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2015 Horn River Basin Surface Water Monitoring Program – Final Report

Geoscience BC Report 2016-13
FINAL Report - Revised
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Geoscience BC

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1. Introduction

In 2011-12 Geoscience BC (GBC) began a baseline water monitoring program in the Horn River Basin (HRB) area located in northeastern British Columbia. The program was initiated to establish an area baseline dataset by collecting surface water quantity, quality and selected biomonitoring (Benthic) information.

GBC is an independent, non-profit organization that generates earth science in collaboration with First Nations, local communities, government, academia and the resource sector. Their independent earth science enables informed resource management decisions and attracts investment and jobs. GBC gratefully acknowledges the financial support of the Province of BC.

GBC, the Horn River Basin Producers Group (HRBPG) and area First Nation Communities (the Fort Nelson First Nation and the Fort Liard First Nation (Acho Dene Koe)) all have a strong commitment to see effective water management occur within the HRB. As such, in 2011 GBC and HRBPG combined to fund the Horn River Basin Surface Water Baseline Monitoring Study that was subsequently awarded to Kerr Wood Leidal Associates (KWL).

This document provides an overview of the program goals, scope and results as well as an update of data collection for the final year of the program (2015) and summary of the entire program dataset 2011-12, 2013, 2014 and 2015.

1.1 The Need for Monitoring

Water availability has and is expected to continue to play a pivotal role in the resource development of the HRB; however, prior to 2010, information in the basin was limited. To begin resolving the lack of information, The BC Ministry of Energy and Mines funded a preliminary assessment of surface water resources (Golder, 2010)[1] which made several recommendations:

1. Install four to seven baseline hydrometric stations within the HRB to collect detailed hydrometric data; and
2. At least three new meteorological stations should be installed within the HRB to better understand the climate spatial and temporal variability.

The data collected during this 2011-12 to 2015 study and follow on programs (4 hydrometric stations are being extended) will be used by the BC Government to characterize the hydrology within the watershed, determine water availability and monitor changes in water supply. The following components were included in the study.

- **Water Quantity:** A total of 7 hydrometric and were installed in May and June of 2012.
- **Climate:** 3 climate stations were installed in July of 2012.
- **Water Quality:** A total of 5 sites are being monitored. Data was used to determine if background levels of naturally occurring elements are above provincial water quality guidelines and whether site-specific water quality objectives should be developed.
- **Biological:** Benthic invertebrate sampling can be used to evaluate changes in the environment that may not be detected using traditional monitoring.

[1] Surface Water Study – Horn River Basin, Oil and Gas Division of BC Ministry of Energy, Mines and Petroleum Resources, Golder Associates, June 2010.

Program Goal

The primary goal of this baseline monitoring program was to characterize surface water, collect water flow data while engaging and training First Nations to allow for sustainable planning and use of water for shale gas development. This data would inform decision making for Government, First Nations and Industry. The program fulfills Geoscience BC's mandate to generate earth science information in partnership with First Nations, the resource sector, universities, governments and communities.

1.2 Program Scope

Baseline hydrology, climate, water quality and biological sampling was determined to be necessary and included. The Horn River Basin Surface Water Monitoring Study consisted of the following scope:

- Water quantity monitoring of seven streams in the HRB Area,
- Full suite climate monitoring at three locations in the HRB Area;
- Water quality monitoring at five locations within the HRB; and
- Benthic invertebrate sampling.

The shallow groundwater (muskeg) monitoring scope was initially required in the RFP study terms of reference. It later was determined that this approach would not provide enough information that could track groundwater direction and link it to surfacewater. It was determined that further consideration was required prior to establishing an effective network. Triton Consultants were commissioned by GBC in 2012 to conduct a "State of Science" report that addressed the shallow groundwater component. This report discussed the existing shallow groundwater information and what steps were required to support the systematic hydrogeological investigation of water resources within Horn River Basin (HRB) in northeastern BC.

GBC is now undertaking further groundwater analysis outside the scope of this study with the Peace Project, a collaborative effort that will generate new information about groundwater in northeast BC's Peace Region. The Peace Project partners include the BC Oil and Gas Commission, the Canadian Association of Petroleum Producers through the Science and Community Environmental Knowledge fund, ConocoPhillips Canada, Progress Energy Canada Ltd., the Province of British Columbia, and the Northern Development Initiative Trust (NDIT).

1.3 First Nation Involvement

An important goal of the study was to develop opportunities to advance First Nations water research and monitoring skills and also to provide project management skills. By including local First Nations Communities in the study it was intended that the study would facilitate a possible future independent First Nations managed water monitoring program. Inclusion of First Nations through this engagement plan provided their better understanding of available water resources in the HRB and fostered trust and understanding of the validity of water data collected.

A program was established to both develop field research and monitoring skills and also provide project management skills:

Research and Monitoring:

The development of technical skills by engaging First Nations members in the water monitoring plan was established by developing and conducting an on-site training course and then on the job training in the following:

- **Hydrometric:** in field hydrometric equipment installation and ongoing water flow measurement to develop hydrometric rating curves.
- **Water Quality:** sampling training and data collection. Grab samples were collected each trip and sent to the laboratory. Results were submitted back to OGC, GBC and FNs.
- **Biomonitoring:** One separate field trip was taken each year to collect Benthic invertebrate samples which were then analysed by an offsite laboratory. Two FN staff were trained in the CABIN program for biomonitoring. This consisted of an online course and a field course in Vancouver. One trainee attended the course in Vancouver.

Project Management:

The program was funded to train several field staff, a project manager and a planner position. Overall there was significant progress made on the field training front and some solid trust relationships were built between our field lead and trainees. A full complement of trainees was not able to be developed, however, those that did participate were of high quality and are now a valuable resource.

First Nations communities will need to consider how sophisticated they wish their water management/hydrology services to be and potentially seek external assistance in the future.

1.4 Program Development

The monitoring network was designed and described by a document entitled Rationale for the Monitoring Network and Site Selection. This document established the rationale for station locations as follows:

1. Initial engagement with First Nations;
2. Prepare a draft site selection and network rationale document;
3. Circulate document to stakeholders for review and comment;
4. Gather additional information, finalize network locations and rationale;
5. Obtain support from First Nations, Trappers and applicable Government agencies; and
6. Communicate the results of the final locations of the monitoring network.

Network Objectives and Criteria

The network objectives were as follows:

- Characterize a baseline of water supply
- Make real-time data on water resources available
- Enhance support of management decisions
- Improve measurement and understanding of water availability
- Provide accurate information
- Enhance ability to determine in-stream flow needs
- Enhance accuracy and reliability of water accounting

Selection Criteria

Site selection criteria is summarized as follows:

1. Watershed characteristics
   - Geographic zone
   - Watershed area
   - Aspect
   - Median elevation
   - Latitude
2. Stakeholder operations considerations
   - Location of existing sites and data quality
   - Traditional ecological knowledge
   - Ability to obtain land tenure
3. Site specific logistics
   - Stable channel section for hydrometric
   - Ground access
   - Telemetry orientation

This process was used to identify station locations for 7 hydrometric and 3 climate stations.

2. Project Team

Horn River Basin Surface Water Monitoring Program was undertaken by a team of contributors. KWL lead the study and two field tasks were both led by a separate subconsultant firms. Local first nations provided support to the field tasks. Details are as follows:

Kerr Wood Leidal Associates Ltd. (KWL): KWL as the overall project managers, performed field oversite and planning, field data QA/QC and data computation and reporting. The KWL project manager worked with the GBC and field service providers to conduct yearly field programs that met the stated project goals. KWL monitored the field data throughout each season and adjusted the program as necessary to make the program more efficient or the data collection more accurate.

Following the field season, KWL water resources specialists reviewed and checked the field data for consistency and accuracy. Edits were made to the water level time series and a discharge time series calculated for each hydrometric station (details below). The climate data was analyzed and water quality and biological sample laboratory results reviewed and QA/QCed. Following the field programs all data results were consolidated and a yearly data summary report written and delivered to GBC.

Peace County Technical Services (PCTS): PCTS of Dawson Creek lead the hydrometric and water quality sampling portion of field program for the duration of the project. Following equipment delivery PCTS installed the seven hydrometric and three climate stations to the required specifications (BC hydrometric standards).

5 open water hydrometric field visits were performed each year, during open water conditions and one ice cover field visit was made each year to measure the winter base flow rate at each site. Further details are provided below. Climate stations were installed and maintained by PCTS throughout the program.

Snow surveys were conducted prior to install in 2011 then repeated to correlate with snow pillows installed with the climate stations.

Environmental Dynamics Inc. (EDI): EDI designed and implement a biomonitoring program using aquatic invertebrates as indicators of aquatic health. Sample results were collected and submitted to Cordillera Consulting and EcoAnalysts Inc. for analysis. Results were QA/QCed and provided to KWL for inclusion in the year data summary reports.

First Nations Participation: First Nations involvement in the water monitoring program has been vital to this project. The Fort Nelson First Nation and the Acho Dene Koe have been involved in the planning and field monitoring portion of this project. Several high quality field people were identified and trained in hydrometric, snow survey, climate, water quality and biomonitoring.

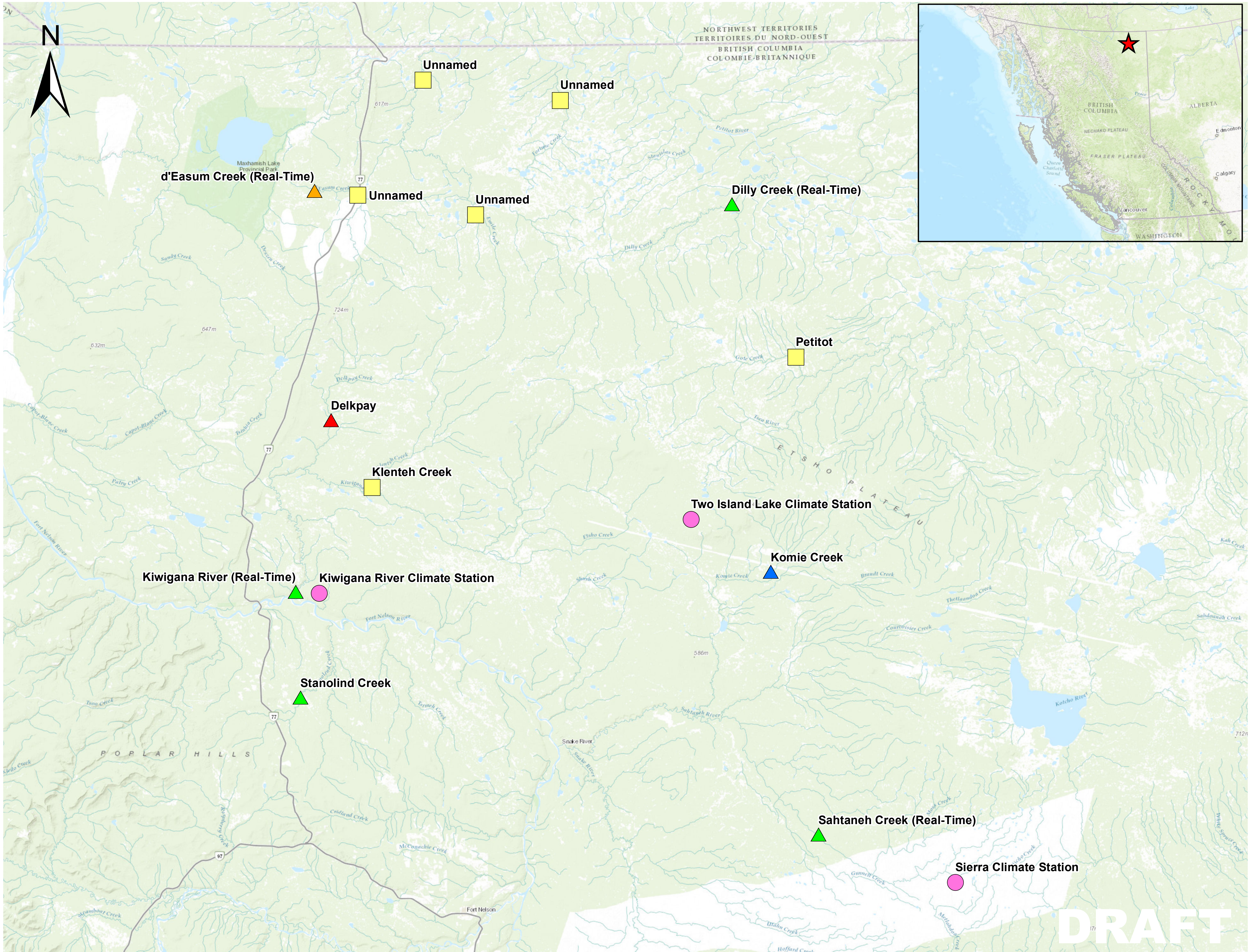
3. Project Data Overview

The data reporting portion of this report presents the most recent data that has been collected for the Horn River Basin Surface Water Monitoring Program during 2015 (Year 4) and a summary of the entire project dataset. This summary presents the baseline data that has been collected over 4 open water seasons and the adjoining winter low flows as follows:

- April 1, 2012 to October 31, 2012;
- Manual measurements of winter low flow in early January 2013;
- April 1, 2013 to October 31, 2013;
- Manual measurements of winter low flow in early January 2014;
- April 1, 2014 to October 31, 2014;
- April 1, 2014 to October 31, 2015.

3.1 2012 - 2015 Hydrometric and Climate Monitoring Program

The stations installed in 2012 and monitored (open water) through October 2015. The locations of the hydrometric and climate stations are presented in Figure 1 and the coordinates of each station is presented in Table 1.



Geoscience BC

Horn River Basin
Surface Water Monitoring Study

Legend

- Hydrometric Station
- Hydrometric Station (with Benthic Invertebrate Sampling)
- Hydrometric Station (with Water Quality Sampling)
- Hydrometric Station (with Water Quality and Benthic Invertebrate Sampling)
- Benthic Invertebrate Sampling Location
- Climate Station

Service Layer Credits: Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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Project No.	Date
2692-002	June 2016

Station Site Map

Figure 1

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Table 1: Coordinates of the hydrometric and climate stations.

Site	Type	Easting*	Northing*
Two Island Lake (real-time)	Climate	551981	6578887
Kiwigana River (real-time)	Climate	494843	6567568
Sierra (real-time)	Climate	592552	6523137
D'Easum Creek (real-time)	Hydrometric	494095	6629320
Delkpay	Hydrometric	496640	6594093
Dilly Creek (real-time)	Hydrometric	558226	6627266
Kiwigana River (real-time)	Hydrometric	491233	6567759
Komie Creek	Hydrometric	564187	6570824
Sahtaneh Creek (real-time)	Hydrometric	571554	6530452
Stanolind Creek	Hydrometric	491929	6551504
*UTM Zone 10			

Data Transfer

'Real-time' station data (see Table 1) is uploaded (via satellite) every 6 hours and transmitted to a provincial data server then onwards to FlowWorks website database (Link to FlowWorks website with the HRB stations can be found here: http://www.geosciencebc.com/s/HornRiverBasin.asp). The 'real-time' hydrometric stations consist of a data logger fixed inside an enclosure and placed beside the stream bank above the assumed max flood level. Stage (water elevation) data from the streams is collected using pressure transducers inserted into protective metal sleeves and inserted into the stream bed/bank. The stations that do not include telemetry consisted of a submersible combination logger /pressure transducer unit.

Since discharge is not measured directly, **stage-discharge relationships (SDR)** are created by measuring instantaneous discharge and water levels across the expected range of flows and relating them to a local datum. The installed pressure transducer and logger records stage (water level) every 15 minutes. Discharge (flow) is calculated from this recorded water level time series by using the equation developed from the SDR.

The discharge measurements collected under this baseline program generally meet "Class A'" hydrometric data standards (Manual of BC Hydrometric Standards, 2009[2]) and are typically given an uncertainty value of +/- 7%.

All of the program's Climate stations are 'real-time' and transmit on a six hour schedule. Each climate station consists of the following; a data logger, satellite transmitter and a five metre tower. The following sensors make up the sensor suite of each station, the logger records the parameters in parenthesis:

- Ambient temperature sensor (hourly minimum, maximum and mean temperatures);
- Dew point temperature (hourly dew point value);
- Barometric pressure (Hourly barometric pressure values);

[2] Manual of British Columbia Hydrometric Standards, Ministry of Environment, 2009

- Relative humidity (hourly relative humidity values);
- Precipitation (Hourly precipitation accumulation)
- Solar radiation (hourly solar radiation)
- Snow Pillow (hourly snow-water equivalent)
- Wind sensor (two and five minute wind velocity and direction, 60 minute mean velocity and direction and peak hourly velocity).

3.2 2012 - 2015 Water Quality Program

Five watersheds, each with one sampling site near a hydrometric station, were chosen for the surface water program: Dilly Creek (Site ID: HRB-1), Kiwigana River (HRB-3), Sahtaneh River (HRB-2), D'Easum Creek (HRB-4) and Stanolind Creek (HRB-5). The locations of the water sampling sites correspond to 5 of the hydrometric sites (Figure 1).

Each standard trip consists of water sample collection for laboratory analyses and recording of field parameters such as temperature, dissolved oxygen, pH, conductivity, salinity, total dissolved solids and turbidity. Analytical parameters for laboratory analyses include general water chemistry, major ions, nitrogen speciation, metals (total and dissolved). Volatile organic compounds (BTEX) and extractable petroleum hydrocarbons (EPH) parameters were collected in early 2015 but were removed for the remainder of the sampling events when it was determined that samples showed these parameters were below detection limits.

A standard QA/QC program used trip blanks and field blanks to ensure data quality. All sampling was conducted using nitrile gloves to avoid contamination and samples were shipped to the lab within 72 hours of collection.

3.3 2011 - 2015 Benthic Program

The purpose of the benthic sampling program was to design and implement a biomonitoring program using aquatic invertebrates as indicators of aquatic health. A Canadian Aquatic Biomonitoring Network (CABIN)[3] approach was used to assess the aquatic health between various watersheds in the HRB using test sites and reference sites. Reference sites are established in areas minimally impacted by human activities and test sites are established in areas downstream or adjacent to human activities.

EDI undertook the Benthic program (see Appendix D). The benthic biomonitoring program established for the HRB involved five reference sites that were selected and initially sampled in 2011 and six test sites that were selected and initially sampled in 2012 (Figure 1). Five of the previously sampled test sites were sampled again in 2013 and 2015. To increase the sample size available for data analysis, additional reference site data collected by the BC Ministry of Environment (MOE) for Environment Canada's model in 2010 and 2011 within the HRB have also been included in the dataset. A statistical analysis was conducted (in the absence of CABIN reference model) to compare results at test and references sites that may be due to differences in water quality.

[3] Environment Canada 2013. Canadian Aquatic Biomonitoring Network (CABIN).

Methods

Benthic invertebrate sampling at each site followed the CABIN protocols[4]. Under the protocol, a kicknet of standard shape and mesh size is placed on the bottom of a creek downstream of the feet of the sampler, who then walks slowly upstream with the net, kicking up rocks (for three minutes) immediately upstream of the net. Through this process, organisms are released from the sediments and are carried into the net by the streamflow, and a representative sample of benthic invertebrates is captured. Each sample collected is then transferred to bottles, preserved, and sent to the lab for analyses. Benthic invertebrates in the samples are then subsampled, sorted, identified, and recorded in the online CABIN database. Non-biotic factors were also sampled at each site, including: substrate characteristics, in-situ water quality, channel morphology and flow.

GIS Analysis

To further examine the results of the benthic biomonitoring program, a desktop GIS study was initiated in 2015 to look at potential relationships between benthic community composition and the type and density of industrial development in the HRB. Benthic community composition at both test and reference sites were compared to the amounts of various industrial activities that have occurred within their respective watersheds and within the local area surrounding each test and reference site.

The type and number of industrial activity sites per km^2 was calculated for each test and reference watershed. Results were also compared to the amount of local vegetation disturbance (qualitatively assessed using high resolution imagery) surrounding each test and reference site. Lastly, a regression analysis of density and type of industrial activity was performed against three matrices of benthic invertebrate health. All spatial data used for the GIS study was obtained through public online sources (e.g. Oil and Gas Commission, IMAP, Bing Imagery, etc).

4. 2015 Monitoring Program Data

The following sections present the results for each component of the HRB monitoring program. The results of the hydrometric and climate program (section 4.1) are provided in Appendix A. The results and final report of for the water quality component are presented in Appendix B (Section 4.2). Lastly, the results and final report for the benthic biomonitoring program are presented in Appendix C.

4.1 Hydrometric Stations

Stage-discharge relationship (SDR) curves

Stage-discharge relationship (SDR) curves developed and updated in 2015 for each hydrometric station are presented in Figures 3 through 9 (Appendix A). Figure 2 presents a sample project SDR for the Kiwigana River. The plotted rating measurements are those used to create the SDR, those rating points that were deemed to be invalid due to ice effects or measurement error were not included. Because the SDR was finalized in 2014 the three measurements performed during 2015 are not used to modify the SDR but included as a check of the SDR validity. The recommended upper limit of applicability for each SDR is a measure of how far the curve can be confidently

[4] Environment Canada 2012a. Canadian Aquatic Biomonitoring Network (CABIN) Field Manual Wadeable streams.

extrapolated beyond the highest discharge measurement (typically 2X the highest measured discharge value).

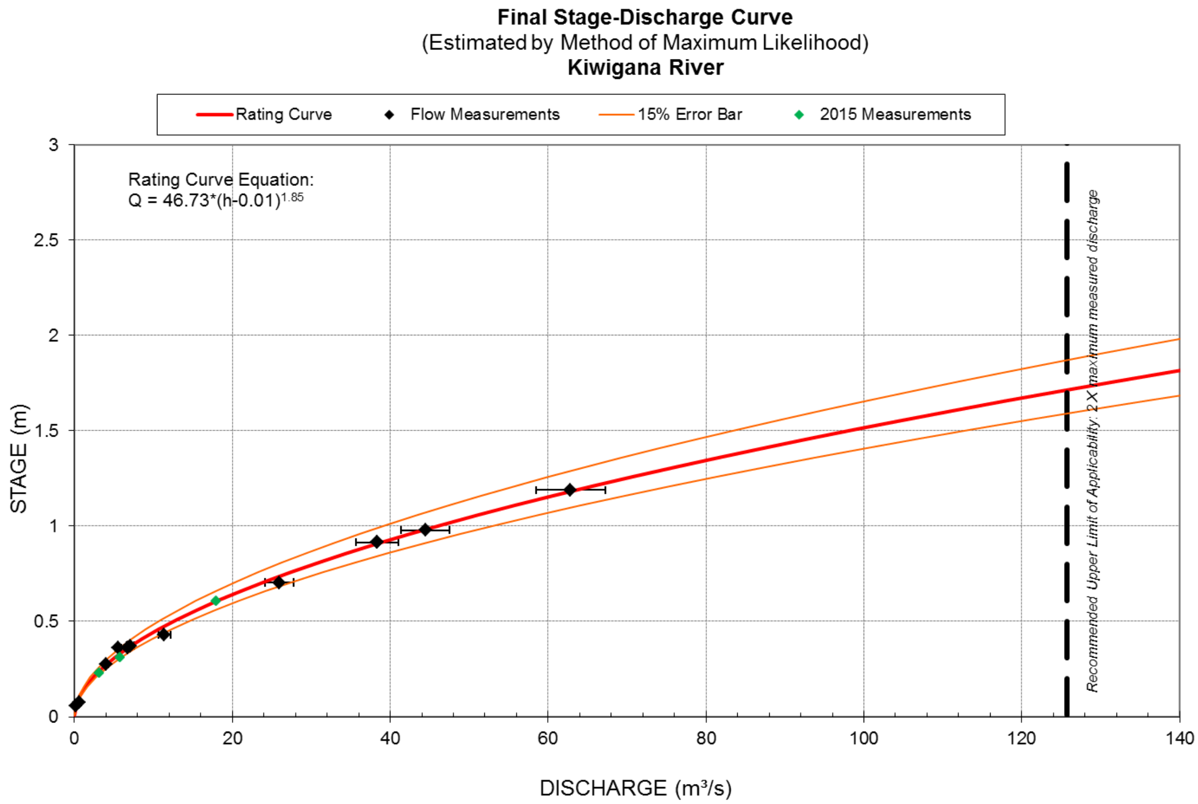

Figure 2: Sample SDR (Kiwigana River)

The Manual of BC Hydrometric Standards recommends a minimum of 10 discharge measurements well-distributed through the range of flows to develop a rating curve or SDR. To date, 11 or more open water measurements of discharge have been collected for each site. With the exception of Stanolind Creek, these SDRs that have been developed are considered final.

Table 2 summarizes the SDR status and water level data record quality for each of the seven hydrometric sites.

Table 2: Hydrometric Site SDR Status and Water Level Record Quality

Site	SDR Status	Water Level Record Quality	Water Level Record Comments on Major Events
D'Easum Creek	Final	Excellent	Two weeks of data missing in May 2014, caused by possible ice in channel
Delkpay	Final	Good	Data not recorded for August and September 2014 because the logger was de-watered
Dilly Creek	Final	Excellent	One month outage in early 2012 caused because the logger was dewatered

Site	SDR Status	Water Level Record Quality	Water Level Record Comments on Major Events
Kiwigana River	Final	Good	One month outage in July/August 2013 caused by logger being pulled from stilling well by an animal One week period of missing data August 2014 caused because the logger was de-watered
Komie Creek	Final	Excellent	One week period of missing data July/August 2015 caused by sediment in stilling well
Sahtaneh Creek	Final	Excellent	Complete dataset
Stanolind Creek	Preliminary, requires intermediate discharge measurements	Excellent	Complete dataset

SDR Discussion

Stanolind Creek has a large gap in the SDR (Figure 7) that corresponds to moderate discharges (between 4 and 18 m^3/s); the SDR for Stanolind Creek will remain preliminary until manual discharges within the identified gap are collected and the SDR updated accordingly.

The SDR for Dilly Creek has been typically classified as provisional because of a high manual measurement collected during an event where the creek spilled beyond the channel top of bank (64 m^3/s on May 16, 2013), did not agree with the rest of the station dataset. However, because follow-up measurements that can confirm this portion of the rating curve have not been collected it was decided to remove this point from the SDR development process and apply an upper limit of applicability of 41.7 m^3/s.

As in previous years the 2015 data from the Kiwigana River and D'Easum Creek hydrometric stations is compared to the Water Survey of Canada gauge at the Fontas River (WSC # 10CA001). The data is compared in terms of water yield ($L/s/km^2$) and presented in Figure 17 (Appendix B).

In general, the 2015 freshet occurred in early-May for all sites and was smallest in magnitude that occurred during the four year monitoring program. The peak discharge of all sites in 2013, with the exception of Stanolind (Figure 14), occurred in mid-June due to a rainfall event. Following the large peak flow in June was a summer drought lasting from late July to October. Most sites showed a slight increase in flow in early October prior to the 2014/2015 winter period.

The surface water yield for D'Easum Creek and Kiwigana River match the general shape of the water yield hydrograph for the Fontas River in 2015 (10CA001). The timing of the freshet, June, July and August rain events match closely for the 3 datasets. Summer base flow yield is very close (approximately 1 $L/s/km^2$) for the all three sites; d'Easum Creek typically had a higher yield during freshet and rain events. The Fontas River yield was less than d'Easum but greater than the Kiwigana River with the exception of the early August rain event which was much heavier in the Fontas River watershed.

Hydrographs

A hydrograph for each hydrometric station was completed by using the corresponding SDR to convert the logger recorded timeseries into discharge values. A hydrograph for the each hydrometric station covers a period of record from April 2012 to the end of season in 2015 (late October). The hydrographs for the hydrometric stations are presented in Figures 10 through 16 (Appendix B). The horizontal blue line on each chart represents the recommended SDR upper discharge limit. For Dilly Creek, only the flows below the SDR limit of applicability are included (≤ 21 m^3/s as discussed in section above, Figure 2).

4.2 Climate Stations

Climate data (Daily Maximum , Minimum and Average Temperatures, precipitation and snow water equivalent) from the three climate stations (Kiwigana River, Sierra, and Two Island Lake) are presented in Figures 18 to 20 (Appendix B). The climate station wind data is presented in Figures 21-23 (Appendix B)

A summary of observations pertaining to the collected climate data is provided below:

- The warmest temperature recorded by any of the stations was 33.2 ^{o}C recorded at the Kiwigana Climate Station on June 26, 2015; the coldest temperature was -38 ^{o}C recorded at the Two Island Lake Climate station on February 8, 2015.
- The peak wind gust (60 min mean) for all stations occurred at the Sierra station on November 19, 2015; 59.4 km/hr (16.5 m/s).

4.3 Water Quality Monitoring Sites

The results from the water quality program are presented into three separate technical reports. The Year 2 technical report outlines the results of the first two years of the water quality program (Year 1: July 2012 to May 2013, Year 2: June 2013 to May 2014). The Year 3 technical report summaries the third year of the program (June 2014 to October 2014), whereas the Year 4 technical report outlines the results of the final year of the program (May 2015 to September 2015). All three water quality technical reports are presented in Appendix C.

A few of the key findings from the water quality program are outlined below:

- Several field parameters collected at each (i.e. conductivity, TDS, and salinity) showed an increasing trend in concentration throughout the course of a year
- Dissolved and total iron concentrations exceeded water quality guidelines for the protection of aquatic life at all sites for most sampling events
- Total cadmium, chromium, and zinc concentrations exceeded water quality guidelines for the protection of aquatic life at the Dilly Creek (HRB-1) and Kiwigana River (HRB-3) sites for the May 2014 sampling event. An exceedance for chromium also occurred for the June 2014 event at the Kiwigana River site
- In April of 2013, updated water quality guidelines for sulphate has been introduced by the BC Ministry of Environment, using the new guideline no exceedances of sulphate has occurred within the HRB dataset
- Sahtaneh River (HRB-2) and Kiwigana River (HRB-3) have consistently high sulphate concentrations overall compared to the other sites

4.4 Benthic Monitoring Sites

The results and analysis of the HRB biomonitoring program are summarized in three documents (see Appendix D):

- The 2014 benthic biomonitoring technical report presented the results of a statistical analysis of reference and test site data collected between 2011 and 2013
- A 2015 desktop GIS study (summarized in a presentation) was conducted in attempts to identify potential linkages between benthic community composition and the type and density of industrial development in the HRB
- A follow-up benthic biomonitoring technical report was completed in 2016 which re-examined all collected benthic data using additional test site data collected in 2015

Key findings outlined of the 2014 technical report were as follows:

- Reference sites (sites within areas minimally impacted by human development) were found to have a higher number of taxon than test sites (sites downstream of human development)
- Reference sites contained more species of benthic invertebrates that are sensitive to effects of disturbance compared to test sites
- A regression analysis was conducted between non-biotic factors and benthic invertebrate metrics. Only latitude (location) was significant. Both reference and test sites contained higher proportions of sensitive species in more northerly sites

Key findings of the 2015 GIS study included:

- In general, industrial activity is more concentrated in test site watersheds compared to reference site watersheds (concentration of activity is normalized by watershed area)
- Test sites were found to be in areas with higher levels of local vegetation disturbances
- A regression analysis conducted between matrices of benthic invertebrate health and industrial activity type and density, revealed no significant nor strong relationships.

The key findings of the 2016 Benthic Biomonitoring report were as follows:

- Results of the follow up analyses confirmed previous findings from 2014: i.e. many of the benthic community matrices at test sites differ compared to reference sites, and the difference reflects lower diversity, lower number of sensitive species compared to reference sites, and higher total abundance of invertebrates in test sites compared to reference sites
- The benthic community did not significantly change among years at the test sites in 2012, 2013, and 2015

5. Discussion

5.1 Hydrology Data

As in previous years, the 2015 data from the Kiwigana River and D'Easum Creek hydrometric stations is compared to the Water Survey of Canada gauge at the Fontas River (WSC # 10CA001). The data is compared in terms of water yield (L/s/km^2) and presented in Figure 17 (Appendix B).

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Water yields were calculated for all seven stations over the 2012 - 2015 period; a plot was created for each of the four years of the monitoring program and they are presented in Figures 24 through 27 in Appendix E.

Winter measurements we performed in four of the seven watersheds in the study area to define the winter baseflow values at the stations. The results of these measurements are presented in Table 3, there was flow present in the streams during each of the eight site visits. While not conclusive, these results suggest that the streams in the area flow year round; however a more intensive winter field program would be required to confirm or refute this.

Table 3: Winter flow manual measurements for the HRB program

Site	Date	Discharge (m^3/s)
Sahtaneh Creek	7-Jan-13	0.0096
Sahtaneh Creek	9-Jan-14	0.1602
d'Easum Creek	9-Jan-13	0.0224
d'Easum Creek	6-Jan-14	0.1098
Dilly Creek	8-Jan-13	0.0451
Dilly Creek	7-Jan-14	0.1079
Kiwigana River	9-Jan-13	0.0908
Kiwigana River	6-Jan-14	0.717

5.2 Water Quality Data

A general trend of increased concentrations of field parameters observed in this water quality program during lower winter flows or low flow periods has been documented elsewhere[5]. Seasonal fluctuations in chemical concentrations is a common phenomenon in most rivers, with lower concentrations during spring freshet and elevated concentrations during the low flow periods[6]

[5] Meays, C. and R. Nordin. 2013. Province of BC Ambient Water Quality Guidelines For Sulphate, Technical Appendix Update April 2013

[6] Meays, C. and R. Nordin. 2013. Province of BC Ambient Water Quality Guidelines For Sulphate, Technical Appendix Update April 2013.

It can be common to see elevated metals in the water column during high flow events as erosional processes during this time can introduce high concentrations of suspended sediment to the stream channel that contain metals.

Local geology, watershed characteristics (e.g. presence of wetlands/muskeg) and high flow events are the most likely sources of the elevated metals observed in the monitoring program. More details are provided in the Surface Water Quality Monitoring Program Update Report in Appendix B.

5.3 Benthic Invertebrate Data

The benthic invertebrate sampling results collected to date appear to indicate differences in aquatic ecosystem health between test and reference sites within the HRB. The level of difference between test and reference sites (located in the pristine locations away from human settlement) was documented. Several metrics at test sites are within the range of variability of un-impacted sites elsewhere in North America (Bode and Novak 1994[7]; Fore et al., 1996[8]; Maret et al. 2003[9]; Sylvestre et al. 2005[10]).

Determining what factors that may be influencing stream health is difficult with the current dataset, as the benthic biomonitoring program was primarily designed as a baseline collection program not an effects assessment. Based on the GIS desktop study, there appears to be a possible correlation between the concentration of industrial development at the watershed scale and benthic community health. However, the mechanism that may be driving this correlation is unclear. There is also a possible relationship between the benthic invertebrate community composition and the amount of local vegetation disturbance at sampling locations; however, these sampling locations were positioned according to CABIN standard methodology. More work would be required to further establish the gradient of aquatic conditions that occur across the region.

In a broader context, the value of this sampling has been to establish trend monitoring and a baseline condition for the state of stream conditions that exists in these watersheds. Once the CABIN model is available, the test sites may fall under one of the following categories compared with model reference sites: similar, mildly divergent, divergent or highly divergent. The differences between test sites and reference sites, which include higher abundance of invertebrates coupled with different community structure, may be similar or somewhat divergent to the reference state. Based on the indicators of aquatic health it is unlikely the test sites would be highly divergent from the reference state. If the test sites are divergent, a further step would be to assess if there is biological significance to a potential difference from pristine conditions.

[7] Bode, R.W. and Novak, M.A. 1994. Development and Application of Biological Criteria for Rivers and Streams in New York State (Chapter 8). In: Davis, W.S. and Simon, T.P. (eds), Biological Assessment and Criteria, Tools for Water Resource Planning and Decision Making. pp. 97-108.

[8] Fore, L.S., Karr, J.R. and Wisseman, R.W. 1996. Assessing invertebrate response to human activities: evaluating alternative approaches. Journal of the North American Benthological Society. 15(2): 212-231.

[9] Maret, T.R., Cain, D.J., MacCoy, D.E., and Short, 2003. T.M. Response of benthic invertebrate assemblages to metal exposure and bioaccumulation associated with hard-rock mining in northwestern streams, USA. Journal of the North American Benthological Society. 22(4): 598-620.

[10] Sylvestre, S., Fluegel, M. and Tuominen, T. 2005. Benthic Invertebrate Assessment of Streams in the Georgia Basin Using the Reference Condition Approach: Expansion of the Fraser River Invertebrate Monitoring Program 1998-2002. Environment Canada, Vancouver. 55 pp.

6. Future Programs and Recommendations

While the GBC/HRBPG has ended, there is interest from other partners in continuing monitoring in a limited way. Below are recommendations on what could be done to continue.

6.1 Hydrologic Monitoring

Following discussions between GBC, OGC, PCTS and KWL a decision was made to extend the hydrometric part of the program and keep four of the hydrometric stations in place and to move three of the hydrometric stations to the South Peace Region. The desire to keep the stations in place was primarily due to a request made by the OGC who values the hydrometric data provided by the four stations. This also provides valuable information to support the Northeast Water Strategy. Table 4 provides a brief summary of the stations and their future locations.

It is recommended that the stations that will remain in place be visited at minimum three times per open water season to maintain the SDRs. The new stations in the South Peace Region will require a more intensive field schedule until new SDRs can be developed and verified.

Table 4: HRB Hydrometric Stations

Station Name	Dataset and SDR Status	Station Data Value	Recommendation
D'Easum Creek	Dataset and SDR are reliable (real time)	Valuable dataset	Keep
Kiwigana River	Dataset and SDR are reliable (real time)	Valuable dataset	Keep
Sahtaneh River	Dataset and SDR are reliable (real time)	Valuable dataset	Keep
Dilly Creek	SDR provisional until (real time) upper portion can be confirmed	Only station in the NE portion of the study area	Keep, but resolve data collection issues
Delkpay Creek	Creek configuration has caused the station SDR to be inconsistent (manual download)	Dataset is valuable but it correlates well with the Kiwigana River	Move to South Peace
Komie Creek	Inconsistent dataset and SDR (manual download)	Limited value due to data collection issues	Move to South Peace
Stanolind Creek	Inconsistent dataset and SDR (manual download)	Limited value due to data collection issues	Move to South Peace

6.2 Water Quality Monitoring

To better characterise the surface water baseline and the observed chemical properties of the collected water for this program, a link to shallow groundwater and formation water chemistry monitoring program is a good direction. The Peace Project groundwater work could look into this.

6.3 Biological Monitoring

The Environment Canada reference condition bioassessment model for the HRB is expected to be completed in 2016. This model will allow an evaluation of the test sites to be compared with a reference condition in efforts to determine the test sites level of divergence (i.e. how similar or different are test sites from reference sites.

The CABIN program terminology is as follows: test sites will each fall under one of the following categories compared with CABIN model reference sites: similar, mildly divergent, divergent or highly divergent.

It is recommended that the test sites be re-evaluated against the reference condition for the HRB when the Environment Canada Bioassessment Model becomes available to determine which category of the test sites fall into. After that, if the test sites are divergent, the next step would be to characterize that difference and assess the biological significance of potential divergence from pristine conditions.

7. Conclusion

7.1 Acknowledgements

KWL wishes to recognize the significant contributions to this study by our study team, First Nations, the Horn River Basin Producers Group and Geoscience BC as follows:

Carlos Salas, VP Oil and Gas, Geoscience BC (Project Management)

Scott Wagner, Shawn Williams (Nexen) and Scott Hillier, ConocoPhillips, HRB Producers Group

Cathy Mackay and Hanna Van de Vosse. Environmental Dynamics Inc. (Benthics and Water Quality)

Barry Ortman, Peace Country Technical Services (Field Program, Hydrometric and Climate)

Darren David, Waterline Resources (Groundwater and Water Quality)

Fort Nelson First Nation (Planning and Field Program)

Fort Liard First Nation (Acho Dene Koe) (Field Program)

Allan Chapman, BC Oil and Gas Commission

7.2 Conclusion

The HRB monitoring program was performed for the HRBPG and GBC by KWL, PCTS and local First Nations partners over the span of four years (2012 – 2015). The program involved hydrometric data, climate data monitoring and water quality and biological sample collection. The field programs were carried out successfully during each open water season (Approximately May through October). The final datasets have been presented in this report along with some comments and recommendations and provide a valuable baseline surfacewater data set for the Horn River Basin.

If you have any questions regarding this report please contact one of the undersigned,

Prepared by:

KERR WOOD LEIDAL ASSOCIATES LTD.

