produce the desired physical changes, combined with the 2-3 year time lag before juveniles can be sampled. Additional (uncontrolled) environmental factors may also confound the results of the study. That said, it is worth considering the potentially beneficial effects of hydrograph changes to enhance or maintain other restoration approaches (e.g., substrate addition/remediation, engineered spurs, etc.).

Numerical modelling was suggested as a potential tool to explore the effects of altering the hydrograph on sediment transport processes. However, it was also noted that numerical modelling of these processes (e.g., winnowing of sand from a gravel bed) would be challenging due to inherent limitations of morpho-dynamic and sediment transport modelling.

Participants familiar with the Kootenai River system commented that a period or sequence of flows (e.g., flows over a period of seven days) may have more of an effect on fish behavior than a discharge magnitude. Results from biological monitoring programs on that system showed that steeper down-ramping was associated with increased spawning activity, suggesting that a relatively rapid decrease in discharge may be an important cue to initiate spawning activity.

Finally, it was noted that flow manipulation should consider the effects on fish behavior (e.g., stimulate spawning, influence site selection, etc.) as well as spawning habitat. These two potential aspects of restoration may be affected differently by river discharge.

3.2.2 Scenario 10 - Moderate to large-scale physical habitat restoration with long-term effectiveness, assume current spawning location (near Burrard Ave. Bridge)

3.2.2.1 Summary Description

This scenario is predicated on the idea that flow regulation has altered the channel form and function within the spawning reach. The scenario proposes to re-engineer the channel to achieve desired habitat conditions (suitable spawning and early rearing habitat) using the now regulated flow regime.

While this approach is conceptually appealing, it also presents some clear challenges. Currently, we do not have any clear empirical or modelled results to suggest that a re-engineered channel is required to reproduce pre-regulation channel dynamics. Continued uncertainties, such as factors that influence spawning location, also increase the risk that biological outcomes might not be achieved despite physical improvements to habitat quality. Large-scale river engineering would also be costly and have significant flooding, geomorphological and public safety implications; thus, this option is considered to have both high uncertainty and high cost. While current information suggests that this option might not have strong support at present, it is presented as part of this planning exercise to ensure that the full breadth of restoration scenarios is considered.

3.2.2.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.10 Information needs identified for Scenario 10.

Information Needs	Notes
Baseline substrate condition	• (see Scenario 1)
Restoration location and area	• Previous modelling studies have investigated the hydraulic impacts of larger-scale channel engineering, including lowering bar elevations and removing vegetation from within the Island Complex. These studies generally concluded that (at present) large-scale re-engineering of the channel has high cost, uncertainty and risk. • Permitting requirements for construction may be challenging. • If these options are being considered, additional studies should be undertaken to evaluate morphological and sediment transport implications. • (see Scenario 1)
Environmental factors affecting spawning site selection	• This approach would require a sound understanding of the factors driving spawning site selection (or would need to rely on currently unproven methods to attract spawning fish) to mitigate the risk that fish do not use the restored habitat. • (see Scenario 1)
Biological goals for substrate condition	• (see Scenario 1)
Downstream geomorphological impacts	• Any channel modifications must consider (potentially unintended) geomorphological impacts.
Conceptual model of how discharge affects substrate	• A sound conceptual model of flow and sediment transport processes is required to design effective channel modifications and mitigate risk of failure. • (see Scenario 1)

Information Needs	Notes
Flood risk	- Any channel modifications must consider the impacts on flooding risk.
Reach-scale hydraulic/sediment transport model	- A complex (2D or 3D) reach-scale morpho-dynamic model would be required to evaluate performance and impacts of channel modifications; however, it may be challenging to accurately simulate sediment transport processes due to modelling limitations.

3.2.2.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Permitting required for construction and maintenance (e.g., Bird Sanctuary).
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Future changes in spawning location.
- Future changes to the flow regime may impact effectiveness and/or function (e.g., changing hydraulics).
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Unintended geomorphological impacts.
- Numerical modelling limitations.
- Limited public support.
- Public safety/navigational hazard.

3.2.2.4 Additional Discussion

Additional items discussed during the workshop included the following:

Previous modelling studies have investigated the hydraulic impacts of larger-scale channel engineering, including lowering bar elevations and removing vegetation from within the Island Complex. These studies generally concluded that (at present) large-scale re-engineering of the channel has high cost, uncertainty and risk. Participants also commented that this option may be very hard to implement due to permitting requirements, Federal wildlife/habitat protections (i.e., Bird Sanctuary), and limited community support. The proximity of the project site to the community of Vanderhoof is clearly a compounding factor.

Participants emphasized that strong evidence to show that restoration action will lead to recruitment is required before implementing any large-scale projects. This should be considered for all experimental approaches as well (i.e., area of habitat required to generate the statistical power to prove that restoration undeniably led to recruitment, and to what degree of recruitment).

3.2.3 Scenario 11 - Manipulate discharge to stimulate recruitment (non-substrate mechanism), spawning location not assumed

3.2.3.1 Summary Description

Restoring a more natural flow regime is an important scenario to consider given the association between recruitment failure and river regulation on several large river systems. Spring freshet conditions are associated with a variety of physical and biological changes in rivers, and positive recruitment-discharge relationships have been observed in some sturgeon populations that have successful recruitment. Since discharge-mediated effects on substrate and spawning location are addressed by Scenarios 7 and 9, respectively, this scenario considers additional, but still undetermined, mechanisms that would increase recruitment.

This type of mechanism for recruitment failure was considered during the initial years of recovery planning, but studies ultimately showed no evident relation between high spring discharge and recruitment success. However, given the known importance of the natural hydrograph to the form and function of riverine habitats, it is still important to consider this potential approach within the current planning framework. For example, continued research from other rivers may identify additional ecosystem components that would benefit White Sturgeon recruitment and that might be restored as an outcome of improvements to the regulated hydrograph.

3.2.3.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.11 Information needs identified for Scenario 11.

Information Needs	Notes
Environmental factors affecting spawning site selection	• Additional information is needed on how the hydrograph influences spawning behavior and site selection.
Flood risk	• (see Scenario 9)
Identify alternate causal mechanism	• Additional evidence is needed to support a non-substrate mediated mechanism for recruitment failure.
Conceptual model of how discharge affects alternate recruitment mechanism	• A sound conceptual model of how flow influences recruitment success is needed to justify any recommended changes to the flow regime.

3.2.3.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Lack of evidence for alternative mechanism for recruitment failure.
- Poor correlation between high spring discharge and recruitment (i.e., limited effectiveness in previous years).
- Unintended geomorphological impacts.
- Inability to implement desired multi-year discharge regime (e.g., operational constraints).
- Potential increases in flooding risk (e.g., ice effects caused by changes in winter flows).

3.2.3.4 Additional Discussion

No additional items were discussed during the workshop pertaining to this restoration scenario, other than those previously described for Scenario 9.

3.2.4 Scenario 12 - Downstream channel modification, spawning at new location downstream of Burrard Ave. Bridge

3.2.4.1 Summary Description

This scenario proposes to modify the channel downstream of the current spawning reach in a way that produces suitable spawning and early rearing habitats in these downstream locations. Since most spawning fish currently migrate upstream to the Vanderhoof reach to spawn, the goal would be to have fish encounter and use better quality spawning habitats prior to reaching their current spawning locations (which have poor interstitial habitat).

Given the complexity associated with large-scale channel re-engineering (Scenario 10), this option would aim to produce specific changes that benefit spawning (e.g., localized increases in water velocity, depth, etc.) and survival through early life stages (e.g., induce scour to maintain interstitial habitats) in a manner that provides greater certainty of results, less cost, and less potential for negative implications for the community of Vanderhoof (e.g., flood risk). Another possible benefit of downstream habitat enhancement is that it might be more amenable for experimental or reversible manipulations outside of the current spawning areas, which are designated as “Critical Habitat” under the Federal Species at Risk Act.

3.2.4.2 Information Needs

The following table lists the information needs for this restoration scenario and provides summarized notes from the workshop discussion.

Table 3.12 Information needs identified for Scenario 12.

