Appendix F

Kabinakagami River Fluvial Geomorphological Component Draft Report

Draft Report

Fluvial Geomorphological Component Kabinakagami River Project

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1. Introduction

A Class EA has recently been initiated for a hydroelectric project along the Kabinakagami River, near Hearst, Ontario. In support of this assessment, a fluvial geomorphological study was undertaken to characterize existing conditions and evaluate sediment transport. A total of eight development sites for hydro plants were identified, four of which have been awarded FIT contracts (Sites 3-6). Each facility is expected to create a lengthy head pond that extends to the next upstream facility, with minimal lateral flooding.

1.1 Aims and Objectives

This assessment aims to characterize the study site from a geomorphic perspective and analyze sediment transport processes within vicinity of the four identified dam facilities. An evaluation of mapping and aerial images preceded a field reconnaissance, which included confirmation of existing geomorphic processes, documentation of evidence of active erosion, and quantification of site conditions. The geomorphic field survey took into account the inundation of the upstream study reaches as reservoirs behind the proposed dams. However, site reconnaissance through the upstream area was necessary in order to gather sufficient information regarding sediment supplies and transportation and to inform the impacts and effects of a change in sediment supply through the downstream section.

Subsequent to the field survey, collected data was integrated with hydraulic modeling to provide insight regarding sediment transport.

- Collect and review pertinent background information, including mapping, historical aerial images, and hydrological reports.
- Confirm channel reach boundaries
- Complete rapid assessments
- Assess sediment mobility, and perform a sediment budget to inform construction of run-of-river hydroelectric projects

2. Background Information

In order to gain a comprehensive understanding of a watercourse, it is important to gather as much data and information as possible. The Ontario Geological Survey Geology Report for the area (#30) was examined to gain perspective on the underlying controls of bedrock and surficial geology on the Kabinakagami River, particularly throughout the study area. Topographic data was collected and examined to gain perspective on the overall channel bed gradient and valley constraints within the study area. The hydrology report produced by HATCH (2011) was reviewed and calculations were made to verify field estimates. Aerial photographs were collected from 1984 and 1986 and compared with 2006 imagery from Google Earth. Finally, reaches were delineated based on channel changes, geology, and topographical mapping.

2.1 Geology and Topography

Information regarding geology within the study area was collected from the Ontario Geological Survey Northern Ontario Engineering Geology Terrain Study #30 for the Calstock Area (McQuay 1980). The report covers an area of approximately 4 000 km^2 with the study area situated at the northeast corner. Due to the large area that the report covers, information gathered from this source was at a broad scale and should be taken as general assessment, rather than detailed information.

Within the current study area, bedrock consists of Paleozoic sediments that are overlain almost completely by overburden materials of Quaternary age. The overburden is mainly composed of level to gently rolling till and glaciolacustrine sediments. During the initial retreat of the Wisconsinan ice front over the study area, the waters of glacial lake Barlow-Ojibway inundated the area and deposited thick layers of silt, clay and sand. The ice front re-advanced over these deposits and deposited ground moraine till, typically 1-5 m thick. Due to the low relief topography and the extensive areas of till and glaciolacustrine sediments, extensive, shallow, poorly drained deposits of organic terrain have developed.

Figure 1 illustrates the geology identified within the OGS study area #30. Specifically, surrounding the Kabinakagami River and the current study area, ground moraine (shown in green) is the most significant landform. According to the OGS report (McQuay 1980), this material consists mainly of clay-rich, relatively stone-free till. Small patches of sandy till were noted in vicinity of large kame features (shown in yellow). Along natural river bank exposures, in water well logs and soil bore holes, ground moraine material was found to be in excess of 15 m thick in places. Rapid assessment surveys through the study area conducted in 2011 indicate a much stonier material, which may be due to the depth to which the river has cut through the overburden and bedrock material (10-15 m as estimated in the field) (PARISH Ltd., 2011).