Chad Davey, M.Sc., R.P.Bio.
Senior Hydrologist

Reviewed by:

Dave Murray, P.Eng., AScT, CPESC
Project Manager

Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of Geoscience BC and the Horn River Basin Producers Group for the Horn River Basin Surface Water Monitoring Program. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

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Revision History

Revision #	Date	Status	Revision	Author
1	December 7, 2016	FINAL	Revision in Introduction	CD/DNM
0	August 30, 2016	FINAL		CD/DNM
A	June 30, 2016	DRAFT	Internal Review	CD/DNM

OQM | Organizational Quality Management Program

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Appendix A

Stage-Discharge Relationships

Final Stage-Discharge Curve
(Estimated by Method of Maximum Likelihood)
Kiwigana River

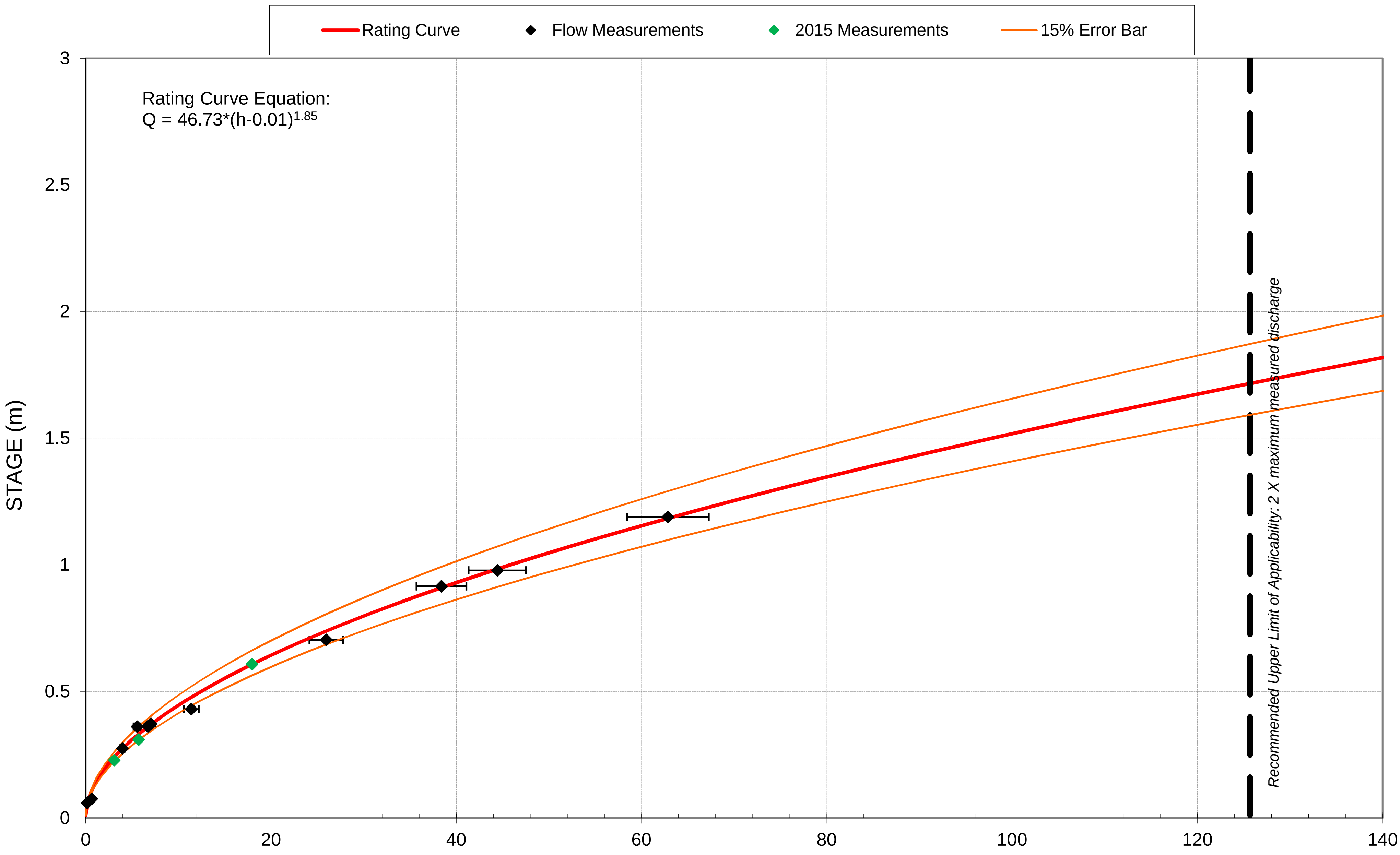

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Figure 3

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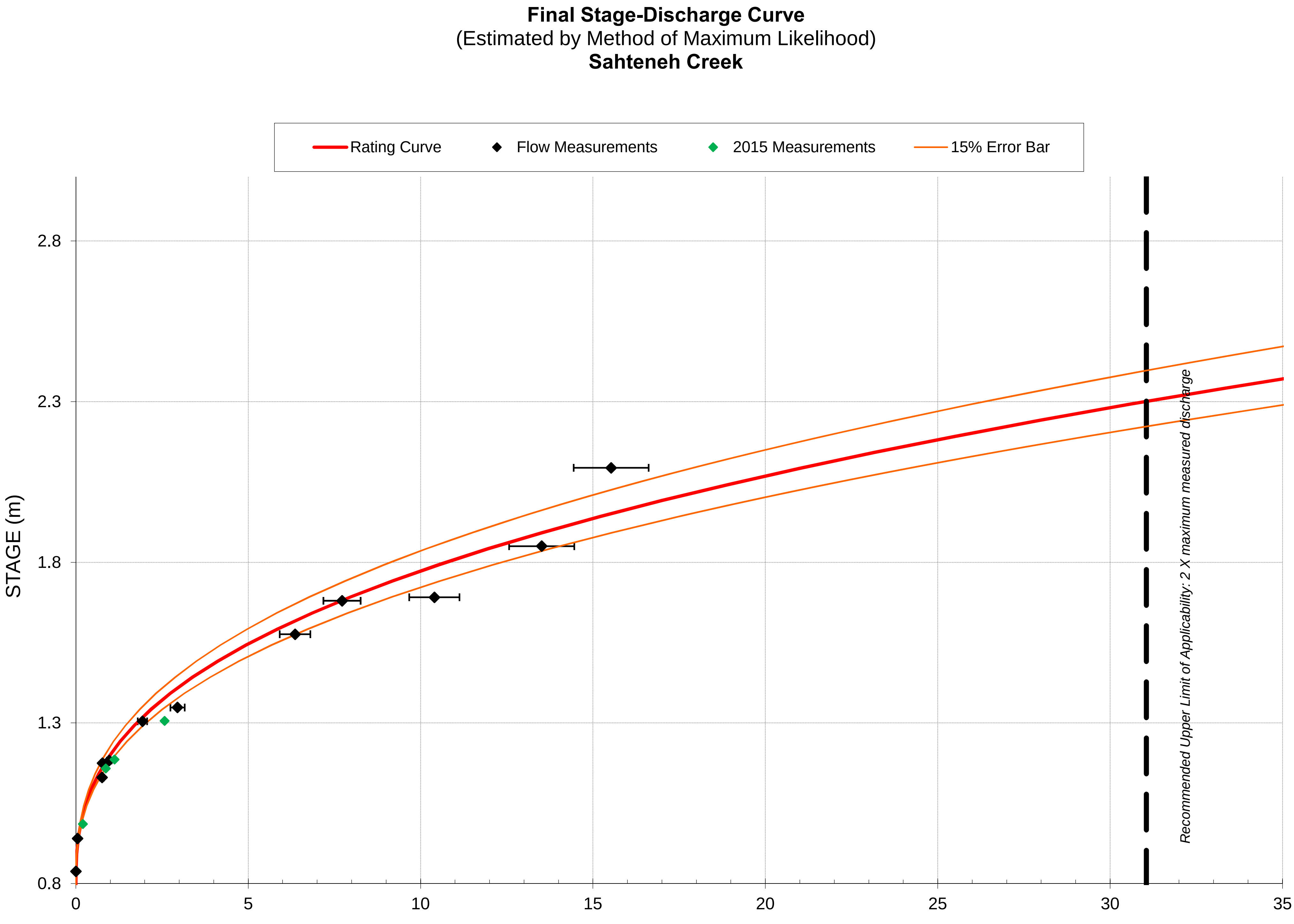

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Figure 4

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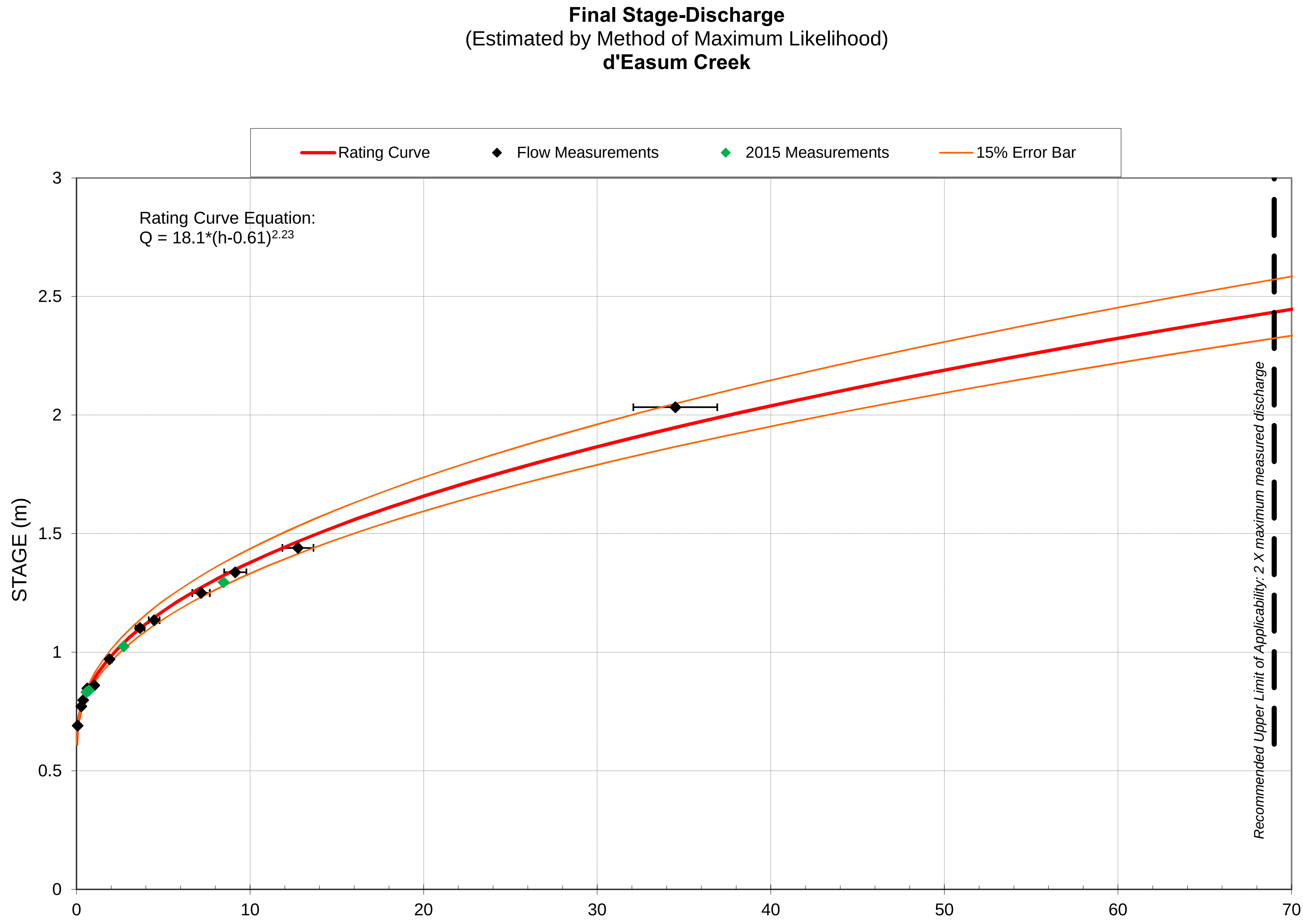

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Figure 5

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Final Stage-Discharge Curve
(Estimated by Method of Maximum Likelihood)
Dilly Creek

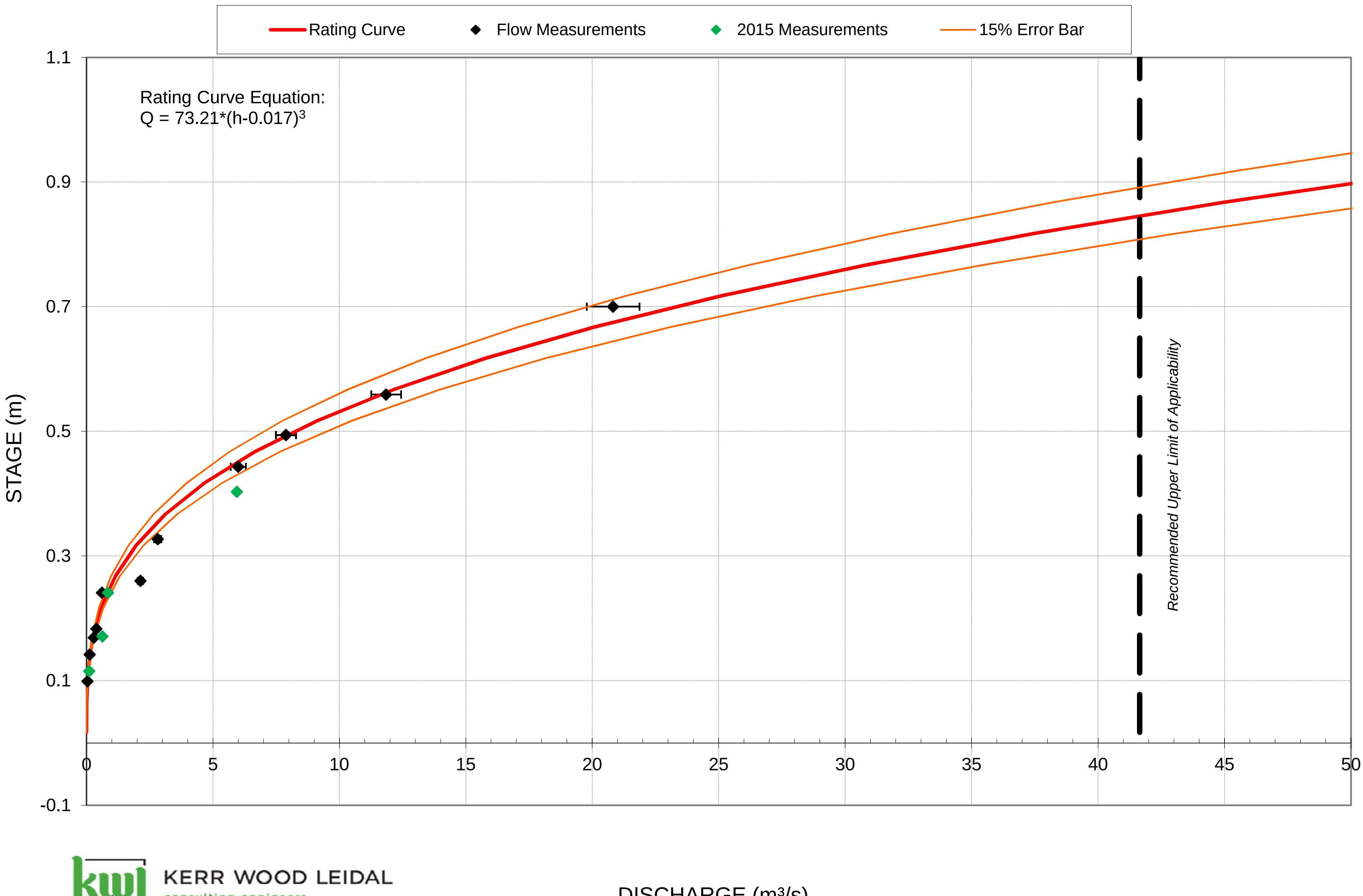

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Figure 6

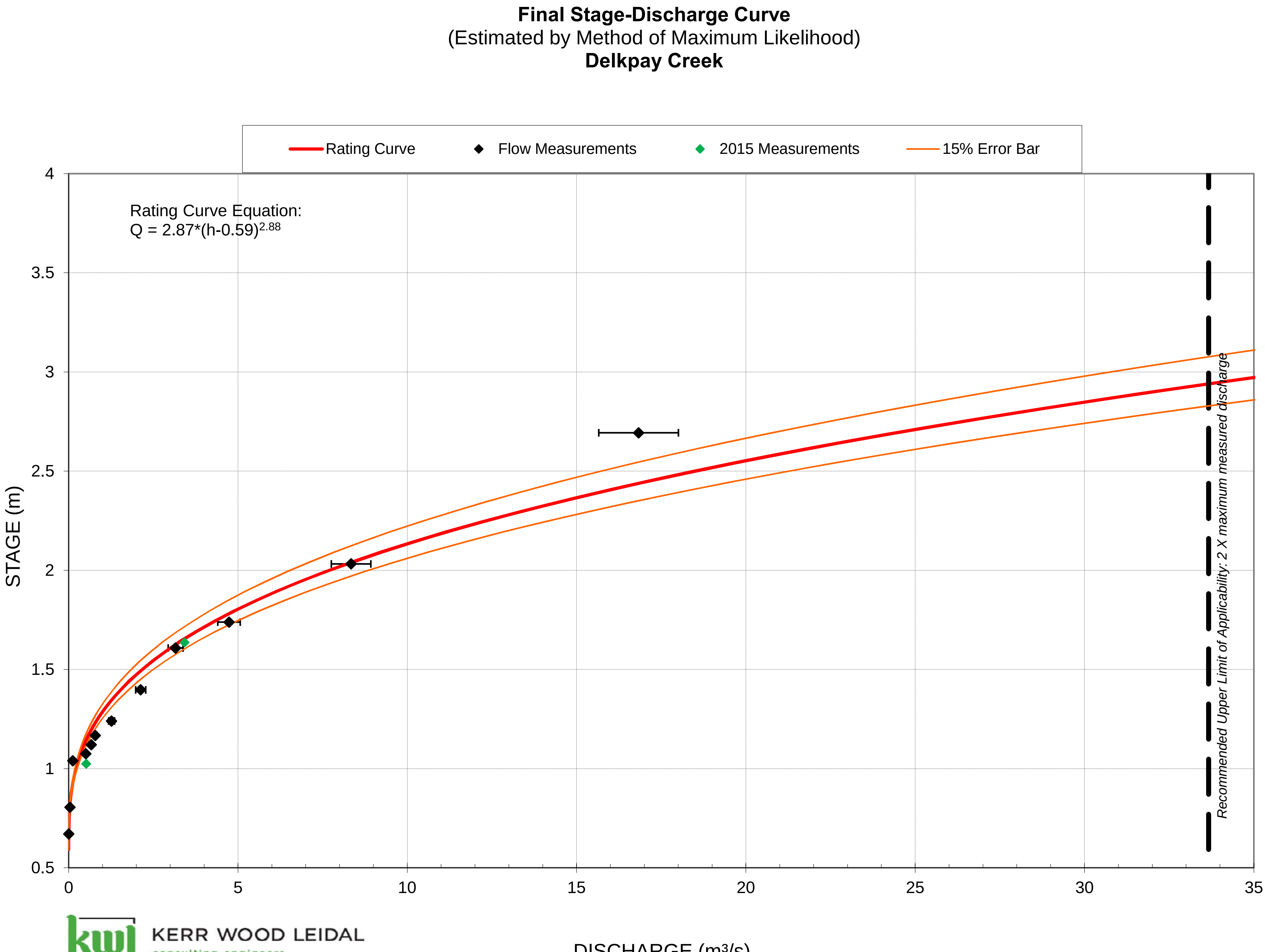

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Figure 7

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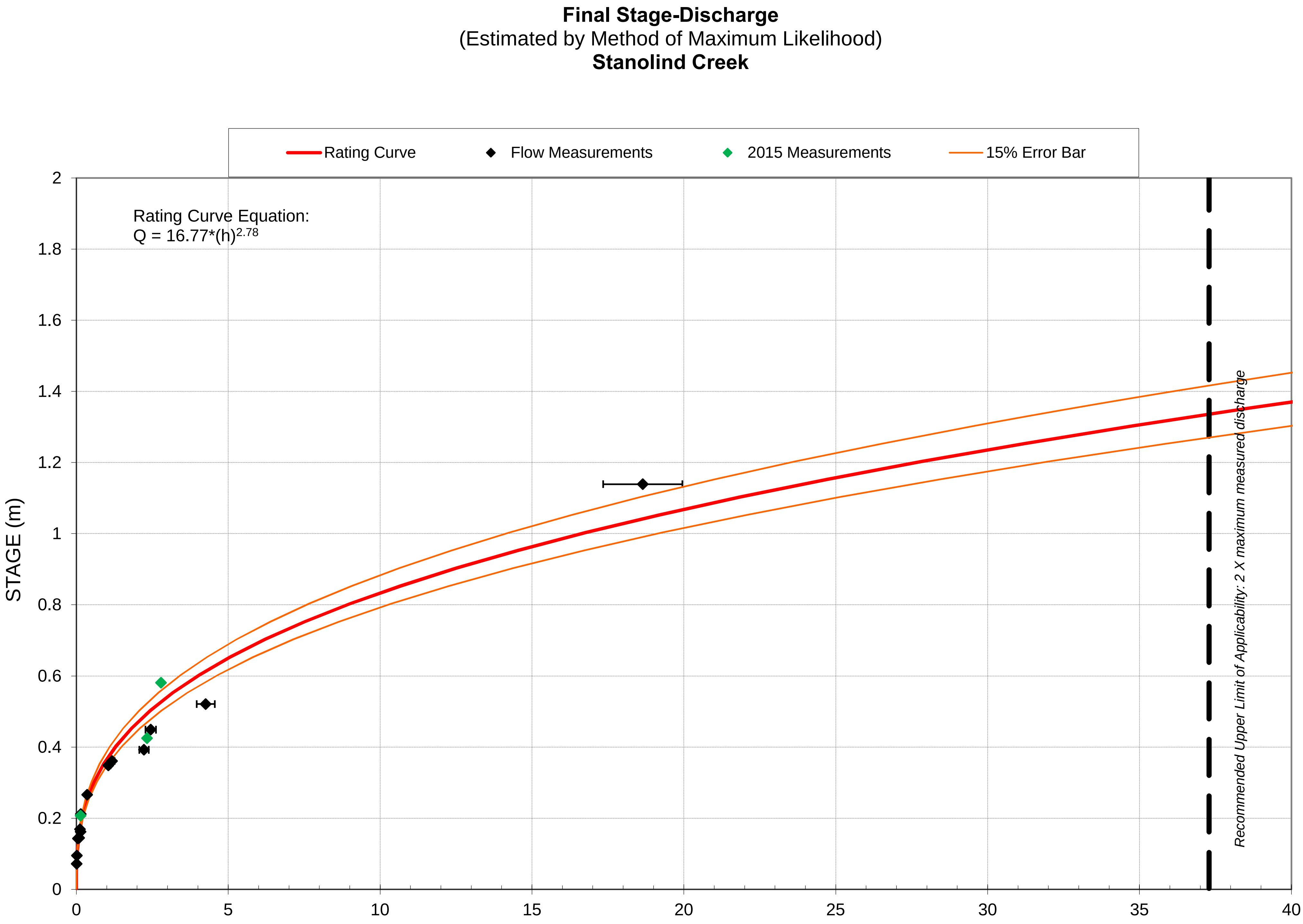

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Figure 8

\\nasvictoria.victoria.kerrwoodleidal.org\Victoria\Projects\2000-2999\2600-2699\2692-002\300-Reports\2015 Report\Data\Rating curves\20160610-Stanolind Creek Rating Curve-2692-002[Rating Curve Figure

Final Stage-Discharge Curve
(Estimated by Method of Maximum Likelihood)
Komie Creek

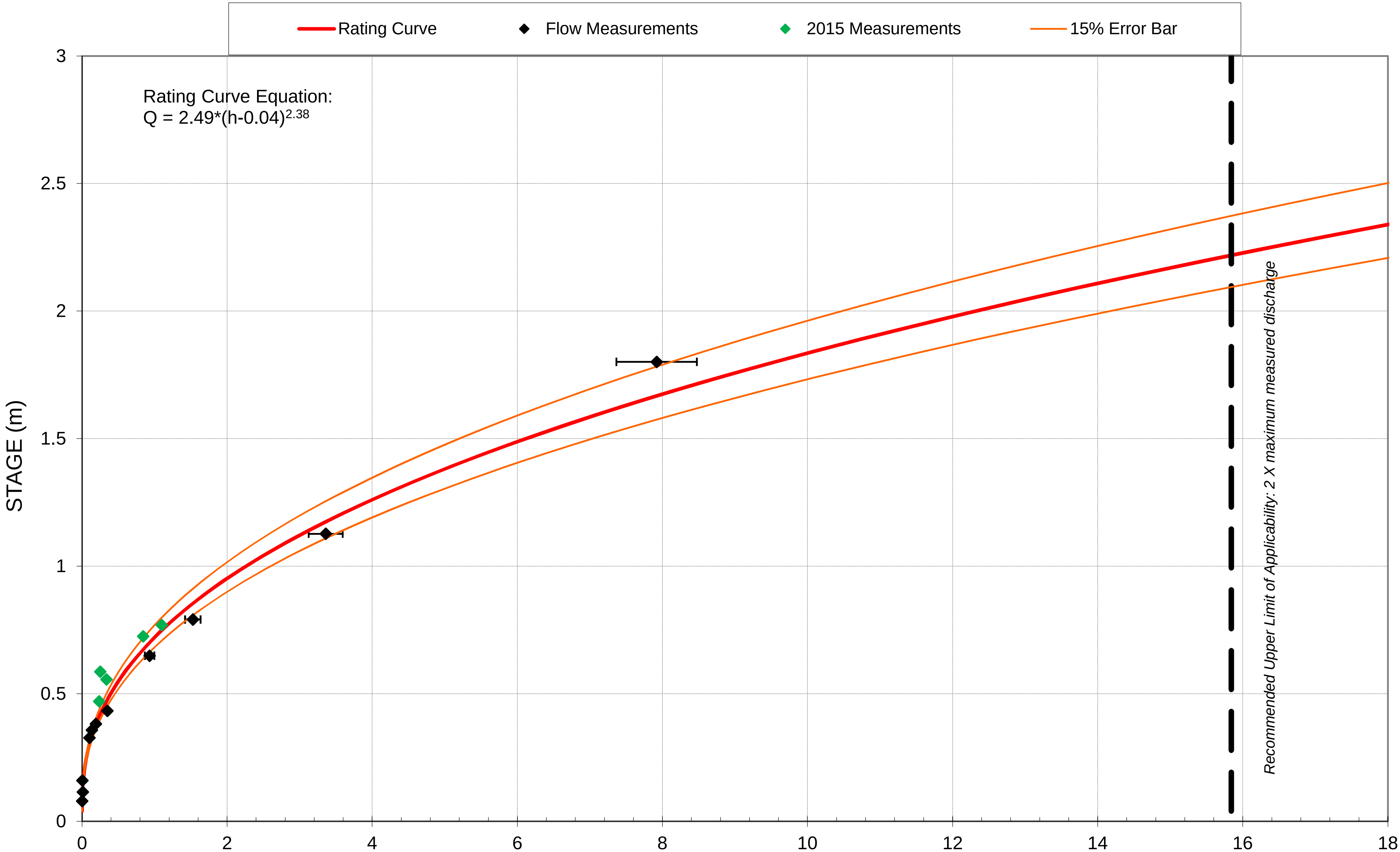

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Figure 9

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Appendix B

Hydrographs and Climate Data

Figure 10 - Kiwigana River Hydrograph

Start Date: April 20, 2012
End Date: September 30, 2015

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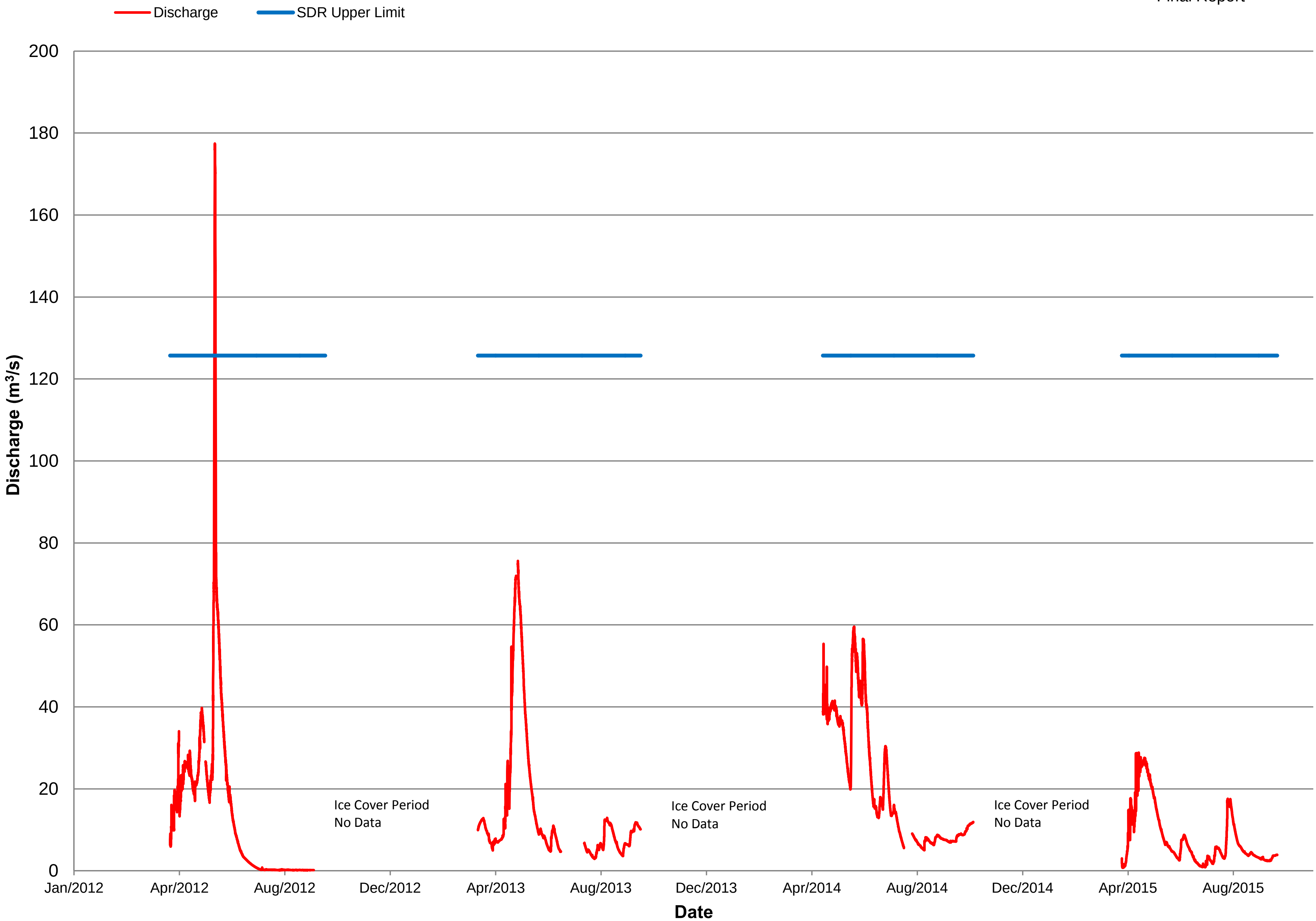

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Figure 11 - Sahtaneh Creek Hydrograph

Start Date: April 20, 2012
End Date: September 30, 2015

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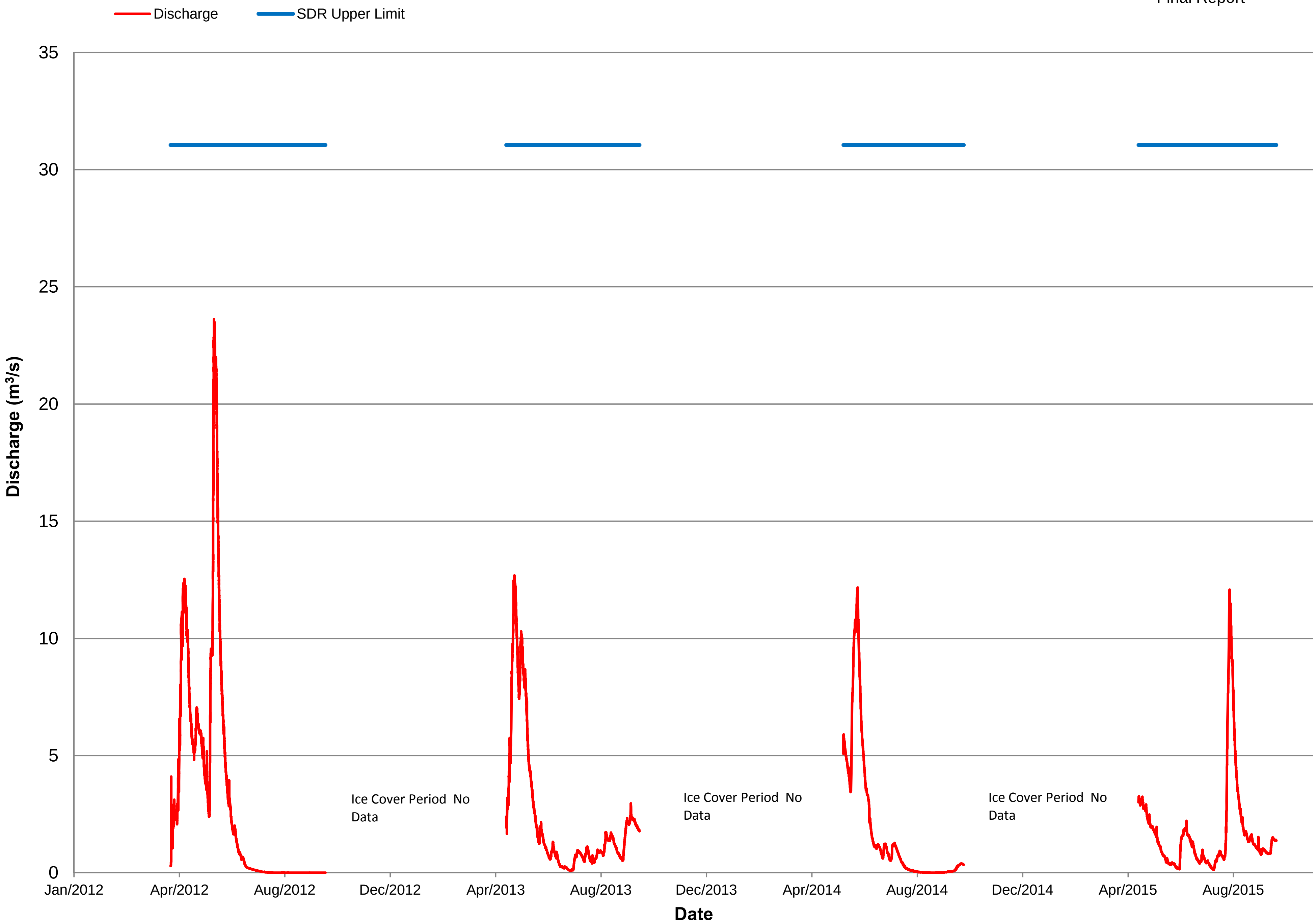

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Figure 12 - d'Easum Creek Hydrograph

Start Date: May 6, 2012
End Date: October 10, 2015

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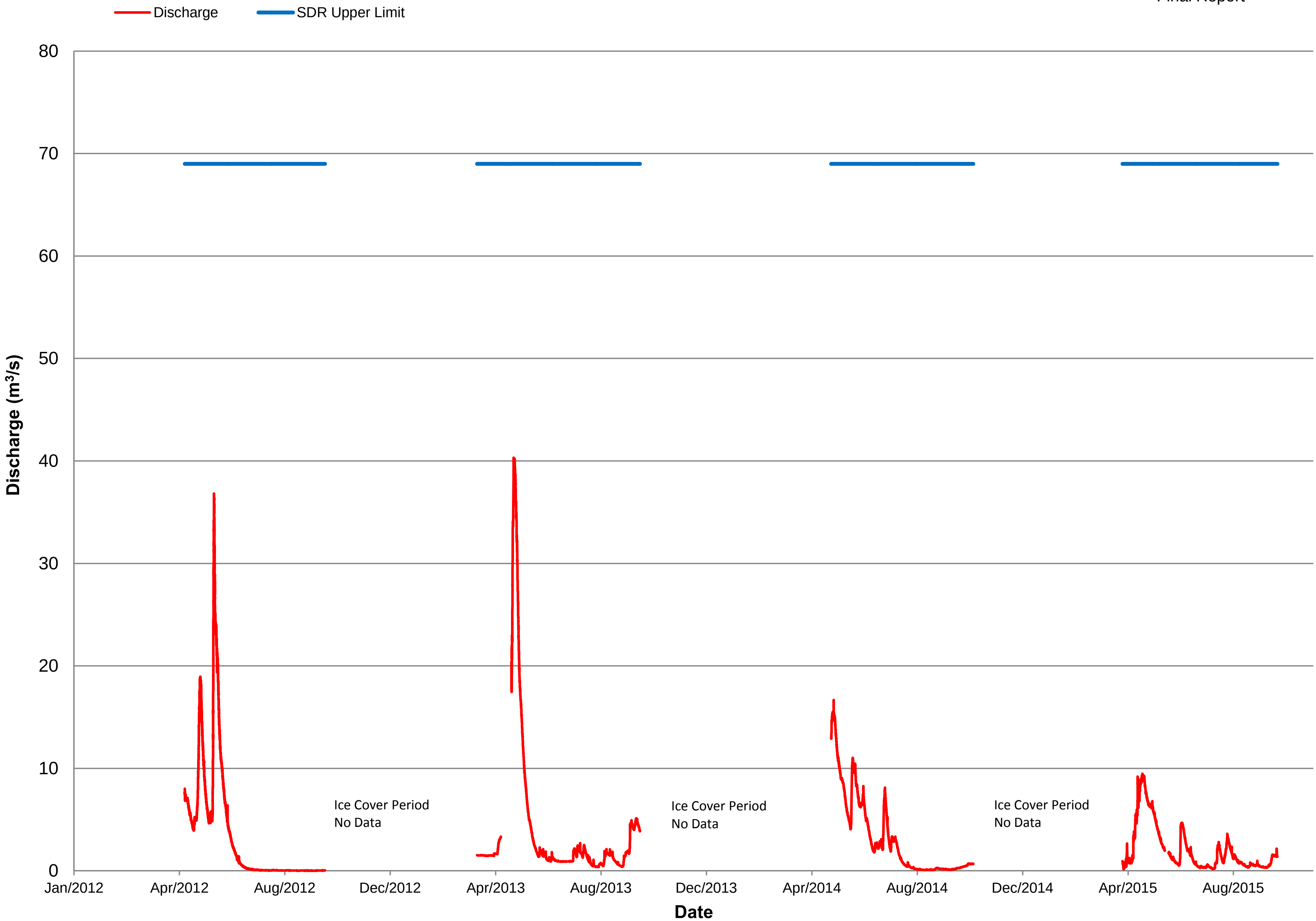

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Figure 13 - Dilly Creek Hydrograph

Start Date: May 9, 2012
End Date: September 30, 2015

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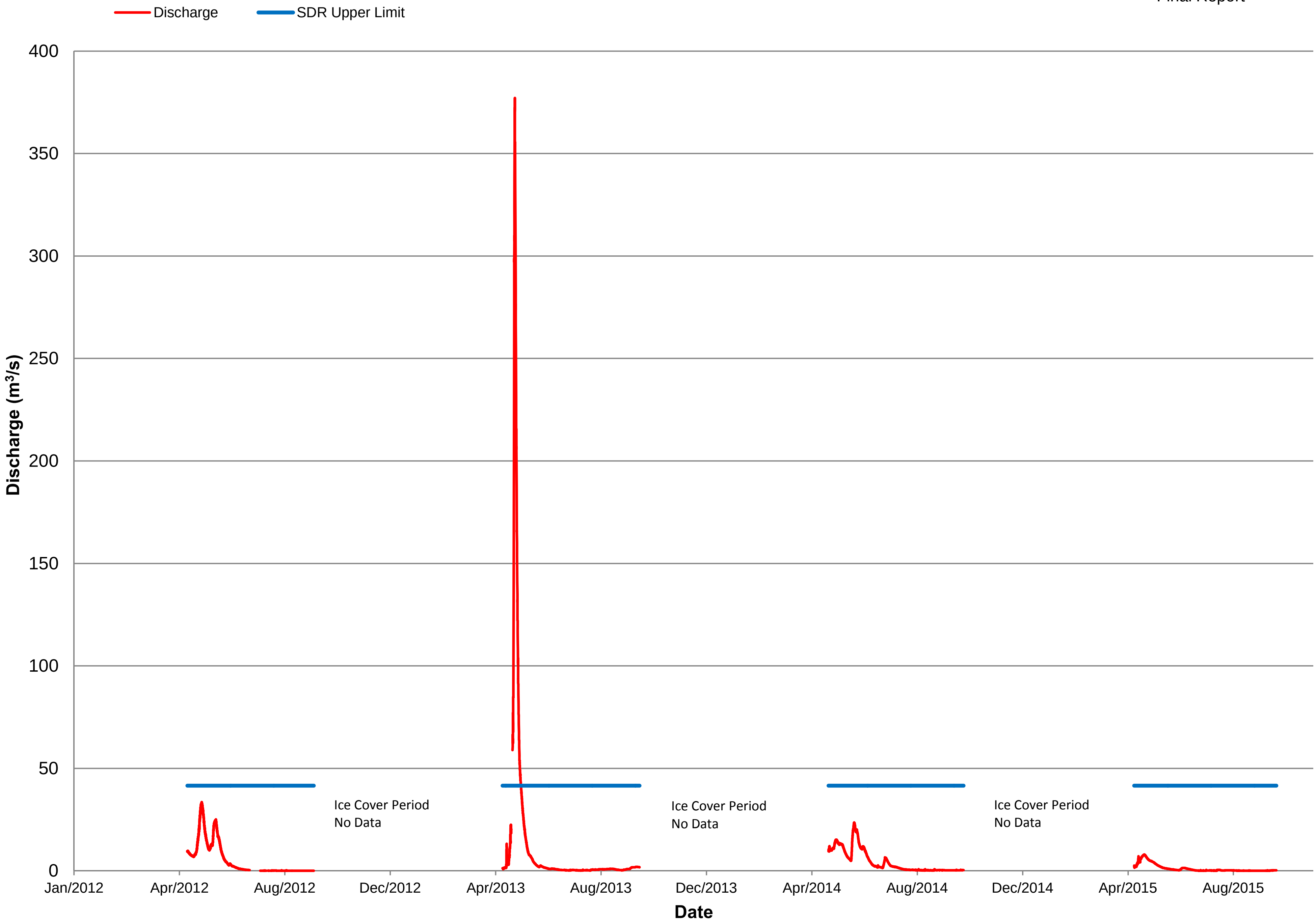

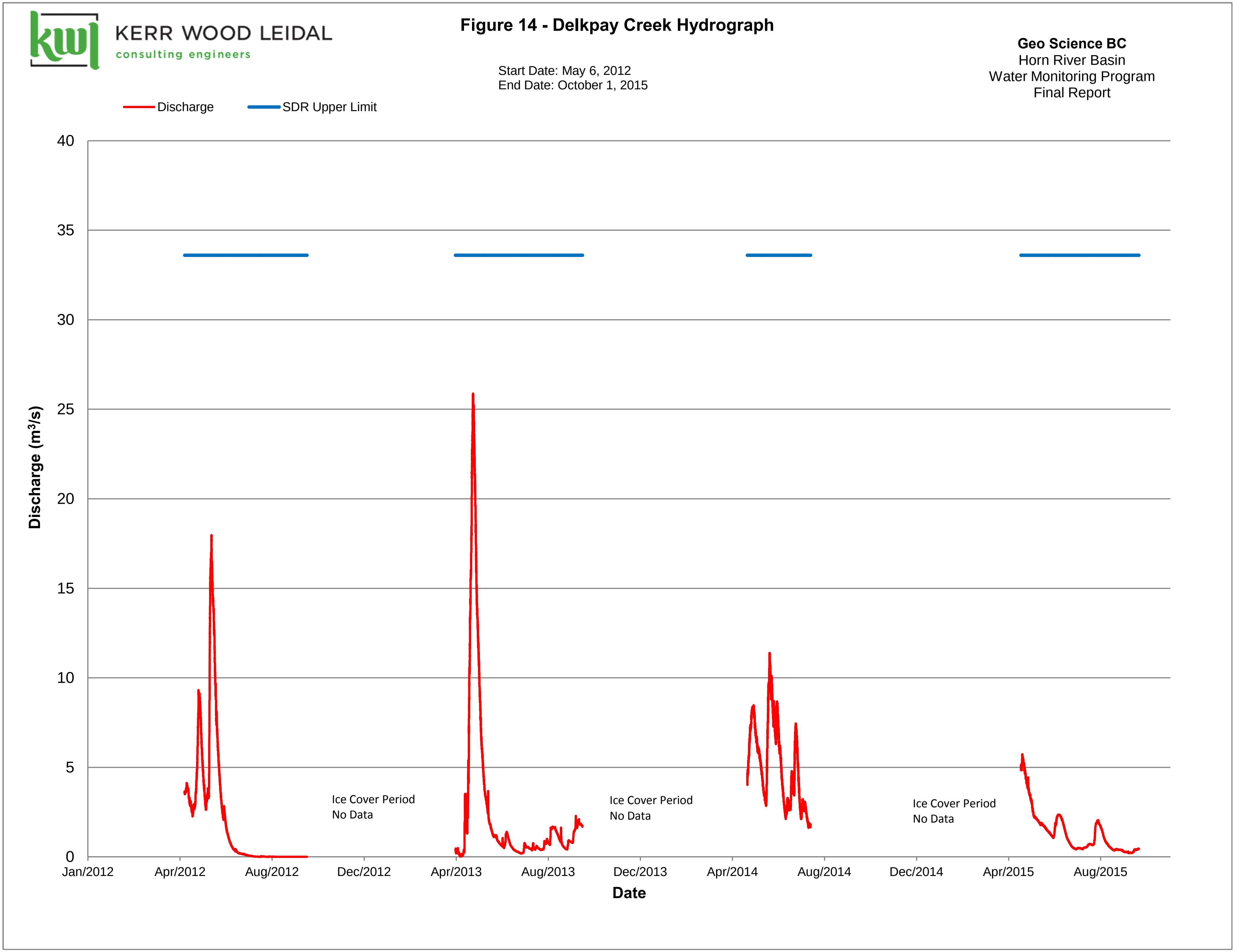
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Figure 14 - Delkpay Creek Hydrograph
Start Date: May 6, 2012
End Date: October 1, 2015
Geo Science BC
Horn River Basin
Water Monitoring Program
Final Report
Discharge
SDR Upper Limit
Discharge (m³/s)
0
5
10
15
20
25
30
35
40
Ice Cover Period
No Data
Ice Cover Period
No Data
Ice Cover Period
No Data
Jan/2012
Apr/2012
Aug/2012
Dec/2012
Apr/2013
Aug/2013
Dec/2013
Apr/2014
Aug/2014
Dec/2014
Apr/2015
Aug/2015
Date

Figure 15 - Stanolind Creek Hydrograph

Start Date: May 6, 2012
End Date: October 1, 2015

Geo Science BC
Horn River Basin
Water Monitoring Program
Final Report

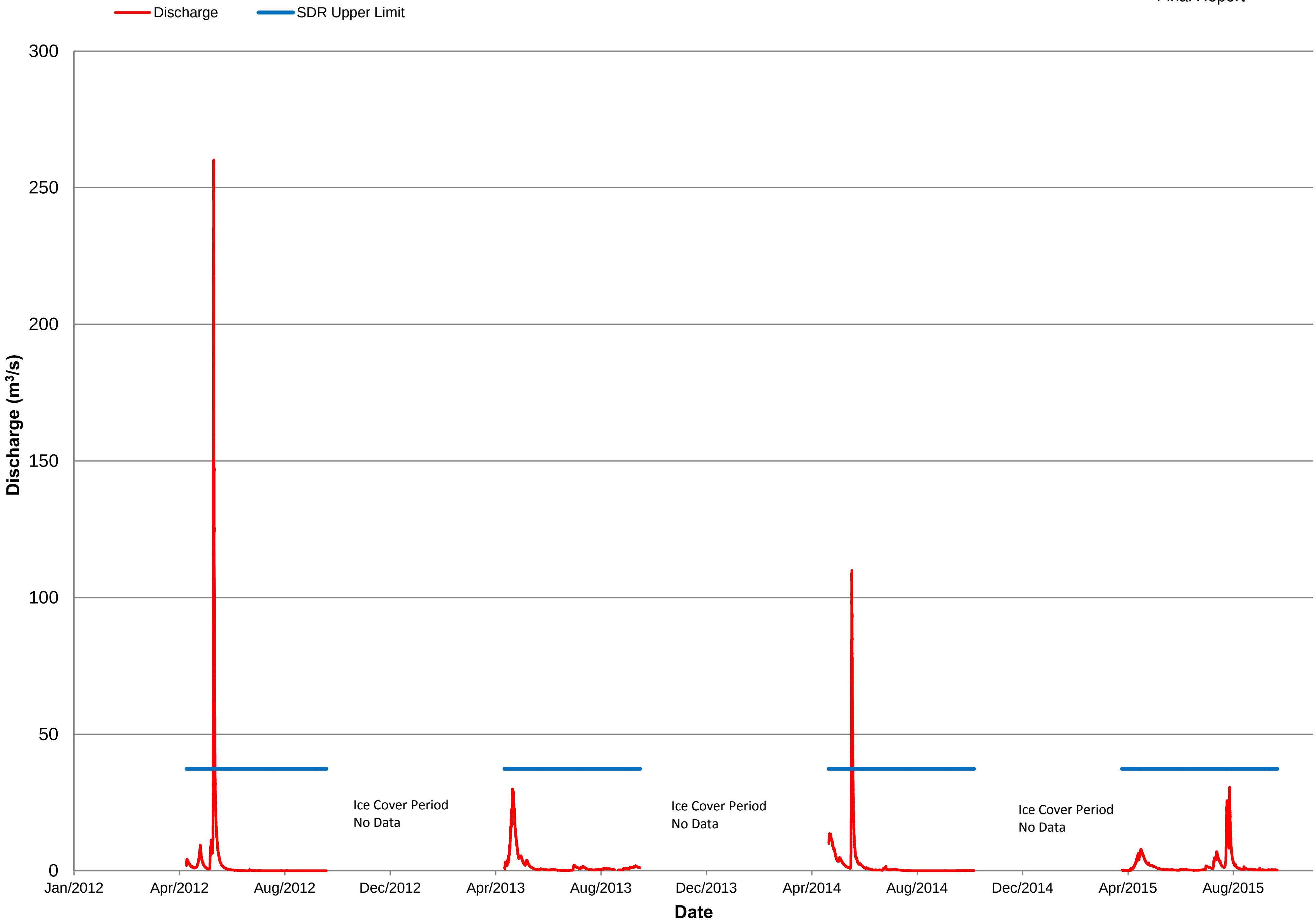

Figure 16 - Komie Creek Hydrograph

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Start Date: May 15, 2012
End Date: September 30, 2015

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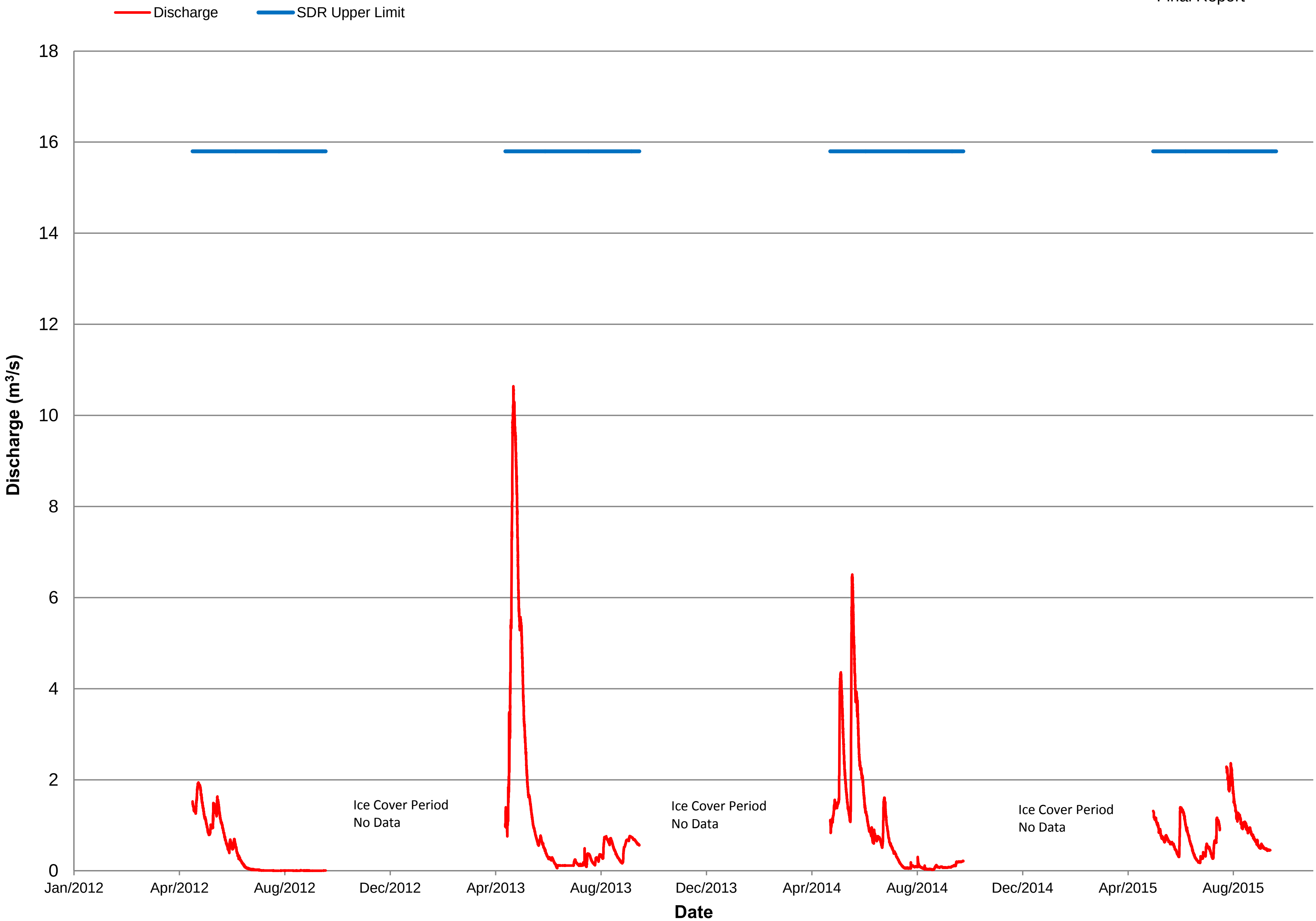

