2015 SEDIMENT TRANSPORT INVESTIGATION ON THE VANDERHOOF REACH OF THE NECHAKO RIVER

FINAL REPORT

Prepared for:

Ministry of Forests, Lands and Natural Resource Operations
4051 18th Avenue
Prince George BC V2N 6H2

31 January 2016

NHC Ref. No. 3000854

northwest hydraulic consultants
water resource specialists

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- Neil Heron
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NOTIFICATION

CITATION

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EXECUTIVE SUMMARY

The onset of flow regulation in the early 1950's, as well as major tributary avulsions, have altered the flow and sediment regimes of the Nechako River causing notable geomorphic change. Juvenile white sturgeon production has declined in conjunction with these changes and has been attributed to the infilling of spawning beds with fine sediment (McAdam *et al.*, 2005). A critically important spawning reach was identified at Vanderhoof and a series of investigations have been conducted to assess the historical and contemporary characteristics of the reach. As part of the ongoing Nechako sturgeon recovery effort, the sediment sampling program developed by Northwest Hydraulic Consultants Ltd. (NHC) in the spring of 2014 was once again implemented in 2015.

The exceptionally high flow experienced in 2015, representing the third largest annual maximum daily discharge since 1952, presented an excellent opportunity to refine our understanding of sediment dynamics within the reach. Bedload and suspended sediment was sampled intensively from March to October with the help of Carrier Sekani Tribal Council, Nechako White Sturgeon Conservation Center and MFLNRO staff. To supplement this data, underwater imagery was taken to assess the availability of suitable larval habitat within the spawning area. In addition, we conducted a reach-scale survey to collect velocity, bathymetry and bankline topography data.

The 2015 suspended load was used to back-calculate a basin sediment yield of 0.05 Mg/km^2/day. This input rate plots below the lower limit of the normal trend for BC watersheds, similarly to other lacustrine landscapes. Data suggests bedload is roughly 12% (±5%) of the total load at Vanderhoof, and average bedload transport rate from the last 3 years was 3,400 m^3/annum. Our revised estimate translates to a total basin yield of about 170,000 m^3 of bedload sediment over the past 50 years, an order of magnitude less than previous estimates obtained by assuming basin yield is 0.7 Mg/km^2/day and bedload is 10% of total load. The later was simply based on regional sediment yield maps from historic observations on unregulated rivers, and the discrepancy emphasizes the benefit of direct site observations.

Year	Bedload sediment transport (m^3/annum)		Suspended sediment transport (m^3/annum)	
	Upper Site	Lower Patch	Left Bank Sensor	Center Pier Sensor
2013	1,050	3,500	-	-
2014	750	2,750	17,400	-
2015	9,250	3,050	33,550	44,100
Average	3,700	3,100		

Bedload transport was higher at the Upper Site than the Lower Patch resulting in the storage of 6,200 m^3 of sediment within the reach. This imbalance suggests high flow years may input a pulse of sediment that becomes stored within side-channels and transported downstream at a much slower rate. This dynamic is logical because backwatering during high flow extends about 1.5 km upstream of the

Burrard Avenue Bridge, causing the deposition of bedload midway through the reach. Bedload transport is more variable at the Upper Site than at the Lower Patch because Upper Site transport rates increase with discharge rather than being moderated by backwatered flow. However, when averaged over time, our estimates indicate that bedload yield through the reach is between 2,000 m^3 and 4,000 m^3 per year. It is unclear what this dynamic looked like in the pre-regulation period as peak flows would have been higher and even more material would be expected to deposit in the upstream area.

During the summer of 2015 the bedload transport rate at the upper site behaved in a hysteretic manner indicating that the availability of bedload sediment within the channel became limited during the high flow period. Bedload material was almost entirely sand finer than 2 mm and no trend was observed between grain size and discharge or transport rate. On account of the magnitude of the 2015 flood, and the minimum amount of coarse material that moved, it is unlikely that coarse material will be mobilized and provide suitable interstitial habitat during any post-regulation flood.

The 2015 suspended sediment load was at least double that of 2014. Three periods of high transport occurred corresponding to freshet, bankfull and overbank conditions. Most of the annual load was transported during the period of peak flow. Cross-channel variation in sediment concentration confirms that Murray Creek significantly influences mainstem concentration during freshet by increasing the load by approximately 20%.

Geomorphic changes detected by digital elevation model (DEM) differencing are highly uncertain at this point, however they do suggest a depositional trend in the downstream portion of the reach. Considerable uncertainty arises as a product of differencing two interpolated elevation models and additional uncertainty analysis based on survey point density would be needed to assess significance of change. Consequently, at this time, reliable change detection is limited to areas that were repeatedly surveyed with high point density. Two such areas include the confluence of Murray Creek and the northern side-channel upstream of the Lower Patch, where the deposition detected by DEM differencing is supported by good data coverage and field observations.

Underwater images show that the bed has remained generally consistent with previous observations and trends. The Lower Patch continues to infill especially within the width of the channel actively conveying bedload downstream, while the Middle Patch remains in good condition. The gravel bed towards the right bank of the Lower Patch was relatively free of fines, as were several pools further upstream. These locations would have provided suitable substrate habitat during the spawning period. However, spawning activity was mostly detected downstream of the island complex within the sand-bedded channel. This spawning area contains the deepest pools of the entire reach, which would have been over 6.5 m deep during spawn.

A sediment cleaning plan is currently being developed for the Nechako to immediately improve the quality of larval habitat at the Lower Patch and to determine the feasibly of this approach towards remediation. The task will need to be performed in April, between ice-off and the onset of sturgeon movement towards the spawning reach in May. Given the site-specific context and goals of the operation, we have identified mechanical cleaning and hydraulic cleaning as two potential techniques which may be used. Of these alternatives, we believe mechanical cleaning is most appropriate.

We recommend the following actions take place in 2016:

- Mechanically remediate the Lower Patch using a 4x4 Walking Excavator
- Sample bedload at the Lower Patch regularly to monitor output of stored sediment and transport over the remediated surface
- No longer sample bedload at the Upper Site unless exceptional flows occur
- Only sample suspended sediment during key periods
- Collect underwater images of the Lower Patch regularly to determine changes in the quality of remediated substrate
- Sample bedload along a new transect downstream of the Burrard Ave. Bridge during the remedial work to help assess the impacts of the work
- Continue to monitor turbidity using the Center Pier sensor and consider temporarily installing a sensor during the remedial work to assess turbidity caused by the construction activity. The primary purpose will be to demonstrate the effect of the cleaning for future permitting activities.

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1 INTRODUCTION

Local hydraulics and bedload sediment transport are key determinants of white sturgeon (*Acipenser transmontanus*) survival during early life stages. Although descriptions of spawning habitat have included a wide range of substrates, it has been shown that small to mid-sized gravel (12-50 mm) free of fine sediment allows for rapid interstitial hiding, decreased predation and increased initial survival over other substrate types (McAdam, 2011). If the gravel substrate has been infilled or covered by sand, larvae cannot access pore spaces and are forced to drift pre-maturely which results in higher predation and decreased survival (Kock *et al*., 2006; McAdam, 2011; Bennett *et al*., 2007).

Flow regulation often imposes new flow and sediment regimes which produce relatively rapid geomorphic change that contrasts with the above description of suitable larval habitat (Church, 1995; Paragamian *et al*., 2001; McAdam and NHC, 2003b). In the Nechako system, reduced freshet discharge and sustained sediment input have caused weaker sediment sorting within the channel, a reduction in bedload grain size and the deposition of fines overtop formerly coarse bars (NHC, 2009; McAdam and NHC, 2003a). The decreased availability of suitable incubation habitat within this system has exacerbated naturally high rates of larval mortality to the point of chronic recruitment failure (McAdam *et al*., 2005; McAdam and NHC, 2003b).

As part of ongoing evaluations of the recovery approaches, the Ministry of Forest, Lands and Natural Resource Operations (MFLNRO) placed coarse cobble-gravel substrate in two known spawning locations in the Nechako River at Vanderhoof, BC during May of 2011. Significant sections of the spawning pads have since infilled especially in areas where sand is actively transported as bedload overtop the immobile gravel and cobble (NHC, 2012; NHC, 2013; NHC, 2014). The present 2015 Sediment Transport Investigation was conducted to supplement and refine previous research by reassessing the condition of the spawning pads, improving the quantification of bed and suspended sediment loads, characterizing the spatial and temporal pattern of sediment transport and identifying significant changes in channel morphology. By chance these studies occurred during a year with a large long flood, which made conditions ideal for advancing the knowledge of sediment transport within the sturgeon spawning reach.

1.1 Background

Development of the Kemano Project in the early 1950's altered the flow regime throughout the Nechako River. Past studies (e.g. McAdam and NHC, 2003a) have identified major geomorphic changes that include vegetation encroachment, the loss of seasonally wetted floodplain and floodplain channels, the reduced ability to transport locally recruited and externally-supplied sediment, the mass mobilization and deposition of sediment from the Cheslatta Fan avulsions, and an increase in flow through the Murray-Cheslatta system.

In conjunction with the changes in flow and sediment supply, there has been a reduction in juvenile white sturgeon production. The low number of juvenile sturgeon has been attributed to changes in spawning habitat, and in particular, the infilling of spawning beds with fine sediment (McAdam *et al*., 2005). A critically important spawning reach has been identified at Vanderhoof (**Error! Reference source not found.**) and a series of investigations have been conducted to assess the historical and contemporary characteristics of the reach. These investigations have revealed the following:

- The spawning reach occurs at a distinct reduction in channel gradient (0.06% upstream to 0.03% downstream (NHC, 2006)).
- Construction of the south causeway to the Burrard Avenue Bridge eliminated floodplain conveyance and reduced channel width promoting the deposition of fine sediment upstream of the bridge (NHC, 2006).
- The Cheslatta fan avulsions that occurred between the late 1950's and 1972 introduced 0.86 to 1.1 million cubic meters of sediment to the Nechako River (NHC, 2009).
- The substrate at the top of the reach is imbricated cobble-gravel while the substrate at the downstream end of the reach is gravel-sand.
- Spawning substrate at the Lower Patch began to infill soon after placement in 2011 due to the advancement of bedload sheets possibly originating from the island complex. Substrate at the Middle Patch remained largely clear of bedload transport and infilling (NHC, 2012).
- The pattern of bedload transport corresponds well with observed infilling of spawning substrate and coarse sand is mobile at the Burrard Avenue Bridge during relatively low flows (NHC, 2012; NHC, 2013).
- Greater bedload transport past the Lower Patch suggests within channel storage and reworking of sediment influences transport rates, but the timing and magnitude of sediment being input to the reach was unclear (NHC, 2014; NHC, 2015).
- The majority of the suspended sediment seems to be supplied during the freshet period however results may be biased by Murray Creek (NHC, 2015).
- The ratio of bedload to total load in 2014 was 5% for the Upper Site and 14% for the Lower Patch, straddling the 10/90 percent split commonly expected in gravel-bed rivers (NHC, 2015).

In summary, the spawning reach at Vanderhoof is located in an area with a marked change in channel gradient that promotes the deposition of sand and gravel sediment that originates from the upstream watershed. Flow regulation and channel confinement have likely increased the deposition of sediment in the reach. This indicates a general agreement with the hypothesized negative effect of fine substrate deposition on recruitment and suggests that understanding the sediment dynamics is critical to recovery action.

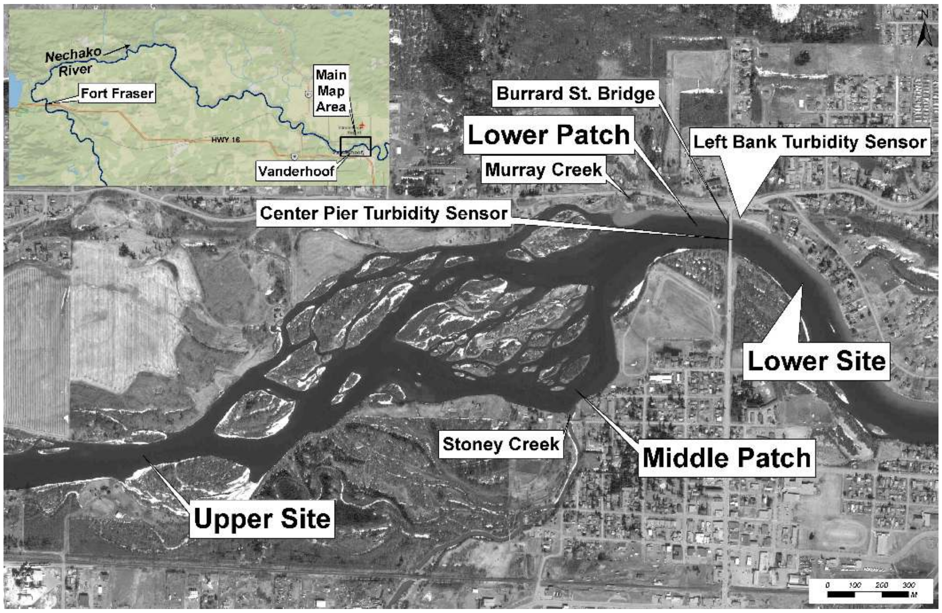

Figure 1 Nechako River at Vanderhoof BC. Spawning substrate was placed at the Middle and Lower Patch while the Upper and Lower Sites are composed of native substrate.

1.2 Study Rationale and Approach

The general research objectives of Nechako Sediment Transport Investigations are to quantify the bedload and suspended sediment load moving through the reach, characterize the spatial and temporal pattern of transport, assess physical changes to the spawning substrate and identify changes in channel morphology. Specific objectives in 2015 were the following:

1) Estimate the total 2015 bed and suspended sediment loads
2) Determine the cause of the apparent imbalance between upstream and downstream sediment transport rates
3) Determine whether bedload sediment becomes supply limited during peak flow
4) Refine bedload-discharge rating curves for the Upper Site and Lower Patch
5) Refine the suspended sediment-turbidity rating curve and compare data collected by the Left Bank and Center Pier turbidity sensors
6) Quantify the impact of Murray Creek on mainstem Nechako suspended sediment concentration
7) Produce detailed maps of reach elevation, bathymetry, velocity and morphological change.

To accomplish these objectives, an intensive sampling program began immediately after ice-off on March 20th and lasted until flows receded below 45 m^3/s on October 17th, 2015. Fortunately, our sampling effort coincided with an exceptionally high flow year providing an excellent opportunity to refine our understanding of reach dynamics. Sampling priority was placed on suspended sediment during tributary freshet and on bedload transport during the period of peak Nechako flow. In addition, a reach-scale survey was conducted to collect data about flow velocity, channel bathymetry and bankline topography. Lastly, underwater images were taken in several locations throughout the reach to assess the availability of suitable larval substrate.

2 METHODS

2.1 Bedload Sampling

Bedload transport was sampled across the Upper Site and Lower Patch transects at evenly spaced intervals spanning the entire channel width (Map 1). The detailed sampling program is provided in previous reports (NHC, 2015) and 2015 bedload data is summarized in Appendix A.

In brief, a Helley-Smith sampler (Figure 2) with a 76.2 mm wide opening and 0.125 mm mesh bag was used to collect one sample from each vertical over a duration of 5 minutes. If transport rates were exceptionally high and the bag became full, additional samples were collected over shorter duration periods. To deploy the sampler, the boat was held in place using an anchor and the sampler was slowly lowered onto the bed. The rope was left slack and monitored to ensure there was no risk of the sampler being dragged due to lateral boat movement. During the period of peak flow, a larger Helley-Smith (Elwha River Sampler) with a 190.5 mm wide opening was used to reduce bias and under-sampling of coarse grains within the bedload. The Lower Patch sampling transect was originally established across the upstream portion of the spawning pad; however, due to concurrent biological research programs during the 2015 spawning period, the transect was temporarily displaced approximately 70 m in the upstream direction. All 2015 bedload samples were dried and individually weighed. Approximately half of the samples were then sieved at the UBC Geography Biogeomorpholgy Lab using ½ phi sieves. For the purposes of this report, grain size classification is based on the length of the b-axis, or the intermediate axis perpendicular to the longest axis. Grain size texture is defined using the Wentworth scale in Table 1.

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Figure 2 Helley-Smith sampler collecting a bedload sample in 2015.

Table 1 Wentworth grain size scale.

Length of b axis (mm)	ϕ (phi)	Wentworth grain size scale
>256	<-8	Boulder
64 - 256	-6 – -8	Cobble
32 - 64	-5 – -6	Very Coarse Gravel
16 - 32	-4 – -5	Coarse Gravel
8 - 16	-3 – -4	Medium Gravel
4 - 8	-2 – -3	Fine Gravel
2 - 4	-1 – -2	Very Fine Gravel
1 - 2	0 – -1	Very Coarse Sand
0.5 - 1	1 – 0	Coarse Sand
0.25 - 0.50	2 – 1	Medium Sand
0.125 - 0.250	3 – 2	Fine Sand
0.064 - 0.125	4 – 3	Very Fine Sand
0.0039 - 0.064	5 – 4	Silt
<0.0039	> 5	Clay

2.2 Suspended Sediment Sampling and Turbidity

Suspended sediment samples were collected across the Burrard Ave. Bridge at equally spaced distance intervals. The detailed sampling program is provided in previous reports (NHC, 2015) and 2015 suspended sediment data is summarized in Appendix B.

In brief, samples were collected with a Bridge Crane and D-74 depth integrating sampler (Figure 3). The winch on the crane, known as a B-reel, uses a brake shoe that is pressed against a brake pad to control the rate of descent and a crank to retract the cable. Target transit rate varied from 0.15 m/s to 0.25 m/s depending on stage and velocity. Nozzle size was selected to prevent overfilling of the sample bottles. Samples from each day were combined and sieved at the UBC Geography Biogeomorpholgy Lab. Samples collected on March 20th and 27th were not combined prior to sieving to isolate the channel section affected by Murray Creek.

Turbidity was continuously monitored by two Analite® turbidity sensors. The first sensor was located several meters from the left bank while the second was installed directly on the south side of the middle bridge pier (Figure 1). The data signal from both sensors periodically became fouled and required maintenance mainly due to the accumulation of vegetation and debris on the sensor. The Center Pier sensor appears to be less susceptible to fouling and bias from Murray Creek and therefore the Left Bank sensor has been discontinued. Center Pier sensor malfunction began on July 20th and it was subsequently replaced by installing the Left Bank sensor on the Center Bridge Pier on October 15th.

Figure 3 Suspended sediment sampler and bridge crane.

2.3 Underwater Imaging

Images of the substrate were taken across the Upper Site and Lower Patch transects, as well as at several exploratory locations within the reach (Map 1). Images were collected using a downward oriented Shark Marine underwater camera mounted to a weighted tripod. As such, the length scale within the field of view was maintained to enable grain size classification. The time period when substrate imagery could be collected was restricted to the latter portion of the flow year as high velocity and turbidity prevented clear imaging. The underwater imagery presented in this report was taken on July 3rd, 2015 at a discharge of approximately 450 m3/s.

2.4 Bathymetric and Topographic Surveying

Bathymetry was surveyed using a Trimble Real-Time Kinematic (RTK) GPS mounted to a survey-grade SonarMite echo sounder. This setup allows for simultaneous collection of depth and water surface elevation data. Geodetic Control Marker (GCM) 653659 located south-east of Vanderhoof was used to position the GPS base station near the Nechako White Sturgeon Conservation Center. The survey data was post-processed by shifting base station coordinates to match the Northing and Easting obtained from Natural Resources Canada PPP results averaged over 33 hours of data logging. Base station elevation was taken from the PPK baseline observation using GCM 653659 (5 min observation). Data was collected over 4 days, from May 12th to 15th, 2015. An additional 6 days in September were spent surveying bankline and island topography during low-flow conditions.

2.5 ADCP Velocity Profiles

An RDI RiverRay Acoustic Doppler Current Profiler (ADCP) was used to collect velocity profiles and discharge estimates across 9 transects distributed throughout the reach. Transects were selected to determine the velocity pattern and proportional discharge being conveyed through different channels. The RTK GPS head was mounted to the ADCP raft and used to feed real-time position into the ADCP software via Bluetooth in order to determine whether moving bottom conditions were present. This is required as the ADCP software assumes the bed is stationary, so a measurement taken with a stationary boat appears to be slowly moving upstream if sufficient bedload is being moved.

Although not presented in this report, results for the ADCP will be used to develop, calibrate and validate a hydrodynamic model that incorporates sediment transport. Reach-scale velocity and near-bed shear stress maps will also be produced for general reference and to provide insight into the availability of different hydraulic conditions for spawning and larval fish. The model will be presented to the Nechako White Sturgeon Recovery Initiative as part of Simon Gauthier-Fauteux's MSc thesis.

3 RESULTS

3.1 Stage-Discharge Rating Curve

Stage and discharge measurements taken in 2015 by the Water Survey of Canada (WSC) were used to refine the high flow portion of the NHC stage-discharge rating curve developed in 2014 (NHC, 2015) (Figure 4). High flow measurements were taken during April and May of 2015 reaching a maximum measured discharge of 578 m^3/s. The rating curve shift applied in 2014 to account for apparent aggradation of the reach was maintained in 2015 because low flow measurements between 200 m^3/s and 480 m^3/s continue to plot in agreement. The curve-derived discharge time-series was corrected to remove all ice effects occurring from 2013 to present and shows good agreement with WSC measured discharge values (Figure 5). In 2015, daily discharge reached a maximum of 676 m^3/s on June 6th. This is the third highest annual daily discharge since the onset of flow regulation in 1952 (Figure 6); the highest being 786 m^3/s in 2007.

