Nechako Sturgeon Spawning Gravel
September 2011 Substrate Assessment

BRITISH COLUMBIA

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

NHC 35762
Final Report
March 12, 2012

nhc
northwest hydraulic consultants

EXECUTIVE SUMMARY

On September 27th and 28th, 2011, Northwest Hydraulic Consultants Ltd. (NHC) conducted an assessment of the sturgeon spawning substrate that was placed in two locations in the Nechako River at Vanderhoof BC. The substrate was originally placed in the river in May 2011 and the primary purpose of the assessment was to assess the condition of the substrate. Of particular interest was whether interstitial spaces between the stones still existed. It is thought that these spaces are required for sturgeon egg and larval survival.

The assessment was conducted with the Ministry of Forests, Lands and Natural Resource Operations personnel and boat and driver support supplied by EDI Environmental Dynamics Inc. The assessment consisted of taking freeze core samples of the substrate and collecting underwater images of the substrate. Visual inspection of the freeze cores and underwater images was used to identify if the interstitial spaces between the placed stones had filled with fine sediment.

The freeze cores and underwater images showed that at the lower site the interstitial spaces were filled with sand and fine gravel. In contrast, at the middle site the spaces were essentially free of fine sediment. The difference between the two sites may be related to where the sites are located and the path that sand and gravel take through the river. In particular the lower site is located directly downstream of an island complex and sand and gravel moving as bedload through the Nechako River appears to have moved directly over the placed substrate.

In contrast, the middle site is located on an outside bend on the right bank of the river and bedload does not appear to have moved over the majority of the placed substrate on account of the morphology and structure of secondary currents at the site. Some sediment infilling was observed at the middle site, and this infilling was likely caused by sediment that was transported in suspension as well as bedload sheets moving on the inside corner past the placed substrate.

NOTIFICATION

CITATION

NHC. 2012. *Nechako Sturgeon Spawning Gravel September, 2011 Substrate Assessment*. Prepared for Ministry of Forests, Lands and Renewable Resources. March 12th, 2012.

CERTIFICATION

Report prepared by:

Andre Zimmermann, PhD, PGeo

Report reviewed by: Barry Chilibeck, MASc, PEng

ACKNOWLEDGEMENTS

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- Zsolt Sary
- Cory Williamson

The following NHC personnel participated in the study:

- Andre Zimmermann   Geomorphologist
- Sarah North   GIS Analyst
- Barry Chilibeck   Senior Reviewer

Field support was provided by EDI Environmental Dynamics Inc.:

- Jason Yarmish

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1 INTRODUCTION

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. Northwest Hydraulic Consultants Ltd, 2002, 2006, 2009) have identified the major geomorphic changes to be vegetation encroachment, the loss of seasonally wetted floodplain and floodplain channels, a reduction in the ability to transport locally recruited and externally supplied sediment, the mass mobilization and deposition of sediment from the Cheslatta 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. A critically important spawning reach has been identified at Vanderhoof and a series of investigations have been conducted to assess the historical and contemporary nature of this reach (Northwest Hydraulic Consultants Ltd, 2006 is particularly relevant). These investigations have revealed the following:

- The spawning reach occurs at a distinct reduction in channel gradient (0.06 % upstream to 0.03 % downstream (Northwest Hydraulic Consultants Ltd, 2006)).
- The substrate at the top of the reach is cobble-gravel while the substrate at the downstream end of the reach is gravel-sand.
- The construction of the south causeway to the Burrard Avenue Bridge, which occurred prior to 1928, eliminated floodplain conveyance and reduced the conveyance width to 150 m. This has promoted the deposition of finer sediment and larger quantities of sediment upstream of the bridge (Northwest Hydraulic Consultants Ltd, 2006).
- The Cheslatta fan avulsions that occurred between the late 1950's and 1972 introduced 0.86 to 1.1 million cubic meters to the Nechako River (Northwest Hydraulic Consultants Ltd, 2009).
- Sand and fine gravel from the Cheslatta avulsions have moved 30 to 40 km downstream of Vanderhoof (Northwest Hydraulic Consultants Ltd., 2003).
- At the end of the last major glaciation, as the ice melted, glaciated lakes and deltas formed and these deposited clays, silts and sands on the landscape resulting in the formation of the Nechako plains (Armstrong and Tipper, 1948; Holland, 1976). On account of the agricultural and forestry land-use in the area, and the fine grained nature of the deposits, the uplands likely contribute suspended and bedload to the Nechako River.
- Regional sediment yield data suggest that over the last 50 years, 2 million cubic meters of bedload may have been supplied to the Nechako River upstream of Vanderhoof1. This contribution is similar in magnitude to the contribution from the Cheslatta fan.

[1] The basin area downstream of the Cheslatta fan, but upstream of Vanderhoof, excluding the area upstream of Fraser Lake is approximately 3600 km^2. The bedload yield has been estimated by assuming the suspended sediment yield is 0.7 $Mg/km^2/day$ (Church et al., 1989) and assuming bedload is 10 % of the suspended load.

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 Cheslatta fan and the upstream watershed. Flow regulation and channel confinement have likely increased the deposition of sediment in the reach.

1.2 Scope of Work

To improve the availability of clean coarse gravel-cobble substrate that White Sturgeon can use to spawn, two patches of substrate were placed in the Nechako River in May of 2011. The substrate is intended to provide interstitial spaces that sturgeon eggs can fall between and larvae can hide in and thereby reduce predation. If the interstitial spaces become filled with fine sediment the effectiveness of the substrate is reduced.

To examine the condition of the substrate following the 2011 freshet, NHC conducted a substrate condition assessment in late September with Ministry of Forests, Lands and Natural Resource Operations personnel and boat and driver support supplied by EDI Environmental Dynamics Inc. The purpose of this report is to document the assessment approach and substrate condition, and make recommendations for additional monitoring, modelling and enhancement opportunities.