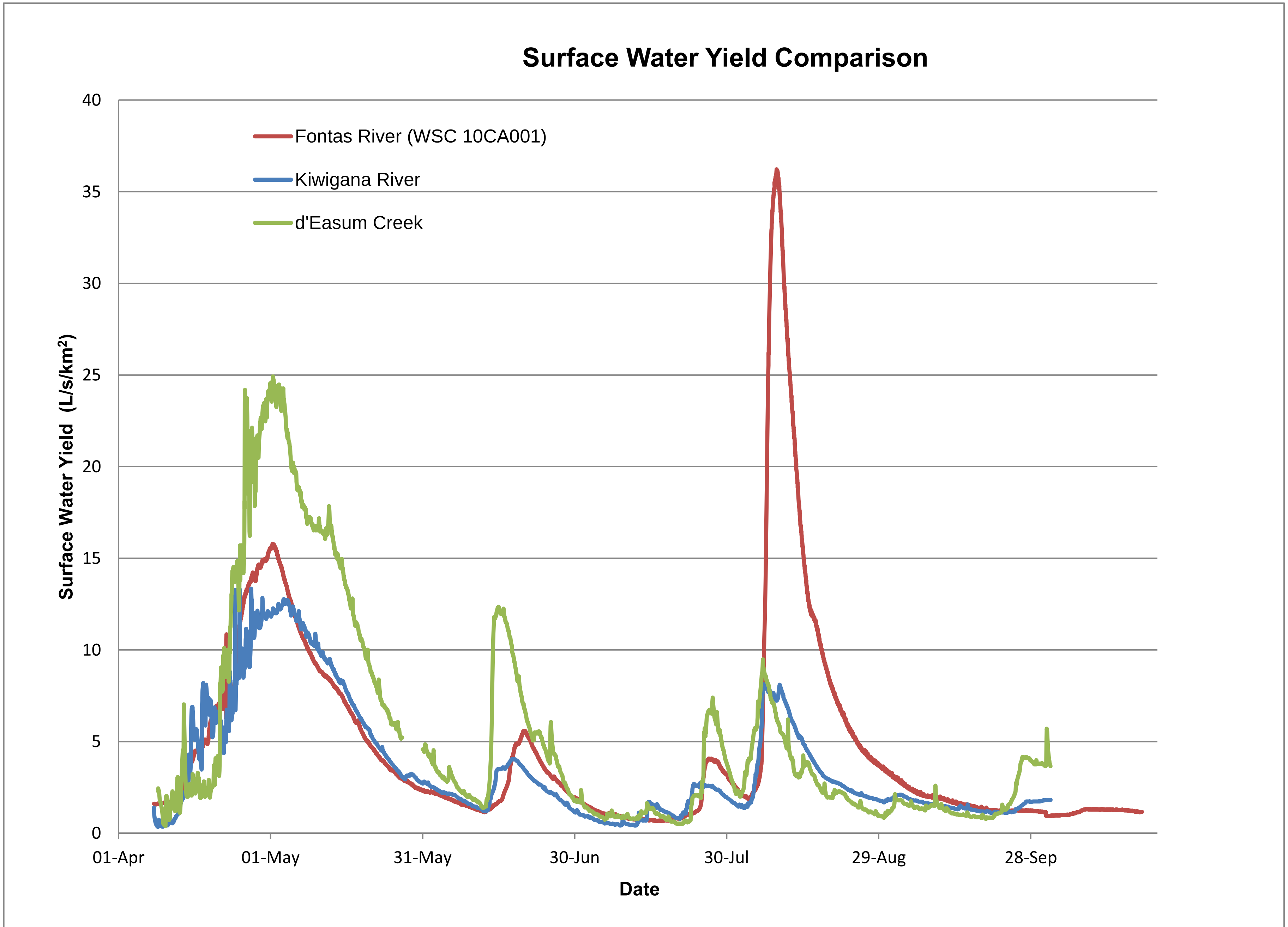

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Figure 17

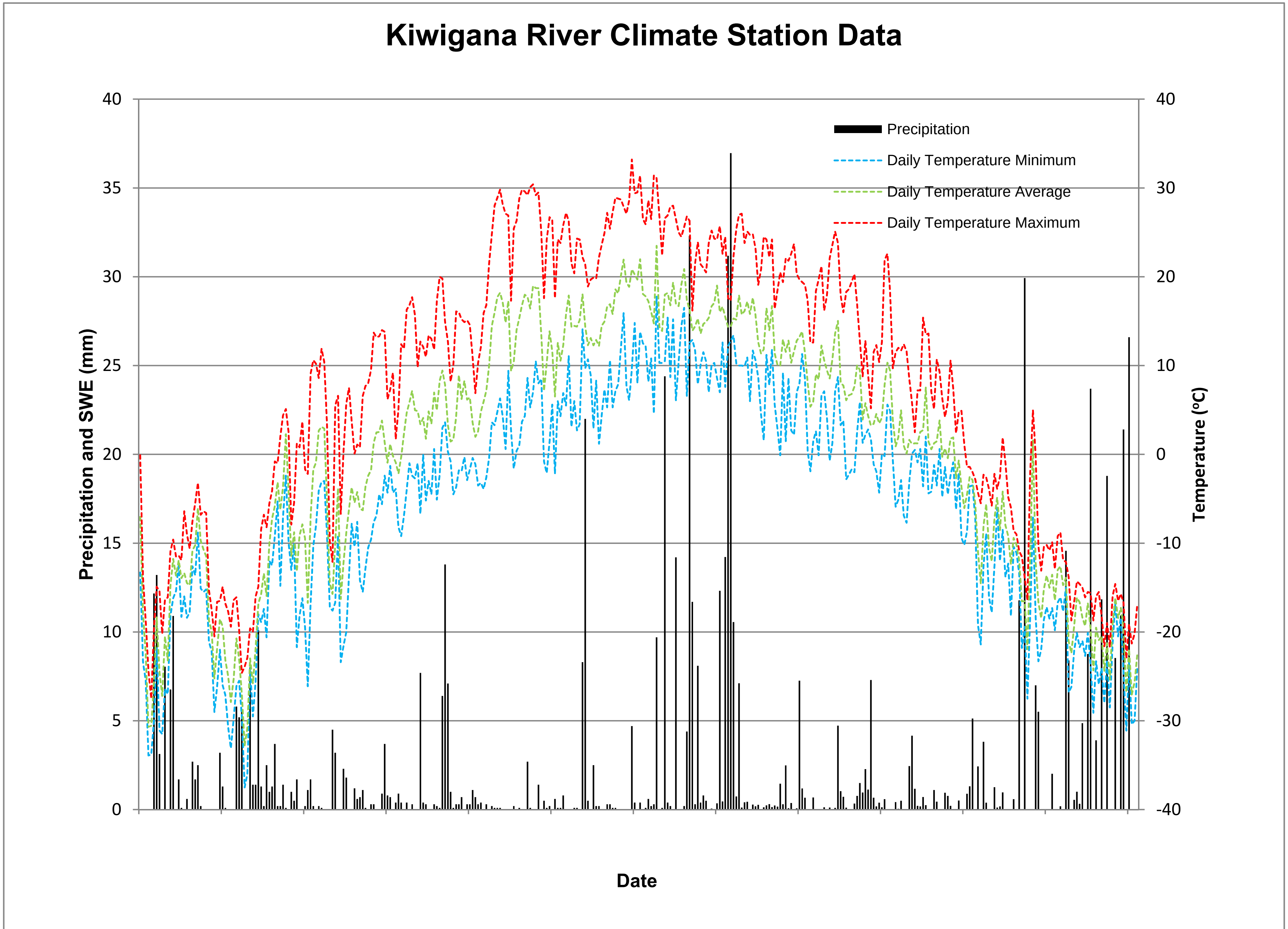

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Figure 18

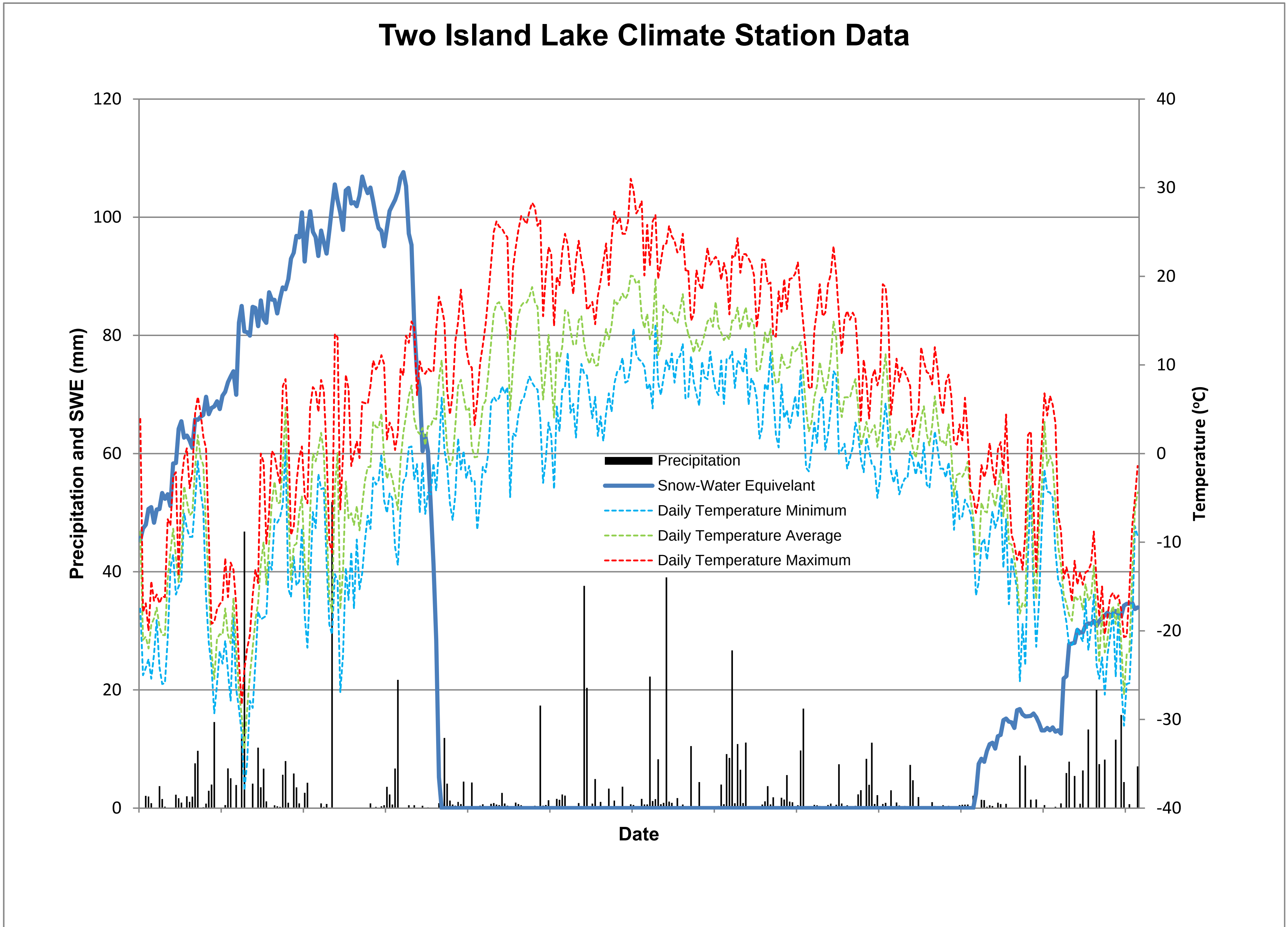

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Figure 19

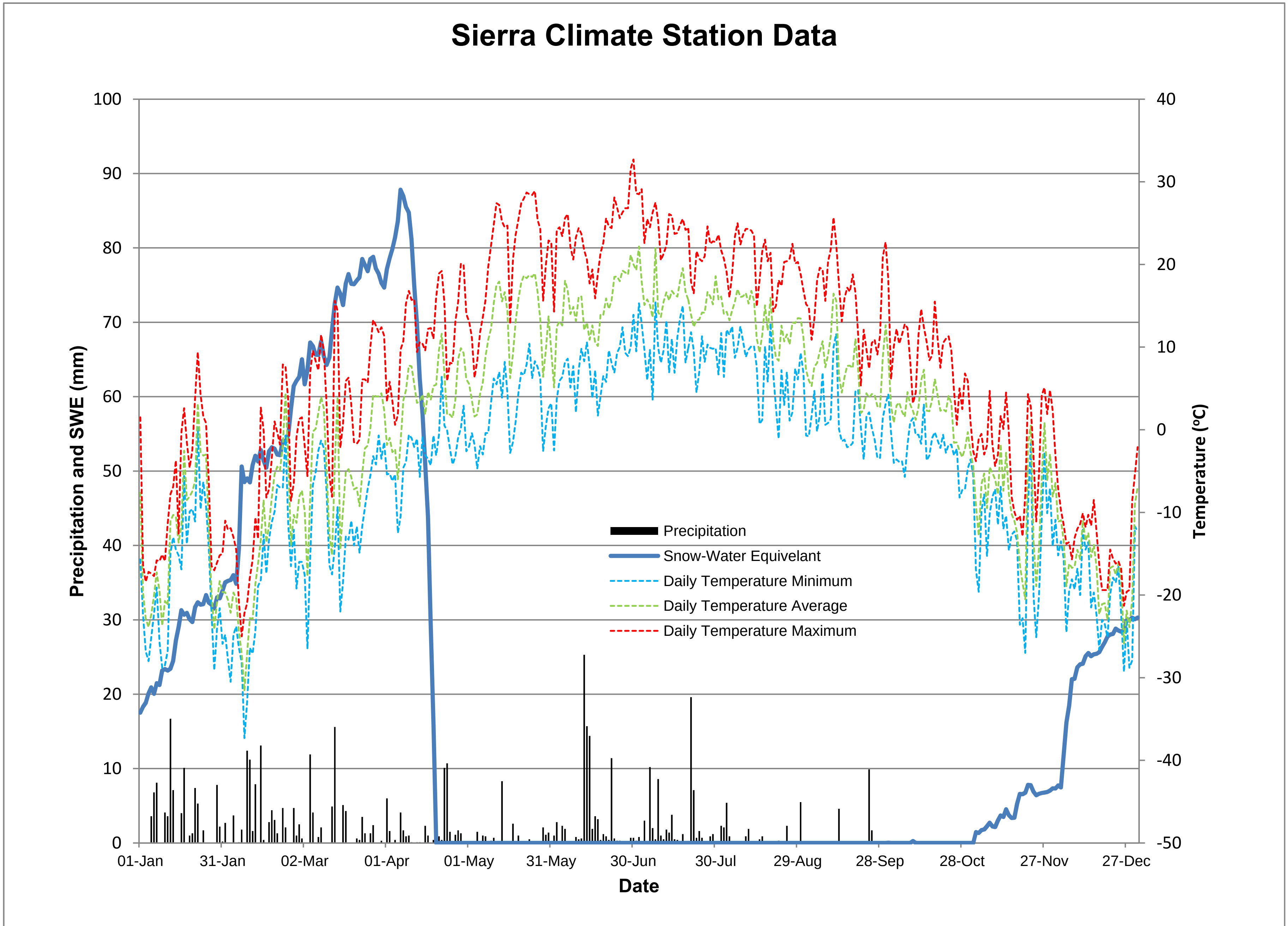

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Figure 20

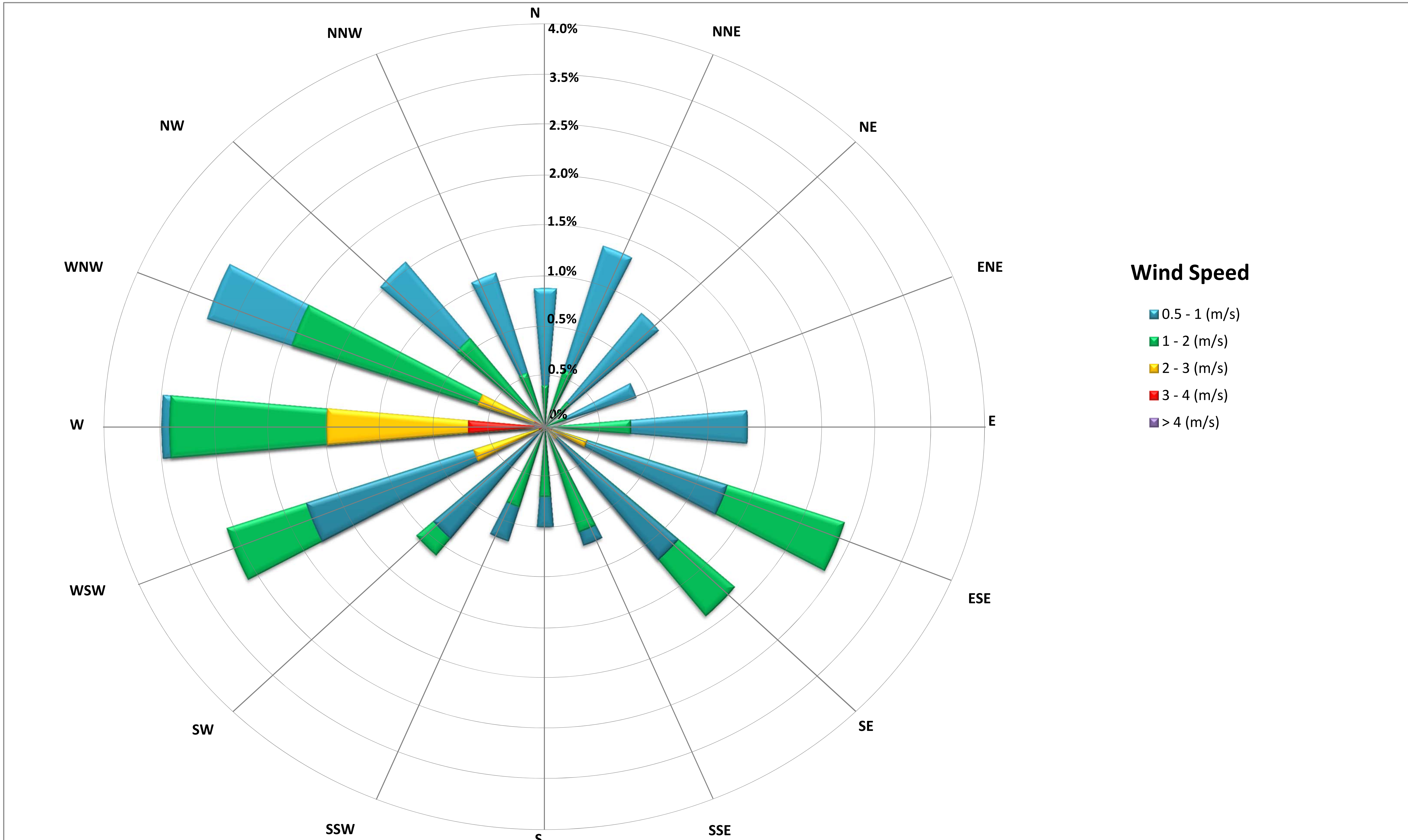

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Figure 21 - Kiwigana River Climate Station Wind Rose

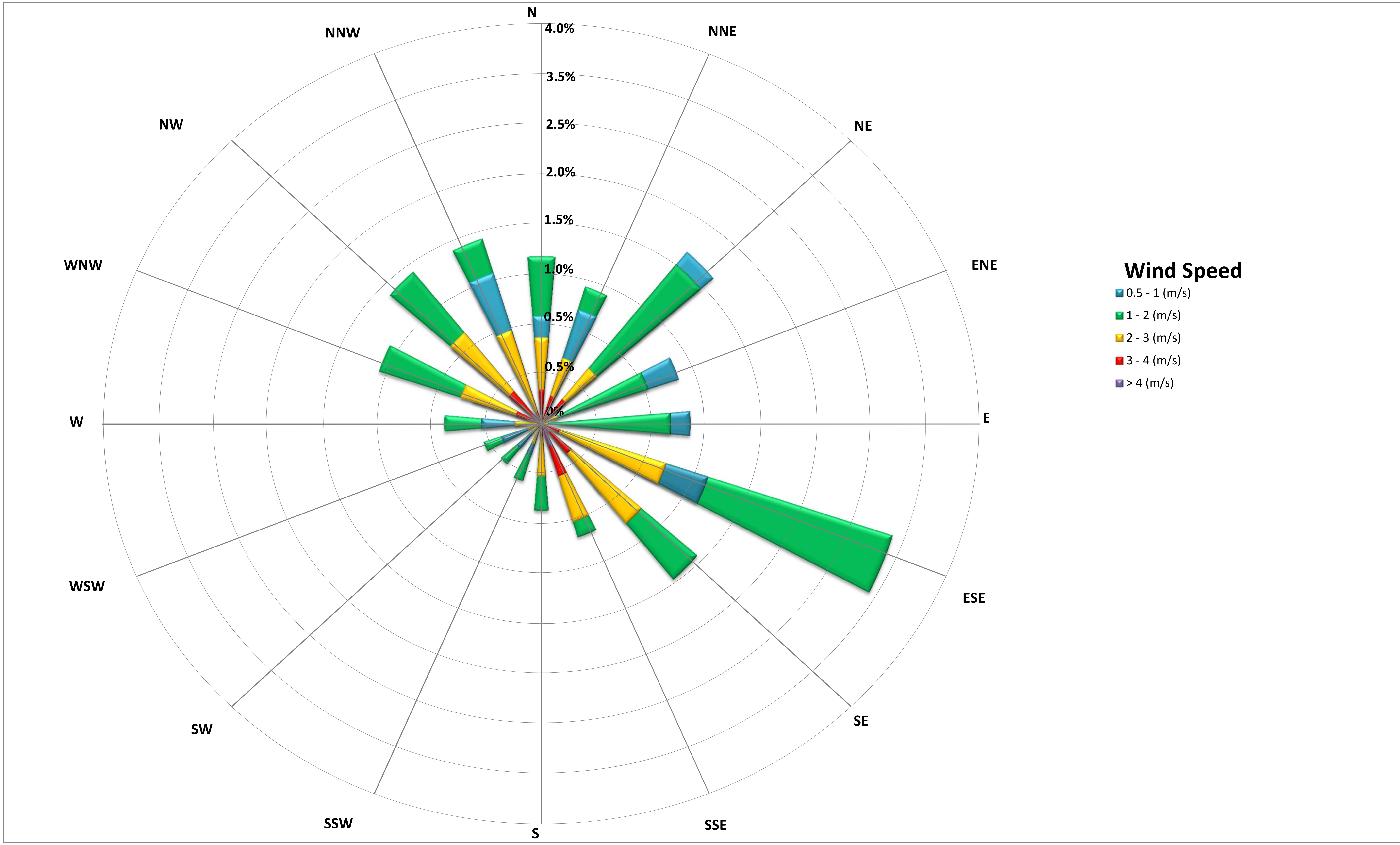

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Figure 22 - Sierra Climate Station Wind Rose

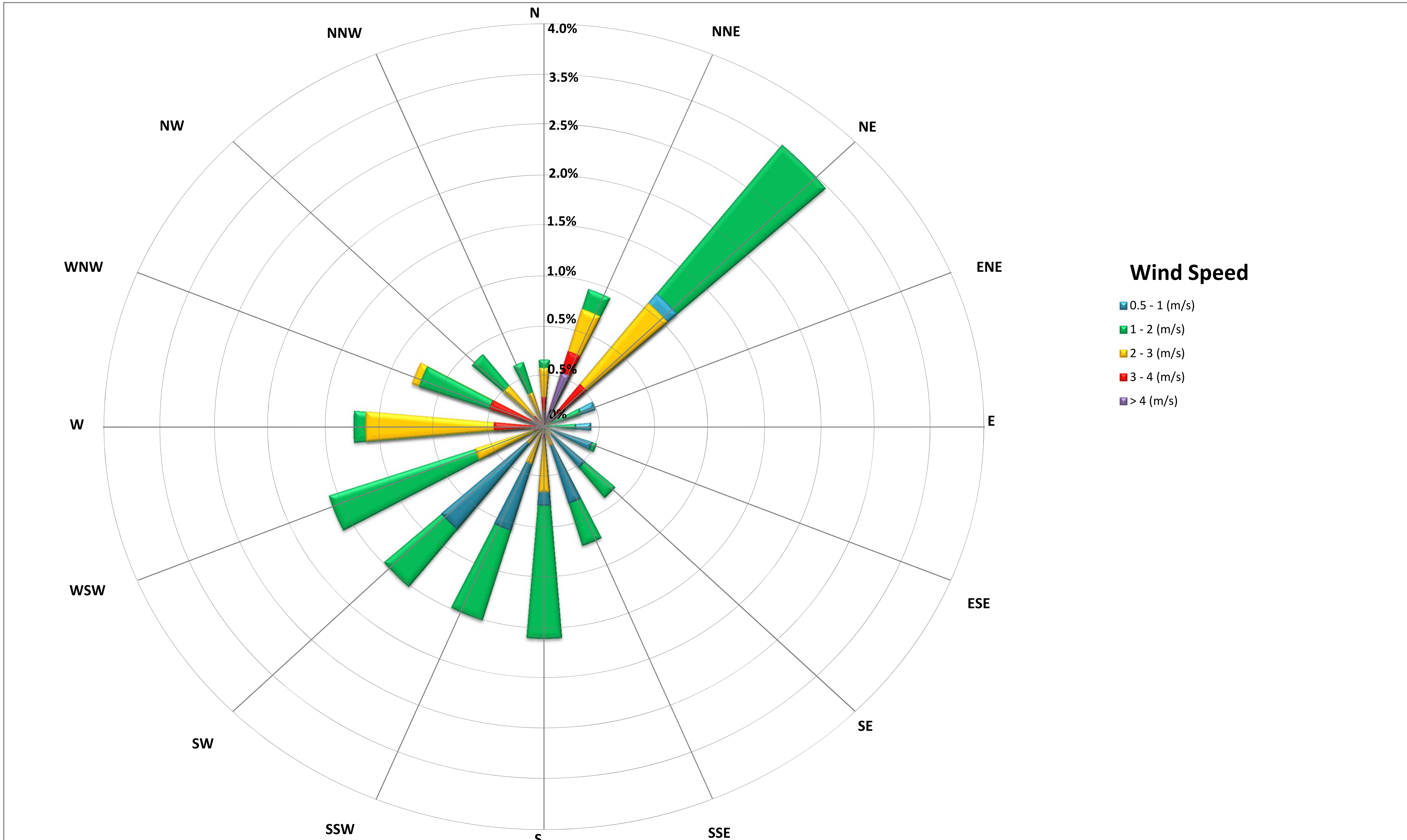

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Figure 23 - Two Island Lake Climate Station Wind Rose

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Appendix C

Surface Water Quality Technical Reports

301 GEORGE STREET
PRINCE GEORGE, BC V2L 1R4
P: (250) 562-5412 ő F: (250) 562-5413

July 5, 2014

EDI Project Number: 14-P-0016

Kerr Wood Leidal Associates Limited
201-3045 Douglas Street
Victoria, BCV8T 4N2

Attention: Dave Murray, P.Eng., A.Sc.T.

Re: Geoscience BC Horn River Basin Water Monitoring Project – Surface Water Quality Program Update – May 2014

Since 2011, EDI has been engaged in the multi-year Geoscience BC Horn River Basin Water Monitoring Project. One of the objectives of the program is to provide a baseline characterization of surface water quality within selected sub-basins of the Fort Nelson River watershed. Collected data will allow comparison of surface water to shallow groundwater and formation water chemistry. Additionally, data will be used to determine if background levels of naturally occurring elements are above provincial water quality guidelines and whether site-specific water quality objectives should be developed.

Selection of sub-basins and individual sites within each sub-basin was based on watershed characteristics, stakeholder considerations, First Nations considerations, and site specific logistics. Five watersheds, each with one sampling site, were chosen for the surface water program: Dilly Creek (HRB-1), Sahtaneh River (HRB-2), Kiwigana River (HRB-3), d'Easum Creek (HRB-4) and Stanolind Creek (HRB-5). To date, two years of data collection have been completed. Year 1 included July 2012 to May 2013, Year 2 included June 2013 to May 2014, and the third and final year of data collection is scheduled to take place between June 2014 and May 2015.

This report summarizes the second year of data collection (Year 2), which includes a total of seven sampling events: August 5, August 21, September 15, and October 6 of 2013 as well as January 7, March 29, and May 24 of 2014. Ice covered conditions were recorded at all sampling stations in January and March 2014. During these sampling events two stations (HRB-5 in January and March 2014; HRB-1 in March 2014) were frozen to the streambed and water samples could not be collected. For context and where appropriate, recent water quality results have been compared to previous sampling events. Data tables for Year 2 field parameters, analytical results and quality assurance and quality control samples have been provided digitally and are listed as attachments to this document. Results and discussions from Year 1 sampling events are available in the May 2013 program update document.

Year 2 of the sampling program followed the same field and laboratory methods as Year 1 with the exception of BTEX/VPH and EPH parameters being removed from laboratory analysis in August following the January 2014 sampling event. These parameters were removed from the program because previous laboratory results indicated concentrations of these parameters were below analytical detectable limits at all sampling stations. In addition, dissolved metal samples were not collected during the May 2014 sampling event.

Field Results

All surface water quality samples and field parameters were collected by Peace Country Technical Services Ltd. Field parameters included dissolved oxygen (DO), temperature, turbidity, total dissolved solids (TDS), salinity, pH, and conductivity. Measured field parameters were within the ranges shown in Table 1. Detailed field data are available in Attachment 1. Across all stations and all sampling events, pH values were consistent, ranging from 7.6 to 8.4. DO concentrations across all stations and events were within fish tolerable levels, ranging from 7.1-12.0 mg/L. At each individual station, TDS, turbidity, salinity, and conductivity values were relatively constant between August and October and then increased during under-ice sampling in January and March. The general trend of increased concentrations during lower winter flows has been previously documented. BC Ministry of Environment (2013) indicated that seasonal fluctuations in chemical concentrations are apparent in most rivers, with lower concentrations during spring freshet and elevated concentrations during the low flow periods[1].

Table 1. **Field parameter ranges measured between August 2013 and March 2014.**

Field parameter	Units	Measured range
Dissolved oxygen	mg/L	7.1-12.0
Temperature	^{0}C	0-21.3
Turbidity	NTU	2.0-14.7
Total Dissolved Solids	mg/L	107-504
Salinity	PSU	69-465
pH	pH	7.6-8.4
Conductivity	µS/cm	151-709

Analytical Results

Concentrations Exceeding Water Quality Guidelines

Analytical results of surface water samples collected between June 2013 and May 2014 indicated several metal parameters with concentrations exceeding provincial water quality guidelines for the protection of aquatic life:

- iron - dissolved and total

[1] Meays, C. and R. Nordin. 2013. Province of BC Ambient Water Quality Guidelines For Sulphate, Technical Appendix Update April 2013.

- cadmium - total,
- chromium - total, and
- zinc – total.

With the exception of iron, metal concentration exceedances were only observed during the May 2014 sampling event. These exceedances occurred at two of the five sampling stations (HRB-1 and HRB-3). Table 2 shows the actual concentrations of the exceedances for these parameters.

Table 2. **Concentrations (mg/L) of cadmium, chromium and zinc exceeding provincial water quality guidelines for the protection of aquatic life during the May 2014 sampling event.**

Parameter	Water Quality Guideline	HRB1	HRB3
Cadmium	0.0000182 and 0.0000190	0.000026	0.000034
Chromium	0.001	No exceedance	0.0013
Zinc	0.0029	No exceedance	0.0075

Concentrations of dissolved and total iron frequently exceeded water quality guidelines throughout Year 2 sampling events (Table 3). These occurrences were observed at all sampling stations. There were a number of instances where the dissolved iron concentration exceeded the guideline, but the total iron concentration did not. All of these instances occurred during the August, September, and October sampling, not during the January and March sampling events. Because of increased bio-availability of dissolved forms compared to total forms of metals, aquatic life guidelines for dissolved metals need to be considered[2]. Most cases in which total iron concentrations exceeded the guideline, dissolved iron also exceeded the guideline. While increases in total suspended solids (TSS) are known to have an increasing effect on metal concentrations, TSS concentrations in the dataset were frequently less than detectable limits (<3.0 mg/L). Therefore total iron concentrations exceeding guidelines were likely a result of higher dissolved iron concentrations.

Table 3. **Surface water analytical parameters exceeding provincial water quality guidelines for the protection of aquatic life (mg/L) from June 2013 to April 2014. Red text indicates concentration exceeding guideline.**

Date	Parameter	WQG*	HRB-1 Dilly	HRB-2 Sahtenah	HRB-3 Kiwigana	HRB-4 d'Easum	HRB-5 Stanolind
Aug 5, 2013	Total iron	1.00	0.974	0.547	1.06	0.658	1.24
	Diss. iron	0.35	0.579	0.322	0.378	0.492	0.978
Aug 21, 2013	Total iron	1.00	1.03	0.637	1.26	0.806	2.19
	Diss. iron	0.35	0.566	0.437	0.538	0.608	1.91
Sep 15, 2013	Total iron	1.00	1.01	0.599	0.690	0.838	1.59
	Diss. iron	0.35	0.593	0.398	0.421	0.644	1.44

[2] Ministry of Environment. 2008. Ambient water quality guidelines for iron. Available at [http://www.env.gov.bc.ca/wat/wq/BCguidelines/iron/iron_overview.pdf]

Date	Parameter	WQG*	HRB-1 Dilly	HRB-2 Sahtenah	HRB-3 Kiwigana	HRB-4 d'Easum	HRB-5 Stanolind
Oct 6, 2013	Total iron	1.00	0.738	0.520	0.720	0.526	0.735
	Diss. iron	0.35	0.426	0.330	0.322	0.376	0.595
Jan 7, 2014	Total iron	1.00	2.09	1.42	1.26	1.70	n/s
	Diss. iron	0.35	1.45	1.01	0.864	1.31	n/s
Mar 29, 2014	Total iron	1.00	n/s	1.85	1.16	2.66	n/s
	Diss. iron	0.35	n/s	0.619	0.061	0.062	n/s
May 24, 2014	Total iron	1.00	0.995	1.040	1.750	0.681	0.844
	Diss. Iron	0.35	n/s	n/s	n/s	n/s	n/s

* BC Water Quality Guidelines for the Protection of Aquatic Life. All concentrations are shown in mg/L.

Comparisons between Year 1 and Year 2

Iron

When compared seasonally between Year 1 and Year 2, total and dissolved iron concentrations were higher on August 5, 2013 (Year 2) than on July 31, 2012 (Year 1) for all sites except HRB-5 (Table 4). Similarly, dissolved iron concentrations were higher on January 7, 2014 (Year 2) than on January 7, 2013 (Year 1) for all sampled sites. Total iron concentration was higher in January 2014 (Year 2) than January 2013 (Year 1) at HRB-2 and HRB-3, but the opposite trend was apparent at HRB-1 and there was almost no difference between the years at HRB-4. While iron concentrations were typically higher during Year 2 than Year 1 for HRB-2, HRB-3, and HRB-4, there is not enough data to suggest an increasing trend. Ultimately, additional water quality data is required to analyse potential trends. Some possible explanations for the difference between Year 1 and Year 2 iron concentrations are outline below.

- The difference between two point samples over only two years could just be due to natural variation or to differences in environmental conditions between the two sampling events such as precipitation, water table level, flow regime, sediment loading, or bedload movement.
- Differences in total suspended solids between the years could also explain differences in total metals (including iron) concentrations. However, a complete set of TSS concentrations were not taken in Year 1 making it difficult to comment on the potential role of TSS in annual variation at this time.

Table 4. **Total and dissolved iron concentrations between paired sampling events as Year 1, Year 2.**

	HRB-1	HRB-2	HRB-3	HRB-4	HRB-5
Total Iron					
July and August	0.651, 0.974	0.396, 0.547	0.202, 1.06	0.443, 0.658	1.76, 1.24
January	2.31, 2.09	0.920, 1.42	0.675, 1.26	1.63, 1.70	Not sampled
Dissolved Iron					
July and August	0.209, 0.579	0.119, 0.322	0.034, 0.378	0.132, 0.492	1.31, 0.978
January	1.32, 1.45	0.275, 1.01	0.063, 0.864	0.326, 1.31	Not sampled

Sulphate Anions

In April 2013 sulphate guidelines were revised by Ministry of Environment. Prior to this, there were two provincial water quality guidelines for sulphate: 50 mg/L and 100 mg/L. The lower concentration was to be used to monitor the health of aquatic vegetation and the higher concentration was to be considered the maximum allowable concentration for freshwater aquatic ecosystems. Based on additional research and literature regarding aquatic toxicology of sulphate, several of which indicated sulphate toxicity was related to water hardness, the sulphate guideline was revised to a 30-day average reflecting toxicity at varying degrees of water hardness. While data presented in this report single point samples, not 30-day averages, there is currently no maximum sulphate guideline. Current 30-day average water quality guidelines for sulphate are listed in Table 5.

Table 5. **Current 30-day average water quality guidelines for sulphate.**

Water Hardness (mg/L)	Guideline (mg/L)
0-30	128
31-75	218
76-180	309
181-250	429
>250	Need to determine based on site water**

In comparing sulphate analytical results from all sampling events (June 2012 to April 2014) to the new water quality guidelines, no exceedances occurred. However, there were samples in January and March 2014 (and January of Year 1 sampling) that had water hardness greater than 250 mg/L above which concentration there is no provincial water quality guideline for the protection of aquatic life assigned to date.

In reviewing the dataset, spatial and temporal trends for sulphate concentrations appear to be emerging (Figure 1). HRB-2 and HRB-3 samples had consistently higher sulphate concentrations than the other three sampling locations, which was consistent with the elevated water hardness at these sites. In comparing sulphate concentrations at all sites during Year 2 sampling events, concentrations were higher in January and March of 2014 compared to August, September and October of 2013. This is consistent with Year 1 sampling where January 2013 showed higher sulphate concentrations for all sites compared to July 2012 and May 2013. This seasonal pattern was most apparent for HRB-2.

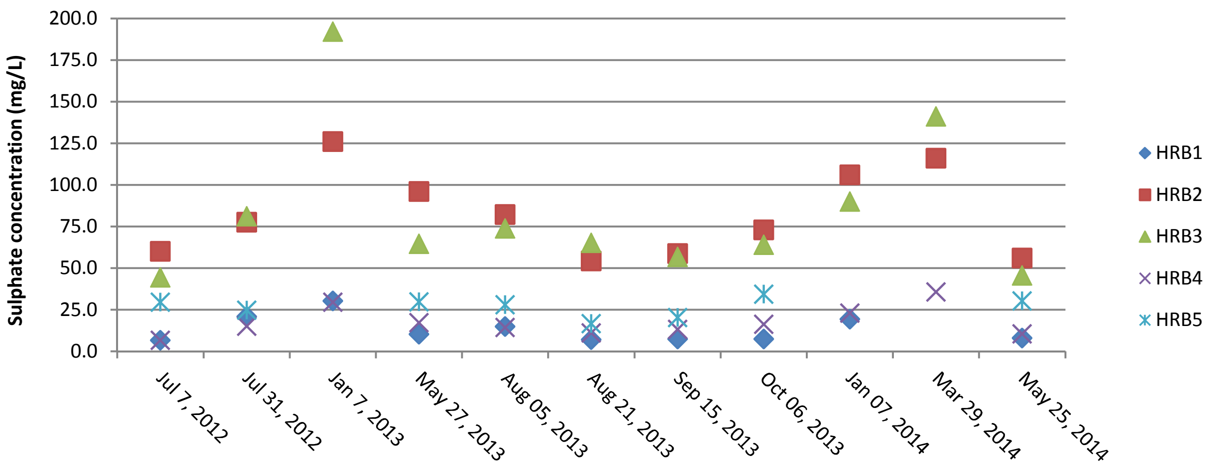

Figure 1. Sulphate concentrations from beginning of sampling program (July 2012) to May 2014.

There are several rationales that could potentially explain the sulphate trends.

1. High sulphate concentrations in Kiwigana (HRB-3) and Sahtenah (HRB-2) watersheds may be naturally occurring as a result of local geology and watershed basin characteristics. Watershed characteristics and drainage patterns could influence mobilization of hydrogen sulphide and sulphate anions from wetland complexes. Physical characteristics of the watersheds should be considered when reviewing the water quality results. For example, higher sulphate concentrations may be expected if Kiwigana and Sahtenah watersheds encompass a higher proportion of muskeg habitat compared to the Dilly, Stanolind, or D'Easum watersheds.
2. Water quality results should also be reviewed in context with hydrology and climate data in an effort to determine potential influences as a result of differences in water regimes between the watersheds. The general trend of increased concentrations during lower flows has been previously documented. Seasonal fluctuations in sulphate concentrations are apparent in most rivers, with low concentrations during freshet and elevated concentrations during the low flow periods. Precipitation and snow melt can also have an effect on sulphate concentrations through freshwater dilution[3].

Quality Assurance and Quality Control

The Quality Assurance and Quality Control (QA/QC) program developed for the surface water component of the project incorporated field training on proper sample collection and handling methods, as well as the collection of QA/QC water samples. Typically, QA/QC programs require the number of QA/QC samples

[3] Meays, C. and R. Nordin. 2013. Province of BC Ambient Water Quality Guidelines For Sulphate, Technical Appendix Update April 2013.

to reflect approximately 10% of the dataset. To date, a field blank and travel blank have been collected during each round of sampling. Also, a duplicate sample has been collected during each sampling event, with the exceptions of March and May 2014. This equates to 20% of samples for field and travel blanks and 17.3% of samples collected with duplicates.

For Year 2 sampling events, field blank analytical results were all below reported detection limits for analytical parameters with the exception of total aluminum in January 2014. Also, travel blank analytical results were below detection limits with the exception of total barium in August 2013 and total barium and total manganese in January 2014 (Table 3). This equates to 0.2% and 0.6% of cases for field and travel blanks respectively. As per sampling protocols, the travel blank accompanied the crew into the field and was returned to the laboratory for analyses unopened by the crew.

Table 6. **Analytical parameters within the field and travel blank samples above detectable concentrations for sampling events between June 2013 and April 2014.**

Date/Parameter	Units	Detectable Concentration	Analytical Result Field Blank	Analytic Result Travel Blank
August 2013				
Total Barium	mg/L	0.000050	<DL	0.000361
January 2014				
Total Aluminum	mg/L	0.0030	0.0065	<DL
Total Barium	mg/L	0.000050	<DL	0.000088
Total Manganese	mg/L	0.000050	<DL	0.000109

Relative percent difference (RPD) between a sample and its duplicate is used as a measure of analytical precision. It is calculated using the following formula:

$$RPD\ (\%) = 2 * [(A-B)/(A+B)] * 100$$

Where A=sample,
B=duplicate

Generally, sample duplicate RPD values less than 20% are considered precise, while values between 20% and 50% are considered suspect and RPD values greater than 50% indicate problems or errors that affect the precision of the analytical result. RPD values are often higher for analytical results close to (within 5-times) the sample detection limit. When duplicate results are less than 5-times the detection limit, the difference between the sample and the duplicate should be less than twice the detection limit (≤2DL) to be considered precise. If the difference between sample and duplicate results are greater than twice the detection limit, RPD values are reported. There were two cases in which RPD values exceeded 20% (total aluminum in September 2013 and total molybdenum in January 2014) and one case in which RPD values exceeded 50%, (dissolved Aluminum in October 2013). All other RPD's within the dataset where either <20% or differences between a sample and its duplicate were ≤2DL.

Conclusion

In conclusion, the Year 2 sampling results indicated that a large number of total iron and dissolved iron concentrations exceeded the provincial water quality guidelines of 1.00 mg/L and 0.35 mg/L respectively. Seasonal comparisons between Year 1 and Year 2 suggest that dissolved iron could be increasing in concentration over time; however, further sampling is required to confirm this trend.

Total cadmium, chromium, and zinc were detected in Year 1, and again in Year 2 sampling. All instances of these metal exceedances occurred in the month of May. Documented decreases in water hardness in May across all sampling locations are likely resulting in the exceedences for zinc and cadmium since water quality guidelines for these parameters are dependent on water hardness.

Sulphate concentrations were below the revised provincial guidelines (updated April 2013) for all Year 2 samples although seasonal trends were detected. A review of QA/QC samples indicated that there were unexpected parameter concentrations regarding field and travel blanks, but only for 0.2% and 0.6% of cases respectively. Similarly, there were only three cases when RPD values for duplicate samples were greater than 20%. The effect of these instances on the quality and validity of the dataset are likely negligible.

Yours truly,

EDI Environmental Dynamics Inc.

Hanna Van de Vosse, B.Sc., R.P.Bio.
Senior Biologist

Attachments

- Year 2 WQ_attachment1_field data.xlsm
- Year 2 WQ_attachment2_non-metals.xls
- Year 2 WQ_attachment3_metals.xlsm
- Year 2 WQ_attachment4_QAQC.xls

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April 16, 2015

EDI Project Number: 14-P-0016

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Attention: Dave Murray, P.Eng., A.Sc.T.

Re: Geoscience BC Horn River Basin Water Monitoring Project – Surface Water Quality Program Update – May 2015

Since 2011, EDI has been engaged in the multi-year Geoscience BC Horn River Basin Water Monitoring Project. One of the objectives of the program is to provide a baseline characterization of surface water quality within selected sub-basins of the Fort Nelson River watershed. Collected data will allow comparison of surface water to shallow groundwater and formation water chemistry. Additionally, data will be used to determine if background levels of naturally occurring elements are above provincial water quality guidelines and whether site-specific water quality objectives should be developed.