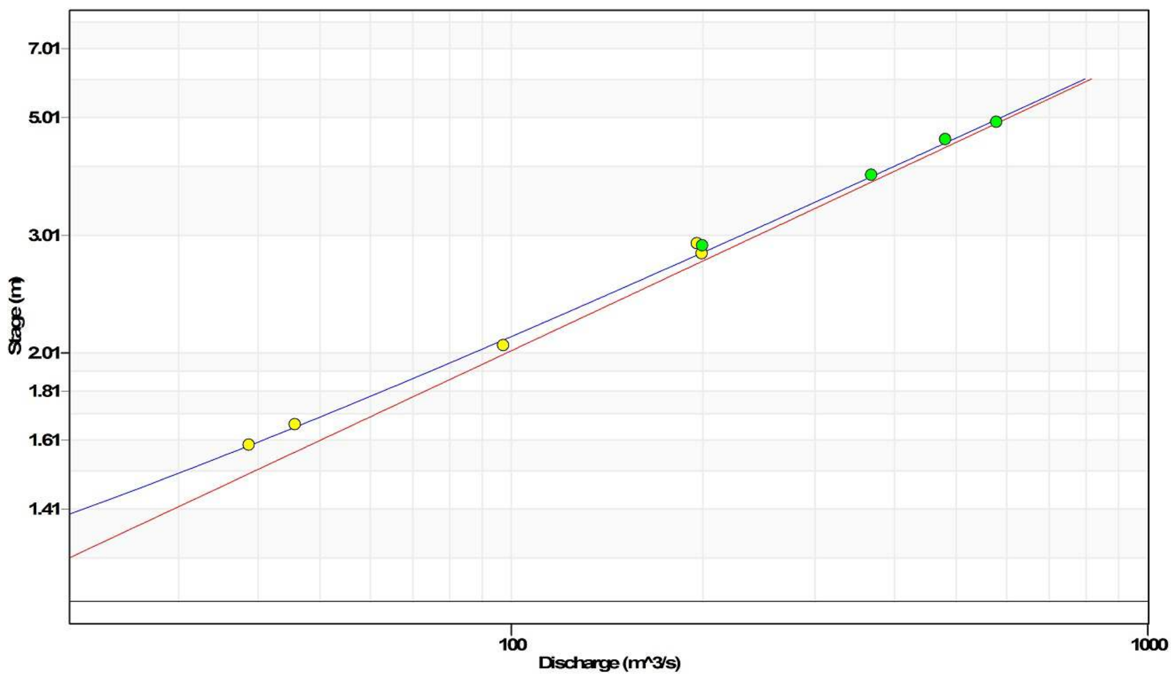

Figure 4 NHC stage-discharge rating curve shown in blue, WSC curve in red. Measurements taken during 2014 and 2015 are shown in yellow and green, respectively.

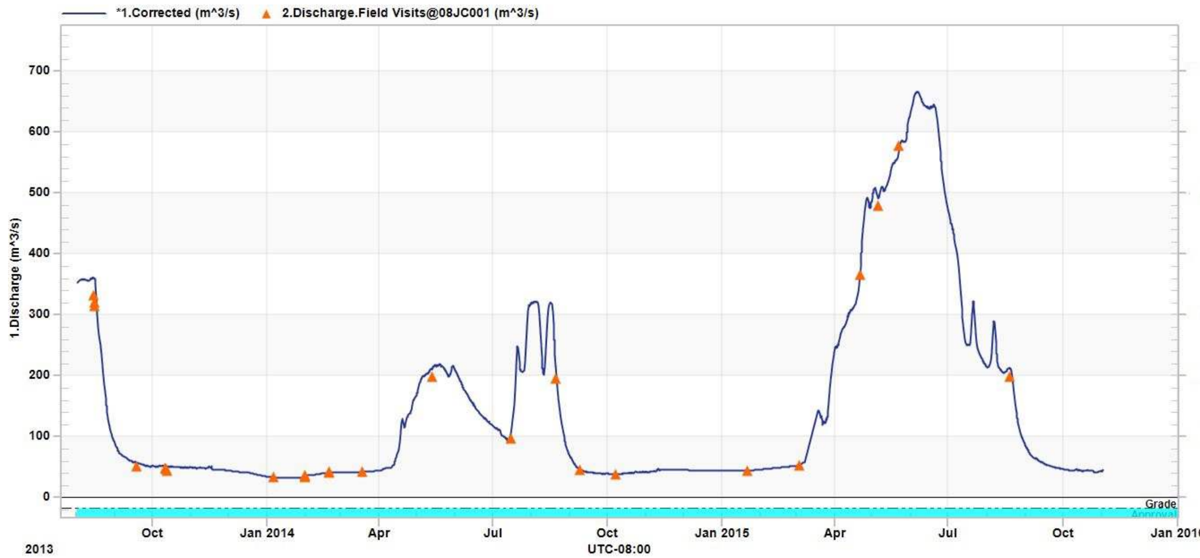

Figure 5 NHC rating curve derived discharge time-series compared to WSC measured values.

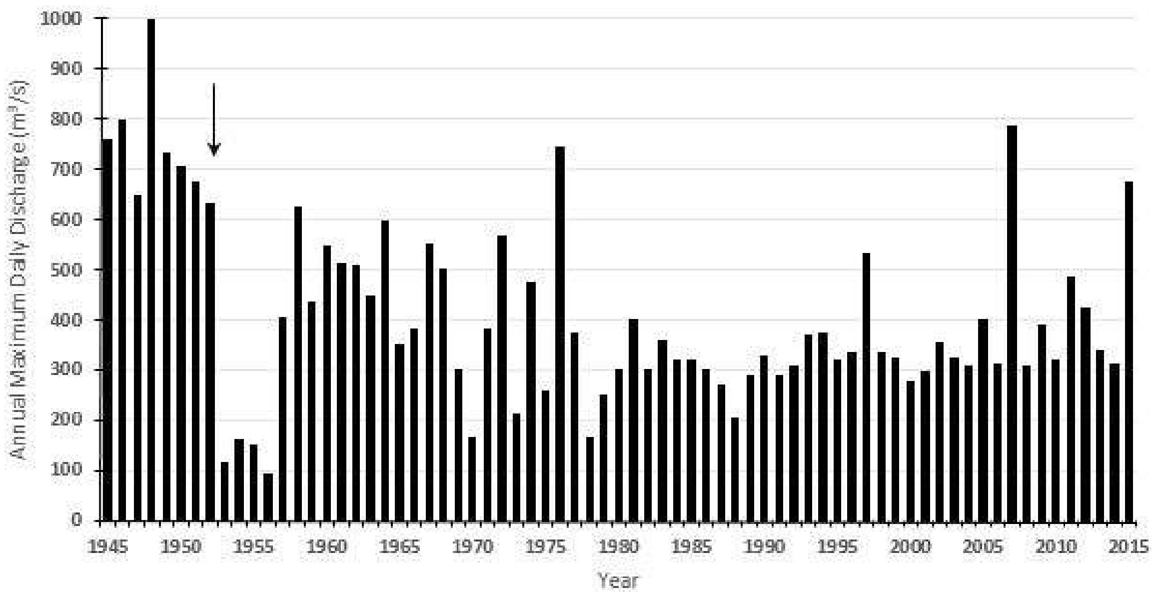

Figure 6 Annual maximum daily discharge for the Nechako River at Vanderhoof. Arrow indicates the onset of flow regulation.

3.2 Bedload Sediment Transport

Data collected at the Upper Site suggests that the supply of bedload sediment became limited during the period of peak annual flow in June. This supply limitation is shown by the hysteresis in Figure 7, where sediment transport declines at a greater rate per unit discharge during the receding limb of the hydrograph. Two separate bedload-discharge rating curves were developed for the Upper Site in order to accurately represent these different transport rates. The rising and falling limb rating curves were applied to the 2013, 2014 and 2015 hydrographs to obtain the annual estimates of sediment transport in Table 2. Predicted daily bedload transport at the Upper Site is in surprisingly good agreement with measured values given the inherent variability associated with sediment transport processes (Figure 8).

Bedload transport at the Lower Patch showed no clear relation with discharge and therefore no rating curve could be used to derive the 2015 annual sediment load (Figure 9). Rather, the estimated 3,050 m^3 in Table 2 was calculated by interpolating daily transport rates between sampled days. The Lower Patch bedload rate remained relatively constant between 100 and 300 g/s/transect for the majority of 2015 until the greatest transport rate of 1,384 g/s/transect was sampled on August 31st at a discharge of approximately 80 m^3/s. The inverse relation between transport rate and discharge occurs because local velocity and bed shear stress are decreased during high flow as a result of backwatering upstream of the Burrard Avenue Bridge (NHC, 2008).

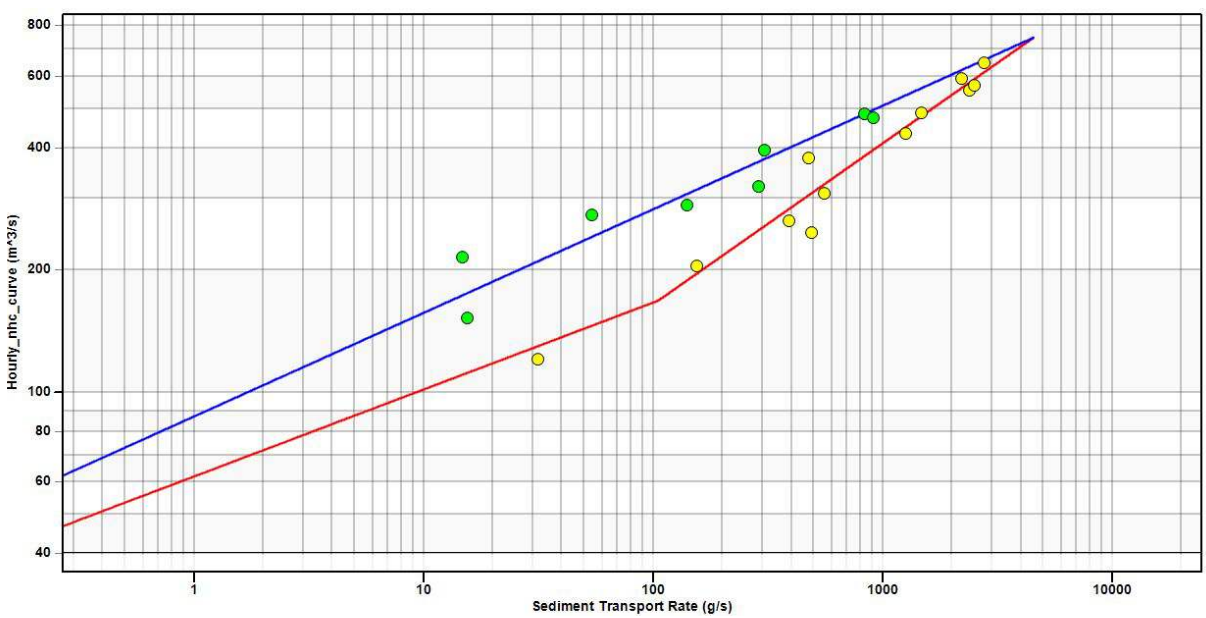

Figure 7 Bedload rating curve developed for the Upper Site showing hysteresis. Transport rate during the rising limb of the 2015 hydrograph is shown in red, transport during the receding limb in blue.

Table 2 Summary of estimated annual sediment transport rate.

Year	Bedload sediment transport (m³/annum)		Suspended sediment transport (m³/annum)	
	Upper Site	Lower Patch	Left Bank Sensor	Center Pier Sensor
2013	1,050	3,500	-	-
2014	750	2,750	17,400	-
2015	9,250	3,050	33,550	44,100
Average	3,700	3,100		

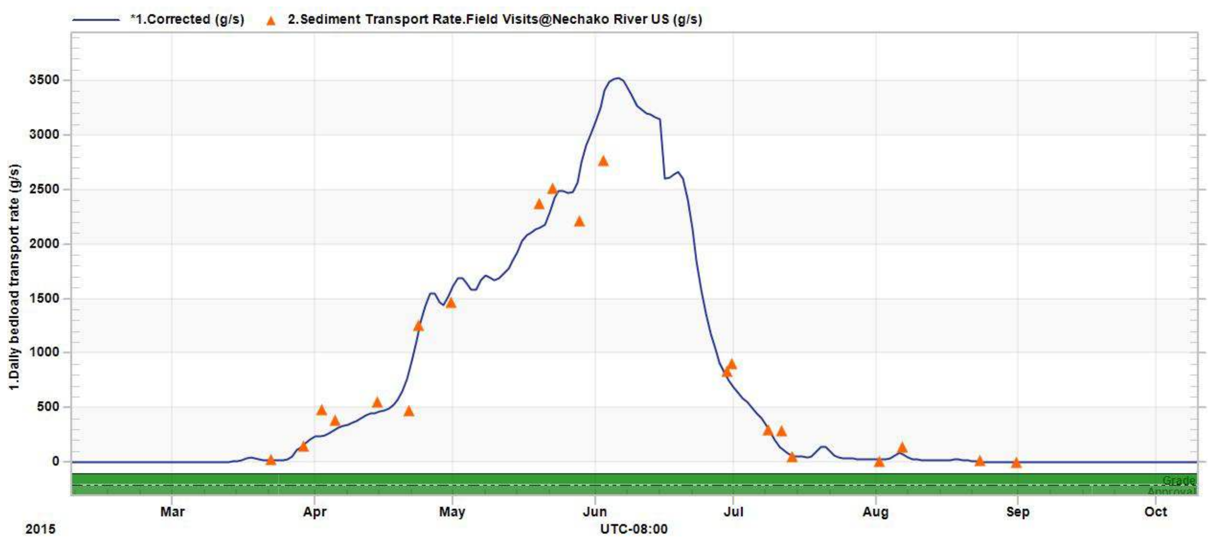

Figure 8 Predicted versus observed bedload transport rate at Upper Site in 2015.

The maximum daily bedload transport rate is predicted to have been roughly 2.5 times greater at the Upper Site than Lower Patch (Figure 10), translating to values of 190 m^3/day and 75 m^3/day respectively. The daily bedload rate at the Upper Site exceeded 75 m^3/day for 61 consecutive days between April 25th and June 24th, 2015. The significant difference in bedload transport between the upstream and downstream extent of the reach suggests 6,200 m^3 of sediment has been stored within the reach in this year (Table 2). This net storage is interesting because previous years have observed the opposite trend with more sediment being output from the reach than input (NHC 2014; NHC, 2015).

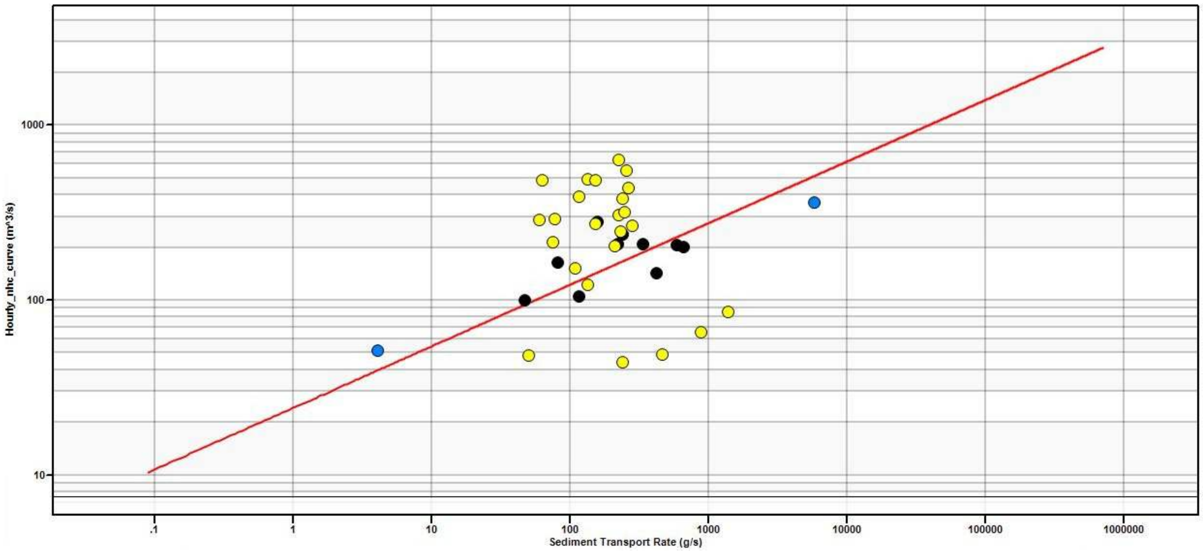

Figure 9 Bedload transport at the Lower Patch showing no clear relation with discharge in 2015. Samples taken in 2015 are yellow, 2014 are black and 2013 are blue. The rating curve used in 2014 is shown in red.

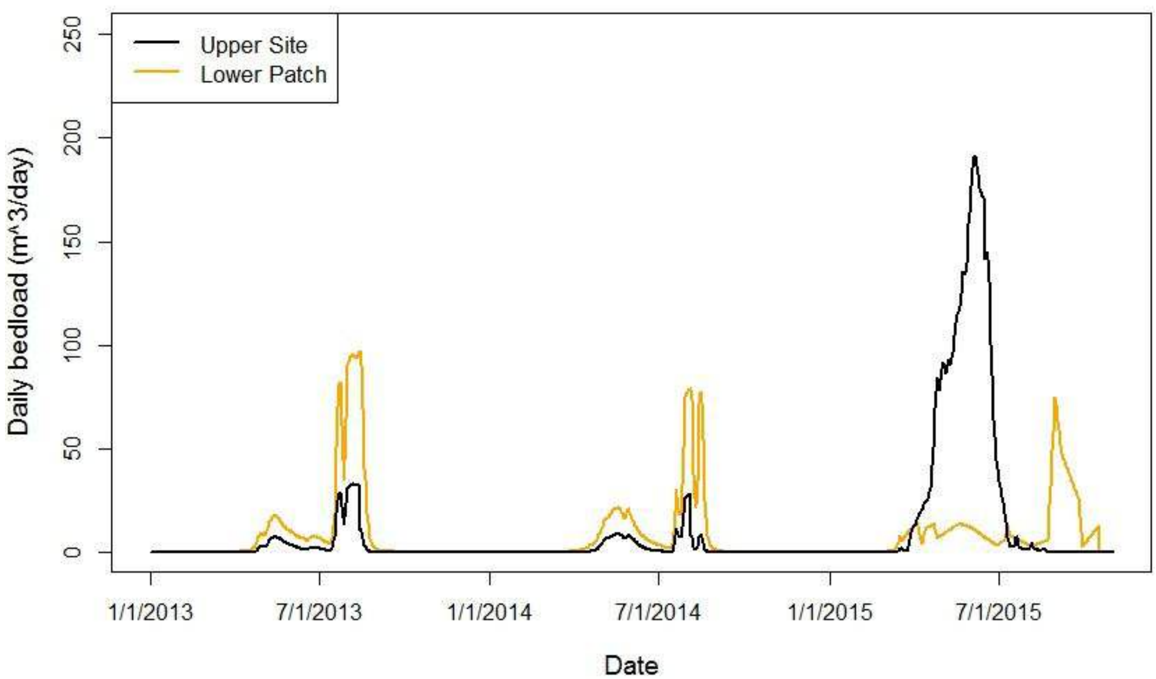

Figure 10 2013-2015 daily bedload at Upper Site and Lower Patch.

The location of highest sediment transport past the Lower Patch has remained fairly consistent over time (NHC, 2014). Figure 11 plots the site with the highest sampled bedload per field visit from 2013 to 2015, omitting the 284.42 g/m/s sampled near Site LP 5 on August 15th, 2013. The majority of bedload seems to be transported past the Lower Patch within a 40 m wide portion of the channel between LP 2 and LP 6, with sites LP 3 and LP 4 most frequently conveying the largest amount. Site LP 3 also transports the greatest magnitude of bedload, however the three highest rates were sampled between August 31st and September 26th, 2015 within a very narrow overall active width. Therefore, it seems reasonable to conclude that most bedload transport occurs at Sites LP 3, LP 4 and LP 5 at rates of 10 to 25 g/m/s during periods of high transport.

The grain size of the bedload sediment does not show a clear relation with increasing transport rate (Figure 12) and was almost entirely sand finer than 2 mm at both sampling sites over the course of the year. Very coarse gravel (45-64 mm) was transported as bedload at the Upper Site on May 28th and June 2nd, 2015 at discharges of approximately 600 m^3/s and 650 m^3/s, corresponding to the highest sampled discharges. However, this very coarse size fraction constituted only 1.4% and 4.4% of the total sampled mass for each date. In fact, only 4% of the May 28th and 7% of the June 2nd sample was coarser than fine gravel (8 mm).

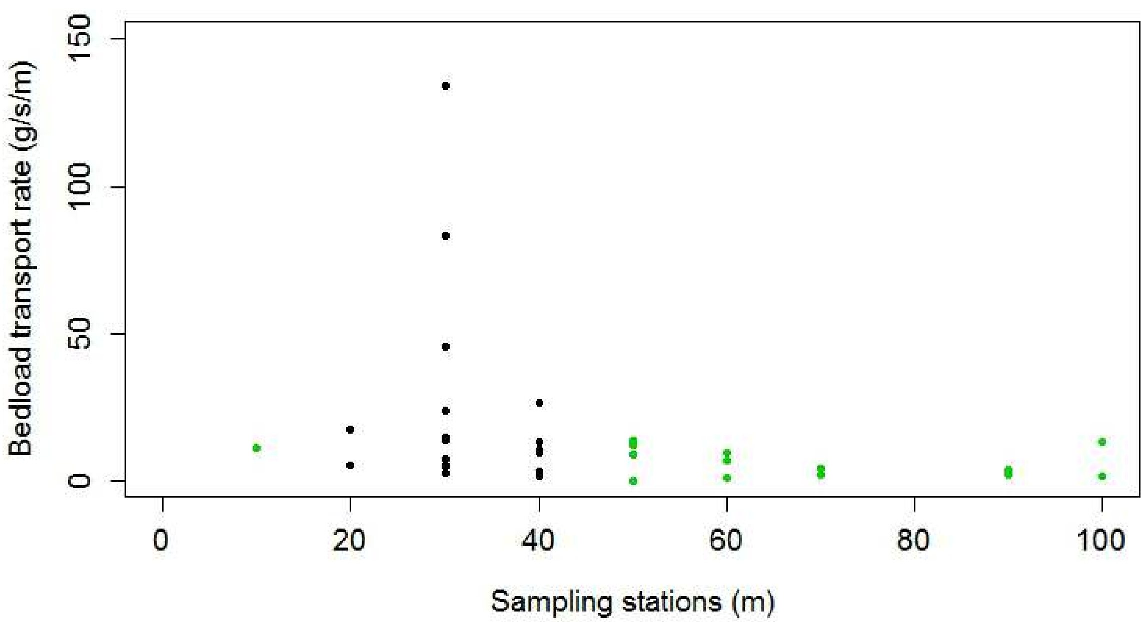

Figure 11 Site with the highest sampled bedload transport using 2013 to 2015 data. Black points correspond to the location of the Lower Patch.