Within the report the Wentworth scale is used to describe substrate size. For reference, the scale is provided in Table 1.

Table 1: Wentworth grain size scale.

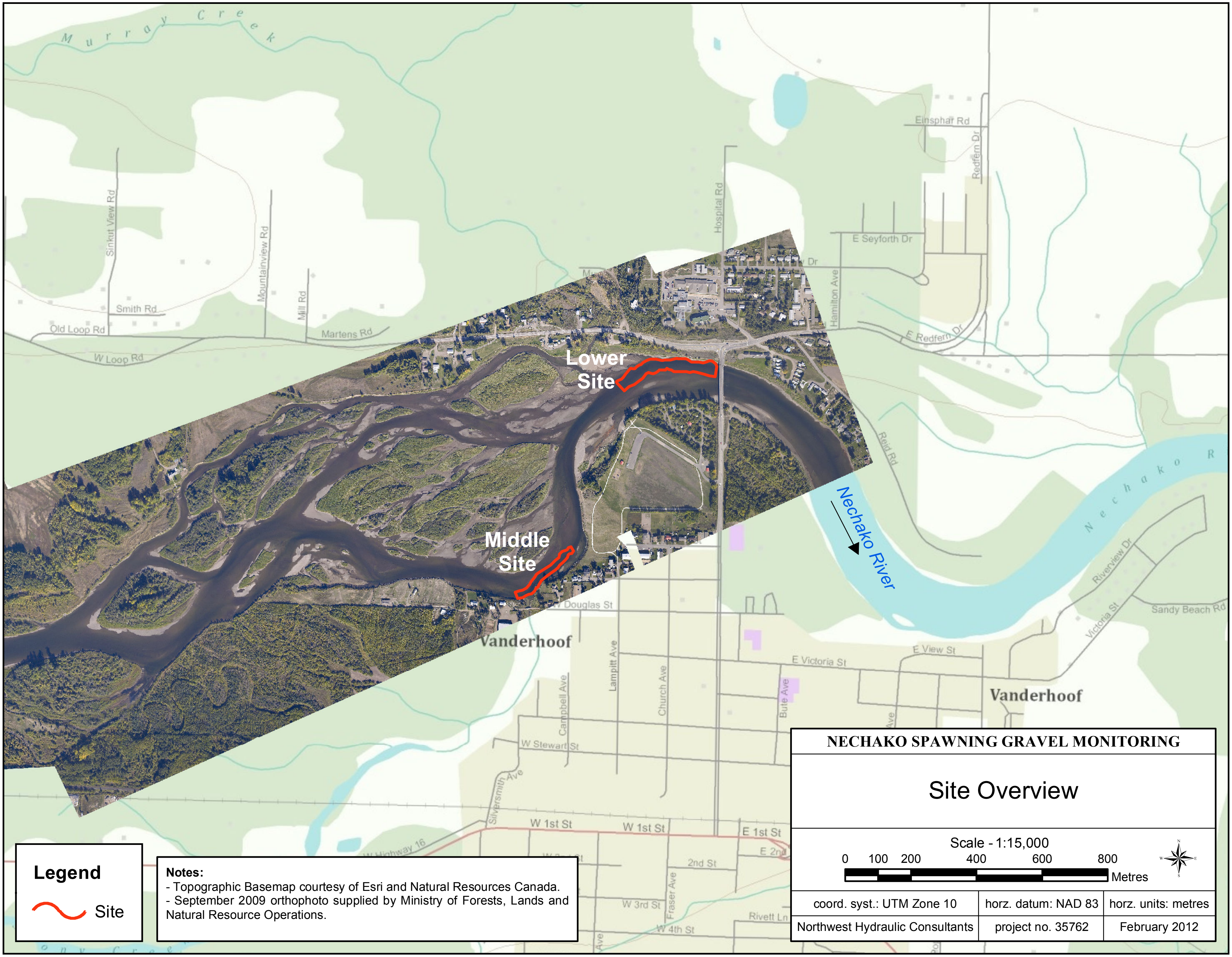
Length of b-axis (mm)	Wentworth Size Class
>256	Boulder
64-256	Cobble
32-64	Very Coarse Gravel
16-32	Coarse Gravel
8-16	Medium Gravel
4-8	Fine Gravel
2-4	Very Fine Gravel
1-2	Very Coarse Sand
0.5-1	Coarse Sand
0.25-0.5	Medium Sand
0.125-0.25	Fine Sand
0.064-0.125	Very Fine Sand
0.0039-0.064	Silt
<0.0039	Clay

2 SITE DESCRIPTION

Substrate was placed in two pools just upstream of the Burrard Avenue Bridge in Vanderhoof BC (Figure 2). The locations are referred to herein as the lower and middle site as an upper site was identified during the planning phase of the project, but no substrate was placed at this third location. As-built surveys were not completed following the placement of the substrate, thus it is difficult to know the exact extent of the placed material; nevertheless, the observed placed substrate appears to more or less correspond to the design drawings.

The lower site is visible in Figure 1 and is just downstream of the confluence of the main channel with a number of smaller channels that flow through an island complex. The middle site is on the right bank of the Nechako River and has a tributary enter the site near the top of the site. At both sites water depths varied between about 0.8 and 2 m and were locally deeper at the middle site. During the sampling the discharge in the Nechako River at Vanderhoof was about 100 m^3/s (based on preliminary WSC data at the 08JC001 gauge). The placed material was specified to be between 20 and 200 mm, with 20-30 % in the 20-40 mm range and 30-50 % being between 150 and 200 mm.

Figure 1: Lower substrate placement location. Substrate was placed in pool on right side of image in the region highlighted by the polygon.



Legend

Site

Notes:
- Topographic Basemap courtesy of Esri and Natural Resources Canada.
- September 2009 orthophoto supplied by Ministry of Forests, Lands and Natural Resource Operations.

