Bow River BioSonics Pilot Survey with Water Quality Ground-truth Monitoring

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This report was prepared by:

Mike Wang	Ph.D, Surface Water Modelling Specialist, AENV
Amy Berlando	B.Sc, Water Quality Specialist, AENV

Reviewed by:

Dinesh Pokhrel	Ph.D, Water Quality Modeller, AENV
Niranjan Deshpande	M.Sc, Water Resource Engineer, P.Eng, City of Calgary
Lawrence Low	Senior Water Resource Technologist, Golder
Tom Tang	M.Sc, Environmental Modelling Team Lead, P.Eng, AENV

Project Team also includes:

Niandry Moreno	Ph.D, GIS and Water Modelling Specialist, P.Eng, AENV
Chris Plahn	Environmental Data Analyst, Golder
Josh Wilson	B.Sc, Water Resource Engineer, P.Eng, Golder
Barry Kobryn	M.Sc, Senior Environmental Scientist, City of Calgary

EXECUTIVE SUMMARY

The Bow River Basin is the most populated river basin in Alberta and the Bow River is a critical water source for many demands within the basin. The Bow River receives and assimilates numerous municipal wastewaters and agricultural return flows along its travel. As such, the water quality (WQ) and quantity of the Bow River Basin is increasingly under stress. Alberta Environment (AENV), The City of Calgary and Golder Associates Ltd. (Golder) are collaborating on the development of an integrated hydrological, hydrodynamic and water quality modelling system to support the protection and management of the Bow River Basin. It has been identified that river bathymetry, rooted vegetation (macrophyte), and sediment are among the key pre-requisite datasets for this model development. However, the conventional survey methods for these data are labor intensive and time consuming, which could not meet the needs for the model development.

This study was initialized to test and validate an innovative survey technique adopting the BioSonics DT-X echosounder©, manufactured by BioSonics Inc., which has been successfully applied for surveying vegetation and sediment in many estuary and lake systems, but not for a shallow riverine system, like the Bow River in Alberta, Canada. The site for this study was selected to be a 500 meter reach on the Bow River just below the City of Calgary's major wastewater treatment plant, the Bonnybrook Plant, where substantial levels of aquatic vegetation exist during summer. Two split beam transducers, one at a frequency of 200 kHz and the other at 400 kHz, were used to emit and receive sonar signals for measuring sediment and vegetation respectively. Other instruments, including a Real Time Kinematics (RTK) GPS unit and Acoustic Doppler Profiler (ADP), were mounted together with the BioSonics echosounders onto an inflatable motor boat to simultaneously collect bathymetry, vegetation, sediment and flow data for this riverine system. The BioSonics survey was performed three times under different growing seasons in 2010.

A ground-truthing water quality monitoring study was undertaken in parallel with the BioSonics survey to validate the BioSonics remotely sensed outputs. A number of water quality parameters were included in this ground-truth monitoring, such as flow/velocities, sediment characteristics, vegetation biomass, and nutrients from water, sediment, and vegetation, etc.

All field works were completed in 2010 and large amounts of data and samples were collected, analyzed, and processed. The field crews also identified several key operating solutions for BioSonics under a shallow riverine environment that included configuring the instrument and designing the voyage traces. An in-house Visual Basic program was developed to decode the BioSonics binary signal outputs. The spatial and temporal patterns of vegetation growth measured by BioSonics were validated by ground-truthing techniques. The ground-truth study results also provided an insight into the comprehensive impacts from the Bonnybrook Plant. It is expected to continue this study in 2011 towards further improving the BioSonics signal calibration and adopting the survey results to enhance the Bow River water quality model

LIST OF ACRONYMS

ADP	Acoustic Doppler Profiler
AENV	Alberta Environment
BOD	Biochemical Oxygen Demand
BRBC	Bow River Basin Council
BRWQM	Bow River Water Quality Model
DO	Dissolved Oxygen
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
GIS	Geographical Information System
Golder	Golder Associates Ltd.
GPS	Geographical Positioning System
LDB	Left Downstream Bank
NH3-N	Ammonia Nitrogen
NO2-NO3-N	Nitrate-Nitrite Nitrogen
RDB	Right Downstream Bank
RTK	Real Time Kinematics
SSRP	South Saskatchewan Region Plan
TDP	Total Dissolved Phosphorus
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WQ	Water Quality
WWTP	Waste Water Treatment Plant

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SECTION 1: INTRODUCTION

Background

The Bow River Basin is the most highly populated river basin in Alberta. The Bow River and its tributaries derive most of their flow from snowmelt typically during early May to mid July (BRBC, 2005) and are the critical water sources for many demands from the basin, including drinking water, irrigation, livestock operations, electricity, industry, recreation, fish and fish habitat, etc. On the other hand, the wastewaters from the local municipalities, industries, and agricultural irrigation canals are generally returned back to the Bow River. As such, the water quality and quantity of the Bow River Basin is increasingly under stress as a result of recent years' economic growth, population increase, and pressure for expansion of resource-based developments.

In response to the potential water quality issues, Alberta Environment (AENV) and the City of Calgary are promoting a cumulative effects environmental management approach to effectively plan for and manage the complex impacts from natural or human activities. The application of the State of the Art water quality models to the Bow River Basin, to evaluate the achievement of environmental outcomes under various management and engineering options, has been identified as a key approach for implementing the water management frameworks for the Bow River Basin (Figure 1).

The City of Calgary initialized the development of the Bow River Water Quality Model (BRWQM) for the Bow River reach mainly within the City Limits in 2004 (Golder 2004a). The City of Calgary then applied the model to develop the total loading management targets for a number of key variables, such as BOD (Biochemical Oxygen Demand), nutrients and suspended solids, in the effluents from its managed wastewater treatment plants (WWTP) and storm sewers (Golder 2004b).

Under the agreement with the City of Calgary, AENV is involved in the expansion of the existing BRWQM to cover the entire Bow River reach. So far, the BRWQM has also been advanced to be an integrated modelling system and is supported by GIS (Geographical Information System) mapping and database system (Figure 2). Spatially, the BRWQM has been expanded to incorporate the mainstem of the Bow River from the Bearspaw Dam to the Bassano Dam, as well as the associated sub-watersheds that drain surface runoffs into this range of reach. In 2009 and early 2010, AENV carried out a number of model simulations to evaluate and compare the impacts from the development scenarios by the South Saskatchewan Regional Plan (SSRP) (AENV, 2010).

One of the key prerequisite datasets for the expansion and upgrade of the BRWQM is the river cross-sectional bathymetry data. River bathymetry defines the unique spatial geometry of a channel and determines how the upstream water routes through the river. However, the collection of bathymetry data used to be labor intensive and time consuming. Consequentially, the bathymetry data are typically missing for most parts of the Bow River. Recently, a more cost-effective survey approach has been developed and applied for river hydraulic survey by coupling Real Time Kinematics (RTK) GPS unit

and Acoustic Doppler Profiler (ADP) instrument. This technique allows collection of channel bathymetry data along with instream flow/velocity data, and surface water elevation data efficiently.

Figure 1. Role of Water Quality Model

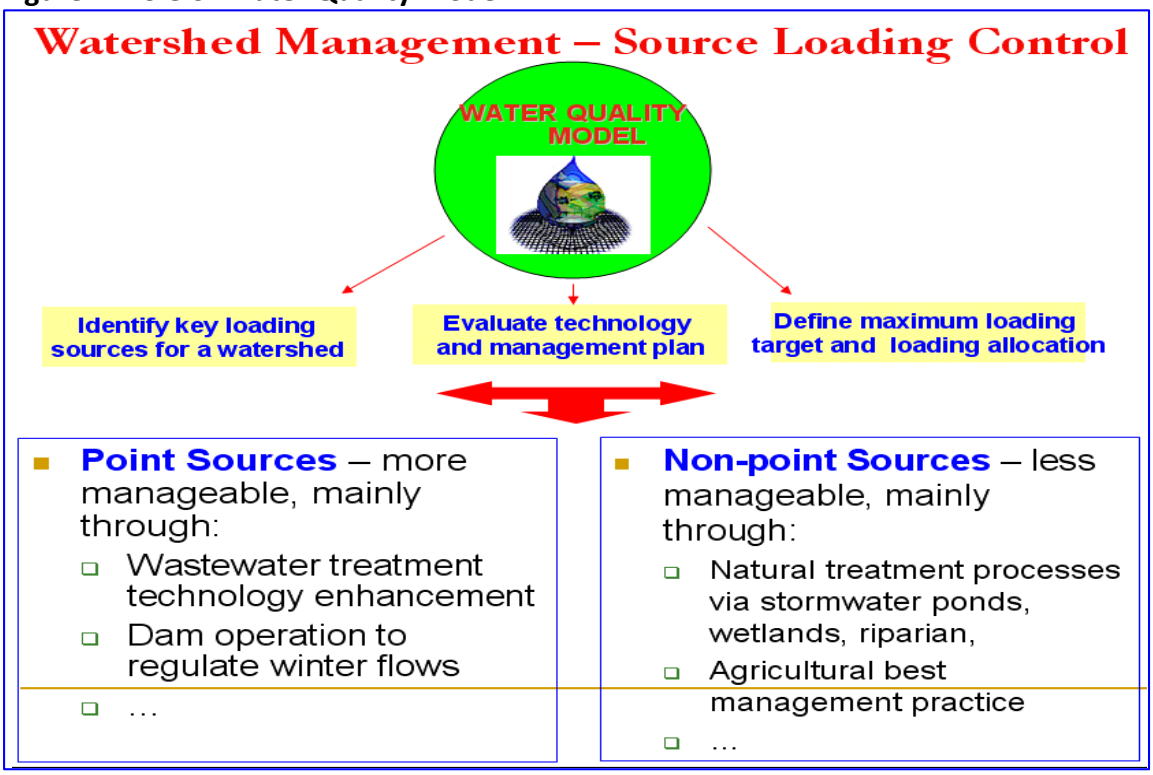
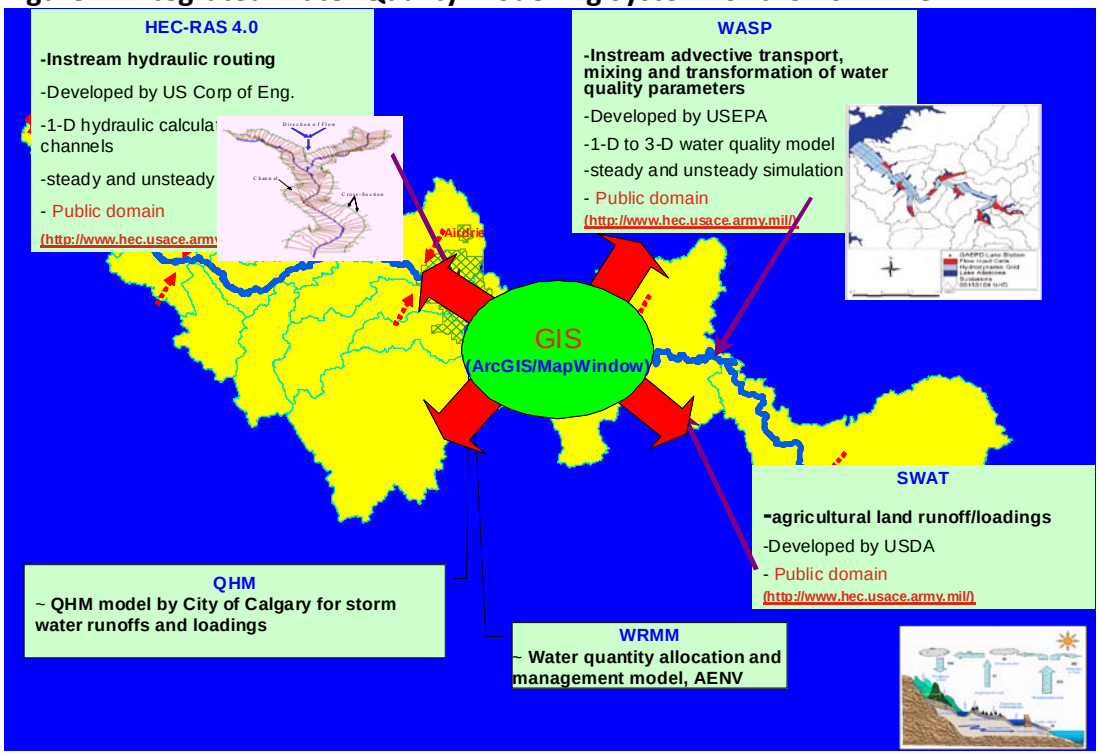