Information Needs	Notes
Baseline substrate condition	• No detailed mapping of existing substrate characteristics is available downstream of the current spawning reach, although the bed is assumed to be predominantly composed of sand. Additional studies may be warranted to investigate whether localized areas with coarser substrates exist (e.g., these areas may be targeted for restoration). • (see Scenario 1)
Substrate addition methods	• (see Scenario 1)
Substrate cleaning methods	• (see Scenario 2)
Effectiveness of substrate cleaning	• (see Scenario 2)
Substrate movement rate	• No sediment transport data exists downstream of the spawning reach; additional sediment sampling programs would be needed to understand sediment transport processes through the area. • (see Scenario 1)
Substrate infilling rate	• No substrate infilling data exists downstream of the spawning reach; additional monitoring programs would be needed to understand infilling rates within the area. • (see Scenario 1)
Restoration location and area	• Potential restoration areas downstream of the spawning reach have not been examined to date; additional studies would be required to determine suitable locations to achieve project goals (which also need to be determined). • (see Scenario 1 and 10)
Environmental factors affecting spawning site selection	• A sound understanding of fish behavior, spawning site selection and egg/larval drift processes would be required to design effective channel modifications and mitigate risk of failure. • (see Scenario 1 and 10)
Biological goals for substrate condition	• (see Scenario 1)
Downstream geomorphological impacts	• (see Scenario 10)
Effectiveness of altering downstream conditions	• Additional information on fish behavior (e.g., site selection), egg/larval drift patterns, reach-scale hydraulics and sediment transport processes are required to design effective channel modifications and mitigate risk of failure.
Conceptual model of how discharge affects substrate	• (see Scenario 1 and 10)
Flood risk	• (see Scenario 10)

Information Needs	Notes
Reach-scale hydraulic/sediment transport model	• (see Scenario 10)
Movement dynamics of spawners downstream of bridge	• Additional information is needed on how to modify habitat and hydraulics so that spawners do not go further upstream. • Restoration design should also consider the origin of spawners, as some fish may access the site from upstream.

3.2.4.3 Risks and Limitations

Primary risks and limitations for this scenario include, but are not limited to, the following:

- Limitations associated with implementation methods.
- Permitting required for construction and maintenance (e.g., Bird Sanctuary).
- Changing/uncertain environmental conditions may negatively impact implementation and monitoring.
- Access/private property.
- Monitoring methods/metrics (both biological and geomorphological) may limit evaluation of success (e.g., results confounded by other environmental variables).
- Future changes in spawning location.
- Future changes to the flow regime may impact effectiveness and/or function (e.g., changing hydraulics).
- Area required to generate sufficient biological response is larger than what can be feasibly restored.
- Unintended geomorphological impacts.
- Numerical modelling limitations.
- Public safety/navigational hazard.

3.2.4.4 Additional Discussion

No additional items were discussed during the workshop pertaining to this restoration scenario, other than those previously described for Scenario 1 (using engineered structures to create suitable habitat and/or attract fish) and Scenario 2 (direct versus indirect approaches towards habitat restoration).

4 SCENARIO RANKING

The potential restoration scenarios have been ranked based on a qualitative assessment of project feasibility, potential effectiveness, risk/cost, and potential outcomes. The assessment and ranking have been reviewed and agreed upon by subject-matter experts at NHC and the Ministry of Environment and Climate Change, who have multiple years of experience related to White Sturgeon habitat restoration on the Nechako River. The ranking was also informed by participant feedback received during the 2022 Nechako Habitat Restoration Workshop.

It is important to note that the ranking is not intended as a selection tool to identify which restoration option to implement. Rather, the purpose of the ranking exercise is to inform the prioritization of information needs which should be addressed in working towards implementation of the highest ranked options. Addressing the information needs for the highest ranked restoration options forms the basis for the recommended study plan to be implemented over the next five years (Section 5).

The restoration scenarios were ranked based on the metrics described above and placed into three groups: “Highest Ranked”, “Moderately Ranked”, and “Lowest Ranked” (Table 4.1).

Highest ranked options generally have the following characteristics:

- Most likely to promote recruitment based on current spawning locations.
- Considered to be generally feasible with some prior experience of implementation (although Scenario 6 is a novel approach which may have challenging permitting requirements).
- Most likely to provide direct biological benefits (i.e., some degree of natural recruitment) OR to significantly advance the overall recovery strategy (e.g., by providing “proof-of-concept” for substrate-based restoration, identifying effective flow-based solutions, or informing effective sediment management programs).
- Most likely to provide benefits within short- to moderate-timescales.

Moderately ranked options generally have the following characteristics:

- Less likely to promote recruitment due to limited fish use (i.e., these areas are not located within current high density spawning areas).
- Considered to be generally feasible, although may require a considerable amount of effort to implement and rely on unproven techniques.
- Direct biological benefits are uncertain, with limited advancement to the overall recovery strategy.
- Generally have moderate to high cost, risk and/or uncertainty.

Lowest ranked options generally have the following characteristics:

- Limited evidence to suggest that these measures would promote recruitment.;
- Direct biological benefits are uncertain, with minimal advancement to the overall recovery strategy.
- Generally have high cost, risk and/or uncertainty.

Table 4.1 Ranking of potential habitat restoration scenarios.

Highest Ranked	Moderately Ranked	Lowest Ranked
Scenario 1 - Repeated substrate addition, assume current spawning location (near Burrard Ave. Bridge)	**Scenario 4** - Substrate addition/remediation to enlarge Middle Patch (upstream of secondary channels), natural spawning site selection	**Scenario 7** - No substrate remediation, assume fish will (periodically) spawn or induce increased spawning at the upstream end of the spawning reach
Scenario 2 - Repeated substrate remediation, assume current spawning location (near Burrard Ave. Bridge)	**Scenario 5** - Substrate addition/remediation to enlarge Middle Patch (upstream of secondary channels), induce increased spawning near Middle Patch	**Scenario 10** - Moderate to large-scale physical habitat restoration with long-term effectiveness, assume current spawning location (near Burrard Ave. Bridge)
Scenario 3 - Combination of substrate addition and remediation, assume current spawning location (near Burrard Ave. Bridge)	**Scenario 8** - Temporary placement of substrate substitute (e.g., retrievable substrate mats, “bioball” carpet, etc.), assume current spawning location (near Burrard Ave. Bridge)	**Scenario 11** - Manipulate discharge to stimulate recruitment (non-substrate mechanism), spawning location not assumed
Scenario 6 - Substrate trapping upstream of the Lower Patch, assume current spawning location (near Burrard Ave. Bridge)	**Scenario 12** - Downstream channel modification, spawning at new location downstream of Burrard Ave. Bridge	
Scenario 9 - Manipulate discharge to maintain habitat quality (substrate) during spawning period, assume current spawning location (near Burrard Ave. Bridge)		

5 RECOMMENDATIONS

Table 5.1 presents the prioritized list of information that is required to implement each restoration scenario (Section 3). Scenarios highlighted in green indicate “Highest Ranked” scenarios (Table 4.1), while scenarios highlighted in orange and red represent “Moderately Ranked” and “Lowest Ranked” scenarios, respectively.

From these prioritized information needs, it is recommended that the following studies be undertaken over the next five years to inform the development and implementation of effective restoration measures:

Recommended geomorphological studies:

- Complete feasibility studies to identify alternative substrate addition/cleaning methods.
- Investigate substrate movement rate and potential for winnowing of fines (e.g., gravel tracers to inform size/composition of placed material).
- Continue monitoring infilling rates at biologically important locations and refine monitoring techniques.
- Complete feasibility study to assess substrate trapping methods.
- Continue refining a conceptual model of how discharge affects substrate conditions within the primary spawning area (this will be partially informed by the other recommended studies; however, additional analysis/modelling would likely be required).
- Assess flood risk associated with substrate addition.

Recommended biological studies:

- Determine restoration location and area required to statistically prove restoration success/effectiveness.
- Investigate environmental factors affecting spawning site selection.
- Refine biological criteria for substrates which promote survival through early life stages with specific emphasis on conditions with similar near bed velocities.
- Investigate whether winnowing of existing substrates can support egg/larval survival.

It is important to note that the ranking and prioritization of restoration options, information needs, and recommended studies may evolve in response to new information gained throughout the study period. It is also important to note that the recommended study plan provides an ambitious research agenda, where it may not be possible to complete all studies within the five-year timeframe due to project complexity. Completion of all recommended studies will significantly advance the recovery effort but will not address all information needs required to implement restoration designs (Table 5.1). Restoration options may still be implemented with remaining uncertainties depending on acceptable levels of risk, or if the remaining uncertainties are addressed through alternative means (e.g., analysis of existing datasets, professional judgement, etc.).

Table 5.1 **Summary of the information needs to be addressed prior to implementation of each restoration scenario; green represents "Highest Ranked" scenarios in Table 4.1, while orange and red represent "Moderately Ranked" and "Lowest Ranked", respectively.**

Information Needs	Scenario 1	Scenario 2	Scenario 3	Scenario 6	Scenario 9	Scenario 4	Scenario 5	Scenario 8	Scenario 12	Scenario 7	Scenario 10	Scenario 11
Baseline substrate condition	✓	✓	✓	✓	✓	✓	✓		✓		✓	
Substrate addition methods	✓		✓			✓	✓		✓			
Substrate cleaning methods		✓	✓			✓	✓		✓			
Effectiveness of substrate cleaning		✓	✓			✓	✓		✓			
Substrate movement rate	✓	✓	✓	✓	✓	✓	✓		✓			
Substrate infilling rate	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Restoration location and area	✓	✓	✓			✓	✓	✓	✓		✓	
Environmental factors affecting spawning site selection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Biological goals for substrate condition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Downstream geomorphological impacts	✓		✓	✓		✓	✓		✓		✓	
Substrate trapping methods				✓								
Effectiveness of altering downstream conditions				✓	✓				✓			
Sediment trap location				✓								
Conceptual model of how discharge affects substrate	✓	✓	✓	✓	✓	✓	✓		✓		✓	
Flood risk	✓		✓		✓	✓	✓		✓		✓	✓
Artificial substrate methods								✓				
Reach-scale hydraulic/sediment transport model				✓	✓				✓		✓	
Identify alternate causal mechanism												✓
Conceptual model of how discharge affects alternate recruitment mechanism												✓
Movement dynamics of spawners downstream of bridge									✓			

6 CONCLUSION

The recommended study plan is intended to advance the recovery efforts for the Nechako White Sturgeon by addressing critical information needs regarding both the biological and geomorphological aspects of effective restoration design. The project was achieved as a joint effort between NHC and the Ministry of Environment and Climate Change Strategy. The evaluation of potential restoration options and identification of key information needs greatly benefitted from feedback and discussions during the interdisciplinary 2022 Nechako Habitat Restoration Workshop held on March 21, 2022. NHC and the Ministry of Environment and Climate Change Strategy would like to thank all participants for their valuable contributions to the project and look forward to continued collaboration as we work towards restoring natural recruitment in affected sturgeon populations.

