KAMA CREEK CULVERT RESTORATION:

AN ASSESSMENT OF LONG-TERM REMEDIATION SUCCESS

by

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A CAUTION TO THE READER

This HBEM thesis has been through a semi-formal process of review and comment by at least two faculty members. It is made available for loan by the Faculty of Natural Resources Management for the purpose of advancing the practice of professional and scientific forestry.

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ABSTRACT

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The purpose of studying the long term remediation success of Kama Creek, Nipigon Bay, Lake Superior, was to follow up on past remediation research with special attention to emerging concerns and the importance of continued monitoring – particularly on small nursery streams. Monitoring is an important part of ecosystem management that provides decision makers with current conditions and possibly more valuable, historical conditions. In the case of Kama Creek, there have been many alterations to the natural stream from railway and road crossings, channel realignment (1960's), and remediation (October-November 2011). The Kama Creek remediation was initiated because of noted declines in Brook Trout (*Savelinus fontinalis*) populations throughout Lake Superior and Kama Creek's own reaches.

Since being recognized as an area of concern, assessments have been completed to establish pre-remediation conditions (2011), post-remediation conditions (2012), and remediation success (2013, 2014, 2015, and 2018). Individually, the research projects indicate the conditions and health of Kama Creek at one point in time, but combined together the studies directly show the re-establishment of ecological components, stream health over time, and success or failure of the remediation techniques. Indirectly, the continued study of Kama Creek illustrates the importance of monitoring remediation projects, ecosystems, and any ecological element.

This habitat assessment of Kama Creek occurred that seven years after the 2011 restoration and continues to demonstrate that the remediation project was successful at increasing the abundance of high quality brook trout habitat. Sediment deposition continues to raise concerns about the long-term changes to the river's morphology and potential impacts on the restored habitat features. However, the current condition of habitat features is maintained and ongoing monitoring s needed to better understand the long-term implications of fluvial geomorphological process on the overall stream habitat quality to decline. The habitat assessment method developed by Kaurin (2015) was an easy-to-follow system encompassing brook trout habitat characteristics and factors influencing such habitat components. This method is susceptible to assessor bias due to the qualitative nature of the assessment and descriptors used for each habitat condition, leaving the accuracy of this method variable between assessors.

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INTRODUCTION

Kama Creek is a small tributary feeding into Lake Superior, located 25km east of Nipigon Ontario. Historically, Kama Creek played an important role in the local brook trout population by providing spawning and nursery habitat. However, in 1962, CP rail redirected the stream through a perched culvert and into a straightened channel, with reduced length and in turn less habitat (Nipigon Bay Remedial Action Plan, 2004). Kama Creek flowed through the redirected channel until 2011, when the stream was remediated (Deacon, 2014). Fortunately, past research done on the 2011 Kama Creek restoration shows that fixing the perched culvert and re-aligning the stream back to its original channel was successful at increasing brook trout habitat. With evidence ranging from increased instream habitat, healthy riparian vegetation, benthic invertebrates, to increased abundances of fish species both above and below the culvert (Kaurin, 2015).

Past assessments classified the remediation as a success but continued to mention sediments being seen filling in the dug-out pools of the engineered riffle-pool systems. As predicted by Kaurin (2015), Kama Creek would likely naturalize by 2016 if excessive riffle and bank erosion does not continue to deposit sediments into pools. If it did, continued infilling would reduce important nursery and refuge habitat and limit the beneficial uses of Kama Creek and the key goals of the restoration project.

The primary goal of this paper was to review the long-term success of Kama Creek's restoration in relation to brook trout habitat by using the habitat assessment created by Kaurin (2015). The secondary goal is to evaluate the effectiveness of the habitat assessment protocol itself and its ability to determine the quality of a stream using multiple assessors over time. In order to evaluate long-term success, visually based habitat parameters within in the Kaurin (2015) habitat assessment were compared to real time conditions of Kama Creek. Effectiveness of the habitat assessment was evaluated through ease of interpretation and assessor variation.

METHODS

Assessing long-term remediation success involved Kaurin (2015) habitat assessment, water quality, and discharge evaluations. Data collection onsite at Kama Creek was used to achieve my primary objective of determining the long-term remediation success. The secondary objective of evaluating the assessment protocol itself was achieved through a critical review of the literature on monitoring in comparison to my field experience and field notes. In Figure 1, the stream reaches are displayed with blue lines along the old stream bed of reach 1; the red lines shown on the active stream bed of reach 2; and the green lines follow reach 3, upstream of the culvert and railway crossing.

Source: Left, Kaurin (2015). Right, Google maps

Figure 1: Kama Creek reach locations. Blue, reach 1 is post 1962 channelization and pre 2011 remediation. Red, reach 2 is pre 1962 channelization (historic condition) and post 2011 remediation. Green, reach 3 is the stream above the culvert crossing.

<u>Habitat Assessment</u>

The primary data collected was a quantitative analysis of habitat parameters compiled in a habitat assessment. The habitat assessment created by Kaurin (2015) acts as a guide for ongoing stream health monitoring projects and uses a rating scale of 0-20 that allows a researcher to determine four 'condition' categories based on the score of each habitat parameter. The four condition categories were: poor (ratings 0-5), marginal (ratings 6-10), suboptimal (ratings 11-15), and optimal (ratings 16-20). To guide the rating process, the four condition categories were outlined with specific sets of habitat characteristics reflecting either poor, marginal, suboptimal, or optimal quality. The specificity in defining the characteristics allows for a rapid habitat assessment that can be done by multiple individuals with little variance.