Figure 2. Integrated Water Quality Modelling System for the Bow River



In addition to the hydraulic information, the development and enhancement of the BRWQM relies extensively on the knowledge of the aquatic ecosystem of the Bow River, i.e., the properties of the sediment and the characteristics of the vegetations. The BRWQM accounts for very complicated physical, chemical and biological processes for a number of the key water quality parameters existing in both the water and the sediment columns, as depicted in Figure 3. These processes determine the fates of the selected parameters and their impacts on the most sensitive water quality parameter of the Bow River, dissolved oxygen (DO). Among all water quality parameters that are of concern, macrophytes and periphyton are considered as the core parameters for the Bow River, since these two parameters regulate the fates of almost all the other water quality parameters for the Bow River.

Historical water quality studies have identified macrophytes as the predominant aquatic vegetation in the Bow River, especially for the reach within and below the City of Calgary. Figure 4 illustrates the relationship of macrophyte and thier profound impacts on many other environmental factors and water quality parameters. Macrophytes control the eutrophication process and regulate the changes in DO and nutrients during its growing season (mainly between May to October of a year) They also impacts the bulk flow of the Bow River water by increasing the shear stresses and introducing higher level of turbulent mixing.

Figure 3. Key Physical, Chemical and Biological Pathways for Water Quality Parameters in Bow River Water Quality Model

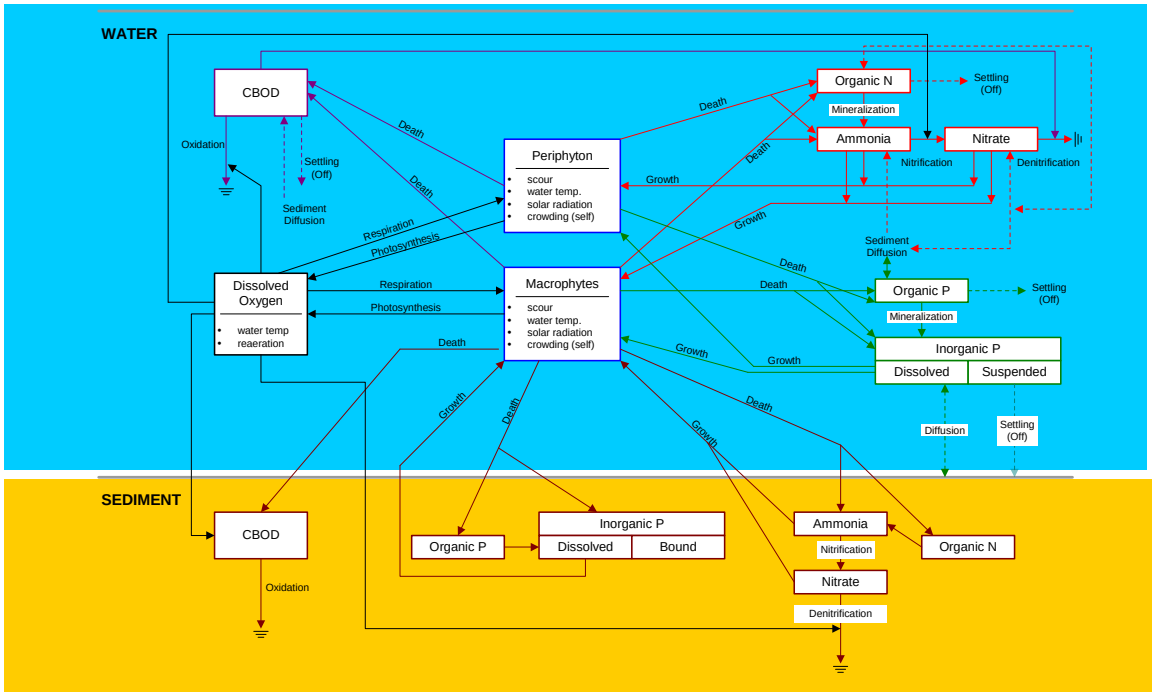
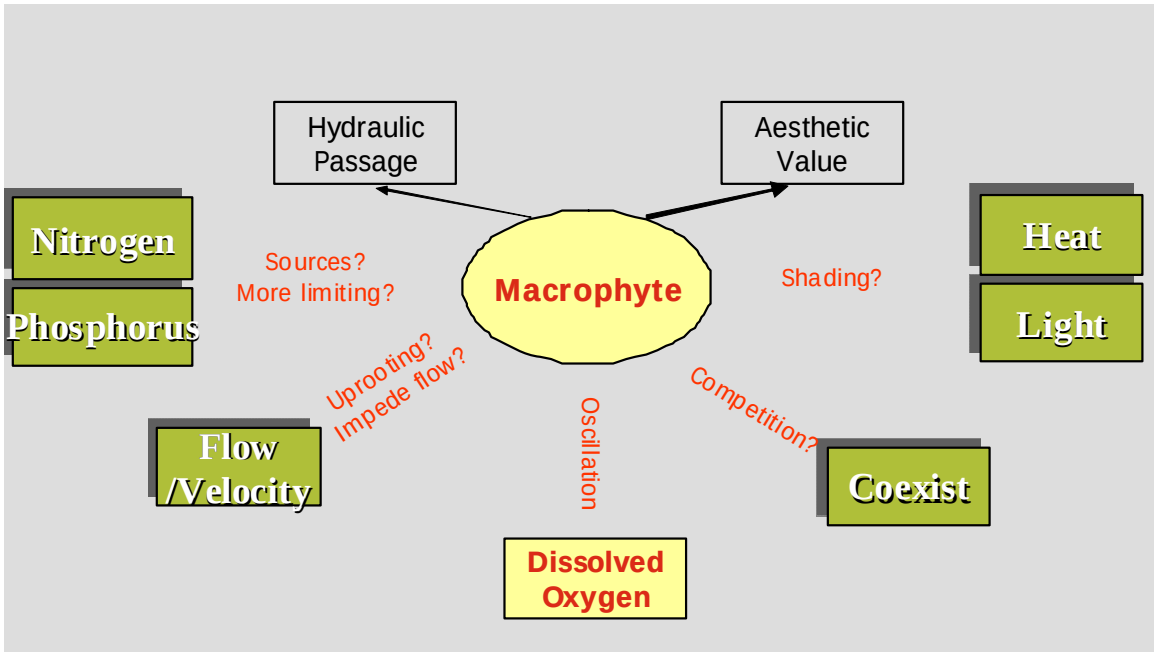


Figure 4. Macrophyte and Its Interactive Relationship with Various Ambient Environmental Factors

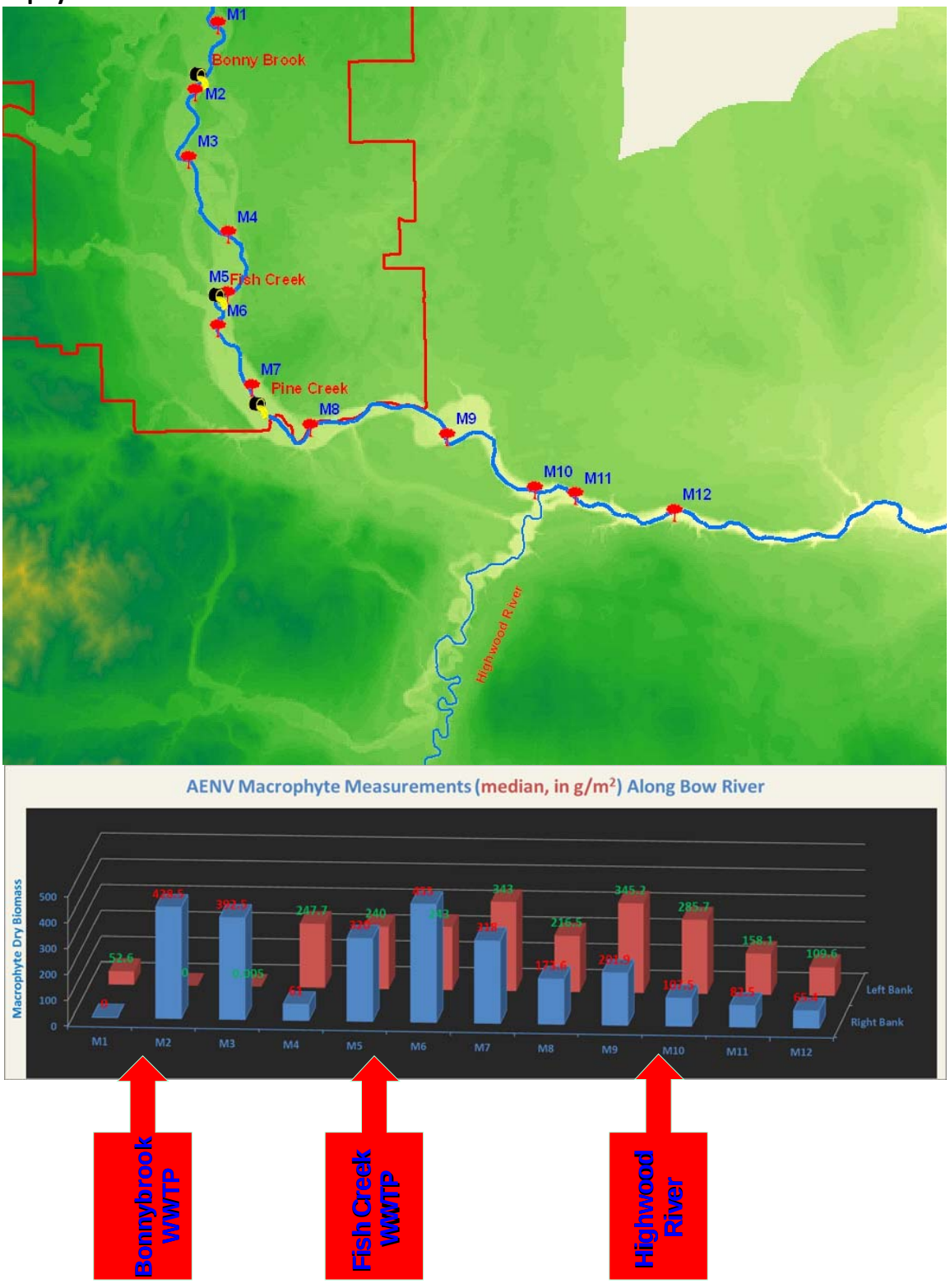


Aquatic macrophytes are also a direct linkage of water quality conditions between the water column and sediment column. The macrophyte is a rooted plant with the capability to take up nutrients from both water and sediment media. The biomass of macrophyte exists mainly within the water column, but it will return to the sediment after dying. Due to the combined impacts of the macrophyte on its ambient environment, macrophytes are considered as one of the few key water quality indicators for the Bow River. Figure 5 is a photo of a macrophyte population established in the Bow River, just downstream of the City of Calgary's Bonnybrook WWTP (taken by Amy Berlando during the summer of 2010), and it is relatively simple to come up with some preliminary conclusions of the summer water quality condition for the Bow River after reviewing the status of macrophyte growth demonstrated in this photo.