NECHAKO SPAWNING GRAVEL MONITORING		
Site Overview		
Scale - 1:15,000 (0, 100, 200, 400, 600, 800 Metres)		
coord. syst.: UTM Zone 10	horz. datum: NAD 83	horz. units: metres
Northwest Hydraulic Consultants	project no. 35762	February 2012

MSN, \\192.168.100.12\projects\35762 Nechako Sturgeon Gravel\GIS\35762_MSN_Fig_Overview1.mxd

Figure 2

3 FREEZE CORE OBSERVATIONS

To collect samples of the substrate a 2.5 or 3 m long metal pipe was hammered into the bed, and then 5 liters of liquid nitrogen were slowly poured into the pipe (Figure 3). While the liquid nitrogen was evaporating heat was extracted out of the substrate around the core and as a result the substrate became frozen to the core (Figure 4). Once the liquid nitrogen quit evaporating the core was pulled from the bed and the sediment sample inspected. The initial sampling plan was to have 6 high quality cores from each of the pads that were distributed across the pad. In total 15 cores were collected, which required 160 Liters of Liquid Nitrogen (Figure 5).

Part way through the sampling it was observed that if the interstitial spaces were free of sediment that the big stones would not be frozen to the core and that the top portion of the core would not have any sediment (Figure 4). This occurred as the river flow provided enough turbulence and water exchange to prevent the water in the interstitial spaces from freezing. Once this was observed, we began to note the elevation of the bed on the core before extracting the core.

The elevation was noted by standing the liquid nitrogen feeding pipe on the bed of the river adjacent to the inserted core. The elevation of the injection tube relative to the top of the core was measured, and this distance was subsequently used to calculate the bed elevation relative to the tip of the core. Distances were considered accurate to +/- 4 cm.

Figure 3: Liquid nitrogen being poured into the funnel that leads into a 20 mm diameter pipe that has an outlet 10-30 cm below the bottom of the core.

Figure 4: Freeze Core # 13 from the middle site. The frosty metal pipe on the left approximates the top of the substrate elevation for this core. The coarser material is the placed material while the finer gravel and sand is the native material. Material between the frosty pipe and the top of the frozen sediment was not recovered as the interstitial spaces were not full of water and did not freeze.

Figure 5: Two 160 Litre dewers of liquid nitrogen are in the back of the truck and a 10 L dewer used to pour liquid nitrogen into the cores is visible in the foreground.

3.1 Lower Site Freeze Core Observations

Map 1 shows the cores and sampling locations at the lower site. In general these cores were characterized as having fine gravel and sand frozen to the pipe up to the water-sediment interface indicating that the interstitial spaces were filled with fines. The fines that filled the interstitial spaces ranged from medium sand to medium gravel. Coarse sand and fine gravel were dominant. In comparison the native material had considerably more medium and coarse gravel.

Most of the material deposited into the interstitial spaces would have been transported as bedload along the bottom of the river and as a result it is likely that the pads progressively filled in a downstream direction. Some of the cores do have finer sand within the matrix that would have been transported as suspended sediment. The sediment that filled in interstitial spaces was not the same at all of the core locations. At some locations it was more dominated by sand (e.g. Core 3), while at other locations it was primarily gravel (Core 2).

Visual inspection of the cores suggests that the substrate at the downstream end of the pad was as filled with fine sediment as substrate near the upstream end of the pad. While the design called for a 20 centimeter thick pad of substrate, the cores suggest that the thickness was spatially variable and in some areas the thickness was less than 20 cm.

Figure 6: Photo of Core 5 from the lower site. Fine gravel and coarse sand fill the interstitial spaces around the larger placed stones. The substrate below the larger stones is the native material. The native material is composed of clast supported gravels with a sand matrix.

Figure 7: Core 3 from the lower site. The abrupt transition at 26 cm represents the transition from the native material (to the right) to the placed material. The fine matrix material that has filled in the interstitial spaces between the placed sediment grades from medium to fine sand at the bottom of the placed material to coarse sand at the top. The vertical coarsening likely represents the progressive infilling of the substrate as coarser material began to move downstream over the pad and infill the pores.

3.2 Middle Site Freeze Core Observations

The freeze cores from the middle site were distinctly different than the cores from the lower site (Map 2). In particular, the top portion of the cores had ice filled interstitial spaces and in general there was only a small amount of fine sediment in the interstitial spaces. Core 8 was from near the upstream end of the pad on the inside corner of the bend, the area most likely to be first exposed to passing bedload, yet fine gravel and coarse sand did not fill the pores (Figure 8). With this core, the interstitial spaces at the base of the placed substrate were partially filled with fine sand and organics that would likely have moved in suspension.

Figure 9 shows Core 8 inserted into the pad, the substrate is about 1.5 core diameters below the insulating rubber sleeve. When the core was extracted no sediment was within at least the first 3 core diameters, suggesting the pore spaces were too free of fines for freezing to occur at the top portion of the core. It appears that the middle pad is still functional and that only the bottom 2-7 cm of the placed sediment has been filled with fine sediment. The fines that have been deposited were likely transported as suspended load.

Figure 8: Core 8 from the middle site. The top portion of the substrate has ice filled interstitial spaces while the bottom portion of the substrate has fine to medium sand with organics in the interstitial spaces. Below the placed material the native substrate is similar to the lower site.

Figure 9: Core 8 inserted into the bed near the upstream end of the middle pad.

Figure 10: A photo of Core 9 showing the ice filled pore spaces. The fine sediment that does occur would have likely moved as suspended sediment. The placed pad was evidently quite thick at this location.

Figure 11: Core 10 from the middle pad. Placed material was relatively thin at this site and confined to the top 10 cm of the core. The rest of the core shows the native material and suggests bedload sheets with a thickness of about 7 cm are common.