In addition to the Upper Site and Lower Patch transects, several other locations were regularly sampled to gain a better understanding of the reach-scale pattern of bedload transport. While only qualitative at this point, results from the additional sampling indicate the majority of sediment being transported into the reach is routed into the side-channels along the north bank. The transport rate sampled in the first side-channel immediately downstream from the Upper Site (Map 1) was very similar to that sampled at the Upper Site, while transport rates further downstream became increasingly variable due to channel complexity and local sediment dynamics. Low transport rates were observed downstream of the Middle Patch as early as April 10th, 2015 ($Q = 280\ m^3/s$) on account of the low velocities associated with the backwatered flow conditions that occur at this discharge and higher.

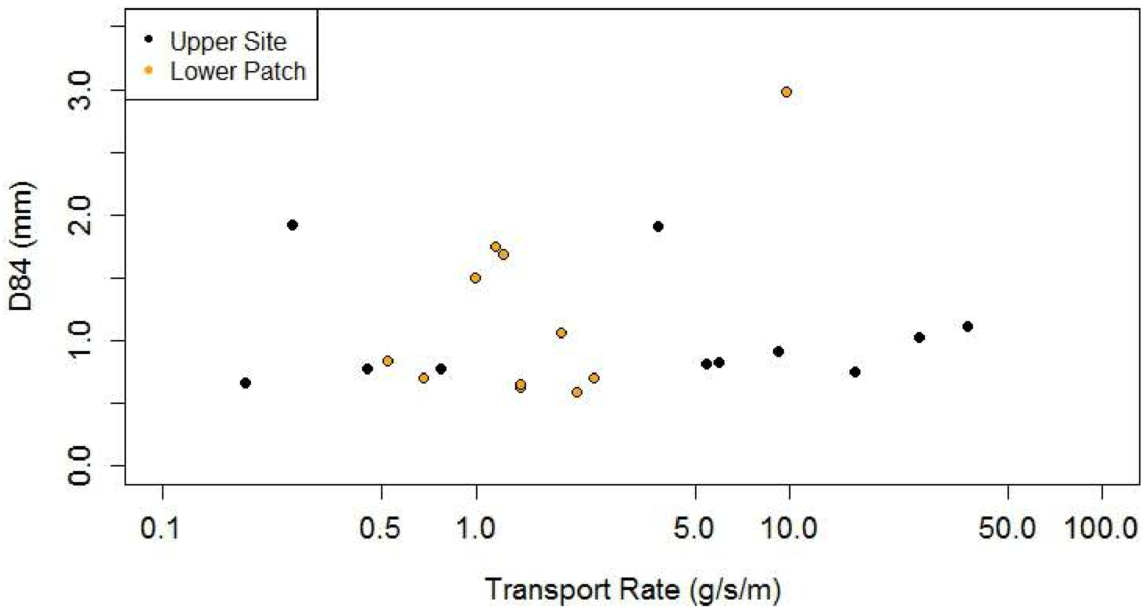

Figure 12 D_{84} grain size of bedload at Upper Site and Lower Patch.

3.3 Turbidity and Suspended Sediment Transport

Suspended sediment sampling was conducted regularly during the 2015 freshet to better understand the sediment contribution from Murray Creek and to improve overall annual estimates for the Nechako. Sampling took place on 6 days between March 20th and April 1st, 2015, increasing the range of sampled concentrations from a previous maximum of 23.3 mg/L in 2014 to a current maximum of 52.7 mg/L sampled on March 29th, 2015. Suspended sediment was sampled an additional 4 times between June 4th and September 26th, 2015, for a total of 10 sampled days.

Cross-channel variation in sediment concentration confirms that Murray Creek significantly influences mainstem Nechako concentration for approximately 20 m nearest to the left bank. On March 20th and 27th, 2015, this 20 m section of the Nechako produced sample concentrations that were respectively 3.4 and 2.4 times greater than the average concentration across the remaining channel distance (Figure 13). Total channel concentration on these dates decreased respectively by 25.6% and 15.6% when the affected 20 m section was omitted from the analysis (Table 3).

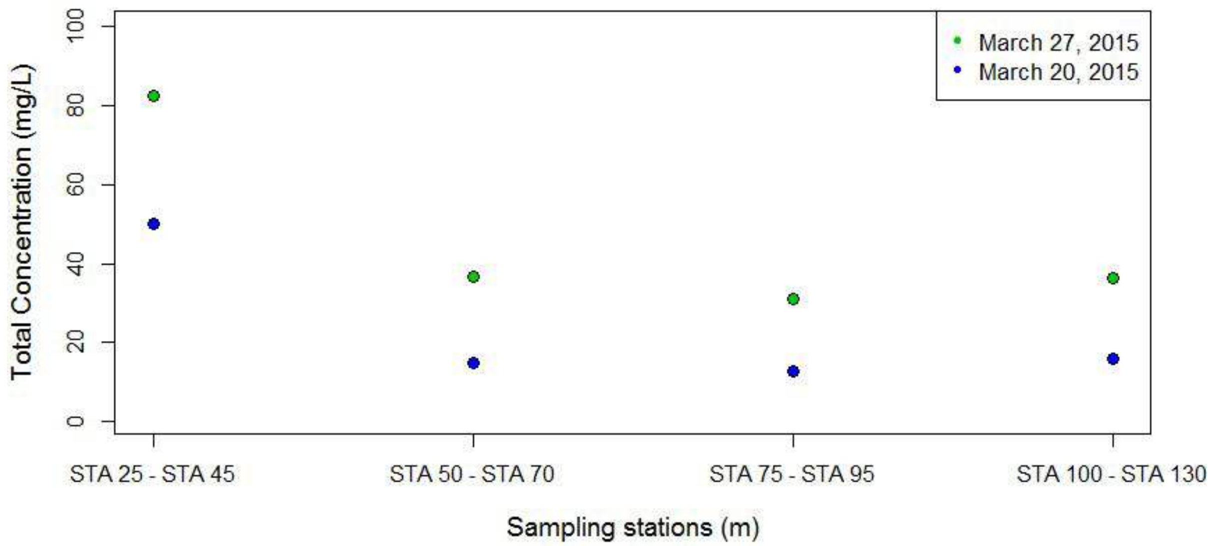

Figure 13 Cross-channel variation in suspended sediment concentration.

Table 3 Murray Creek influence on Nechako total suspended sediment concentration.

Date	Measured SS concentration (mg/L)		Estimated SS concentration (mg/L)	
	Including Murray	Excluding Murray	% difference	Adjusted value
3/20/2015	19.79	14.72	-25.6	
3/27/2015	41.61	35.13	-15.6	
3/24/2015	36.54		-20.0	29.23
3/26/2015	27.21		-20.0	21.77
3/29/2015	52.74		-20.0	42.19

The left bank turbidity sensor provided continuous data throughout the 2015 freshet. Data from this sensor shows a relatively low peak turbidity this year, reaching only 285 FNU compared to the 443 FNU peak in 2014. The overall freshet event in 2015 was also relatively short, with turbidity beginning to spike on March 9th and lasting until approximately April 15th, 2015 (Figure 14). Although somewhat less clear due to ice-effects, the turbidity pulse in 2014 seemed to span from the week of March 16th to the week of May 5th, 2014.

The Center Pier turbidity sensor provided data that was less influenced by Murray Creek and therefore more indicative of the mainstem Nechako conditions. Comparison between both sensors indicates that mainstem turbidity reached only a fraction of left bank turbidity values, with a maximum peak turbidity of 68 FNU (Figure 14). The Center Pier data also shows a prolonged turbidity pulse throughout the month of June as a result of the high water conditions (Figure 15).

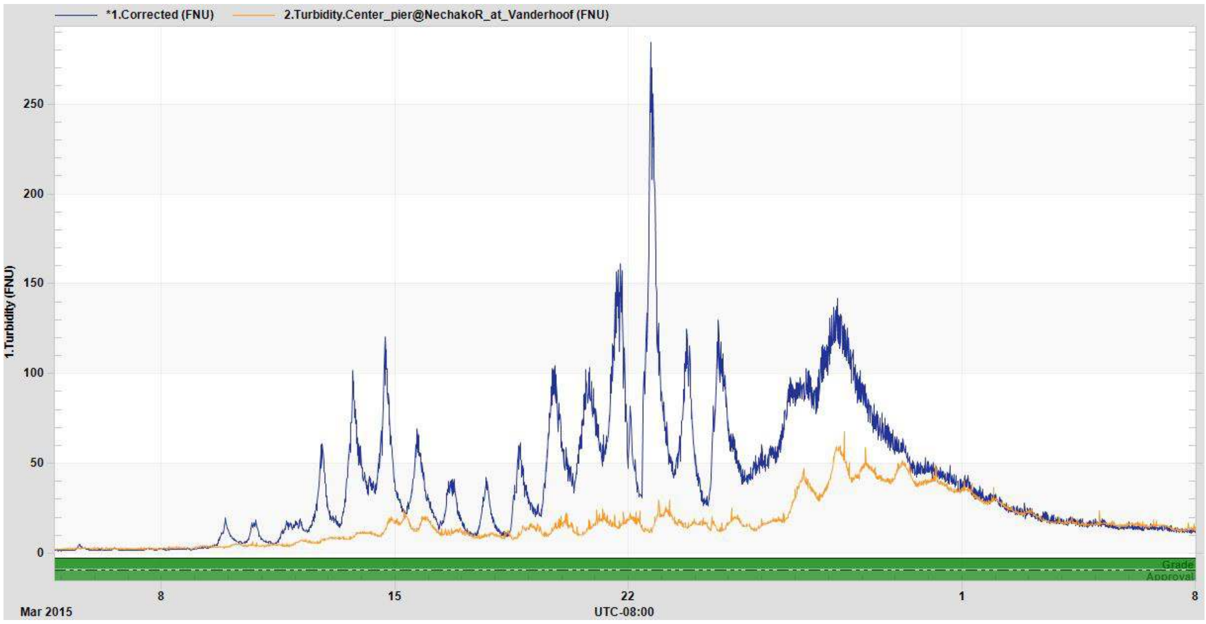

Figure 14 Daily turbidity pulses during 2015 freshet. Left Bank sensor shown in blue, Center Pier sensor shown in orange.

Separate suspended sediment-turbidity rating curves were developed from Left Bank and Center Pier sensor data. For the Center Pier curve, sampled sediment concentrations were adjusted to exclude the influence of Murray Creek by reducing the total channel-wide concentration by 20% (Table 3). This correction was applied to data collected between March 20th and March 29th based on field observations of a clear sediment plume extending downstream from the creek confluence. The adjusted concentrations plot in agreement with data collected throughout the rest of 2015 and was used to define the final rating curve for the mainstem Nechako (Figure 16). The relation between sampled sediment concentration and Left Bank turbidity showed greater scatter due to the rapid fluctuations of Murray Creek and the rating curve was defined simply as a best fit to the data (Figure 17). This curve was only used to generate the Left Bank sensor estimate of annual suspended load in Table 2.

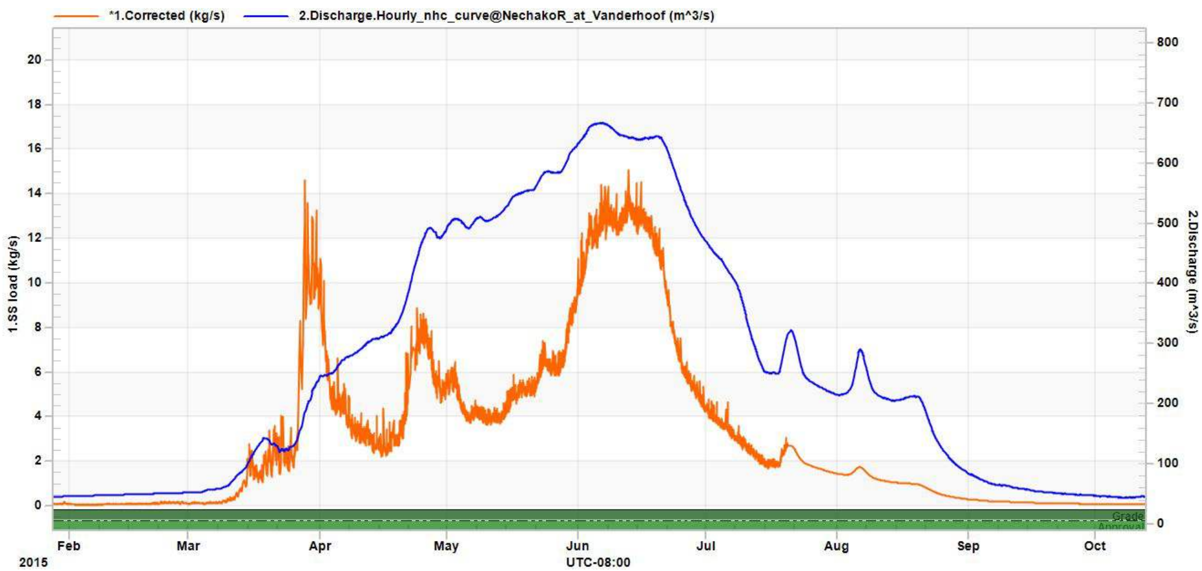

Figure 15 **Suspended sediment load derived using Center Pier rating curve plotted against discharge. Sediment load is shown in orange, discharge in blue.**

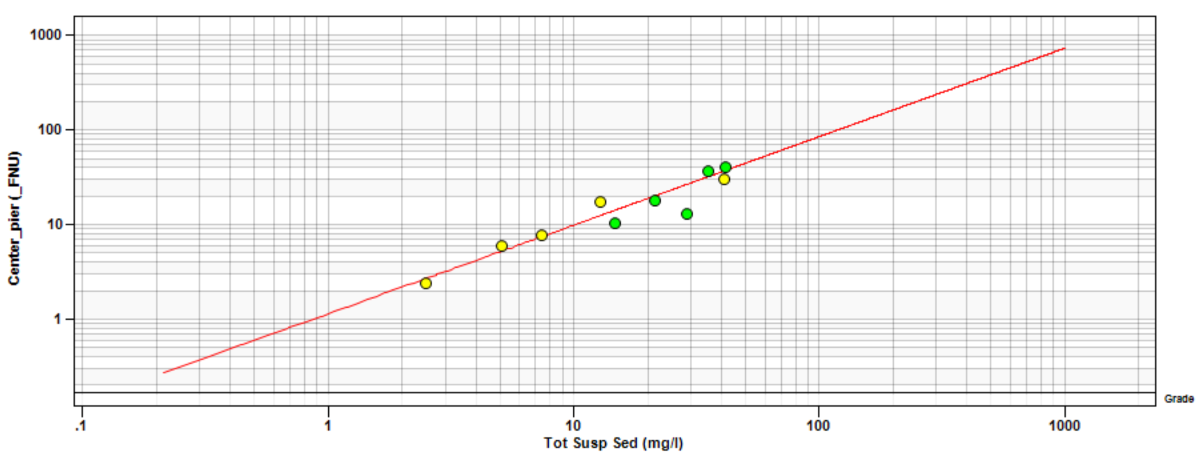

Figure 16 **Suspended sediment-turbidity rating curve for the mainstem Nechako (Center Pier). Green points indicate adjusted values to exclude the influence of Murray Creek.**

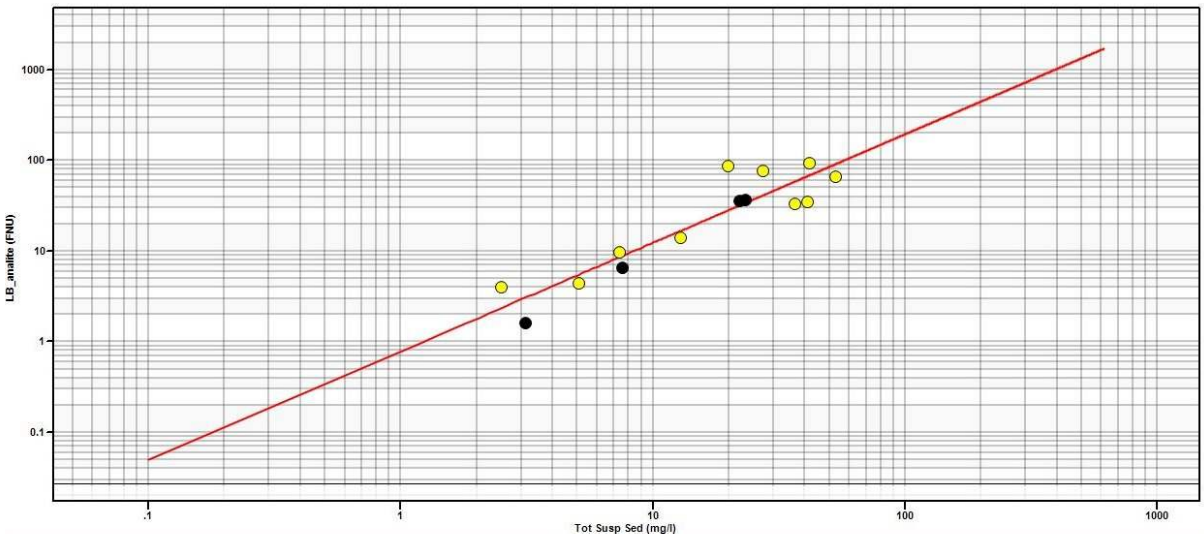

Figure 17 Suspended sediment-turbidity rating curve from the Left Bank sensor. Suspended sediment samples from 2015 shown in yellow, 2014 in black.

The total annual suspended sediment load transported in 2015 was at least double that of 2014 judging from directly comparable estimates (Table 2) generated using the same Left Bank turbidity rating curve (Figure 17). Three distinct periods of high sediment transport occurred in 2015 (Figure 15). The first pulse corresponds to early season tributary input as fine sediments associated with the snow melt and freshet conditions entered the main channel. The second, intermediate pulse in late April occurred as discharge rapidly increased from about 300 m^3/s to 500 m^3/s achieving bankfull flow conditions. The third pulse which occurred during the period of peak flow in June transported the majority of annual load. The large rise in turbidity and associated load in June is likely due to the bed becoming more mobile and/or the flow reaching fine sediment along upper banks that had not been accessed in a number of years. The last time discharge exceeded 590 m^3/s, the point at which concentration increased dramatically, was in 2007. It is interesting to note that the magnitude of suspended sediment transport was similar between the freshet and high flow period.

The signal from Left Bank sensor was fouled between July 5th and September 3rd, 2015, which coincided with senor malfunction on the Center Pier from July 20th to October 14th, 2015. Both periods of missing data were filled by interpolation using a recession curve. Although this data gap introduces some additional uncertainty, the implications are not significant for the study on account of the relatively low turbidity and suspended sediment transport during the period with the data gap. At present, the Left Bank sensor has been removed and the Center Pier sensor is transmitting data.

3.4 Underwater Imagery

Underwater imagery taken on July 3rd, 2015 during a discharge of approximately 450 m^3/s shows substrate at the Upper Site is composed mostly of cobble with large gravel and minimal fines. This substrate composition was expected from previous observations (NHC, 2013; NHC, 2014). Some sand and fine gravel is seen in Photo 1 taken at site US 3, which is located within the 30 m width that transports the largest amount of bedload past this transect (US 2 – US 4 on Map 1). Site US 3 was actively transporting sediment during the period the image was taken as evidenced by a sampled bedload rate of 225 g/s on June 30th and 85 g/s on July 8th, 2015.

Images taken across the Lower Patch show a completely sand bed at site LP 1 located approximately 10 m from the left bank. Sites LP 2 through LP 6 extend roughly 60 m into the channel and show a bed composed of cobble and gravel with fine gravel and sand infilling interstices to varying degrees (Appendix C). The LP 3 site clearly shows placed spawning substrate with fine sediment deposited overtop (Photo 2), which is consistent with previously observed trends (NHC, 2013; NHC, 2014). Sites LP 2 to LP 6 correspond to the 40 m wide section with the highest bedload transport rates past this transect (Figure 11). The amount of fine sediment infilling coarser framework seems to decrease past site LP 6 until approximately 10 m from the right bank. Sites LP 8 and LP 9 in particular show a gravel bed relatively free of fines.

The placed spawning substrate at the Middle Patch remains generally free of fine sediment (Photo 3). However, a section of the Middle Patch near the confluence of Stoney Creek approximately 10 m upstream from site MP 1 (Map 1) did contain a significant amount of fine sediment deposited within the interstices and overtop the coarse framework. Site MP 3 located at the downstream most extent of the spawning pad also had a large proportion of fine sediment.