Figure 5. Photo of Macrophyte at Bow River near Bonnybrook Wastewater Treatment Plant

To effectively perform Bow River water quality management, AENV launched a macrophyte monitoring program in 1981. Twelve macrophyte monitoring sites were selected along the Bow River, with the most upstream site just above the Bonnybrook WWTP and the most downstream site around Carseland (Figure 6).

Figure 6. AENV Launched Macrophyte Monitoring Sites and Statistic Summary of Macrophyte Measurements



However, AENV only performs macrophyte sampling once every year and the sampling time is usually set around the first week of September. At each site, a field crew usually takes macropyte samples from locations near the banks of the river, so the sampling is limited to the shallower water. Figure 6 presents the statistic summary of macrophyte measurements (during 1981 to 2010) from both banks of each monitoring site. It is clear, based on this figure, that the macrophyte abundances and distributions along the Bow River are closely related to the major nutrients sources and their locations as indicated in this figure.

At present, AENV is promoting the cumulative effect management approach for protection of the water quality conditions in the Bow River, and the BRWQM system was identified as the key tool to support best management decision making for this complex river basin. There is a significant need to enhance the BRWQM to be able to reliably represent the receiving waters responses to cumulative impacts from human developments, which leads to more detailed requirements of data for macrophytes, sediment, and bathymetry. This study, therefore, was designed to explore and identify a more cost-effective and reliable survey approach for the Bow River.

SECTION 2: STUDY OBJECTIVES

Due to the Bow River water quality management needs and the requirements for enhancing the BRWQM, a pilot scale study was designed to test and validate a new survey approach proposed by Golder Associates Ltd (Golder). This approach is based on the BioSonics instrument developed by BioSonics Inc, USA. It is sonar and GPS based technique and is capable of providing a platform for integrated survey of bathymetry, sediment, vegetation and flow/velocity. The study objectives for this phase of work are defined to be as below:

- To develop a reliable and cost-effective approach, using BioSonics© technology, to perform an integrated field survey of bathymetry, hydraulic flow/velocity, sediment, and vegetation;
- To validate the bathymetry and hydraulic flow/velocity data from this study against the data collected for the same range of reach by Golder for other projects;
- To validate the sediment and vegetation data obtained from BioSonics against the sampling data collected and analyzed by AENV staffs using conventional sampling techniques;
- To study the seasonal variation patterns of aquatic vegetation growth via multiple sampling events scheduled during different seasons of a year;
- To understand the influence of the wastewater plumes on the cross-sectional water quality conditions and the growth of aquatic vegetation;
- To determine the stoichiometry of the sampled biomass (macrophyte and periphyton), i.e. the composition of nitrogen, phosphorus and carbon in the dry biomass of the collected biomass samples, as well as the sediment properties.

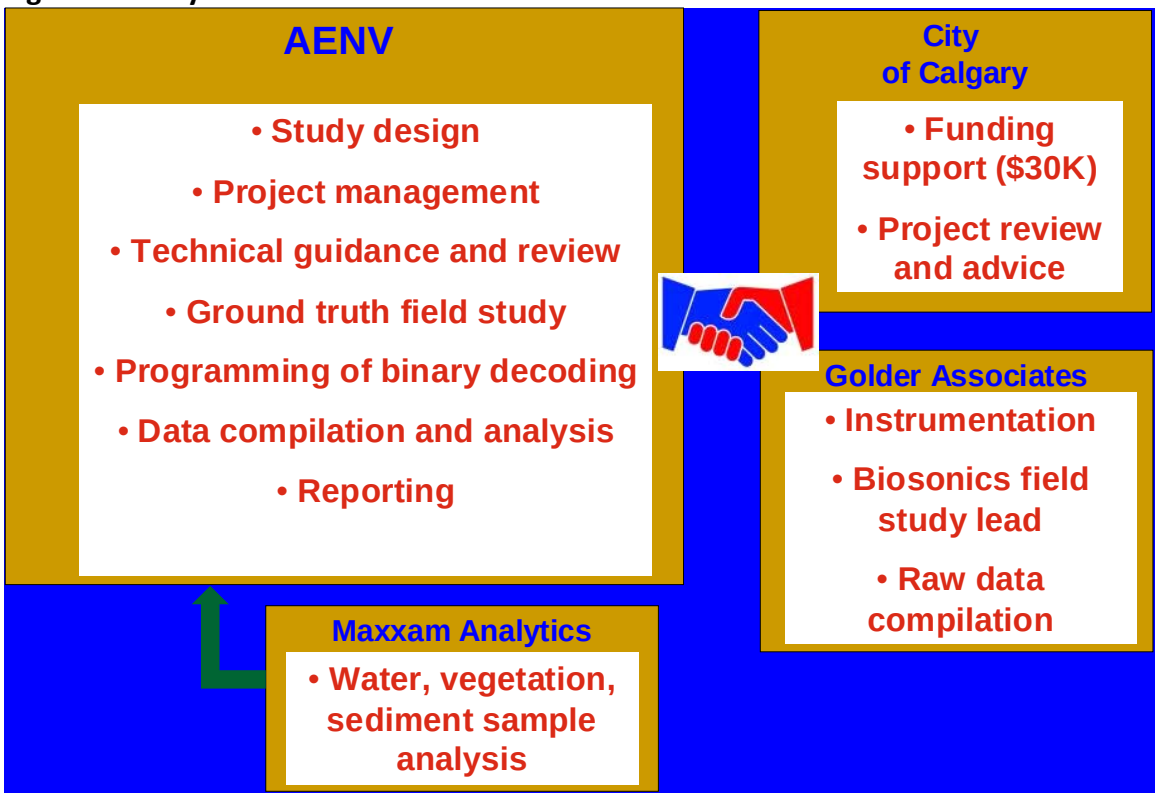
SECTION 3: STUDY DESIGN AND APPROACH

Study Team and Budget

This study was undertaken by a team combined of specialists from three organizations, AENV, the City of Calgary, and Golder. Each organization made unique contributions to the study, as shown in Figure 7.

The total budget for this phase of study was $30,000, which was provided by the City of Calgary to cover the instrumentation and BioSonics field work costs and the commercial laboratory analysis cost. AENV contributed to the technical and management requirements and the WQ ground-truth works for this study.

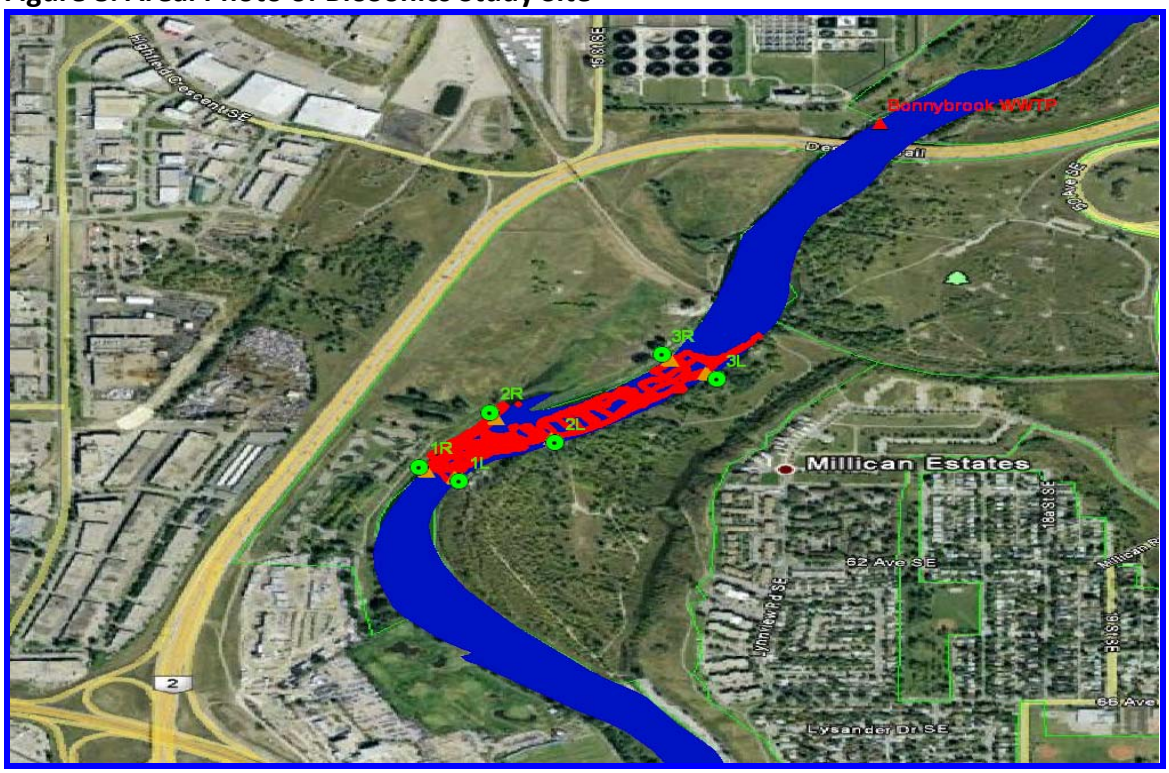
Figure 7. Study Team and Relevant Roles



Study Site

The study site was selected to be just below the Bonnybrook Wastewater Treatment Plant, one of the key sewage treatment systems operated by the City of Calgary (Figure 8). This length of the selected reach was about 500 m, and typically exhibits very different growth patterns of aquatic vegetations between its right bank and left bank during growing season. This site was also selected because it provides good routes for field crews to access the river and launch the boat.

Figure 8. Areal Photo of BioSonics Study Site*



(*: this picture is sourced from the air photo by Google Earth, 1R, 2R and 3R are the selected right bank ground truth monitoring sites, 1L, 2L and 3L are the left bank sites)

BioSonics Survey Approach

This study was initialized to test and validate an innovative survey technique using a BioSonics DT-X echosounder©, which was manufactured by BioSonics Inc., USA, and has been successfully applied for surveying vegetation and sediment in many estuary and lake systems, but not usually for a shallow riverine system, such as the Bow River in Alberta, Canada. This section of the report presents the following information:

- background theory on which the BioSonics technique is based;
- how the BioSonics instrument is integrated with other river monitoring tools to achieve a multi-purposed eco-system survey;
- how the survey traces were configured for supporting efficient data collection and analysis;
- the timing arrangement for the field trips;
- the methods adopted for processing and analyzing the collected raw sonar data.