Selection of sub-basins and individual sites within each sub-basin was based on watershed characteristics, stakeholder considerations, First Nations considerations, and site specific logistics. Five watersheds, each with one sampling site, were chosen for the surface water program: Dilly Creek (HRB-1), Sahtaneh River (HRB-2), Kiwigana River (HRB-3), d'Easum Creek (HRB-4) and Stanolind Creek (HRB-5). To date, three years of data collection have been completed. Year 1 included July 2012 to May 2013, Year 2 included June 2013 to May 2014, and Year 3 included June 2014 to April 2015.

This report summarizes the third year of data collection (Year 3), which includes a total of four sampling events: June 22, August 11, August 23, and October 6 of 2014. Year 3 of the sampling program followed the same field and laboratory methods as previous years. Field data from Peace Country Technical Services (PCTS) were not available at the time this summary report was prepared. Data tables for Year 3 analytical results and quality assurance and quality control (QA/QC) samples have been provided digitally and are listed as attachments to this document. Results and discussions from Year 1 and Year 2 sampling events are available in the May 2013 and May 2014 program update documents.

Field Results

All surface water quality samples and field parameters were collected by Peace Country Technical Services Ltd. Field parameters included dissolved oxygen (DO), temperature, turbidity, total dissolved solids (TDS), salinity, pH, and conductivity. Measured field parameters were within the ranges shown in Table 1. Detailed field data are available in Attachment 1. Across all stations and all sampling events, pH values were consistent, ranging from 7.51 – 8.78. DO concentrations across all stations and events were within tolerable ranges for fish, ranging from 6.54 – 14.6 mg/L. Turbidity values were consistent between all sampling events and stations; no spikes were observed.

Table 1. Field parameter ranges measured between June 2014 and April 2015.

Field parameter	Units	Measured Range	Median Value
Dissolved oxygen	mg/L	6.54-14.6	8.69
Temperature	^{0}C	2.9-25.9	14.0
Turbidity	NTU	1.62-7.96	4.67
Total Dissolved Solids	mg/L	91.6-285	221
Salinity	PSU	65.4-208	146.5
pH	pH	7.51-8.78	8.22
Conductivity	µS/cm	129-408	308

Analytical Results

Concentrations Exceeding Water Quality Guidelines

Analytical results of surface water samples collected between June 2014 and April 2015 indicated one physical parameter and three metal parameters with concentrations exceeding provincial water quality guidelines for the protection of aquatic life:

- total suspended solids (TSS);
- chromium – total; and
- iron – dissolved and total.

TSS and total chromium concentration exceedances were only observed during the June 2014 sampling event and only at HRB3. Table 2 shows the actual concentrations of the exceedances for these parameters in comparison to guidelines. Field turbidity values were not elevated within this sample.

Table 2. Concentrations (mg/L) of the physical and metals parameters exceeding provincial water quality guidelines for the protection of aquatic life during the June 2014 sampling event.

Parameter	Water Quality Guideline	HRB-3
TSS	25 mg/L above background when background ≤ 25 mg/L	54.4
Total chromium	0.001	0.00147

Concentrations of dissolved and total iron frequently exceeded water quality guidelines throughout Year 3 sampling events and were observed at all sampling stations (Table 3). Total iron spikes may be associated with elevated TSS concentrations where the dissolved iron portion is relatively low (e.g., HRB-3 June 2014). However the vast majority of total iron exceedances can be attributed to elevated dissolved iron concentrations and are particularly noticeable in lower flow conditions (e.g., October 2014) when dissolved concentrations increase. This pattern is to be anticipated given the lack of freshwater input to offset groundwater influences and is illustrated with other metals in the dataset.

Table 3. **Surface water analytical parameters exceeding provincial water quality guidelines for the protection of aquatic life (mg/L) from June 2014 to April 2015. Red text indicates concentrations exceeding guidelines.**

Date	Parameter	WQG*	HRB-1 Dilly	HRB-2 Sahtenah	HRB-3 Kiwigana	HRB-4 d'Easum	HRB-5 Stanolind
Jun 22, 2014	Total iron	1.00	0.586	0.787	1.88	0.529	0.925
	Diss. iron	0.35	0.294	0.568	0.203	0.306	0.535
Aug 11, 2014	Total iron	1.00	1.13	0.745	0.679	0.982	2.04
	Diss. iron	0.35	0.553	0.326	0.216	0.688	1.67
Aug 23, 2014	Total iron	1.00	0.947	0.935	0.620	0.819	2.06
	Diss. iron	0.35	0.366	0.209	0.346	0.576	1.73
Oct 6, 2014	Total iron	1.00	1.35	0.804	0.922	0.946	1.68
	Diss. iron	0.35	0.638	0.431	0.473	0.649	1.23

* BC Water Quality Guidelines for the Protection of Aquatic Life. All concentrations are shown in mg/L.

Cadmium

In February 2015, cadmium guidelines were revised by the BC Ministry of Environment. Dissolved cadmium is a better indicator of cadmium toxicity to aquatic life for three reasons: (1) it is more bioavailable and ecologically relevant; (2) concentrations in the aquatic environment are less variable than total cadmium; and (3) dissolved salts were used during toxicity tests. Therefore, the revision focused on dissolved cadmium rather than total cadmium. The revision also introduced additional categories of water hardness to calculate site-specific guidelines. Comparing cadmium analytical results from all sampling events in Year 3 to the revised water quality guideline for dissolved cadmium, no exceedances occurred. All hardness concentrations for all sampling events were within the lower and upper bounds for the long-term guideline.

Quality Assurance and Quality Control

The QA/QC program developed for the surface water quality component of the project incorporated field training on proper sample collection and handling methods, as well as the collection of QA/QC water samples. Typically, QA/QC programs require the number of QA/QC samples to reflect approximately 10% of the dataset. To date, a field blank and travel blank have been collected during each round of sampling. Also, a duplicate sample has been collected during each sampling event within Year 3. This equates to 25.0% of samples for field and travel blanks and 12.5% of samples collected with duplicates.

For Year 3 sampling events, field blank and travel blank analytical results were all below reported detection limits for analytical parameters. As per sampling protocols, the travel blank accompanied the crew into the field and was returned to the laboratory for analyses unopened by the crew.

Relative percent difference (RPD) between a sample and its duplicate was used as a measure of sampling and analytical precision. It is calculated using the following formula:

RPD (%) = 2 * [(A-B)/(A+B)] *100

Where A=sample,
B=duplicate

Generally, RPD values less than 20% are an indication of good precision while values between 20% and 50% are considered suspect and RPD values greater than 50% indicate problems or errors that affect the precision of the analytical result. For analytical results close to (within 5-times) the sample detection limit, RPD values can be inherently elevated; therefore, precision is calculated differently. When analytical results are less than 5-times the detection limit, the difference between the sample and the duplicate should be less than twice the detection limit (≤2DL) to be considered precise.

There were six instances in which RPD values between the sample and corresponding field duplicate exceeded 20% (Table 4). Environmental heterogeneity likely explain the differences in measurement of precision. However, two of the six have RPD values well above 50% (August 11 – dissolved manganese and October 6 – total aluminium) which would suggest errors in the data regarding these parameters. Comparison of laboratory replicate results for these parameters indicated both were within acceptable ranges. All other parameters either had RPD values less than 20% or differences between the sample and its duplicate were less than two times the detection limit (<2DL).

Table 4. Instances of relative percent difference (RPD %) between samples and duplicates from June 2014 to April 2015.

Sampling Event	Sample Site	Parameter	RPD (%)
June 22, 2014	HRB3	dissolved lithium	20.42
August 11, 2014	HRB1	dissolved manganese	130.64
August 23, 2014	HRB1	total aluminum	23.77
October 6, 2014	HRB4	total aluminium	94.51
October 6, 2014	HRB4	total managanese	20.62
October 6, 2014	HRB4	total molybdenum	25.84

Conclusion

In conclusion, the Year 3 sampling results indicated;

- A large number of total iron and dissolved iron concentrations exceeded the provincial water quality guidelines of 1.00 mg/L and 0.35 mg/L respectively.
- Total chromium and TSS concentrations exceeded provincial water quality guidelines during the June 2014 sampling event at sampling station HRB-3.
- Cadmium concentrations were below the revised provincial water quality guidelines (updated February 2015).
- A review of QA/QC samples indicated that field blank and travel blank analytical results were all below reported detection limits for analytical parameters.

- In light of the extremely high RPD values, it is recommended that dissolved manganese data from August 2014 and total aluminium data from October 2014 be considered suspect and excluded from further data analyses.

Yours truly,

EDI Environmental Dynamics Inc.

Hanna Van de Vosse, B.Sc., R.P.Bio.
Senior Biologist

Attachments

- Year 3 WQ_attachment1_field data
- Year 3 WQ_attachment2_non-metals
- Year 3 WQ_attachment3_metals
- Year 3 WQ_attachment4_QAQC

ENVIRONMENTAL DYNAMICS INC.

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March 28, 2016

EDI Project Number: 14-P-0016

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Attention: Dave Murray, P.Eng., A.Sc.T.

Re: Geoscience BC Horn River Basin Water Monitoring Project – Surface Water Quality Final Program Update – Year 4, March 2016

Since 2011, EDI has been engaged in the multi-year Geoscience BC Horn River Basin Water Quality Monitoring Project. Primary objective of the four year program is to provide baseline characterization of surface water quality within selected sub-basins of the Fort Nelson River watershed. Collected data may also allow comparison of surface water to shallow groundwater and formation water chemistry. Additionally, data will be used to determine if background levels of naturally occurring elements are above provincial water quality guidelines and whether development of site-specific water quality objectives would be appropriate.

Selection of sub-basins and individual sites within each sub-basin was based on watershed characteristics, stakeholder considerations, First Nations considerations, and site specific logistics. Five watersheds, each with one sampling site, were chosen for the surface water program: Dilly Creek (HRB-1), Sahtaneh River (HRB-2), Kiwigana River (HRB-3), d'Easum Creek (HRB-4) and Stanolind Creek (HRB-5).

This report summarizes surface water quality data collected during the final year of the program, Year 4. Between May 2015 and September 2015, four sampling events occurred at each of the five sampling sites. Data tables for Year 4 field parameters, analytical results, and quality assurance and quality control (QA/QC) samples have been provided digitally and are listed as attachments to this document.

Field Results

All surface water quality samples and field parameters were collected by Peace Country Technical Services Ltd. Field parameters included dissolved oxygen (DO), temperature, turbidity, total dissolved solids (TDS), salinity, pH, and conductivity. Measured field parameters were within the ranges shown in Table 1. Detailed field data are available in Attachment 1. Across all stations and all sampling events, pH values were consistent, ranging from 7.48 – 7.91. DO concentrations across all stations and events were within tolerable ranges for fish, ranging from 9.26 – 10.17mg/L.

Table 1. Field parameter ranges measured between May and September 2015.

Field parameter	Units	Measured Range	Median Value
Dissolved oxygen	mg/L	8.04 - 12.70	8.99
Temperature	^{0}C	8.90 – 19.30	13.65
Turbidity	NTU	1.54 – 13.40	4.37
Total Dissolved Solids	mg/L	96.0 – 255.0	176.5
Salinity	PSU	70.6 – 189.0	128.5
pH	pH	7.30 – 8.19	7.69
Conductivity	µS/cm	135.4 – 361.0	248.0

While the majority of samples had turbidity values well below 10 NTU, a large turbidity spike was observed at HRB3 (13.4 NTU) during the May sampling event (Table 2). Freshet may be responsible for some of this increase since all other sites also had higher values in May (ranging between 4.22 and 6.23); however, freshet may not fully explain the 2.5-fold increase in turbidity observed at HRB3. Possible explanations may also include localized disturbance upstream of the HRB3 site. Sampling error or equipment malfunction are less likely explanations since a corresponding spike in TSS (15.8 mg/L) also occurred for this particular sample.

Table 2. Comparison of turbidity field values (Turb. in NTU) and analytical results for total suspended solids (TSS in mg/L) for samples collected between May and September 2015.

	HRB1 DILLY		HRB2 SAHTENAH		HRB3 KIWIGANA		HRB4 D'EASUM		HRB5 STANOLIND	
	Turb.	TSS	Turb.	TSS	Turb.	TSS	Turb.	TSS	Turb.	TSS
May 13, 2015	4.22	<3.0	6.20	5.6	13.40	15.8	5.09	3.2	6.23	4.6
Jun 10, 2015	2.51	<3.0	8.61	3.9	4.78	<3.0	2.53	<3.0	2.17	<3.0
Jul 27, 2015	4.51	3.9	4.70	10.7	3.22	5.4	1.54	3.6	2.89	7.4
Sept 9, 2015	5.90	<3.0	3.81	<3.0	4.60	<3.0	3.20	<3.0	2.75	<3.0

At each individual station, conductivity, TDS and salinty values showed a similarly increasing trend in concentrations from May to September (Figure 1). This is consistent with typical seasonal fluctuations reported by BC Ministry of Environment (2013) with lower concentrations during spring freshet and elevated concentrations during the low flow periods[1].

[1] Meays, C. and R. Nordin. 2013. Province of BC Ambient Water Quality Guidelines For Sulphate, Technical Appendix Update April 2013.

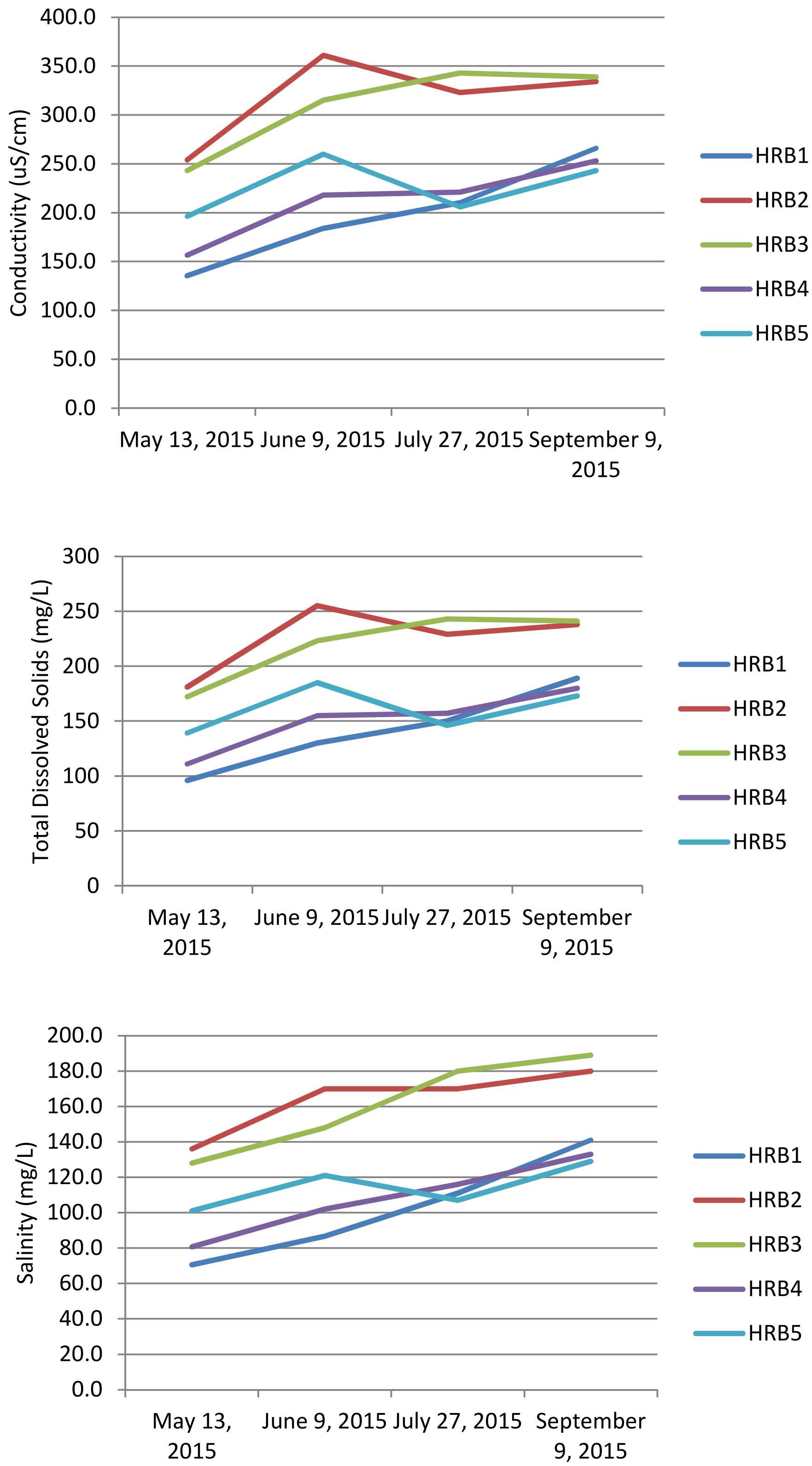

Figure 1. Field values for conductivity, TDS, and salinity of samples collected between May and September 2015.

Analytical Results

Concentrations Exceeding Water Quality Guidelines

Analytical results of surface water samples collected between May 2015 to September 2015 indicated nearly all physical and metal parameters were below provincial water quality guidelines for the protection of aquatic life. Iron (total and dissolved forms) was the only parameter that exceeded these guidelines. Dissolved metals analyses were not conducted in May at any of the five sites nor in June at HRB1 (Dilly).

Because of increased bio-availability of dissolved forms of metals compared to total forms, aquatic life guidelines for dissolved metals need to be considered[2]. Concentrations of dissolved iron frequently exceeded water quality guidelines throughout Year 4 (Table 3). These occurrences were observed at all sampling stations at various months. However, dissolved iron consistently exceeded water quality guidelines (i.e. at every site) in September at a higher concentration than previous 2015 sampling events. These increases correspond to low summer streamflow. This is consistent with typical seasonal fluctuations reported by BC Ministry of Environment (2013) with lower concentrations during spring freshet and elevated concentrations during the low flow periods.

There were a few instances in which total iron concentrations exceeded water quality guidelines. In comparing total suspended solids (TSS) concentrations with elevated total iron concentrations, it appears that TSS had a negligible effect on total iron concentrations. Elevated TSS concentrations in the dataset did not occur at the same time or location as increased total iron concentrations. Total iron concentrations exceeding water quality guidelines are largely the result of elevated concentrations of the dissolved form of the metal. In fact, for each case of total iron exceedances, guidelines for dissolved iron were also exceeded (Table 2).

Table 3. Total and dissolved iron concentrations in surface water samples collected from May 2015 to September 2015. Red text indicates concentrations exceeding provincial guidelines for the protection of aquatic life.

Date	Parameter	WQG*	HRB-1 Dilly	HRB-2 Sahtaneh	HRB-3 Kiwigana	HRB-4 d'Easum	HRB-5 Stanolind
May 13	Total iron	1	0.409	0.651	1	0.503	0.670
	Diss. iron	0.35	-	-	-	-	-
June 10	Total iron	1	0.492	0.816	0.357	0.598	0.780
	Diss. iron	0.35	-	0.303	0.113	0.395	0.570
July 27	Total iron	1	0.909	0.724	0.616	1.05	0.943
	Diss. iron	0.35	0.455	0.328	0.297	0.623	0.533
Sept 9	Total iron	1	1.29	0.753	0.684	0.994	1.67
	Diss. iron	0.35	0.740	0.471	0.417	0.701	1.37

* BC Water Quality Guidelines for the Protection of Aquatic Life. All concentrations are shown in mg/L.

[2] Ministry of Environment. 2008. Ambient water quality guidelines for iron. Available at [http://www.env.gov.bc.ca/wat/wq/BCguidelines/iron/iron_overview.pdf]

Quality Assurance and Quality Control

The QA/QC program developed for the surface water quality component of the project incorporated the collection of quality control samples. One field blank and one travel blank along with two duplicate samples were collected during Year 4, equating to 20% of the total number of samples. MOE (2013) [3] considers a level of quality control between 20 and 30% appropriate.

Relative percent difference (RPD) between a sample and its duplicate was used as a measure of sampling and analytical precision. It is calculated using the following formula:

RPD (%) = 2 * [(A-B)/(A+B)] *100
Where A=sample,
B=duplicate

Generally, RPD values less than 20% are an indication of good precision while values between 20% and 50% are considered suspect and RPD values greater than 50% indicate problems or errors that affect the precision of the analytical result. For analytical results close to (within 5-times) the sample detection limit, RPD values can be inherently elevated; therefore, precision is calculated differently. When analytical results are less than 5-times the detection limit, the difference between the sample and the duplicate should be less than twice the detection limit (≤2DL) to be considered precise.

There were two instances in which RPD values between the sample and corresponding field duplicate exceeded 20%, both of which occurred during the June 2015 sampling event: total aluminum (27.99%) and total titanium (36.31%). Comparison of laboratory replicate results indicated both of these parameters were within acceptable ranges (total aluminum 17% RDP and total titanium <2DL). Environmental heterogeneity likely explain these differences in measurement of precision. All other parameters either had RPD values less than 20% or differences between the sample and its duplicate were less than two times the detection limit (<2DL). Analytical results of field and travel blanks were within expected values (e.g., parameter concentrations were below detection levels).

Conclusion

In conclusion, the Year 4 sampling results indicated that a large number of total iron and dissolved iron concentrations exceeded the provincial water quality guideline of 1.00 mg/L and 0.35 mg/L respectively. These were the only parameters that exceeded provincial guidelines for the protection of aquatic life. A review of quality control samples indicate Year 4 dataset is valid and effects two elevated RPD values on data quality are likely negligible.

[3] MOE. 2013. British Columbia field sampling manual for continuous monitoring plus the collection of air, air-emissin, water, wastewater, soil, sediment and biological samples.

Comparison to previous years

In comparing parameters across all four years of data collection, trends in iron concentrations appear consistent. Both dissolved and total forms are frequently elevated above provincial water quality guidelines for aquatic life at all sites over multiple years (see attachment 5). Total iron spikes may be associated with elevated TSS concentrations where the dissolved iron portion is relatively low (example May 2013). However the vast majority of total iron exceedances can be attributed to elevated dissolved iron concentrations and is particularly noticeable in lower flow conditions, such as January 2014, when dissolved concentrations increase. This pattern is anticipated given the lack of freshwater input to offset groundwater influences and is illustrated with other metals in the dataset.

Other metal exceedances are sporadically noted in the dataset and include: dissolved aluminum (4); chromium (5); copper (4); silver (1); thallium (1); and zinc (2), where the number in parentheses indicates the number of exceedances. Total cadmium had been noted as exceeding guidelines in prior water quality reports; however in February 2015 MOE revised the guideline to better address water hardness effects on the toxcitity of cadmium and account for bio-availabity of dissolved forms. The revised guideline is now only applicable to the dissolved form of cadmium. Applying the revised guideline to samples collected prior to February 2015, no exceedances of dissolved cadmium are noted.

Yours truly,

EDI Environmental Dynamics Inc.

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Reviewed by:

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Attachments
Year 4 WQ_attachment1_field data.xlsm
Year 4 WQ_attachment2_non-metals.xls
Year 4 WQ_attachment3_metals.xlsm
Year 4 WQ_attachment4_QAQC.xls
Years 1-4 WQ_attachment5_iron.xls

KERR WOOD LEIDAL
consulting engineers

Appendix D

Benthic Biomonitoring Technical Reports and GIS Desktop Study

Geoscience BC Horn River Basin Water Project: Benthic Biomonitoring Technical Report

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DATE: April 2014

2012 ENVIRONMENTAL EMPLOYER OF THE YEAR

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EXECUTIVE SUMMARY

Benthic macroinvertebrates (benthics) are bottom dwelling organisms that are commonly used as biological indicators to assess the health of aquatic ecosystems because of their sedentary lifestyle, relatively long lifespan, and short generation times (Beatty et al. 2006). The pollution tolerance of benthics varies with some taxa being more sensitive than others (Barbour et al. 1999). The absence of more pollution sensitive taxa combined with the increased presence of more pollution tolerant taxa may indicate impairment to an aquatic environment, providing powerful information for interpreting cumulative effects (Zimmerman 1993).

In 2011, EDI designed and implemented a benthic biomonitoring program in the Horn River Basin (HRB), in northeast BC, as part of the Geoscience BC and HRB Producers Group (HRBPG) HRB Water Project (the Project). The aim of the Project is to monitor the deep, shallow, and surface water components of watersheds in the HRB to gain an understanding of water quality and quantity in the region and build First Nations capacity in water management. Oil and gas activities have been increasing in the HRB and to understand the potential impacts of these activities on the aquatic environment, better characterization of the watersheds in the HRB is required.

The objective of this Project is to perform baseline monitoring of the benthic community in the HRB using a standardized approach to biomonitoring, which will provide preliminary insights into the health of the aquatic environment in the HRB. The data collected will also contribute towards the development of a Canadian Aquatic Biomonitoring Network (CABIN) reference model for the Horn River Basin area by complementing work already being conducted by agencies in the HRB. Reference sites are established in areas minimally impacted by human activities and test sites are established in areas downstream or adjacent to human activities. The model evaluates the benthic community at a test site to determine if it is statistically different from the reference sites, in which case the test site is considered impaired. This model allows for monitoring of test sites to be completed at any single point within the HRB with a single sampling event, and will become a cost effective and defendable tool to monitor the biological aspects of water quality in the HRB.

Prior to the completion of a CABIN reference model, it is in the interest of HRBPG to establish the baseline condition of sites that have potential for future impacts due to oil and gas development. This technical report presents the results of an assessment of the variation and trends in the benthic macroinvertebrate data collected to date during the first three years (2011 – 2013) of the baseline biomonitoring program. To increase the sample size available for data analysis, an additional two years of reference site data collected by the BC Ministry of Environment (MOE) in 2010 and 2011 within the HRB were included in the dataset.

Reference sites selected by MOE and for the HRB Project were chosen as per CABIN reference site selection criteria. Reference sites are located in areas minimally impacted by human activities and were selected to cover a variety of geographical, hydrological, and biological conditions to capture the natural variability amongst reference sites and ensure future test sites can be evaluated against comparable reference conditions (Environment Canada 2012a; Environment Canada 2013). Test sites selected for the HRB

Project were chosen based on proximity to current and anticipated developmental activities, primarily oil and gas activities such as seismic lines, well sites and access roads. Benthic data from 15 reference sites sampled in 2010 and 2011 and six test sites sampled in 2012 and 2013 were used in our analysis. Among test sites, one of the original test sites was inaccessible in 2013, so a replacement site was selected for sampling instead. Sampling was repeated at the remaining test sites in 2013 in an effort to determine if there are temporal differences in the biological community at test sites.

For our assessment of the baseline monitoring data, we used several commonly used benthic metrics (e.g. proportion of Ephemeroptera taxa, taxa richness, Shannon-Wiener diversity index) to represent the health of the benthic community at each site. Analysis of Covariance (ANCOVA) was performed to determine if metrics were significantly different between reference and test sites. To determine if there was also an influence of habitat on the metrics, habitat parameters were used as covariates in these analyses. Habitat parameters included in analyses were chosen because of their correlation with specific metrics. Paired t-tests were performed on metrics for test sites sampled in 2012 and re-sampled in 2013 to determine if there was a change in the benthic community between years.

Our results suggest that there is a difference in the benthic community between reference sites and test sites, and within test sites, there appears to be no change in the benthic community between years. When comparing reference and test sites, the proportions of pollution sensitive taxa (i.e., EPT individuals and Plecoptera individuals) were significantly lower at test sites and the proportions of more pollution tolerant taxa (i.e., Diptera and non-insects and Chironomidae) were significantly higher at test sites. Furthermore, test sites were dominated by few taxa, which may indicate community imbalance, enrichment, or environmental stress (Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013). The Shannon-Wiener Diversity Index indicated that species diversity is lower at test sites in 2013 compared to reference sites, which can indicate decreased water quality, and the Hilsenhoff Family Level Biotic Index was significantly higher at test sites, with higher values indicating higher proportions of more pollution tolerant taxa in the benthic assemblage. A visual examination of the composition of taxa with different pollution tolerances at each site also suggests that water quality may be lower at test sites as there appears to be a higher proportion of more pollution tolerant taxa and a lower proportion of pollution sensitive taxa at test sites. The reason for these observed differences in pollution tolerant and pollution sensitive taxa between reference and test sites may be related to environmental factors within their watersheds including forest clearing and linear development activities which can alter the aquatic environment. These activities could lead to introduction of sediment, increased chemical or contaminant loading, lowered dissolved oxygen levels and increased nutrient enrichment any of which can influence biotic assemblages (Hilsenhoff 1987, Rosenberg and Resh 1993; NCSU 2014). Continued data collection would be required to determine if there is a trend of decreasing or increasing stress on these aquatic environments compared to the baseline condition developed through this project.

We also found that reference sites and test sites located further south in the HRB had a higher proportion of more pollution tolerant taxa suggesting water quality may be lower further south, potentially due to a higher amount of industrial activity in the southern region of the HRB around Fort Nelson, BC. However, our small sample size, especially in the southern portion of the HRB, may have contributed to this result.

Furthermore, our study design did not allow for direct comparison of reference sites to test sites on the same reach, which may have indicated point sources of pollution potentially impacting test sites. As such, we cannot be certain that test sites have been impacted at this time, only that the data suggest that there is a difference in the aquatic environment at the two site types during the baseline phase of biomonitoring. We also provide potential recommendations for future data collection which will build capacity and relations with the Fort Nelson and Fort Liard First Nations and we suggest ways to improve the current biomonitoring program until the CABIN reference model is complete.

ACKNOWLEDGEMENTS

The Horn River Basin Producers Group (HRBPG) funded this project through Geoscience BC. Numerous members of HRBPG provided their interest and input to initiate this project. Lyn Anglin followed by Carlos Salas administered the project for Geoscience BC. Dave Murray with Kerr Wood Leidal managed the overall HRB Water Project.

Stephanie Strachan provided advice on CABIN and current information on the progress of Environment Canada's work in the Horn River Basin. Chelton van Geloven with the Ministry of Natural Resource Operations shared data and the results of his analysis for reference site selection. Kirsten Heslop with Ministry of Environment provided results of MOE sampling.

Kayly Deneron with Acho Dene Koe First Nations in Fort Liard, NT assisted in collecting benthic field data in 2011. Eva Needlay assisted in collecting benthic field data in 2011, 2012, and 2013. Marilyn Norby with Fort Nelson First Nation coordinated scheduling of Eva for this work. Mark Racicot and Cathy Mackay with EDI conducted field data collection. Angela White with Encana Corporation assisted in collecting benthic field data in 2011.

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1 INTRODUCTION

In 2011, EDI designed and implemented a benthic macroinvertebrate biomonitoring program in northeast BC as part of the Geoscience BC Horn River Basin (HRB) Water Project (the Project). The HRB is approximately 11,000 km^2 and incorporates 42 watersheds within the Peace Region (Salas et al. 2014; Figure 1). The Project was initiated in 2008 by Geoscience BC, the HRB Producers Group (HRBPG), and the BC Ministry of Natural Gas Development, with involvement by the Fort Nelson and Fort Liard (Acho Dene Koe) First Nations. The aim of the Project is to monitor the deep, shallow, and surface water components in the HRB to gain an understanding of water quality and quantity in the region and build First Nations capacity in water management (Salas et al. 2014). Kerr Wood Leidal Associates Ltd. was retained by the HRBPG to manage the surface water component of the Project. They in turn retained EDI to design and implement the benthic biomonitoring program.

The purpose of an aquatic biomonitoring program is to evaluate potential changes in the aquatic biological community that cannot be detected by traditional water quality monitoring techniques in order to assess the health of the aquatic environment. Aquatic biomonitoring programs are often used to complement traditional water quality monitoring techniques where water chemistry and physical stream characteristics are used to evaluate the health of aquatic environments. However, these traditional approaches only provide a "snap shot" of water quality conditions at the time of the sampling event, whereas aquatic biomonitoring programs can indicate what conditions were like leading up to a sampling event (Environment Canada 2013).

Benthic macroinvertebrates are bottom dwelling organisms that sustain exposure to stream water and sediments throughout their life cycle (Environment Canada 2013). They are commonly used as biological indicators to assess the health of aquatic ecosystems because of their sedentary lifestyle, relatively long lifespan, and short generation times (Beatty et al. 2006). Benthic macroinvertebrates are also generally abundant in aquatic ecosystems and easy to sample, and can be a valuable source of food for fish and wildlife (Merritt and Cummins 1996; Beatty et al. 2006; Environment Canada 2013). Some benthic macroinvertebrate taxa are extremely sensitive to pollutants while others are highly tolerant, providing powerful information for interpreting cumulative effects (Barbour et al. 1999). Pollution can relate to a wide range of impacts which influence benthic assemblages such as increased sedimentation, lowered dissolved oxygen, higher organic content or impacts from chemical interactions and contaminants that can be deleterious to benthic invertebrates (Hilsenhoff 1987; Environment Canada 2013; NCSU 2014). While both pollution sensitive and pollution tolerant taxa may be present in "clean" waters, it is the absence or decreased presence of pollution sensitive taxa combined with the increased presence of pollution tolerant taxa that may indicate impairment to an aquatic environment (Zimmerman 1993).

Environment Canada developed the Canadian Aquatic Biomonitoring Network (CABIN) program to provide a standardized approach to aquatic biomonitoring across Canada. A set of standard national protocols are used for study design, field sampling, data entry, laboratory work, and analysis of biological monitoring data. Individuals are trained through a combination of online training modules and field certification workshops depending on the level of certification desired (i.e., Project Manager, Field

Technician, Data Analyst, or Data Entry Technician). The CABIN system of biomonitoring uses benthic community data from a group of unimpaired reference sites to build a region-specific statistical reference model to which a test site is evaluated against. Reference sites are established in areas minimally impacted by human activities and are used to represent natural conditions. Test sites are established within areas of suspected impairment due to human activities. Using a region-specific reference model, the benthic community at a test site is evaluated using multivariate statistical analysis to determine if the benthic community at the test site is statistically different from the reference condition, in which case the test site is considered impaired (Environment Canada 2013).

A CABIN reference model for this area of northeastern BC is currently under development and is expected to be completed in the next few years (Stephanie Strachan, Environment Canada, pers. comm.). A CABIN reference model will allow monitoring to be completed at any single point within the model's geographical range with a single sampling event. Once this reference model is completed, test sites can be sampled over several years and compared to reference sites to determine if they are in an impaired state at the time of sampling and if that level of impairment changes over time. This will provide a cost effective and defendable tool to monitor the biological aspects of water quality in the HRB.

The objective of this Project is to perform baseline monitoring of the benthic community in the HRB using a standardized approach to biomonitoring, which will provide preliminary insights into the health of the aquatic environment in the HRB. The data collected will also contribute towards the development of a CABIN reference model by complementing work already being conducted by the BC Ministry of Environment (MOE) and Environment Canada in and around the HRB. The completion of this model will provide the HRBPG with a defendable tool to characterize the aquatic health throughout the HRB. Until recently, water quality information in the HRB has been lacking and development pressures, historically forestry and recently oil and gas activities such as seismic lines, well sites and access roads, have been increasing due to increased potential for unconventional natural gas resources in the area (BC MEM 2011). Better characterization of the watersheds in the HRB is needed to understand the potential impacts of these activities on the aquatic environment to implement effective mitigation measures.

It is in the interest of HRBPG to establish the baseline condition of sites where there is potential for future impacts due to oil and gas development. This technical report presents the results of an assessment of the variation and trends in the benthic macroinvertebrate data collected to date during the first three years (2011 – 2013) of the baseline biomonitoring program, including an additional two years of reference site data collected by MOE in 2010 and 2011 within the HRB. We also provide potential recommendations for future data collection which will build capacity and relations with the Fort Nelson and Fort Liard First Nations and we suggest ways to improve the current biomonitoring program until the CABIN reference model is complete.

2 METHODS

2.1 Study Design and the Reference Condition Approach

To monitor the baseline conditions of the benthic community in the HRB, our study was designed using the Reference Condition Approach (RCA; Reynoldson et al. 1997). RCA is a standardized method of collecting benthic community data and measuring aquatic health. The RCA is used by the BC Ministry of Environment (MOE) and Environment Canada who are currently collecting aquatic habitat and benthic macroinvertebrate data in the HRB region for the purpose of developing a CABIN reference model. To aid in the development of this CABIN reference model, EDI engaged with MOE and Environment Canada to select sites in and around the HRB that would complement work already being conducted by both government agencies in the region.

In addition to the RCA, the before-after control impact study design (BACI, Smith 2002) is another commonly used method for assessing the health of the aquatic environment. Under the BACI design, a feature of concern that is a potential point source of pollution is identified that could impact the aquatic environment. Sample sites are established upstream (i.e. control sites) and are paired with sites in the same water body (e.g., same stream) downstream of the feature of concern (i.e. impact sites) (Smith 2002). Sampling is conducted at the upstream and downstream sites before and after the feature of concern is developed and parametric statistics are used to assess whether this development has caused a change in the aquatic conditions at the downstream sites (Smith 2002). In the HRB, activities that could influence the aquatic environment such as seismic lines, access roads and well sites are widespread, smaller scale and shorter-term relative to larger, features of concern that are considered point sources of potential pollution. Therefore, an RCA design which allows for the cumulative effects of these multiple, smaller-scale activities on the landscape to be examined, is a more appropriate design for monitoring the aquatic environment in the HRB.

Under the RCA design, a region of interest is identified based on hydrological (e.g., BC major watershed, BC watershed group) or biogeographic (e.g., BC ecoprovince, BC ecoregion) boundaries. A wide range of reference sites which have minimal to no anthropogenic influences, representing the variety of biological communities within the region, are identified. The variation in the habitat and benthic data collected from these reference sites are used to develop a region-specific statistical reference model that identifies the range of benthic assemblages expected to be found at sites that have been minimally influenced by human activities (i.e., are in "reference condition"). Test sites representing areas with potential anthropogenic influences are then identified within the region; and using the region-specific reference model, the benthic assemblages at the test sites are evaluated against the reference condition using multivariate statistical analysis to assess whether the test sites fall within the normal range of variability. If a test site falls outside of the normal range of variability, it is considered to be impacted by anthropogenic influences and the degree of impairment (i.e. how far outside the range of natural variability) is also provided as a result of comparison to the reference model. The RCA design has several advantages over the BACI design including the ability to use environmental characteristics to account for natural variability in biological communities between reference sites, the ability to examine the influence if multiple sources of pollution, not just one point source, the ability to extrapolate to other sites or types of impacts within the region of concern, and the ability to provide a measure of deviation that qualifies the degree of impairment at test sites Reynoldson et al. 1999).

Prior to the completion of the CABIN reference model, we wanted to provide the HRBPG with a summary of the benthic community assemblage at reference and test sites during the baseline phase of monitoring. We also designed the study to compare the benthic community of reference sites and test sites, as current activities could already be influencing test sites. However, reference sites, which were only accessible via helicopter, were not sampled after 2011 due to budgetary constraints, preventing reference sites and test sites from being sampled on the same year. Therefore we caution that any significant differences observed between site types should also consider the influence that natural yearly environmental variability may have on the results. The study was also designed to examine temporal changes (i.e. changes between years) in the benthic community at reference and test sites. Although we could not sample reference sites beyond 2011, five of the test sites where sampled in both 2012 and 2013, therefore for these test sites, we examine temporal variation in the benthic community.

2.2 Site Selection

Reference sites selected by MOE and sites selected by EDI for the HRB Project were chosen as per CABIN reference site selection criteria. Reference sites are located in areas minimally impacted by human activities within a wide variety of geographical, hydrological, and biological conditions to represent the natural variability among reference sites within the region (Environment Canada 2012a; Environment Canada 2013). The sites selected were specifically focussed on the HRB, which is a geologically defined area of petroleum resources in northeast BC.

A GIS desktop exercise was performed to identify primary sampling strata comprising ecoregions, major watersheds, watershed groups, and sub-strata comprising altitude and stream order. These data were analyzed using layers that indicated the degree of anthropogenic impact within each stream reach and all of the candidate reference sites with minimal or no human impairment were identified (C. van Geloven, Ministry of Natural Resource Operations, pers. comm). Candidate reference sites were further narrowed down depending on practical constraints such as site access. Of the remaining pool of candidate reference sites, sites were selected within each stratum as much as possible to ensure that no stratum was over or under represented. Prior to field sampling, the selected candidate reference sites were discussed during consultation with local/regional experts. During helicopter access to the candidate sites, sites were confirmed or rejected as suitable considering visual impairment of the watershed and suitability of the reach for benthic sampling of wadeable streams.

Based on these criteria, five reference sites were selected and sampled in 2011 for the HRB Project. An additional two years of reference site data collected by MOE in 2010 and 2011 within the HRB were included in the dataset to increase the sample size available for our assessment (Table 1), resulting in a total of 15 reference sites. These candidate reference sites have not yet been designated for inclusion into the

CABIN reference model for the region, and are therefore only considered "candidate" reference sites at this time. The data has been shared with Environment Canada. For the purposes of this report, we will refer to them as reference sites here forward.

All candidate test sites within the HRB were selected based on proximity to current and anticipated developmental activities. In coordination with the overall HRB Water Study, test sites were selected to coincide with the water quality sites and were considered of interest and within the downstream area of future development activities based on consultation with the HRBPG. Current development in the HRB is primarily related to oil and gas activities such as seismic lines, well sites and access roads located upstream of test sites or on lands adjacent to test sites, with historic forestry activities in the region. Another benefit of selecting these sites as benthic sites is that numerous data parameters would be collected at the locations including meterologic, hydrometric, and surface water quality data.

Six test sites were selected and sampled in 2012 (Figure 1). Five of the six test sites were resampled in 2013; one of the original test sites (Dilly Creek) was inaccessible in 2013, so a replacement site (Tsea Creek) was selected for sampling instead. Test sites were sampled again in 2013 in an effort to determine if there are temporal differences in the biological community at test sites and to initiate a baseline dataset with repeated sampling.

Six of the MOE reference sites, one of the Project reference sites, and two of the Project test sites were located outside of the HRB boundary (Figure 1). However, those sites located outside of the boundary were still located within the same major watersheds as sites located inside the boundary. Most sites were located within 32 km of the boundary; reference site UPET002 was located approximately 100 km east of the boundary. As a precautionary measure, we analyzed the dataset with and without the most distant site to determine if this site had a disproportionate influence on the results due to its greater distance from the boundary. The same general trends were found in the data; therefore this site was retained in the dataset. The importance of finding unimpaired and suitable sampling sites dictated considering sites beyond the Project boundary, which is defensible because similar regional characteristics exist and the sites are within the same major watershed basins.

Table 1. Sample site information for all data used in analyses.

Data Source	Site Type	Year Data Collected	Site Names	No. of Sites*	Duplicate Performed (Y/N)
Ministry of Environment	Reference	2010	FNR001, MUSK001, MUSK002, TSEA001, TSEA002	5	Y (TSEA002)
Ministry of Environment	Reference	2011	LFRT002, LFRT003, LFRT005, LPET004, UPET002	5	N
HRB Project	Reference	2011	HRB01, HRB02, HRB03, HRB04, HRB05	5	Y (HRB05)
HRB Project	Test	2012	d'Easum Creek, Delkpay Creek, Kiwigana River, Sahtaneh River, Stanolind Creek, Dilly Creek	6	N
HRB Project	Test	2013	d'Easum Creek, Delkpay Creek, Kiwigana River, Sahtaneh River, Stanolind Creek, Tsea Creek	6	N

*2012 and 2013 data were collected at 5 out of 6 of the same sites. Tsea Creek was sampled in 2013 instead of Dilly Creek, which was inaccessible at the time of sampling in 2013 due to road conditions.

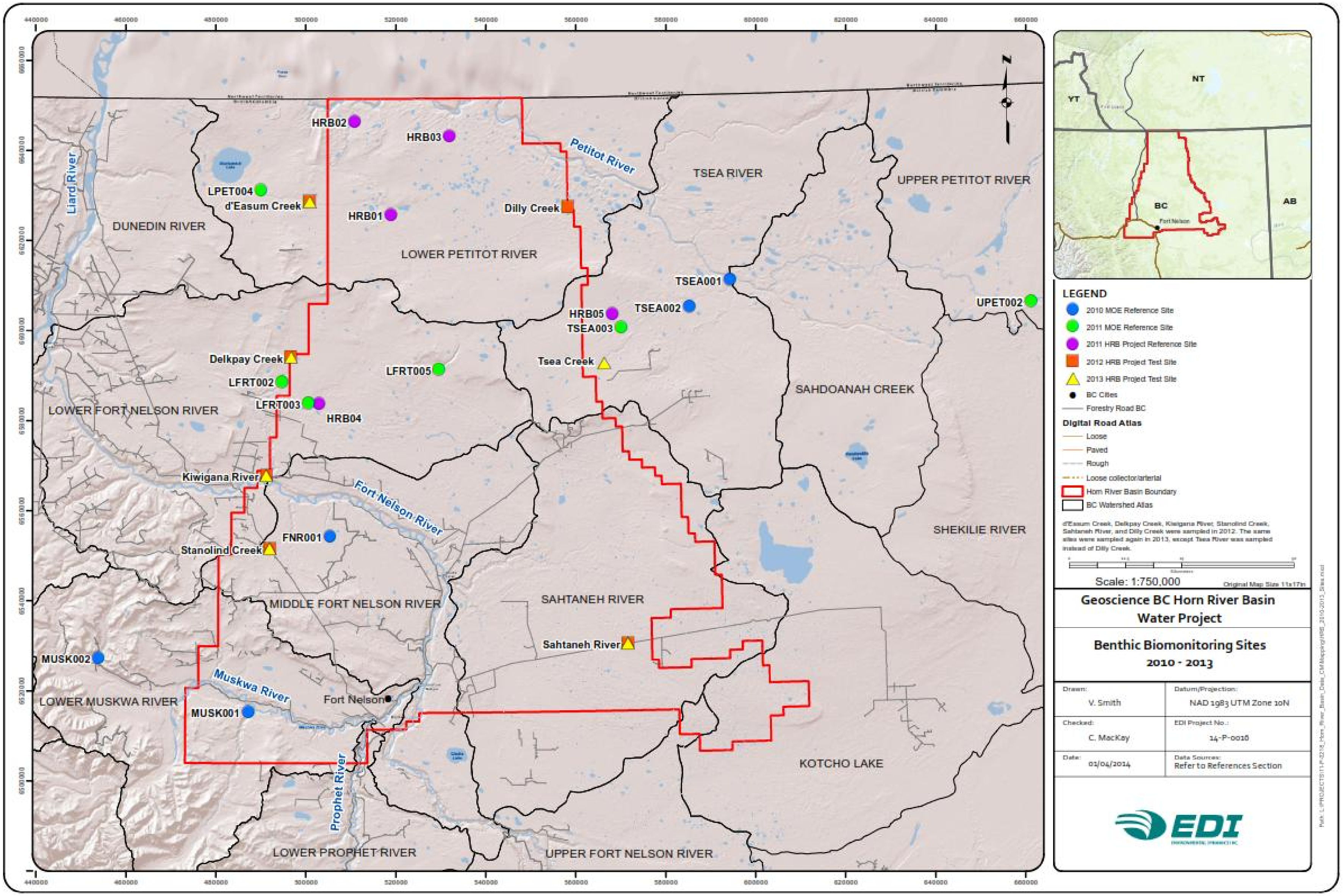


Figure 1. Horn River Basin Project Area.