In total, there were eleven habitat parameters used in the habitat assessment of Kama Creek: epifaunal substrate/available cover, pool substrate characterization, pool variability, sediment deposition, channel flow status, channel alteration, frequency of riffles or bends, channel sinuosity, bank stability (condition of banks), bank vegetation protection, and riparian vegetation zone width. In order to rate each habitat parameter, the actual stream condition observed was compared to the characteristics detailing each condition category.

Table 1 shows each habitat parameter within the Kaurin (2015) habitat assessment, along with a brief description of the parameter.

Table 1: Description of parameters measured in the Habitat Assessment

Parameter	Description of parameter
Epifaunal Substrate/ Available Cover	Includes the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, and undercut banks, available as refugia, feeding, or sites for spawning and nursery functions of aquatic macrofauna
Pool Substrate Characterization	Evaluates the type and condition of bottom substrates found in pools
Pool Variability	Rates the overall mixture of pool types found in streams, according to size and depth
Sediment Deposition	Measures the amount of sediment that has accumulated in pools and the changes that have occurred to the stream bottom as a result of deposition. Deposition occurs from large-scale movement of sediment
Channel Flow Status	The degree to which the channel is filled with water
Channel Alteration	Is a measure of large-scale changes in the shape of the stream channel
Frequency of Riffles (or Bends)	Is a way to measure the sequence of riffles and thus the heterogeneity occurring in a stream
Channel Sinuosity	Evaluates the meandering or sinuosity of the stream
Bank Stability (condition of banks)	Measures whether the stream banks are eroded (or have the potential for erosion)
Bank Vegetation Protection	Measures the amount of vegetative protection afforded to the stream bank and the near-stream portion of the riparian zone
Riparian Vegetation Zone Width	Measures the width of natural vegetation from the edge of the stream bank out through the riparian zone

Source: Kaurin 2015

Water Quality

Water quality assessments were done at the downstream end of the culvert. Parameters observed included, water temperature, conductivity, dissolved oxygen, pH, total dissolved solids, and turbidity. Assessing water quality involved the use if a YSI ProPlus multi-parameter probe and a secchi tube to determine turbidity.

Setting up the YSI ProPlus consisted of lowering the probe into the pool from the top of the culvert, so that the entire probe is submerged and in a stable position. In order to obtain accurate results, the probe was left in the water until all parameter values presented on the handheld display were steady. Turbidity tests were done with the secchi by filling the tube with water and slowly releasing water through a valve at the bottom of the tube until the observer can see the secchi. The remaining water level determines the level of clarity in the sample. Values for each water quality parameter were recorded each day monitoring occurred at Kama Creek (Oct 27, Nov 4, Nov 10).

Discharge

The discharge calculations were focused on reach 2 where flow data and water levels were recorded during the fall. Although reach 1 was dammed off after the remediation activities concluded, water continues to seep into the old channel and raise concerns about the long-term integrity of the artificial riverbank that dams this channel. The bed of reach 1 was essentially empty, but since a small amount of water is present, the depth and flow of the water in reach 1 only required visual observations as flow measurements could not be taken.

Discharge was calculated at two sites along reach 2 of Kama Creek; the first ‘Kama 1’ was at E0425854 N5425787 and the second ‘Kama 2’ at E0425991

N5425726. Kama 1 was a deep pool 20m upstream of Kama Creek's mouth, while Kama 2 was a sediment filled pool 30m downstream of the culvert.

The collection of discharge data was comprised of two main components, first a cross-sectional stream profile, and second water flow measurements. The stream profiles were done at the most representative areas within a small stretch of Kama Creek with uniform flow (i.e., no in-stream obstructions, back eddies, riffles, or rapids). Kama 1 had the most representative pool within the downstream half of reach 2. The site of Kama 2 followed a standard selection criteria (reference) but was located in the upstream half of reach 2 in order to represent a noticeable difference in the morphology of Kama 1 and 2. In reach 2, the downstream half is a near perfect example of a riffle-pool sequence, where the upstream half resembled more of a step- pool system. Both locations provide unique insights about the affects of discharge on stream sinuosity and velocity, two aspects of the river that restoration activities sought to improve (i.e. increase sinuosity and decrease velocity).

Once the stream profile sites were selected, stakes were placed on both the left and right stream banks so that the plane between them was perpendicular to the flow of the creek. A tape measure was strung along the stream's width and held taut by the stakes on the banks. With the tape measure as reference, the stream width was recorded at both sites. Depth measurements were taken every 25cm starting on the left stream bank. Recorded depth measurements were plotted on a graph with depth on the y-axis and distance out on the x-axis.

With the depths recorded and plotted every 25cm across the width of the stream, the flow measurements were then taken in between each depth location using a Global

Water Flow Meter FP111. Flow velocity differs with depth, with the fastest flow is at the surface and the slowest flow in the water column is at the bottom of the stream. The mean velocity within a column of water has been found to be at 0.63 of stream depth. Therefore, flow velocity was taken at 60% of stream depth at each velocity measurement location.

When all depth measurements were completed, the stream profile was shown on the graph. Flow velocities for each column of water between the depth locations were then recorded and discharge calculated. Each square in the graph represents $6.25cm^2$ or $0.00625m^2$ of water in the stream. Discharge for each panel was calculated by multiplying the total area by the respective velocity. This was done for every panel until all values were totaled to calculate the total discharge for the cross-sectional stream profile.

RESULTS

The purpose of the 2018 Kama Creek research was to continue monitoring the restoration’s success in providing fish habitat in the creek using a combination of habitat assessments, water quality, and discharge data. The objectives contributed to a long-term monitoring plan of Kama Creek’s restoration an resulting improvements to brook trout habitat (Kaurin, 2015). The research also assesses the effectiveness of the habitat assessment in rating the habitat and stream quality.