APPENDIX A

BACKGROUND INFORMATION FOR THE 2022 NECHAKO HABITAT RESTORATION WORKSHOP

1 INTRODUCTION

1.1 Goals for recovery planning

The Nechako River White Sturgeon (*Acipenser transmontanus*) population has been undergoing almost complete recruitment failure since about 1967. There is a pressing need to implement restoration strategies that promote natural recruitment due to the limited number of remaining wild adult sturgeon (< 500 fish). While hatchery inputs provide a stopgap measure against extirpation, the recovery goal for the Nechako White Sturgeon is a naturally recruiting population.

The objective of developing a 5-year habitat restoration plan is to provide the foundation for the implementation of long-term restoration actions. Recovery efforts to date underscore that effective, long-term habitat restoration will require a sound understanding of both the biological habitat requirements and geomorphological processes that affect habitat characteristics. The aim of this interdisciplinary workshop is to discuss habitat restoration scenarios, assess their feasibility from a biological and geomorphic perspective, and identify the knowledge gaps that will need to be addressed to implement effective restoration.

2 GENERAL BACKGROUND

2.1 History of recovery effort

Recovery efforts for Nechako White Sturgeon began in 2001, after sampling from 1995-1999 confirmed the presence of recruitment failure (RL&L, 2000). The recovery program has included a broad set of projects focussed on both the biology (e.g., spawn monitoring, juvenile monitoring, adult telemetry) and geomorphology of the system (e.g., bedload sediment sampling, collection of freeze-cores, flow modelling). Biological studies have expanded from laboratory studies (McAdam, 2011), to small-scale experimental restoration in 2008 (McAdam, 2012), to larger scale restoration at two locations within the spawning reach in 2011 (McAdam et al., 2018; NHC, 2012). Numerous geomorphological studies have informed our understanding of reach-scale hydraulics (Gauthier-Fauteux, 2017, 2018; NHC, 2006, 2008), sediment transport and riverine substrates (NHC, 2014, 2015, 2016a, 2018, 2020a). Table 2.1 provides a concise description of the key developments in the progress of habitat restoration for this population.

Table 2.1 Key developments in habitat restoration efforts for Nechako white sturgeon.

Year	Development
2001	The initiation of recovery planning (see Korman and Walters, 2001).
2003-2005	Identified relationship between substrate change and recruitment failure (McAdam et al., 2005; NHC, 2003a, 2003b).
2004-present	Initial identification of the spawning reach in 2004 (Liebe et al., 2004) followed by annual spawn monitoring.
2006-present	Biological laboratory and field studies of larval habitat requirements (Baker et al., 2014; Boucher et al., 2014, 2018; McAdam, 2011, 2012).
2011	Medium/large scale substrate restoration experiment on the Nechako River: two patches ~30 x 80 m each of clean substrate placed at known spawning locations (McAdam et al., 2018; NHC, 2012).
2011-present	Geomorphic monitoring studies related to the substrate augmentation in 2011 (Gauthier-Fauteux, 2017; NHC, 2012, 2013, 2014, 2015, 2016a, 2018, 2020a).
2013-2014	Juvenile monitoring identifies low-level recruitment in 1994, 1995, 2007 and 2011 (EDI, 2013; McAdam, *unpublished*).
2016, 2020	Gravel cleaning experiment to determine feasibility of physical cleaning using in-stream machinery (NHC, 2016b) or divers (NHC, 2021).
2017-2019	Detailed geomorphic studies targeting substrate composition at specific spawning sites (NHC, 2018, 2020a).
2018	Hydrodynamic modelling to investigate potential physical controls on reach-scale hydraulics, evaluate how such controls may have altered flow conditions over time and to investigate alternative restoration measures (Gauthier-Fauteux, 2018).

2.2 Potential causes of recruitment failure

Multiple hypotheses have been considered to explain the onset of recruitment failure[1] (Nechako White Sturgeon Recovery Initiative, 2004); however, the timing of recruitment failure, which occurred 15 years after the completion of Kenney Dam, limits the support for many hypotheses (Figure 2.1). The discordance between post-regulation high flow events and (unexplained) recruitment pulses in 1994/95, 2007 and 2011 (Figure 2.2), highlights that recruitment is not directly linked to flow magnitude, but rather to a combination of factors and/or to indirect impacts of flow regulation. While flow regulation has undoubtably led to multiple changes in the river morphology (e.g., loss of side-channels, vegetation encroachment, etc.) (NHC, 2018), studies to date have not been able to identify a direct link between the effects of flow regulation and the onset of recruitment failure.

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[1] Past hypotheses are discussed in greater detail in the workshop materials.

2.3 Current working hypothesis with greatest support

The current working hypothesis with greatest support is that the substrate composition changed within the critical spawning reach located near Vanderhoof, BC (Figure 2.3), thereby reducing the quality of early rearing (interstitial) habitat. Support for this hypothesis is predicated on three main points:

- Gauge data and station maintenance notes from the Water Survey of Canada (WSC) gauge[2] located immediately downstream of the Burrard Avenue (Ave.) Bridge, which indicate that a period of sediment accumulation occurred between about 1968 and 1993 (which corresponds well with the onset of recruitment failure around 1967) (NHC, 2018, 2020b).
- The fact that other hypotheses do not provide a reasonable explanation for the 15-year time lag between dam completion in 1952 and the onset of recruitment failure.
- Biological findings which indicate the importance of interstitial habitats (McAdam, 2011), including findings from the Kootenai (Kock et al., 2006; Paragamian et al., 2001) and Columbia rivers (McAdam, 2015) that also identify changes in substrate condition as a plausible leading hypothesis.

While this leading hypothesis may provide a causal mechanism for recruitment failure, a more detailed understanding of how geomorphic/hydraulic processes are driving physical change within the spawning reach is needed, as well as how these physical changes may or may not result in successful recruitment. This information will be critical in implementing strategies that can provide long-term improvements in juvenile recruitment. Future research to address these issues may include testing hypotheses in controlled (e.g., laboratory or flume setting) and/or field environments, potentially including up to large-scale *in-situ* experiments (e.g., physical channel and/or flow alteration).

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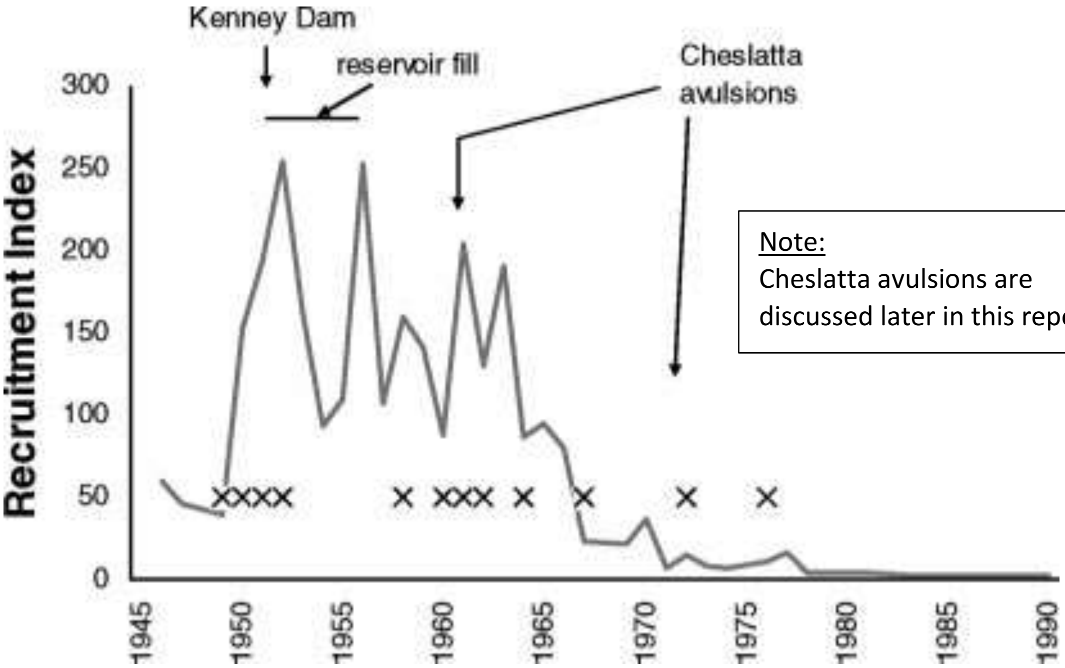
[2] WSC gauge (08JC001) Nechako River at Vanderhoof.