2.3 Aquatic Habitat and Benthic Macroinvertebrate Sampling Protocol

Aquatic habitat and benthic macroinvertebrate data collected by MOE and for the HRB Project were sampled according to the CABIN field sampling protocol (Environment Canada 2012a). At each site, riffles and glides were targeted for sampling. Various habitat parameters related to geographical characteristics, reach and riparian characteristics, substrate characteristics, in-situ water quality, and channel morphology and flow were collected. Habitat parameters selected for use in our analyses are described in Section 2.5 of this report. Benthic macroinvertebrates were collected using a three minute travelling kick technique with a 400μm mesh kick net. Substrate and debris upstream of the kick net were disturbed by kicking and turning rocks over to dislodge macroinvertebrates. After the three minutes, the kick net was removed from the water and all macroinvertebrates and debris in the net and collection cup were rinsed carefully into the sample jar. Samples collected in 2010, 2011, and 2012 were preserved with a 10% buffered formalin solution in the field, at a ratio of 1:3 parts formalin to water, and were transferred to a 70% ethanol solution upon arrival at the EDI office in Prince George before shipment to a taxonomy laboratory (Environment Canada 2012b). Samples collected in 2013 were preserved with a 70% ethanol solution in the field. For quality control and assurance purposes, one duplicate sample was collected by MOE in 2010 and one duplicate sample was collected as part of the HRB Project in 2011 (Table 1). Duplicate samples were collected upstream of the first kick net sampling event in a riffle or glide that had not been disturbed by the first kick net sampling event. No duplicate samples were collected by MOE in 2011 or as part of the HRB Project in 2012 or 2013.

Macroinvertebrate samples collected by MOE in 2010 and 2011 and for the HRB Project in 2013 were sent to Cordillera Consulting in Summerland, BC, for enumeration and identification to the lowest taxonomic level possible. Macroinvertebrate samples collected for the HRB Project in 2011 and 2012 were sent to EcoAnalysts, Inc. in Moscow, ID, for enumeration and identification; the 2011 samples were identified to the family taxonomic level and the 2012 samples were identified to the lowest taxonomic level practicable.

2.4 Benthic Macroinvertebrate Metrics

Specific benthic macroinvertebrate metrics (hereby referred to as metrics) were chosen to represent the composition and health of the benthic macroinvertebrate community at each reference site and test site (Table 2). Metrics were chosen based on their use in other bio-assessment field studies and how informative they are at quantifying the composition and health of benthic macroinvertebrate communities (Rosenberg and Resh 1993). Metrics were also chosen to minimize redundancy and to aid in making inferences about the biological data. All metric calculations performed on data collected by EDI were completed using the Analytical Tools in CABIN (Environment Canada 2013). All metric calculations performed on data collected by MOE were completed in Microsoft Excel using CABIN analysis protocols.

Table 2. Benthic macroinvertebrate metric calculations and rationale for use.

Metric	Calculation	Rationale	Reference
Total Abundance	N = total number of individuals collected in each sample	Total abundance may be reduced under certain types of environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
Taxa Richness	S = total number of taxa collected in each sample	Reflects the health of benthic macroinvertebrate communities; as water quality decreases, taxa richness generally decreases.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
EPT Richness (Ephemeroptera + Plecoptera + Trichoptera)	S_{EPT} = total number of taxa in the EPT orders collected in each sample	In general, the majority of taxa in the EPT orders are considered sensitive to pollution; as water quality decreases, EPT richness generally decreases.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Dominant Taxa	% = (n/N)*100 The total number of individuals in the most abundant taxa (n) is expressed in terms of a percent of the total number of individuals collected in each sample.	Indicates balance in benthic macroinvertebrate communities; a community dominated by relatively few taxa may indicate community imbalance, enrichment, or environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% EPT Individuals (Ephemeroptera + Plecoptera + Trichoptera)	% = (∑ EPT individuals/N)*100 The total abundance of EPT individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of taxa in the EPT orders are considered sensitive to pollution; a decreased composition of these benthic macroinvertebrates may indicate toxic stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Ephemeroptera (Mayflies)	% =(∑ E individuals/N)*100 The total abundance of Ephemeroptera individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of taxa in the Ephemeroptera order are considered sensitive to pollution; a decreased composition of these benthic macroinvertebrates may indicate toxic stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013

Metric	Calculation	Rationale	Reference
% Plecoptera (Stoneflies)	% =(∑ P individuals/N)*100 The total abundance of Plecoptera individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of taxa in the Plecoptera order are considered sensitive to pollution; a decreased composition of these benthic macroinvertebrates may indicate toxic stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Trichoptera (Caddisflies)	% =(∑ T individuals/N)*100 The total abundance of Trichoptera individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of taxa in the Trichoptera order are considered sensitive to pollution; a decreased composition of these benthic macroinvertebrates may indicate toxic stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Diptera and Non-insects	% =(∑ D individuals/N)*100 The total abundance of Diptera and non-insect individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of taxa in the Diptera and non-insect orders are considered tolerant of pollution compared to taxa in the EPT orders; a stressed habitat may display an imbalance between these taxa, with an increased composition of Diptera and non-insect taxa.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Chironomidae	% =(∑ Ch individuals/N)*100 The total abundance of Chironomidae individuals is expressed in terms of a percent of the total number of individuals collected in each sample.	In general, the majority of genera in the Chironomidae family are considered opportunistic and highly tolerant to pollution compared to taxa in the EPT orders; a community dominated by Chironomidae genera may indicate community imbalance, enrichment, or environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
Hilsenhoff Family-level Biotic Index (FBI)	$FBI = \sum_{i=1}^{S} n_i \, t_i / N$ n = number of individuals of the i_{th} family t = tolerance value of i_{th} family N = total number of individuals collected in each sample	Used to classify water quality and the degree of organic pollution in aquatic environments; the Hilsenhoff FBI ranges from 0 to 10, with 0 representing excellent water quality and 10 representing very poor water quality.	Hilsenhoff 1988; Rosenberg and Resh 1993; Environment Canada 2013
Shannon-Weiner Diversity Index (H)	$H = -\sum_{i=1}^{S} P_i \, Ln P_i$ S = total number of species P_i = proportion of S made up of the i_{th} species (i.e., n_i/N)	The most commonly used diversity index; considers both richness and evenness; as water quality decreases, species diversity (i.e., the value of *H*) generally decreases.	Rosenberg and Resh 1993; Environment Canada 2013

2.4.1 Pollution Tolerance Values and the Family-level Biotic Index (FBI)

We chose to further explore the Hilsenhoff Family-level Biotic Index (FBI) due to its utility as an indicator of pollution in freshwater aquatic environments. Although the FBI was originally used to examine organic pollution in an agricultural context (Hilsenhoff 1988), the FBI is indicative of changes in the aquatic parameters such as dissolved oxygen and organic matter (Hilsenoff 1987) which may be influenced by other activities relevant to our study area such as forest clearing and linear developments. A closer examination of the FBI and tolerance values for benthic taxa at reference and test sites may also aid in the development of the CABIN model for this region.

The FBI ranges in value from zero to ten, with zero representing excellent water quality with organic pollution unlikely and ten representing very poor water quality with severe pollution likely (Table 3). The index calculates a pollution tolerance score for an assemblage of benthic macroinvertebrates (e.g., a sample from a single site) by weighing the relative abundance of each taxon (i.e., family) in terms of its tolerance value (Rosenberg and Resh 1993).

Table 3. Evaluation of water quality using the family-level biotic index (Hilsenhoff 1988).

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00 – 3.75	Excellent	Organic pollution unlikely
3.76 – 4.25	Very good	Possible slight organic pollution
4.26 – 5.00	Good	Some organic pollution probable
5.01 – 5.75	Fair	Fairly substantial pollution likely
5.76 – 6.50	Fairly poor	Substantial pollution likely
6.51 – 7.25	Poor	Very substantial pollution likely
7.26 – 10.00	Very poor	Severe organic pollution likely

The FBI was calculated for each reference site and test site. While the index gives an overall indication of water quality and stream health at each site, it does not provide information on what taxa contribute to the value and the proportion of each taxon at a sample site. If the FBI is low, it is generally assumed the benthic macroinvertebrate assemblage is comprised of a high proportion of EPT taxa, which are typically considered sensitive to pollution (Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013). Likewise, if the FBI is high, it is generally assumed the benthic macroinvertebrate assemblage is comprised of a high proportion of Diptera taxa, which are typically considered more pollution tolerant. While this may generally be the case, some EPT taxa can tolerate elevated levels of pollution (e.g., Caenidae = 7) and some Diptera taxa cannot tolerate elevated levels of pollution (e.g., Tipulidae = 3).

To identify what taxa contribute to the benthic macroinvertebrate assemblage at each site, site-specific tolerance value graphs were created for all sites in the HRB using regional tolerance values for benthic macroinvertebrates in the Pacific Northwest (Barbour et al. 1999) (Figures 8 – 12). Taxa were grouped by order (i.e. Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Diptera, and Other) and the total number of individuals in each order was displayed for each tolerance value. The tolerance value graphs for each test site and reference site were then grouped based on their inclusion within the same 1:50,000 BC Watershed Atlas group (i.e. Lower Petitot River, Tsea River, Lower Fort Nelson River, Middle Fort Nelson River, and Sahtaneh River). The graphs and corresponding FBI values were visually compared to analyze general trends within each BC Watershed Atlas group to determine whether aquatic conditions at the test sites differ from conditions at the reference sites. The tolerance value graphs enable us to directly compare reference and test sites within the same watershed, providing us with further information on the state of the aquatic environment at these sites. Specific reference sites and test sites were selected to represent general trends in the FBI and tolerance value data within each BC Watershed Atlas group (Table 4). Rationale for why specific sites were selected is present in Table 4.

Table 4. Sites selected to represent general trends in the FBI and tolerance value data.

BC Watershed Atlas Group	Sites Selected for Graphing	Rationale for Selection
Lower Petitot River	1. Reference site LPET004 on d'Easum Creek 2. d'Easum Creek test site	LPET004 and the d'Easum Creek test site are the only reference test sites located on the same watercourse in this watershed. The FBI and tolerance value data for the remaining reference and test sites in this watershed displayed the same general trends as the sites selected for the tolerance value graphs.
Tsea River	1. Reference site TSEA001 on the Tsea River 2. Tsea River test site	TSEA001 and the Tsea River are the only reference and test sites located on the same watercourse in this watershed. The FBI and tolerance value data for the remaining reference and test sites in this watershed displayed the same general trends as the sites selected for the tolerance value graphs..
Lower Fort Nelson River	1. Reference site LFRT005 on the Kiwigana River 2. Kiwigana River test site	A reference site and test site are also located on Delkpay Creek; however, we wanted to display trends for a larger watercourse to give an indication of what the FBI and tolerance value data look like in a larger scale aquatic system. There are three reference sites associated with the Kiwigana River test site. We selected LFRT005 as the representative reference site because it is located the furthest upstream compared to all other reference sites associated with the Kiwigana River. The FBI and tolerance value data for the remaining reference sites and test sites in this watershed (including Delkpay Creek) displayed the same general trends as the sites selected for the tolerance value graphs.
Middle Fort Nelson River	All sites were selected	Only one reference site and test site are located in this watershed as of 2013; therefore, all sites were selected for the tolerance value graphs.
Sahtaneh River	All sites were selected	No reference sites currently exist in this watershed and only one test site is located in this watershed as of 2013; therefore, only the two years of test site data are displayed to allow for visual comparison between sample years.

2.5 Habitat Parameter Analyses

Benthic macroinvertebrates have specific habitat requirements for their survival. In turn, the habitat characteristics of a water body can influence the benthic assemblage within that water body. The CABIN reference model uses various multivariate analyses to group sites based on habitat similarities, which allows for comparison between a group of reference sites and selected test sites (Environment Canada 2013). Due to our small sample size, the use of multivariate analyses to group reference and test sites based on habitat parameters is not possible at this time. However, some of the habitat parameters collected at each site can still be used to help explain any potential differences observed in benthic community between reference and test sites. Therefore, to control for the influence of habitat on benthic community composition, habitat parameters should be included in any analyses examining differences in metrics between reference and test sites.

Habitat parameters included in our analyses were selected based on the following criteria:

- Previous use as candidate habitat parameters in two CABIN reference models in northern BC to group reference sites (i.e., the Fraser River Georgia Basin (FRGB) model (Sylvestre et al. 2005) and the Skeena River Assessment System (SkeenRIVAS) model (Perrin et al. 2007); and
- Habitat parameters that are statistically correlated with metrics, which may indicate that the habitat parameters have an influence on the benthic community composition.

The habitat parameters chosen for further analyses based on their correlation with metrics are presented in Table 5. Some habitat parameters were categorical in nature (e.g., periphyton coverage or embeddedness, each on a scale of one to five) so could not be examined using correlations, and the dataset was too small to warrant pairwise comparisons.

Table 5. Significant correlations between habitat parameters and benthic macroinvertebrate metrics.

Habitat Parameters	Benthic Macroinvertebrate Metrics											
	Total Abundance	Taxa Richness	EPT Richness	% Dominant Taxa	% EPT Individuals	% Ephemeroptera	% Plecoptera	% Trichoptera	% Diptera and Non-Insects	% Chironomidae	Hilsenhoff Family-level Biotic Index	Shannon-Wiener Diversity Index
<u>Substrate Characteristics</u>												
% Boulder	-	-	-	-	-	-	-	+✓	-	-	-	-
% Cobble	-	-	-	-	- ✓	- ✓	-	-	+✓	+✓	-	-
% Gravel	-		-	-	-	+✓	-	-	-	-✓	-	-
% Pebble	-	-	-	-	+✓	+✓	-	-	-	-✓	-	-
<u>Channel Characteristics</u>												
Average Depth (cm)	-	-	-	-	+✓	+✓	-	-	-	- ✓	-	-
Average Velocity (m/s)	-✓	-	-	-	-	-	-	-	-	-	-	-
Bankfull Width (m)	-	-	-	-✓	-	-	-	-	-	-	-	-
<u>Water Quality Characteristics</u>												
Conductivity (µS/cm)	+✓	-	-	-	- ✓	-	- ✓	-	-	-	+✓	-
Temperature (°C)	-	-	-	-	-	-	-	-	-	-	-	-
pH	-	-	-	-	-	-	-	-	-	-	-	-
Turbidity (NTU)	-	-	-	-	-	-	-	-	-	-	-	-
<u>Geographical Characteristics</u>												
Latitude	-	+✓	+✓	-	+✓	-	-	+✓	- ✓	-	-	-
Longitude	-	+✓	+✓	-	-	-	-	-	-	-	-	-
Slope (m/m)	-	-	-	-	-	-	-	-	-	-	-	-
Altitude (m)	-	-	-	-	-	-	-	+✓	-	-	-	-

Check marks indicate significant correlations ($p < 0.05$) between habitat parameters and benthic macroinvertebrate metrics. A '+' or '-' indicates the direction of the relationship as either positive or negative.

2.6 Statistical Analyses

2.6.1 Examining Influence of Site Type and Habitat Variation on Metrics

Differences in metrics between site types were examined using an Analysis of Covariance (ANCOVA) design that assumes all observations are independent. Reference site data from 2010 and 2011 were grouped together for analyses because they are independent samples. Test site data from 2012 and 2013 were analyzed separately because they are not independent. Separating test sites by year lowered the sample size for test sites (n = 6) compared to reference sites (n = 15). Habitat parameters that were significantly correlated with metrics (Table 5) were included as covariates when analyzing differences between site types. Variation in metrics may be related to variation in habitat and/or site type; therefore both variables were included in the model to explain as much variation in the metrics as possible. There may also be habitat differences between site types, therefore including these habitat parameters in the analyses controls for these potential differences.

For those sites where duplicate samples were collected, metrics presented were calculated by averaging the metrics for the two samples to account for variability between duplicate samples at a site. However, there was a fivefold increase in the number of individuals (i.e., total abundance) collected between the two samples at site HRB05 in 2011. When examining the 'total abundance' metric for all reference sites, the duplicate sample for HRB05 was an extreme outlier and would not allow for normalization of the data. For this reason, we decided to exclude this duplicate sample from all analyses and used only the first sample performed at this site.

2.6.2 Examining Temporal Variation at Test Sites

To determine if there are changes in any of the metrics over time, typically repeated measures ANOVA would be performed using reference and test sites that were designed to be directly compared (i.e. in a BACI design), and year would be included as a covariate in the analysis to determine if there is a temporal change in the difference between reference and test site results. However, our study was not designed to allow for direct pairing of reference and test sites (see Section 2.1 Study Design). Instead we performed paired t-tests on the five replicated test sites comparing 2012 and 2013 data to determine if there were any significant changes in metrics between years. For any significant changes in benthic metrics, we can also determine the direction of that change and if it suggests increased or decreased impairment at test sites.

For all analyses discussed in Section 2.6, we performed Kolmogorov-Smirnov tests on metrics to determine if observations were normally distributed. For metrics that were not normally distributed (see Table 6), square-root or log10 transformations were performed to normalize the data. All figures are presented using untransformed data. All statistical analyses were performed using SPSS Statistics 17.0 (SPSS 2008).

3 RESULTS

3.1 Variation in Benthic Macroinvertebrate Metrics between Site Types

The levels of variation in benthic community metrics at reference and test sites are presented in box-and-whisker plots (Figures 2 – 7), displaying the mean and spread of the data. The boxplots show the middle 50% of the data within the grey box, while vertical lines (whiskers) present the spread of the data (upper 25% and lower 25% of the data). Due to small sample sizes, test site data were distributed completely within the grey box, resulting in no whiskers for these plots. The solid black line within the grey box represents the median, while the dotted line represents the mean. Dots represent outliers, observations that lie more than 1.5 times above or below the median, and n equals the sample size.

Test sites in both years had significantly higher total abundance of benthic macroinvertebrates compared to reference sites (p= 0.002 and p = 0.031, respectively) (Table 6; Figure 2). Although total abundance was higher for test sites, taxa richness and EPT richness did not differ between reference and test sites in either year (Table 6).

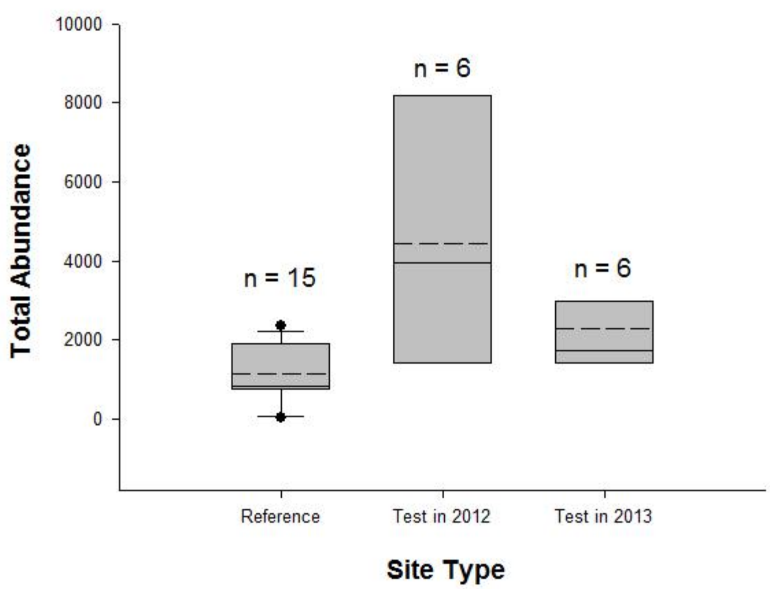


Figure 2. Difference in total abundance of benthic macroinvertebrates between reference sites and 2012 and 2013 test sites in the Horn River Basin.

There was a significantly higher proportion of EPT individuals (% EPT individuals) in reference sites compared to both 2012 (p =0.001) and 2013 (p =0.002) test sites (Table 6; Figure 3). The proportion of EPT individuals was also influenced by the latitude of the sample site, where reference and test sites at higher latitudes (more northerly) had a higher proportion of EPT individuals. Although this relationship was significant for analyses which included both 2012 test sites (p = 0.001) and 2013 test sites (p = 0.002), R^2 values were relatively low (2012: R^2 = 0.293; 2013: R^2 = 0.300) suggesting this relationship is fairly weak (Table 6, Figures 4 and 5). When examining EPT individuals separately (% Ephemeroptera, % Plecoptera, % Trichoptera), only the proportion of Plecoptera significantly differed between reference and test sites; with higher proportions of plecopterans at reference sites relative to both 2012 test sites (p = 0.002) and 2013 test sites (p = 0.005) (Table 6).

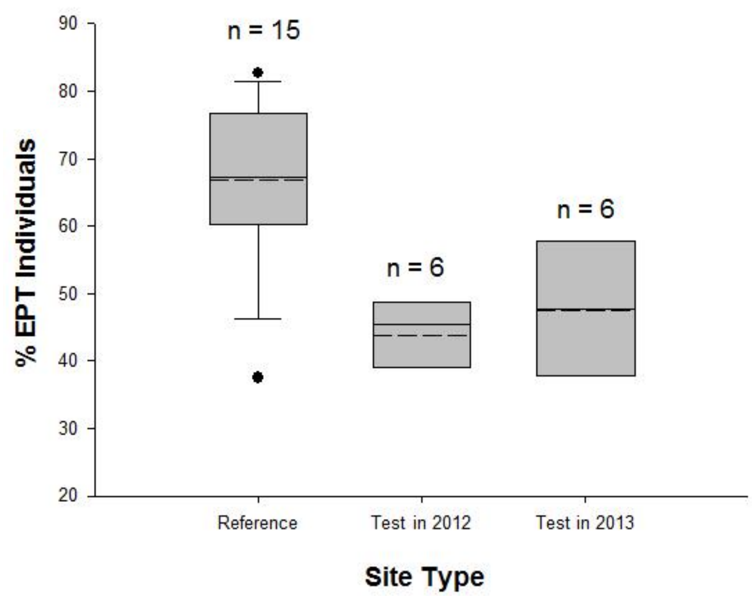


Figure 3. Difference in the proportion of EPT individuals between reference sites and 2012 and 2013 test sites in the Horn River Basin.

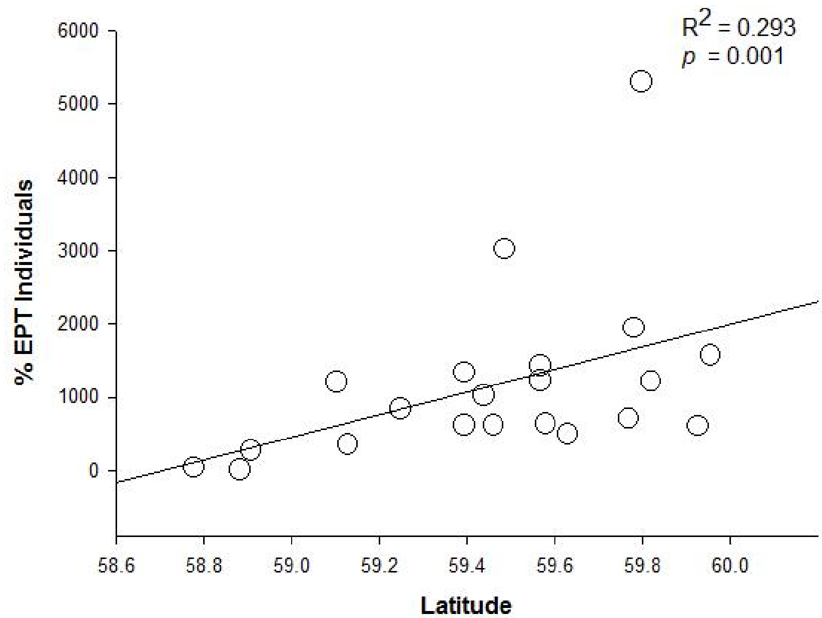


Figure 4. Relationship between the proportion of EPT individuals and latitude at both reference and 2012 test sites.

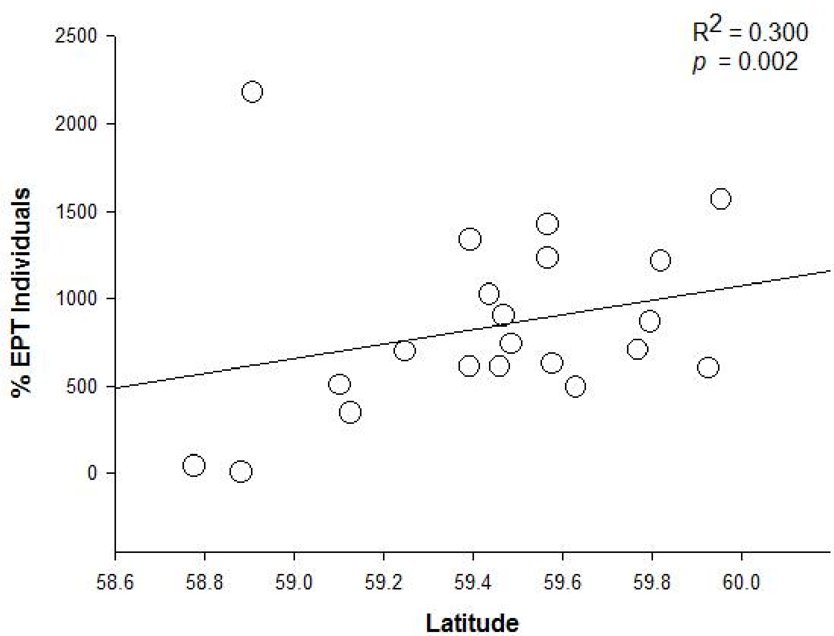


Figure 5. Relationship between the proportion of EPT individuals and latitude at both reference and 2013 test sites.

The proportion of Diptera and non-insects (% Diptera and Non-Insects) was significantly lower in reference sites compared to test sites sampled in both 2012 (p = 0.024) and 2013 (p = 0.010) (Table 6, Figure 6). The proportion of Diptera and non-insects was also influenced by the latitude of the sample sites, where higher proportions were found at lower latitude (more southerly) sites for both site-types. This relationship was consistent for both years of test-site sampling: 2012 (p = 0.007) and 2013 (p = 0.005) (Table 6). Furthermore, the proportion of the Dipteran family Chironomidae (% Chironomidae) was significantly lower in reference sites compared to both 2012 test sites (p = 0.003) and 2013 test sites (p < 0.001), but this was not influenced by any of the habitat parameters (Table 6).

The FBI of water quality was found to be significantly lower (i.e., better water quality) at references sites compared to test sites in both 2012 (p = 0.006) and 2013 (p = 0.002) (Table 6; Figure 7). The Shannon-Wiener Diversity Index was significantly lower (i.e., less diversity) at test sites in 2013 relative to reference sites (p = 0.039); although this relationship was not significant for the 2012 test site data (p = 0.116), the direction of the relationship remained the same (Table 6; Figure 8). Consistent with this finding, test sites also had a higher proportion of dominant taxa (% Dominant Taxa) compared to reference sites. This result was close to significant for the 2012 test site data (p = 0.051), but highly significant for the 2013 data (p = 0.007) (Table 6; Figure 9).

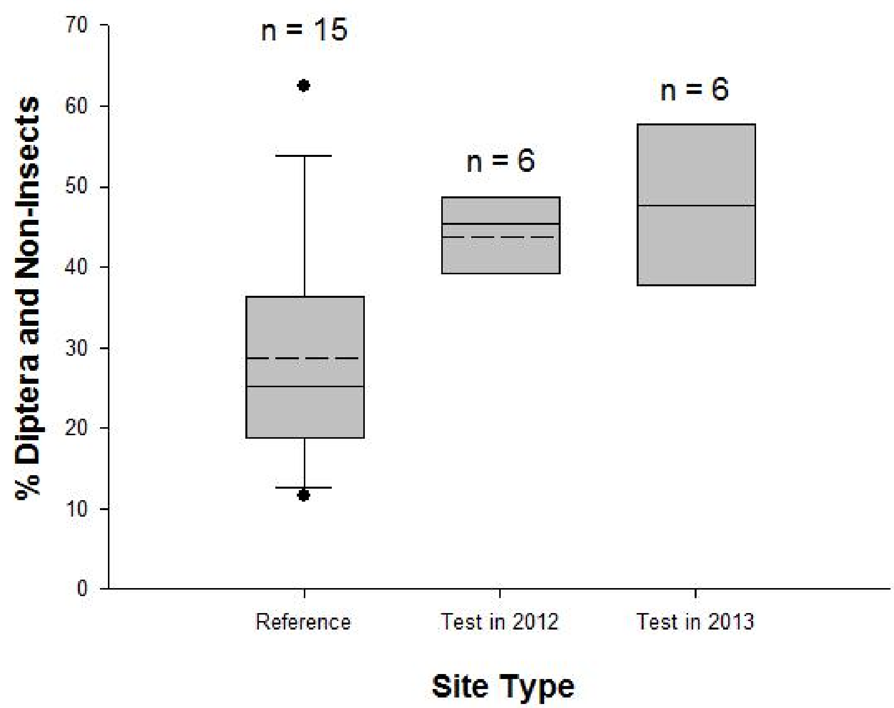


Figure 6. Difference in the proportion of Diptera and Non-Insects between reference sites and 2012 and 2013 test sites in the Horn River Basin.

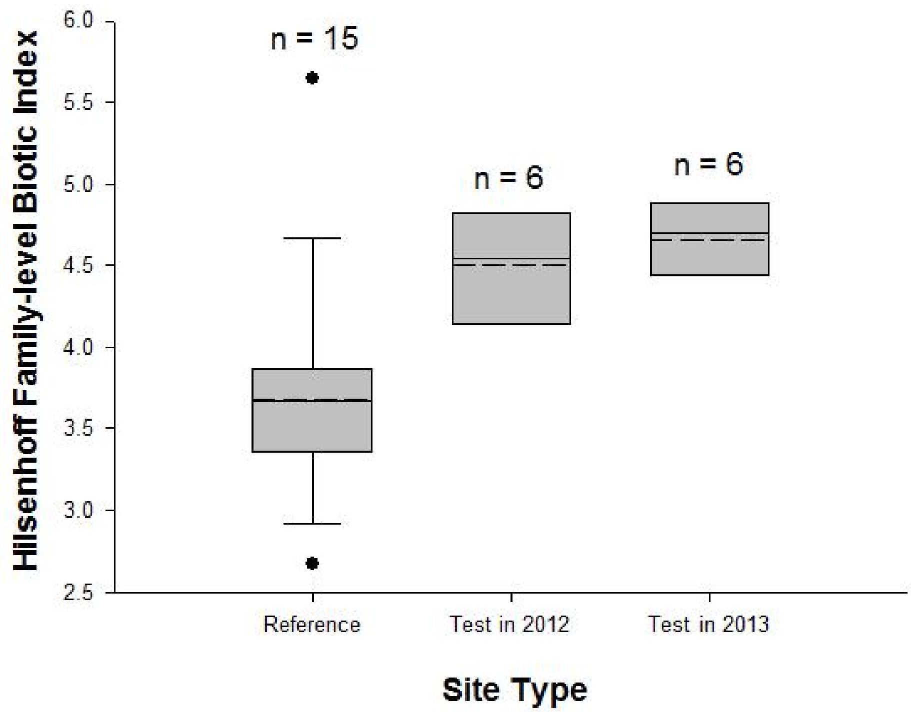


Figure 7. Difference in the Hilsenhoff Family-level Biotic Index between reference sites and 2012 and 2013 test sites in the Horn River Basin.

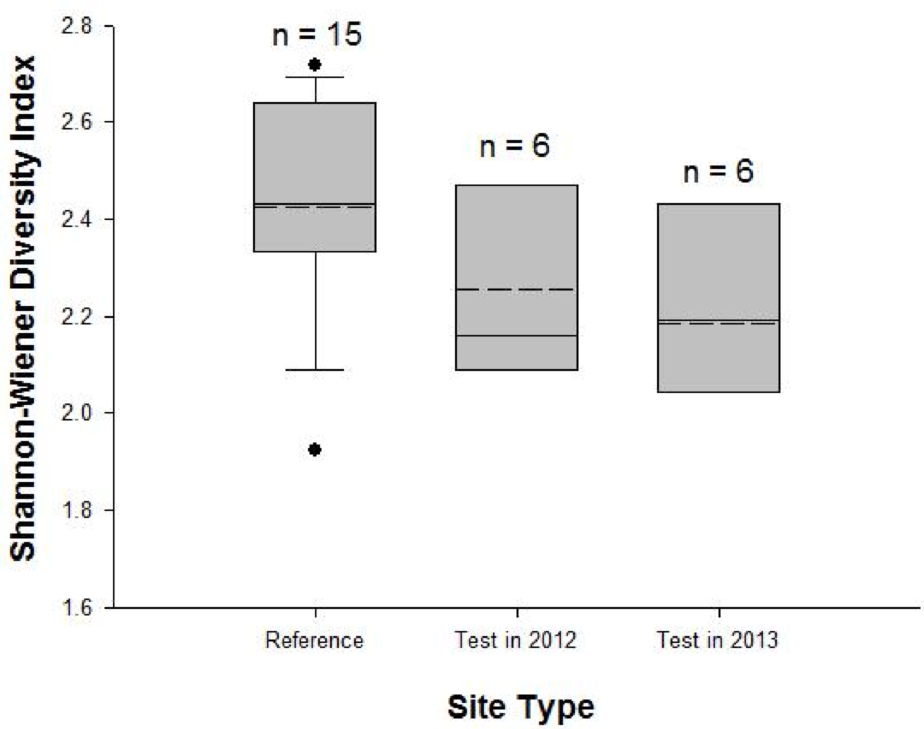


Figure 8. Difference in the Shannon-Wiener Diversity Index between reference sites and 2012 and 2013 test sites in the Horn River Basin.

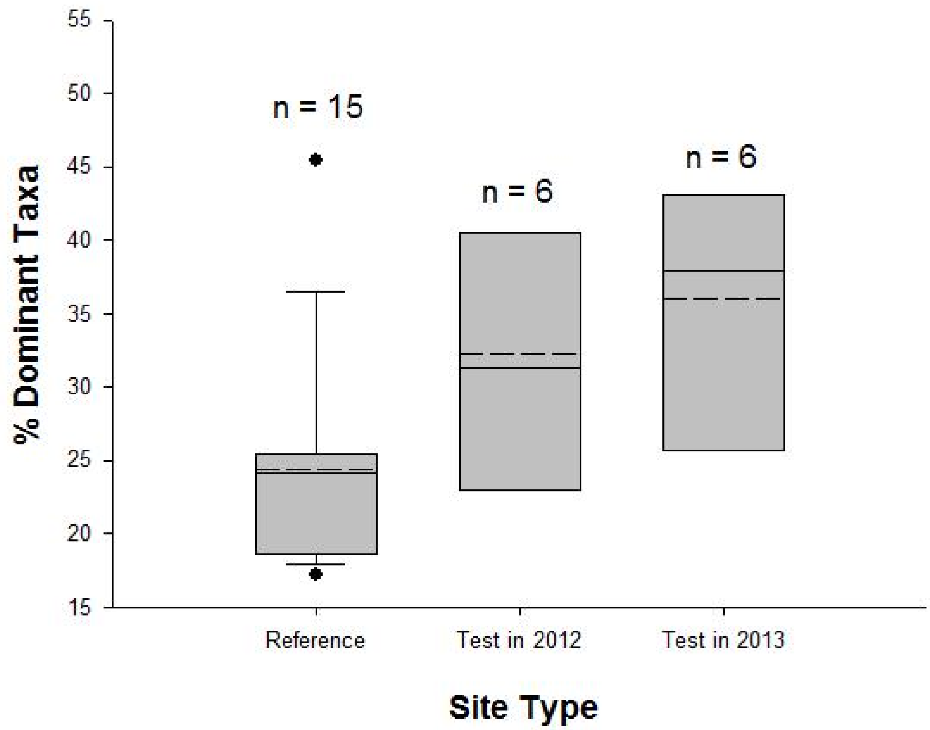


Figure 9. Difference in the proportion of dominant taxa between reference sites and 2012 and 2013 test sites in the Horn River Basin.

We also found that other metrics were influenced by the latitude of the sample site, even though we found no significant differences between reference and test sites. At higher latitudes (more northerly) the EPT richness was significantly higher across site-types for both years of test-site data ($p = 0.006$ and $p = 0.001$, respectively), with high R^2 values indicating strong linear relationship between latitude and EPT richness (2012: $R^2 = 0.946$; 2013: $R^2 = 0.988$, Table 6, Figures 10 and 11). Taxa richness also increased at more northerly latitudes, as well as more westerly longitudes, although these relationships were only found to be significant with the 2013 test site data (latitude: $p = 0.005$; longitude: $p = 0.012$) (Table 6). In addition, for analyses that included 2013 test sites, the proportion of Trichoptera (% Trichoptera) increased at sites with higher altitudes ($p = 0.009$) and at sites with a higher proportion of boulders in the stream substrate ($p = 0.008$) (Table 6).

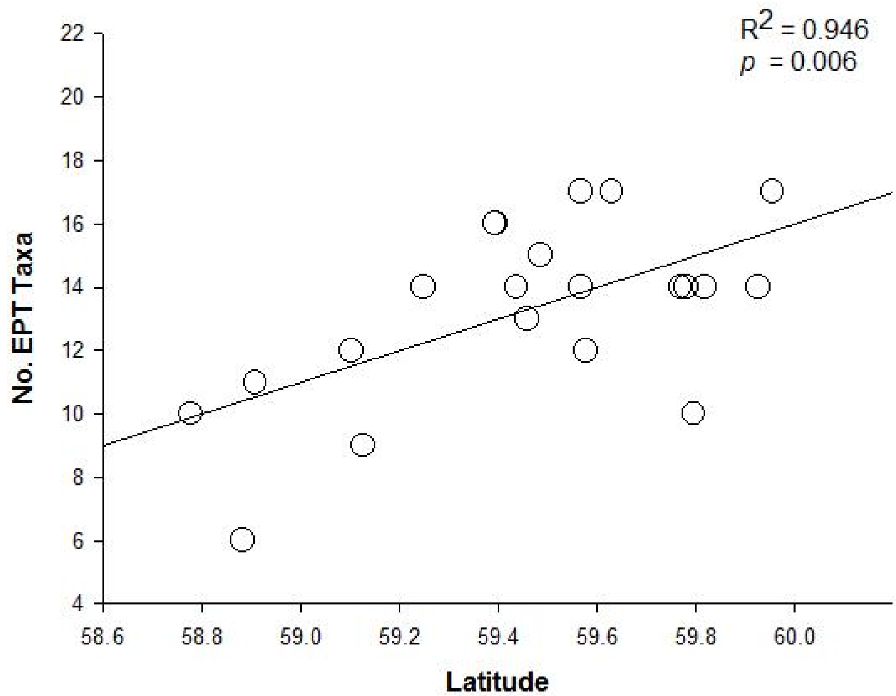


Figure 10. Relationship between the EPT taxa richness and latitude at both reference and 2012 test sites.

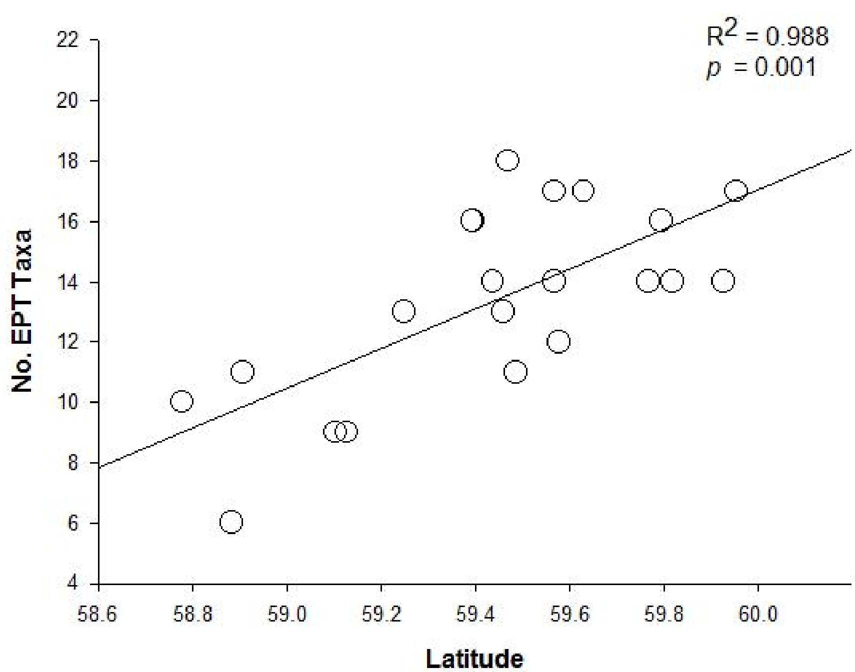


Figure 11. Relationship between the EPT taxa richness and latitude at both reference and 2013 test sites.

Table 6. Analysis of Covariance (ANCOVA) results comparing benthic macroinvertebrate metrics between site types and relationships with habitat parameters.

Benthic Macroinvertebrate Metric	Transformation Required	Mean[1] (SD) for Reference Sites (n = 15)	Mean[1] (SD) for Test Sites (n = 6)	Site Type Significance[2]	Habitat Parameters Significance[3]			
Analyses Using 2012 Test Sites								
Total Abundance	Square root transformation	1138.30 (739.99)	4451.96 (3248.02)	**$p = 0.002$**	No significant habitat parameters			
Taxa Richness	-	23.17 (4.26)	24.33 (3.27)	$p = 0.556$	No significant habitat parameters			
EPT Richness	-	13.53 (3.18)	12.67 (1.97)	$p = 0.750$	**Latitude**	**$\beta = 4.941$**	**$R^2 = 0.946$**	**$p = 0.006$**
% Dominant Taxa	-	24.33 (7.02)	32.26 (9.87)	$p = 0.051$	No significant habitat parameters			
% EPT Individuals	-	66.91 (11.92)	44.97 (11.13)	**$p = 0.001$**	**Latitude**	**$\beta = 19.202$**	**$R^2 = 0.293$**	**$p = 0.008$**
% Ephemeroptera	Square root transformation	29.11 (17.27)	16.52 (7.67)	$p = 0.113$	No significant habitat parameters			
% Plecoptera	Square root transformation	15.80 (9.18)	4.82 (6.69)	**$p = 0.002$**	No significant habitat parameters			
% Trichoptera	-	22.00 (12.04)	23.62 (16.60)	$p = 0.500$	**Latitude**	**$\beta = 21.948$**	**$R^2 = 0.990$**	**$p = 0.008$**
% Diptera and Non-Insects	-	29.49 (13.27)	43.75 (8.78)	**$p = 0.024$**	**Latitude**	**$\beta = -20.40$**	**$R^2 = 0.526$**	**$p = 0.007$**
% Chironomidae	-	13.38 (8.32)	29.89 (13.52)	**$p = 0.003$**	No significant habitat parameters			
Hilsenhoff Family-level Biotic Index	Log_{10} transformation	3.68 (0.65)	4.50 (0.36)	**$p = 0.006$**	No significant habitat parameters			
Shannon-Wiener Diversity Index	-	2.43 (0.21)	2.25 (0.24)	$p = 0.116$	No significant habitat parameters			

Benthic Macroinvertebrate Metric	Transformation Required	Mean[1] (SD) for Reference Sites (n = 15)	Mean[1] (SD) for Test Sites (n = 6)	Site Type Significance[2]	Habitat Parameter Significance[3]			
Analyses Using 2013 Test Sites								
Total Abundance	Square root transformation	1138.30 (739.99)	2293.05 (1544.64)	**$p = 0.031$**	No significant habitat parameters			
Taxa Richness	-	23.17 (4.26)	23.50 (3.67)	$p = 0.252$	**Latitude**	**$\beta = 6.331$**	**$R^2 = 0.428$**	**$p = 0.005$**
					Longitude	**$\beta = 2.175$**	**$R^2 = 0.327$**	**$p = 0.012$**
EPT Richness	-	13.53 (3.18)	13.00 (3.41)	$p = 0.687$	**Latitude**	**$\beta = 6.742$**	**$R^2 = 0.988$**	**$p = 0.001$**
% Dominant Taxa	-	24.33 (7.02)	36.00 (10.01)	**$p = 0.007$**	No significant habitat parameters			
% EPT Individuals	-	66.91 (11.92)	45.28 (13.20)	**$p = 0.002$**	**Latitude**	**$\beta = 19.967$**	**$R^2 = 0.300$**	**$p = 0.012$**
% Ephemeroptera	Square root transformation	29.11 (17.27)	22.13 (13.31)	$p = 0.394$	No significant habitat parameters			
% Plecoptera	Square root transformation	15.80 (9.18)	5.76 (3.27)	**$p = 0.005$**	No significant habitat parameters			
% Trichoptera	-	22.00 (12.04)	17.39 (11.09)	$p = 0.485$	**% Boulder**	**$\beta = 0.764$**	**$R^2 = 0.511$**	**$p = 0.008$**
					Altitude	**$\beta = 0.022$**	**$R^2 = 0.488$**	**$p = 0.009$**
% Diptera and Non-Insects	-	29.49 (13.27)	47.60 (10.68)	**$p = 0.010$**	**Latitude**	**$\beta = -22.576$**	**$R^2 = 0.439$**	**$p = 0.005$**
% Chironomidae	-	13.38 (8.32)	34.06 (12.9)	**$p < 0.001$**	No significant habitat parameters			
Hilsenhoff Family-level Biotic Index	Log_{10} transformation	3.68 (0.65)	4.66 (0.26)	**$p = 0.002$**	No significant habitat parameters			
Shannon-Wiener Diversity Index	-	2.43 (0.21)	2.18 (0.27)	**$p = 0.039$**	No significant habitat parameters			

[1] Values presented are the untransformed mean metric for each site type with the standard deviation in parentheses.

[2] Significant *p*-values ($p < 0.05$) indicating a relationship between the metric and site type or habitat parameters are in **bold.**

[3] β = the slope of the regression line when examining the relationship between the metric and habitat predictor variable. Positive (+) β-values indicate positive relationships and negative (-) β-values indicate negative relationships. R^2 indicates how well the observations fit the model of the relationship between the metrics and habitat parameters. Values closer to 1 indicate a stronger model to support the relationships observed.

3.2 Temporal Variation in Metrics at Test Sites

We found no significant differences in any of the measured metrics between the two years of sampling at test sites (all $p < 0.100$, Table 7), indicating no temporal differences in metrics at test sites between 2012 and 2013.

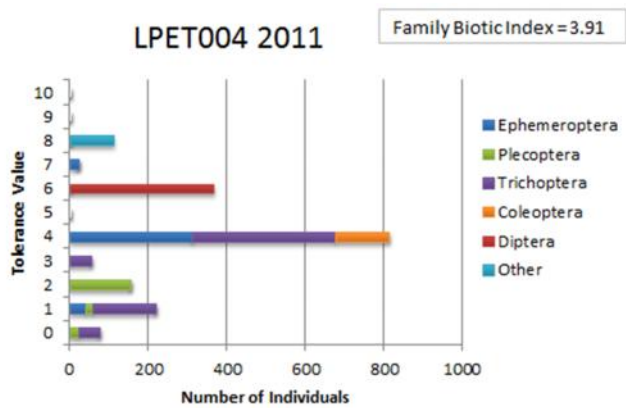
Table 7. Paired t-test results comparing test sites in 2012 and 2013 to determine if there are temporal changes in metrics within test sites. Values presented are the untransformed mean of the metric with the standard deviation in parentheses.