Habitat Assessment

The habitat assessment rated brook trout habitat features of Kama Creek from the culvert to the stream mouth in reach 2. Over the course of reach 2, different flow characteristics were present. Starting with a short riffle-pool sequence from the culvert, to a step-pool system in the middle, and back to riffles and pools near the mouth. Figures 2 and 3, reach 2 demonstrate the deep pools followed by riffle runs within 40m from Kama Bay downstream at the mouth of the river. Approximately 40m further upstream the morphology switched to fast and shallow step-pool series.

Source: Field Data

Figure 2: Downstream views of riffle-pool sequence in reach 2 within 40m of stream mouth.

Source: Field Data

Figure 3: Upstream view and downstream view of step-pool sequence in reach 2, 40m upstream.

Table 2 shows each habitat parameter and the corresponding rating criteria, along with the scores assigned per year. The green circles are scores relating to the assessment of reach 1 in 2011; while, red, blue, and purple circles outline reach 2 assessment scores for the years 2012, 2014, and no change between 2012 to 2014 respectively (Kaurin, 2015). Yellow circles are the scores from the habitat assessment completed for this study.

Table 2: Habitat Assessment Parameters and Assessment Values for Kama Creek (Reach 1 2011, Reach 2 2012, Reach 2 2014, Reach 2 no change from 2012-2014, Reach 2 2018)

Habitat Parameter	Condition Category			
	Optimal	Suboptimal	Marginal	Poor
1.Epifaunal Substrate/ Available Cover	Greater than 50% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient)	30-50% for low gradient streams) mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of new fall, but not yet prepared for colonization (may rate at high end of scale)	20-40% (10-30% for low gradient streams) mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed	Less than 20% (10% for low gradient streams) stable habitat; lack of habitat is obvious; substrate unstable or lacking
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Pool Substrate Characterization	Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common	Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present	All mud or clay or sand bottom; little or no root mat; no submerged vegetation	Hard-pan clay or bedrock; no root mat or submerged vegetation
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Pool Variability	Even mix of large-shallow, large-deep, small-shallow, small-deep pools present	Majority of pools large-deep; very few shallow	Shallow pools much more prevalent than deep pools	Majority of pools small-shallow or pools absent
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5-30% (20-50% for low-gradient) of the bottom affected; slight deposition in pools	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30-50% (50-80% for low-gradient) of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent	Heavy deposits of fine material, increased bar development; more than 50% (80% for low-gradient) of the bottom changing frequently; pools almost absent due to substantial sediment deposition
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed	Water fills >75% of the available channel; or <25% of channel substrate is exposed	Water fills 25-75% of the available channel, and/or riffle substrates are mostly exposed	Very little water in channel and mostly present as standing pools
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 years) may be present, but recent channelization is not present	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted; instream habitat greatly altered or removed entirely
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

7a. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key; in streams where riffles are continuous, placement of boulders or other large, natural obstruction is important	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7b. Channel Sinuosity	The bends in the stream increase the stream length 3 to 4 times longer than if it was in a straight line; (note - channel braiding is considered normal in coastal plains and other low-lying areas; this parameter is not easily rated in these areas)	The bends in the stream increase the stream length 2 to 3 times longer than if it was in a straight line	The bends in the stream increase the stream length 1 to 2 times longer than if it was in a straight line	Channel straight; waterway has been channelized for a long distance
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected	Moderately stable; infrequent, small areas of erosion mostly healed over; 5-30% of bank in reach has areas of erosion	Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

9. Vegetative Protection	More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally	70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining	50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining	Less than 50% of the streambank surfaces covered by vegetation disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
10. Riparian Vegetative Zone Width	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted the zone	Width of riparian zone 12- 18 meters; human activities have impacted the zone only minimally.	Width of riparian zone 6-12 meters; human activities have impacted the zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Source: Kaurin 2015

In terms of providing suitable brook trout habitat and restoration attempts to improve such habitat, the most prominent issue with Kama Creek was the concern with erosion and sediment deposition (Cox, 2015; Kaurin, 2015). The upper portion of reach 2 had the most signs of sediment removal and deposition over the full stretch downstream of the culvert. Fast flowing shallow water moved sediments from their originally placed position of the restoration, to various places downstream. As stated in Lakehead University's request for proposal Kama Creek restoration (2011), sediments were embedded between 25 and 50% of the particles size. The flow of Kama moved smaller cobbles and gravels downstream while many larger cobbles and boulders stayed in place. After years of flows through the channel, smaller sediments were concentrated within 40m of the stream mouth, as well as, forming a depositional fan in Kama Bay itself. The upper portion of reach 2 had a high ratio of large to small sediments that lead to infilled pools and hard-bottomed shallow runs. Which in turn created a system of fast flowing water with low sinuosity. Figure 4 shows a notable 10-meter section of the straightened, fast flowing water with a large point bar and undercuts on both the stream banks.

Source: Field Data

Figure 4: Sediment deposition and undercut banks in reach 2. Top, upstream view of point bar on right side of stream. Bottom left, upstream view of right bank showing point bar and undercut bank. Bottom right, upstream view of left bank showing point bar and undercut bank.