Images were also taken for exploratory purposes within the first side-channel along the north bank immediately downstream of the Upper Site and at its confluence with the mainstem (Map 1). The northern half of this side-channel typically conveys the majority of incoming bedload that has been transported past the Upper Site, while the southern half typically conveys a smaller quantity of coarser bedload likely scoured from the island front. Site MU 5 (Map 1) is located in the high velocity, deep section nearest the southern bank and has a substrate composed of coarse gravel completely devoid of fine sediment (Appendix C). Photo 4 was taken where this side-channel re-enters the mainstem and shows a natural cobble and gravel bed containing a wide range of gravel sizes and a relatively low proportion of sand. This site is located in a deep area that provides a range of flow conditions including high velocity flow exiting the side-channel, low velocity flow behind the island and turbulent flow along the current seam. The location of Photo 4 is labeled as “Exploratory Site” in Map 1.

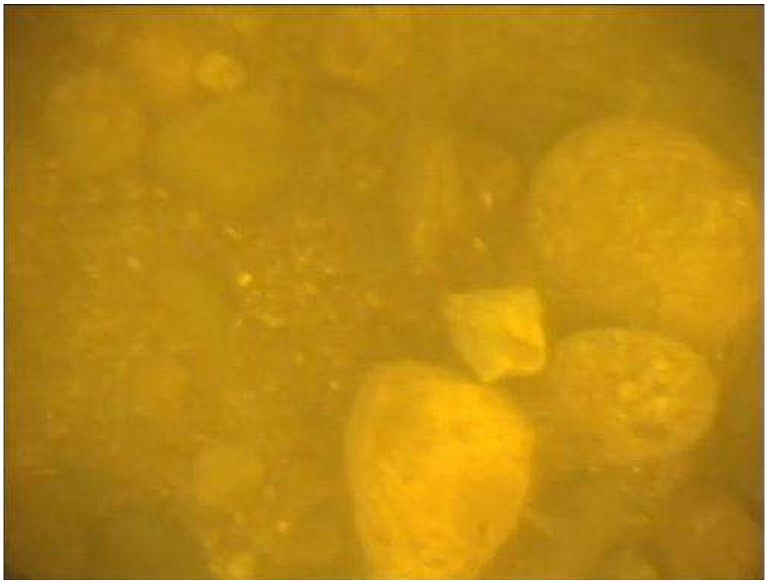

Photo 1 Substrate at site US 3.

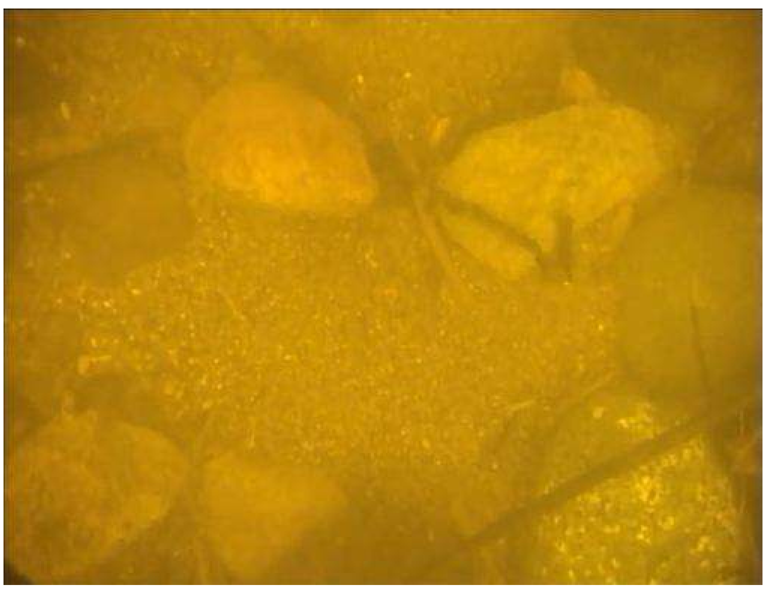

Photo 2 Substrate at site LP 3.

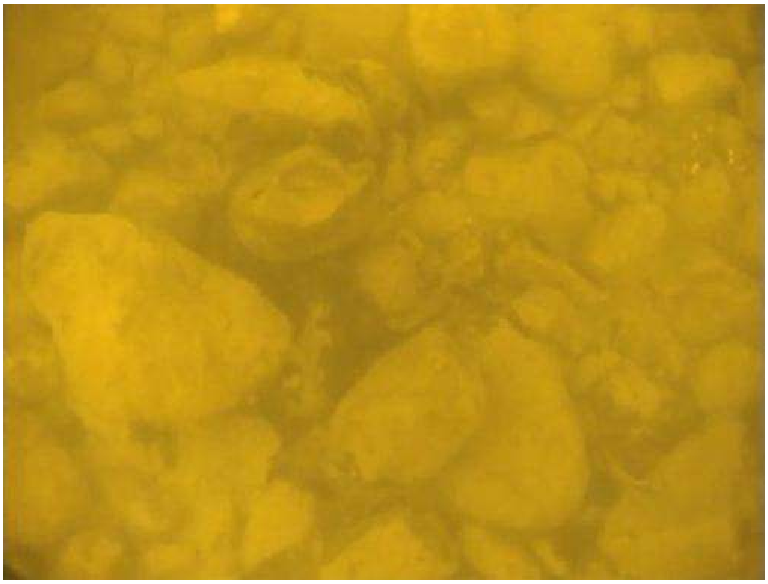

Photo 3 Substrate at site MP 2.

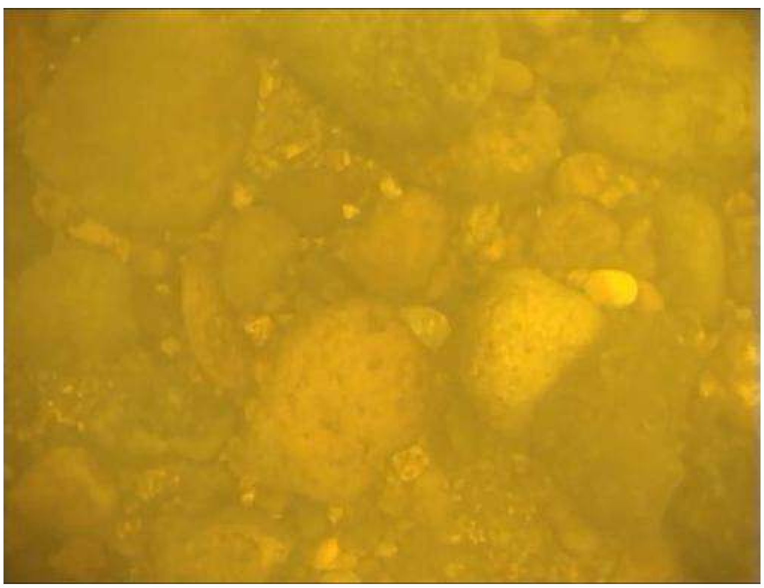

Photo 4 Exploratory site at 432340 E, 5986339 N.

3.5 Bathymetric and Topographic Survey

A high-resolution, reach-scale 2015 digital elevation model (DEM) was created using bathymetric, topographic and bankline survey data (Map 2). This elevation map clearly shows the thalweg along the south channel as well as local scour holes along channel constrictions, bends and in areas of flow convergence. The 2015 elevation model was subtracted from a previous DEM developed by NHC using 2006/07 survey data (NHC, 2008) to assess geomorphic change that has occurred since 2006/07 (Map 3). It is important to note that the 2015 elevation map is substantially more detailed than the previous DEM and that this causes considerable uncertainty by producing artefacts of interpolation. An uncertainty analysis based on data point density would need to be conducted to assess the significance of detected elevation changes.

A preliminary assessment of Map 3 suggests deposition has occurred mainly in the downstream portion of the reach. Deposition detected at the Murray Creek confluence and within the small northern side-channel immediately upstream of the Lower Patch is likely real as this area had fairly good data coverage in 2006/07 and in 2015. The Lower and Middle Patches themselves appear as areas of positive elevation change since they were placed post-2007. No significant change is seen in the upstream end of the reach which is consistent with observations of an imbricated cobble-gravel bed.

Figure 18 indicates the majority of elevation change was minor deposition in the 0.2-0.5 m range. This range of aggradation occurred over 25% of the total reach area. The total aggraded and degraded areas represent 29% and 7% of the reach respectively, with 64% showing no discernable change.

Map 4 shows the depth throughout the spawning reach when it was surveyed from May 12-15th during a discharge of approximately 525 m^3/s. The deepest areas occurred well downstream of the island complex within the single-thread channel and were up to 6.5 m deep. Fairly deep sections were present further upstream at channel constrictions and in areas of flow convergence.

A longitudinal profile of bed and water surface elevation was conducted along the main channel of the spawning reach. Figure 19 shows a steep water surface slope past the Upper Site (located on the figure at a downstream distance of 300 m) reflecting the high velocity flow through this narrow channel section. A clear non-uniform flow profile is seen upstream of the bridge where water surface slope decreases to zero due to the backwatered conditions. Backwatering is seen to extend about 1.5 km upstream from the bridge, which spatially corresponds to the reinforced section of right bank located about halfway between the confluence of Stoney Creek and the next westerly point.

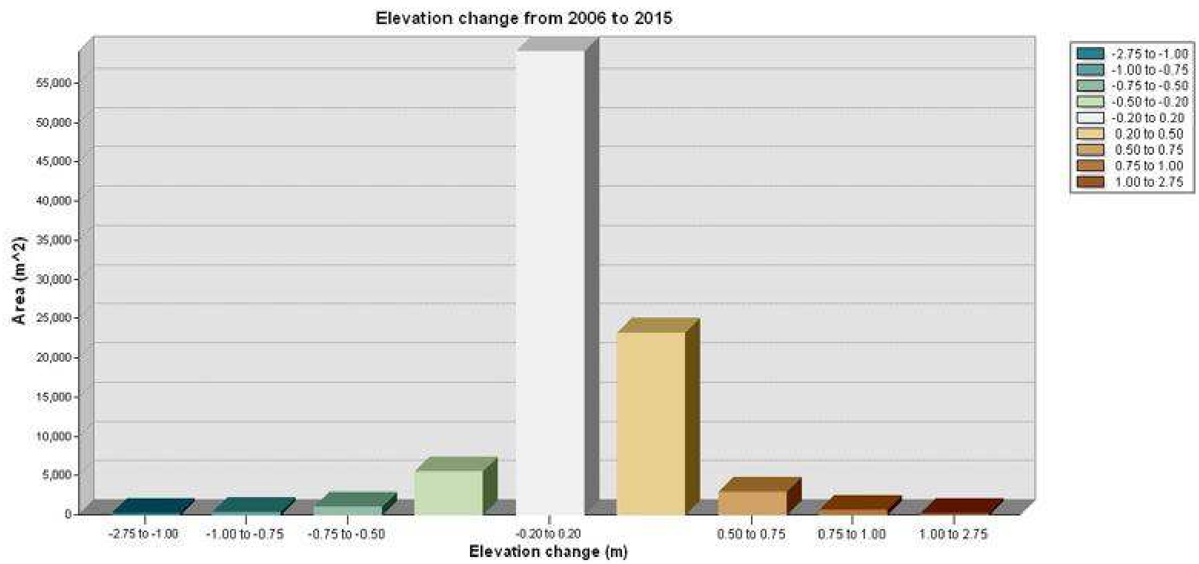

Figure 18 Classified elevation change from 2006/07 to 2015.

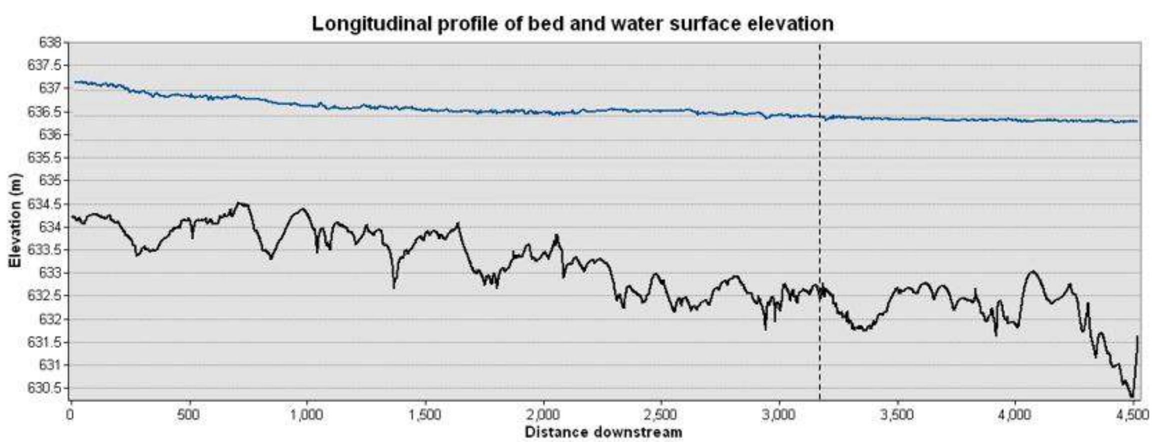

Figure 19 Longitudinal profile of the channel bed and water surface elevation within the spawning reach. The dashed line indicates the location of the Burrard Ave. Bridge.

4 INTERPRETATION AND ANALYSIS

The Nechako basin sediment input has been estimated in previous reports by assuming the suspended sediment yield is 0.7 $Mg/km^2/day$ (Church *et al*., 1989) and that bedload is 10% of the total load (NHC, 2012; NHC, 2013; NHC, 2014). A basin area of 3,600 km^2 has been used for these calculations, rather than the entire watershed as much of the watershed includes lakes. The 3,600 km^2 basin area, corresponds to the area downstream of the Cheslatta fan and upstream of Vanderhoof, but excludes the area northwest of Fraser Lake. Data collected in 2015 was used to improve our basin yield estimate by refining the 0.7 $Mg/km^2/day$ and 10% assumptions.

Firstly, the total 2015 suspended sediment load of 44,100 m^3 was used to back-calculate the annual specific sediment yield assuming the suspended load is representative of basin input. In practice the 2015 load is anticipated to be larger than average due to the large freshet. This analysis produced a specific sediment yield of 0.05 $Mg/km^2/day$, which plots similarly to lacustrine landscapes below the lower limit of the normal trend for BC watersheds (Figure 20). This result is plausible because the Nechako drainage basin generally has low relief, as well as numerous marshes and low gradient areas to intercept upstream sediment supply. Secondly, the average of all 2014 and 2015 data was used to determine that the ratio of bedload to total load is roughly 12% at Vanderhoof. It varies by as much as 5 % depending on which measurement site is used.

The last three years of data suggest the mean annual bedload yield is between 3,000 and 4,000 $m^3/annum$. Our revised estimates translate to a total basin yield of about 170,000 m^3 of bedload sediment over the past 50 years, an order of magnitude less than the value obtained using the original assumptions.

The average from the last three years of 3,400 m^3 of bedload material input is somewhat less than previous analysis stating the annual sand supply from 1953 to 1986 was roughly 8,800 $m^3/annum$, with 5,000 m^3 being contributed from valley wall and bank erosion and 3,800 m^3 from tributaries (Rood, 1999). The current rate of sediment input from banks and valley walls is likely to be less than it was during this earlier period as vegetation encroachment and slope stabilization would increase with time after regulation. It is interesting that basin sediment yield is relatively low despite the presence of watershed disturbances that typically produce high runoff and sediment contribution including agriculture, logging, forest fires and mountain pine beetle attack.

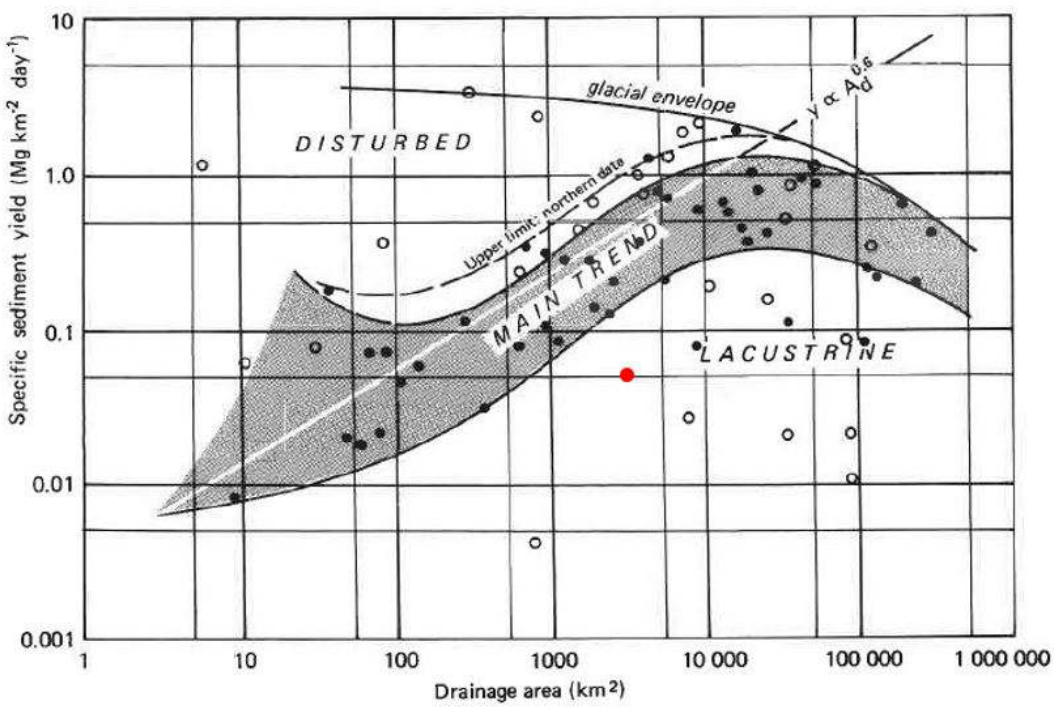

Figure 20 Suspended sediment yield for BC watersheds adapted from Church *et al*., 1989. The Nechako basin is plotted in red.

4.1 Bedload Sediment

The difference in annual bedload transport between the upstream and downstream extent of the reach suggests 6,200 m^3 of sediment was stored within the reach in 2015. This deposition helps explain the seemingly unsustainable imbalance between Upper Site and Lower Patch transport in 2013 and 2014 (NHC 2014; NHC, 2015). It is interesting that the annual transport rates for 2013 and 2014 show a ratio of 1:3 in terms of input versus output bedload sediment, while the 2015 ratio is the inverse at 3:1. This finding suggests that an interesting sediment dynamic may occur where a high flow year will input a pulse of sediment that becomes stored within side-channels and subsequently transported downstream at a much slower rate. This dynamic is logical considering the downstream section of the reach backwaters during high flow causing deposition midway through the reach (Figure 19). It is also consistent with previous findings, as the 2013 and 2014 hydrographs would have had limited stream power to erode and transport sediment from upstream while maintaining relatively high shear stress downstream. The variability in annual transport rate between the Upper Site and Lower Patch reflects this dynamic as well, because Upper Site transport is driven by peak flow and ranges from about 500 m^3 to 10,000 m^3, while Lower Patch transport is moderated by backwatering and ranges only from 2,000 m^3 to 4,000 m^3 (Table 2). However, when averaged over several years, annual bedload transport through the reach is on the order of 2,000 m^3 to 4,000 m^3. It is important to note that although this estimate may be useful for the planning of future restorative works, it remains dependent on the sequence and magnitude of annual hydrographs.

A large supply of sediment was required to sustain the high transport rates needed to deliver such a pulse into the reach. The first major source of bedload sediment is supplied from tributary input during the freshet. This exogenous input occurs annually regardless of Nechako flow level. In addition, periods of high flow such as 2015 may have sufficient stream power to recruit more sediment through local bank erosion along glaciolacustrine terrace scarps and through the mobilization of sediment previously deposited on bars, in pools and in areas infrequently exposed to high shear stress like side-channels.

Interestingly, hysteresis in the bedload transport rate suggests the availability of sediment within the active width of the channel became limited during the flood. The availability of bedload sediment likely decreased shortly after maximum wetted width and stream power were achieved as readily mobile material would have been moved as the flood waters were going up. Sediment supply may become limited fairly rapidly during peak flow since the bedload is largely sand, which can be entrained easily and transported in saltation at high velocity over considerable distances. The speed and distance of particle transport are important because bedload is often conveyed in a step-wise manner through stretches of river that link one depositional zone to the next; depositional zones being characterized by distinct reductions in channel gradient. Two such depositional reaches include the gradient break located approximately 35-45 km upstream of the spawning reach and the spawning reach itself (Figure 2 in NHC, 2013). Therefore, supply limitation at the Upper Site may have occurred because the duration of high flow was sufficient to transport sediment deposits through the river segment that links these two depositional areas. Years with less stream power do not show hysteresis and transport rates generally follow the capacity limited trend experienced during the rising limb of the 2015 hydrograph (Figure 21).