Note:
Cheslatta avulsions are discussed later in this report.

Figure 2.1 **Historic pattern of projected recruitment (years when flow at Vanderhoof exceeded 500 m^3/s are indicated by an 'X'). Figure reproduced from McAdam et al. (2005).**

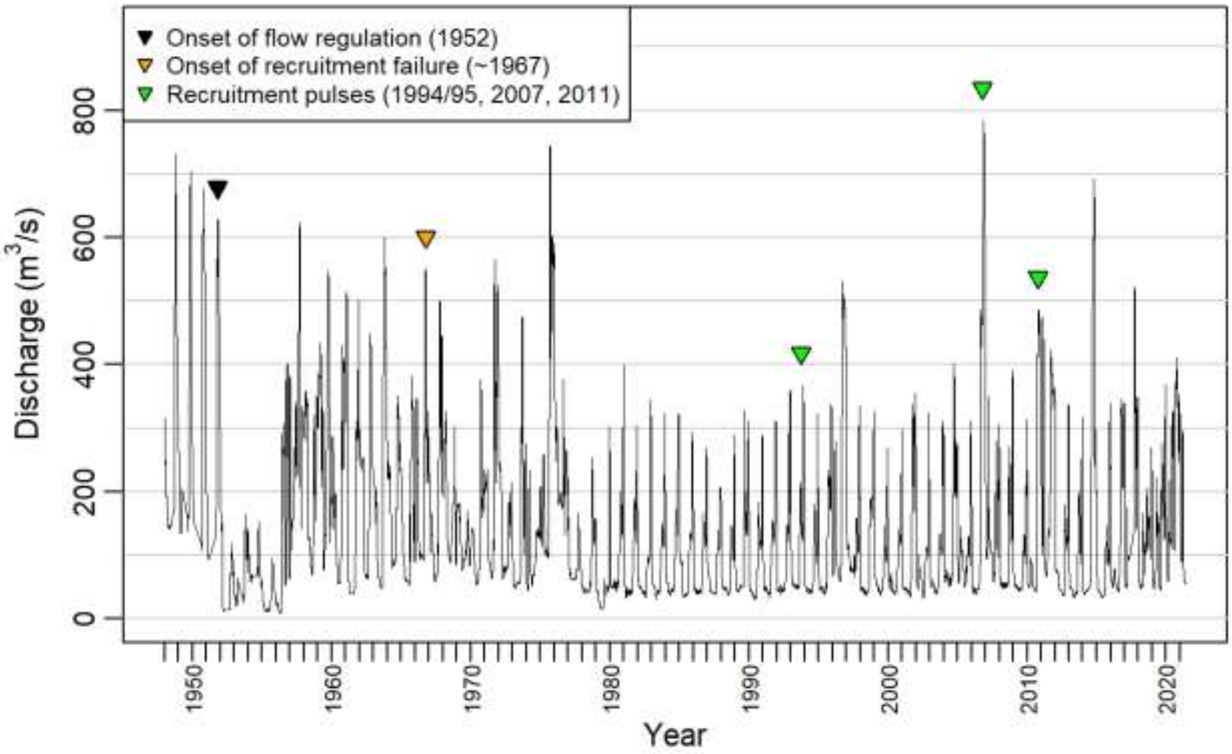


Figure 2.2 **Key recruitment events plotted in relation to mean daily discharge at WSC gauge (08JC001) Nechako River at Vanderhoof from 1948 to present.**

Figure 2.3 Overview map of the critical spawning reach on the Nechako River at Vanderhoof, BC.

3 BIOLOGICAL BACKGROUND

3.1 Spawning

White Sturgeon return annually to spawn in the critical spawning reach at Vanderhoof, which is the only known spawning location for this population (McAdam, pers. comm., 2022). Continued annual spawning suggests that recruitment failure was not caused by a decrease in spawning activity. Spawning has been detected throughout the 3 km spawning reach, but in recent years, most of the spawning activity appears to be concentrated downstream of the Island Complex (i.e., just upstream and downstream of the Burrard Ave. Bridge) (McAdam, pers. comm., 2022). Spawning also tends to occur in deeper areas that have a relatively high flow velocity; however, not all high velocity areas are used for spawning.

Understanding the environmental factors that influence habitat selection by spawning adults is important as it determines the rearing locations of early life stages (i.e., egg and yolksac larvae). Given that 'clean' gravel-cobble substrates provide the most suitable habitat for early life stages, spawning site selection does not appear to be based on substrate type because the majority of spawning occurs over sandy gravel and infilled cobbles downstream of the Island Complex (see Figure 2.3). Thus, site selection appears to be driven by other environmental factors (e.g., near-bed hydraulics), which remain unknown at this time.

The presence of relatively deep, high velocity flow and apparently suitable cobble substrates at the upstream end of the spawning reach (Upper Site on Figure 2.3) raises the possibility that the primary spawning location shifted from an upstream, historical site to the current spawning location in response to flow regulation. While such an effect makes intuitive sense, there is limited supporting evidence. Given the absence of data to suggest that the primary spawning location has changed, habitat restoration efforts are currently focussed on the areas where fish are presently spawning (i.e., Lower Site, Lower Patch and potentially Middle Patch on Figure 2.3).

3.2 Eggs

The egg stage lasts about 9 days (when incubated at 15°C). Eggs are negatively buoyant and become adhesive shortly after fertilization. While *in-situ* research on eggs is limited, the presence of roughness elements on the river bottom (e.g., voids between large clasts) is expected to increase egg survival for several reasons, including that exposed eggs may be more prone to predation (Caroffino et al., 2010).

Eggs captured on sampling mats are most often covered in sand. While excessive sand cover can limit egg survival (Koch et al., 2006), the effects of a thin layer on the egg surface are uncertain and may in fact provide a form of protection. However, sand covered eggs could also be prone to downstream displacement (e.g., saltation over embedded substrates) or other limitations (e.g., impaired respiration). Mortality rates during the egg stage are naturally high, so even slight increases in mortality caused by increased sand cover may negatively affect recruitment.

Given the limited amount of research completed on eggs to date, a more complete understanding of the factors that affect egg survival is warranted. For example, understanding egg drift distance prior to settlement would help determine the required length of habitat restoration sites. Determining what substrate characteristics enhance egg retention and survival is another area that requires further investigation, the findings of which could inform habitat restoration planning and design (e.g., optimal grainsize distribution for placed substrates).

3.3 Yolksac larvae

The yolksac larvae stage lasts for about 12 days (at 15°C) from hatch until larvae emerge from substrate, drift downstream and begin feeding. Laboratory and field studies have shown that an inability to access interstitial hiding habitat leads to downstream drift and increased predation (McAdam, 2011, 2012). Findings for this life stage therefore provide a very clear link between substrate alteration and increased mortality, which may have caused recruitment failure.

Additional growth and physiological benefits of substrate rearing indicate that hiding by yolksac larvae is a required component of their life history (Baker et al., 2014; Boucher, 2012; Boucher et al., 2014). Lab and field studies suggest that larval hiding habitat would naturally occur in the immediate vicinity of spawning and egg rearing habitat (McAdam, 2011, 2012), which emphasizes that restored habitat must be located where fish prefer to spawn. While the need for interstitial habitat is clear, a more refined understanding of conditions that optimize larval growth, development, and survival is required to improve habitat restoration planning. Further studies investigating the effects of substrate composition and thickness on larval retention and survival will also provide important guidance for habitat restoration design.

4 GEOMORPHOLOGY BACKGROUND

4.1 Geomorphic context

The Nechako River watershed covers approximately 47,000 km^2 of the Interior Plateau in west-central British Columbia. Prior to the construction of Kenney Dam in 1952, the Nechako River drained a series of large lakes on the leeward side of the Coast Mountains[3] in a physiographic region known as the Nechako Plateau. Downstream of the present-day location of Kenney Dam, the Nechako River flows through an expansive area comprised of the Nechako Plains (Holland, 1976). Three large, ice-dammed lakes existed within this region during the last period of deglaciation, centered around Prince George, Fort St. James and Vanderhoof (Holland, 1976). Thick deposits of silt, interbedded with fine sand and clay accumulated within the lakes during the post-glacial period, which now form high (20 m) glaciolacustrine terraces along the valley sides.