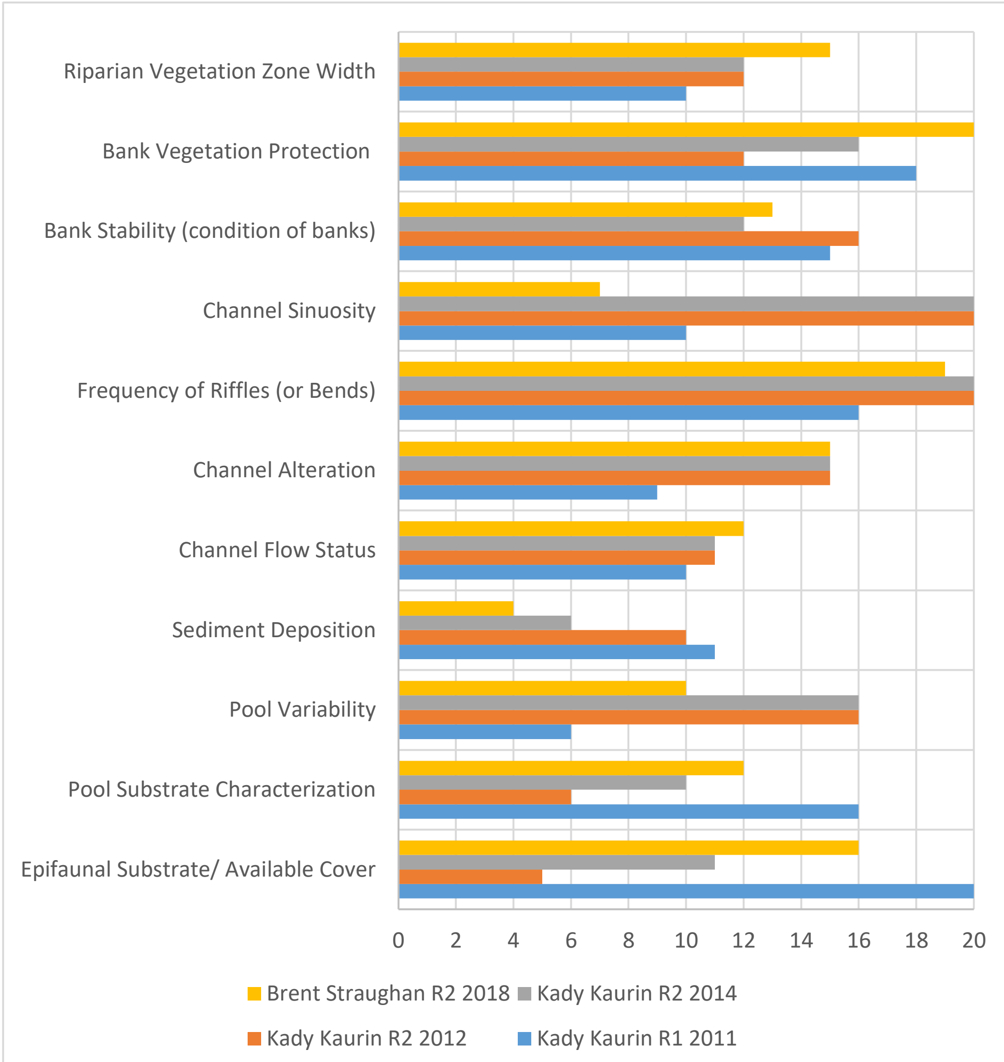
Table 3 and Figure 5 compared habitat assessment values from 2011, 2012, 2014, and 2018. In order to estimate the overall quality of Kama Creek, individual scores were scored and divided by 200. Quality was split into four categories; poor was 0-0.34, marginal was 0.35-0.64, suboptimal was 0.65-0.84, and optimal was 0.85-1.0 (Kaurin, 2015). Most of the 2018 condition category assessment values were either similar or increasing to those of past studies except, pool variability, sediment deposition, and channel sinuosity. Since eight of the eleven characteristics in the 2018 assessment were comparable to or improvements upon past studies, the resulting overall quality was 0.72.

Throughout all assessment years', individual condition scores often varied from year to year, but the total scores of Kama Creek were statistically indifferent. The total score of Kama Creek remained in the suboptimal class across all study times.

Table 3: Total Values from Kama Creek Habitat Assessments in Reach 1 and Reach 2

Condition Category	2011	2012	2014	2018
- Epifaunal Substrate/ Available Cover	20	5	11	16
- Pool Substrate Characterization	16	6	10	12
- Pool Variability	6	16	16	10
- Sediment Deposition	11	10	6	4
- Channel Flow Status	10	11	11	12
- Channel Alteration	9	15	15	15
- Frequency of Riffles (or Bends)	16	20	20	19
- Channel Sinuosity	10	20	20	7
- Bank Stability (condition of banks)	15	16	12	13
- Bank Vegetation Protection	18	12	16	20
- Riparian Vegetation Zone Width	10	12	12	15
- Total Score	141 (141/200 = 0.71)	143 (143/200 = 0.72)	149 (149/200 = 0.75)	143 (143/200) = 0.72)

Source: Kaurin 2015



Source: Field Data

Figure 5: Total observation values from Kama Creek Habitat Assessments in Reach 1 and Reach 2

The condition categories that saw notable improvement over sample years were those that had characteristics relating to in-stream and riparian vegetation; including, riparian vegetation zone width, bank vegetation protection, pool substrate characterization, and epifaunal substrate/available cover. This pattern of increased quality ranking in terms of vegetation characteristics over time is related to floral successional patterns that showed naturalization of Kama Creek riparian structures.

Some conditions did not show significant growth or decline across the years, such as, bank stability, frequency of riffles or bends, channel alteration, and channel flow status. Though no significant improvement or decline in stream morphology may be a result of the slow to change nature indicative of a river itself (Wolman, 1967; Tabacchi *et. al.*, 1998). Characteristics related to stream morphology, therefore, follow a longer time scale and will show significant results decades after restoration.