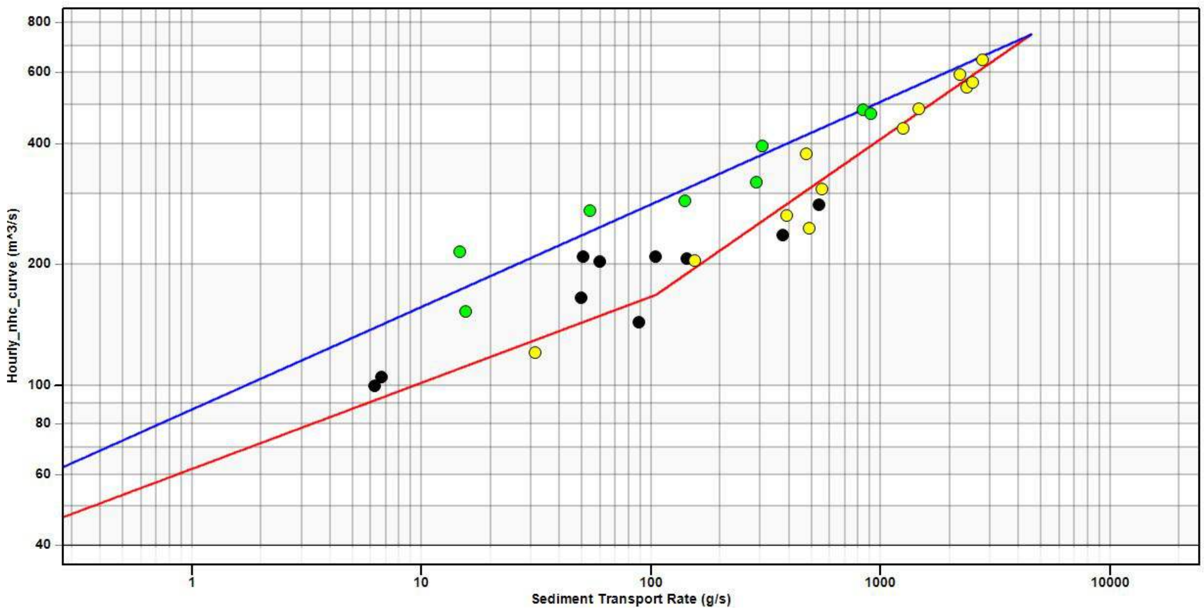

Figure 21 Figure 7 with April through August 2014 bedload transport shown in black.

The Lower Patch bedload rating curve was shown to be non-applicable during high flow, backwatered conditions (Figure 9). Consequently, estimates of annual transport during high discharge years such as 2007 are highly uncertain. One possible way of achieving better bedload estimates at the Lower Patch is to develop a rating curve using shear stress rather than discharge. To do so, hydrodynamic model simulations would need to be run to determine near-bed shear stress for a range of discharge values. This could be accomplished using a previously developed flow model (NHC, 2008).

No trend was observed between the grain size distribution of bedload material and increasing discharge or transport rate (Figure 12). The lack of a rapid increase in bedload grain size indicates that the coarse substrate armoring the bed at the Upper Site did not become mobile during the highest observed flows. Calculations using the bathymetric survey data indicate that the Upper Site had a shear stress of 17.0 Pa during a discharge of 525 m^3/s. This estimated stress would have been sufficient to mobilize grains up to 17.5 mm assuming a Shields parameter of 0.06 is appropriate. In contrast, the bed at this location is largely composed of sediment in the 64-180 mm range, suggesting shear stress was insufficient to move the D_{50} grain size. The very low proportion of gravel within the bedload likely occurs because sand is the dominant size fraction of sediment being input to the channel (Rood, 1999) and because of bed structuring that decreases larger grain mobility. Therefore, suitable interstitial habitat within the reach is more likely to be provided by processes such as winnowing and sediment sorting than by the mobilization of coarse material.

4.2 Turbidity and Suspended Sediment

The turbidity time-series provided by the Left Bank and Center Pier turbidity sensors indicate the turbidity pulse from Murray Creek freshet occurs earlier, is more cyclic and has a much higher concentration than Nechako freshet (Figure 14). These findings are what would be expected for a smaller tributary system. However, no clear cross-channel trend was found in relative grain size concentration during the period when Murray Creek was heavily influencing overall concentration. A greater proportion of very fine sediment may have been expected within the Murray Creek affected section, but we found no evidence of this.

The 2015 suspended sediment load was at least double the 2014 load despite having a relatively short freshet period. As seen in Figure 22, three periods of high transport seemed to have occurred throughout the year as flows began to access and mobilize sediment from different sources. The first pulse of sediment was transported during freshet and corresponds to the annual exogenous input from tributaries. This supply of fine sediment became exhausted soon after the tributary freshet was over resulting in a sharp drop in the transport rate. As discharge rapidly increased from about 320 m^3/s to 500 m^3/s, bankfull flow began to access new endogenous sources of sediment in areas that are not annually wetted including along the upper part of cut banks, bar tops and from low-lying vegetated islands. When discharge began to stabilize around 520 m^3/s, the supply of suspended sediment once again became exhausted causing transport rate to decrease until the next increase in flow. The majority of the annual suspended sediment load was transported during the third period when peak flow and overbank conditions were reached. As discharge rose from 520 m^3/s to 675 m^3/s, sediment being supplied to the channel originated from both endogenous and exogenous sources including from the erosion of terrace scarps and the mobilization of within-channel and floodplain sediment deposits. Transport towards the end of this period rapidly declined as flows began to recede back into the previously wetted channel and were no longer accessing new sources of sediment.

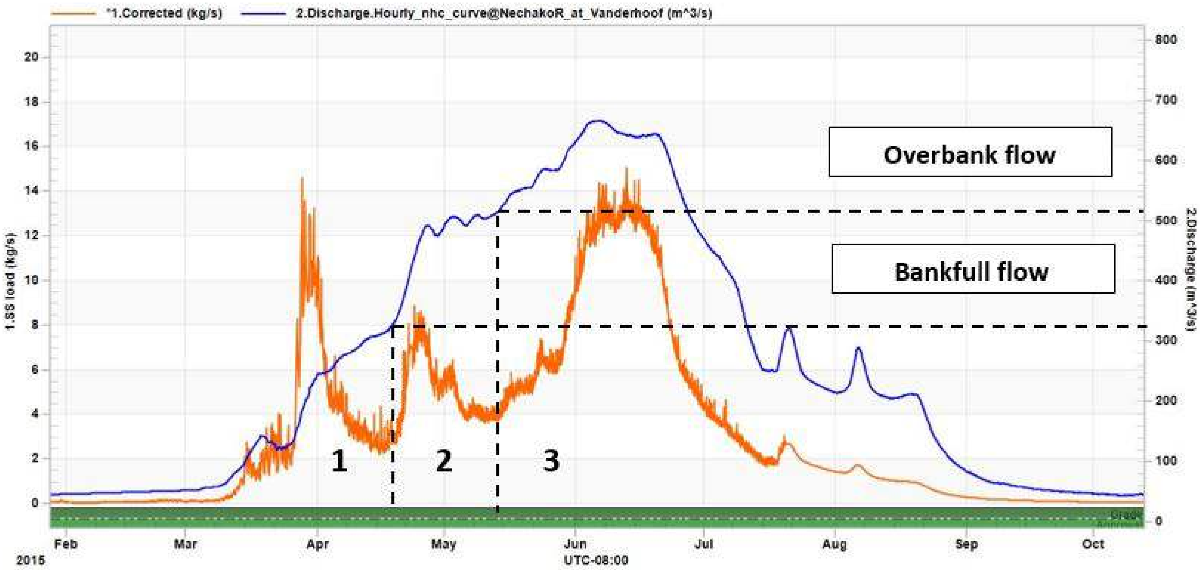

Figure 22 Modification of Error! Reference source not found. **showing relation between sediment load and discharge.**

Very fine sediment (<0.064 mm) accounted for between 83% and 95% of the total sample concentration throughout the year. Although suspended sediment may have been expected to coarsen over time as the system transitions from freshet to high flow conditions, this was not observed as backwatered conditions maintained the D_{84} grain size between 0.06 mm and 0.08 mm. Coarsening of the suspended load likely occurred at the Upper Site as increasing shear velocity began to bring bedload material into suspension. To this end, the Rouse number can be used to determine the mode of sediment transport by relating particle settling velocity to shear velocity. For a discharge of 525 m^3/s, shear velocity at the Upper Site is estimated to be 0.13 m/s translating to about 50% suspension of 1 mm sized grains and 100% suspension of 0.5 mm grains. At this flow level, particles larger than 2 mm would not be suspended and would be transported as bedload past the site.

4.3 Underwater Imagery

The underwater imagery taken on July 3rd, 2015 remains generally consistent with previous observations and trends (NHC, 2013; NHC, 2014). The 40 m width between sites LP 2 and LP 6 of the Lower Patch is of particular concern as infilling of the substrate continues within the active width of the channel. Sediment that has infilled the coarse framework becomes essentially static and lost to erosional force because shear stress is insufficient to mobilize cobble and large gravel. Consequently, even modest sediment transport rates will degrade the quality of this habitat over time. The relative lack of sand and fine gravel seen at sites US 2 to US 4 of the Upper Site during the receding limb of the hydrograph is consistent with bedload supply limitation, since these locations were actively transporting large volumes of sediment during the rising limb. The minimal amount of infilling that has occurred at the Middle Patch is consistent with bedload samples returning very low transport rates within the southern, mainstem channel.

From the imagery, it seems that coarse substrate devoid of fine sediment was available in several areas within the reach during the spawning period. These areas of suitable larval habitat included the majority of the Middle Patch as well as several naturally sorted areas further upstream; providing coarse cobble and gravel substrate in a range of hydraulic conditions.

4.4 Bathymetric and Topographic Survey

Maps 3 and 4 suggest that complex habitat in a wide range of hydraulic conditions was available within the reach during the 2015 spawning season. Relatively deep pools were located in both high velocity and low velocity sections of the river with very different turbulence intensities. Pools were also present in areas of flow convergence such as channel constrictions and side-channel confluences. However, the deepest pools remained downstream of the island complex within the single-thread channel and were over 6.5 m deep during the spawning period.

Spawning activity detected downstream of the Burrard Avenue bridge may be indicative that fish were concentrating in the deepest pools available. However, the substrate at this location is comprised almost entirely of sand and is therefore not conducive to larval survival. Suitable larval habitat was available during the spawning period at the Middle Patch and in pools with naturally sorted sediment farther upstream. The concentration of spawning activity below the bridge may also be related to water velocity, as water surface slope is seen to increase once it flows past the bridge constriction causing backwater (Figure 19).

As previously mentioned, geomorphic changes detected by differencing the high-resolution 2015 DEM from the previous 2006/07 DEM (NHC, 2008) are highly uncertain and additional analysis is required to assess the significance of results. Nonetheless, deposition within the northern most side-channel immediately upstream of the Lower Patch (Map 3) is likely true and is consistent with observations made this year of large advancing sand dunes in the area (Photo 5). A fairly marked gravel-sand transition located near the upstream most extent of backwatering also corroborates this trend. The largest dunes observed this year had a 0.5 m high advancing face and were located just upstream of this small side-channel, well within the backwatered portion of the reach. Deposition at the confluence of Murray Creek is also likely to be true and is supported by good data coverage and field observation. This area appears to be a depositional zone for both Murray Creek and Nechako bedload and can be clearly seen on the 2015 DEM (Map 2). A high resolution survey of this deposit was done in October 2015 to establish baseline data needed to determine the rate of fan growth should repeat surveys be conducted in the future.

Photo 5 Advancing dune deposited within side-channel as flow receded (looking upstream).

5 APPROACHES TO SEDIMENT CLEANING

Gravel cleaning has been utilized in both artificial and natural river channels to remove settled sediments and improve inter-gravel flow. For salmonids, the improved flows within the gravel bed increased dissolved oxygen delivery, metabolic water removal and egg-to-fry survival within the redd.

In constructed spawning channels, constructed first by the IPSFC (International Pacific Salmon Fisheries Commission) and later through Fisheries and Oceans Canada Salmonid Enhancement Program (SEP), gravel cleaning was required to sustain high egg-to-fry survival and enhance recruitment supporting fisheries. Spawning channels were constructed for pink, chum and sockeye salmon which dig redds in the base of the channel to deposit fertilized eggs.

Broadcast spawning white sturgeon do not directly modify the spawning substrate but require a clean gravel matrix for larval sturgeon habitat. Therefore, settled fine sediment has to be removed from the critical Nechako spawning reach located at Vanderhoof.

Gravel cleaning techniques which have been used previously at salmon spawning channels include:

1. Gravel replacement: Removing the sediment-laden spawning gravels and replacing them with clean re-screened and graded gravel. This was an equipment-intensive technique that required additional gravel to be provided due to losses in handling. Often gravels were stored, re-screened and stockpiled for future use.

2. Air/Water Cleaner: Utilizing a specially constructed air/water cleaner (first designed by IPSFC Engineers) to dislodge sediments from the gravel and flush them downstream. The rake-like apparatus only cleaned about 20-30 cm depth and repeated use led to coarsening on the spawning channels, or pumping of sediments from the base of the channel.

3. Qualicum Method: Using a large bulldozer to manipulate the gravel bed, the flows were used to flush the sediments out the gravel and downstream. This method proved to be one of the more cost and operational effective gravel cleaning procedures. The scarification and turning of the gravels helped re-sort and even out the gradation, and the mechanical action broke up sediment and algal accumulations.

4. Riffle Sifter/Gravel Gertie: Developed at the University of Washington and used in natural rivers, the Gertie used a jetted stream of water to dislodge and flush sediments from the gravel. It concentrated the sediments and discharged them to land while recirculating the cleaning water. The device was slow and could not clean extensive areas such as spawning channels, and was limited by the depth of flow it could operate in.

These methods were all developed for different applications, but all intended to loosen and remove fine sediments from the voids in graded gravels. Due to their relatively long length and low water velocity, spawning channels act as a filter and accumulated sediments build up from the base of the gravel matrix, eventually filling the voids in the bed. When cleaned, these channels would discharge high concentrations of suspended sediment along with organic matter (i.e., algae, dead eggs, etc.) that required pumping and treatment.

A sediment cleaning plan is currently being developed for the Nechako to immediately improve the quality of larval habitat at the Lower Patch and to determine the feasibly of such an approach towards remediation. The task will need to be performed within a relatively short operating window in April; between ice-off and the onset of sturgeon movement towards the spawning reach in May. General issues that must be addressed when choosing an appropriate sediment removal technique include removal efficiency and effectiveness, downstream sediment management, access and costs.

Given the site-specific context and goals of the operation, based on our review of available technologies, we have identified two potential techniques that may be used in 2016: mechanical cleaning using a Spyder Excavator and hydraulic cleaning using a floating suction dredge.

Mechanical cleaning would use an S2-3 Kaiser 4x4 Spyder Walking Excavator to rake, scarify and sift the cobble bed using a large 1.5 m-wide toothed bucket (Figure 23). This method would be efficient in removing fines from the surface and subsurface layer, is highly maneuverable and would be able to access areas relatively easily with low impact. This method also has a lower cost and higher productivity relative to suction dredging, but does not remove the sediment from the water column. In cases where the habitats downstream are already composed of sands and silts, this may not be a critical issue or constitute serious harm. One potential complication with this method is the variable ice condition and water level in April because the excavator can operate in a maximum water depth of 2 m. This limitation will be problematic should 2016 be another high flow year similar to 2015. In previous years (2013 and 2014), depth was roughly 2.8 m in the deepest part of the channel at this time (Q = 150 m^3/s) making operations feasible given the approximate 6 m reach of the excavator. Table 4Table 4 provides a general guideline of discharge levels during which the task may be performed before maximum depth is exceeded. A discharge of 150 m^3/s or below would be ideal for the operation, while flow over 200 m^3/s will become increasingly limiting in terms of the area the excavator can access.

Table 4 Estimated maximum depth at Lower Patch for various discharge levels

Discharge (m^3/s)	Maximum Depth at Lower Patch (m)
100	2.4
150	2.8
200	3.1
250	3.4
300	3.7

Figure 23 Example of a walking excavator used for in-channel site restoration.

An alternative approach would be to use a small hydraulic suction dredge operated by divers. The dredge head would be modified to lift the finer sediment but only “rattle and bounce” the larger gravels and cobbles. Advantages of this method include that it is unaffected by water level and fines are actually removed from the channel rather than deposited downstream. The sediment discharge would have to be pumped and treated on land. The productivity would be low and the cost per unit area relatively high given the divers, equipment, pumping and safety requirements.

Mechanical sorting, sifting and raking of the cobble-gravel spawning beds at Vanderhoof using the 4x4 Spyder Excavator is thought to be the most promising technique to clean the larval habitat. This is due to the following factors:

1. Need to clean areas in relatively deep, fast flowing water;
2. Requirement to access the river and move over a wide area; and
3. Need to physically move, sort and level area of the river bed once cleaned.

We investigated the costs and availability of the Spyder Excavator through the services offered by Nu Creek Developments Ltd., who provided a quote of approximately $18,000 for 3 days of work in the river and an initial site assessment.

6 CONCLUSIONS AND RECOMMENDATIONS

The 2015 suspended load was used to calculate a basin sediment yield of 0.05 Mg/km^2/day. This input rate plots similarly to lacustrine landscapes, below the lower limit of the normal trend for BC watersheds. Data suggests bedload is roughly 12% (±5%) of the total load at Vanderhoof and bedload data from the last three years suggests the estimated basin sediment yield is 3,400 m^3/annum. Our revised estimate translates to a total basin yield of about 170,000 m^3 of bedload over the past 50 years, an order of magnitude less than previous estimates obtained by assuming basin yield is 0.7 Mg/km^2/day and bedload is 10% of total load.

Bedload transport was higher past the Upper Site than the Lower Patch resulting in the storage of 6,200 m^3 of sediment within the reach. This imbalance may be indicative of an interesting sediment dynamic where high flow years provide a sediment pulse that becomes stored within side-channels and transported downstream at a much slower rate. This dynamic is logical because backwater extends about 1.5 km upstream of the Burrard Ave. Bridge during high flow, causing deposition of bedload midway through the reach. Bedload transport at the Upper Site is more variable than at the Lower Patch, as Upper Site transport rates increase with discharge while Lower Patch transport is moderated by backwatered flow. However, when averaged over time, our estimates indicate that bedload yield through the reach is between 2,000 m^3/annum and 4,000 m^3/annum.

Hysteresis in bedload transport indicates the availability of sediment within the active width became limited during the period of high flow. Bedload transport rates are often higher on the rising limb of the hydrograph compared to the falling limb as the available material is exhausted and the bed becomes more sorted and armored. Bedload material was almost entirely sand finer than 2 mm and no trend was observed between grain size and discharge or transport rate. As coarse sediment was not mobilized even during the period of peak flow in June 2015, representing the third highest flow since the onset of regulation in 1952, suitable interstitial habitat within the reach is more likely to be provided by processes such as winnowing and sediment sorting than by the mobilization of coarse material.

The total suspended sediment load in 2015 was at least double that of 2014. Three periods of high transport occurred; an initial pulse of exogenous sediment from tributary freshet, a second pulse from bankfull flow mobilizing endogenous sediment from bar tops and cut banks and a third pulse from overbank flow accessing sediment from terrace scarps and the floodplain. Most of the annual load was transported during the period of peak flow. Cross-channel variation in sediment concentration confirms that Murray Creek significantly influences mainstem concentration by increasing it approximately 20%.

Results from underwater imagery remain generally consistent with previous observations and trends. Although the cobble-gravel substrate at the Lower Patch has infilled to various degrees, the gravel bed towards the right bank seems relatively free of fines. Substrate at the Middle Patch has not infilled with fine sediment except for near the Stoney Creek confluence and near the downstream most extent of the pad. Several pools further upstream showed natural sediment sorting with a cobble-gravel bed containing a range of gravel sizes and a relatively low proportion of sand. These locations would have provided suitable larval habitat in a range of hydraulic conditions during the spawning period. However, the deepest pools of the entire reach were located downstream of the island complex within the sand-bedded single-thread channel.

Although geomorphic changes detected by DEM differencing are highly uncertain at this point, they do suggest a depositional trend in the downstream portion of the reach. Deposition at the confluence of Murray Creek and within the small northern side-channel immediately upstream of the Lower Patch is supported by good data coverage and field observations.