Background Theory of BioSonics Survey

BioSonics is a hydro-acoustic based technique that employs the propagation of under-water sound to detect objects of interest. It employs a sound transducer to create a pulse of sound (usually called "Ping") into the water and then receive the reflection (echo) of the pulse (Figure 9). The sound pulse echoed back from an underwater object will carry some unique footprints, which could be processed digitally for creation of a color coded graph, called an echogram. Figure 10 demonstrates the echograms for sediment and rooted vegetations (BioSonics, 2010). These echograms are useful for interpretation of the nature of a particular underwater object.

In this phase of the study, Golder employed two split beam transducers of BioSonics DT-X echosounder, one at frequency 200 kHz and the other at 400 kHz, to transmit and receive sonar signals for measuring sediment and vegetation respectively. Meanwhile, other instruments were also mounted together with the BioSonics echosounder onto an inflatable motor boat, which includes (Figure 11):

- a Real Time Kinematics (RTK) GPS unit for determining and logging the locations;
- an Acoustic Doppler Profiler (ADP) Sontek M9 unit for measuring velocity of the river flow;
- cameras for taking under water images or video clips;
- Lawrence Fish Finder for collection of another independent set of sonar signals for validation of BioSonics sonar signals;

- laptop and relevant software for storing, processing and visualizing real time sonar data during a survey.

All the above instruments were synchronized with the BioSonics DT-X echosounder, which allows simultaneous collection of bathymetry, vegetation, sediment, and flow/velocity data for characterizing the surveyed riverine system.

Figure 9. Illustration of BioSonics Technique

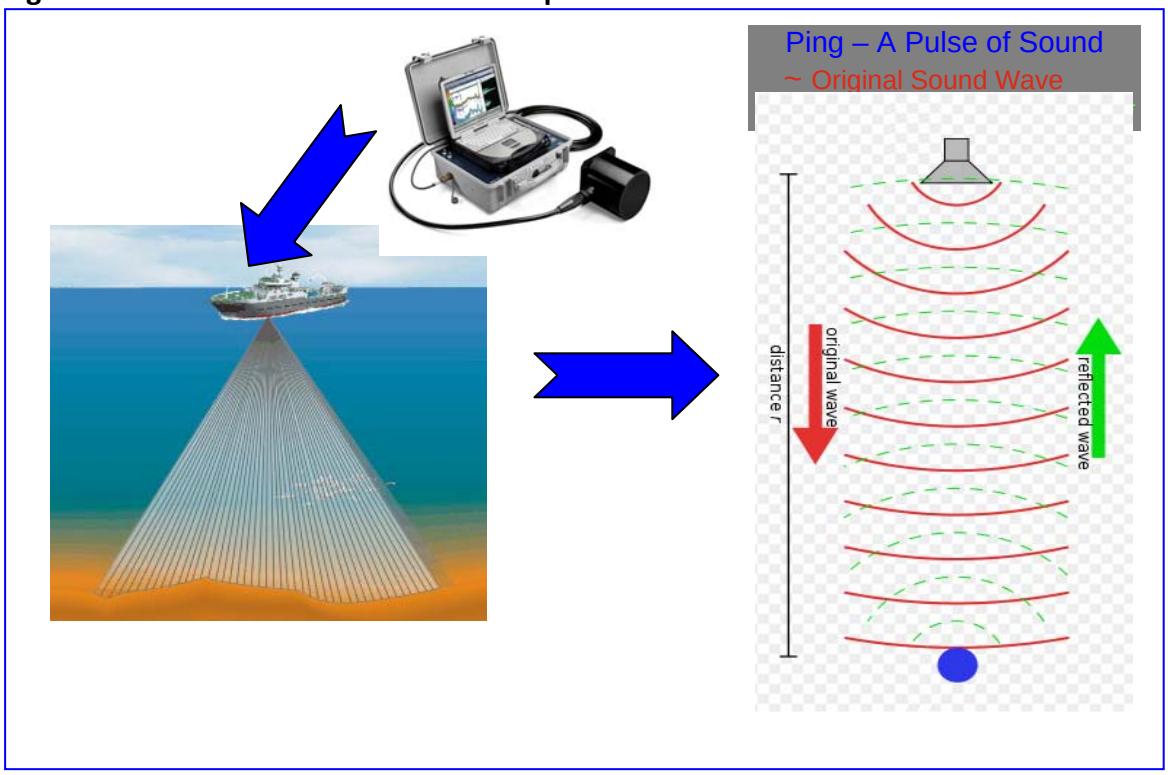
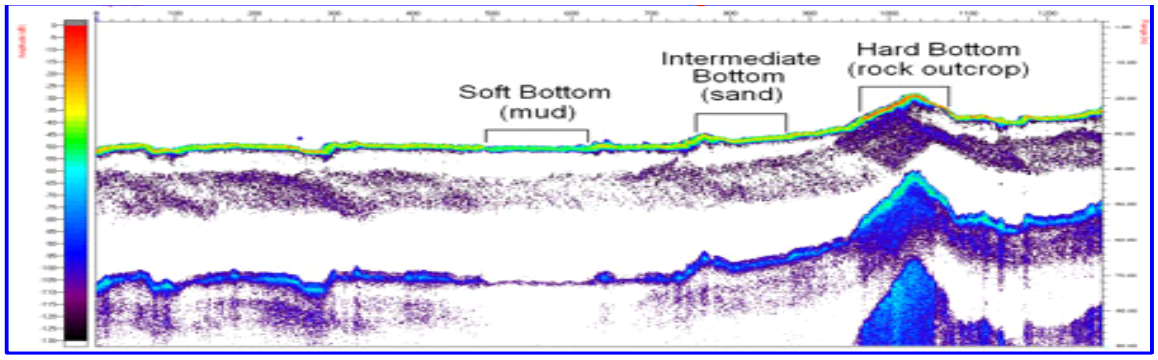


Figure 10. BioSonics Echograms of Bottom Sediment and Rooted Vegetation

Bottom Sediment



Rooted Vegetation

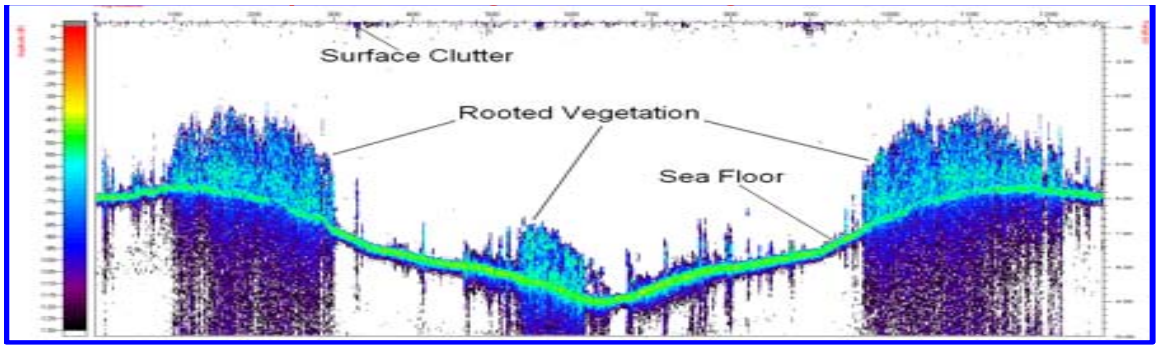
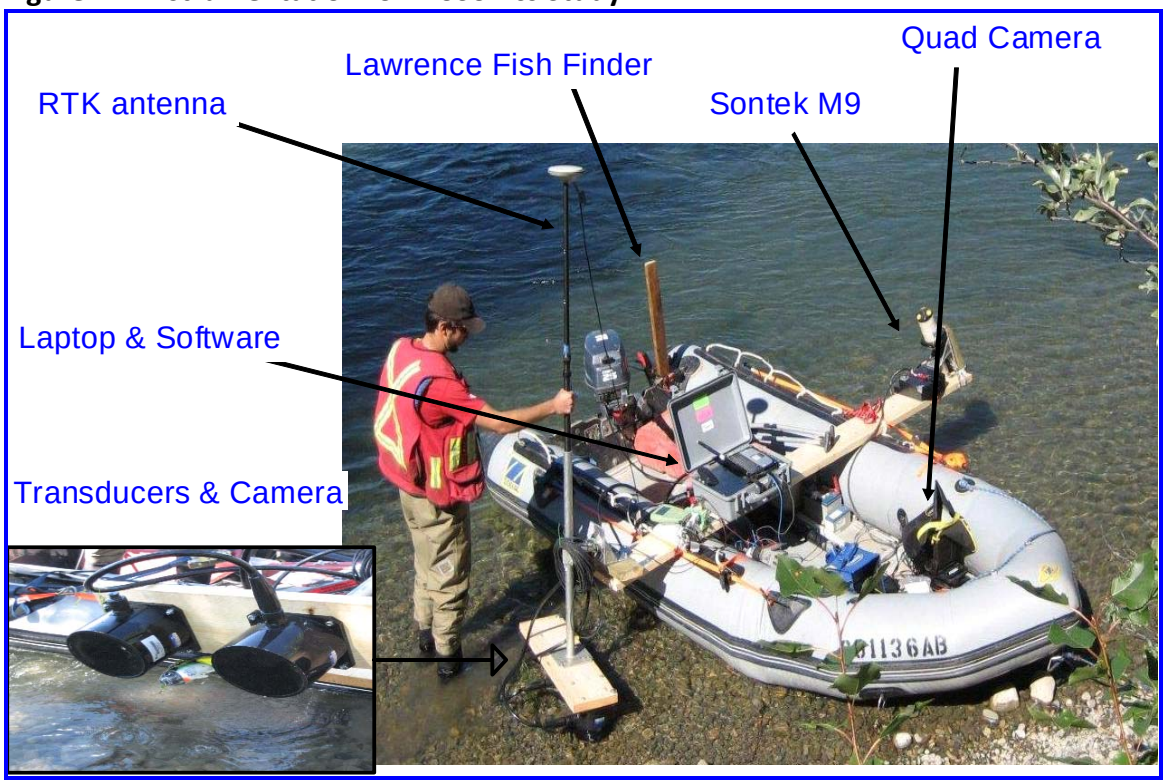


Figure 11. Instrumentation for BioSonics Study



BioSonics Transducer Configuration

BioSonics transducer is the core component of the entire survey instrument assembly. There are a number of parameters that need to be configured for a transducer before a field trip in order for the collection of quality sonar signals. The Golder and AENV field staff used several trial runs to identify the optimal ranges for the key parameters of the BioSonics transducers. Table 1 documents the values that were identified and used for several key parameters of the BioSonics transducers, as well as some recommendations of whether future adjustments should be considered for these parameters.