The most conspicuous attribute on site was the uniformly flattened stream bed caused by large cobbles and boulders from riffles flushed into down-stream pools. This caused a decline in quality assessment of three condition categories related to sediment deposition, pool variability, and channel sinuosity. Each condition/category saw a significant decline in ranking from the 2014 habitat assessment and the 2018 assessment. Sediment deposition continues to be the largest decline in ranking since monitoring began in 2012.

Continued sediment deposition directly influenced the pool variability and channel sinuosity conditions and created more homogenous pool sediments and depths. As the stream develops shallower pools, channel incision, point bars, undercut banks, and large sediments begins to occur over extended lengths. This further affects velocity and sediment deposition leading further sediment deposition over time.

Water Quality

Water quality measurements, though not the main focus of this study, present a snapshot in time to accompany and support the habitat assessment and previous water sampling. All quality parameter values collected with the YSI ProPlus multi-parameter probe and the secchi tube are presented in Table 4.

Table 4: Water quality results from Kama Creek, downstream end of culvert

Parameter	Oct. 27, 2018	Nov. 4, 2018	Nov. 10, 2018
Temp (˚C)	3.8	3.1	0
Conductivity	99.16	99.95	100.11
DO (%)	32.3	47.4	53
DO(ppm)	4.26	6.36	7.74
SPC	44.9	40.9	41.6
pH	7.27	7.3	8.04
ORP	23.1	38.5	79.7
Turbidity (cm)	>120	>120	>120

Source: Field Data

These water quality results indicate that Kama Creek provides suitable habitat in terms of water chemistry, since the parameter values are within brook trout tolerances (Raleigh, 1982). Kama Creek along with other streams within the area have shown and continue to show water quality measurements consistent with fish habitat and water quality guidelines (Rob Stewart, Pers. Commun., 2019).

Discharge

Discharge was examined in both reach 1 and reach 2 but was only calculated at two sites within reach 2. There was some concern of water seeping through the constructed embankment into reach 1 (Cox, 2015). The flow in reach 1was so low that velocity was immeasurable with the water meter, therefore, was less than the devices minimal measurement of 0.05m/s. This left photo documentation to best represent the extent of seepage in reach 1 and is shown in Figure 6.

Source: Field Data

Figure 6: Downstream views of pre-restoration Kama Creek (reach 1)

The discharge calculation from Kama 1 site near the mouth of Kama Creek revealed stream discharge to be 0.1214m^3/s. Kama 1 was a deep slow pool with fine sediments and woody riparian vegetation on the banks. Onsite conditions of this site are shown in Figure 7.

Source: Field Data

Figure 7: Discharge assessment site from reach 2, Kama 1 Top, downstream view of Kama 1 site. Bottom left, upstream view from Kama 1. Bottom right, downstream view from Kama

The discharge calculation from Kama 2 site close to the culvert revealed stream discharge to be $0.1183 m^3/s$. Kama 2 was a remediation constructed pool that has been partly infilled with larger sediments, resulting in a shallow pool with a developed point bar connected to the left bank. Onsite conditions of this site are shown in Figure 8.

Source: Field Data

Figure 8: Discharge assessment site from reach 2, Kama 2. Top, upstream view of Kama 2 site. Bottom left, upstream view from Kama 2. Bottom right, downstream view from Kama 2.

Average fall discharge calculations from 2011, 2012, and 2013 are $0.033812 m^3/s$, $0.0135 m^3/s$, and $0.2883 m^3/s$ respectively (Kaurin, 2015). Compared to $0.11985 m^3/s$ calculated from this study, there is marked increase n 2018 from 2011 and 2012, but is nearly half the flow calculated in 2013. The higher discharge values in 2013 and 2018 can cause increases in velocity and in turn cause sinuosity to decrease. Which would only exacerbate the sedimentation concern within reach 1 of Kama Creek.

DISCUSSION

The habitat assessment developed by Kaurin (2015) provided an easy to follow monitoring protocol with outputs that showed changes through time representative of characteristics shown by past photos and assessments compared to current conditions. Results from the assessment done for this study determined Kama Creek to be in suboptimal condition, which was the case in the past two assessment periods in 2012 and 2014. The suboptimal ratings from 2012 to 2018 classified the restoration as a success, but ideally an improvement from the suboptimal rating in 2012 to an optimal rating in following years would have been seen. As pointed out by both Kaurin (2015) and Cox (2015) sedimentation was an issue with the restoration since day one. Combining past observations of sediment problems with evidence of sediment deposition and erosion found by this study, restoration did not properly account for the flow rates experienced in reach 2, which resulted in the constructed riffle-pool sequences to change from the design (Cox, 2015).

In Figure 9, the general changes seen from 2012 to 2018 are shown. As previously mentioned, the vegetative recovery over the six years was the most significant improvement. With well-developed, non-woody species dominating stream banks and open areas the woody shrub and tree species had colonized the riparian zone. Some sedimentation can be seen, but the amount of change from this, shown in Figure 9, is minimal.

Source: Left, Kaurin (2015). Right, Field Data
Figure 9: Comparison of Kama Creek from 2012 and 2018. Left, downstream view from culvert in 2012. Right, downstream view from culvert in 2018.

Figure 10 is a representative section of reach 2, demonstrating morphological change. A level-logger in the stream was used as a reference and (red arrows) and indicates the development of the step-pool sequence over the originally dug out riffle-pool found in reach 2. In general, a riffle-pool stream has an even slope with distinct sections of slow, deep, and flat water separated by narrower stretches of larger sediments with fast, shallow, and white water (Rosgen, 1994). Step-pool systems, on the other hand, follow a staircase like form of uniform width with shallow, and flat water sections separated by a build-up of sediments that cause an abrupt drop in elevation (Laronne and Carson, 1976; Wooldridge and Hickin, 2002).