From the Kenney Dam to Vanderhoof, the Nechako River geomorphology is composed of a series of repeating channel morphologies that range from steeper bedrock controlled reaches to low gradient sand bed reaches, generally referred to as sedimentary links (Rice, 1999). Two substantial sedimentary links exist upstream of the Nautley River, a tributary of the Nechako River, each about 50 km in length. Along the course of each link, the channel transitions from being controlled by bedrock or non-alluvial deposits, to being predominantly cobble-, gravel- and eventually sand-bedded. Between the Nautley River and Vanderhoof, the channel has a consistent profile controlled by a series of bedrock outcrops, after which it transitions to an alluvial channel just upstream of Vanderhoof. The White Sturgeon spawning reach is located within and immediately downstream of this transition, where the morphology of the river changes from a wandering gravel bed river to a meandering sand bed river in response to a reduction in channel gradient (0.065% to 0.005%). The channel gradient remains very low over the next 45 km, until the Nechako River reaches the confluence with the Stuart River and the (bedrock-controlled) Isle Pierre rapids.

The three main sedimentary links upstream of Vanderhoof exert a large influence on the physical characteristics of the Nechako River (i.e., channel morphology, dominant grain size and ultimately the type of aquatic habitat that exists). The linkages also constrain the ability of the river to convey coarse sediment downstream; in particular, gravel and cobble cannot readily be moved through the low gradient, sand-bedded reaches. Finally, and potentially most important to sturgeon spawning habitat, the large sand-bedded reaches provide an almost unlimited supply of sand to downstream reaches where they occur.

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[3] The Kenney Dam raised the water level of these pre-existing lakes to form the Nechako Reservoir.

4.2 History of flow regulation

The post-regulation flow regime of the Nechako River at Vanderhoof is now about 50% of pre-regulation discharge (mean annual discharge 1987-2017 = 119 m^3/s). The substantial out-of-basin diversion has decreased discharge throughout most of the year, although some variation in peak flows still occurs due to environmental conditions and/or reservoir operations. As shown in Table 4.1, the peak daily flow at Vanderhoof has nearly reached, or exceeded the pre-regulation mean annual peak discharge of 658 m^3/s (NHC, 2003a) several times since the onset of flow regulation.

Table 4.1 Years when maximum daily discharge has exceeded 600 m^3/s at Vanderhoof during the post-regulation period (1952-2021).

Year	Maximum daily discharge at Vanderhoof (08JC001)
1952	629 m^3/s
1958	625 m^3/s
1964	600 m^3/s
1976	744 m^3/s
2007	784 m^3/s
2015	693 m^3/s

4.3 Morphological changes

The morphology of the Nechako River has changed in response to flow regulation; however, the general planform of the river has remained remarkably stable since at least the 1940's (NHC, 2018). The primary forms of morphological change that occurred throughout the river and within the Vanderhoof spawning reach include channel narrowing through the encroachment of vegetation, abandonment of secondary channels, and fan growth at tributary confluences (NHC, 2003a, 2018; Rood, K. M. and Neill, 1987). The near complete elimination of ice jams has also presumably dampened the historical disturbance regime of the system, likely contributing to the increase in vegetation and reducing the extent of bed scour and sediment entrainment during jamming events.

Historical imagery of the spawning reach dating back to 1928 shows that morphological change has been ongoing since 1946, including an increase in vegetation within the Island Complex, as deciduous species colonized higher bar tops between 1966 and 1973 and grasses and sedges colonized much broader areas between 1973 and 1985 (NHC, 2018). The lateral stability of the channel also appeared to have increased during this period, evidenced by the reduction in the number of wetted secondary channels between 1946 and 1985.

The morphology of the channel around the Burrard Ave. Bridge has remained fairly stable over time, evidenced by the continued presence of relatively stable bar features as far back as 1928 (NHC, 2018). While a constriction in channel width caused by the bridge could influence upstream hydraulics, the bridge was present well before the onset of recruitment failure[4], indicating that it was not a direct cause of the collapse. While some bridge-related construction did occur around the onset of recruitment failure (e.g., changes to the southern approach in 1968), no major bank modifications could be identified which would have changed the waterway geometry below bankfull flow. Additionally, no morphological evidence was found on the aerial imagery to suggest that local hydraulics or substrate characteristics had been noticeable altered (NHC, 2018).

The primary evidence to suggest that morphological change led to recruitment failure around 1967 is gauge data and station maintenance notes from the WSC gauge (08JC001) located immediately downstream of the Burrard Ave. Bridge (see Figure 2.3). A specific gauge analysis at this site suggests that there was a period of bed instability from the late-1960's to the late-1990's that resulted in a gradual raising of the bed elevation, which may have included shorter cycles of aggradation and degradation (Figure 4.1). Increased sediment deposition during this period is also supported by the gauge maintenance notes stating that there was significant sediment movement throughout the 1970's and 1980's. While the rise in stage observed across all flows is considered most likely to reflect bed aggradation, differences in the stage heights at different flows may provide additional insight into how the properties of the bed and/or channel margins may have changed.

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[4] The southern bridge causeway, which eliminated most of the flow conveyance along the floodplain, predates the earliest aerial photographs taken of the area in 1928.

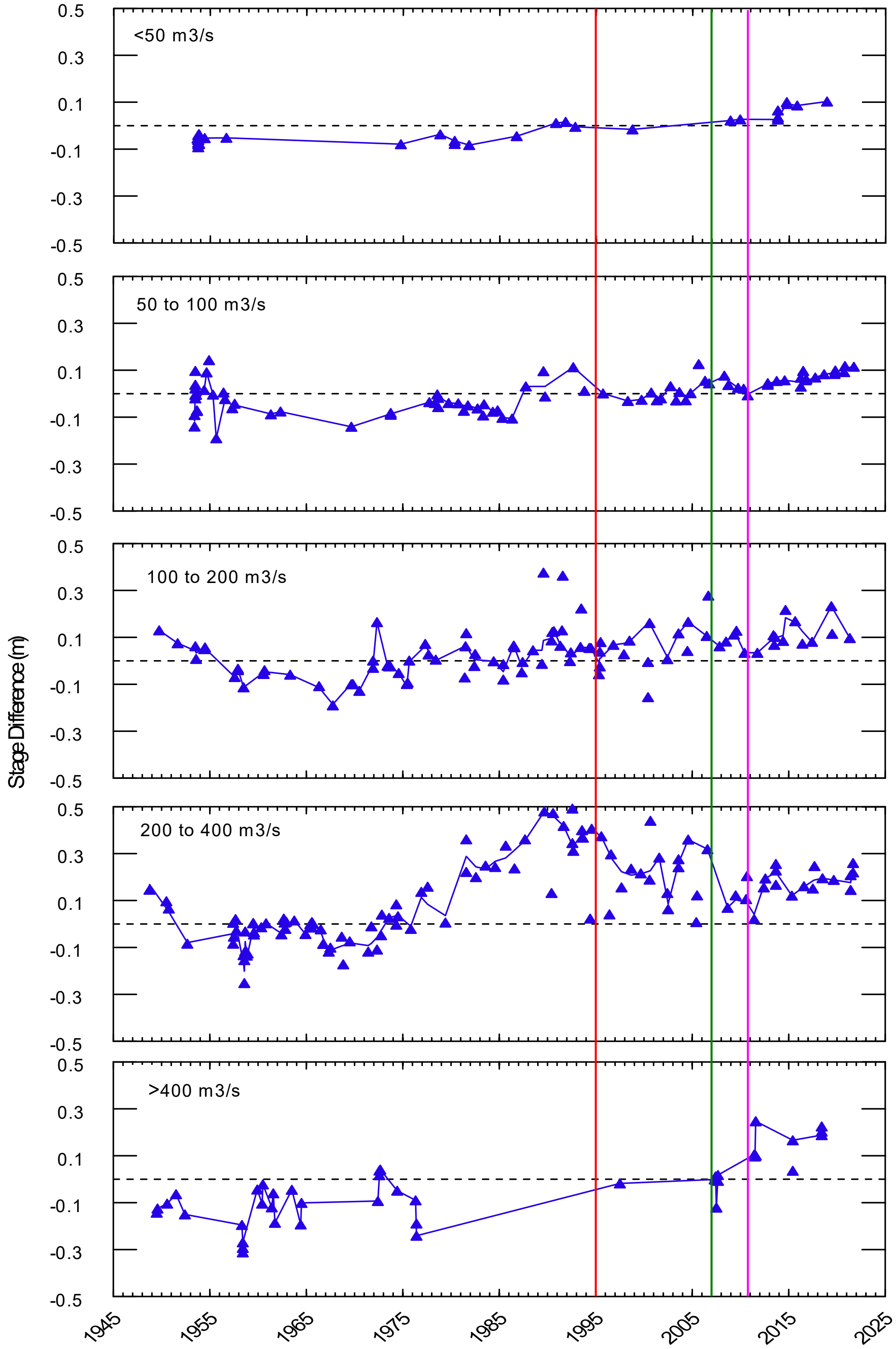

Figure 4.1 **Specific gauge analysis for various flow bands for WSC gauge 08JC001 at Vanderhoof. Loess with a tension of 0.05 is shown. Vertical lines indicate recent recruitment pulses.**

4.4 Hydraulics

Reach-scale hydraulics have been investigated by several studies over the past 15 years (Gauthier-Fauteux, 2017, 2018; NHC, 2006, 2008). The studies have found that the hydraulic gradient through the spawning reach decreases at high flows, which in part explains the depositional character of the reach (NHC, 2006). The flattening of the water surface slope at high flows appears to be caused by the break in channel gradient (0.065% to 0.005%) that occurs approximately 1 km downstream of the Burrard Ave. Bridge, as it appears to create a backwatering effect once flows exceed about 225-275 m^3/s (Gauthier-Fauteux, 2017). This is further supported by two hydrodynamic modelling studies that identify a positive relation between discharge and velocity at the upstream end of the spawning reach, and a negative relation downstream of the Island Complex (Gauthier-Fauteux, 2017; NHC, 2008).