Table 1. Identified and Recommended BioSonics Parameter Settings

	Set Values	Recommendations
Transmit Pulse Duration	0.4 ms	-
Start Range	0 m	-
End Range	5 m	Reduce to 3 m
Data Collection Threshold Value	-130 dB	-
Environmental Input (pH, temperature, conductance)	Variables	Taken measured values from channel centre
Bottom Peak Threshold	-50 dB	Suggested to be reduced for areas with dense vegetation growth

Survey Trace Design

The survey trace is the route field crews select to follow along the river during a BioSonics survey. Survey trace is crucial as it determines how well the collected data are able to represent the spatial distribution of the object being surveyed. Properly designed survey trace also allows for more efficient collection of quality data.

Golder and AENV field crews experimented different patterns of survey traces during this phase of the study, which are shown in Figure 12. The BioSonics traces in Figure 12(a) made very detailed and dense coverage of the targeted reach. However, these traces were based on more or less random voyages across the channel and unavoidably, resulted in several places with substantial data gaps (areas without trace coverage as highlighted by the yellow circle in this figure). This pattern of traces also ended up with much longer field time and efforts for completion of the survey.

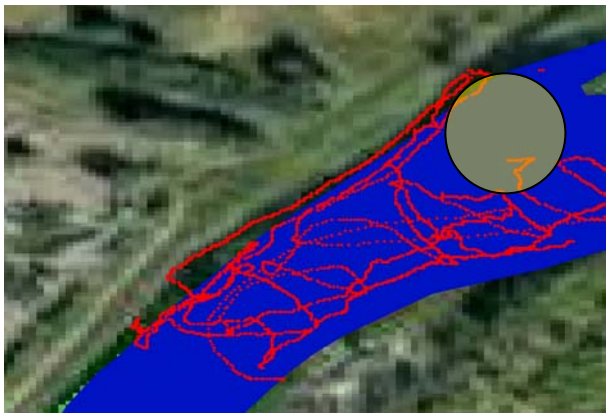
The design of the trace in Figure 12(b) is much more structured, and the actual survey was able to be completed within much shorter time frame than the one shown in Figure 12(a). However, there are still a number of areas that are loosely covered by the traces.

The trace designed and implemented as shown in Figure 12(c) is regarded as the most preferred pattern of survey traces. This trace follows a well structured and consistent route, which allows for balanced coverage of the survey channel both laterally and longitudinally. This pattern of trace design could usually be followed most efficiently in

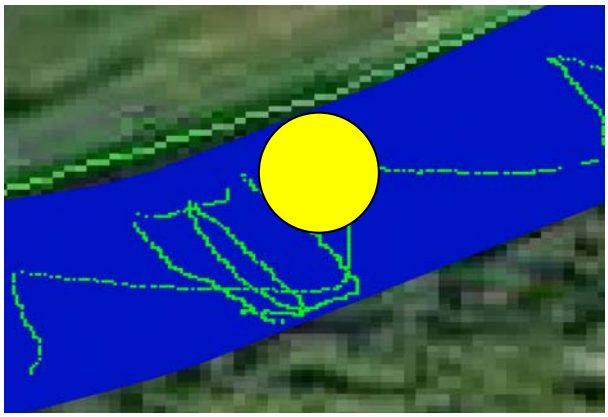
the field, which could also effectively avoid the occurrences of areas with unevenly distributed data gaps.

Figure 12. Comparison of Survey Traces Applied for Different BioSonics Field Surveys

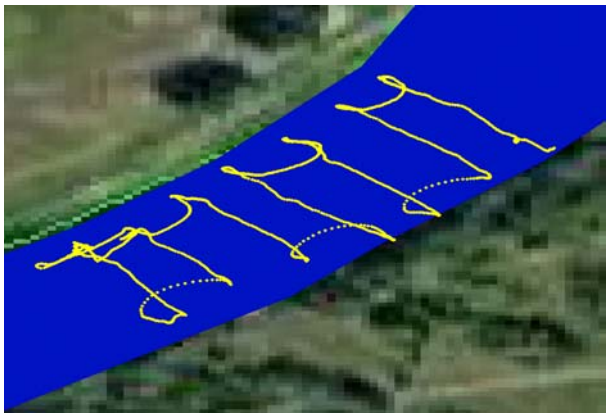
(a) Trace 1



(b) Trace 2



(c) Trace 3



Field Trip Timing

Field trip timing for this study mainly considered two major factors, the seasonal change of the vegetation growth, and the available funding. Based on these, three trips were scheduled for this phase of the study:

- the first trip occurred on July 26, 2010, when the growth condition was near optimal in a year;
- the second trip occurred on September 2, 2010, when the biomass of macrophyte reached its peak amount;
- the third trip occurred on October 15, 2010, when the aquatic vegetation started to die off.

Data Analysis Methods

This BioSonics survey was designed to be an integrated field data collection process for channel bathymetry data, sonar data for both vegetation and bottom sediment, and flow velocity data.

Channel bathymetry data was analyzed using Environmental Systems Research Institute (ESRI)'s ArcMap GIS program. The collected channel three dimensional data (x, y, z) were compiled and loaded into ArcMap to generate Digital Terrain Model (DTM). Three channel cross-section profiles were then derived based on the developed DTM, which were compared and evaluated against the relevant cross-section profiles provided from the City of Calgary's Bow River Flood Plain Mapping project in 2009/2010 (also called O'Connor data).

The raw sonar data collected from BioSonics DT-X echosounder were split first into two groups of data using Visual Acquisition 6, a freeware provided by BioSonics Inc. The two groups of split data are sonar signals from 200 kHz and 400 kHz transducers respectively. The 200 kHz sonar data are more useful for analyzing sediment, while the 400 kHz data are specifically for analyzing vegetation.

One of the challenges that needed to be dealt with during this study was that the raw sonar data are in binary format, which is not directly applicable to general user. BioSonics Inc provides commercial software to support the binary sonar data analysis and visualization (EcoSav 1.0 and 2.0). The algorithms used in these programs were recognized to be limited for analyzing the vegetations in deep waters, such as ocean or estuary waters. However, these equations were found not very applicable when used for calculating shallow water vegetations.

As such, the project team decided to develop an in-house program to decode the binary formatted data based on the BioSonics' publicly provided document on the binary data formats (BioSonics, 2010). This in-house program was developed using Visual Basic for Application (VBA) and a simple user interface was developed to facilitate the data analysis tasks (Figure 13). The decoded sonar data include the following information of a ping (a pulse of sonar echo), which is demonstrated in Figure 14:

- ping number
- latitude and longitude of a ping;
- time of a ping,
- bottom weakness of a ping,
- range (vertical distribution) of a ping;
- target strength in dβ.

Figure 15 shows the target strength profile decoded from a particular sonar ping using the in-house developed binary data decoding program. In the future, the study team is capable of using this decoding program to test and develop the algorithms that could be applied to predict the rooted plant biomass using the sonar echo signals. Tecplot Focus 2010 (by Tecplot Inc) was also applied in this study to support visualization and animation of the decoded sonar signals.