Source: Left, Kaurin (2015). Right, Field Data
Figure 100: Comparison of a stream section from 2012 and 2018. Left, upstream view of stream section site in 2012. Right, upstream view of stream section in 2018. Red arrows, showing level logger for reference.

The most representative comparison of the 2018 condition with the 2012 condition is shown in Figure 11. Below is the same section of reach 2 with a downed log for reference. In 2012, the riffle-pool sequences are clearly visible and distinct, whereas in 2018, the sequencing became blurred due to larger riffle sediments flushed into downstream pools. During the onsite data collection, the riffle-pool sequences that existed in 2012 were no longer distinct but some evidence of previous pool locations was distinguishable. Wider widths, the presence of smaller sediments placed in pool sections, and steep banks were characteristic of the proposed pool designs (Lakehead University, 2011).

Source: Left, Kaurin (2015). Right, Field Data

Figure 111: Comparison of a stream section from 2012 and 2018. Left, downstream view of stream section site in 2012. Right, downstream view of stream section in 2018. Red arrows, showing downed tree for reference.

As with the past comparisons, 2012 conditions mirrored that of the proposed design and constructed channel bed, but in 2018, sedimentation altered the channel. Figure 12 below shows the effects sedimentation caused to Kama Creek over time; such as, point bar development, constricted flow, and undercut banks. The 2012 channel contained a functional riffle section composed of large cobbles and boulders, while the following pool was wide and deep (Kaurin, 2015). In 2018, the same section of reach 2 had lost functionality of the riffle section and the pool had become filled with large cobbles and boulders. Evidence of decreased riffle functionality was the developed point bar causing constricted flow, undercut banks, and channel incision (Lakehead University, 2011).

Source: Left, Kaurin (2015). Right, Field Data

Figure 12: Comparison of a stream section from 2012 and 2018. Left, downstream view of stream section site in 2012. Right, upstream view of stream section in 2018. Red arrows, showing point on right bank for reference.

Though sediment deposition has caused significant change from the original restoration design, not all changes may negatively affect the brook trout habitat in Kama Creek. In terms of cover, brook trout prefer areas of low stream bottom visibility, water depths greater than 15cm, water velocity less than $15 cm \cdot s^{-1}$, over hanging and instream vegetation, instream objects, rocky substrate, undercut banks, and surface turbulence (Giger, 1973; Wesche, 1980). Optimal riverine brook trout habitat (Raleigh, 1982) includes cold spring-fed water, silt-free rocky substrate in riffle-run areas, areas of slow deep water, approximately 1:1 riffle-pool ratio, well vegetated stream banks, abundant instream cover, and relatively stable flow and temperature regimes. Spawning habitat is characteristically larger sediments with high amounts of inter-gravel oxygen (McFadden, 1961).

It is not just the presence or absence of such features pertaining to cover, habitat, and spawning that is of importance but also the processes that generate them (Imhof *et. al.*, 1996; Roni *et. al.*, 2002). At the time of the 2018 assessment, the first 130m downstream of the culvert no longer had the 1:1 riffle to pool ratio, depths greater than

15cm, or areas of slow deep water. Whereas, the stretch of Kama Creek further downstream retained the approximate 1:1 riffle-pool ratio, depths greater than 15cm, and slow deep pools. Resulting in few pools for the young-of-the-year to use as refuge below the culvert but nearly two thirds of reach 2 as possible spawning habitat for adults. This ratio may not be as ideal as when initially remediated but Kama Creek has shown signs of naturalization and looking past the creek itself into Kama Bay, revealed a vast shallow and sandy area with a large mat of vegetation about 25m from the creek's mouth. This vegetation mat and ample shallow vegetated waters along the shoreline may provide enough refuge for the young-of-the-year to offset the limited creek space.

Further naturalization of Kama Creek may allow stream morphology to settle back into and match pre-1960 diversion and pre-remediation flow regimes. Even if the resulting creek form is spawning habitat dominant, the bay may be able to support an abundance of refuge habitat to offset the number of pools in Kama Creek.

CONCLUSION

The habitat assessment for reach 2 of Kama Creek found that seven years after the 2011 restoration, the remediation project was successful at increasing the abundance of high quality brook trout habitat. If sediment deposition and resulting effects continue without intervention, however, it may cause overall stream habitat quality to decline. The habitat assessment method developed by Kaurin (2015) was an easy-to-follow system encompassing brook trout habitat characteristics and factors influencing such habitat components. This method is susceptible to assessor bias due to the quantitative nature of the assessment and descriptors used for each habitat condition, leaving the accuracy of this method variable between assessors.

Remediation

The restoration was deemed a success by allowing access to stream habitat above the culvert and the increased length of reach 2 over reach 1, as well as, the quality of habitat conditions scores from the habitat assessment. Monitoring should focus on the sedimentation rate and its effects in reducing pool effectiveness that has already begun homogenizing nearly two thirds of reach 2 and may not provide refuge habitat for young-of-the-year brook trout as the project intended. Ideal areas of slow flowing, deep, and turbid water with plenty of cover ideal for brook trout are now only clearly present as designed within fifty meters from the stream mouth (Giger, 1973; Wesche, 1980). Even with sediment deposition decreasing pool abundance, it also created cover habitat in the form of undercut banks. There is also an abundance of shallow shoreline connected to the creek mouth that supports cover habitat features for brook trout.

Without brook trout population data, it is difficult to definitively judge the usefulness of Kama Creek at providing for the local brook trout population. Since, there is uncertainty around population level reactions to habitat change because only a selection of all habitat features present in a system will ultimately limit populations at any time (Rosenfeld, 2003). Expanding the focus of this study in determining remediation success to include a brook trout population establishment and growth would make the successful determination more robust.