4 UNDERWATER CAMERA OBSERVATIONS

Underwater images of the substrate were collected with NHC's Video-GPS data acquisition system. The system collects GPS data from a handheld GPS and still images from a SeaViewer Underwater Camera. Subsequently the images are reviewed and good images are saved and the dominant substrate type in each image is classified. For this project substrate types included:

- Sand
- Gravel (clean of sand in interstitial spaces)
- Cobble (clean of sand in interstitial spaces)
- Gravel/Sand, and
- Cobble/Sand

The location of each of the images was subsequently plotted in GIS and color coded using the substrate type. These data are shown in Map 1 and Map 2.

4.1 LOWER SITE UNDERWATER CAMERA OBSERVATIONS

The underwater camera photos from the lower site show that much of the placed substrate had sand and gravel washed in around the placed material (Photo 1). Two of the images at the downstream end of the pad suggest that the interstitial spaces are not completely full of fines; however, these conditions are rare. The underwater images also suggest that freshwater mussels have extensively colonized the pads. Mussels were also collected with the freeze cores.

Photo 1: Image of substrate 46 m upstream of end of downstream placed substrate pad. Fines are visible around most of the large stones. It appears that four mussels have colonized the area in the image.

Photo 2: Image of substrate 28 m upstream of end of downstream placed substrate pad. Fine gravel is visible around all of the cobbles.

Photo 3: Image of substrate 23 m upstream of end of downstream placed substrate pad. Fines are visible around some of the large stones, but some interstitial spaces remain. Two mussels have colonized the substrate.

4.2 MIDDLE SITE UNDERWATER CAMERA OBSERVATIONS

The underwater camera images from the middle site show that the majority of the interstitial spaces were clear of fine sediment (e.g. Photo 4, Photo 5 and Photo 6). However, along the left bank side of the pad, particularly near the upstream end of the pad, there were areas where sand/fine gravel had washed in over top of the placed substrate (e.g. Photo 7 and the area downstream of Core 8 on Map 2). In general the middle site interstitial spaces remain clear of fine sediment, however, bedload sheets have likely filled portions of the substrate along the left edge of the pad.

4.3 NATIVE MATERIAL UNDERWATER CAMERA OBSERVATIONS

To compare the pad substrate to the native material a limited number of underwater images were taken in areas outside of the placed substrate. These images show that the native substrate is primary gravel (Photo 8). In some areas the gravel is covered with a drape of coarse sand (e.g. Photo 9). The sand drape over the gravel substrate further emphasizes that there is a large supply of sand bedload in the Nechako River.

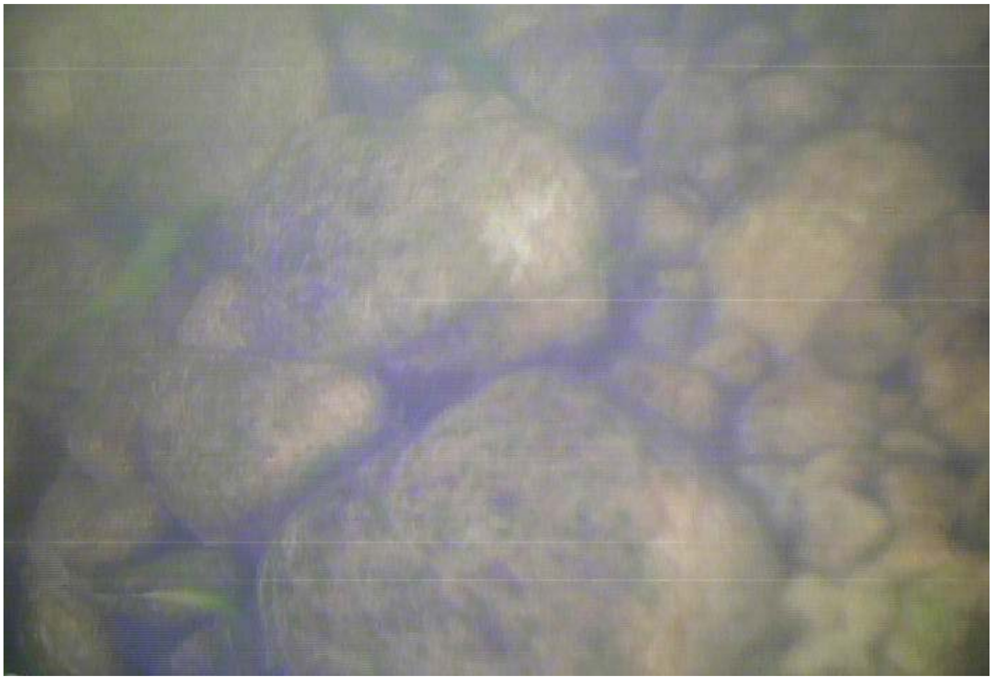


Photo 4: Placed substrate near the center of the middle pad. Sand and gravel are not visible in the interstitial spaces.