Figure 13. Interface of BioSonics Sonar Data Decoding Program Developed by AENV

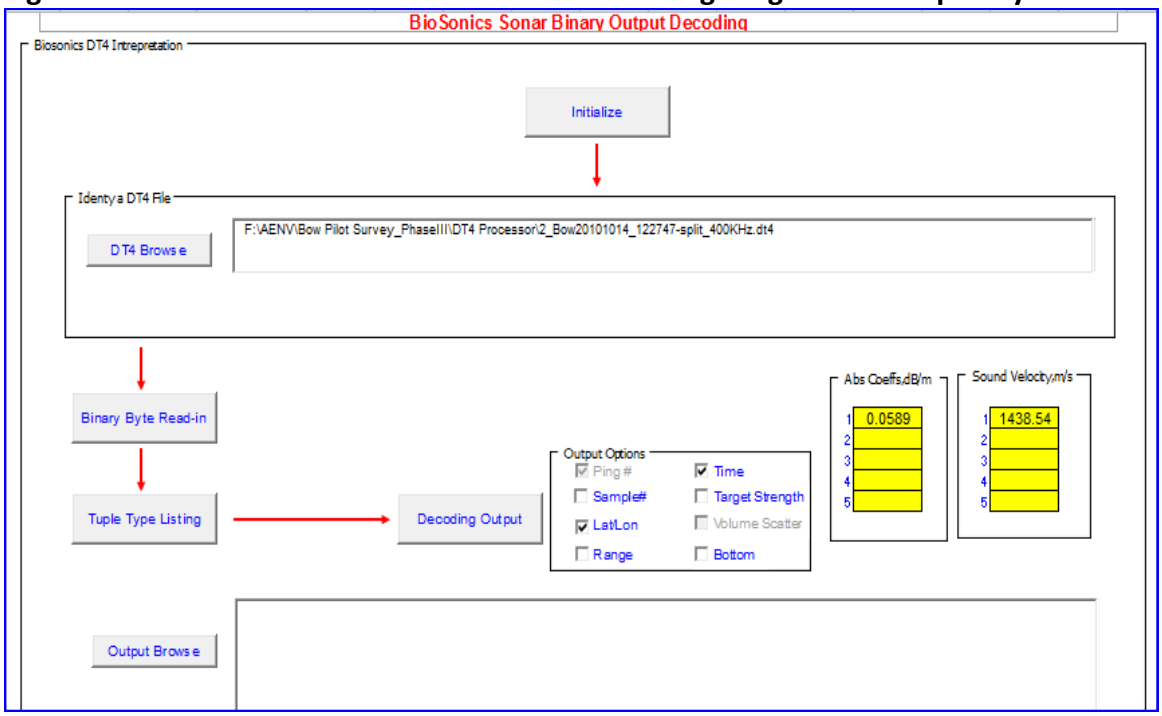


Figure 14. Decoded Information from BioSonics Sonar Binary Data

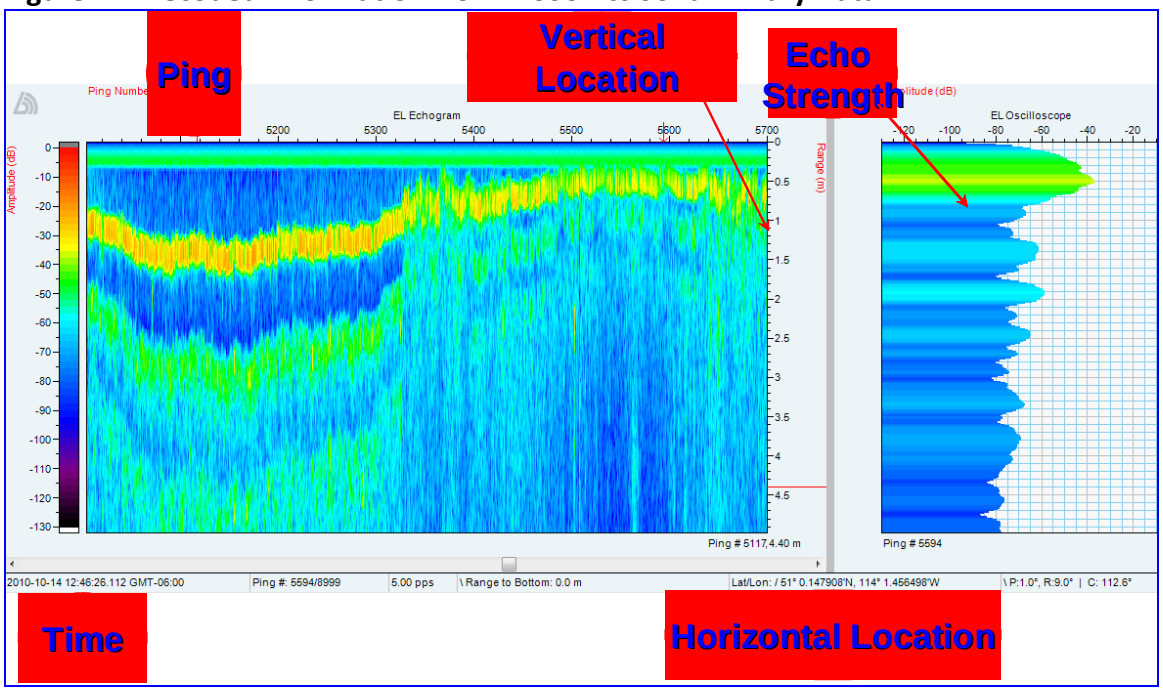
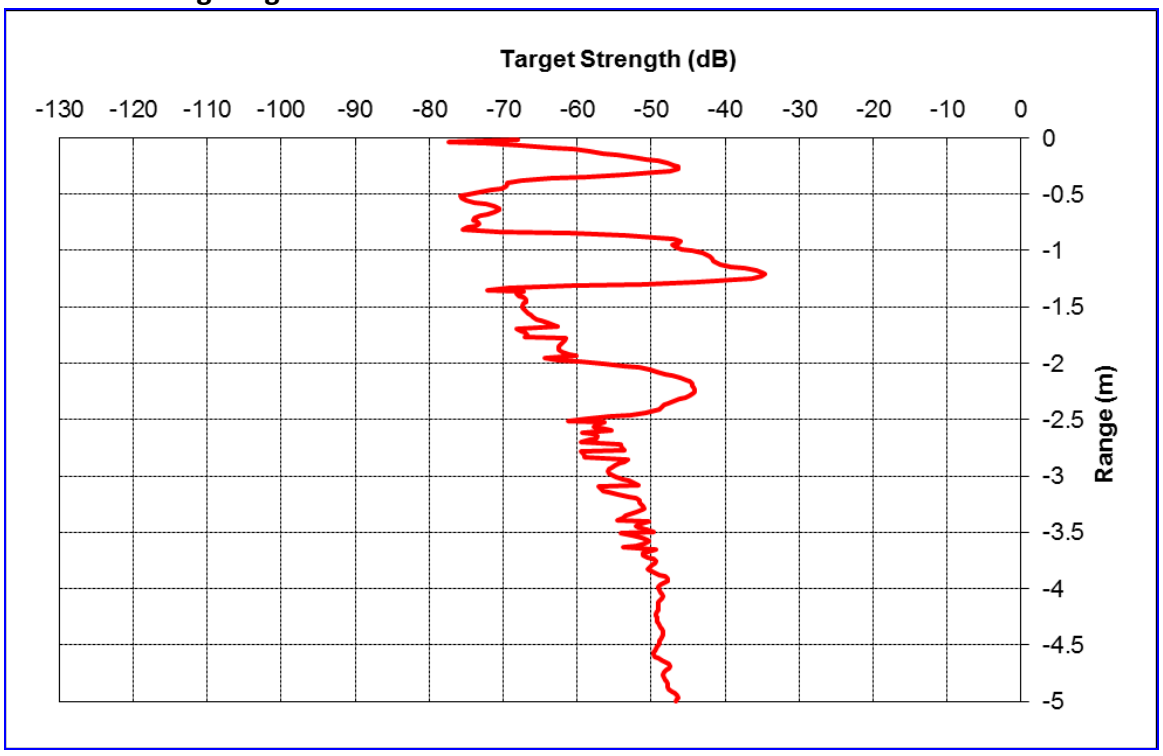


Figure 15. Decoded Target Echo Amplitude Profile Generated from AENV Developed Sonar Decoding Program



The horizontal velocity vector results from M9 Sounder were analyzed by using both ArcMap and Tecplot program to understand the changes of its magnitude and the flow directions.

Other BioSonics survey data include photos and images of the field, as well as the movie files from under-water cameras. These image data provide valuable qualitative information for associating the BioSonics sonar signals with the actual biomass growth along the river. These image data were categorized based on the time and location that were taken and then were compared with the decoded BioSonics sonar signal.

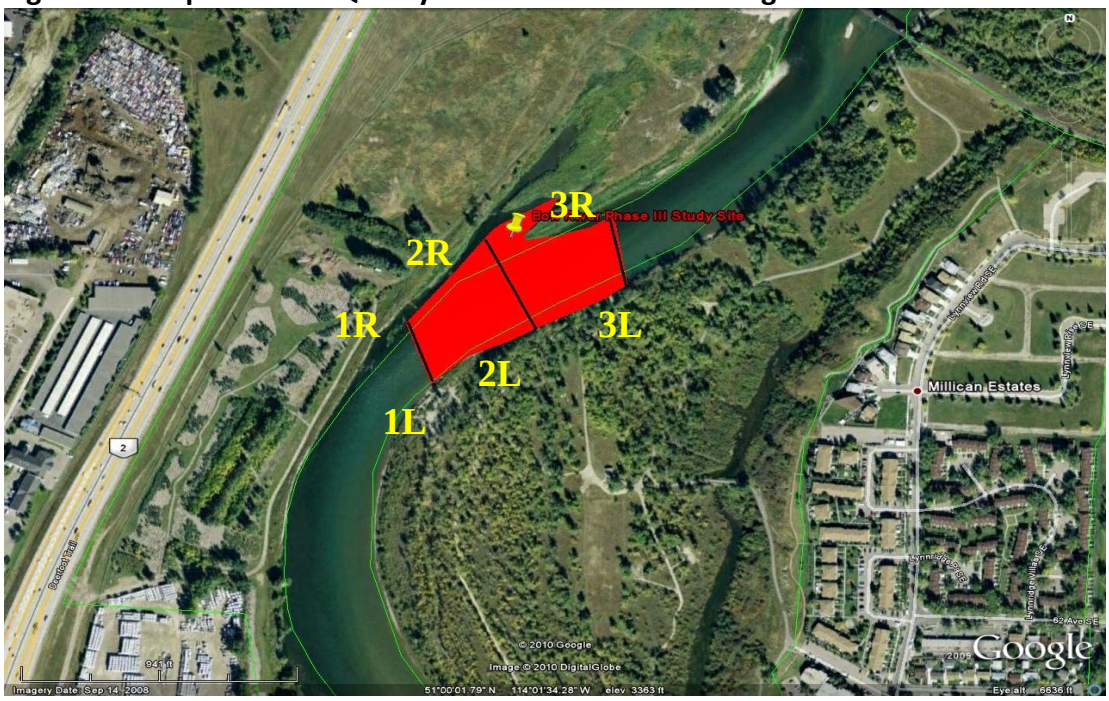
Water Quality Ground-truth Study Approach

Sampling Sites and Timing

A pre-determined 500 m reach of the Bow River downstream of the Bonnybrook WWTP in Calgary was surveyed three times during the growing season; on July 27th, Aug 31st, and Oct 14th, with BioSonics sonar technology. For each of the sonar surveys, field measurements and samples were collected the following day in order to validate the BioSonics technology's ability for prediction of biomass and to understand the spatial and temporal differences for various water quality parameters, as well as determine the stoichiometry of sediment and aquatic vegetation in the area affected by the WWTP discharge.

Within the reach three transects were chosen to collect the field measurements: a downstream site-transect 1, a middle site-transect 2, and an upstream site-transect 3. At each transect, benchmark points were set at both banks of the river using RTK rover. The bench markers provided exact location information and served as a reference point for each trip (Figure 16).

Figure 16. Map of Water Quality Ground Truth Monitoring



Selected Parameters

The water quality parameters that AENV was capable of carrying out in-house analysis were collected each field trip. Due to budget constrains; the parameters that AENV had no in house analytical capacity were only collected in some of the trips, and were submitted to Maxxam Analytics for analysis. The list of the water quality parameters and the field trips are shown in Table 2.

Table 2. Selected Sampling Parameters

	Parameter	Analysis	Trip 1	Trip 2	Trip 3
Physical	Macrophyte Density	AENV	x	x	X
	Periphyton Density	AENV	x	x	X
	Depth & Velocity	AENV	x	x	X
	Light Availability	AENV	x	x	X
	Temperature	AENV	x	x	X
Water Chemistry	Dissolved Oxygen (DO)	AENV	x	x	X
	Conductivity	AENV	x	x	X
	Total Dissolved Solids (TDS)	AENV	x	x	X
	pH	AENV	x	x	X
	Ammonia-Nitrogen (NH_3-N)	Maxxam		x	X
	Nitrate & Nitrite-N ($N0_2$-NO_3-N)	Maxxam		x	X
	Total Kjeldahl Nitogen (TKN)	Maxxam		x	X
	Ortho-Phosphate (PO_4-P)	Maxxam		x	X
	Total Phosphorus (TP-P)	Maxxam		x	X
	Total Dissolved Phosphorus (TDP-P)	Maxxam		x	X
Sediment	Total Nitrogen	Maxxam		x	X
	Total Phosphorus	Maxxam		x	X
	Total Organic Carbon (TOC)	Maxxam		x	
	Moisture	Maxxam		x	
	Particle Size	Maxxam		x	
Macrophyte Tissue	Total Nitrogen	Maxxam		x	
	Total Phosphorus	Maxxam		x	
	Total Organic Carbon (TOC)	Maxxam		x	
Periphyton Tissue	Total Nitrogen	Maxxam		x	
	Total Phosphorus	Maxxam		x	
	Total Organic Carbon (TOC)	Maxxam		x	
	Chlorophyll a (chla)	Maxxam		x	

Sampling and Analytical Methods

Quadrat Sampling

For each sampling trip four locations within each transect, two right banks and two left banks, were selected and sampled with a 1ft x 1ft sampling quadrat (Appendix A). Care was taken within each transect to not disturb the surrounding area for future sampling events. Sampling was first carried out at the most downstream transect and moved upstream to avoid disturbance and contamination. At each transect the field technicians waded out to the deepest safe working depth to select two representative places to drop the quadrats. Effort was made to wade to a depth that was accessible by boat in order to achieve overlap with the sonar measurements made on the previous day. Each quadrat location was labelled with the transect number (1-3), the bank from which it was sampled ("R" - right bank, "L" - left bank), and the replicate number (1-2). Within each quadrat the following measurements were taken in this order during every trip:

- the distance from the benchmark point to the location where the quadrat was dropped;
- the water depth at quadrat location;
- the first and second dominant substrates and their coverage (Table B1 of Appendix B);
- the three dominant macrophyte species and their estimated percent coverage. The algae coverage on the macrophytes was also described;
- the coverage and type of periphyton on the substrate was described;
- light readings were taken at the surface, middle, and bottom of the water column;
- macrophyte and periphyton samples were collected where possible;
- point velocity was measured within the quadrat with Smith and Price meter after the vegetation was removed.

Aquatic Vegetation Sampling

To measure macrophyte biomass all the rooted plants from within the quadrat were removed and drained into the macrophyte net then transferred to labelled plastic bags. Extra care was taken to include the roots and rhizomes as well. The macrophyte samples were taken to the AENV lab to determine dry weight biomass (AENV, 2006).