After a very informative year in 2015, we recommend the following actions take place in 2016:

- Mechanically remediate the Lower Patch using the 4x4 Walking Excavator
- Sample bedload immediately upstream and downstream of the Lower Patch during the remedial work to help assess the impacts of the work
- Sample suspended sediment during the freshet period and during the remedial work to assess fine sediment dispersal from the Lower Patch
- Continue to monitor turbidity using the Center Pier sensor and consider temporarily installing an additional sensor during the remedial work to assess turbidity caused by the construction activity. The primary purpose will be to demonstrate the effect of cleaning on river turbidity for future permitting.
- Collect underwater images of the Lower Patch in summer and late-fall to determine changes in the quality of remediated substrate
- Sample bedload at the Lower Patch at approximately every 100 m^3/s change in discharge to monitor output of stored sediment and transport over the remediated surface
- No longer sample bedload at the Upper Site unless exceptional flows occur

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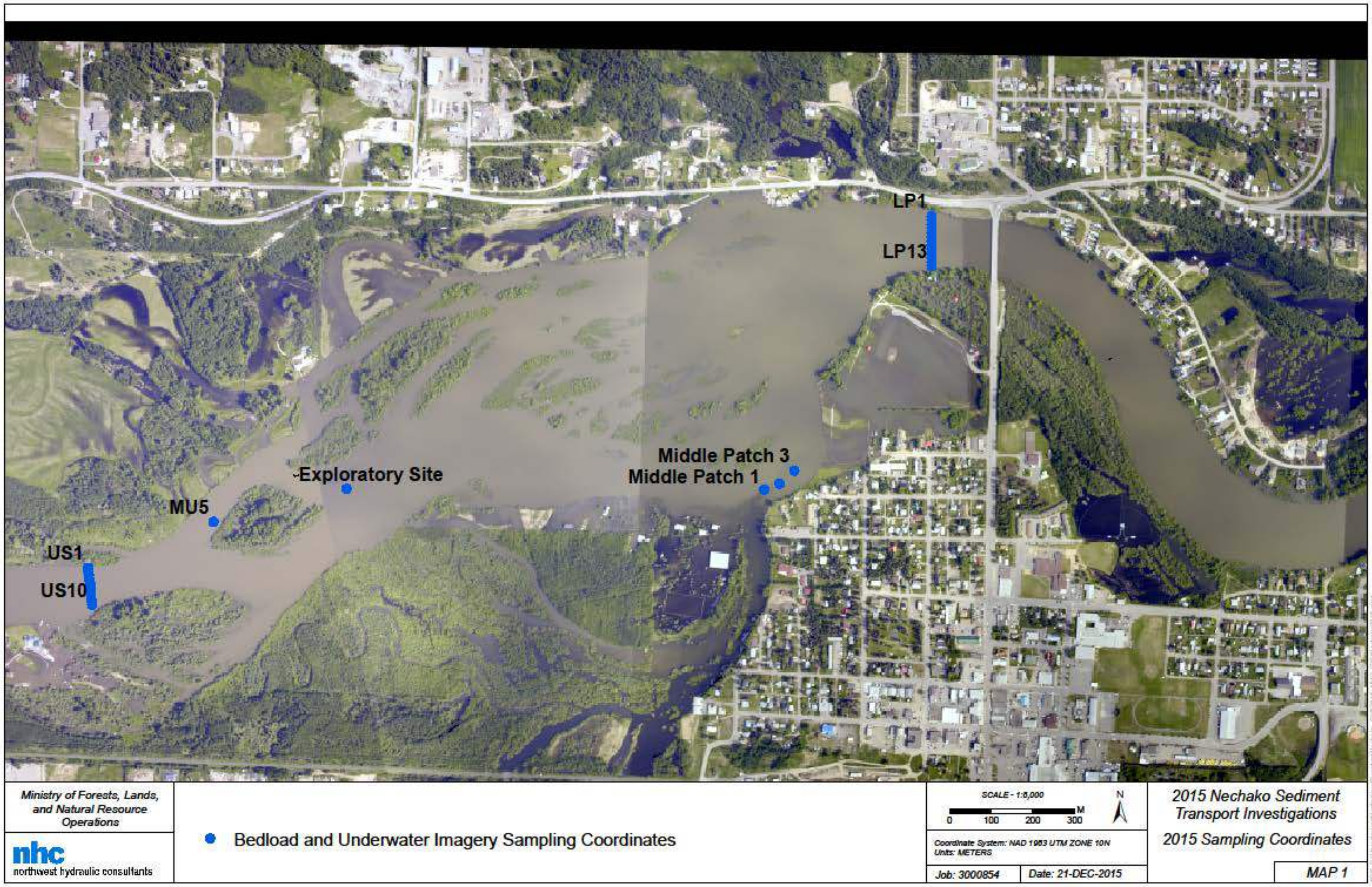
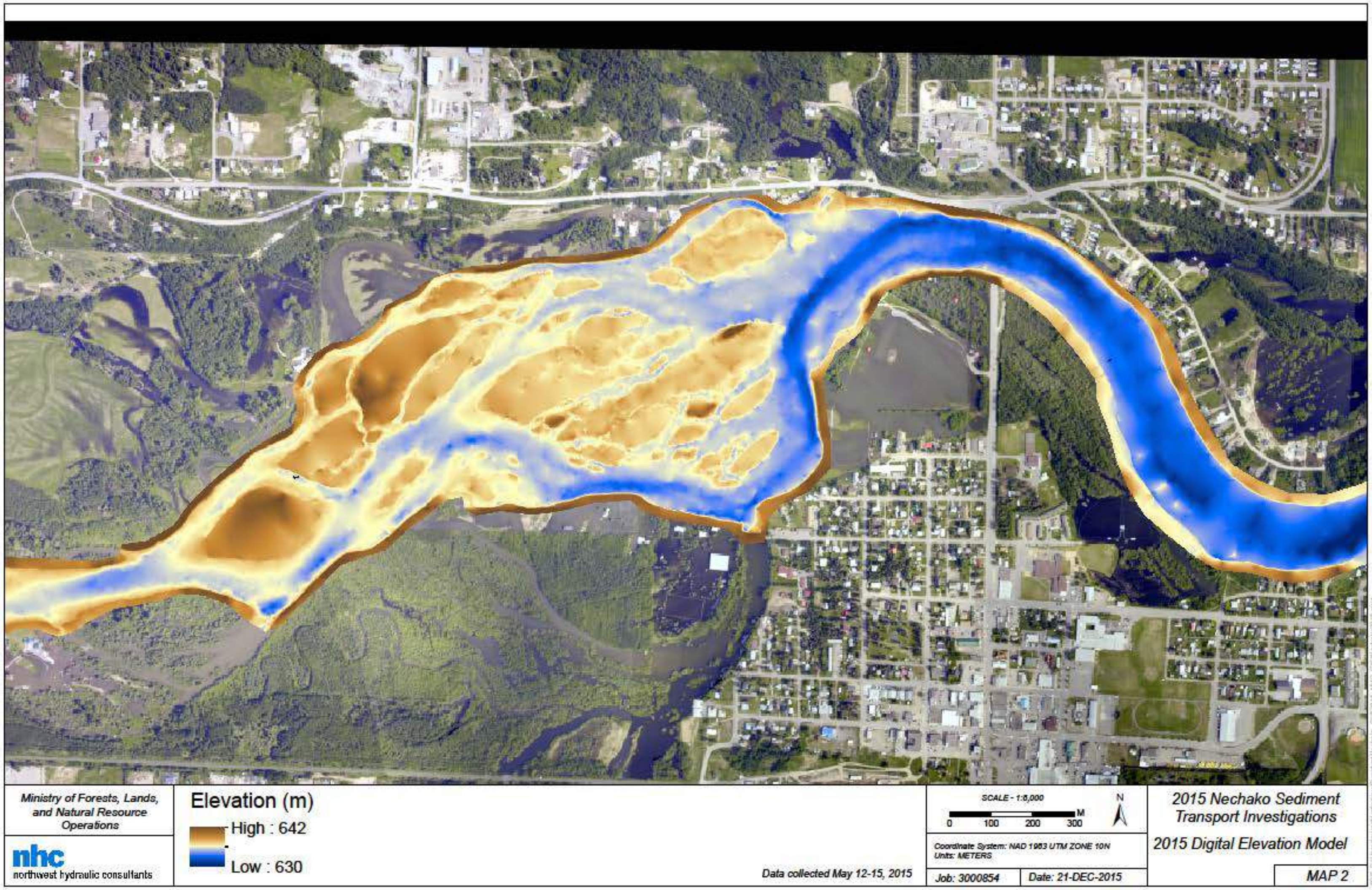
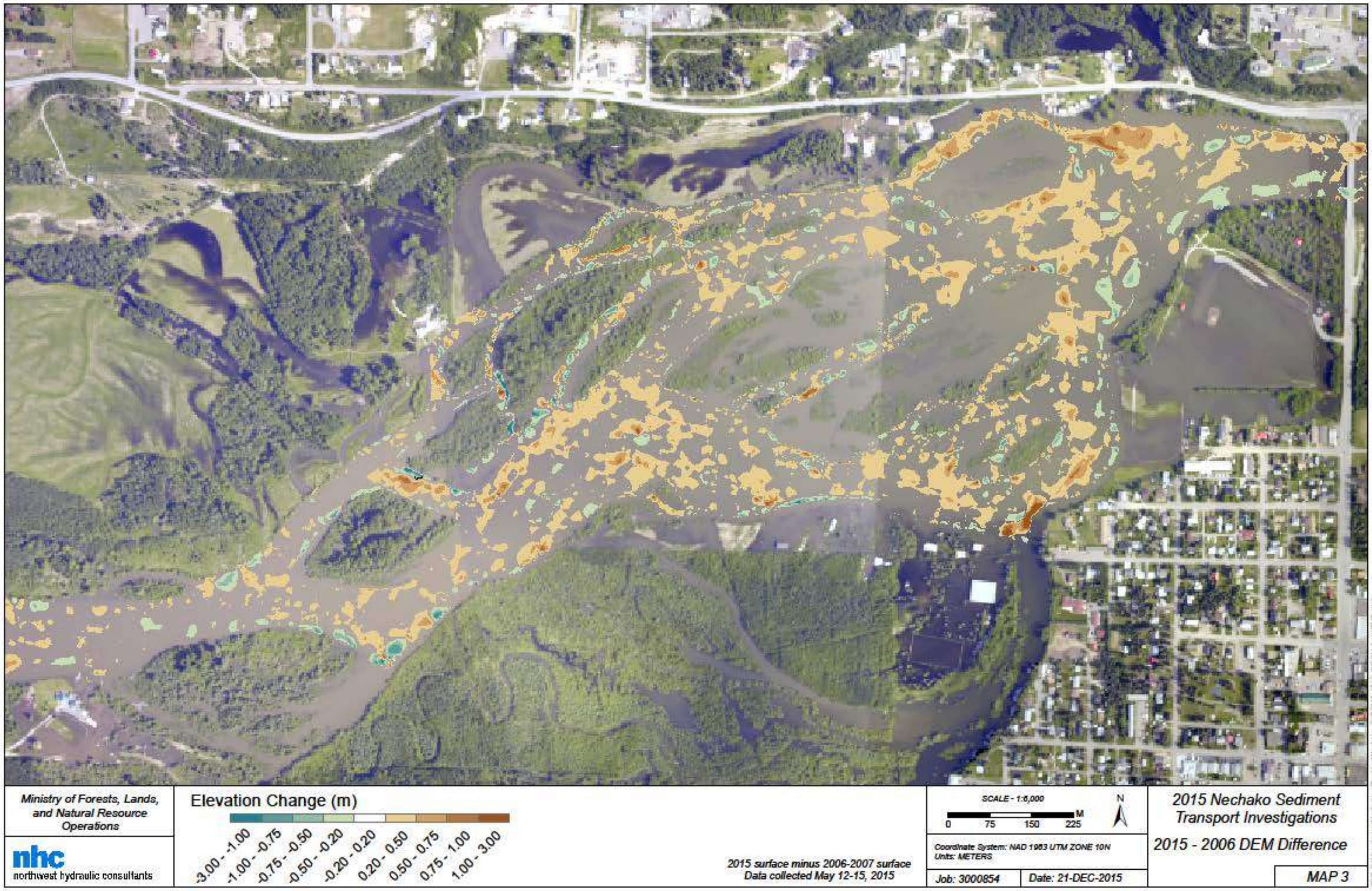
Maps



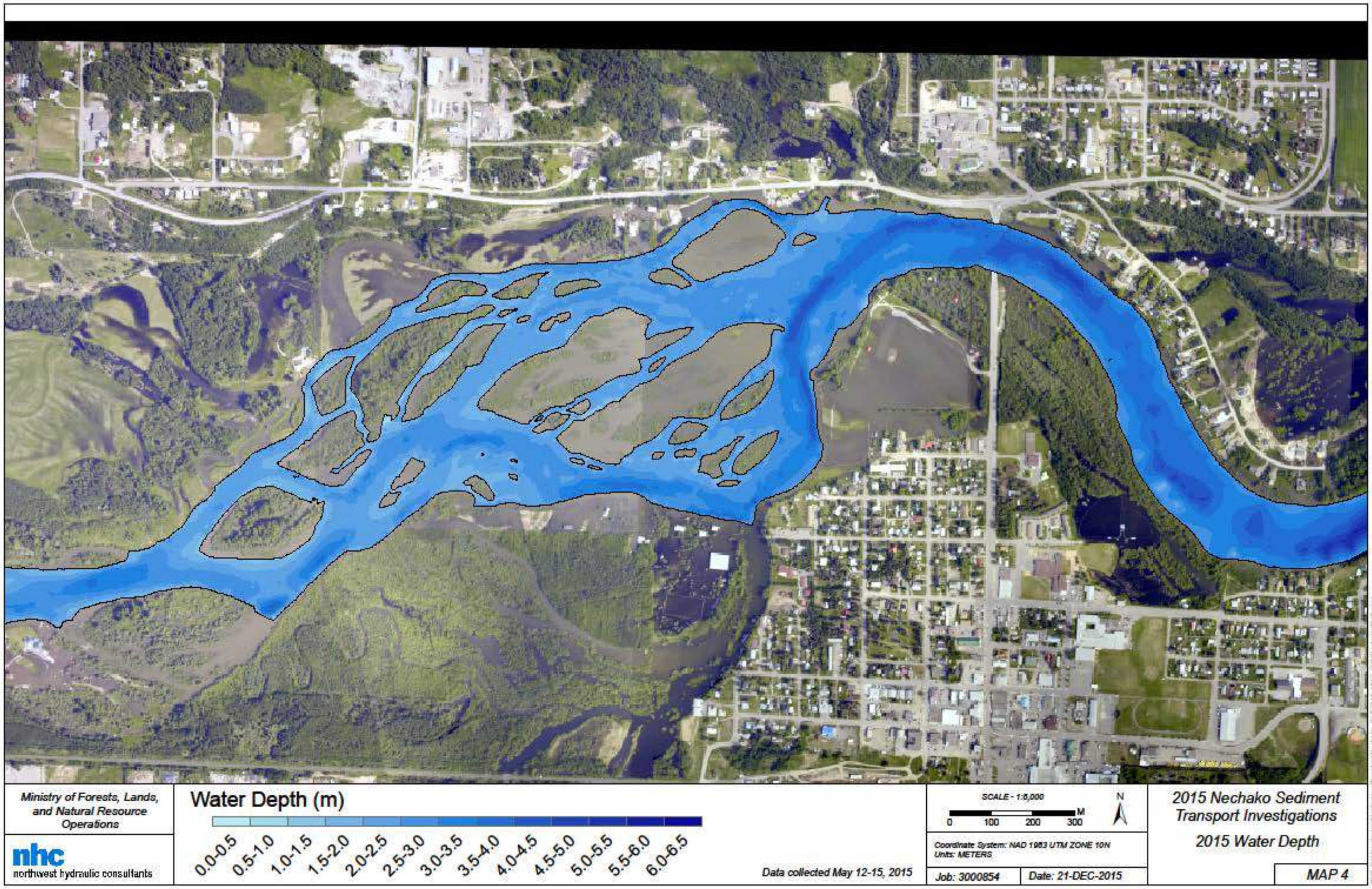
Map 1 2015 bedload and underwater imagery sampling locations



Map 2 2015 Digital Elevation Model



Map 3 Elevation change from 2006/07 to 2015



Map 4 **Water depth during discharge of approximately 525 m^3/s. Overbank flow depths not shown.**

Appendix A Bedload Transport Data

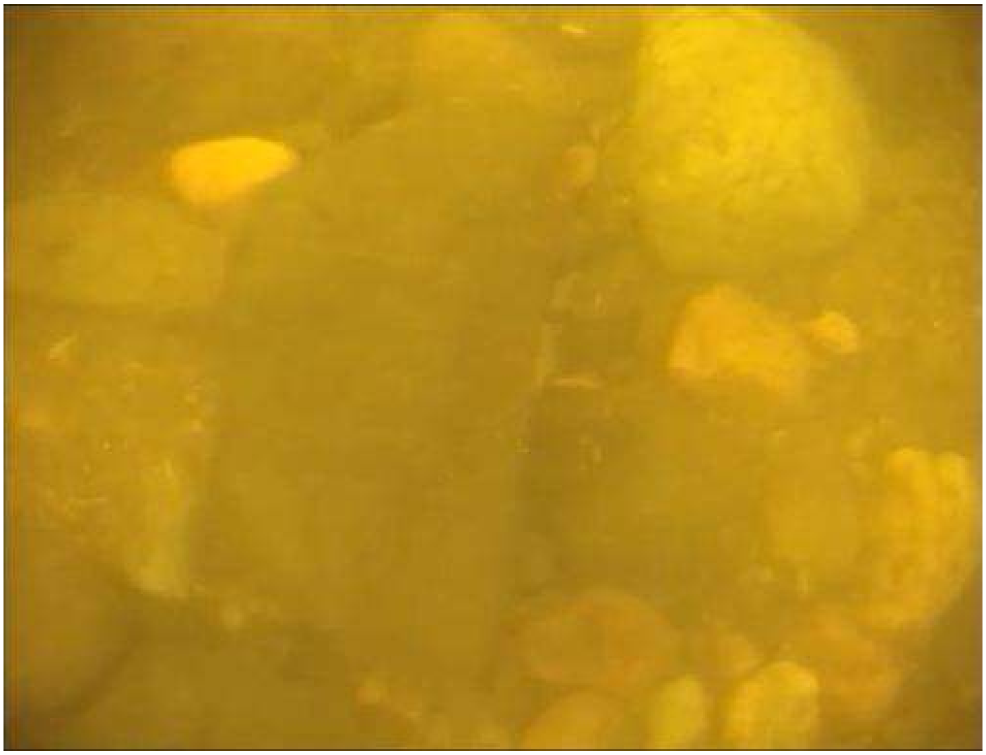
Date Collected	Sites Sampled	Sample Size (g)	Transport Rate (g/s/section)	d50 (mm)	d84 (mm)	d16 (mm)
03/22/2015	LP1 - LP11	307.48	134.51	0.39	1.68	0.26
03/29/2015	LP1 - LP12	476.42	208.41			
04/02/2015	LP2 - LP12	529.12	231.46	0.39	0.60	0.28
04/05/2015	LP1 - LP13	643.06	281.30			
04/10/2015	LP1 - LP12	175.58	76.81			
04/14/2015	LP2 - LP13	514.42	225.03			
04/21/2015	LP1 - LP10	544.56	238.22	0.40	0.71	0.27
04/23/2015	LP1 - LP12	600.62	262.74			
04/26/2015	LP1 - LP13	304.01	132.99			
04/30/2015	LP1 - LP11	349.29	152.80	0.38	0.62	0.27
05/19/2015	LP1 - LP12	582.84	254.96			
06/01/2015	LP1 - LP12	514.29	224.97	0.41	1.06	0.28
06/29/2015	LP1 - LP12	142.64	62.40	0.35	0.84	0.26
07/08/2015	LP2 - LP11	263.81	115.40	0.44	1.75	0.28
07/11/2015	LP1 - LP10	565.78	247.50			
07/13/2015	LP2 - LP12	349.63	152.94	0.39	0.65	0.27
08/01/2015	LP2 - LP12	170.04	74.38	0.35	0.70	0.26
08/06/2015	LP1 - LP12	136.68	59.79			
08/23/2015	LP2 - LP12	248.60	108.75	0.37	1.50	0.27
08/31/2015	LP2 - LP10	3,165.53	1,384.75			
09/07/2015	LP2 - LP10	2,017.76	882.66	0.80	2.99	0.36
09/26/2015	LP2 - LP7	1,063.32	465.14			
09/29/2015	LP3 - LP4	115.36	50.46			
10/17/2015	LP2 - LP3	549.20	240.24			

03/22/2015	US2 - US8	71.56	31.30	0.40	0.78	0.28
03/29/2015	US1 - US8	398.80	155.07			
04/02/2015	US1 - US9	1,118.66	489.35	0.48	0.82	0.34
04/05/2015	US2 - US7	895.90	390.82			
04/14/2015	US1 - US9	1,268.05	554.70			
04/21/2015	US1 - US8	1,086.95	475.48	0.47	0.82	0.33
04/23/2015	US1 - US9	2,715.49	1,257.75			
04/30/2015	US1 - US9	3,165.03	1,465.97	0.46	0.75	0.32
05/19/2015	US1 - US7	5,428.85	2,374.83			
05/22/2015	US1 - US9	5,743.19	2,512.33			
05/28/2015	US1 - US8	12,652.32	2,213.88	0.59	1.02	0.38
06/02/2015	US1 - US7	15,846.10	2,772.72	0.65	1.12	0.41
06/29/2015	US1 - US9	1,906.31	833.91	0.57	0.91	0.38
06/30/2015	US1 - US9	2,075.65	907.98			
07/08/2015	US1 - US8	695.67	304.32	0.76	1.92	0.38
07/11/2015	US1 - US8	657.70	287.71			
07/13/2015	US2 - US8	123.43	53.99	0.42	0.78	0.28
08/01/2015	US2 - US8	29.41	14.70	0.42	0.67	0.29
08/06/2015	US2 - US6	321.07	140.45			
08/23/2015	US3 - US8	35.35	15.46	0.84	1.92	0.40
08/31/2015	US2 - US8	0.00	0.00			