Two areas of glaciolacustrine landforms occur to the north and south of the current study area. According to the OGS study report #30, these deposits are believed to have been deposited in glacial lake Barlow-Ojibway during the last stages of the Wisconsinan deglaciation (McQuay 1980). The material is thinnest in vicinity of bedrock outcrops, becoming thicker to the north and changing gradually from sand to varved silt

and clay to the north. To the south, approximately 8.5 km upstream of the study area, a large section of glaciofluvial landforms is present as kame material consisting of deep, well drained sands and gravels. This material may be providing a source of sediment to the River. An examination of Google Earth imagery from 2006 shows a more sinuous section of river with more deposits and bar formations through the area of kame material than downstream through the glaciolacustrine material and bedrock.

Topography in vicinity of Kabinakagami River and through the OGS report #30 study area is relatively flat with low relief less than 15 m of elevation change. Areas of poor drainage conditions where overburden consists of silty clayey till and glaciolacustrine deposits have resulted in areas of wet, shallow organic deposits. Contour data indicates that Kabinakagami River is situated within a confined valley system. Valley walls range in height from 6.5 m to 17 m and valley widths range from 100 m to 500 m.

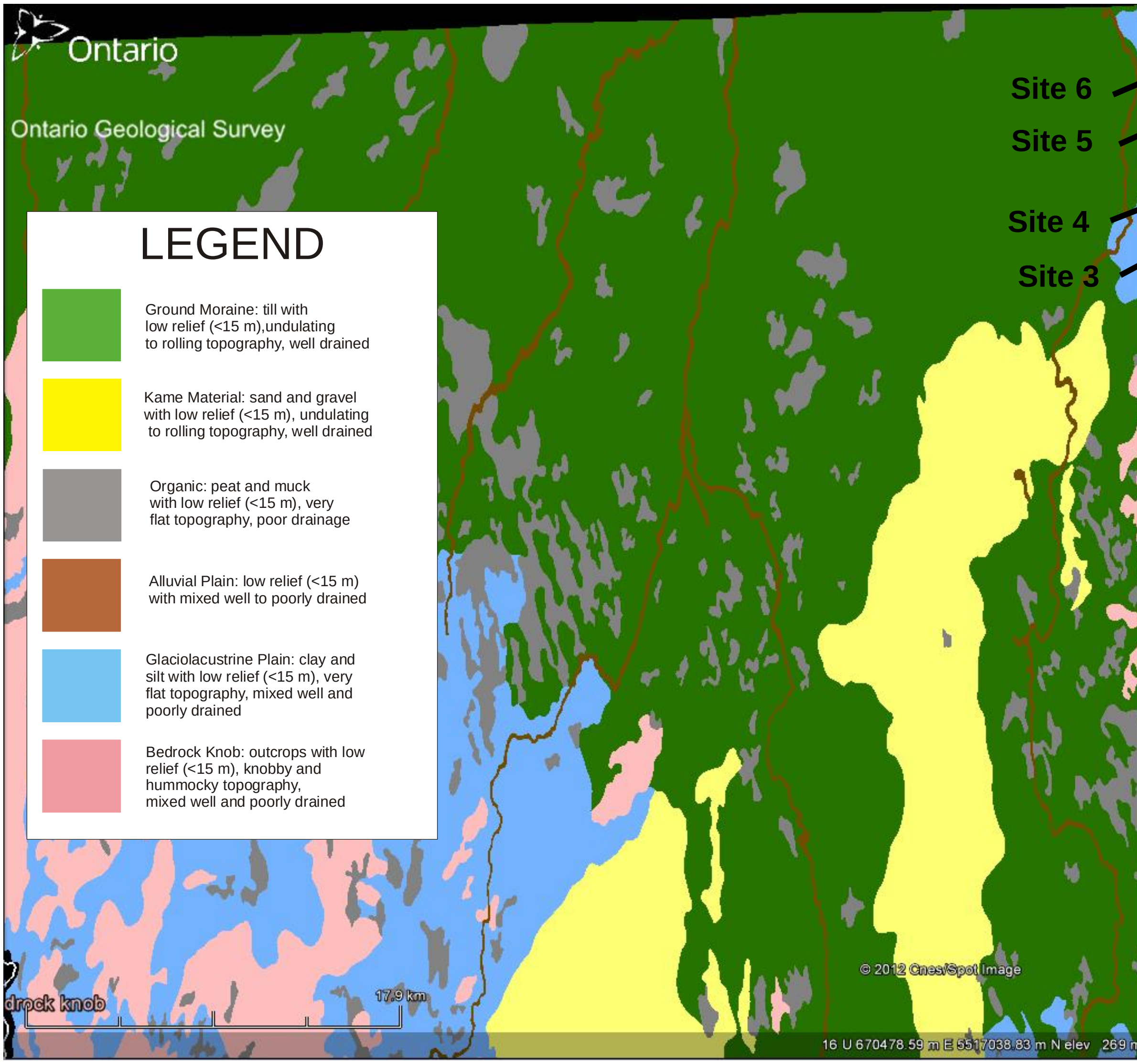

Figure 2.1: Ontario Geological Survey Google Earth Engineering Geology Terrain (NOEGTS) data. [http://www.mndm.gov.on.ca/mines/ogs_earth_e.asp] McQuay, D.F. 1980.

2.2 Hydrology

A review of the Hydrology report (HATCH, 2011) was completed in order to gain a full understanding of forces and controls at play within the Kabinakagami River system. Data was collected from the Water Survey of Canada (WSC) for six rivers with similar basin characteristics and latitudes that are in close proximity to the Kabinakagami River. A comparison of the data was undertaken to understand the variation in runoff and flow patterns across the region. Results indicated that the flow series for the Kabinakagami River, at the WSC stream gauge is free from significant