Benthic Macroinvertebrate Metric	Mean in 2012	Mean in 2013	T-statistic	p-value
Total Abundance	4385.26 (3626.79)	2451.72 (1671.40)	0.762	0.489
Taxa Richness	24.20 (3.63)	22.20 (2.05)	1.136	0.319
EPT Richness	12.40 (2.07)	12.00 (2.65)	0.229	0.830
% Dominant Taxa	31.07 (10.55)	38.68 (8.46)	-1.421	0.228
% EPT Individuals	45.84 (12.22)	42.33 (12.36)	0.912	0.413
% Ephemeroptera	16.07 (8.48)	23.19 (14.59)	-0.887	0.425
% Plecoptera	5.37 (7.33)	5.70 (3.64)	-0.822	0.457
% Trichoptera	24.40 (18.43)	13.45 (6.09)	1.580	0.189
% Coleoptera	9.44 (5.98)	6.99 (6.11)	0.679	0.535
% Diptera and Non-Insects	43.90 (9.81)	50.57 (8.75)	-1.359	0.246
% Chironomidae	28.23 (14.41)	36.35 (12.99)	-1.538	0.199
Hilsenhoff Family-level Biotic Index	4.46 (0.38)	4.74 (0.17)	-2.133	0.100
Shannon-Wiener Diversity Index	2.28 (0.26)	2.14 (0.28)	0.929	0.405

3.3 Pollution Tolerance Values and the FBI

In the Lower Petitot River Watershed, the FBI for reference site LPET004 on d'Easum Creek in 2011 indicated very good water quality and there appeared to be a high proportion of pollution sensitive taxa relative to pollution tolerant taxa. The FBI for the d'Easum Creek test site indicated very good water quality in 2012 and good water quality in 2013. The proportion of more pollution tolerant Diptera taxa (red bar) was high at the d'Easum Creek test sites for both years (Table 3; Figure 12).

Reference Site



Test Site

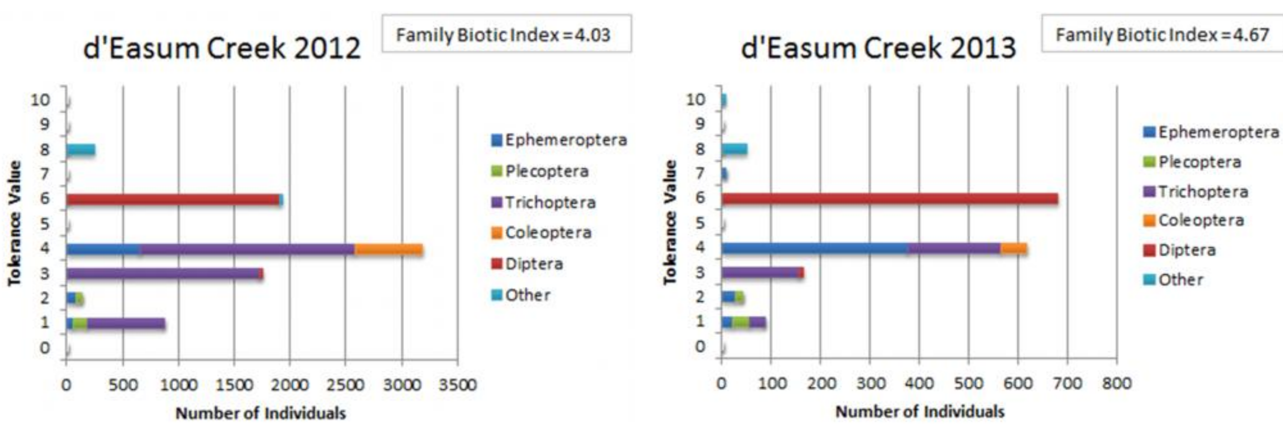
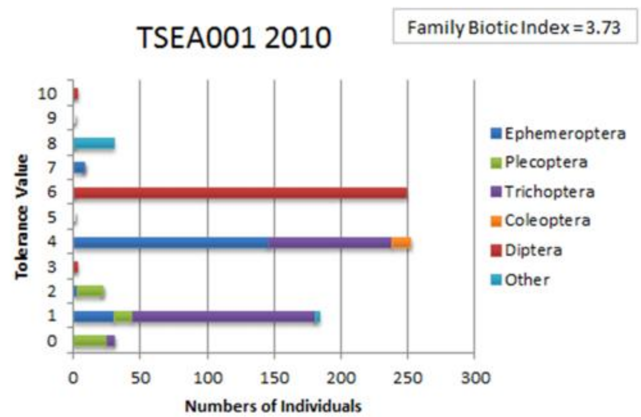


Figure 12. Tolerance value graphs for sites located in the Lower Petitot River watershed on d'Easum Creek. d'Easum Creek is a direct tributary to the Petitot River.

In the Tsea River watershed, the FBI for reference site TSEA001 on the Tsea River in 2010 indicated excellent water quality and a moderately high proportion of pollution sensitive taxa relative to pollution tolerant taxa. In 2013, the FBI for the Tsea River test site indicated very good water quality and the proportion of pollution sensitive taxa was lower at the Tsea River test site in 2013, particularly for taxa with a tolerance value of 0 or 1 (Table 3; Figure 13).

Reference Site



Test Site

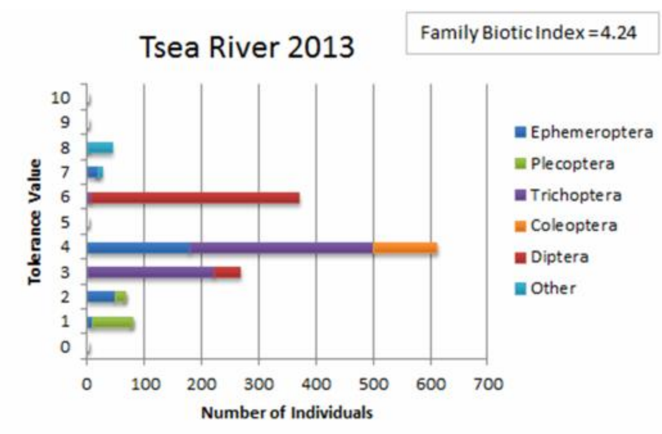
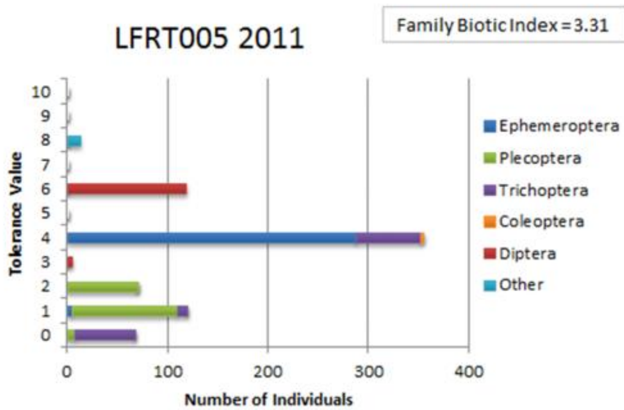


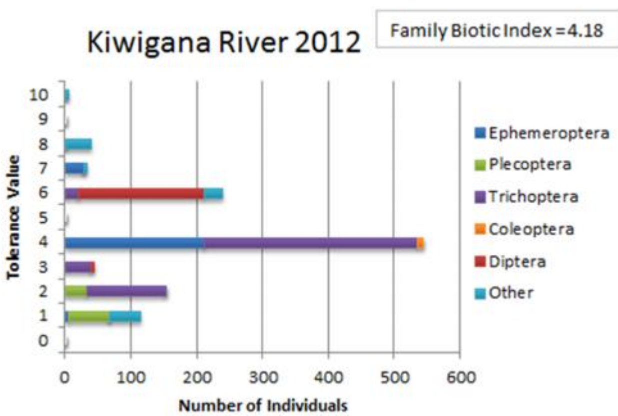
Figure 13. Tolerance value graphs for sites located in the Tsea River watershed on the Tsea River. The Tsea River is a direct tributary of the Petitot River.

In the Lower Fort Nelson River Watershed, the FBI for reference site LFRT005 on the Kiwigana River in 2011 indicated excellent water quality and there was a high proportion of pollution sensitive taxa relative to pollution tolerant taxa. The FBI for the Kiwigana River test site indicated very good water quality in 2012 and good water quality in 2013. The proportion of pollution tolerant taxa was high at the Kiwigana River test for both years, particularly in 2013 (Table 3; Figure 14).

Reference Site



Test Site



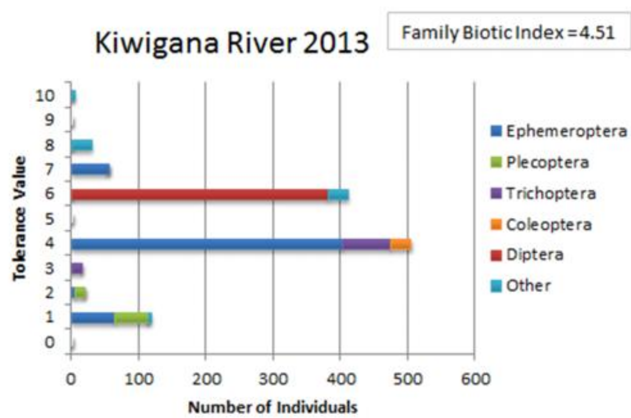
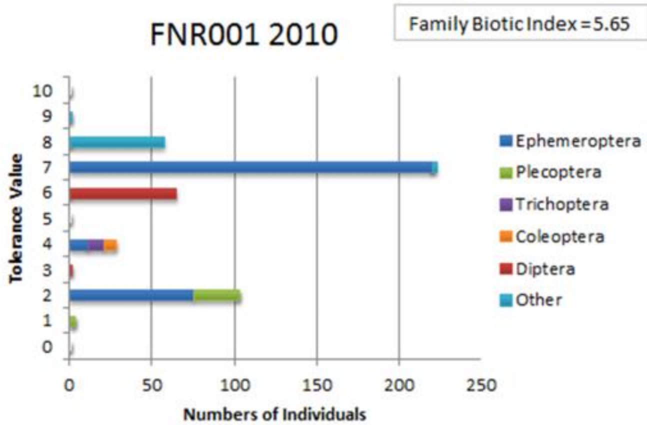


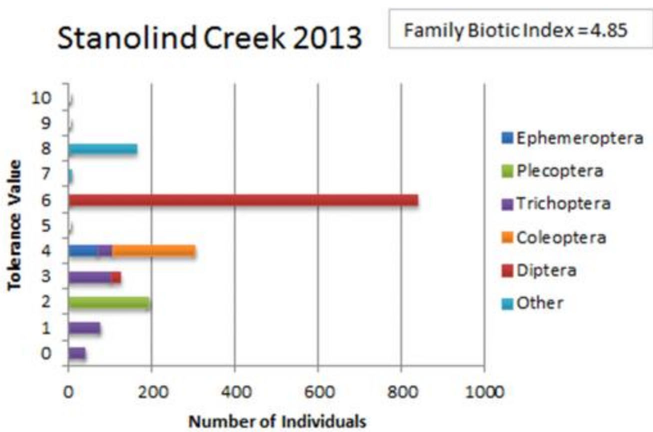
Figure 14. Tolerance value graphs for sites located in the Lower Fort Nelson River watershed on the Kiwigana River. The Kiwigana River is a direct tributary to the Fort Nelson River.

In the Middle Fort Nelson River Watershed, the FBI for reference site FNR001 on Tsimeh Creek in 2010 indicated fair water quality and the proportion of pollution tolerant taxa relative to pollution sensitive taxa appeared to be high. The most dominant pollution tolerant taxa were from order Ephemeroptera (i.e., Caenidae), not order Diptera. In 2012 and 2013, the FBI for the Stanolind Creek test site indicated good water quality and there appears to be a high proportion of pollution tolerant taxa relative to pollution sensitive taxa (Table 3; Figure 15).

Reference Site



Test Site



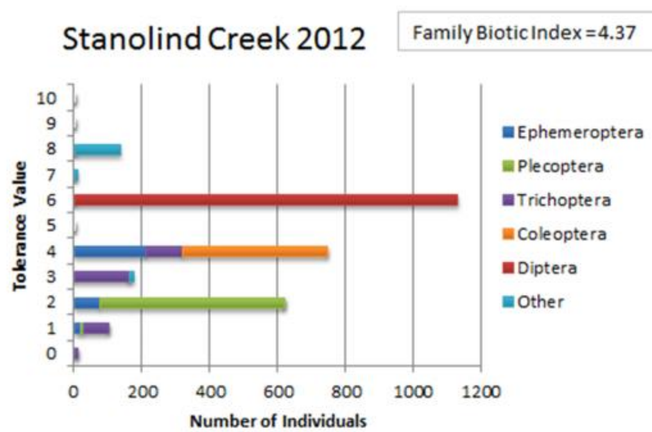


Figure 15. **Tolerance value graphs for sites located in the Middle Fort Nelson River watershed. Reference site FNR001 is located on Tsimeh Creek. Tsimeh Creek and Stanolind Creek are direct tributaries to the Fort Nelson River.**

In the Sahtaneh River Watershed, the FBI for the Sahtaneh River test site in 2012 and 2013 indicated good water quality and the proportion of pollution tolerant taxa is high relative to pollution sensitive taxa, and Diptera is by far the most dominant taxa collected in the 2012 and 2013 kick samples (Table 3; Figure 16).

<u>Test Site</u>

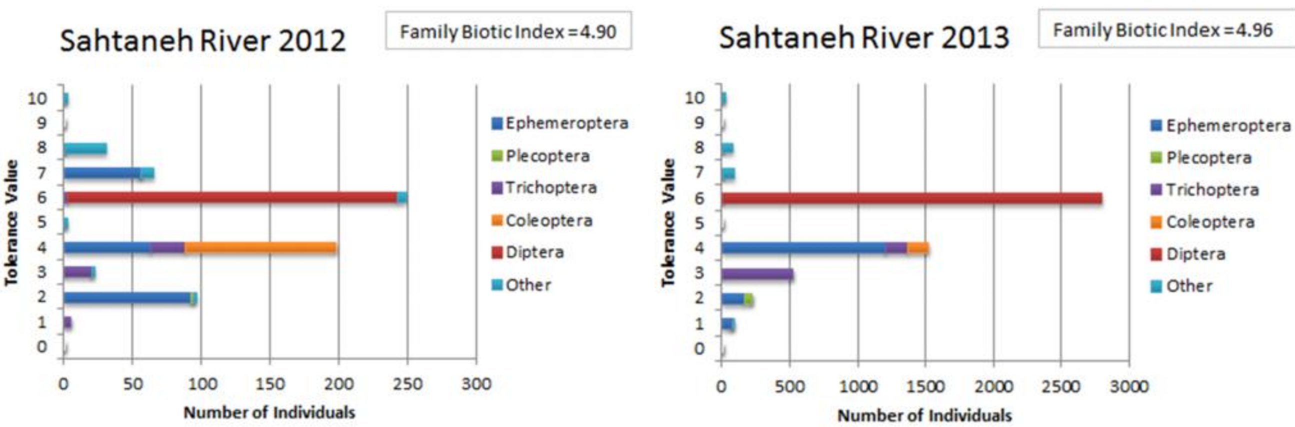


Figure 16. Tolerance value graphs for sites located in the Sahtaneh River watershed. There are no reference sites in the Sahtaneh River watershed.

4 DISCUSSION

4.1 Variation in Benthic Metrics between Site Types and Influence of Habitat

Based on the metrics that we analyzed, the results of the statistical analyses suggest that there is a difference in the aquatic benthic communities between reference sites and test sites. The proportion of EPT individuals (Figure 3) and Plecoptera individuals, both groups that are generally considered pollution sensitive, were significantly lower at test sites. Although we found that reference sites had a lower abundance of macroinvertebrates overall (Figure 2), and lower abundance can indicate environmental stress and lowered aquatic health, the proportion of Diptera and non-insects (Figure 6), and the Dipteran family Chironomidae, both generally considered more pollution tolerant, were significantly higher at test sites. Furthermore, the dominant taxa made up a higher proportion of the benthic assemblage at test sites (Figure 9), which may indicate community imbalance, enrichment, or environmental stress (Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013).

We found that the Shannon-Wiener Diversity Index was significantly lower at test sites in 2013 (i.e. less diverse) compared to reference sites. The Shannon-Weiner Diversity Index is the most commonly used diversity index and considers both richness and evenness of the benthic community structure (Rosenberg and Resh 1993; Environment Canada 2013). It is generally understood that as water quality decreases, so does species diversity; as such, the lower Shannon-Wiener Diversity Index suggests lower species diversity at test sites in 2013. Although this relationship was not significant when examining test sites in 2012, the direction of the relationship was the same (Figure 8). We also found that the FBI was significantly higher at test sites (Figure 7), with higher values indicating higher proportions of more pollution tolerant taxa in the benthic assemblage.

Together these results suggest that water quality may be degraded at test sites and higher amounts of pollution may be present in the aquatic environment. The reason for these observed differences in pollution tolerant and pollution sensitive taxa between reference and test sites may be related to environmental factors within their watersheds including forest clearing and linear developments which can alter the aquatic environment. Pollution potentially caused by these land use activities includes increased sedimentation, increased chemical or contaminant loading, lowered dissolved oxygen levels and increased nutrient enrichment which influence biotic assemblages (Hilsenhoff 1987, Rosenberg and Resh 1993; NCSU 2014). Continued data collection would be required to determine if there is a trend of decreasing or increasing stress on these aquatic environments compared to the baseline condition developed through this project.

Our study design did not allow for direct comparison of reference sites to test sites on the same reach, which may have indicated point sources of pollution potentially impacting test sites. As such, we cannot be certain that test sites are being impacted at this time, only that the data suggest that there is a difference in the aquatic environment at the two site types during the baseline phase of biomonitoring. Furthermore, because sites were selected and sampled using the RCA design, our reference sites and test sites were not sampled in the same years. Therefore we caution that the significant differences we observed between site types should also consider the influence that natural yearly environmental variability may have on the results.

We found that various habitat parameters seemed to influence the metrics we analyzed. For instance, the proportion of Trichoptera individuals appeared to increase with the proportion of boulders in the substrate complex and the altitude of the sample site. These relationships were only observed for analyses that included 2013 test site data. Increased boulder coverage could create more habitat for Trichoptera individuals, which are aquatic during the immature stages of their lifecycles and typically construct a case before pupation that they fasten to the underside of a large rock or log (Merritt and Cummins 1996). The increased proportion of Trichoptera with increasing altitude is less understood and more data should be collected before inferences are made (Table 6).

In addition, the geographic location of the reference sites and test sites appeared to significantly influence several of the metrics we analyzed (Table 6). Our results suggest that reference sites and test sites located further north in the HRB generally had more EPT taxa, a higher proportion of EPT individuals, and a lower proportion of Diptera and non-insects compared to sites located further south (Figures 4, 5, 10 and 11). For analyses including 2012 test sites, the results suggest that sites located further north in the HRB had a greater proportion of Trichoptera individuals compared to sites located further south, while sites located further northwest in the HRB had higher taxa richness compared to sites located further southeast (Table 6). Exploring potential reasons for this geographical gradient across the HRB is outside the scope of this technical report; however, if we were to speculate as to why our results suggest that sites located further south or southeast in the HRB may have degraded water quality, the higher amount of industrial activity in the southern region of the HRB around Fort Nelson, BC may be a contributing factor. However, our small sample size, especially in the southern portion of the HRB and other physical geographic differences may have contributed to this result. Regardless, even with this observed latitudinal gradient across the HRB, we still found differences in metrics between reference sites and test sites after excluding the variation attributed to latitude, which increases confidence in our results that the benthic community differs between site types.

4.2 Pollution Tolerance Values in Relation to the Family-level Biotic Index

Examining a biotic index such as the FBI and having an understanding of the pollution tolerance values for each family of macroinvertebrate represented in a benthic assemblage can add additional insight when attempting to determine the health of an aquatic environment. Generally, EPT taxa are considered sensitive to pollution and Diptera taxa are considered more tolerant to pollution (Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013). However, some EPT taxa can tolerate elevated levels of pollution while some Diptera taxa cannot (Barbour et al. 1999).

The pollution tolerance value graphs (Figures 12 - 16) visually display the proportion of each macroinvertebrate order by tolerance value at each reference site and test site in the HRB. Reference sites and test sites were grouped based on inclusion within the same BC Watershed Atlas group to account for some of the natural variability found among sites in the HRB. The general trends in the tolerance value graphs indicate that a higher proportion of more pollution tolerant taxa (i.e., Diptera taxa) and a lower proportion of pollution sensitive taxa (i.e., EPT taxa) were found at test sites compared to reference sites, suggesting that water quality may be lower at test sites.. These results are consistent with the results of the statistical analyses (see Section 4.1). When we visually examine the tolerance graphs, a notable observation is that extremely pollution sensitive taxa, with a pollution tolerance value of zero, are almost completely lacking at test sites. It is only the Middle Fort Nelson River watershed (Figure 15) that has zero tolerance taxa present at the test sites. In contrast to the majority of test sites, these extremely pollution sensitive taxa are present for the majority of reference sites (Figures 12 – 14, 16). Since it is the increased presence of more pollution sensitive taxa coupled with the absence or decreased presence of pollution sensitive taxa that may indicate impairment to an aquatic environment (Zimmerman 1993), this may suggest water quality is generally lower at test sites. When the tolerance value graphs for reference site and test sites in the Middle Fort Nelson River watershed were visually compared, the majority of the more pollution tolerant taxa at the reference site (i.e., FNR001) were from the order Ephemeroptera, not Diptera; which was unique among the reference sites (Figure 15). Furthermore, the FBI value for this reference site was higher than the FBI values calculated for all other reference sites in the HRB. These results suggest that the aquatic environment at this reference site, which is located in the southern portion of the HRB, may be different compared to all other reference sites in the HRB, which indicates that there is natural variability among reference sites in the HRB. If this is the case, it may not be appropriate to compare the benthic community at the Stanolind Creek test site to the benthic community at this reference site because the aquatic environment is not comparable between the two sites. There are very few reference sites established in the southern portion of the HRB, therefore to account for the natural variability we have observed among reference sites, more reference sites should be established within the HRB, particularly in the southern region if possible.

5 RECOMMENDATIONS

Outlined below are some potential recommendations for the current biomonitoring program that will help build capacity and relations with the Fort Nelson and Fort Liard First Nations. We also provide suggestions to refine the data collection and analysis procedures until a CABIN reference model is available for the region.

1) Continue the biomonitoring program with involvement from the Fort Nelson and Fort Liard First Nations to strengthen relations with First Nations, build further First Nations capacity in water management, and collect additional aquatic habitat and benthic macroinvertebrate data that can contribute to the development of a CABIN reference model. The Fort Nelson and Fort Liard First Nations have participated in the surface water monitoring component of the Project since it was initiated in 2008 and both First Nations groups have continued collecting field data for the water quality hydrometric study aspect of the Project. Therefore we suggest:

- Utilizing individuals that were certified at the CABIN Field Technician level at the beginning of the biomonitoring program in 2011 from the Fort Nelson and Fort Liard First Nations to continue field data collection in the HRB and data entry into the online CABIN database.

- Provide opportunities for more individuals from the Fort Nelson and Fort Liard First Nations to become CABIN certified at the Field Technician level to build further First Nations capacity in water management.

2) Until the CABIN reference model for the region is complete, we suggest the following refinements to the current biomonitoring program which will improve data collected for future analyses. We realize that all of these recommendations may not be feasible; however, consideration for these refinements will improve upon future analyses to better our understanding of the aquatic environment in the HRB.

- In addition to any new reference or test sites established, it is a priority to complete benthic sampling at the same reference sites and test sites each year to allow for better comparison of results between site types and among years.

- All test sites should have a reference site associated with them, preferably on the same river or stream. Having established reference sites in the HRB, we realize this can be difficult to achieve due to the limited occurrence of suitable reference stream reaches. The landscape is heavily influenced by beaver activity making it difficult to find riffles and suitable wadeable reaches. In 2011 many reaches that met the criteria of reference locations based on GIS analysis were completely dry at the time of sampling rendering them unsuitable. If a reference site cannot be located on the same river or stream as a test site, we suggest that expert opinion be used to select an alternate reference site on either (1) a direct tributary to the main watercourse the test site is on, or (2) another tributary within the same watershed the test site is in. In either scenario, the aquatic environment at the reference site must be representative of baseline conditions in the HRB. This consideration is important for pairwise comparison between test and reference sites and not necessarily pertinent to contribution of reference sites to the CABIN model.

- In addition to the habitat data required for the CABIN reference model, consider collecting more detailed habitat information that can be used to examine relationships between habitat parameters and benthic data to further control for the influence of habitat on the benthic community. Habitat parameters related to the proportion of vegetative coverage or other stream substrate or soil information may be informative. CABIN protocol was followed in this study which calls for categorical data, whereas if data were collected as continuous variables it would provide more effectiveness for future assessments until the CABIN reference model is complete.

Furthermore, we want to stress the importance and value of completing and contributing to a CABIN reference model in the region. Once the CABIN reference model is complete, test sites within the HRB can be evaluated against the "reference condition" to determine if the test sites are impaired and the degree of impairment. This will provide a cost effective and defendable tool for the HRBPG to monitor water quality in the HRB. There are several advantages to contributing to the development of a CABIN reference model for this area. For example, other industry partners or not-for-profit organizations could also be contributing to the development of the reference model, further expanding reference site coverage. In addition, the reference model can be refined and recalibrated after it is initially completed as new reference sites are sampled and the data is incorporated into the reference model (Environment Canada 2013).

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APPENDIX A. DATA TABLES

Table 8. Benthic macroinvertebrate metrics for reference sites.

Reference Site	Year Sample Collected	Watercourse Name	BC Watershed Atlas Group	Benthic Macroinvertebrate Metrics													
				Total Abundance	Taxa Richness	EPT Richness	% Dominant Taxa	% EPT Individuals	% Ephemeroptera	% Plecoptera	% Trichoptera	% Diptera and Non-insects	% Chironomidae	Hilsenhoff Family-level Biotic Index (FBI)	Equivalent FBI Water Quality Rating	Shannon-Weiner Diversity Index
UPET002	2011	Petitot River	Upper Petitot River	2,017	28	17	18.37	60.93	24.78	8.45	27.70	23.03	18.37	4.01	Very good	2.72
LPET004	2011	d'Easum Creek	Lower Petitot River	1,835	22	14	19.55	66.03	20.51	10.58	34.94	19.87	19.55	3.91	Very good	2.44
HRB01	2011	Unnamed tributary	Lower Petitot River	942	23	14	30.45	74.86	2.51	40.23	32.12	25.14	6.42	2.67	Excellent	2.28
HRB02	2011	Emile Creek	Lower Petitot River	1,894	26	17	28.26	82.61	65.22	9.32	8.07	16.46	9.32	3.51	Excellent	2.35
HRB03	2011	Fortune Creek	Lower Petitot River	837	27	14	18.56	72.01	19.81	24.53	27.67	19.49	4.09	3.36	Excellent	2.68
TSEA001	2010	Tsea River	Tsea River	819	29	17	23.11	60.06	22.77	6.93	30.36	31.03	23.11	3.73	Excellent	2.64
TSEA002*	2010	Unnamed tributary	Tsea River	820	21	12	18.57	67.19	28.07	20.07	19.05	28.26	13.06	3.68	Excellent	2.43
HRB05*	2011	Gote Creek	Tsea River	2,357	24	14	25.15	60.30	25.45	8.79	26.06	36.36	25.15	3.72	Excellent	2.33
LFRT002	2011	Delkpay Creek	Lower Fort Nelson River	1,319	23	14	25.37	77.55	28.86	11.08	37.61	7.87	7.58	3.08	Excellent	2.38
LFRT003	2011	Kiwigana River	Lower Fort Nelson River	2,100	25	16	17.14	63.49	14.60	11.75	37.14	21.59	17.14	3.67	Excellent	2.65
LFRT005	2011	Kiwigana River	Lower Fort Nelson River	755	22	13	24.17	80.79	38.74	24.17	17.88	16.23	6.62	3.31	Excellent	2.46
HRB04	2011	Klenteh Creek	Lower Fort Nelson River	795	26	16	21.07	76.73	44.65	16.04	16.04	19.50	3.77	3.86	Very good	2.54
FNR001	2010	Tsimeh Creek	Middle Fort Nelson River	484	22	9	45.45	71.69	63.22	6.40	2.07	13.43	1.03	5.65	Fair	1.92
MUSK001	2010	Akue Creek	Lower Muskwa River	77	18	10	24.68	51.95	20.78	22.08	9.09	36.36	24.68	3.58	Excellent	2.39
MUSK002	2010	Kledo Creek	Lower Muskwa River	24	12	6	25.00	37.50	16.67	16.67	4.17	33.33	20.83	3.38	Excellent	2.20
			Mean (Standard Deviation)	**1,138 (740)**	**23 (4)**	**14 (3)**	**24.33 (7.02)**	**66.91 (11.92)**	**29.11 (17.27)**	**15.80 (9.18)**	**22.00 (12.04)**	**29.49 (13.27)**	**13.38 (8.32)**	**3.68 (0.65)**	-	**2.43 (0.21)**

*Duplicate samples were collected at reference sites TSEA002 and HRB05. Value presented for TSEA002 is the mean of the two samples. The value presented for HRB005 is the original sample as the duplicate sample for HRB05 was an extreme outlier and was removed from the data set.

Table 9. Benthic macroinvertebrate metrics for test sites.

Test Site	BC Watershed Atlas Group	Benthic Macroinvertebrate Metrics												
		Total Abundance	Taxa Richness	EPT Richness	% Dominant Taxa	% EPT Individuals	% Ephemeroptera	% Plecoptera	% Trichoptera	% Diptera and Non-insects	% Chironomidae	Hilsenhoff Family-level Biotic Index (FBI)	Equivalent FBI Water Quality Rating	Shannon-Weiner Diversity Index
d'Easum Creek 2012	Lower Petitot River	8,150	19	10	22.39	65.03	9.51	2.15	53.37	27.61	22.39	4.03	Very good	2.20
d'Easum Creek 2013	Lower Petitot River	1,670	24	16	36.53	51.80	25.45	2.99	23.35	45.21	36.53	4.67	Good	2.20
Dilly Creek 2012	Lower Petitot River	4,786	25	14	38.21	40.60	18.81	2.09	19.70	42.98	38.21	4.72	Good	2.12
Tsea River 2013	Tsea River	1,500	30	18	22.61	60.00	16.81	6.09	37.10	32.75	22.61	4.24	Very good	2.43
Delkpay Creek 2012	Lower Fort Nelson River	8,340	26	15	47.24	36.21	16.07	0.72	19.42	54.20	47.24	4.80	Good	2.01
Delkpay Creek 2013	Lower Fort Nelson River	2,186	22	11	39.22	33.99	16.67	6.86	10.46	50.00	39.22	4.72	Good	2.18
Kiwigana River 2012	Lower Fort Nelson River	1,643	28	14	23.19	51.01	14.78	5.80	30.44	45.51	8.98	4.18	Very good	2.67
Kiwigana River 2013	Lower Fort Nelson River	1,207	24	13	26.69	57.67	43.56	7.05	7.05	39.57	15.03	4.51	Good	2.44
Stanolind Creek 2012	Middle Fort Nelson River	3,100	22	12	36.07	39.00	9.68	17.89	11.44	46.92	36.07	4.37	Good	2.12
Stanolind Creek 2013	Middle Fort Nelson River	1,821	19	9	40.75	27.74	3.76	10.40	13.58	61.56	40.75	4.85	Good	2.17
Sahtaneh River 2012	Sahtaneh River	694	26	11	26.47	37.94	30.30	0.29	7.35	45.29	26.47	4.90	Good	2.40
Sahtaneh River 2013	Sahtaneh River	5,375	22	11	50.23	40.47	26.51	1.16	12.79	56.51	50.23	4.96	Good	1.68
Mean (Standard Deviation)		**3,373 (2,674)**	**24 (3)**	**13 (3)**	**34.13 (9.68)**	**45.12 (11.64)**	**19.33 (10.76)**	**5.29 (5.04)**	**20.50 (13.85)**	**45.68 (9.54)**	**31.98 (12.78)**	**4.58 (0.31)**	-	**2.22 (0.25)**

Table 10. Habitat parameters for reference sites.

Reference Site	Year Sample Collected	Watercourse Name	BC Watershed Atlas Group	Habitat Parameters														
				Substrate Characteristics				Channel Characteristics			Water Quality Characteristics				Geographical Characteristics			
				% Boulder	% Cobble	% Gravel	% Pebble	Average Depth (cm)	Average Velocity (m/s)	Bankfull Width (m)	Conductivity (µS/cm)	Temperature (°C)	pH	Turbidity (NTU)	Latitude	Longitude	Slope (m/m)	Altitude (ft)
UPET002	2011	Petitot River	Upper Petitot River	3	61	2	34	39	0.97	98.0	209.0	10.9	8.1	15.60	59.5669	-120.2478	0.05	1505
LPET004	2011	d'Easum Creek	Lower Petitot River	28	59	2	11	22	0.45	23.7	226.0	13.7	8.3	3.91	59.8189	-123.1786	0.24	1414
HRB01	2011	Unnamed tributary	Lower Petitot River	12	56	3	29	17	0.27	50.0	106.4	7.8	5.3	21.00	59.7682	-122.6646	0.01	1607
HRB02	2011	Emile Creek	Lower Petitot River	6	50	0	44	32	0.39	29.5	183.0	8.2	-	-	59.9543	-122.8073	0.00	1246
HRB03	2011	Fortune Creek	Lower Petitot River	3	14	10	73	53	0.23	22.5	76.4	9.5	-	-	59.9254	-122.4303	0.00	1509
TSEA001	2010	Tsea River	Tsea River	-	-	-	-	-	1.22	53.0	143.0	7.5	7.6	16.40	59.6296	-121.3302	1.31	1355
TSEA002	2010	Unnamed tributary	Tsea River	0	18	11	71	-	1.31	12.0	144.0	7.5	7.7	14.00	59.5778	-121.4929	2.24	1551
HRB05	2011	Gote Creek	Tsea River	2	10	9	79	23	0.44	14.9	78.0	7.7	-	-	59.5669	-121.7951	-	1902
LFRT002	2011	Delkpay Creek	Lower Fort Nelson River	3	49	4	43	21	0.56	12.8	265.0	11.9	8.3	3.75	59.4367	-123.0950	0.50	1374
LFRT003	2011	Kiwigana River	Lower Fort Nelson River	29	55	1	15	27	1.04	30.2	239.0	13.1	7.9	5.63	59.3936	-122.9894	0.61	1328
LFRT005	2011	Kiwigana River	Lower Fort Nelson River	5	44	5	46	21	0.77	12.6	137.1	10.7	7.9	8.52	59.4597	-122.4792	0.20	1807

Reference Site	Year Sample Collected	Watercourse Name	BC Watershed Atlas Group	Habitat Parameters														
				Substrate Characteristics				Channel Characteristics			Water Quality Characteristics				Geographical Characteristics			
				% Boulder	% Cobble	% Gravel	% Pebble	Average Depth (cm)	Average Velocity (m/s)	Bankfull Width (m)	Conductivity (µS/cm)	Temperature (°C)	pH	Turbidity (NTU)	Latitude	Longitude	Slope (m/m)	Altitude (ft)
HRB04	2011	Klenteh Creek	Lower Fort Nelson River	1	25	9	65	35	0.15	14.8	269.9	7.9	-	-	59.3928	-122.9484	0.00	1378
FNR001	2010	Tsimeh Creek	Middle Fort Nelson River	0	3	27	70	47	0.54	5.1	194.0	8.5	7.5	9.90	59.1273	-122.9068	1.29	1171
MUSK001	2010	Akue Creek	Lower Muskwa River	0	20	19	61	34	1.35	40.0	153.0	8.0	7.7	464.60*	58.7782	-123.2225	1.29	1108
MUSK002	2010	Kledo Creek	Lower Muskwa River	3	75	4	18	27	0.90	19.2	135.0	6.7	7.8	7.50	58.8823	-123.8009	3.36	1486
			Mean (Standard Deviation)	**7 (10)**	**39 (23)**	**8 (8)**	**47 (23)**	**31 (11)**	**0.71 (0.40)**	**29.2 (23.7)**	**170.6 (62.4)**	**9.3 (2.2)**	**7.6 (0.8)**	**51.89 (136.99**	**59.4852 (0.3443)**	**-122.4926 (0.9147)**	**0.79 (1.01)**	**1,449 (215)**

Table 11. Habitat parameters for test sites.

Test Site and Year of Sampling	BC Watershed Atlas Group	Habitat Parameters															
		Substrate Characteristics				Channel Characteristics			Water Quality Characteristics				Geographical Characteristics				
		% Boulder	% Cobble	% Gravel	% Pebble	Average Depth (cm)	Average Velocity (m/s)	Bankfull Width (m)	Conductivity (µS/cm)	Temperature (°C)	pH	Turbidity (NTU)	Latitude	Longitude	Slope (m/m)	Altitude (ft)
d'Easum Creek 2012	Lower Petitot River	14	63	2	21	14	0.06	15.4	464.7	10.3	7.8	7.64	59.7958	-122.9869	0.89	1473
d'Easum Creek 2013	Lower Petitot River	6	70	0	24	27	0.67	11.2	250.0	7.2	6.5	3.71	59.7958	-122.9869	0.89	1473
Dilly Creek 2012	Lower Petitot River	12	66	0	22	13	0.05	30.6	368.5	13.8	7.9	5.32	59.7803	-121.9645	0.03	1460
Tsea River 2013	Tsea River	2	73	2	23	25	0.28	13.7	130.0	7.4	7.0	5.85	59.4689	-121.8303	0.07	2047
Delkpay Creek 2012	Lower Fort Nelson River	7	65	2	26	14	0.08	5.4	367.5	10.7	7.8	1.89	59.4852	-123.0594	0.01	1443
Delkpay Creek 2013	Lower Fort Nelson River	2	80	3	15	22	0.40	10.3	300.0	8.0	6.5	5.83	59.4852	-123.0594	0.01	1443
Kiwigana River 2012	Lower Fort Nelson River	8	72	1	19	12	0.18	40.6	620.7	14.7	8.2	8.38	59.2487	-123.1537	0.03	862
Kiwigana River 2013	Lower Fort Nelson River	0	16	6	78	30	0.43	50.0	340.0	8.5	6.5	28.00	59.2487	-123.1537	0.03	862
Stanolind Creek 2012	Middle Fort Nelson River	19	47	2	32	10	0.07	12.1	274.0	11.8	7.8	8.89	59.1028	-123.1411	0.57	1230
Stanolind Creek 2013	Middle Fort Nelson River	1	62	0	37	21	0.20	13.8	330.0	7.3	7.2	3.11	59.1028	-123.1411	0.57	1230
Sahtaneh River 2012	Sahtaneh River	13	45	1	41	9	0.01	9.6	489.5	12.5	7.8	1.16	58.9078	-121.7570	0.33	1660
Sahtaneh River 2013	Sahtaneh River	6	70	3	21	33	0.49	14.0	400.0	8.9	6.8	4.29	58.9078	-121.7570	0.33	1660
Mean (Standard Deviation)		**8 (6)**	**61 (17)**	**2 (2)**	**30 (17)**	**19 (8)**	**0.24 (0.21)**	**18.9 (13.9)**	**361.2 (126.0)**	**10.1 (2.6)**	**7.3 (0.6)**	**7.01 (7.04)**	**59.3608 (0.3255)**	**-122.6659 (0.6242)**	**0.31 (0.34)**	**1,404 (331)**

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consulting engineers

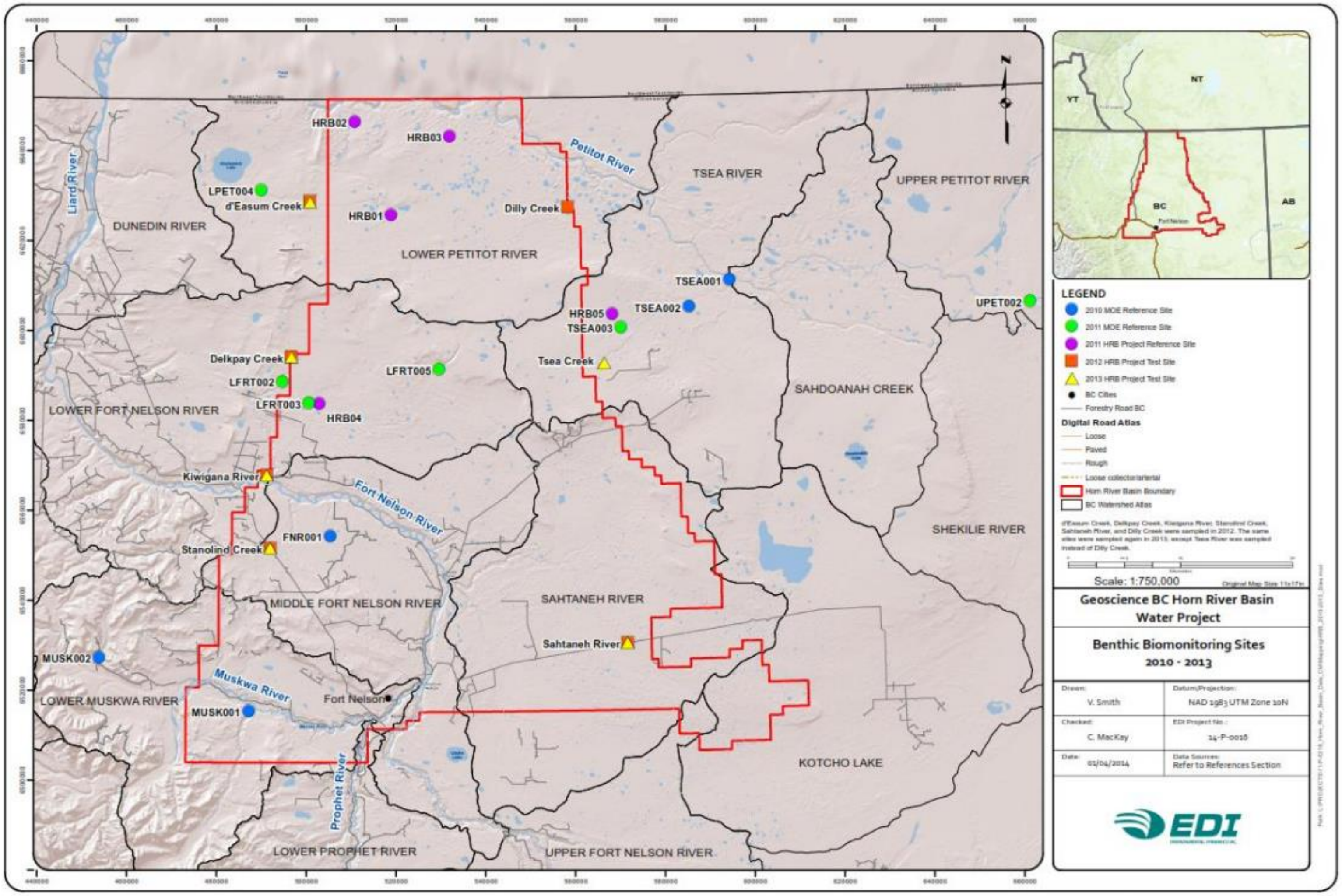
Horn River Basin
Surface Water Monitoring Project
2015 Study: Benthic Sampling Analysis

Kerr Wood Leidal Associates Ltd.
Chad Davey, M.Sc., R.P.Bio
June, 2015

Outline

- Introduction
- Objectives
- Method
- Results
- Next Steps

Horn River Basin Project Area



Introduction

- A benthic invertebrate monitoring program was conducted between 2010 and 2013 in the HRB area.
- The purpose of the program was to develop a aquatic health baseline of within the Horn River Basin area.
- Two types of benthic sites were selected for the baseline: areas minimally affected by human development (i.e. reference sites) and areas in close proximity to development (i.e. test sites).
- The key results of the benthic monitoring program include:
  - Reference sites are more species rich in benthic biota (i.e. greater number of species) than test sites;
  - Reference sites contain more pollution sensitive species of benthic invertebrates than test sites;
  - At test sites, the benthic community did not appear to change between the two sampling years.
- The results of the program show a divergence between benthic communities within test sites versus reference sites, however the reason for this divergence is not known.

Rationale and Project Objectives

Purpose:

- The main purpose of this GIS study is to investigate possible relationships between industrial development and the divergent benthic communities observed between test versus reference sites.

Project Objectives:

1. At the watershed scale, determine the density of industrial development (O&G, Forestry, Mining) within test watersheds versus reference watersheds;

2. At a local scale, qualitatively investigate differences in local habitat quality (canopy cover differences, disturbance/development in the vicinity of the sample site) at test sites versus reference sites; and

3. Identify relationships, if any, between the density of specific types of industrial activity within a watershed and indices of aquatic health using a regression analysis (ANOVA).

Methods

Approach:

- Obtain publically available spatial data on industrial activities.
- Organize, filter and sort data that is relevant to the study area and appropriate time frame.
- Conduct a desktop GIS exercise (ArcMap 10.2) to analyse acquired spatial data.

Methods: GIS Data Acquisition

Data Acquisition:

- Publically available data was obtained from:
  - Oil and Gas Commission (OGC)
  - Imap and Data BC
  - BC Water Resource Atlas
- Spatial data was collected for:
  - O&G activity (wells, waste disposal areas/wells, roads, water crossings, water withdrawals locations, pipelines ROW's and incidents, and seismic cuts.
  - Forestry (cut blocks, roads)
  - Mining (aggregate mines)
- Spatial data and various background reports were also supplied by EDI Environmental Dynamics Ltd.
- Imagery was obtained from Bing Maps and georeferenced into ArcGIS.

Methods Cont.

Data filtering

- In many cases, data sets from publically available sites were filtered and clipped to isolate the relevant spatial information for this project. Data that was not relevant to the project study area was deleted.