If present, rocks were removed from the quadrat and sampled for periphyton biomass. The template method was used to quantitatively sample the epilithic algae (AENV, 2006). This method was used to sample the upper surfaces of the stones present within the quadrat (the area exposed to direct stream flow). The 2X2 cm template was placed over a randomly chosen area. The samples were stored in a petri dish for dry weight biomass determination.

Dry Weight Determination

The macrophyte samples were washed using a sieve tray to remove rocks, debris and invertebrates. Each sample was placed on a pre-weighed aluminium foil pan. The sample was placed in the oven at 105 ^{o}C for 24 hours. The dried sample was removed from the oven and weighed on a balance. The spatial density of the biomass in g/m^2 was calculated by multiplying dry weight of the sample with area conversion factor 10.76 (AENV, 2006).

For each periphyton sample, the slide was removed from the petri dish and placed in an oven at 105 ^{o}C for at least 12 hours. After 12 hours, the slide was removed from the oven and placed in a dessicator to cool to room temperature. The sample was then weighed on

an analytical balance (American Public Health Association, 2005). To convert to g/m^2, the final dry weight was divided by the template area used, and then multiplied by 10000.

Water Chemistry

YSI multi-probe datasonde (Appendix A) was used to measure DO concentration at sampling sites. The datasonde was deployed at both banks of each transect. The sonde was placed into the flow and allowed to stabilize before the measurements were recorded. For each sampling trip, the sonde was calibrated with known standards prior to deployment in the River. Water samples were also collected in DO/BOD bottles to measure DO concentration in the lab using Winkler method. Water temperature was also measured at site using another calibrated thermometer. These measurements (DO and temperature) were compared with the YSI recorded measurements.

In trip two and three, water quality grab samples were taken for nutrient analysis from flowing water at both the LDB (left downstream bank) and RDB (right downstream bank) of each transect. Prior to filling of river water in sampling bottles, the sample bottles were triple rinsed to eliminate possible contaminations. Water samples for total phosphorus were preserved with 5% hydrochloric acid (HCl) solution and total dissolved phosphorus were first filtered at the AENV lab and then preserved with 5% HCl. All samples were placed in cooler and transported to Maxxam Analytics laboratory for chemical analysis.

Sediment Collection

The spoon and bucket method was used to collect a composite sediment sample from each bank within the study area. The sediment samples were placed in a container and brought to AENV lab for pre-treatment or pre-processing At the AENV lab the composite sample was well mixed then allowed to settle. The supernatant was pored off and the settled sediment was sent to Maxxam Analytics laboratory in Calgary.

Chlorophyll a Sampling

In trip three, three rocks where possible, were chosen from each quadrat and a template area was scraped off as described previously for the periphyton biomass sampling. Algae were placed from the scalpel directly onto a GF/C filter. A light sprinkling of powdered magnesium carbonate ($MgCO_3$) was applied to the sample as a preservative. The filter paper was then folded and wrapped in aluminium foil and labelled with sampling site name, sampling date, "epilithic chlorophyll", and total surface area of scrape (e.g., three rocks x 4 cm^2=12 cm^2). The samples were placed in a Whirlpac bag and stored at -4°C until delivered to Maxxam Analytics laboratory in Calgary.

Periphyton and Macrophyte Tissue sampling

For the periphyton tissue analysis, one composite sample of rock scrapings representative of the variation from each bank within the transect area was scraped and placed into a petri dish. A minimum of 2 g of periphton tissue was collected and any small rocks or invertebrates were removed from the sample. No preservative chemicals were used and the samples were kept cool until delivered to Maxxam Analytics laboratory in Calgary.

For macrophyte tissue sampling, one composite sample of entire specimens representative of the variation from each bank within the transect was collected and placed into a Ziploc bag. A minimum of 10 g of macrophyte tissue was collected and any small rocks or invertebrates were removed from the sample. No preservative chemicals were used and the samples were kept cool and damp until delivered to Maxxam Analytics laboratory in Calgary.

Data Analysis Methods

All measured and analytical data were compiled into an Excel spreadsheet and compared and reviewed for possible errors. ArcGIS 9.3 was used to map the data in order to support the comparison of the spatial differences between the sampling data.

The data was also organized into different tables for each trip and sorted based on the transect number and the bank from which it was collected. For each transect, an average was taken from the two quadrat samples from each bank to compare the dry weight density values. Basic summary statistics were used to compare the spatial and temporal differences between the data. Regression analysis was done to determine the relationship between velocity, light availability, nutrient concentration and macrophyte and periphyton density. The stoichiometry results for the tissue analysis and nutrient ratios were compared with existing literature values to evaluate nutrient limitation conditions for the sampled biomass.

SECTION 4: RESULTS AND DISCUSSION

BioSonics Survey

Vegetation and Sediment

One of the key objectives for this phase of the study was to test and evaluate the BioSonics methods for mapping aquatic vegetation and sediment in a shallow riverine system. To achieve this, the BioSonics DT-X echosounder was used to survey the defined study area three times in 2010. The collected BioSonics sonar data were compiled, decoded and compared with the monitored macrophyte biomass data, the digital photo images, and the video clips of macrophyte along different locations of the Bow River.

The decoded BioSonics sonar data from three different locations along a selected cross-section were plotted using Tecplot Focus 2010 and are presented in Figures 17 to 19. These figures are used to evaluate sonar signals produced from the right bank, the middle channel, and left bank respectively.

Three circular underwater photo images in Figure 17 to 19 taken from relevant locations of a cross-section are attached at the top of each of the figures. These photo images are used to associate the actual vegetation growth with the related sonar echo signals. The middle part of each of the figures shows the survey trace (yellow lines) adopted for the BioSonics survey trip, and the red triangle symbol indicates the exact location from which a sonar echogram were generated. The sonar echogram was placed at the lower part of each of the figures

The echogram plots are the decoded underwater target strength (in dB), which could be used to interpret different underwater objects and their properties. Target strength represents the energy level of the echo reflected from an underwater object. The rainbow colored spectrum is selected in these echogram plots to represent a range of different levels of echo energy (between -20 to -100 dB).

Theoretically, the target strengths echoed back from harder underwater object tend to be stronger than these from softer object. For example, for a typical underwater aquatic environment, target strength from water is usually the weakest, while target strength from channel bottom is the strongest. The target strength from aquatic vegetation is in between the target strengths from water and bottom sediment.

The X-axis of an echogram is ping number, which is related to the horizontal locations of a series of reflected sound pulses, and the Y-axis is range value, which is related to the vertical depth of an echo. In reality, the channel bottom depths of the selected Bow River sampling reach are usually within -1.5 to -2 m. As such, the target strength signals below -2.0 m in the echogram figures are actually the mirrored ghost images which should not be considered in the data analysis. In the future survey, it is suggested to adjust the transducer's bottom range level from -5 m to -2.5 m so as to minimize the ghost image areas in an echogram plot.

The underwater photo in Figure 17 indicates that very dense macrophyte growth existed at the right bank of the Bow River. The vegetation growth was so dense that the channel bottom was entirely submerged beneath the macrophytes. The echogram in this figure discloses that the channel bottom was located at a range around -0.7 m, as the peak strength of the echo showing up at this depth. There are two unique features that could be observed for the underwater target strengths for the echogram in Figure 17:

- The "quiet energy zone" representing the water column layer is not very identifiable at the site near the right bank. Usually, echo target energy representing water column are below -100 dB. However, this low energy response layer is totally missing in this figure. The echogram shows higher level of "noise" for the underwater layer above the bottom sediment;

- The target energy strength for the sediment layer is relatively weaker (below -40 dB) than it is expect to be (greater than -20 dB).

These two observations are justified by the fact that intensive growth of macrophyte took place at the right bank of this section of the Bow River. Dense macrophyte growth within the water column resulted in significant reduction of energy for the sonar pulses before they reached the sediment layer, which accordingly reduced the echo strength from the bottom layer. In addition, due to the existence of almost saturated level of vegetations in the water, elevated levels of "echo noise" were produced from the submerged plants.

The underwater photo images and sonar echograms shown in Figures 18 and 19 share many similarities. These images all indicate that the rooted plants were missing at both the middle and the left bank of the channel. The water columns of these two locations possessed high clarity, and the bottoms were covered with coarse rubble and debris. Associated with these features in the images, the echograms in Figures 18 and 19 demonstrate the following characteristics that do not appear in the right bank echogram:

- Much more evident sediment layers with strong echo energy for both of these two sites. The target energy strengths raised to be as high as -20 dB;

- Much more identifiable water column layers with consistent "noise free" zone above the sediment layers.

The "quiet energy zones" overlying the sediment layers in these two echograms are associated with the water column. Water is weak when responding to sonar signals, and as such yields very low level of echoes if it is free of high concentration of suspended substances. The only difference between the two echograms in Figures 18 and19 is the depth of the "quiet energy zones", where the depth of "quiet energy zone" for the middle channel doubles the one for the left bank. This indicates that much deeper of water exists around the center of the channel than the water along the bank, which is entirely agreeable with any regular river cross-sectional profiles.