statistical anomalies. The seasonal flow pattern for the Kabinakagami River was evaluated and compared based on the six other rivers examined. A plot of the seven rivers revealed that the Kabinakagami River has the lowest spring flow and the second highest winter flow with changes occurring slightly after the other rivers. Several other checks were performed on data for the seven rivers including flow distribution, annual flow variability, mean annual runoff, and regional runoff. All data and examined trends within the Kabinakagami River system were determined to be statistically consistent with the six rivers in close proximity.

As described in the Hydrology report (HATCH, 2011), a flood frequency analysis was undertaken for the annual maximum daily flow series at the WSC stream gauge on the Kabinakagami River. A return period flood of 100 years resulted in a mean daily flow of 368 m^3/s and the 1,000 year return period flood had a mean daily flow of 435 m^3/s. A plot of the annual maximum daily discharge on a 3-parameter log-normal distribution was produced and is provided in **Appendix C**. According to this plot, the 1 to 1.25 year flood event is approximately 171 m^3/s.

For the purpose of the current sediment transport study, the focus was on frequent flood events such as the 2-year, 10-year, and 25-year events, rather than the 100-year event described by HATCH (2011). The plot of annual maximum daily discharge was applied by PARISH Geomorphic Ltd. to determine the 1.25 year flood event, which typically relates well to the bankfull flow event. Calculations were performed on data collected in the field (PARISH Geomorphic Ltd., November 2011), resulting in an estimated bankfull flow of 171 m^3/s, which coincides with the mean annual flood and is comparable to the values attained by HATCH (2011). Overall, the following conclusions were made following the review of the design floods for the Kabinakagami River:

- The instantaneous flood peaks are 0.44% higher than the mean daily flood peaks;
- The 1951-1986 flood series is sufficient to define the 1:100-year and 1:1000-year floods
- The peak unit runoff of floods is lower than in other regional rivers due to the attenuating effect of Kabinakagami Lake.