Problems encountered:

- Missing or incomplete metadata documents
- Data not current and/or lacks temporal information
- Data not publically available (i.e. current pipeline information)
- Poor visual quality of orthophotos and basemaps

Results- Watershed Scale (Objective #1)

Development		Test Watersheds			Reference Watersheds			Normalized by Watershed Area		
Major Activity	Activty Type	# of sites	Total Area (km2)	Total Length (km)	# of sites	Total Area (km2)	Total Length	Sites in Test Watersheds (#/km^2)	Sites in Reference Watersheds (#/km^2)	Percent Difference (Test : Reference)
Oil and Gas	Sumps	76	-	-	85	-	-	0.0211	0.0137	54
	Pipeline Incidents	17	-	-	14	-	-	0.0047	0.0023	109
	Section 8 Withdrawals	40	-	-	67	-	-	0.0111	0.0108	3
	Section 9 Withdrawals	103	-	-	227	-	-	0.0285	0.0366	-22
	Water Crossings	356	-	-	426	-	-	0.0987	0.0687	44
	Well Sites	328	12.5	-	394	9.7	-	0.0909	0.0635	43
	Pipline ROW	130	5.3	-	149	6.75	-	0.0360	0.0240	50
	Ancillary Sites	4386	62.9	-	4521	55.7	-	1.2156	0.7291	67
	Waste Disposal Sites	351	1.4	-	239	1.2	-	0.0973	0.0385	152
	Facility Sites	24	0.7	-	25	0.9	-	0.0067	0.0040	65
	Siesmic Lines (Post 2006)	31773	-	10923	20692	-	9989	8.8063	3.3369	164
	Siesmic Lines (Pre 2006)	5596	-	8614	3146	-	8893	1.5510	0.5073	206
	Development Roads	36	-	233	36	-	409	0.0100	0.0058	72
	Access Roads	1100	-	1000	1214	-	1284	0.3049	0.1958	56
Forestry	Cutblocks	45	15.3	-	11	2.8	-	0.0125	0.0018	603
	Roads	48	-	137.8	51	-	90	0.0133	0.0082	62
Mining	Aggregate mines	0	-	-	5	-	-	0.0000	0.0008	-

- When normalized by watershed area, O&G activity is more concentrated in test watersheds compared to reference watersheds.
- Forestry activity is 6 times more concentrated in test watersheds compared to reference watersheds.

Results - Local Scale (Objective #2)

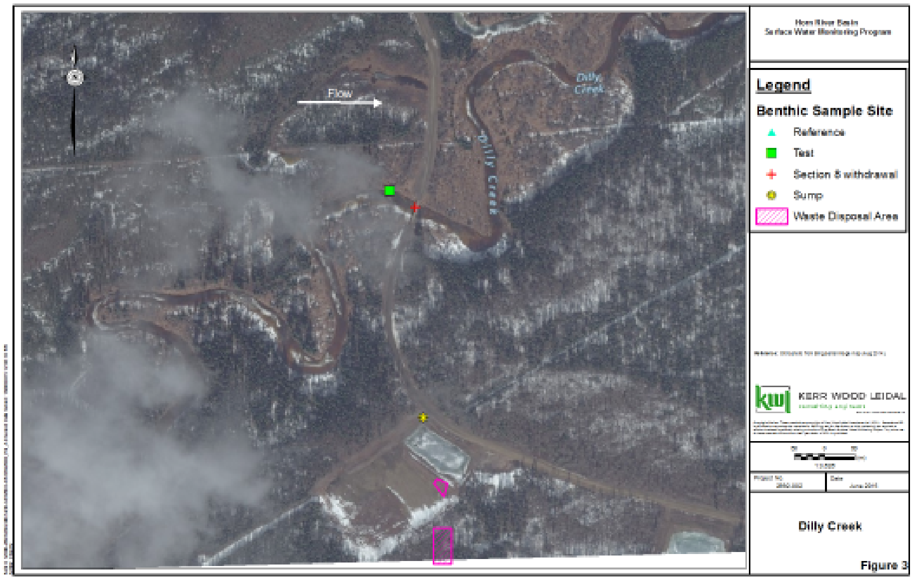
Test Sites

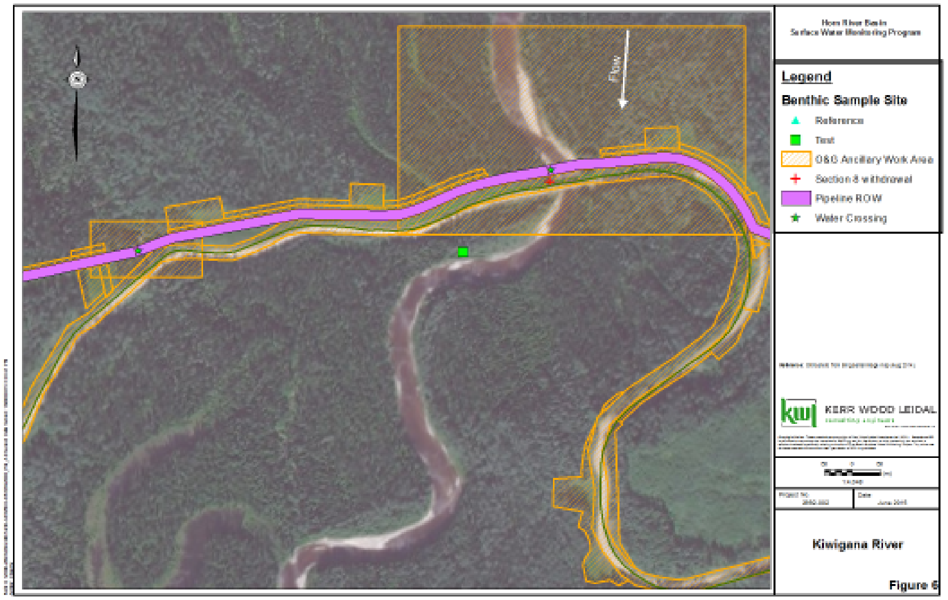
- Local scale images of tests sites show human development occurring in close proximity to the benthic samples sites.

Results - Local Scale (Objective #2)

Test Sites

- Local scale images of tests sites show human development occurring in close proximity to the benthic samples sites.

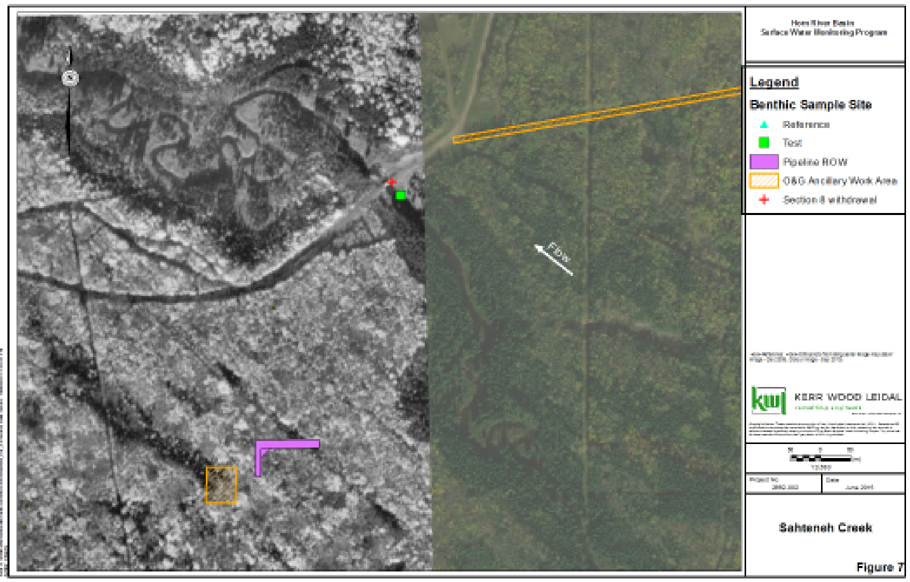


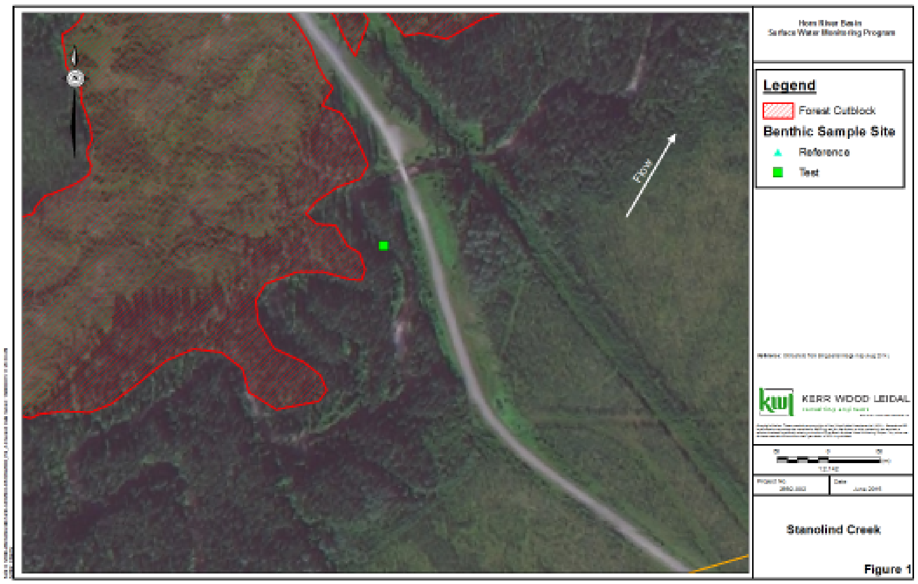


Results - Local Scale (Objective #2)

Test Sites

- Local scale images of tests sites show human development occurring in close proximity to the benthic samples sites.





Results - Local Scale (Objective #2)

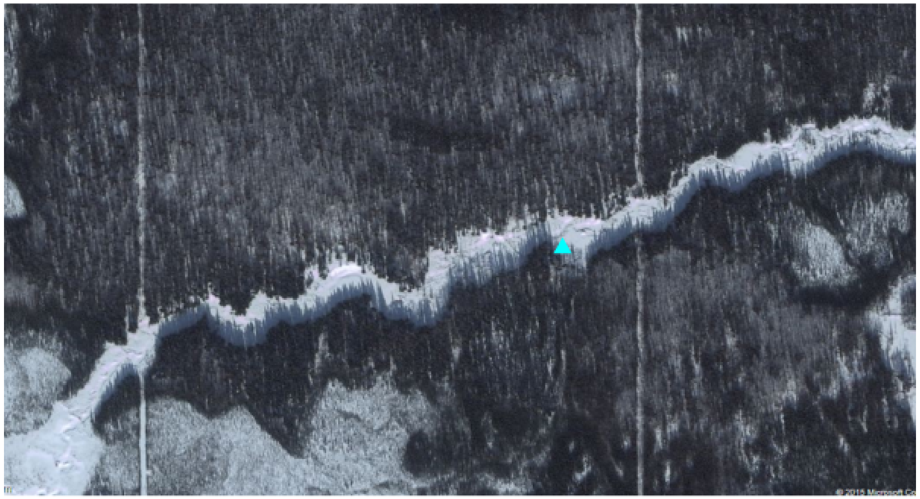
Test Sites

- Local scale images of tests sites show human development occurring in close proximity to the benthic samples sites.

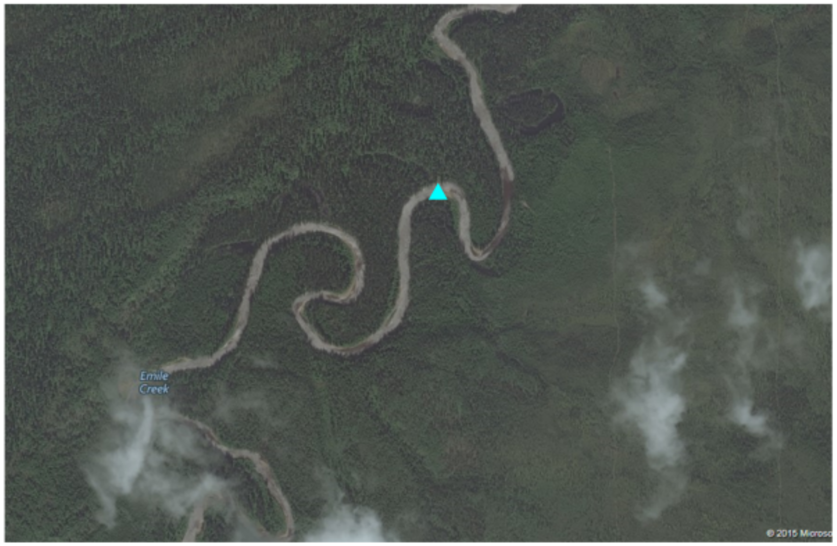
Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.



Site HRB01. Lower Petitot River Watershed

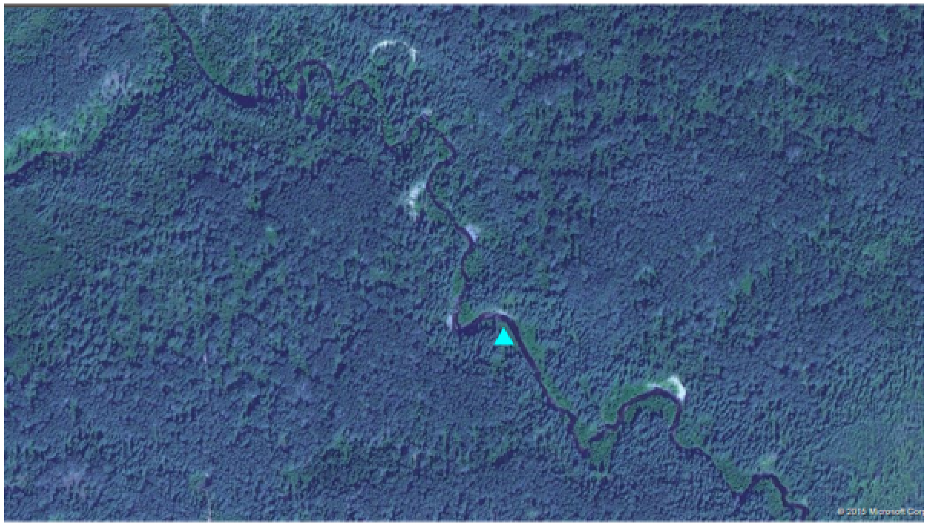


Site HRB02. Lower Petitot River Watershed

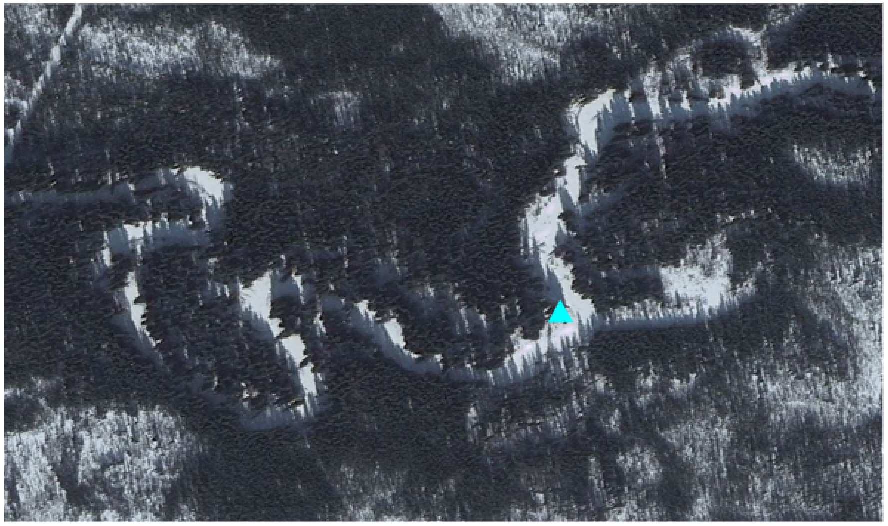
Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.



Site HRB03. Lower Petitot River Watershed

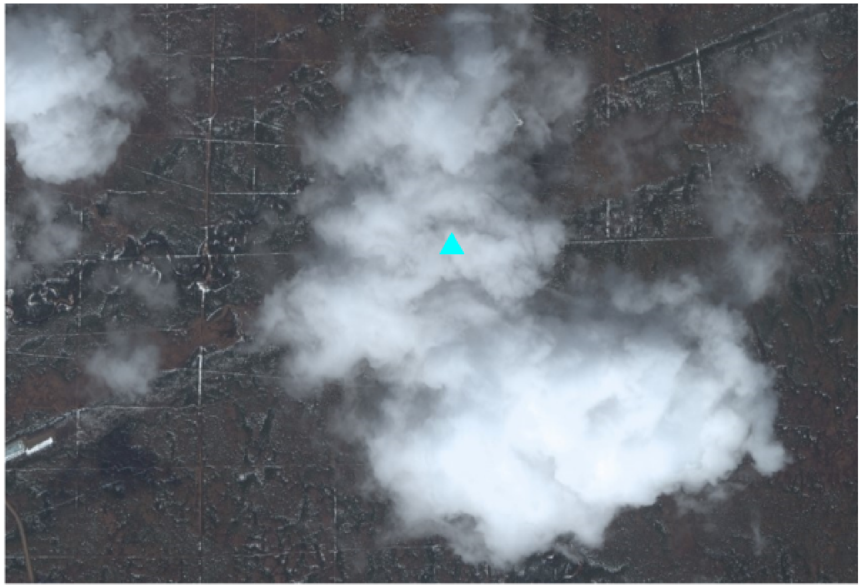


Site HRB04. Lower Petitot River Watershed

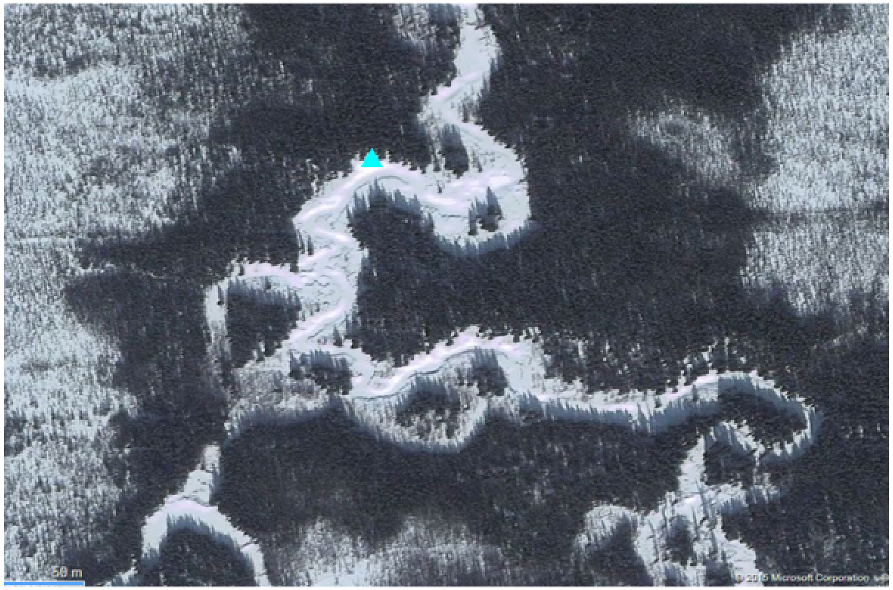
Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.



Site HRB05.
Lower Petitot
River Watershed



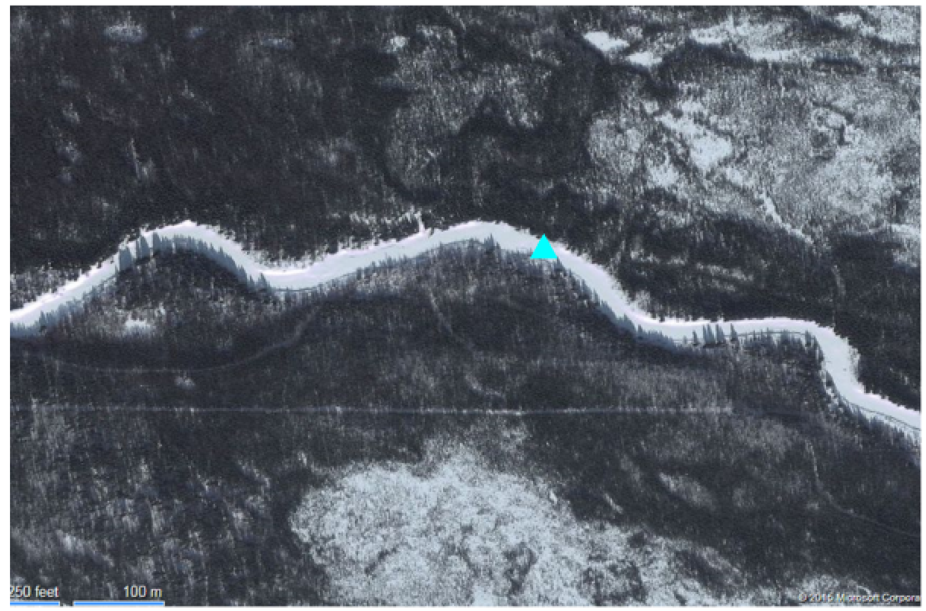
Site FNR001.
Tsiemeh Creek
Watershed

Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.

Site LFRT002. Lower Fort Nelson River Watershed



Site LFRT003. Lower Fort Nelson River Watershed

Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.

Site LPET004. Lower Petitot River Watershed

Site LFRT005. Lower Fort Nelson River Watershed

Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.

Site MUSK001. Lower Muskwa River Watershed

Site MUSK002. Lower Muskwa River Watershed

Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.

Site TSEA001. Tsea River Watershed

Site TSEA002. Tsea River Watershed

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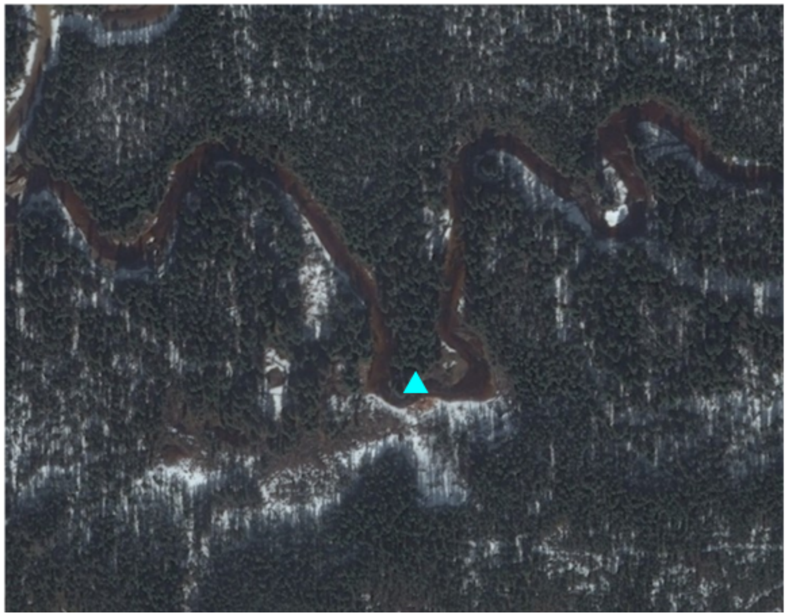
Results - Local Scale (Objective #2)

Reference Sites

- In contrast, most reference sites show little to no human development occurring in close proximity to the benthic samples sites.



Site TSEA003. Tsea River Watershed

Site UPTE002. Upper Petitot River Watershed

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consulting engineers

Results - Local Scale (Objective #2)

Local Scale Summary

- All test sites are located in areas where recent industrial development has occurred in the vicinity. In 3 out of 7 **test sites**, disturbed riparian vegetation was found adjacent to the sample location.
- In contrast, only 3 out of 15 **reference sites** have industrial development in the vicinity, and only 1 of these 3 sample sites are adjacent to areas with disturbed riparian vegetation. The 12 remaining reference sites are in undisturbed areas.

Results - Regression Analysis (Objective #3)

- To address objective 3, a regression analyses of density and type of industrial activity against indices of benthic invertebrate health (i.e. % Plecoptera, % Chironomidae, % EPT, Shannon Weiner Diversity) was conducted.

	% Plecoptera		% Chironomidae		% EPT		Shannon Weiner Diversity index	
Development Type	**r2**	**p-value**	**r2**	**p-value**	**r2**	**p-value**	**r2**	**p-value**
Well Sites (#)	0.10	0.16	0.00	0.93	0.00	0.91	0.14	0.09
Well Sites (#/km2)	0.00	0.97	0.00	0.78	0.05	0.32	0.02	0.54
Water Crossings (#)	0.03	0.43	0.00	0.77	0.00	0.95	0.22	0.03
Water Crossings (#/km)	0.03	0.44	0.04	0.41	0.06	0.30	0.05	0.33
Waste Disposal Sites (#)	0.10	0.17	0.00	0.99	0.00	0.81	0.09	0.20
Waste Disposal Sites (#/km)	0.05	0.35	0.01	0.64	0.00	0.87	0.04	0.36
Forestry Cut Block (km2)	0.01	0.67	0.04	0.36	0.16	0.08	0.00	0.81
Pipeline Incident	0.13	0.10	0.11	0.14	0.04	0.36	0.01	0.70

- Results from this analyses **do not** show a relationship between type/density of industrial activity and indices of benthic community health (i.e. no significant nor strong regression relationship was found).

Conclusions

1. At a watershed scale, there is more developmental activity per km^2 within test watersheds than in reference watersheds.
2. At a local scale, all test sites are located in areas where recent industrial development has occurred in the vicinity. In contrast, the majority of reference sites are in undisturbed areas.
3. No significant nor strong relationships between type/density of industrial activity and indices of aquatic health was found in this study.

Next Steps

- **Re-sample test sites and paired sites upstream** (~ 200 m) to assess of there is a relationship between local riparian vegetation disturbance and benthic community composition.
- Check with Environment Canada to see when the reference condition for the HRB will be made available.
  - When reference condition is available for the HRB, test sites can be re-evaluated to confirm if there is a divergence between test versus reference sites.

Horn River Basin Water Project: Benthic Biomonitoring Update

Prepared For
Geoscience BC

Submitted to Kerr Wood Leidal
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15P0245
March 2016

Down to Earth Biology

ENVIRONMENTAL DYNAMICS INC.

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EXECUTIVE SUMMARY

In 2011, EDI initiated a benthic invertebrate biomonitoring program in northeast BC as part of the Geoscience BC Horn River Basin (HRB) Water Project (the project). The objective of biomonitoring was to use invertebrates as indicators of aquatic health. EDI collected four years of benthic data (2011, 2012, 2013 and 2015) and used data shared by Ministry of Environment from their sampling in 2010 and 2011. Sample sites were in two categories: reference sites that were positioned in pristine areas, and test sites located in areas with historic activities from multiple sources. The sampling was designed to provide a basis for future biomonitoring.

Data from fifteen reference sites sampled in 2010 and 2011 were pooled and compared against either six or seven test sites sampled in each year of 2012, 2013 and 2015. Of the twelve metrics selected, we found significant differences in eight of those metrics in at least one year compared to the reference sites. In general these individual metrics indicated water quality was lower at test sites compared to reference sites. For example, Hilsenhoff Family-Level Biotic Index (FBI) results can be compared to a water quality scale ranging from very poor to excellent. Our FBI scores indicated that water quality at our test sites was "Good" during 2012 and 2013 sampling years and "Fair" in 2015, and "Excellent" at the reference sites. However, other metrics indicated there was not a significant difference between reference and test sites.

All data was entered to the CABIN (Canadian Aquatic Biomonitoring Network) database and reference data was shared with Environment Canada. Environment Canada currently is developing a multivariate model to characterize the reference condition in this region. This will allow data from test sites in 2012, 2013, and 2015 to be compared against the reference condition using the CABIN tool. When sites are resampled in the future, the results and data from this project will provide a basis for assessment of future trends. This could be accomplished using CABIN or a customized risk assessment using a multimetric approach.

Our work shows that biomonitoring using benthics is a cost effective and defendable tool to monitor the integrity of the aquatic environment in the HRB. An objective in this project was to build capacity in First Nations for water management. Because of this project, several technicians completed CABIN training and gained field experience under the guidance of a CABIN certified project manager.

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ACKNOWLEDGEMENTS

The Horn River Basin Producers Group (HRBPG) funded this project through Geoscience BC. Numerous members of HRBPG provided their interest and input to initiate this project. Lyn Anglin followed by Carlos Salas administered the project for Geoscience BC. Dave Murray with Kerr Wood Leidal managed the overall HRB Water Project.

William Needlay of Fort Nelson First Nation and Cathy Mackay with EDI conducted field data collection in 2015. Eva Needlay of Fort Nelson First Nation, Kayly Deneron of Fort Liard (Acho Dene Koe) First Nation, and Mark Racicot with EDI participated in field data collection in previous years.

AUTHORSHIP

This report was prepared by EDI Environmental Dynamics Inc. Staff who contributed to this project include:

Chelsea Coady, M.Sc. R.P.Bio. .... Primary Author

Allison Patterson, M.Sc. .... Statistical Support

Cathy Mackay, M.Sc., P.Ag., R.P.Bio. .... Program Design, Senior Review

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1 INTRODUCTION

In 2011, EDI designed and implemented a benthic invertebrate biomonitoring program in northeast BC as part of the Geoscience BC Horn River Basin (HRB) Water Project (the project). The HRB is approximately 11,000 km^2 and incorporates 42 watersheds (Salas et al. 2014; Map 1). The project was initiated in 2008 by Geoscience BC, the HRB Producers Group (HRBPG), and the BC Ministry of Natural Gas Development, with involvement by the Fort Nelson and Fort Liard (Acho Dene Koe) First Nations. The project aim is to gain an understanding of water quality and quantity in the region and build First Nations capacity in water management (Salas et al. 2014).

The objective of the biomonitoring program is to use benthic invertebrates as indicators of aquatic health. Benthic invertebrates (referred to here as benthics) are bottom dwelling organisms that are commonly used as biological indicators to assess the health of aquatic ecosystems because of their sedentary nature, relatively long lifespan, and abundance (Beatty et al. 2006). Metrics are measurements of biological attributes that are used in combination to indicate aquatic condition. For example, certain metrics rely on the varied sensitivity of benthics to environmental influences whereby the abundance or diversity of sensitive taxa and tolerant taxa are quantified (Barbour et al. 1999; Zimmerman 1993).

The baseline program was designed with these objectives in mind: (1) compare between sites located in pristine locations (reference sites) and sites downstream of various environmental influences (test sites), and (2) quantify the current state of test sites to establish a basis for future monitoring and (3) engage First Nations technicians in biomonitoring. This report provides an update to the Geoscience BC Horn River Basin Water Project: Benthic Biomonitoring Technical Report provided in 2014 (EDI 2014) by providing an additional year of test site data (2015), completing the baseline data collection for this program.

2 METHODS

2.1 SAMPLING SITES

All sampling methodology was performed per CABIN standards. Table 1 shows the reference and test sites sampled throughout the baseline sampling program.

Table 1. Sample sites used in analyses.

Data Source	Site Type	Year Data Collected	Site Names	No. of Sites*
Ministry of Environment	Reference	2010	FNR001, MUSK001, MUSK002, TSEA001, TSEA002	5
Ministry of Environment	Reference	2011	LFRT002, LFRT003, LFRT005, LPET004, UPET002	5
HRB Project	Reference	2011	HRB01, HRB02, HRB03, HRB04, HRB05	5
HRB Project	Test	2012	d'Easum Creek, Delkpay Creek, Kiwigana River, Sahtaneh River, Stanolind Creek, Dilly Creek	6
HRB Project	Test	2013	d'Easum Creek, Delkpay Creek, Kiwigana River, Sahtaneh River, Stanolind Creek, Tsea Creek	6
HRB Project	Test	2015	d'Easum Creek, Delkpay Creek, Dilly Creek, Kiwigana River, Sahtaneh River, Stanolind Creek, Tsea Creek	7

*2012 and 2013 data were collected at 5 out of 6 of the same sites. Tsea Creek was sampled in 2013 instead of Dilly Creek, which was inaccessible at the time of sampling in 2013 due to road conditions.

2.2 BENTHIC METRICS

Specific benthic metrics (hereby referred to as metrics) were chosen to represent the composition and health of the benthic community at each reference site and test site (Table 2)[1]. Metrics were chosen based on their use in other bio-assessment field studies and how informative they are at quantifying the composition and health of benthic communities (Rosenberg and Resh 1993). Metrics were also chosen to minimize redundancy and to aid in making inferences about the biological data. All metric calculations performed on data collected by EDI were completed using the Analytical Tools in CABIN (Environment Canada 2013). All metric calculations performed on data collected by MOE were completed in Microsoft Excel using CABIN analysis protocols.

Table 2. Benthic metric calculations and rationale for use (EDI 2014).

Metric	Rationale	Reference
Total Abundance	Total abundance may be reduced under certain types of environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
Taxa Richness	Reflects the health of benthic macroinvertebrate communities; as water quality decreases, taxa richness generally decreases.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
EPT Richness (Ephemeroptera + Plecoptera + Trichoptera)	In general, the majority of taxa in the EPT orders are considered sensitive to water quality; as water quality decreases, EPT richness generally decreases.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Dominant Taxa	Indicates balance in benthic macroinvertebrate communities; a community dominated by relatively few taxa may indicate community imbalance, enrichment, or environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% EPT Individuals (Ephemeroptera + Plecoptera + Trichoptera)	In general, the majority of taxa in the EPT orders are considered sensitive to impairment in water quality; a decreased composition of these benthic macroinvertebrates may indicate environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Ephemeroptera (Mayflies)	In general, the majority of taxa in the Ephemeroptera order are considered sensitive to impairment in water quality; a decreased composition of these benthic macroinvertebrates may indicate environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Plecoptera (Stoneflies)	In general, the majority of taxa in the Plecoptera order are considered sensitive to impairment in water quality; a decreased composition of these benthic macroinvertebrates may indicate environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Trichoptera (Caddisflies)	In general, the majority of taxa in the Trichoptera order are considered sensitive to impairment in water quality; a decreased composition of these benthic macroinvertebrates may indicate environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Diptera and Non-insects	In general, the majority of taxa in the Diptera and non-insect orders are considered tolerant to impairment in water quality compared to taxa in the EPT orders; a stressed habitat may display an imbalance between these taxa, with an increased composition of Diptera and non-insect taxa.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
% Chironomidae	In general, the majority of genera in the Chironomidae family are considered opportunistic and highly tolerant to pollution compared to taxa in the EPT orders; a community dominated by Chironomidae genera may indicate community imbalance, enrichment, or environmental stress.	Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013
Hilsenhoff Family-level Biotic Index (FBI)	Used to classify water quality; the Hilsenhoff FBI ranges from 0 to 10, with 0 representing excellent water quality and 10 representing very poor water quality. See Appendix B for more details.	Hilsenhoff 1988; Rosenberg and Resh 1993; Environment Canada 2013
Shannon-Wiener Diversity Index (H)	The most commonly used diversity index; considers both richness and evenness; as water quality decreases, species diversity (i.e., the value of *H*) generally decreases.	Rosenberg and Resh 1993; Environment Canada 2013

2.3 STATISTICAL ANALYSES

We compared a group of 15 reference sites sampled in 2010 and 2011 by Ministry of Environment and EDI with a group of test sites sampled annually. Pooled data from 15 reference sites were compared with 6, 6 and 7 test sites in each year 2012, 2013 and 2015, respectively. To examine differences in benthic metrics between reference sites and test sites we performed an Analysis of Covariance (ANCOVA). We included specific habitat parameters related to geography (e.g. latitude), streambed characteristics (e.g. proportion of cobble substrate), channel characteristics (e.g. water velocity) or in-situ water quality parameters (e.g. water temperature) which may have an influence on these benthic metrics[1]. All proportional data (e.g. proportion of Chironomidae taxa out of all taxa sampled) were log transformed and the metric "Total Abundance" was log transformed to satisfy assumptions of ANCOVA. All analyses were performed using RStudio (Version 0.99.892, 2009-2016).

[1] See Benthic Biomonitoring Technical Report (EDI 2014) for further details on sampling, selection of metrics, habitat parameters and statistical analysis.

3 RESULTS

The levels of variation in benthic metrics at reference and test sites are presented in error bar plots (Figures 1-10) displaying the mean and error bars (95% confidence intervals) for the model as well as the individual data points. Numbers above error bars indicate sample sizes. Of the twelve metrics listed in Table 2, there were significant differences between reference sties and 2015 test sites in eight metrics (Table 3).

Table 3. Summary of statistical findings for the twelve metrics tested between reference sites and 2015 test sites.

Significant Differences		No Significant Difference
Total Abundance	Hilsenhoff Family-level Biotic Index (FBI)	Taxa Richness
% Diptera and Non-Insects	Shannon-Wiener Diversity Index	EPT Taxa Richness
% Chironomidae	% Dominant Taxa	% Ephemeroptera
% Plecoptera	% EPT	% Trichoptera

Test sites in 2012 and 2015 had significantly higher abundance of benthics compared to reference sites (p= 0.003 and $p < 0.0001$, respectively). A similar pattern occurred between the 2013 test sites and reference sites; however, the result was not significant ($p = 0.09$)[2] (Figure 1; Table 4). For several test sites in 2015 the abundance of benthics was one or two orders of magnitude higher than in 2012 and 2013 sampling years which appeared to be driven by the higher number of Chironomidae individuals (Table 4, Figure 3).

Table 4. Abundance of invertebrates in test site samples.

Test Site	Year 2012		Year 2013		Year 2015	
	Total Abundance	%Chironomidae	Total Abundance	%Chironomidae	Total Abundance	%Chironomidae
D'easum Cr	8150	22%	1670	37%	6160	63%
Delkpay Cr	8340	47%	2186	39%	32,100	80%
Dilly Cr	4786	38%	Not sampled		15,200	67%
Kiwigana R	1643	9%	1207	15%	16,050	66%
Sahntaneh R	694	26%	5375	50%	11,033	62%
Stanolind Cr	3100	36%	1821	41%	16,150	47%
Tsea Cr	Not sampled		1500	23%	5750	61%

Similar to our previous findings (EDI 2014), the proportion of certain benthics also differed between reference and test sites. The proportion of Diptera and Non-insects, which are considered tolerant to decreases in water quality, was significantly higher at test sites in all years compared to reference sites (all $p < 0.01$, Figure 2). The proportion of individuals from the Dipteran Family Chironomidae, considered tolerant to decreased water quality, was significantly higher at test sites in all years compared to reference sites (all $p < 0.02$, Figure 3). The proportion of EPT individuals (i.e. Ephemeroptera, Plecoptera and Trichoptera), which are considered sensitive to decreased water quality, were significantly lower at test sites compared to reference sites for all test sites sampling years (all $p < 0.002$). When examining the EPT individuals separately, only the proportion of Plecoptera individuals were significantly lower at test sites for

[2] When comparing references sites and 2013 test sites in the previous report (EDI 2014) this result was found to be significant; however, the data were not log transformed. Log transformation is appropriate for these data.

all years (all $p < 0.002$, Figure 4), whereas the proportion of Ephemeroptera individuals was only lower at test sites in 2015 ($p < 0.0001$) and the proportion of Trichoptera individuals did not significantly differ between reference and test sites for any years (all $p > 0.32$).

Taxa richness, which generally decreases with decreasing water quality, and EPT taxa richness, which focuses on sensitive taxa (i.e. Ephemeroptera, Plecoptera and Trichoptera) did not differ between reference and test sites for any of the test site years (taxa richness: $p > 0.08$, Figure 5 and EPT taxa richness: $p > 0.14$, Figure 6).

The Hilsenhoff Family-Level Biotic Index (FBI) provides an indication of water quality and stream health. A low number is assumed to indicate good water quality and a benthic community with a high proportion of more sensitive taxa (i.e. EPT taxa). Conversely a high FBI value is assumed to indicate poor water quality and a high proportion of less sensitive taxa (i.e. Diptera and Non-insect taxa). Supporting the findings already reported, the FBI was significantly higher at test sites compared to reference sites in all years (all $p < 0.002$, Figure 7), indicating lower water quality at test sites. The Shannon-Wiener Diversity Index, a measure of the species diversity, was significantly lower (i.e. less diversity) at test sites compared to reference sites when comparing reference sites with test sites in 2013 and 2015 (both $p < 0.04$); although this relationship was not significant for the 2012 test site data ($p = 0.12$), the direction of the relationship remained the same (Figure 8). Consistent with this finding, the dominant taxa comprised a higher proportion of the benthic community at test sites compared to reference sites for all test site years (all $p < 0.05$) (Figure 9).

Latitude was the only habitat parameter among those we tested as covariates that influenced any metrics. More southerly sample sites had a higher proportion of Diptera and Non-insects for all sites (reference and test sites) in all years. The proportion of Trichoptera individuals increased at more northerly latitudes for all sites in all years (all $p < 0.03$). EPT taxa richness (Figure 10) and taxa richness both increased with more northerly latitudes. This cofactor was accounted for within the statistical analysis.

4 DISCUSSION

Similar to previous results (EDI 2014), we found a difference in the benthic communities between reference and test sites in 2015 for many, but not all of the metrics. The proportion of EPT individuals and Plecoptera individuals, both groups that are generally considered sensitive to decreases in water quality, were significantly lower at test sites. In relation, the proportion of Diptera and non-insects and the Dipteran family Chironomidae, both generally considered tolerant to decreases in water quality, were significantly higher at test sites. The dominant taxa made up a higher proportion of the benthic assemblage at test sites, which may indicate community imbalance or environmental stress (Rosenberg and Resh 1993; Sylvestre et al. 2005; Environment Canada 2013). Our index-based metrics (Hilsenhoff Family-Level Biotic Index and Shannon-Wiener Diversity Index) also suggested that test sites had lower water quality and less species diversity compared to reference sites. This trend was consistent across all test site sampling years.

We found no difference in taxa richness or EPT taxa richness between reference and test sites for any of the test site sampling years. Richness metrics are considered a reliable metric to indicate water quality because they use presence/absence type data, suggesting that with impairment of the aquatic environment, taxa are not just reduced but eliminated (Resh et al. 2000). While metrics that rely on proportional or count data (e.g. proportion of EPT individuals, abundance etc.) may be more sensitive to changes in the benthic community assemblage, richness metrics may be useful at detecting more profound changes. Because each metric relies on different information from the benthic community, it is important to consider various metrics to improve confidence in the results and reduce the risk of incorrectly assessing the health of the aquatic environment (Fore et al. 1996).

The lack of any difference in taxa richness and specifically, EPT taxa richness between reference and test sites suggests that test sites may only be slightly or moderately different than reference sites. In addition, although the Hilsenhoff Family-Level Biotic Index (FBI) was higher at test sites, indicating poorer water quality compared to reference sites, Hilsenhoff (1988) categorizes FBI results on a water quality scale ranging from very poor water quality to excellent water quality. Water quality at our test sites is categorized as “Good” during 2012 and 2013 sampling years and “Fair” in 2015 compared to “Excellent” for reference sites (Appendix B) indicating a slight or moderate level of impairment according to this index. Furthermore, when we compare test site results in the HRB with results from un-impacted sites from other studies within BC and elsewhere in North America, several of the benthic metrics are within the range of variability of un-impacted sites (Bode and Novak 1994; Fore et al., 1996; Maret et al. 2003; Sylvestre et al. 2005).

We found that reference sites and test sites located further north in the HRB generally had higher EPT taxa richness, a higher proportion of EPT individuals, and a lower proportion of Diptera and non-insects compared to sites located further south. One interpretation of this result is that the observed latitudinal gradient may be the result of higher amounts of development and human presence in the southern portion of the HRB. Another interpretation is that the difference is due to varying reference conditions in different regions within the study area. Our sampling was not designed to assess or interpret this result. This pattern was found as coincidence to our statistical analysis and it is noteworthy should future sampling and analyses be conducted.

5 CONCLUSION

There are two well-known assessment methods for benthic biomonitoring: multivariate modelling and the multimetric approach. Environment Canada currently is developing a multivariate model, the Canadian Aquatic Biomonitoring Network (CABIN) reference model, which is expected to be completed in 2016 (Stephanie Strachan, Environment Canada, pers. comm.). CABIN is a tool housed on-line for use by those trained and certified in the standard methodology (Environment Canada 2013). CABIN users enter their data on-line and a multivariate model that is based on regional data runs internally. The output indicates to the user whether their test site(s) is stressed compared to the reference condition. Alternatively, the multimetric approach selects a set of metrics in several categories such as taxa richness, tolerance/intolerance, and trophic structure. Numerous sites are sampled across a range of conditions including pristine sites, and sites ranging from minimally to severely impacted by a variety of influences. The selected metrics are used in a formula for an overall index, which quantifies where a test site falls within a gradient of biological health and integrity (Karr and Chu 1999).

Multivariate modelling and the multimetric approach both have advantages and our data provide the basis to use either in future biomonitoring. EDI collected four years of benthic data (2011, 2012, 2013 and 2015) and obtained two years of reference site data (2010 and 2011) collected by Ministry of Environment. The benthic data collected in the HRB Water Project to date allows a preliminary assessment of aquatic health at reference sites and test sites by statistically comparing several benthic metrics between the two site types, similar to a multimetric approach. Because reference sites and test sites were not collected in the same years, we caution that any significant differences observed between site types may be influenced by the natural variability among years.

Reference site data from this project were provided to Environment Canada for use in developing the CABIN model. Once the CABIN reference model is complete, data from test sites in 2012, 2013, and 2015 can be compared against the reference condition. If these sites are resampled in the future, the data we collected will provide a basis for assessment of future trends using the CABIN model, or it will provide a basis for customized risk assessment using a multimetric approach. The results show there are some differences between site types, and quantifies the difference so that trends can be assessed in future biomonitoring.

These results show that biomonitoring using benthics is a cost effective and defendable tool to monitor the health and integrity of the aquatic environment in the HRB. An objective in this project was to build capacity in First Nations for water management. Because of this project, several technicians completed CABIN training and gained field experience under the guidance of a CABIN certified project manager.