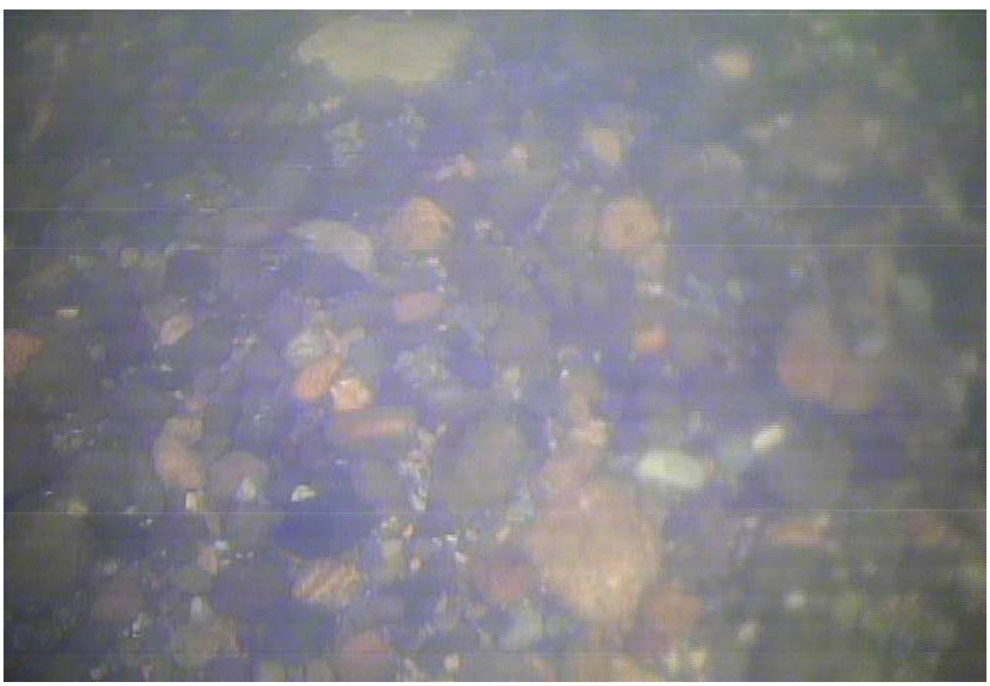


Photo 5: Photo from near the center of the middle pad that shows gravel with no visible sand.

Photo 6: Photo illustrating open interstitial spaces between placed material in middle pad. If sand/gravel bedload was moving over this substrate we would expect to see some material under the large stone in the upper right corner of the image.

Photo 7: Photo with sand and fine gravel being deposited overtop of coarse gravel substrate. Sand and fine gravel appear only in top portion of image suggesting that the finer material has been washed in as part of a bedload sheet that was moving along the inside corner of the river. Photo is from area between core number 11 and 12 on the left bank side of the placed material (see Map 2).

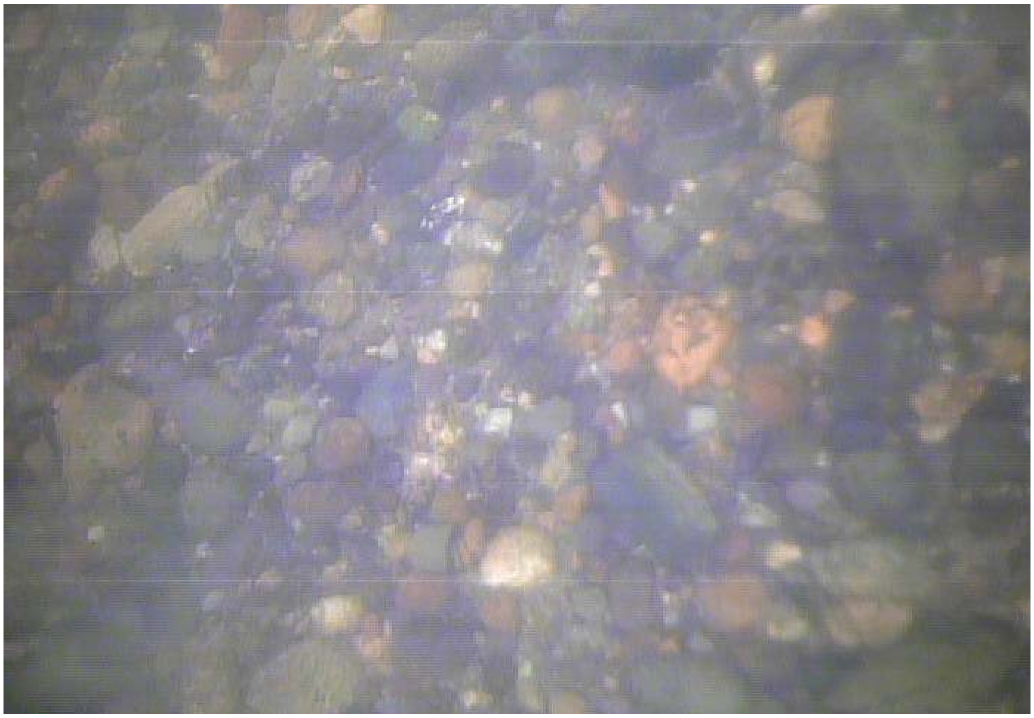


Photo 8: Image of native substrate that does not have a sand drape over the gravel. Photo taken 45 m upstream of lower pad in center of channel.

Photo 9: Image of native substrate showing sand drape over gravel. Photo taken just upstream of lower pad in center of channel.

5 2011 Freshet and Sediment Mobility

The 2011 freshet had a discharge of peak about 500 m^3/s and lasted for about two months (Figure 12). Based on daily data from 1962-2005, the 2011 flood peak had a return interval between 2 and 5 years; however, the duration was exceptionally long. Despite the relatively high flows the placed substrate did not move. Images of the substrate suggest that the placed material will remain stable during most, if not all, flood events.

Large flood events may be able winnow some of the fines from around the edges of the placed substrate and locally modify the placed substrate. In particular, locally steep slopes and high points that formed during the placement of the substrate may become less pronounced during the flood. If winnowing of the fines does occur during high flows, the discharge in the river will need to recede relatively quickly if the interstitial spaces are to be preserved.

Despite a two month long freshet with a discharge of 500 m^3/s, there are no signs that the transport of sand and gravel became supply limited (Photo 1 and Photo 2 show an abundance of fine substrate in the lee of large cobbles). On account of flow regulation, the inputs from the Cheslatta fan and sediment supply from the upland areas, as well as field observations following the 2011 freshet, it is unlikely that high flows can exhaust the supply of gravel and sand.

The infilling of the interstitial spaces appears to occurs because of two distinct processes. At the middle pad there is evidence that the lower portion of the interstitial spaces are being filled by fine sand and organics that are moved as suspended sediment. In contrast, at the lower site extensive filling of the interstitial spaces has occurred due to bedload transport.