2.3 Historic Aerial Photographs

Aerial photographs from 1984 and 1986 were examined in order to gauge channel migration and the upstream advancement of knickpoints (i.e. rapid sections). Several meander bends were measured on both the 1986 photos and 2006 Google Earth imagery and resulted in migration rates of less than 1cm over 100 years. Through reach 1, the upstream migration of knickpoints were measured and ranged from 0 to 7 cm over 100 years. Due to distortion that is innate in all aerial photographs, the error associated with the above measurements was calculated. A percent average was taken based on several measurements between the 1986 air photos and the Google Earth 2006 imagery, resulting in a 0.0049% error. In essence, the measurements and migration rates calculated have very little error associated with them and can be considered accurate.

2.4 Reach Delineation

Reaches are lengths of channel (typically 200m to 2km) that display similarity with respect to valley setting, planform, floodplain materials, and land-use/cover. Reach length will vary with channel scale since the morphology of low-order watercourses will vary over a smaller distance than those of higher-order watercourses. At the reach scale, characteristics of the stream corridor exert a direct influence on channel form, function and processes.

The Kabinakagami River is a large, pristine system, with limited observed changes in land-use/cover and geologic controls. Due to the large scale and limited variability in channel form, tentative reach breaks were fitted to a manageable study area and refined following the field reconnaissance. A total of three study reaches were ultimately delineated within a 12km section of channel that encompasses proposed facility sites 3, 4, 5 and 6 (**Figure 2.2**). Upstream sites 3 and 4 are situated within Reach 1, which extends approximately 4.4km to confluence with a major tributary. Site 5 is situated within Reach 2, which measures 4.7km and is characterized by recurrent sections of exposed bedrock. The upstream limit of Reach 6 coincides with a marked increase in channel width, which continues approximately 2.9km. It is important to note that the upstream limit of Reach 1 and downstream limit of Reach 3 were influenced by the study limits and are not representative of a specific change in channel conditions. Overall, the considerable length of each reach was deemed sufficient to gain a general understanding of the dominant geomorphic form and processes within each section.