Numerical simulations have shown that as flows increase from 78 m^3/s to 460 m^3/s, the proportion of the total discharge conveyed along the southern (mainstem) channel decreases, as does the peak velocity within it (NHC, 2008). In contrast, velocity within the main secondary channel increases substantially between 78 m^3/s and 460 m^3/s, while changes at higher flows are less remarkable. The limited change in water velocity throughout the reach once discharge exceeds 460 m^3/s indicates that any further increase in discharge is mainly accommodated by an increase in water depth. The maximum shear stress for all simulated flows (75 m^3/s to 775 m^3/s) was also found to vary only within a narrow range, between about 16 N/m^2 and 23 N/m^2 (Gauthier-Fauteux, 2017). Consistent with the previously described backwatering effect, the location of maximum shear stress within the reach (and thus sediment transport capacity) was found to shift upstream from the Middle/Lower Patch to the Upper Site as discharge increases from 45 m^3/s to 375 m^3/s. Above these flows, the spatial distribution of shear stress remained similar but the magnitude of the values increased; the highest shear stresses occur around the Upper Site and downstream of the Burrard Ave. Bridge, with very low shear stresses throughout the middle portion of the spawning reach.

The potential hydraulic effects of the Burrard Ave. Bridge were investigated to determine whether the bridge constriction may have altered reach-scale hydraulics. Gauthier-Fauteux (2018) found that, while local hydraulics near the bridge (i.e., 200 m upstream) are influenced by the bridge constriction once discharge exceeds ~300 m^3/s, simulating a wider channel cross-section at the bridge location does not noticeably reduce the upstream water surface elevation or steepen the hydraulic gradient. This finding suggests that the bridge causeway does not sufficiently constrict the channel to cause large-scale backwater propagation for flows up to 525 m^3/s. Rather, it appears that the flow dynamics upstream of the bridge result from the physical properties of the channel, including the channel geometry, roughness and downstream gradient. This is further supported by the review of historical imagery, which did not identify any major morphological changes around the bridge location that could have significantly reduced the waterway opening during moderately high flows (300 to 500 m^3/s) since 1928 (NHC, 2018).

4.5 Sediment supply

Limited information is available regarding the pre-impoundment sediment transport regime of the Nechako River. However, the amount of gravel being supplied to the mainstem channel was likely low even prior to regulation. This is supported by the lake-headed nature of the system, as coarse sediment produced by the headwater tributaries in the Coast Mountains would have deposited within upstream lakes prior to reaching the main river. In addition, pre-dam aerial imagery taken in 1947 immediately upstream of the future dam site shows that the morphology of the Nechako River resembled that of a sand-bedded river, as evidenced by the presence of scroll bars and dune bedforms similar to those observed within the sand-bedded reach downstream of Vanderhoof (Figure 4.2). The capacity of the river to convey gravel through this reach, as well as the overall sediment load, appear to have been low given the presence of truncated kettle lakes with no appreciable deltaic deposits. The presence of (~50 km) long sedimentary links controlled by non-alluvial features also suggests that the river would have had a very limited capacity to transport gravel past certain locations (e.g., Fort Fraser). Thus, it would appear that gravel was historically supplied to the river through erosion of the upland plateau and the few exposed glaciofluvial deposits along the upper river, as well as through tributaries incised into these same deposits.

Figure 4.2 Air photo (AA1128-0145) taken on 1947-09-16 showing the historic (pre-impoundment) morphology of the Nechako River immediately upstream of the Kenney Dam. Flow is from left to right.

Sediment samples and a continuous turbidity record were used to back-calculate the specific sediment yield for the basin. The sediment yield at Vanderhoof was estimated to be approximately 0.05 Mg/km^2/day, which is below the typical sediment yield for BC watersheds (Church et al., 1989) but similar to other lacustrine landscapes. The sediment transport capacity of the upper Nechako River (i.e., from Cheslatta Falls to Vanderhoof) was estimated by NHC (NHC, 2009) using a 1-D numerical model, producing an estimated transport capacity of between 16,000 m^3/year and 340,000 m^3/year using a mean annual flow at Cheslatta Falls of 83 m^3/s[5]. However, it is important to note that this estimate represents the total transport capacity, and therefore includes both bedload and suspended fines. The average bedload transport rate into the spawning reach was estimated to be 2,000-4,000 m^3/year based on sampling conducted between 2013 and 2017 (NHC, 2014, 2015, 2016a, 2018), although nearly 9,500 m^3 was estimated to have entered the reach during a high flow year in 2015. In addition to bedload, the suspended sediment load in 2014 and 2015 was estimated to be around 17,500 m^3 and 44,000 m^3, respectively, based on a sediment-turbidity rating curve established at the Burrard Ave. Bridge (NHC, 2016a). The higher sediment transport rates observed in 2015 occurred in response to high discharge[6], suggesting that high flow years may result in a net input of sediment to the spawning reach. From these estimates, the ratio of bedload to total load appears to be roughly 12% (+/-5%) on average.

Despite uncertainty in the estimates above, the Nechako River appears to transport relatively little sediment compared to other rivers of the same size in BC. However, this may not necessarily be due to sediment supply limitation, as the estimated sediment loads are in general agreement with the lower bound estimates of transport capacity. Rather, the overall transport capacity and supply may be relatively low within the system. Interestingly, these estimates are somewhat less than, yet comparable to initial sediment input estimates stating that the annual sand supply from 1953 to 1986 was roughly 8,800 m^3/year, with 5,000 m^3 being contributed from valley wall and bank erosion and 3,800 m^3 from tributaries (Rood, 1993).

Historical sediment inputs included sediment that was generated with commencement of spills through the Skins Lake Spillway to the Murray-Cheslatta system. Rood and Neill (1987) estimated that 10 million m^3 of sediment was entrained as the Cheslatta River channel widened and incised 5 to 15 m below the historic floodplain. The authors estimate that 96% of the mobilized material would have been deposited within Cheslatta Lake, leaving 400,000 m^3 of finer sediment to be transported further downstream and into the Nechako River; however, this sediment would have been silt-sized due to the upstream lakes, and thus carried in suspension throughout the Nechako River. A more recent review of aerial photos taken over the last two decades does not show appreciable ongoing erosion along this section of the Cheslatta River.

Additional sediment inputs to the Nechako River have resulted from the Cheslatta River avulsions that occurred between the late 1950's through to 1972. These avulsions contributed an estimated 860,000 m^3 to 1,100,000 m^3 of sediment to the Nechako River (NHC, 2009). While it was initially hypothesized that sediment derived from the Cheslatta avulsions deposited within the spawning reach in the late-1960's to early-1990's (producing the apparent rise in bed level detected by the specific gauge analysis), subsequent numerical modelling showed that the bulk of the Cheslatta avulsion material was more likely to have been retained in the low-gradient, depositional sand-bed reaches upstream (NHC, 2009). Another potential source of fine sediment to the spawning reach is the large sand-bedded reach located

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[5] Mean annual flow based on flow record at WSC 08JC001 (Nechako River at Vanderhoof) and WSC 08JA017 (Nechako River at Cheslatta Falls) from 1962 to 2005.

[6] The maximum daily discharge in 2015 reached 695 m^3/s, representing the third highest daily discharge since the onset of flow regulation; the highest being 785 m^3/s in 2007.

upstream of the Nautley River. Given that this area contains a vast amount of sand (on the order of 10 Mm^3) and has a low upstream channel gradient, relatively minor changes in downstream hydraulic head could mobilize large amounts of material. This hypothesis has not been investigated to date.

While these findings create some uncertainty about the source of the material that deposited near the Vanderhoof gauge (as detected by the specific gauge analysis), the timing of those changes is not in doubt. Nevertheless, a more detailed understanding of river-scale sediment transport processes would be helpful to understand past and future events, and how they may have and/or continue to affect recruitment.