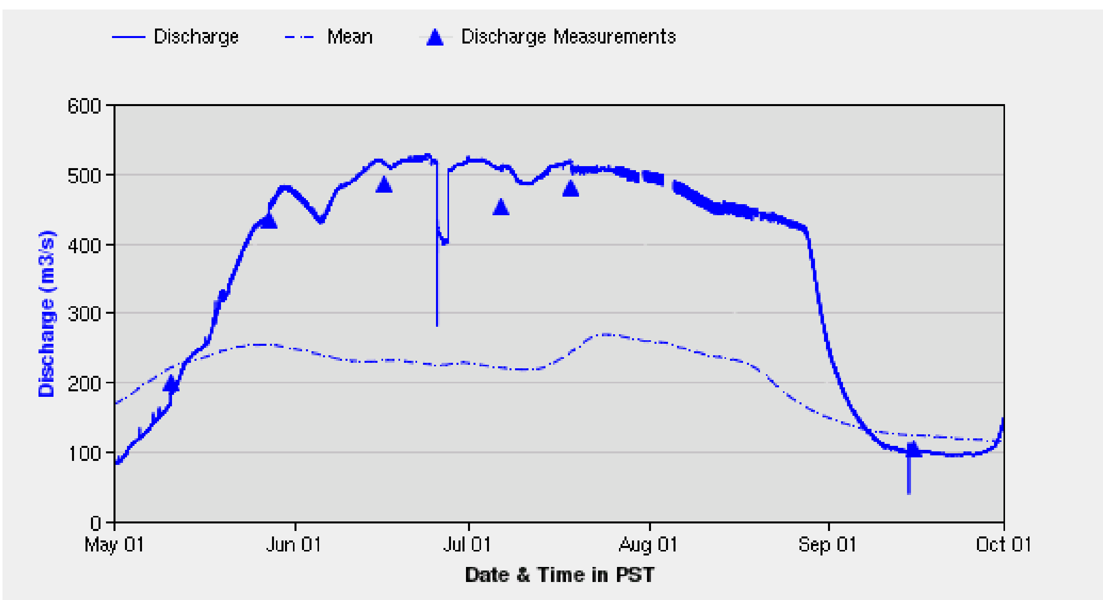


Figure 12: Discharge data from WSC 08JC001 real-time gauge. Accessed March 5th, 2012. Note gauged flows were 6 to 12 % less than predicted suggesting peak was less than plotted.

5.1 Characteristics of Suspended Sediment Transport

Little to no suspended sediment will be transported during low and moderate discharge values, while during higher flows the suspended sediment will generally be smaller than approximately 0.25 mm. Material in suspension can travel a considerable distance before interacting with the bed and thus both the upstream and downstream portion of the pads are susceptible to infilling caused by suspended sediments.

The across channel variability in suspended sediment concentrations is likely relatively small, and thus, the location of the pads is unlikely to significantly alter the infilling rate associated with suspended sediments. Based on the middle pad, infilling rates associated with suspended sediment appear relatively slow and it will likely take a few more years before the interstitial spaces are filled by suspended sediments. Runoff events that generate a large input of suspended sediment may cause more rapid infilling.

5.2 Characteristics of Bedload Transport

Sediment larger than approximately 0.25 mm will primarily move along the bed of the river as bedload. The movement of bedload is strongly dictated by the near bed shear stresses which are governed by the hydraulics of the flow and can vary significantly within a river as a result of the morphology of the channel. As such the movement of bedload can be very heterogeneous across and along the channel and as a result some areas can experience considerably more transport than other areas.

Furthermore, bedload often moves as sheets, such as the gravel sheet shown in Figure 13. The movement of the sheet progresses in a linear fashion from upstream to downstream. Observations from the placed substrate suggest bedload sheets composed of coarse sand and fine gravel may have moved over the lower site and along the left bank edge of the upper site. The movement of a bedload sheet is likely to only proceed once the interstitial spaces are essentially filled and thus pads subject to bedload sheets are apt to fill progressively in a downstream direction.

At the middle site it appears that bedload is moving along the inside corner of the river and avoiding the placed substrate. In contrast, at the lower site bedload has moved over top of the placed material and filled the interstitial spaces. Within the study area it appears that bedload sheets can infill interstitial spaces much quicker than suspended sediment processes; however, bedload sheets are more localized.

Figure 13: Photo of a gravel sheet on the Fraser River.

6 Conclusions and Recommendations

The freeze cores and underwater images demonstrate that the interstitial spaces at the lower site were predominantly filled with sand and fine gravel. These sediments were likely transported overtop of the lower pad as bedload that may have originated from the island complex upstream.

At the middle site some infilling occurred due to the deposition of suspended sediment and the movement of bedload sheets on the left side of the pad; however, in general the interstitial spaces remain free of fines. The hydraulics associated with the middle site appear to be directing bedload around the inner corner of the Nechako River and as a result the majority of the bedload appears to be passing along the edge of the placed substrate. If the same pattern of bedload transport is maintained and the supply of suspended sediment does not increase considerably, the interstitial spaces associated with the middle site may stay clear for a couple more years.

Underwater video images and snorkel inspections of the pads are likely effective means of monitoring when the substrate is filled and could be conducted on an annual basis to assess the condition of the middle pad and changes in the lower pad. Large flood events may be capable of temporarily removing some of the fine sediment that has been deposited in the pads; however, the supply of fine sediment within the Nechako River appears to be limitless, and the removal of fines is apt to be short lived.

If new pads were placed, or existing pads were to be cleaned, intercepting the bedload with large pit traps could be explored as a possible means of reducing infilling and maintenance costs. Hydraulic cleaning of the pads after the summer freshet may provide a means of cleaning the pads; however, further investigations are required and wide spread regulatory approval would be required.

To improve our understanding of bedload transport through the site a numerical model could be used to evaluate if the hypothesized bedload transport pattern can be reproduced. The results from this investigation would help inform how to locate new pads and pad maintenance options.