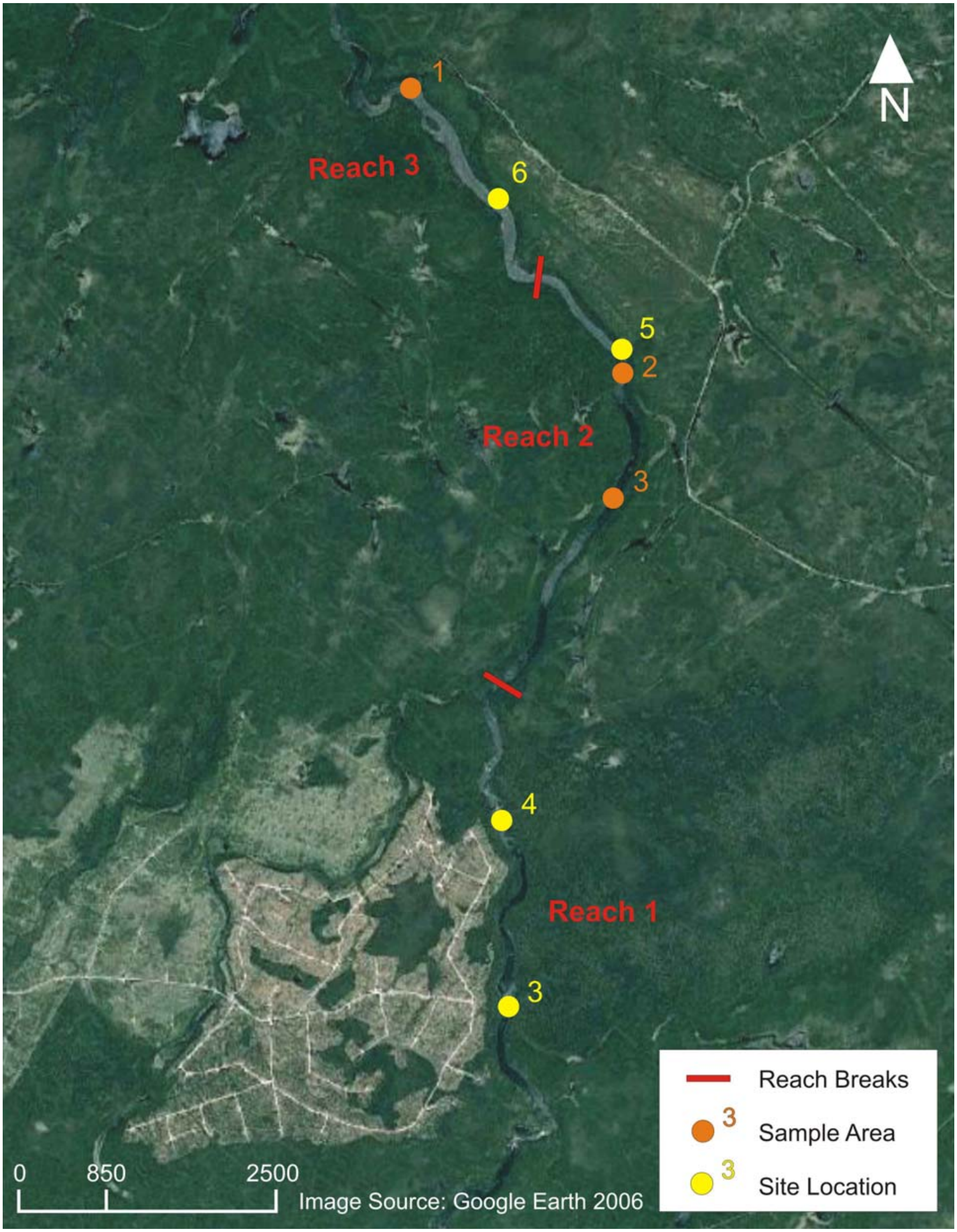

Figure 2.2. Delineated reaches along the Kabinakagami River within the study area.

3. Reach Characterization

In order to document existing conditions, a field investigation was completed for each reach. During the site visit, field assessments were completed to assess channel stability and stream health. These reach walks were completed via foot and canoe on November 15, 2012. A photographic record of observed conditions within each study reach is provided within **Appendix A.**

3.1 Rapid Assessment

The Rapid Geomorphic Assessment (RGA) survey documents observed indicators of channel instability (MOE, 1999). Observations are quantified using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel-widening and planimetric adjustment. The index produces values that indicate whether the channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40) or adjusting (score >0.40). These categories identify if the channel is relatively static (i.e. In Regime), natural adjustments within what is normally expected for a watercourse (i.e. Transitional), and actively adjusting and unstable.

A Rapid Stream Assessment Technique (RSAT) survey provides a broader view of the system by also considering the ecological functioning of the stream (Galli, 1996). Observations include in-stream habitat, water quality, riparian conditions, and biological indicators. Additionally, the RSAT approach includes semi-quantitative measures of bankfull channel dimensions, type of substrate, vegetative cover, and channel disturbances. RSAT scores rank the channel as maintaining a low (<20), moderate (20-35) or high (>35) degree of stream health.

Table 3.1: Summary of RGA results.

Reach	Factor Value				Stability Index	Condition
	Aggradation	Degradation	Widening	Planimetric Adjustment		
R1	0.38	0.29	0.50	0.14	0.33	Transitional/Stressed
R2	0.38	0.14	0.50	0.29	0.33	Transitional/Stressed
R3	0.38	0.14	0.63	0.29	0.36	Transitional/Stressed

Overall, the reaches observed along the Kabinakagami River displayed characteristics typical of large, bedrock-influenced systems. Bankfull widths were generally wide, with a localized thalweg. The Kabinakagami is generally confined; however, degree of confinement increased in the downstream direction. The valley setting along reaches 2 and 3 transitioned among confined and moderately confined sections, resulting in a wide and fluctuating range of floodplain widths. Riparian vegetation is predominantly cedar forest and channel disturbances were largely non-existent. Bed morphology was muted through the study area. Deposits of slightly larger material were loosely identified as riffles, while slight depressions containing slightly finer bed material were loosely defined as pools. From this point on,

the use of the terms ‘riffle’ and ‘pool’ should be understood as slight differences in substrate size rather than the significant variations in bed profile and substrate size as is the traditional definition.