4.6 Sediment transport

A bedload sampling program was initiated in 2013 to investigate the rates and timing of sediment transport within the spawning reach. NHC (2014) found that fine gravel and coarse sand are mobile at relatively low flows, and that cross-channel bedload transport rates are not directly correlated with discharge, local velocity, or local shear stress at all sites. Subsequent evaluation of the reach-wide sediment budget has identified a discharge-mediated imbalance between sediment inputs and outputs, where a positive relationship exists between discharge and bedload transport rate at the Upper Site (with hysteresis detected during high 2015 discharge) and a weak (or negative) relationship exists at the Lower Patch (NHC, 2016a). This finding is consistent with numerical modelling studies showing that the relation between discharge and velocity also transitions from positive to negative in the downstream direction (Gauthier-Fauteux, 2017). Together, these findings imply that the net effects on reach-scale sediment storage may be affected by discharge patterns over multiple years, where high flow years may input a pulse of sediment to the reach (especially within the Island Complex; see paragraph below) that is subsequently transported out of the reach over the course of several years at more moderate rates. However, the factors and/or hydraulic conditions affecting sediment transport past the Lower Patch remain uncertain given the weak relation between discharge at bedload transport and wide scatter in the data. Whether bedload transport rates increase or shift systematically within the lower portion of the spawning reach in response to certain flow conditions and/or periods of the year remains a potential subject for future research.

Sediment sampling programs have also identified spatial patterns in how sediment is typically routed through the reach (Gauthier-Fauteux, 2017; NHC, 2016a). During moderate to high flows, most of the bedload entering the reach is routed through the northern secondary channels of the Island Complex, with comparatively little sediment being transported along the southern mainstem channel. The preferential passage of bedload through the secondary channels likely (or at least partially) explains why the Middle Patch substrate has infilled at a much slower rate compared to the Lower Patch, which is located just downstream of where sediment re-enters the mainstem channel. The location of where the side-channels re-enter the mainstem also appears to explain a spatially consistent lane of high sand transport over the Lower Patch (located 20 to 50 m from the north bank), despite the relatively even distribution of shear stresses across the channel. Additional sampling downstream of the Burrard Ave. Bridge showed that bedload tends to be transported along the inside point bar, with comparatively little sediment conveyed along the outer bank, despite having similar bed material and high shear stress (NHC, 2014, 2018, 2020a). These fine-scale patterns of sediment transport are relevant when evaluating the causes of ongoing recruitment failure and must be considered in the design of effective long-term remediation.

4.7 Substrate composition

Reach-wide substrate sampling and monitoring programs were initiated in 2011 to monitor the condition of the constructed spawning pads and to explore substrate characteristics throughout the reach. Freeze-core sampling and underwater imagery showed that substrates at the upper end of the spawning reach were predominantly composed of imbricated cobbles with less than 10% sand (NHC, 2013). Despite the lack of surficial fines, the quality of interstitial habitat at-depth was limited due to sand infilling the base of the substrate and to the imbricated/tightly-packed arrangement of the cobbles.

Freeze-cores taken at the Middle Patch in 2012 showed that only a small amount of fine sediment had infilled the voids within the upper layer of placed substrate (NHC, 2012, 2013). However, fine sand and organics were found to infill the base of the substrate in some areas. Ongoing monitoring since 2012 indicates that the Middle Patch still provides functional interstitial habitat 10 years after placement, especially in areas that are not commonly exposed to bedload transport (NHC, 2016a, 2021).

Freeze-cores taken at the Lower Patch showed that the placed substrate began to infill with coarse sand and fine gravel shortly after placement (NHC, 2012, 2013). The cores also showed that the native substrate had considerably more medium and coarse gravel than the placed material (which was coarser). Ongoing monitoring has since shown both spatial and temporal variation in the amount of surficial fines (NHC, 2018, 2020a), although the cross-channel pattern of infilling has remained generally consistent with the previously described patterns of sediment transport (i.e., high degree of infilling along lanes of high bedload transport). While several studies have identified areas along the northern margin of the Lower Patch that appear to have remained relatively free of fines, these areas are very localized, small in extent and may still be periodically exposed to sand transport (NHC, 2013, 2018, 2020a).

Freeze-cores collected in 2012 downstream of the Burrard Ave. Bridge showed that the substrate was generally composed of a sandy gravel (NHC, 2013). The gravel framework appeared relatively stable due to the presence of oxidation layers in the profile, suggesting relatively little vertical exchange of the bed material. Additional freeze cores collected in 2017 to investigate the substrate composition at greater depths also showed that the substrate is composed of a sandy gravel, and no evidence was found to suggest that this area historically had a clean cobble-gravel bed. It is possible that a prolonged period of scour could winnow fine sediment from the bed and increase the proportion of coarser gravels on the surface, potentially creating areas with suitable early rearing habitat. Further investigation of whether winnowing of existing substrates may have supported periodic recruitment is warranted.

Overall, a variety of substrate types exist within the spawning reach, including some localized areas where the substrate is composed primarily of coarse gravel and cobble with limited surficial sand. The presence of areas with apparently suitable substrate highlights two key uncertainties. First, is the degree to which small areas of suitable substrate correspond with spawning locations. This also leads to the related question of how we might influence either the location of suitable substrate, or the location of spawning fish, such that they occur at the same location. The second critical uncertainty is the distinction between surficial substrate composition and the quality of interstitial habitats at-depth (i.e., within the subsurface layers). While further biological studies are required, laboratory studies to date show that larvae prefer to hide underneath the surficial layer of grains, and that hydraulic refuges created behind embedded cobbles provide sub-optimal hiding habitat. These findings may explain why the existing substrate does not support recruitment and may be used to specify biological requirements for future restoration design.

5 CONCEPTUAL PLAN (2022)

The highly endangered status of the Nechako White Sturgeon makes it imperative that short-term actions are implemented to restore natural recruitment, while parallel studies (i.e., studies to be identified in this workshop) provide the information required support long-term solutions. As outlined in Table 5.1, future research and restoration activities include biological studies to address various attributes of the egg stage in relation to substrate conditions, as well as a variety of geomorphological studies.

Table 5.1 Summary of biological and geomorphological studies planned for the Nechako River.

Study	Description
Pilot substrate cleaning	Testing a proprietary substrate cleaning mechanism in side-channels to evaluate biological and physical effectiveness (2022).
Medium/large scale substrate cleaning	Conduct experimental cleaning at the Lower Patch at a scale sufficient to influence recruitment. Effects are expected to be temporary due to subsequent infilling (2023, anticipated).
Egg and habitat evaluations	Studies will evaluate factors including how substrate composition affects egg settlement, retention, and dispersion (Ongoing in partnership with UBC).
Environmental influences on spawning location	Evaluation of egg monitoring data from 2004 to present to identify spatial patterns and potential environmental correlates.
Large scale egg releases	Release of ~250,000 fertilized eggs occurred in 2011 and 2021 over the Middle Patch and in 2016 over cleaned areas of the Lower Patch. Future releases are planned to test whether they lead to any detectable recruitment (genetic tags allow eggs to be traced to the parents). Although the number of eggs released appears large, this is still less than the fecundity of one large female, and as a result the expected effect size is low for any single year of study. Conducting this study over multiple years improves our understanding of egg responses to substrate while also, potentially, stimulating recruitment from fertilized eggs placed on known substrate (ongoing).
Substrate infilling and winnowing evaluation	Temporal variation in substrate conditions and responses to discharge will be evaluated using *in-situ* substrate monitoring grids (2022).

The goal of this workshop is to discuss habitat restoration scenarios based on the information provided, assess their feasibility from a biological and geomorphic perspective and identify the knowledge gaps that will need to be addressed to implement effective restoration. To facilitate discussion on potential information needs, some of the potential measures to consider include:

- Repeated substrate addition.
- Repeated habitat remediation (cleaning).
- Enlarging the Middle Patch and using environmental manipulation to promote spawning at that site (or away from sediment transport zones).
- Manipulating discharge to maintain the quality of interstitial habitat (at least locally) during the spawning period.
- Modifying the channel to promote recruitment. This may also be combined with habitat restoration (e.g., channel manipulation to maintain quality of restored substrates).
- Trapping/removing sand bedload upstream of spawning habitat.

Some of the data gaps that may need to be addressed include:

- Environmental factors that affect spawning site selection.
- Relationship between discharge and habitat quality at local scales.
- Sediment sources and/or causes of the apparent aggradation between the late-1960's and early-1990's.
- Conditions and/or processes that led to recruitment pulses in 1994/95, 2007 and 2011.
- Contemporary sediment sources that may affect habitat quality within the spawning reach.
- Historical (and contemporary) effects of ice-jams on habitat quality and gravel supply.
- Effective measures to add and/or remediate spawning substrate.
- Total area of restoration/remediation required to achieve biological goals.
- Optimal (or at least functional) substrate composition to support biological requirements.
- Mobility of placed substrate depending on location; this includes both downstream displacement and *in-situ* "vibration" of the grains that may release infilled fines.
- The rate at which placed/remediated substrate will infill depending on location.
- Optimal locations for substrate addition/remediation.
- Increases in flood risk due to gravel placement.

We anticipate that workshop participants will include members of the Nechako, Columbia, and Kootenay(i) River recovery programs, which will promote the dissemination of any insights to other recovery programs. Participants from academia will hopefully provide insight into specialized knowledge regarding geomorphology studies in particular. Given the goal of identifying additional research studies, the workshop leaders also hope that the discussions will serve as a starting point for mutually interesting research opportunities.