Recommendations

Kama Creek has the ability to provide research and teaching opportunity in conjunction with rehabilitation into the future. Further studies placing emphasis on both habitat assessment and population surveys would be able to follow the naturalization of a stream that did not necessarily follow restoration design plans, as well as, determine if the brook trout population is increasing. Expanding study focus into Kama Bay would add insight on habitat use of the larger system.

Kama Creek is a unique case of disturbances with a well-documented history that has potential to provide insight into the stream restoration field, as well as, improve local brook trout populations through the improvement of habitat characteristics. With the plethora of railway crossings across Canada, continued research at Kama Creek will build strong foundational knowledge that can be applied to other streams impacted by crossings and bring us one step closer to restoring aquatic ecosystems.

LITERATURE CITED

Cox, C. (2015). Kama Creek Monitoring: Examining Water Loss and Sediment Transport in a Remediated Stream.

Deacon, K. (2014). Aquatic Benthic Macroinvertebrate Communities after Remediation of Kama Creek, Thunder Bay District, Ontario, 2014.

Giger, R. D. (1973). Streamflow requirements of salmonids. AFS-62-1. Oregon Wildlife Comm., Portland. 117 pp.

Imhol, J., Fitzgibbon, J., & Annable, W. (1996). A hierarchical evaluation system for characterizing watershed ecosystems for fish habitat. Canadian Journal Of Fisheries And Aquatic Sciences, 53(S1), 312-326. doi: 10.1139/f96-011

Kaurin, K. T. (2015). Monitoring for Success in Stream Restoration: A Case Study of the Kama Creek, North Shore of Lake Superior.

Lakehead University. (2011). Request for Proposal Kama Creek Restoration.

Laronne, J., & Carson, M. (1976). Interrelationships between bed morphology and bed-material transport for a small, gravel-bed channel. Sedimentology, 23(1), 67-85. doi: 10.1111/j.1365-3091.1976.tb00039.x

McFadden, J. T. (1961). Wildlife Monographs, No. 7, A Population Study of the Brook Trout, *Salvelinus fontinalis* (Nov., 1961), pp. 3-73

Nipigon Bay Remedial Action Plan. (2004). Clearwater and Kama Creek Design Study and Restoration.

Raleigh, R. F. (1982). Habitat suitability index models: Brook trout. U.S. Dept. Int., Fish Wildl. Servo FWS/OBS-82/10.24. 42 pp.

Roni, P., Beechie, T., Bilby, R., Leonetti, F., Pollock, M., & Pess, G. (2002). A Review of Stream Restoration Techniques and a Hierarchical Strategy for Prioritizing Restoration in Pacific Northwest Watersheds. North American Journal of Fisheries Management, 22(1), 1-20. doi: 10.1577/1548-8675(2002)022<0001:arosrt>2.0.co;2

Rosenfeld, J. (2003). Assessing the Habitat Requirements of Stream Fishes: An Overview and Evaluation of Different Approaches. Transactions Of The American Fisheries Society, 132(5), 953-968. doi: 10.1577/t01-126

Rosgen, D. (1994). A classification of natural rivers. CATENA, 22(3), 169-199. doi: 10.1016/0341-8162(94)90001-9

Tabacchi, E., Correll, D., Hauer, R., Pinay, G., Planty-Tabacchi, A., & Wissmar, R. (1998). Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology, 40(3), 497-516. doi: 10.1046/j.1365-2427.1998.00381.x

Wesche, T. A. (1980). The WRRI trout cover rating method: developments and application. Water Resour. Res. Inst., Water Resour. Ser. 78. 46 pp.

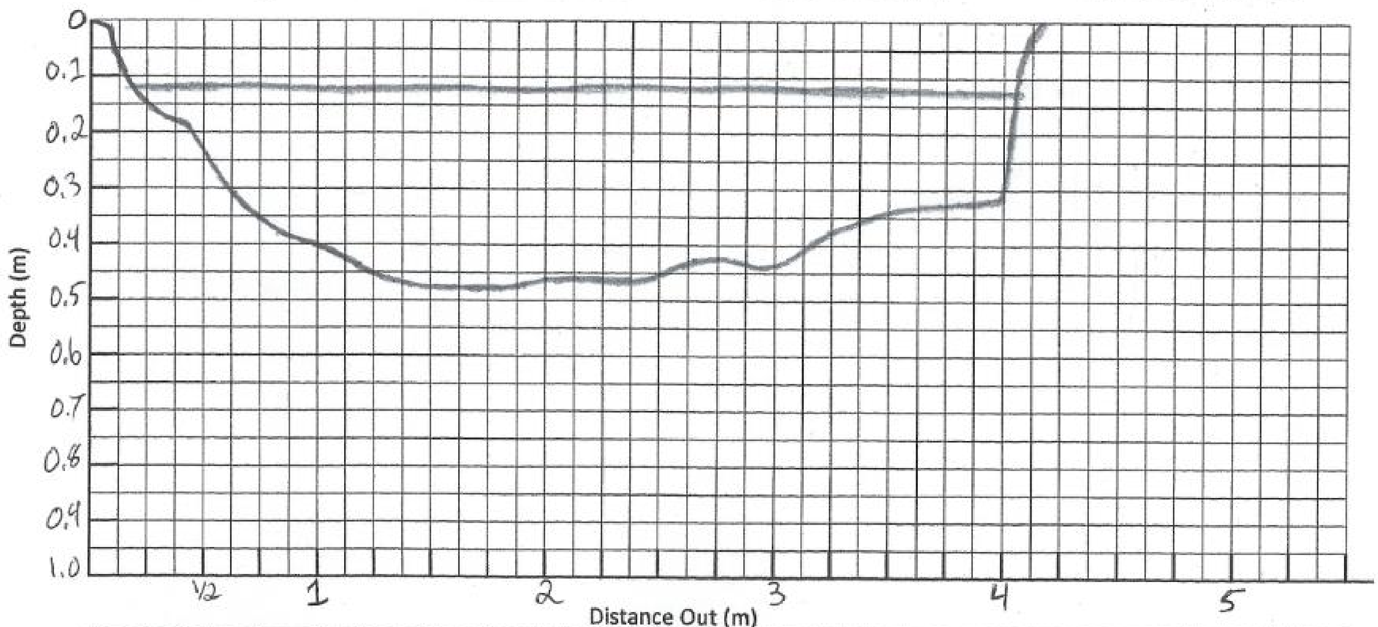
Wolman, M. (1967). A Cycle of Sedimentation and Erosion in Urban River Channels. Geografiska Annaler. Series A, Physical Geography, 49(2/4), 385. doi: 10.2307/520904