Rapid field surveys identified substrate as fairly coarse and consistent through each reach; riffle features were dominated by cobbles and pools consisted of gravel to small cobble material. Scattered boulders and sections of exposed bedrock were also common throughout. The estimated width to depth ratio for all three reaches is noted as exceedingly high. In addition, very little pronounced bed morphology was observed (i.e. ill-defined pools). Both conditions are highly unusual but could possibly be explained by bedrock controls influencing the system. RGA scores specific to each reach are displayed in **Table 3.1**, while an overall summary of reach characteristics is provided in **Table 3.2.**

The degree of stability, observed geomorphic processes, and level of ecological health were also consistent through all three reaches. The RGA stability index produced scores ranging from 0.33 to 0.36, suggesting each reach is in a transitional state. Widening and minor evidence of aggradation accounted for the noted instability. Observed indicators of widening included: fallen/leaning trees, occurrence of large organic debris, exposed tree roots, steep bank angles throughout a majority of a reach, and an extensive length of basal scour. The presence of lateral bars, mid-channel bars and poor longitudinal sorting of bed materials were the primary indicators of aggradation. The RSAT rankings ranged from 34 to 35, indicating a high degree of ecological health throughout the study area.

Reach 1 displayed the highest gradient and was characterized by limestone cascade features and large boulders throughout riffles. An island formation was observed near mid-reach, just upstream of Site 4 and displayed long riffle runs along either side. Bankfull dimensions were fairly consistent, with widths ranging from 70 to 85m and depths from 1.2 to 1.3m. Bank materials consisted of till material ranging from 0.02 to 0.06m in size.

Reach 2 was observed to have a lower gradient than Reach 1, with more defined pooling and longer transition areas between riffle features. Long sections of exposed limestone bedrock were noted along bank toes and along the channel bed. Numerous bar deposits were also present, with material ranging in size from gravel to cobbles. Bank materials consisted of silt to fine sands with till ranging from 0.1-0.2m. Channel disturbances were again minimal, with some wood debris along the banks.

The overall channel width and degree of valley confinement increased through Reach 3. Through this section, bankfull level was generally defined by a plateau along the valley wall. Gradient was moderate and similar to that of Reach 2. Riffle material was dominated by large fragments of bedrock material and boulders embedded within coarse sands. Bank materials through this reach were comprised of medium to fine sands and silts. Depositional features were observed towards the bottom half of the reach, most notably being a large island feature near mid-reach and large medial bar towards the downstream end.

Table 3.2: Summary of reach characteristics.

Reach		R1	R2	R3
Channel Length (m)		4, 426	4, 720	2, 883
Sinuosity		1.10	1.04	1.19
Gradient (%)		0.48	0.21	0.39
Entrenchment (m)		110-260	100-220	150-500
Average Bankfull Width (m)		77.5	85.0	125.0
Average Bankfull Depth (m)		1.25	2.00	1.30
Width to Depth Ratio		62.0	42.5	96.2
Substrate (cm)	Riffle*	0.1-0.8 with boulders	Exposed bedrock with pebbles to 0.1	Cobbles (0.1-0.2) with boulders
	Pool**	vcs-0.05 with boulders	Pebbles to 0.05 with small cobbles & boulders	vcs-gravel with cobbles & boulder
RGA	Stability Index	0.33	0.33	0.36
	Dominant Process	Widening	Widening	Widening
RSAT		34	35	35

*Slightly coarse material deposited on the bed.
** Slightly finer material located within slight depressions on the bed.