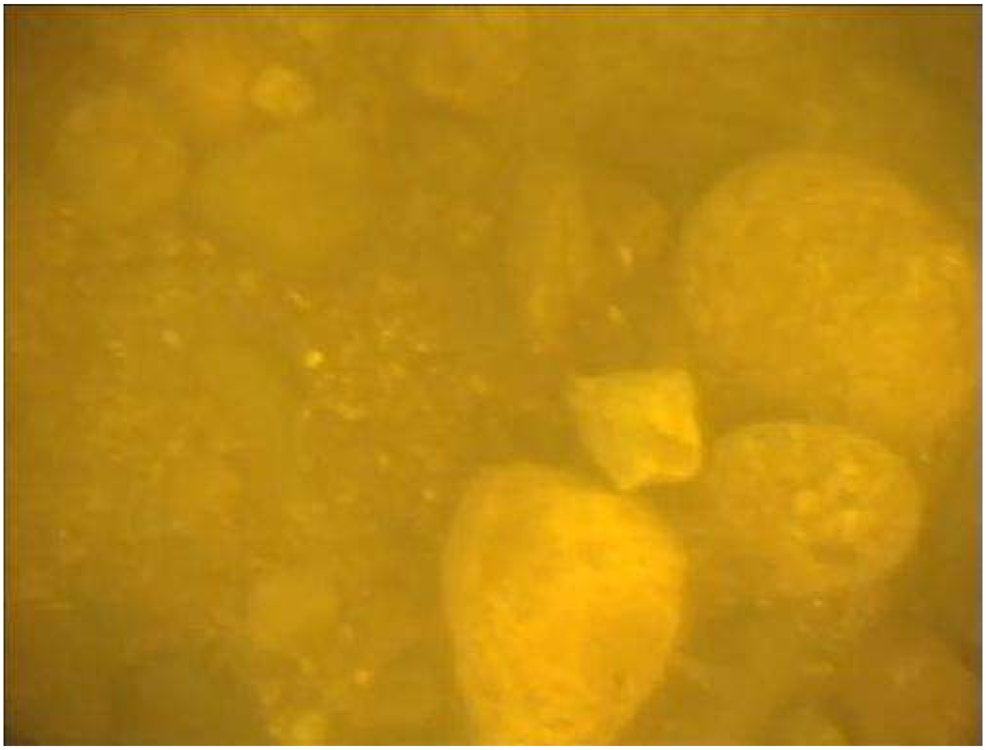
Appendix B Suspended Sediment Data

Date Collected	Position (m)	Mass (mg)					Volume (L)	Concentration (mg/L)
		500 µ	250 µ	125 µ	64 µ	<64 µ		
3/20/2015	25 - 45	0.4	0.3	1.2	3.4	53.3	1.173	50.0
3/20/2015	50 - 70	0.8	0.7	2.5	2.0	26.2	2.148	15.0
3/20/2015	75 - 95	0.9	2.4	4.0	0.9	16.9	1.967	12.8
3/20/2015	100 - 130	0.2	2.8	1.9	0.8	26.8	2.049	15.9
		0.5	**1.7**	**2.4**	**1.7**	**30.4**	**1.854**	**19.8**
3/24/2015	25 - 130	**3.5**	**1.8**	**26.6**	**7.2**	**337.0**	**10.292**	**36.5**
3/26/2015	25 - 135	**0.2**	**6.9**	**16.8**	**7.8**	**208.0**	**8.808**	**27.2**
3/27/2015	25 - 45	0.1	1.6	4.2	1.1	123.9	1.585	82.6
3/27/2015	50 - 70	4.9	3.2	9.1	4.3	87.7	2.967	36.8
3/27/2015	75 - 95	0.1	0.4	3.2	4.3	73.7	2.634	31.0
3/27/2015	100 - 135	0.3	2.5	2.3	1.9	93.6	2.760	36.4
		1.2	**2.0**	**4.4**	**2.8**	**94.6**	**2.522**	**41.6**
3/29/2015	25 - 140	**4.0**	**2.2**	**17.6**	**7.4**	**634.7**	**12.627**	**52.7**
4/1/2015	25 - 140	**1.9**	**7.4**	**7.4**	**9.8**	**461.1**	**11.860**	**41.1**
6/4/2015	15-45, 85, 125-145	1.1	0.5	1.8	1.5	52.8	3.840	15.0
6/4/2015	55-75, 95-115	0.3	0.8	2.6	3.5	77.1	5.197	16.2
		0.8	**0.6**	**2.1**	**2.4**	**63.2**	**5.383**	**12.8**
7/6/2015	20 - 140	**0.5**	**1.7**	**1.7**	**1.1**	**48.0**	**7.198**	**7.4**
8/8/2015	25 - 135	**0.5**	**0.2**	**1.4**	**1.1**	**18.0**	**4.181**	**5.1**
9/26/2015	30 - 110	**0.1**	**0.3**	**0.1**	**0.7**	**2.9**	**1.639**	**2.5**

Appendix C Underwater Imagery



07/03/2015 Upper Site US2



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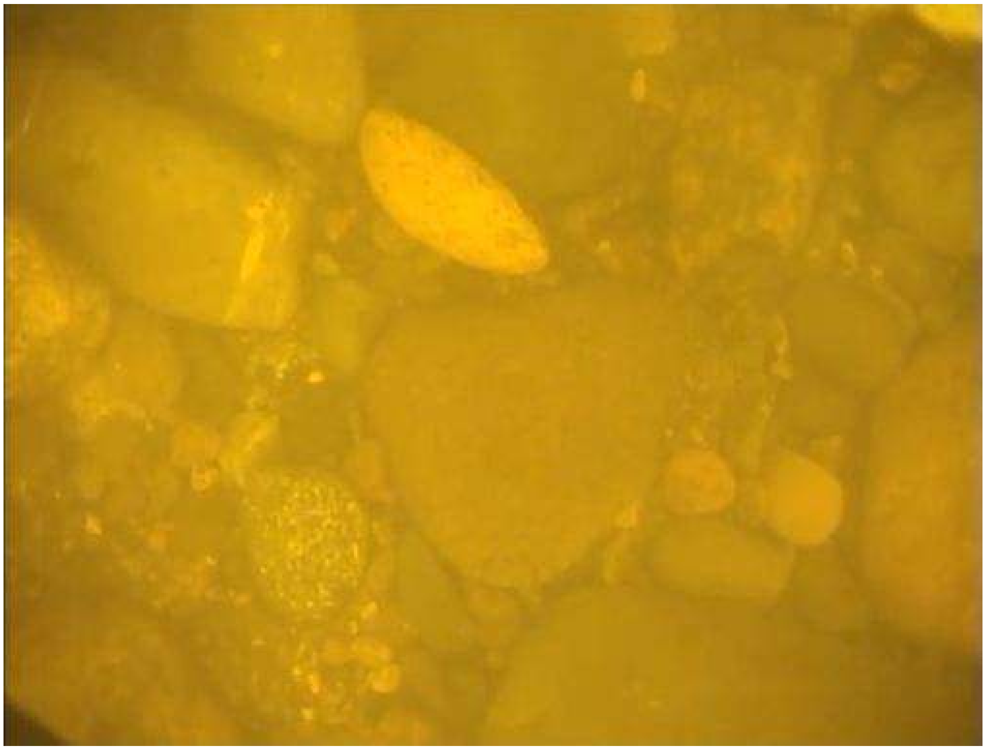

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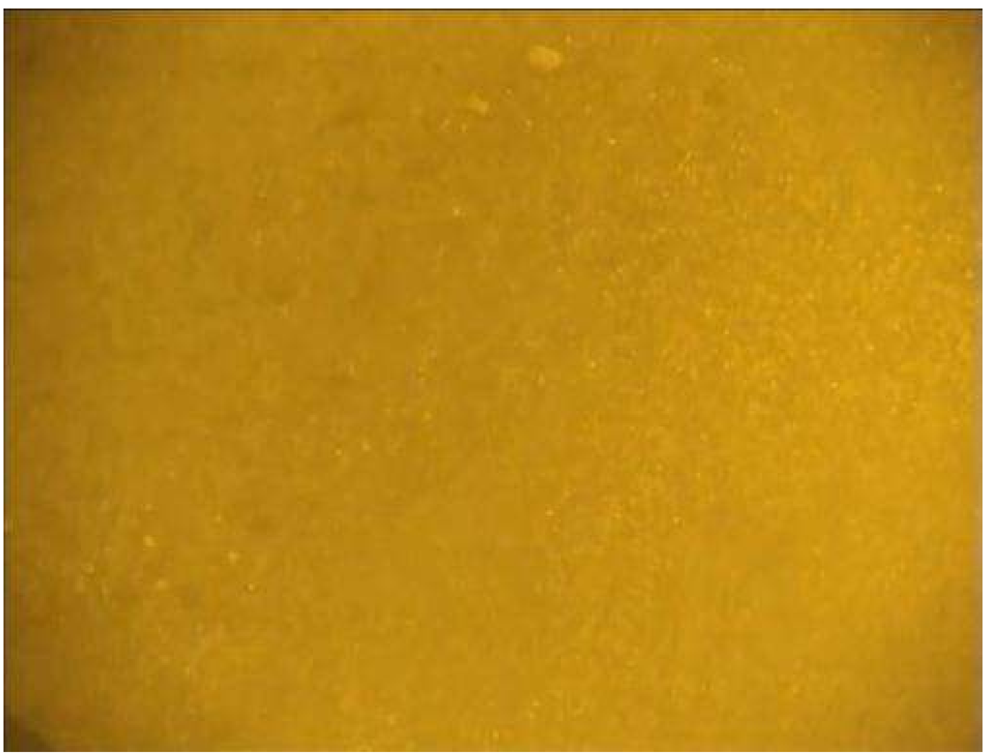

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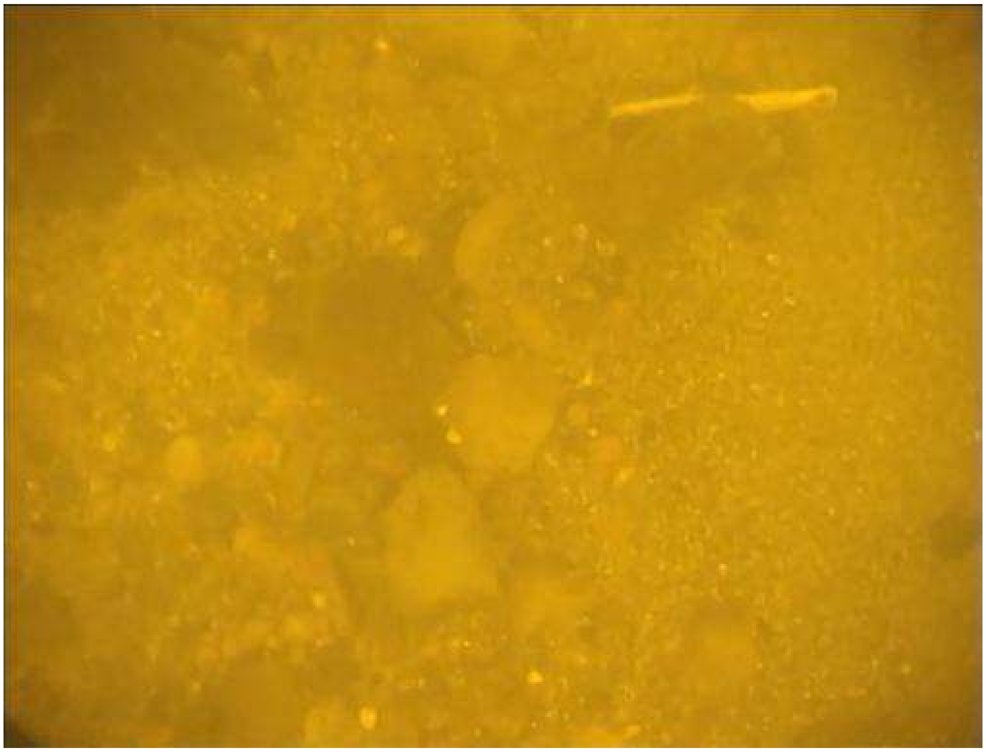

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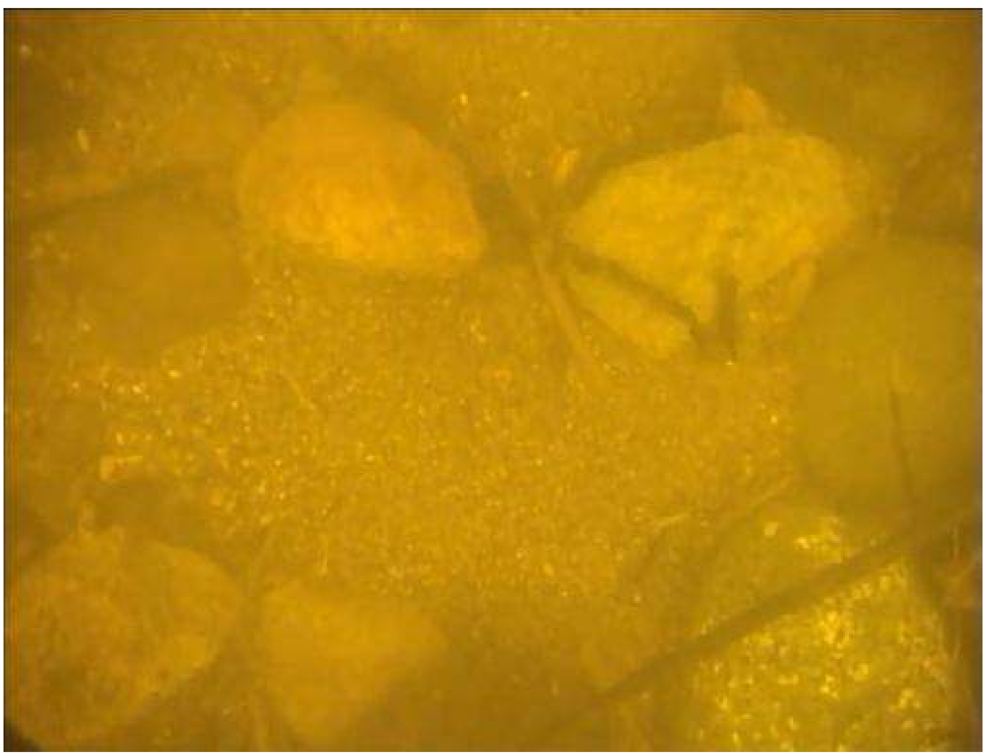

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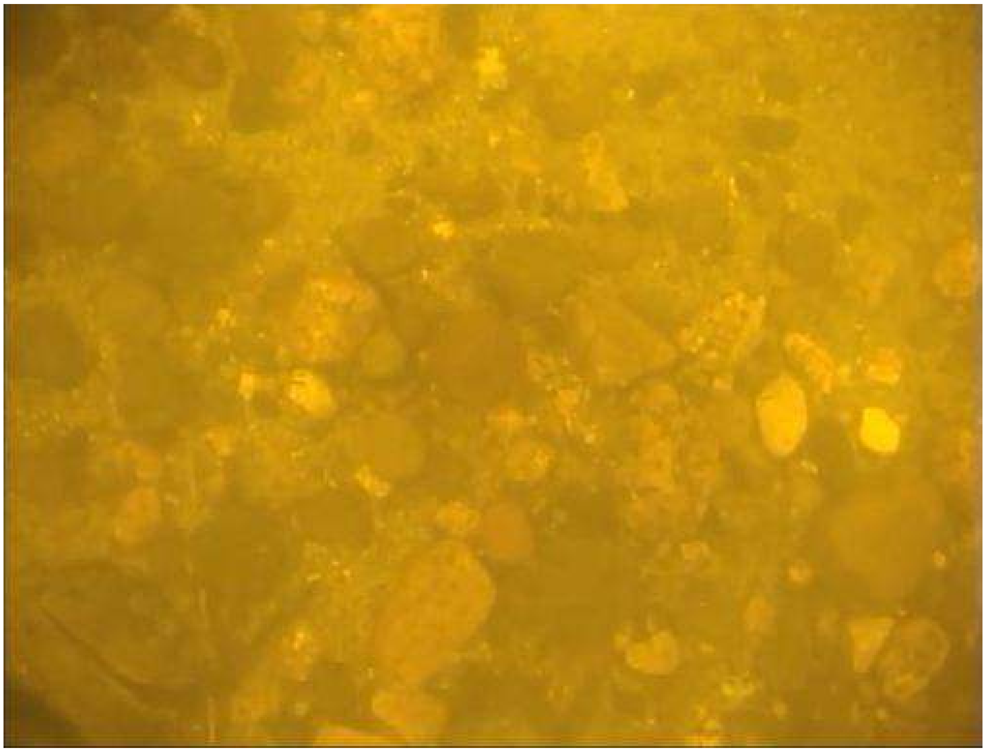

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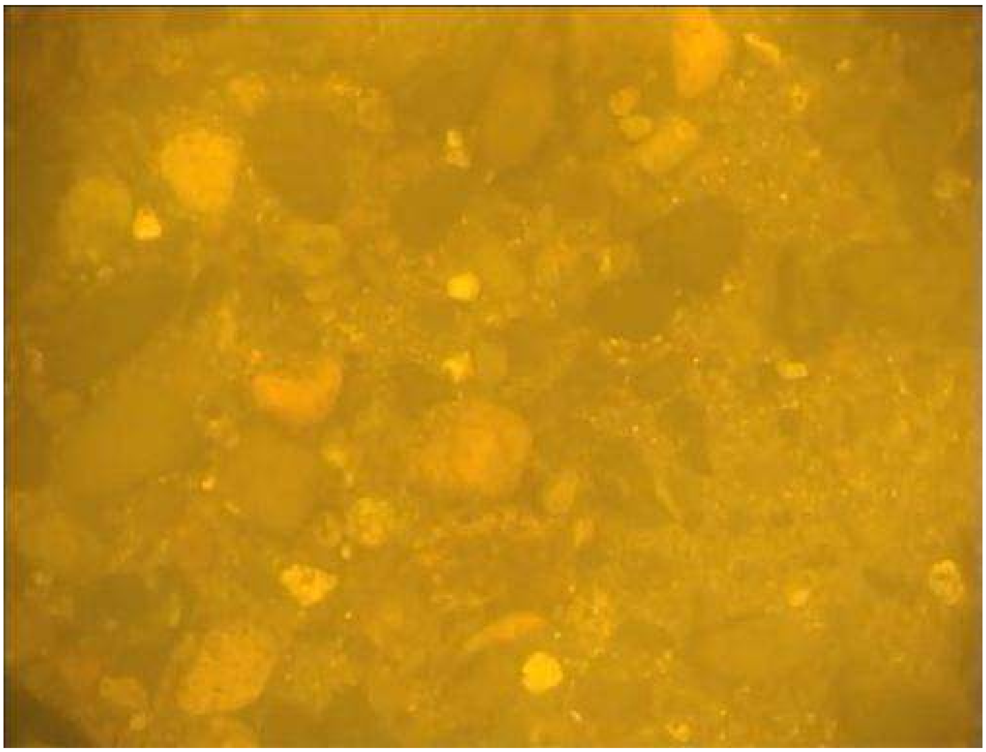

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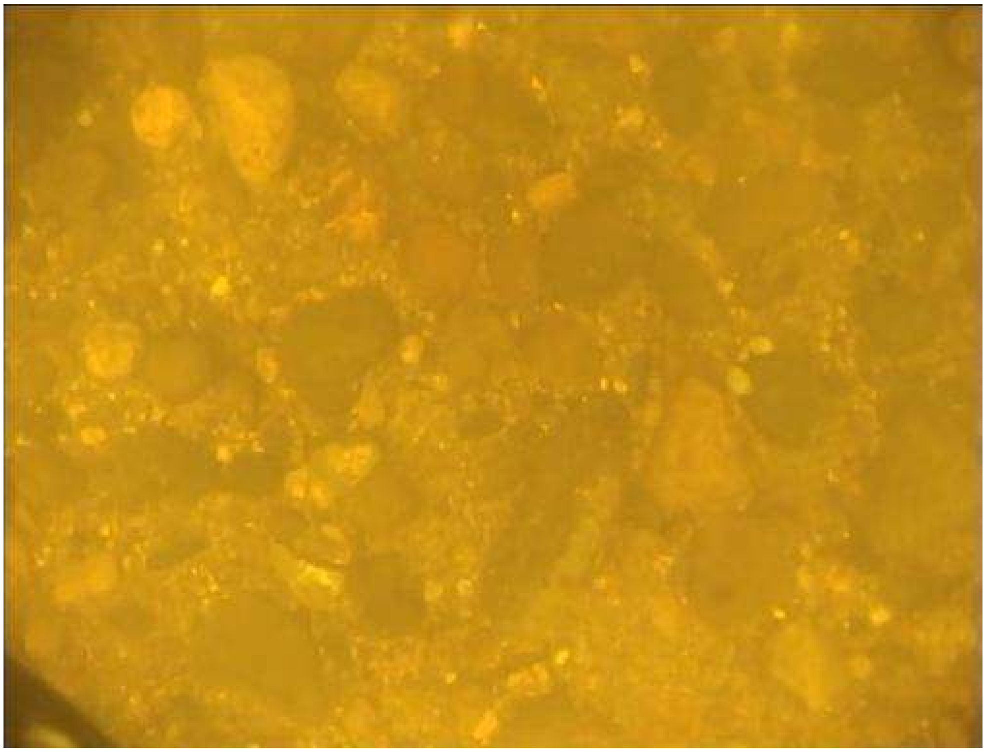

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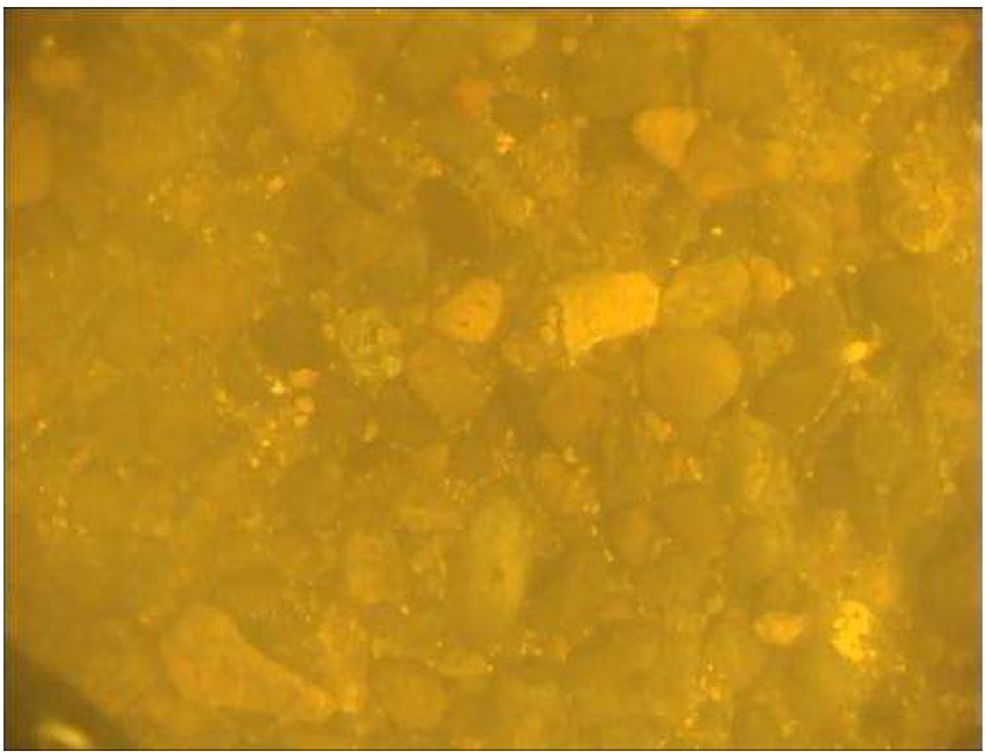