6 REFERENCES

Baker, D. W., McAdam, S. O., Boucher, M. A., Huynh, K. T., and Brauner, C. J. (2014). Swimming performance and larval quality are altered by rearing substrate at early life phases in white sturgeon, Acipenser transmontanus (Richardson, 1836). *Journal of Applied Ichthyology*, 30(6), 1461–1472.

Boucher, M. A. (2012). *The effect of substrate rearing on the growth, development, and survival of larval White Sturgeon (Acipenser transmontanus) during early ontogeny*. M.Sc. Thesis. University of Northern British Columbia, Prince George, BC.

Boucher, M. A., McAdam, S. O., and Shrimpton, J. M. (2014). The effect of temperature and substrate on the growth, development and survival of larval white sturgeon. *Aquaculture*, 430, 139–148.

Boucher, M. A., Baker, D. W., Brauner, C. J., and Shrimpton, J. M. (2018). The effect of substrate rearing on growth, aerobic scope and physiology of larval white sturgeon Acipenser transmontanus. *Journal of Fish Biology*, 92(6), 1731–1746.

Caroffino, D., Sutton, T., Elliott, R., and Donofrio, M. (2010). Early Life Stage Mortality Rates of Lake Sturgeon in the Peshtigo River, Wisconsin. *North American Journal of Fisheries Management*, 30, 295–304.

Church, M., Kellerhals, R., and Day, T. J. (1989). Regional clastic sediment yield in British Columbia. *Canadian Journal of Earth Sciences*, 26(1), 31–45.

EDI (2013). *Recruitment Biochronology of Nechako White Sturgeon*. Final Report. Prepared by EDI Environmental Dynamics Inc. for BC Ministry of Forest, Lands and Natural Resource Operations. 25 + app pp.

Gauthier-Fauteux, S. (2017). *Linking Fluvial Dynamics to White Sturgeon Habitat in the Nechako River, BC.* (M.Sc. thesis). University of British Columbia, Vancouver, BC.

Gauthier-Fauteux, S. (2018). *2018 Hydrodynamic Modelling Nechako River at Vanderhoof, BC*. Draft Report. Prepared by S. Gauthier-Fauteux for Ministry of Environment and Climate Change Strategy. 1–103 pp.

Holland, S. S. (1976). *Landforms of British Columbia: a physiographic outline*.

Koch, T. J., Congleton, J. L., and Anders, P. J. (2006). Effects of sediment cover on survival and development of white sturgeon embryos. *N. Am. J. Fish. Manage.*, 26, 134–141.

Korman, J., and Walters, C. (2001). *Nechako River White Sturgeon Recovery Planning: Summary of stock assessment and Oct 2–3, 2000 workshop*. 31 pp.

Liebe, R., Rublee, B., Sykes, G., and Manson, R. (2004). *Adult white sturgeon monitoring: Nechako River 2004*. Report prepared by Triton Environmental Consultants, Ltd., for Alcan Primary Metals, Kitimat, British Columbia.

McAdam, S. O. (2011). Effects of substrate condition on habitat use and survival by white sturgeon (Acipenser transmontanus) larvae and potential implications for recruitment. *Canadian Journal of Fisheries and Aquatic Sciences*, 68(5), 812–822. doi:10.1139/f2011-021.

McAdam, S. O. (2012). *Diagnosing causes of white sturgeon (Acipenser transmontanus) recruitment failure and the importance of substrate condition of yolksac larvae survival*. University of British Columbia, Vancouver, B.C.

McAdam, S. O. (2015). Retrospective weight-of-evidence analysis identifies substrate change as the apparent cause of recruitment failure in the upper Columbia River white sturgeon (Acipenser transmontanus). *Can. J. Fish. Aquat. Sci.*, 68, 812–822.

McAdam, S. O., Crossman, J. A., Williamson, C., St-Onge, I., Dion, R., Manny, B. A., and Gessner, J. (2018). If you build it, will they come? Spawning habitat remediation for sturgeon. *Journal of Applied Ichthyology*, 34(2), 258–278.

McAdam, S. O., Walters, C. J., and Nistor, C. J. (2005). Linkages between white sturgeon recruitment and altered bed substrates in the Nechako River, Canada. *Trans. Amer. Fish Soc.*, 134, 1448–1456.

Nechako White Sturgeon Recovery Initiative (2004). *Recovery Plan for Nechako white sturgeon*. Prepared by Golder Associates Ltd. 87 pp.

NHC (2003a). *Nechako River Geomorphology Assessment. Phase I: Historical Analysis of Lower Nechako River*. Prepared by Northwest Hydraulic Consultants for BC Ministry of Water, Land and Air Protection, Victoria BC, North Vancouver.

NHC (2003b). *Nechako River Geomorphology Assessment. Phase II: Detailed Analyses of Potential White Sturgeon Habitat Sites* (33683). Prepared by Northwest Hydraulic Consultants for BC Ministry of Water, Land and Air Protection, Victoria BC, North Vancouver.

NHC (2006). *2D Hydrodynamic model development Nechako River at Vanderhoof*. Final Report.

NHC (2008). *Nechako River at Vanderhoof Hydrodynamic Model Upgrade Final Report* (3–4623). Prepared by Northwest Hydraulic Consultants for BC Ministry of Environment, North Vancouver. 39 pp.

NHC (2009). *Upper Nechako River Morphological and Sediment Transport Overview: Final* (34339). Prepared by Northwest Hydraulic Consultants for Nechako Enhancement Society, North Vancouver. 38 pp.

NHC (2012). *Nechako Sturgeon Spawning Gravel September, 2011 Substrate Assessment*. Prepared by Northwest Hydraulic Consultants for Ministry of Forests, Lands and Natural Resource Operations, North Vancouver. 60 pp.

NHC (2013). *Nechako Sturgeon Spawning Gravel: September 2012 Substrate Assessment*. Prepared by Northwest Hydraulic Consultants for Ministry of Forests, Lands and Natural Resource Operations, North Vancouver. 88 pp.

NHC (2014). *Nechako River 2013 Sediment Transport Investigations*. Prepared by Northwest Hydraulic Consultants for the Ministry of Forests, Lands and Natural Resource Operations, North Vancouver BC. 48 pp.

NHC (2015). *2014 Sediment Transport Investigation on the Vanderhoof Reach of the Nechako River*. Prepared for Ministry of Forests, Lands and Natural Resource Operations, North Vancouver. 42 pp.

NHC (2016a). *2015 Sediment Transport Investigation on the Vanderhoof Reach of the Nechako River.* Final Report. Prepared for the Ministry of Forests, Lands and Natural Resource Operations by Northwest Hydraulic Consultants Ltd., North Vancouver, BC. 69 pp.

NHC (2016b). *Spawning Substrate Restoration on the Nechako River at Vanderhoof, BC.* Final Report. Prepared for Ministry of Forests, Lands and Natural Resource Operations, North Vancouver. 35 pp.

NHC (2018). *2017 Nechako River Geomorphology Report.* Draft Report. Prepared for the Ministry of Forests, Lands, Natural Resource Operations and Rural Development by Northwest Hydraulic Consultants Ltd., North Vancouver, BC. 83 pp.

NHC (2020a). *Nechako River White Sturgeon 2019 Spawning Substrate Assessment and Monitoring*. Draft Report. Prepared for the Ministry of Forests, Lands, Natural Resource Operations and Rural Development by Northwest Hydraulic Consultants Ltd. 1–29 pp.

NHC (2020b). *Review of changes in hydraulic geometry using WSC data on the Nechako River*. Prepared for Rio Tinto Alcan by Northwest Hydraulic Consultants Ltd., North Vancouver, BC. 98 pp.

NHC (2021). *Nechako River White Sturgeon 2020 Spawning Substrate Restoration and Monitoring*. Final Report. Prepared by Northwest Hydraulic Consultants Ltd. for the Ministry of Environment and Climate Change Strategy. 1–61 pp.

Paragamian, V. L., Kruse, G., and Wakkinen, V. (2001). Spawning Habitat of Kootenai River White Sturgeon, Post-Libby Dam. *North American Journal of Fisheries Management*, 21(1), 22–33.

Rice, S. (1999). The nature and controls on downstream fining within sedimentary links. *Journal of Sedimentary Research*, 69(1), 32–39.

RL&L (2000). *Fraser River White Sturgeon Monitoring Program - Comprehensive Report (1995 to 1999).* Final Report Prepared for BC Fisheries. RL&L Report No. 815F. 92 p + app. pp.

Rood, K. M. (1993). *Identification and ranking of sources contributing sediment to the Upper Nechako River* (NFCP 89-03). Final. Prepared by Ken Rood & Associates for Nechako Fisheries Conservation Program.

Rood, K. M., and Neill, C. R. (1987). *A study of some aspects of the geomorphology of the Nechako River*. Prepared by Reid Crowther & Partners Ltd. and Northwest Hydraulic Consultants Ltd. for Fisheries and Oceans Canada, Vancouver, BC. 84 + app. pp.