7 REFERENCES

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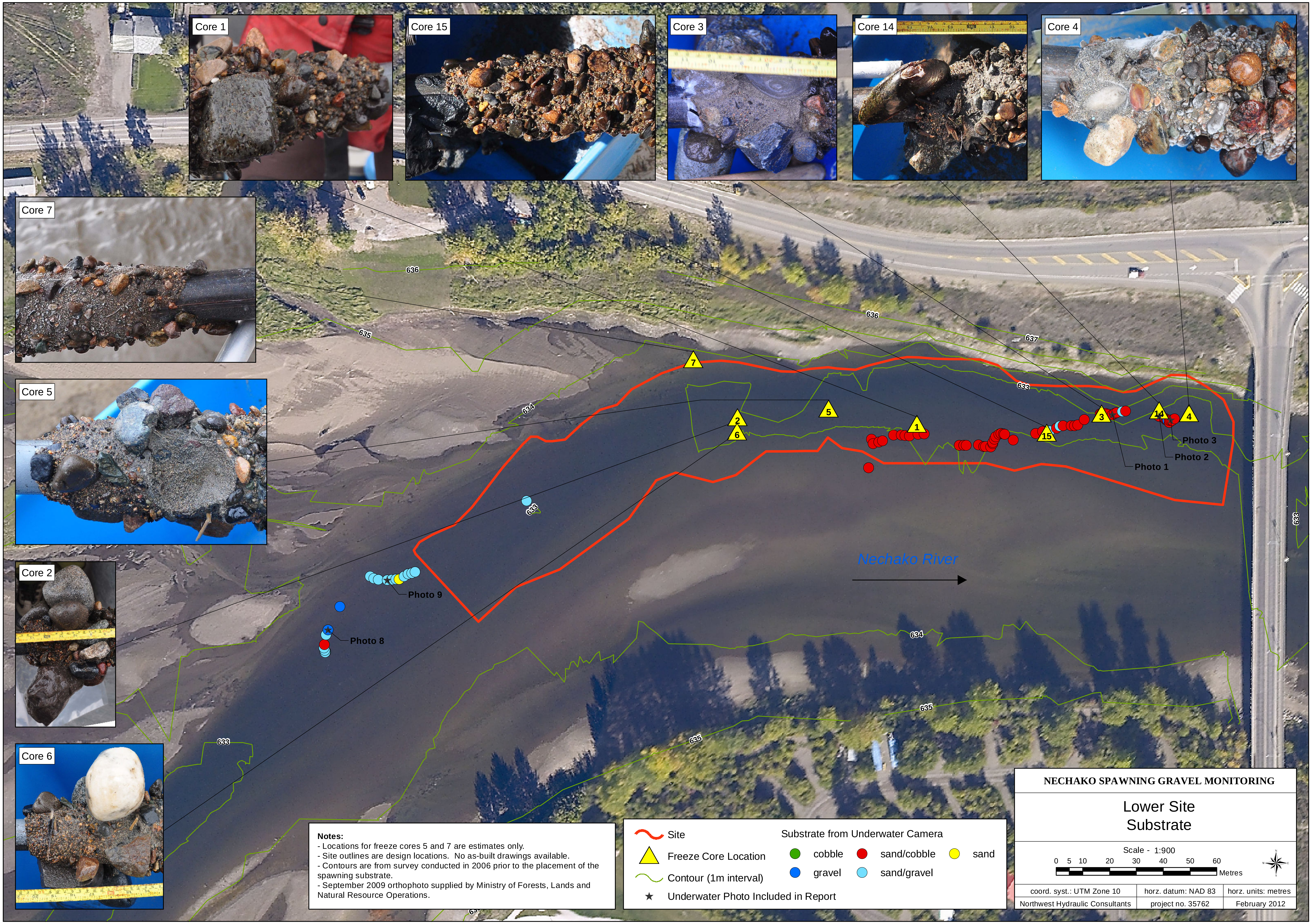
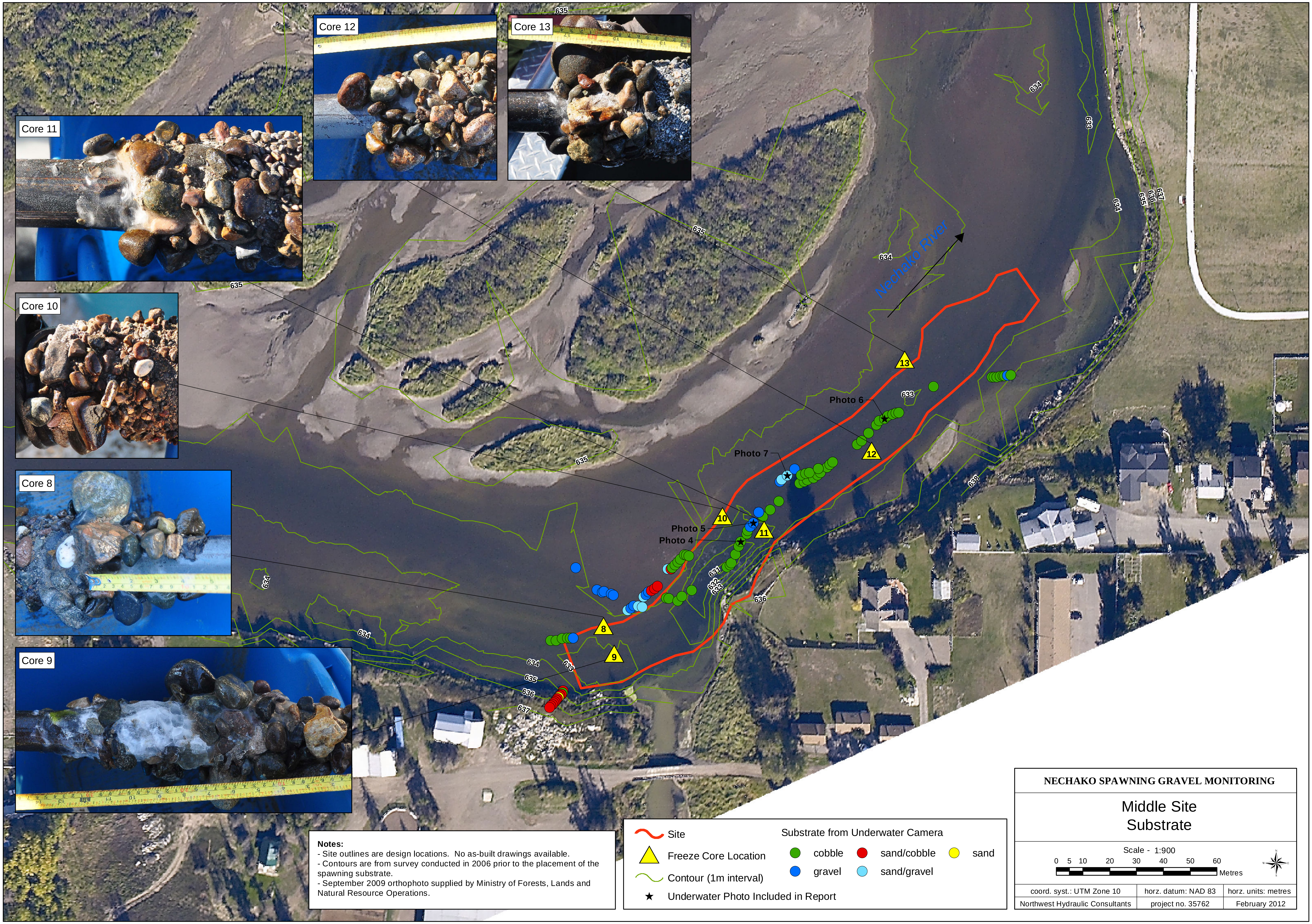
MAPS