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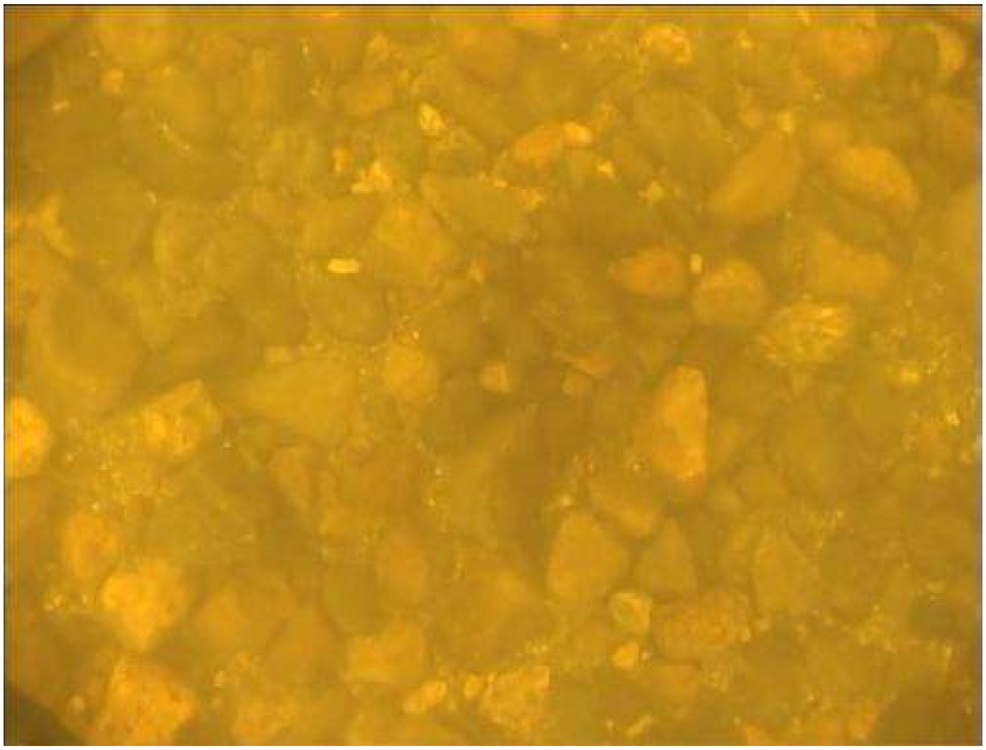

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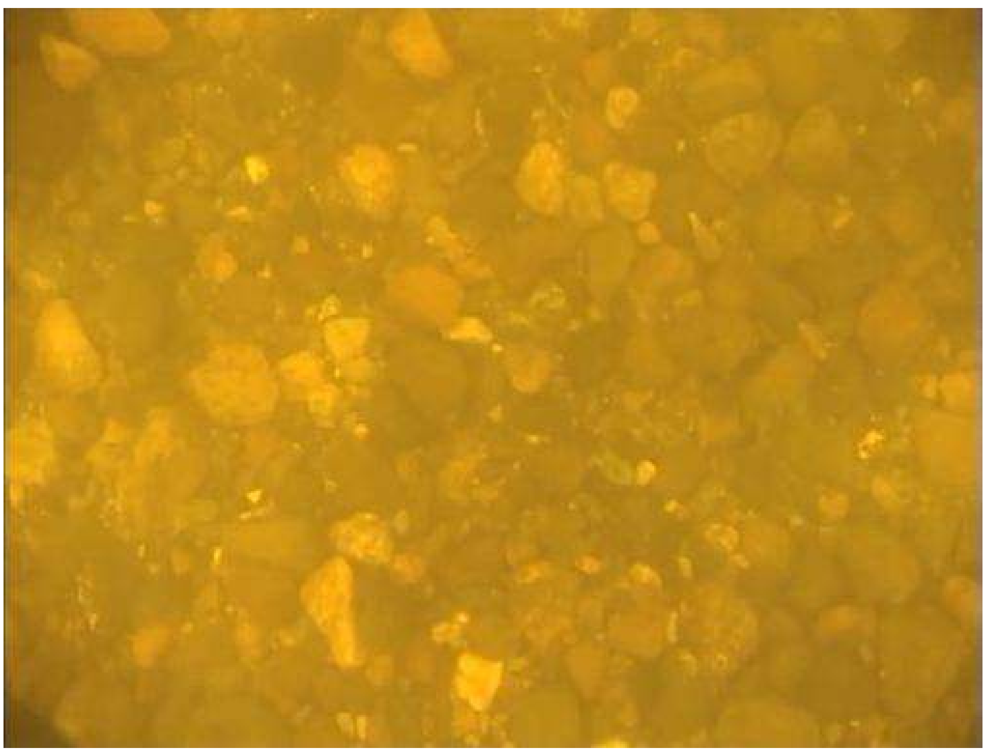

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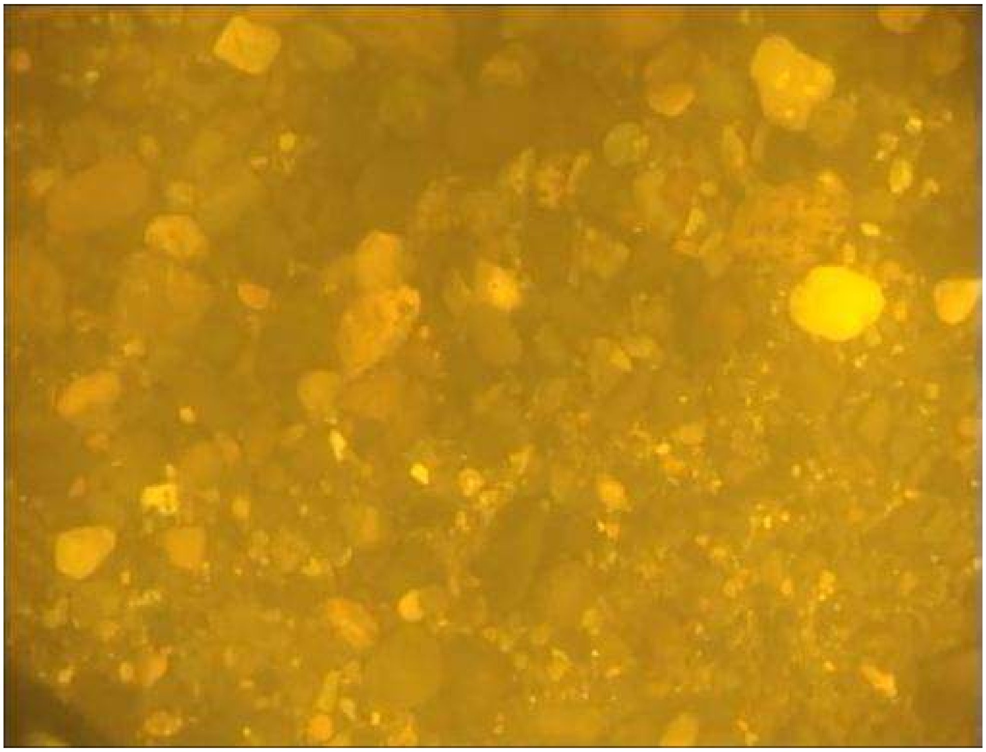

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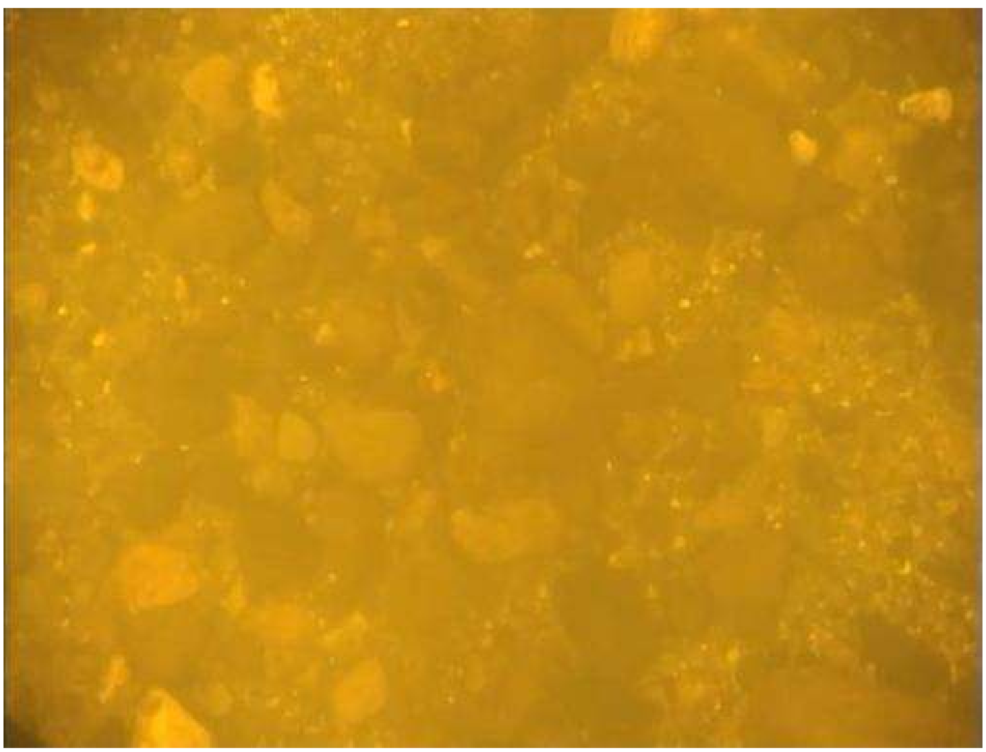

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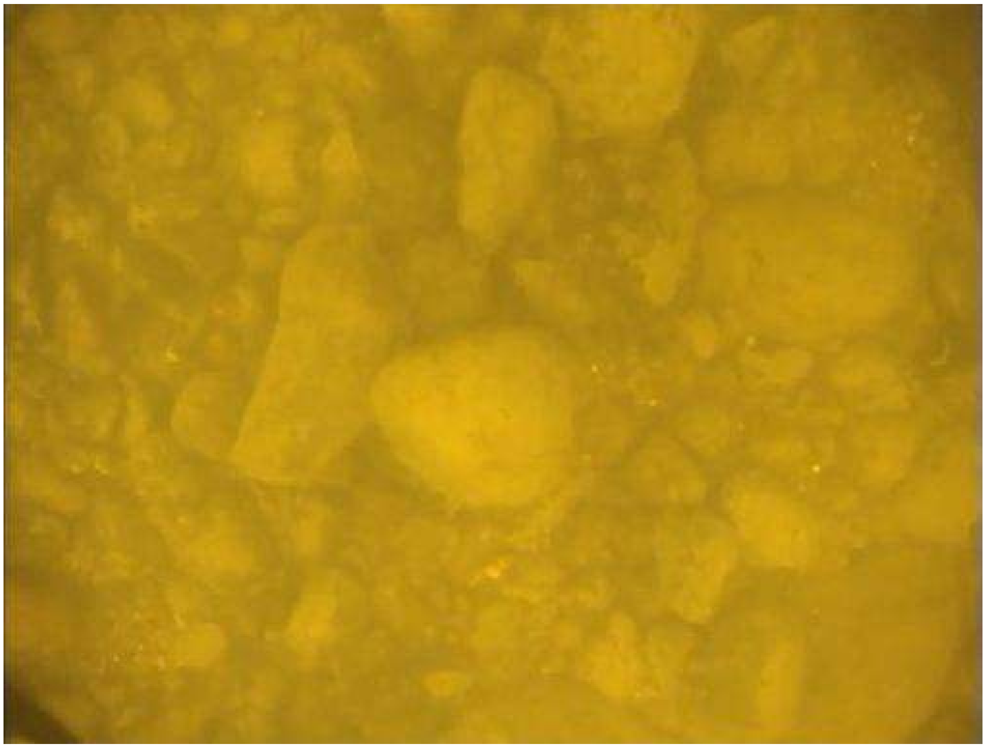
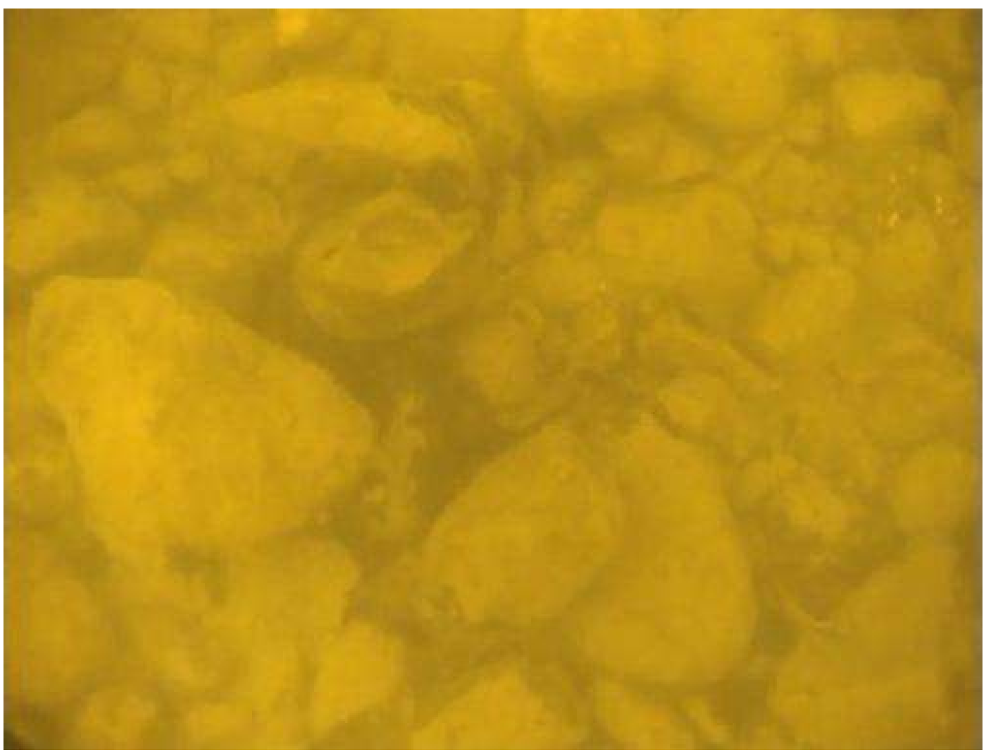


07/03/2015 Middle Patch 1 at 433343 E, 5986337 N



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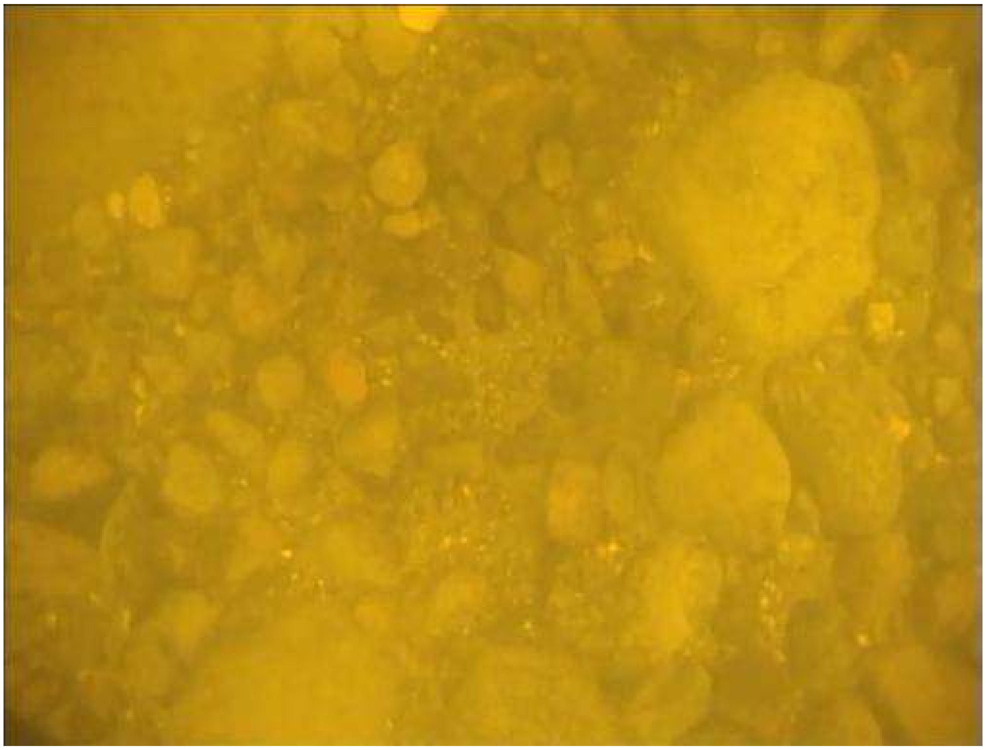

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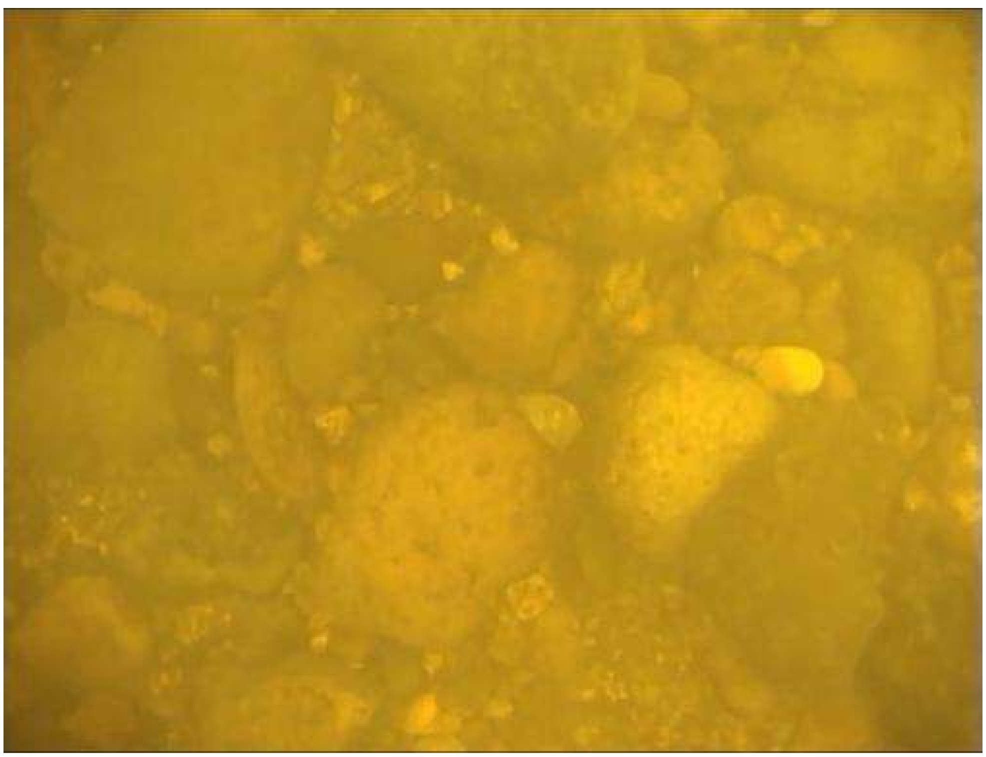
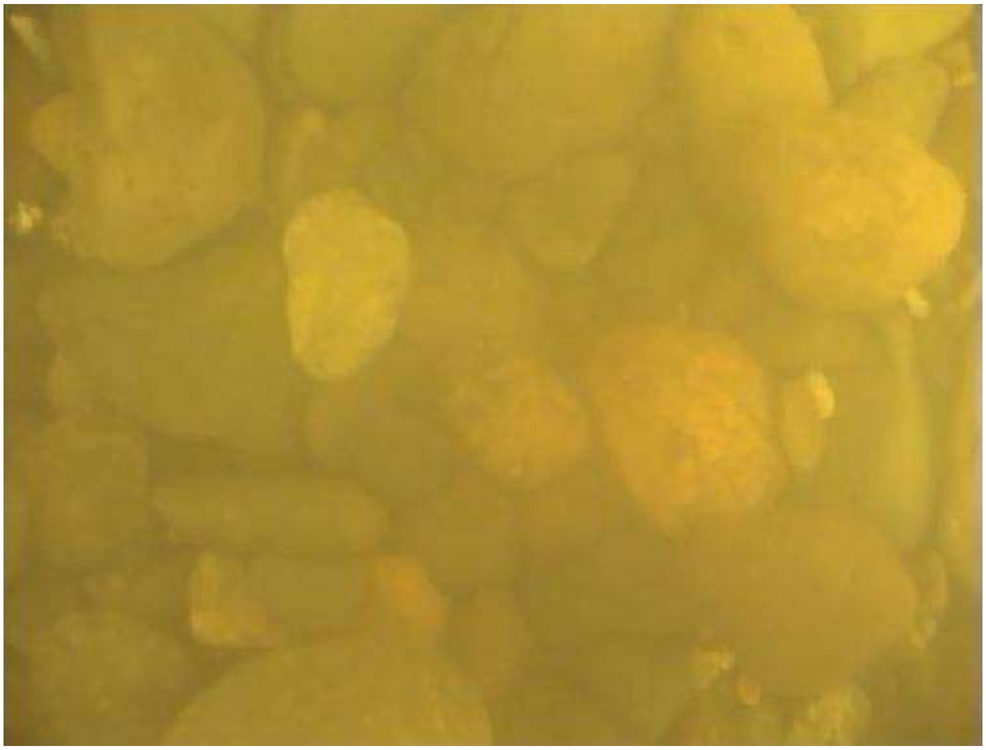


07/02/2015 Exploratory site 432340 E, 5986339 N



07/02/2015 MU5 at 432020 E, 5986260 N