4. Results

The following presents results of several analyses completed to assess sediment characteristics, channel form and hydraulic capacity.

4.1 Sediment Sampling

In order to characterize the sediment being transported throughout the Kabinakagami system, direct measurements were made at a series of sampling sites. Sample sites of mobile sediment were identified by areas of sediment accumulation, notably bar formations. Three distinct bar features were located between reaches 2 and 3 and subsequently surveyed by means of a Wolman pebble count. These pebble counts provided sizing distributions which can be viewed in **Appendix B**.

4.2 Cross-sectional Form

Due to difficulties regarding site access, the PARISH field crew was unable to transport survey equipment to the site. An agreement was made with HATCH that cross-section locations would be marked and surveys would be completed by their survey team. Bankfull dimensions and hydraulic geometry was estimated through coordination of a qualitative assessment (RSAT) and data provided by the site surveyor. Broad dimensions were assumed in order to retain conservative results.

4.3 Hydraulic Capacity

Hydraulic capacity at bankfull stage within the study area was roughly estimated at 171m^3/s. In lieu of available cross-sectional data, this discharge was derived from Manning's equation and a qualitative assessment of general channel dimensions and verified through direct measurement of hydraulic velocities. Manning's equation provides a hydraulic velocity based on hydraulic radius, slope, and Manning's roughness coefficient:

(Manning, 1889) $$V = (R_h^{2/3} * S^{1/2}) / n$$

where v is the mean velocity; R_h, hydraulic radius; S, slope of the energy gradient; and n, resistance coefficient.

A conservative energy gradient of 0.5% was utilized, which was derived from a provided longitudinal survey (HATCH, 2011) and corroborated by contour mapping. Manning's n was set to a standard 0.033 and an average depth of 1.0m was used as a surrogate for hydraulic radius. It is common practice to utilize average depth in the absence of a measured hydraulic radius, especially in gravel bed rivers of wide and shallow form.

To estimate discharge, the resulting velocity of 2.14m/s was applied to a rough estimate of channel area of 80.0m^2 (width of 80.0m and depth of 1.0m), which resulted in the discharge of 171m^3/s. When compared

to the best fit distribution of annual maximum daily discharge (**Appendix C**), this flow coincides with the 1-year mean annual flood event.

5. Analyses

The Analyses section provides a discussion of field and data analysis results.

5.1 Sediment Mobility

Based on the field observations, it would appear that the substrate through each of the study reaches is fairly consistent; comprising a minor amount of fines, with large gravel/cobble comprising a large fraction, with boulders representing to largest sizes. Thus, the substrate mix could be described as D16 of 4 cm, a D50 of 20 cm and a D84 of 40cm. Interestingly, the bars that were sampled essentially consist of the lower half of that particle size range (D16 of 0.4 cm, D50 of 4 cm and a D84 of 20 cm).

In order to assess the mobility of the river sediment, a variety of exercises were completed. They included the determination of a critical shear stress for various particle sizes followed by a check of permissible velocity for either the D_{50}, or D_{84} particle size. With respect to the channel boundary conditions, the tractive force analyses used channel depths of 1.0m and 1.2m, which represent conditions at bankfull stage. At these channel depths, the boundary shear stress is equivalent to 49.05N/m^2 and 58.86N/m^2, respectively. The Shields equation was used to determine the shear stress at which the bed particles will be entrained. Within the Shields equation, a dimensionless value of 0.05 was selected, based on the gradation of particle sizes (Julien, 1998). This dimensionless Shields parameter was then applied in the modified critical shear stress equation (Komar and Carling, 1991). The results for the critical shear stress analyses are shown below in **Table 5.1**. As a check, the permissible velocity method of Komar (1987) was also used. His equation was derived for poorly sorted gravels. As a comparative reference, the average velocity at bankfull flow was calculated to be 2.14m/s.

Table 5.1: Summary of critical shear stress results.