Core 1
Core 15
Core 3
Core 14
Core 4
Core 7
Core 5
Core 2
Core 6
636
635
634
633
637
Nechako River
Photo 1
Photo 2
Photo 3
Photo 8
Photo 9
Notes:
- Locations for freeze cores 5 and 7 are estimates only.
- Site outlines are design locations. No as-built drawings available.
- Contours are from survey conducted in 2006 prior to the placement of the spawning substrate.
- September 2009 orthophoto supplied by Ministry of Forests, Lands and Natural Resource Operations.
Site
Freeze Core Location
Contour (1m interval)
★ Underwater Photo Included in Report
Substrate from Underwater Camera
cobble
sand/cobble
sand
gravel
sand/gravel
NECHAKO SPAWNING GRAVEL MONITORING
Lower Site
Substrate
Scale - 1:900
0 5 10 20 30 40 50 60
Metres
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
Northwest Hydraulic Consultants
project no. 35762
February 2012

Map 1



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Map 2

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APPENDIX A:
COMPLETE PHOTO COLLECTION

Photo 10: Core 1 Lower Substrate Site.

Photo 11: Core 1 Lower Substrate Site.

Photo 12: Core 2 Lower Substrate Site.

Photo 13: Core 2 Lower Substrate Site.

Photo 14: Core 2 Lower Substrate Site.

Photo 15: Core 2 Lower Substrate Site.

Photo 16: Core 2 Lower Substrate Site.

Photo 17: Core 2 Lower Substrate Site.

Photo 18: Core 2 Lower Substrate Site.

Photo 19: Core 2 Lower Substrate Site.

Photo 20: Core 3 Lower Substrate Site.

Photo 21: Core 3 Lower Substrate Site.

Photo 22: Core 4 Lower Substrate Site.

Photo 23: Core 4 Lower Substrate Site.

Photo 24: Core 4 Lower Substrate Site.

Photo 25: Core 4 Lower Substrate Site.

Photo 26: Core 5 Lower Substrate Site.

Photo 27: Core 5 Lower Substrate Site.

Photo 28: Core 5 Lower Substrate Site.

Photo 29: Core 5 Lower Substrate Site.

Photo 30: Core 6 Lower Substrate Site.

Photo 31: Core 6 Lower Substrate Site.

Photo 32: Core 6 Lower Substrate Site.

Photo 33: Core 7 Lower Substrate Site.

Photo 34: Core 8 Middle Substrate Site.

Photo 35: Core 8 Middle Substrate Site.

Photo 36: Core 8 Middle Substrate Site.

Photo 37: Core 8 Middle Substrate Site.

Photo 38: Core 8 Middle Substrate Site.

Photo 39: Core 9 Middle Substrate Site.

Photo 40: Core 9 Middle Substrate Site.

Photo 41: Core 9 Middle Substrate Site.

Photo 42: Core 9 Middle Substrate Site.

Photo 43: Core 9 Middle Substrate Site.

Photo 44: Core 9 Middle Substrate Site.

Photo 45: Core 9 Middle Substrate Site.

Photo 46: Core 9 Middle Substrate Site.

Photo 47: Core 10 Middle Substrate Site.

Photo 48: Core 10 Middle Substrate Site.

Photo 49: Core 10 Middle Substrate Site.

Photo 50: Core 10 Middle Substrate Site.

Photo 51: Core 10 Middle Substrate Site.

Photo 52: Core 10 Middle Substrate Site.

Photo 53: Core 11 Middle Substrate Site.

Photo 54: Core 11 Middle Substrate Site.

Photo 55: Core 12 Middle Substrate Site.

Photo 56: Core 12 Middle Substrate Site.

Photo 57: Core 12 Middle Substrate Site.

Photo 58: Core 12 Middle Substrate Site.

Photo 59: Core 13 Middle Substrate Site.

Photo 60: Core 13 Middle Substrate Site.

Photo 61: Core 14 Lower Substrate Site.

Photo 62: Core 14 Lower Substrate Site.

Photo 63: Core 14 Lower Substrate Site.

Photo 64: Core 15 Lower Substrate Site.

Photo 65: Core 15 Lower Substrate Site.