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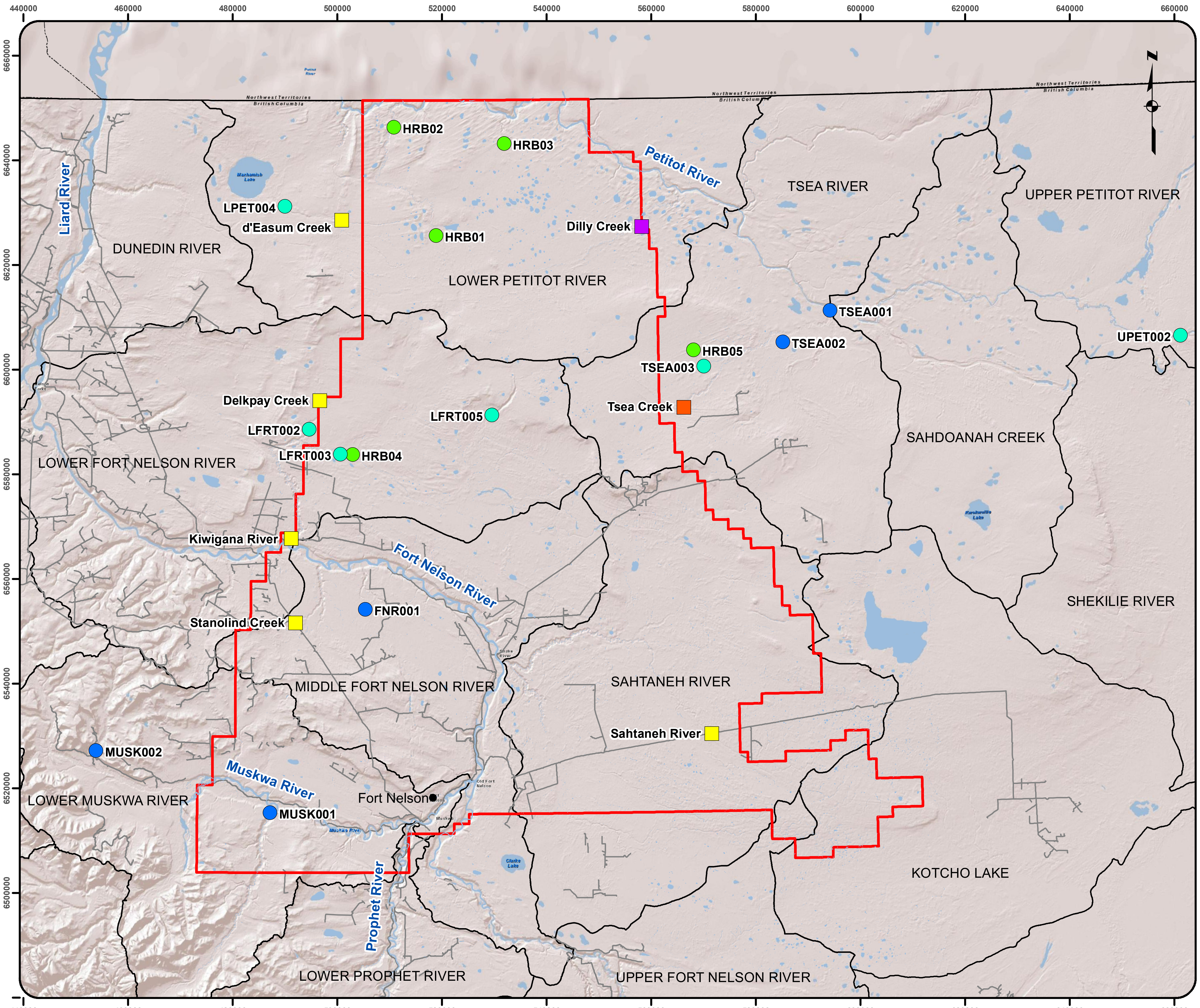

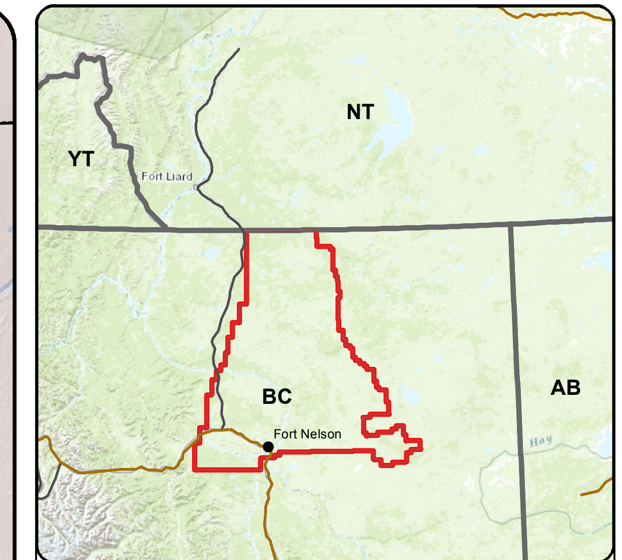

LEGEND

- 2010 MOE Reference Site
- 2011 MOE Reference Site
- 2011 HRB Project Reference Site
- HRB Project Test Site sampled in 2012, 2013, and 2015
- HRB Project Test Site sampled in 2012 and 2015
- HRB Project Test Site sampled in 2013 and 2015
- BC Cities
- Horn River Basin Boundary
- BC Watershed Atlas
- Forestry Road BC

Digital Road Atlas

- Loose
- Paved
- Rough
- Loose collector/arterial

No sites were sampled in 2014.

0 12.5 25 50 Kilometers

Scale: 1:750,000

Original Map Size 11x17in

Geoscience BC Horn River Basin Water Project

Map 1. Benthic Biomonitoring Sites 2010 - 2015

Drawn: V. Smith	Datum/Projection: NAD 1983 UTM Zone 10N
Checked: C. Coady	EDI Project No.: 15-P-0245
Date: 17/03/2016	Data Sources: Refer to References Section

EDI ENVIRONMENTAL DYNAMICS INC.

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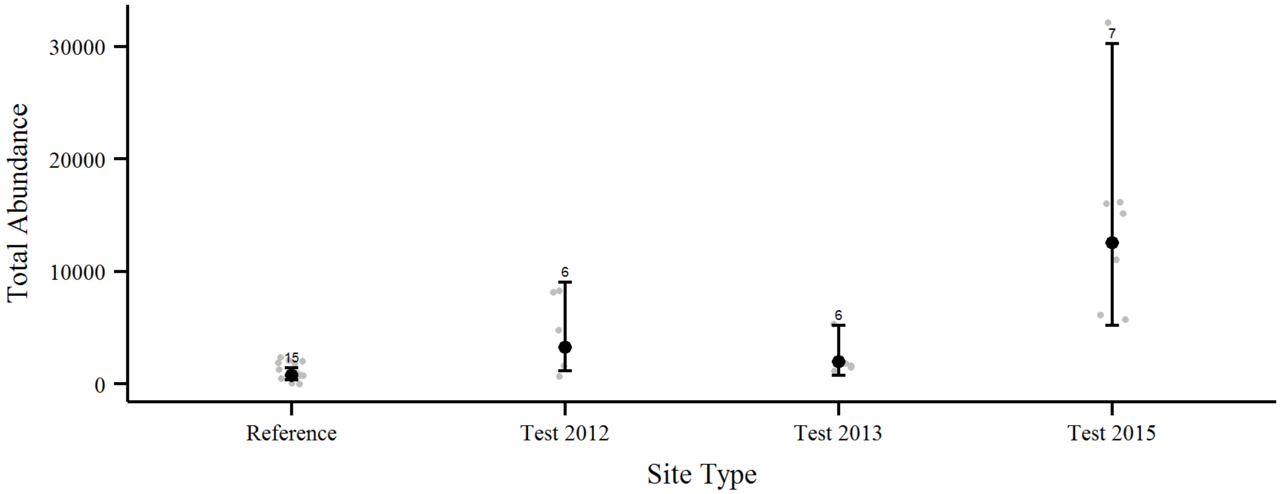

Figure 2. Significant differences in abundance of benthics at reference and test sites (only in 2012 and 2015).

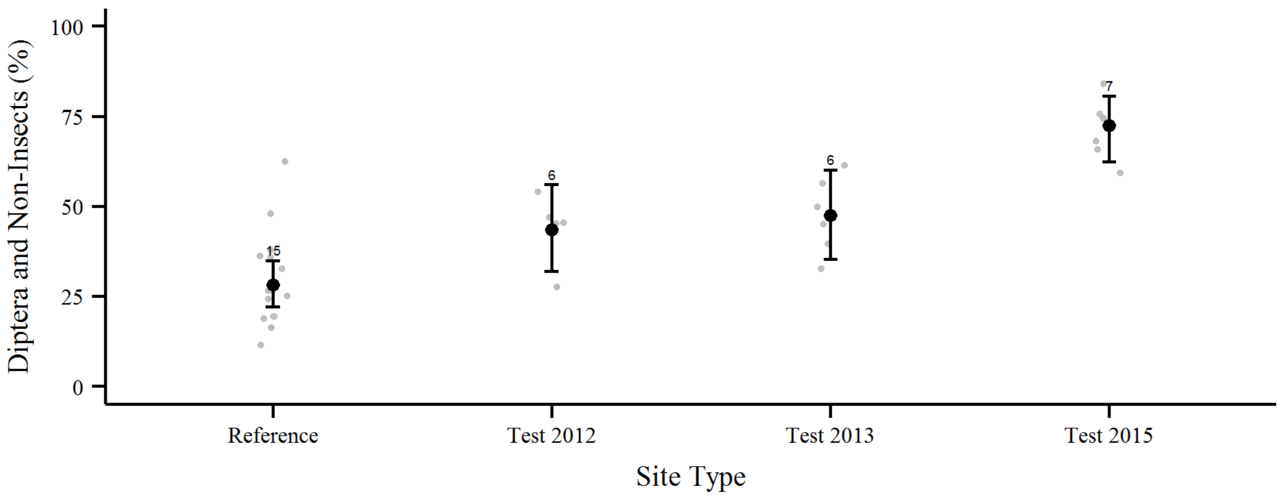

Figure 3. Significant difference in the proportion of Diptera and Non-Insects at reference and test sites.

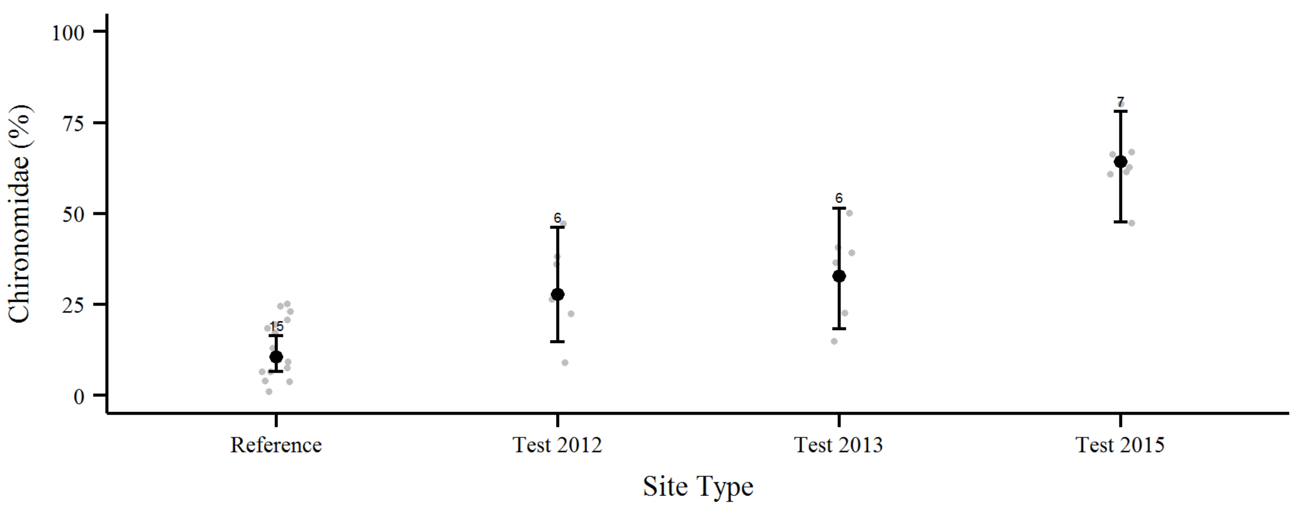

Figure 4. Significant difference in the proportion of Chironomidae at reference and test sites.

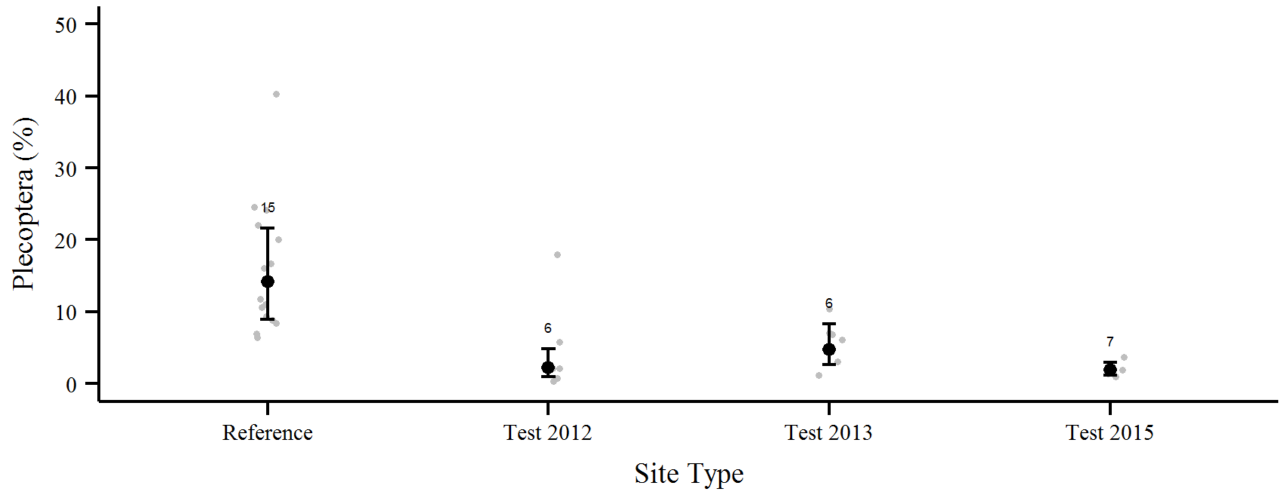

Figure 5. Significant difference in the proportion of Plecoptera at reference and test sites.

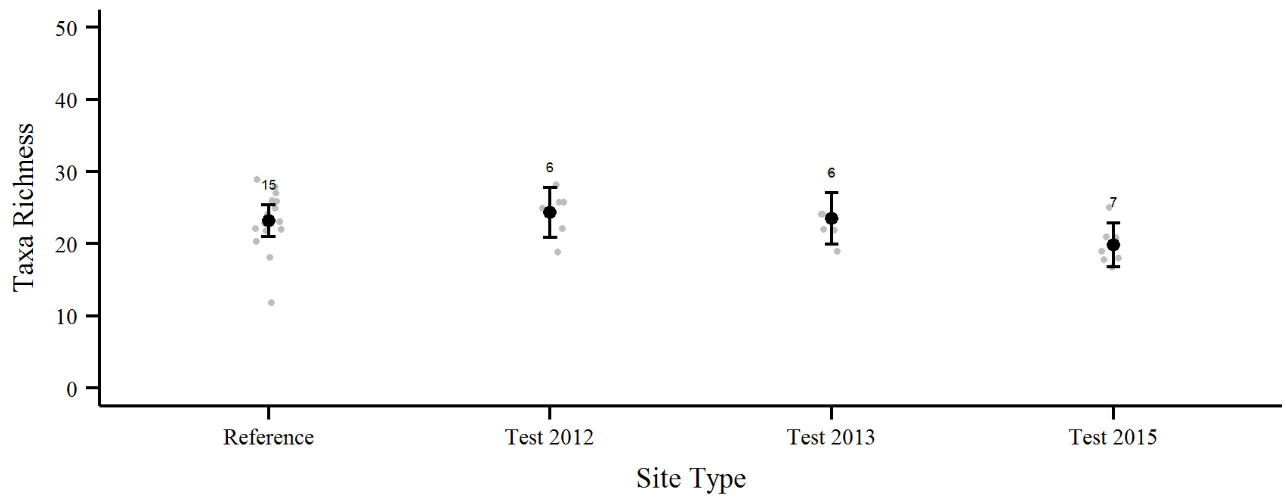

Figure 6. No difference in taxa richness at reference and test sites.

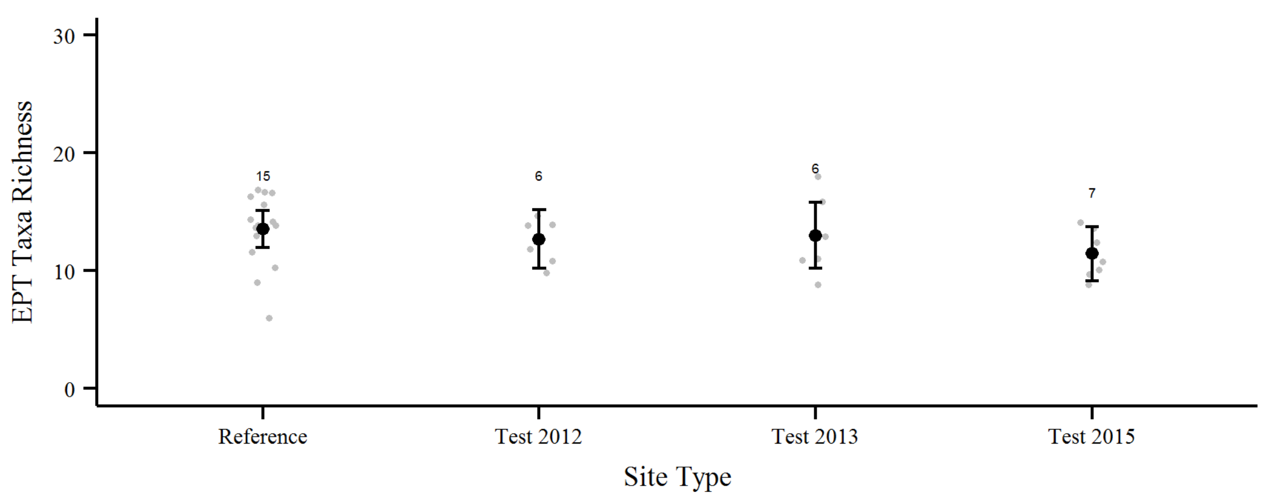

Figure 7. No difference in EPT taxa richness at reference and test sites.

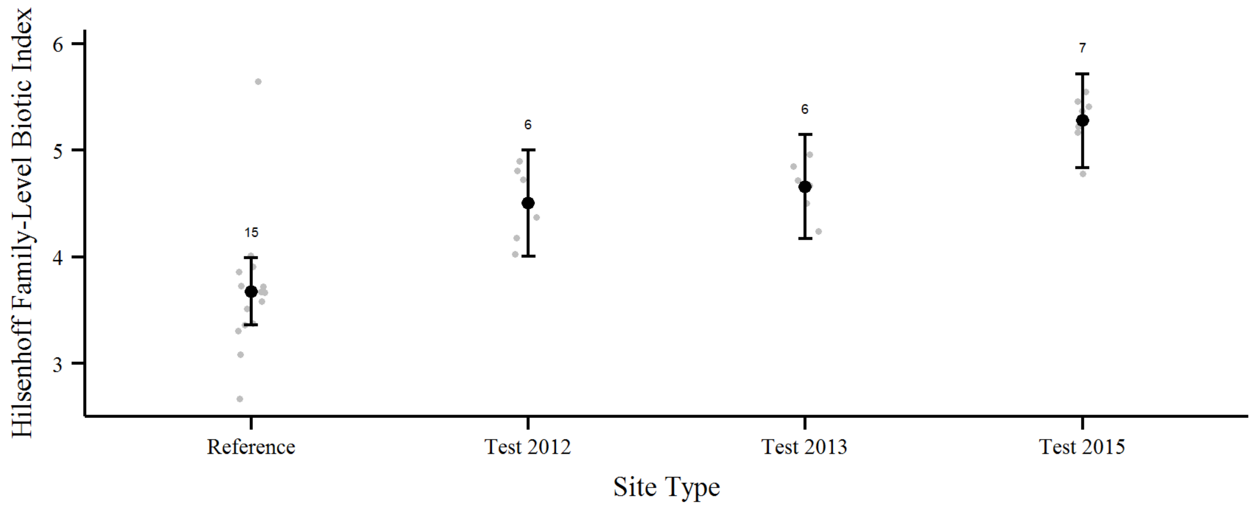

Figure 7. Significant difference in the Hilsenhoff Family-Level Biotic Index at reference and test sites.

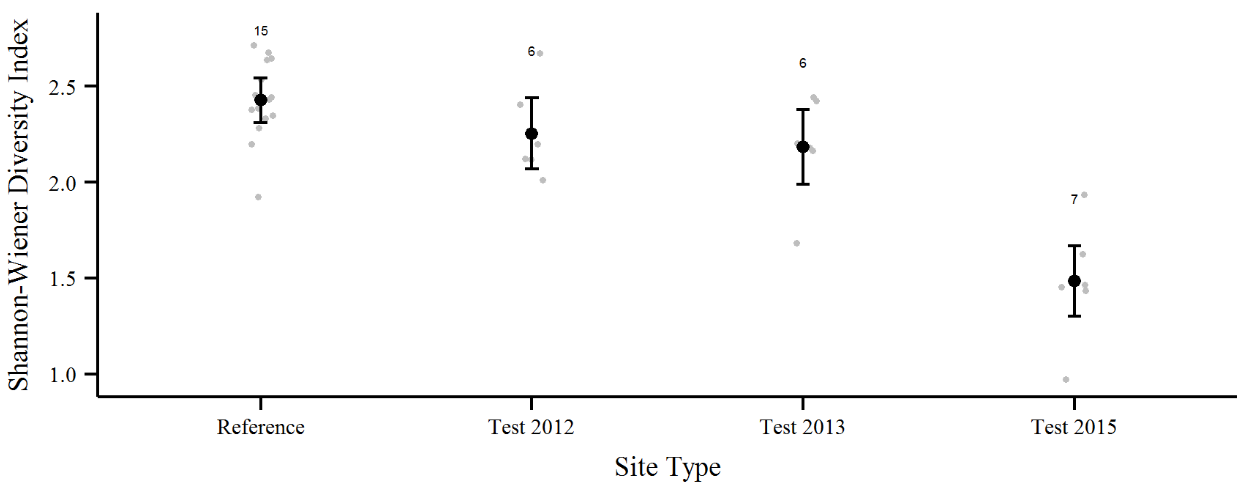

Figure 8. Significant difference in the Shannon-Wiener Diversity Index at reference and test sites (in 2013 and 2015).

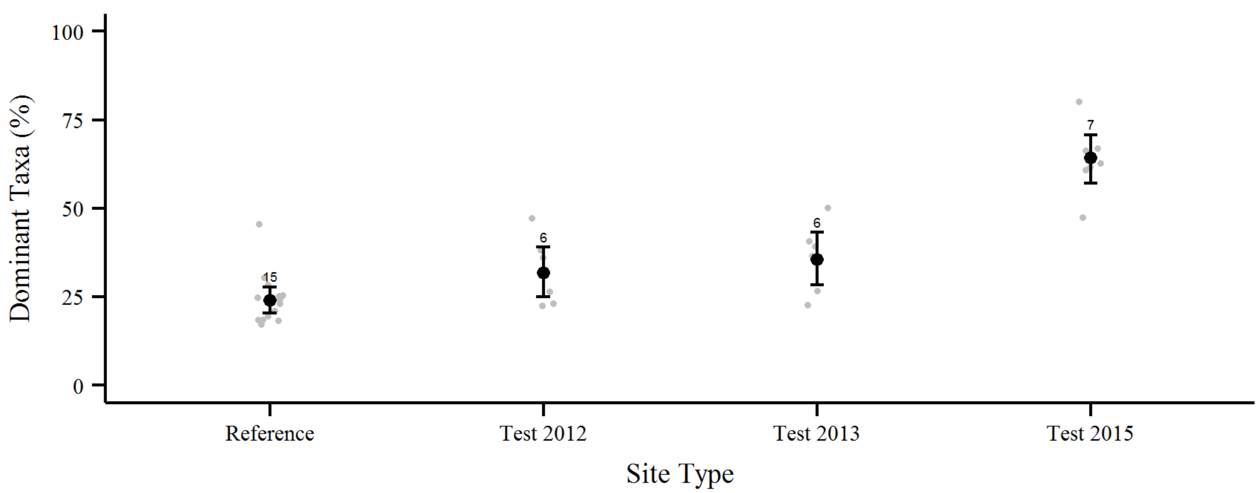

Figure 8. Significant difference in proportion of the dominant taxa at reference compared to test sites.

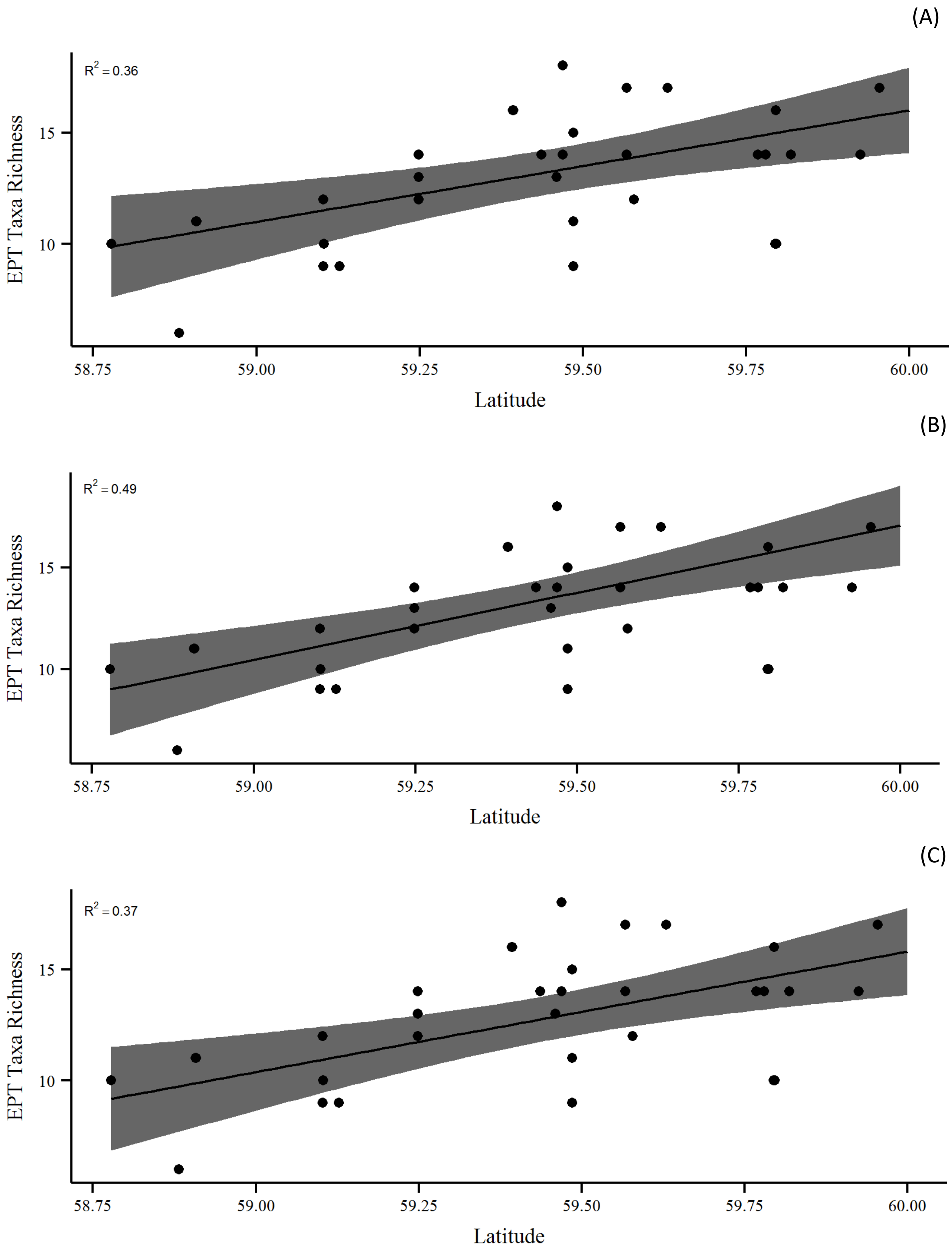

Figure 10. Significant increase in EPT taxa richness at more northerly latitudes. Graphs include all reference sites. (A) also includes tests sites in 2012, (B) also includes test sites in 2013 and (C) also includes test sites in 2015.

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APPENDIX A. SUPPLEMENTARY STATISTICAL ANALYSIS RESULTS

Results for Analysis of Variance Test (ANOVA) comparing Reference Sites with Test Sites

Metric	Reference Sites Mean	Lower CI	Upper CI	Test Sites Mean	Lower CI	Upper CI	Site Type Significance	Significant Habitat Parameters
2012 Test Sites compared with Reference Sites								
% Chironomidae	10.48	6.58	16.29	27.74	14.66	46.18	**p = 0.02**	none
% Diptera and Non-Insects	28.60	23.34	34.52	41.92	31.83	52.73	**p = 0.01**	**Latitude, p = 0.01**
% Ephemeroptera	25.76	17.49	36.22	15.47	7.75	28.52	p = 0.16	none
% Trichoptera	17.47	12.03	24.70	22.66	12.76	36.97	p = 0.42	**Latitude, p = 0.0004**
% Plecoptera	14.12	8.92	21.63	2.21	0.99	4.88	**p = 0.0004**	none
% EPT	67.80	61.34	73.64	44.91	34.27	56.04	**p = 0.001**	none
% Dominant Taxa	23.83	20.31	27.75	31.63	25.06	39.02	**p = 0.05**	**none**
EPT Taxa Richness	13.39	12.08	14.70	13.01	10.94	15.09	p = 0.75	**Latitude, p = 0.0004**
Taxa Richness	23.17	20.99	25.34	24.33	20.89	27.77	p = 0.56	Latitude was not significant p = 0.07
Total Abundance	748.61	391.36	1431.97	3236.37	1160.61	9024.59	**p = 0.02**	none
Shannon-Wiener Diversity Index	2.43	2.31	2.54	2.25	2.07	2.44	p = 0.12	none
Hilsenhoff Family-Level Biotic Index	3.68	3.36	3.99	4.50	4.00	5.00	**p = 0.009**	none
		2013 Test Sites compared with Reference Sites						
% Chironomidae	10.48	6.67	16.09	32.74	18.24	51.51	**p = 0.004**	none
% Diptera and Non-Insects	28.60	23.34	34.52	41.92	31.83	52.73	**p = 0.002**	**Latitude, p = 0.01**
% Ephemeroptera	25.76	16.74	37.46	18.73	8.86	35.34	p = 0.41	none
% Trichoptera	17.23	11.77	24.52	17.69	9.56	30.41	p = 0.93	**Latitude, p = 0.01**
% Plecoptera	14.12	10.12	19.36	4.75	2.67	8.31	**p = 0.002**	none
% EPT	67.80	61.04	73.88	44.93	33.84	56.56	**p = 0.002**	none
% Dominant Taxa	23.83	20.31	27.75	35.45	28.43	43.16	**p = 0.006**	**none**
EPT Taxa Richness	13.24	11.95	14.54	13.72	11.65	15.80	p = 0.69	**Latitude, p = 0.0004**
Taxa Richness	22.84	21.04	24.63	24.33	21.46	27.19	p = 0.37	**Latitude, p = 0.004**

Metric	Reference Sites Mean	Lower CI	Upper CI	Test Sites Mean	Lower CI	Upper CI	Site Type Significance	Significant Habitat Parameters
Total Abundance	748.61	407.85	1374.088	2003.48	766.92	5233.85	p = 0.09	none
Shannon-Wiener Diversity Index	2.43	2.30	2.55	2.18	1.99	2.38	**p = 0.04**	none
Hilsenhoff Family-Level Biotic Index	3.68	3.37	3.98	4.66	4.17	5.14	**p = 0.002**	none
		2015 Test Sites compared with Reference Sites						
% Chironomidae	10.48	6.84	15.72	64.24	47.59	78.05	**p < 0.0001**	none
% Diptera and Non-Insects	28.49	22.91	34.82	71.57	62.07	79.48	**p < 0.0001**	**Latitude, p = 0.05**
% Ephemeroptera	25.76	17.36	36.43	3.69	1.81	7.40	**p < 0.0001**	none
% Trichoptera	17.73	12.17	25.10	12.82	7.14	21.96	p = 0.32	**Latitude, p = 0.03**
% Plecoptera	14.12	10.67	18.45	1.90	1.20	3.00	**p < 0.0001**	none
% EPT	67.80	61.43	73.56	18.44	13.07	25.38	**p < 0.0001**	none
% Dominant Taxa	23.83	20.31	27.75	64.24	57.09	70.81	**p < 0.0001**	**none**
EPT Taxa Richness	13.24	11.95	14.54	13.72	11.65	15.80	p = 0.14	**Latitude, p = 0.003**
Taxa Richness	22.97	21.26	24.70	20.26	17.73	22.79	p = 0.08	**Latitude, p = 0.003**
Total Abundance	748.61	410.92	1363.83	12564.16	5221.50	30232.33	**p < 0.0001**	none
Shannon-Wiener Diversity Index	2.43	2.30	2.55	1.48	1.30	1.67	**p < 0.0001**	none
Hilsenhoff Family-Level Biotic Index	3.68	3.38	3.98	5.28	4.84	5.72	**p < 0.0001**	none

APPENDIX B. HILSENHOFF FAMILY LEVEL BIOTIC INDEX

Evaluation of water quality using the family-level biotic index (Adapted from Hilsenhoff 1988).

Family Biotic Index	Water Quality
0.00 – 3.75	Excellent
3.76 – 4.25	Very good
4.26 – 5.00	Good
5.01 – 5.75	Fair
5.76 – 6.50	Fairly poor
6.51 – 7.25	Poor
7.26 – 10.00	Very poor

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Appendix E

Water Yield Figures

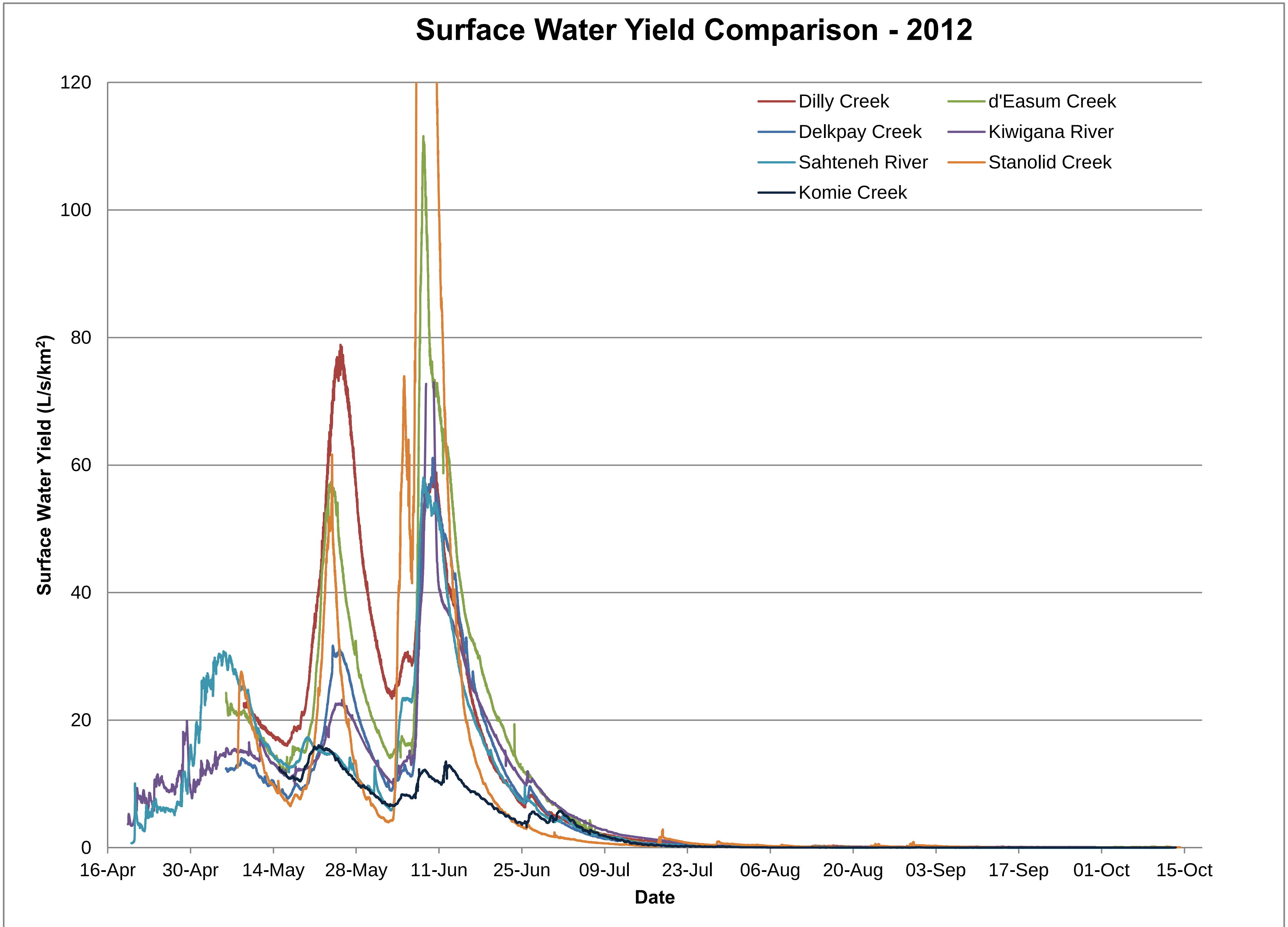

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Figure 24

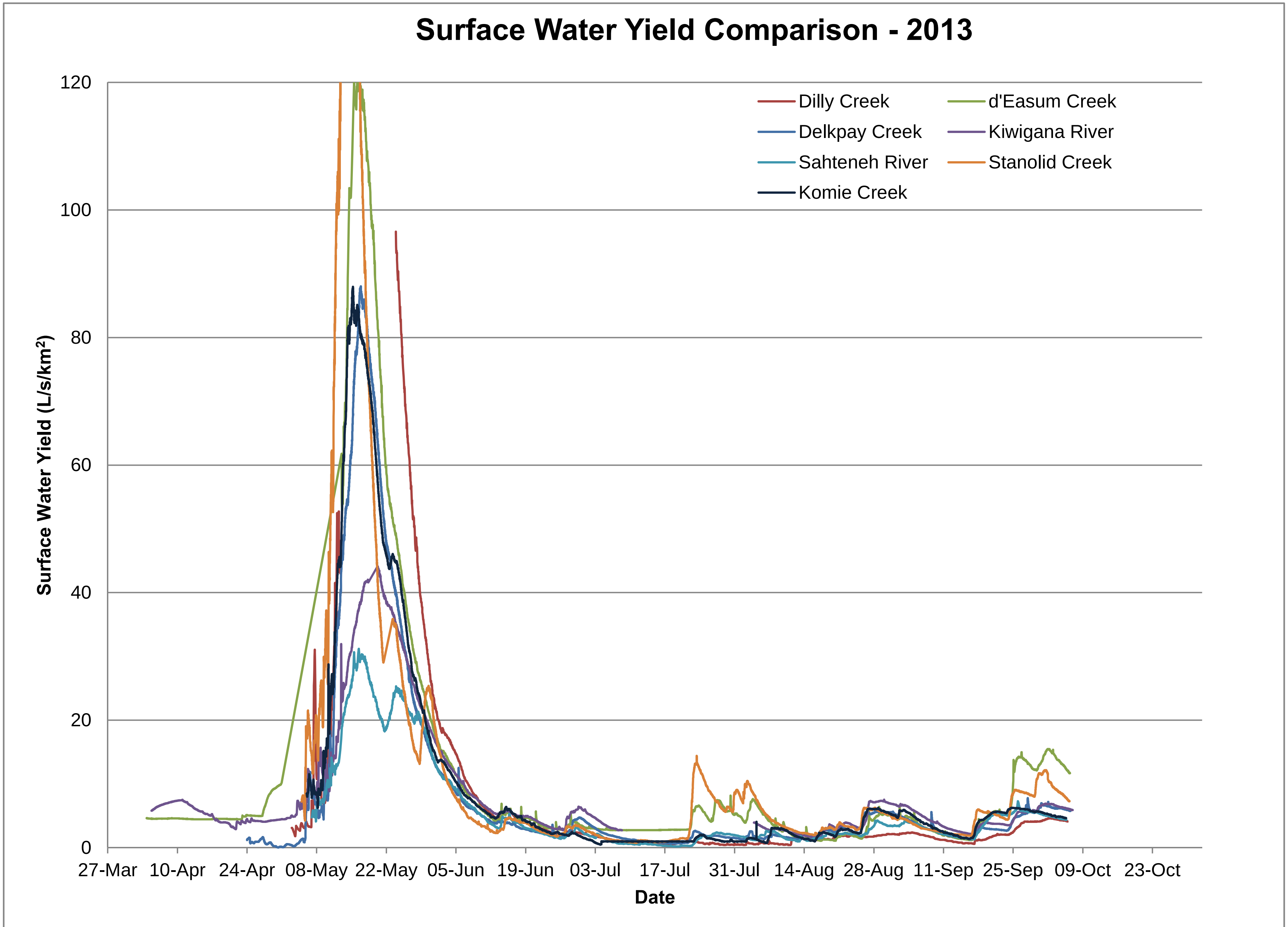

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Figure 25

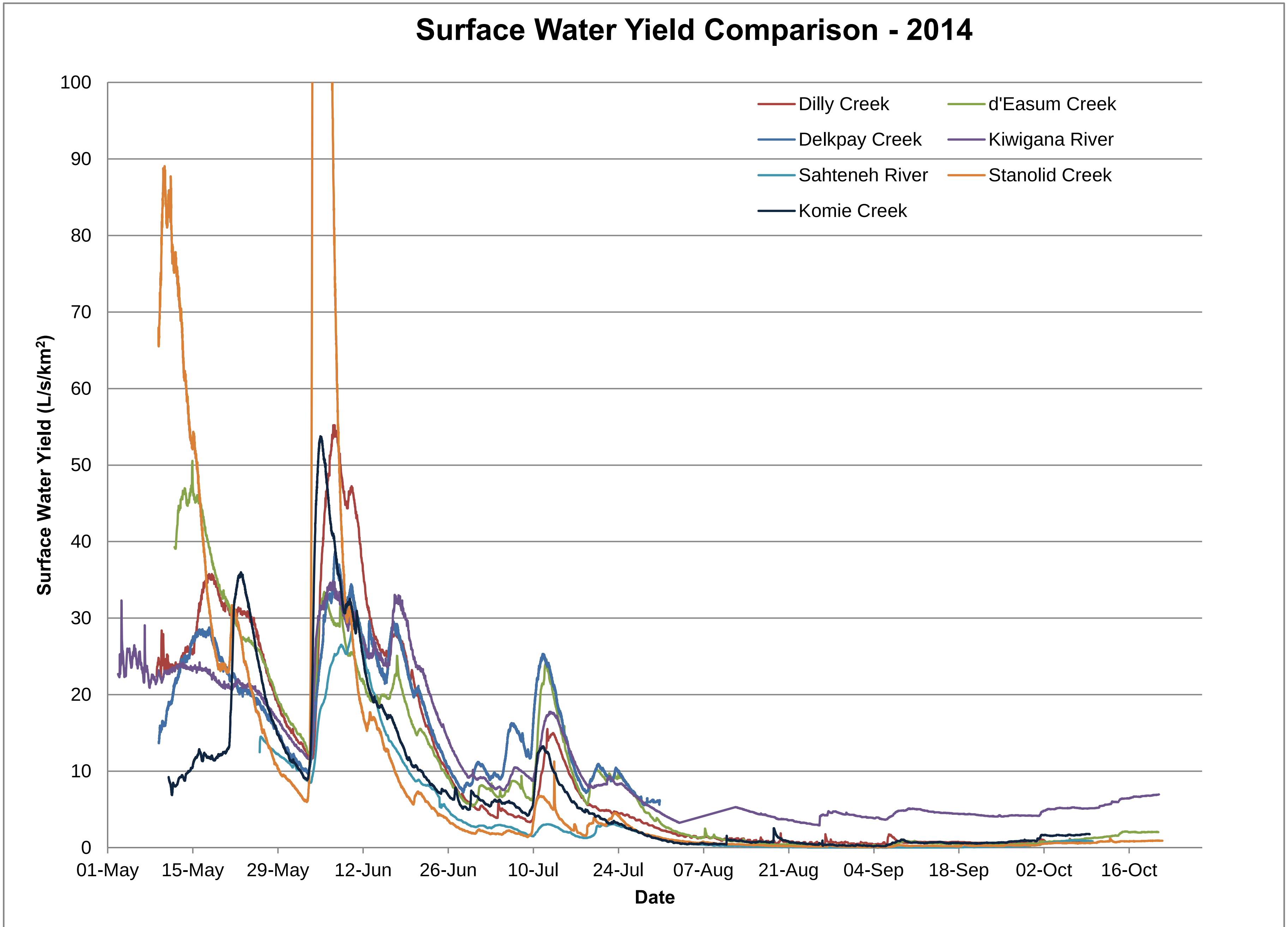

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Figure 26

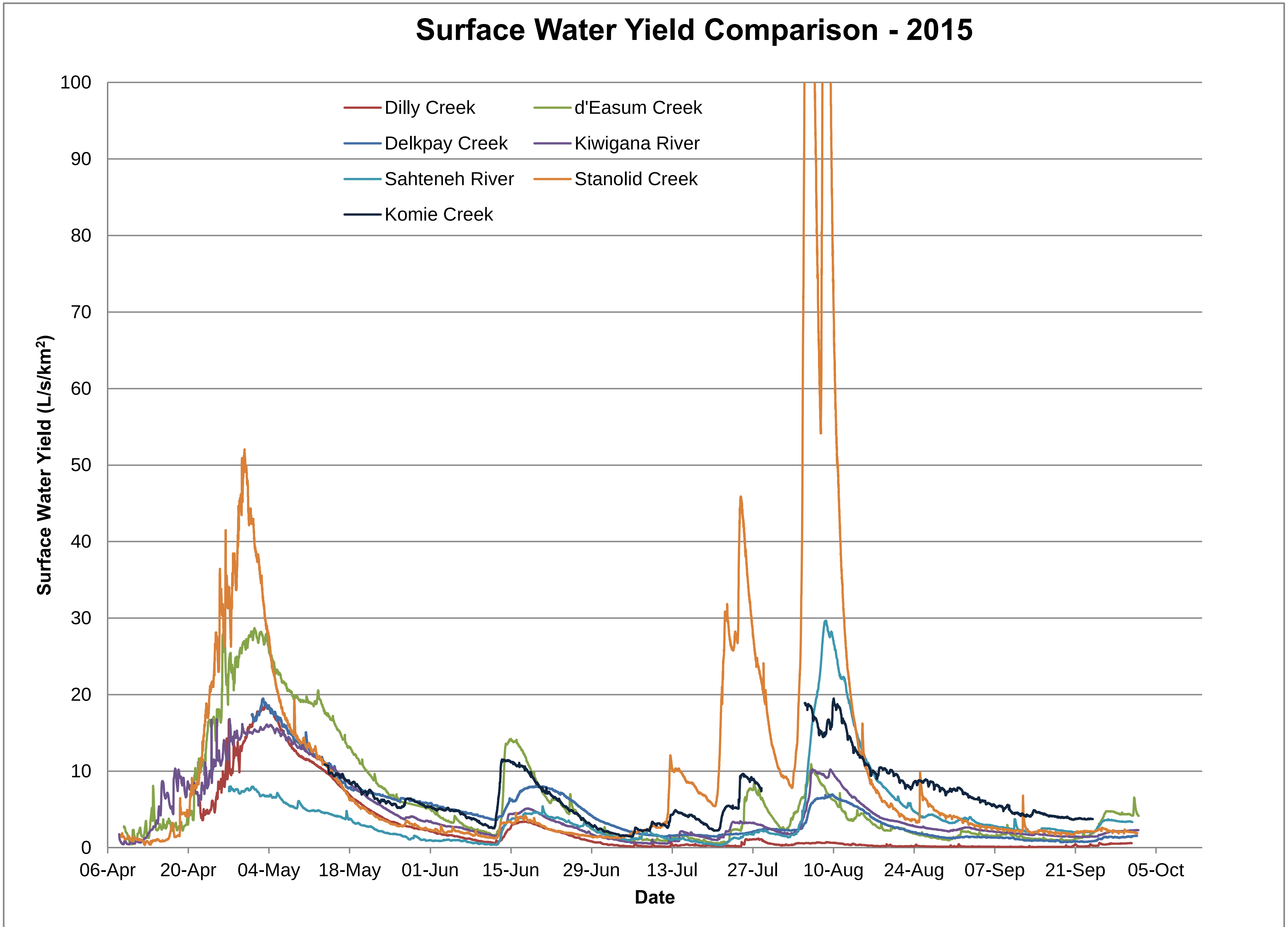

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Figure 27