	0.4cm	**4.0cm**	**20.0cm**
Critical Shear (N)	3.2	32.4	162.0
Permissible Velocity (m/s)	0.35	1.08	3.11

The results from **Table 5.1**, seem to indicate that particle sizes of 20cm and finer could be moved at flow conditions that approach bankfull stage. Depending upon the depth and flow condition, it would appear that the 20cm sized cobble is close to threshold conditions, and while the critical shear is not exceeded, it is plausible that if this particle size is mobilized from an upstream area, it could stay mobile. It is also worth noting that the three sampled bar deposits had maximum particle sizes in the range of 20cm. This further supports the results that this size of particle can be moved, but can also be deposited once the hydraulic conditions fall below the necessary thresholds.

5.2 Sediment Budget

To help assess the possible implications of the proposed facilities on the sediment dynamics, a crude sediment budget was performed (Reid and Dunne, 1996). The budget is primarily a qualitative approach, as necessitated by the timing of the field work and relative lack of channel dynamics (large sources of sediment supply and areas of accumulation). The study reaches are quite wide and shallow, likely due to the close proximity of bedrock. Further, there are several large knickpoints that offer substantial energy dissipation of flows. Through both the field survey and desktop assessment of maps and aerial photography, there were few identified areas of sediment supply. These would typically include any instances of bank erosion, valley wall contact and material brought in from tributary channels. Throughout this site, there was little evidence of sediment supply and production. Thus, it seems that most of the sediment that is moved by the river likely originates from within the active channel. This is plausible, as the river reaches had a very similar sediment size distribution and had remarkably consistent bed morphology. In other words, most of the site displayed a plane bed morphology comprised of gravel, cobbles and boulders, given that particles 20cm and finer could be transported by a bankfull flow event.

There were also few areas of notable sediment deposition. There were relatively few point bars and marginal bars. Where the gradient tended to flatten out and the channel dimensions became wider, there were more bars, typically in the form of transverse medial features. That said, the thickness of the bars was relatively low ($<$80cm) and were likely highly transient. Therefore, it would appear that the river in this area has a sediment budget that is pretty much in balance. There is little sediment supply and little deposition, which likely offset one another. The river itself is highly competent and seems to have the potential to mobilize a large portion of its bed during higher flow events.

6. Summary and Implications

Given the wide, shallow form of the Kabinakagami River, it is apparent that the study reaches are largely bedrock controlled. While this helps with respect to stability (i.e. controlling incision), it does produce river forms that can be less functional in terms of their dynamic nature, given structural and lithologic controls, with less variable bed morphology, as compared to alluvial systems. For this site, there seems to be little with respect to sediment supply. There are few large valley wall contacts, the overall extent of bank erosion is low (in part due to its wide shallow form, which also coincides with relatively low banks), and event material from tributaries is low (based on minimal evidence of depositional features in the confluence areas). Thus, sediment that is produced and conveyed is largely generated from within the channel boundary and from the prominent knickpoints.

The site is fairly competent with respect to entraining and moving sediment. Based on the particle size of the bed and bars that were sampled, the coarsest fraction on the bars, roughly corresponds to the median particle size on the bed. This size of observed cobble is approximately 20cm. Based on the open channel hydraulics; this size of particle could be entrained at flow stages that are close to the bankfull (or full bank stage). Incidentally, the calculated bankfull capacity was approximately 171 m^3/s, which when compared to the hydrology study essentially matches the mean annual flood. A check of the permissible velocity of the bars sediments, also confirm that a large portion of the particles 20cm and smaller can be moved during large flows that approach the bankfull discharge.

Thus, while the river is competent at moving particle sizes that are 20cm and finer, there are few notable bar features. This suggests that the sediment supply is limited. While the transport potential is high, the degree on sediment storage within the study reaches is low. Therefore, it would appear that the sediment budget is in relative balance in this site. The location of greatest sediment storage is at the downstream end (near site 6), where the energy gradient seems to flatten and the channel width increases, indicating that the shear stress and velocities reduce enough to produce deposition.

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