Wooldridge, C., & Hickin, E. (2002). Step-pool and cascade morphology, Mosquito Creek, British Columbia: a test of four analytical techniques. Canadian Journal Of Earth Sciences, 39(4), 493-503. doi: 10.1139/e01-087

APPENDICES

Cross-Sectional Profile and Discharge Calculation for Kama Creek

Date: Nov. 4, 2018 Site ID: Kama 1 UTM Easting: 0425854 UTM Northing: 5425787



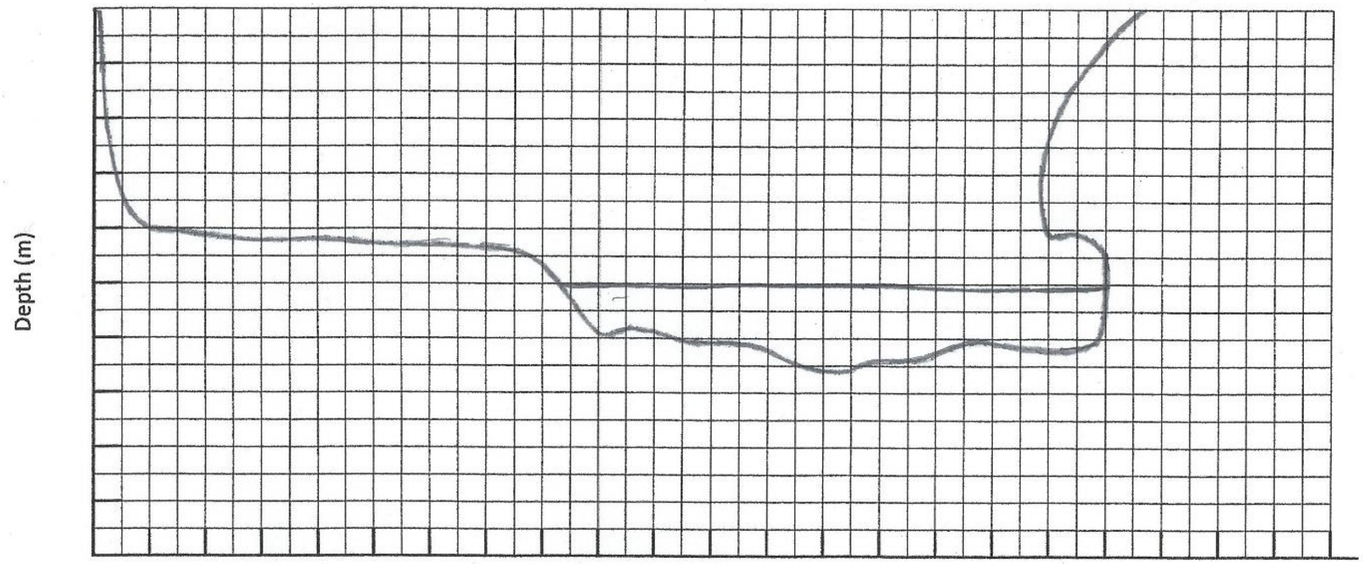
# of squares:		1.5	7	10	11.5	13	13.5	14	13.5	13.5	12.5	12.5	11	9	8	8						
Area (m^2):		0.009	0.044	0.063	0.072	0.081	0.084	0.088	0.084	0.084	0.078	0.078	0.069	0.056	0.05	0.05						
Flow velocity ($m\ s^{-1}$):		0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.05						
Discharge ($m^3\ s^{-1}$):		.0005	.0044	.0063	.0072	.0081	.0084	.0088	.0084	.0084	.0078	.0078	.0138	.0113	.01	.0025						

Area of one square = 0.00625 m^2

Total Discharge (Q) = 0.1214 $m^3\ s^{-1}$

Cross-Sectional Profile and Discharge Calculation for Kama Creek

Date: Nov. 4, 2018 Site ID: Kama 2 UTM Easting: 0425991 UTM Northing: 5425726



Distance Out (m)

# of squares:									1.5	3.5	4	4.5	5.5	6	4.5	4	4	4.5				
Area (m^2):									0.009	0.022	0.025	0.028	0.034	0.039	0.028	0.025	0.025	0.028				
Flow velocity ($m\ s^{-1}$):									0.1	0.4	0.7	0.5	0.7	0.6	0.5	0.5	0.1	0.05				
Discharge ($m^3\ s^{-1}$):									.0009	.0088	.0175	.0141	.0241	.0225	.0141	.0125	.0025	.0014				

Area of one square = ____________ m^2

Total Discharge (Q) = 0.1183 $m^3\ s^{-1}$