Figure 17. Underwater Photo and Decoded BioSonics Echogram – Right Bank

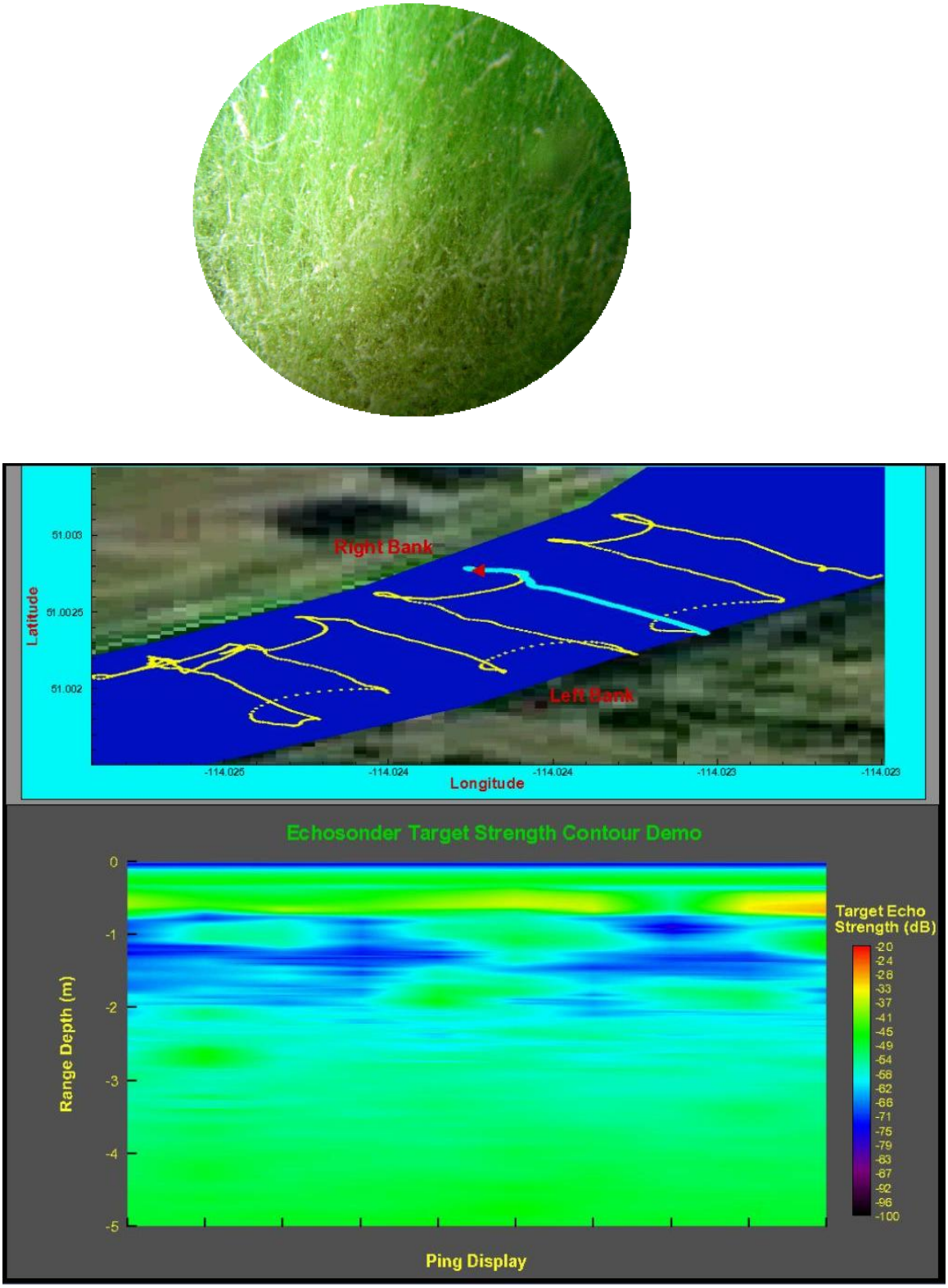


Figure 18. Underwater Photo and Decoded BioSonics Echogram – Middle Channel

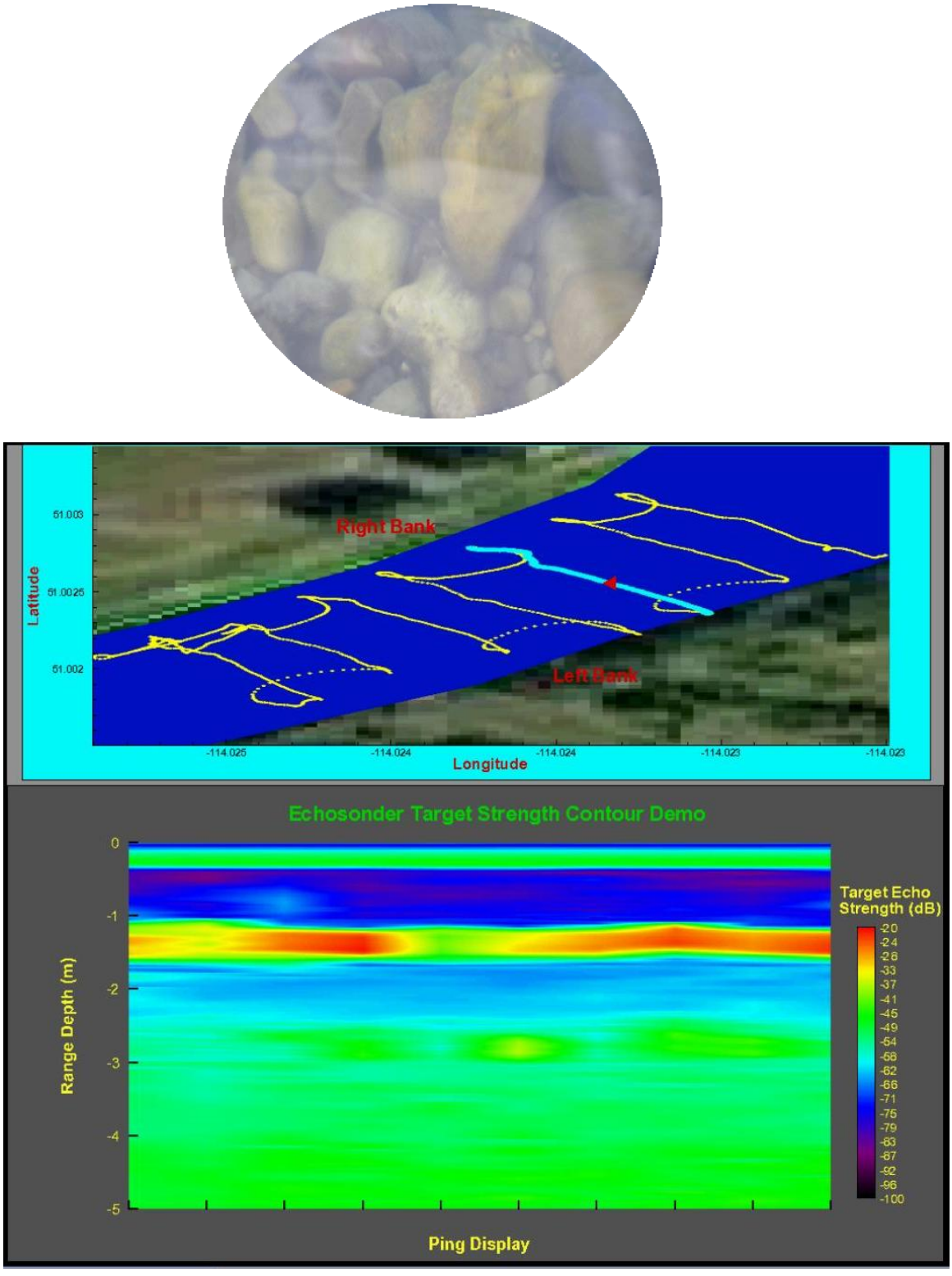
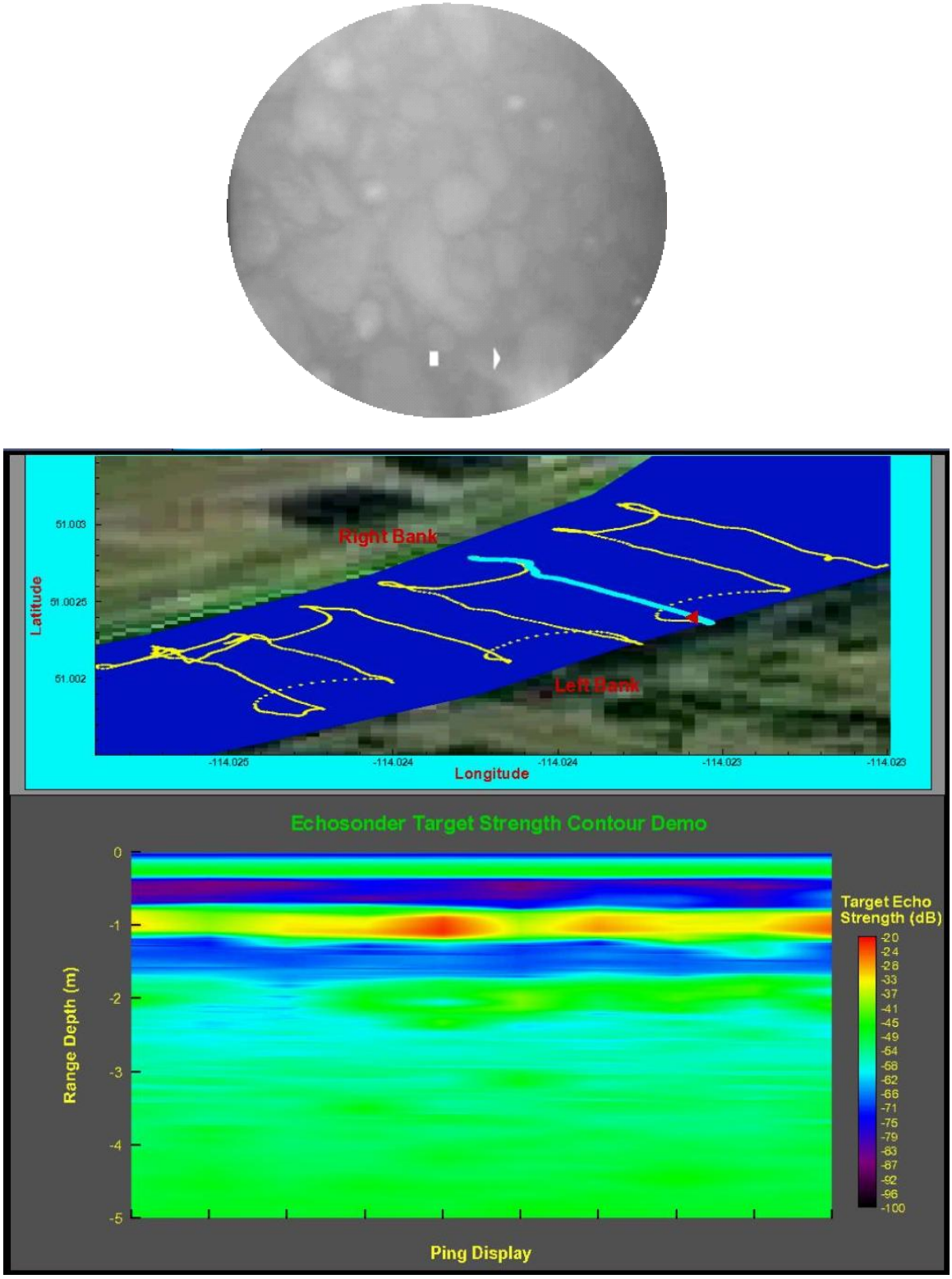


Figure 19. Underwater Photo and Decoded BioSonics Echogram – Left Bank



Based on the above comparisons and analysis of the underwater images and the associated echograms, the following two approaches were proposed to be applied for using BioSonics sonar to evaluate macrophyte distribution in a shallow riverine system:

- Using sediment layer echo strength change for vegetation interpretation

  When vegetation is sparse in the water column, the echo strength from the sediment layer is typically strong, because less echo energy of the sediment layer gets lost during the sonar propagation through the water column.

  Figure 20 shows an underwater echogram and the echo amplitude profile for Ping 918, which corresponds to a river segment with minimal growth of vegetation. The echo amplitude plot on the right starts with a very quiet energy zone for the surface depth. But the amplitude peaks quickly to be -20 dB, around the depth of -1.5 m, and then it quickly goes back to quiet level below -1.5 m.

  However, when vegetation growth becomes dense in the water column, more energy loss would occur for the echoes of the sediment layer, which results in less significant echo peak corresponding to the sediment layer. Figure 21 illustrates an underwater echogram corresponding to dense vegetation growth. The echo amplitude profile for Ping 3641 indicates an increase of echo energy around the depth of -1 m. However, this increase of echo energy is much more gradual in comparison to the sharp increase shown in Figure 21. The echo peaks gradually to be -40 dB around the depth of -0.8 m.

  It is obvious that the echo responses for the sediment layer are very different, depending upon the magnitude of vegetation biomass in the river. A mathematical correlation equation between sediment echo strength and macrophyte biomass density could potentially be built for mapping and assessing the underwater macrophyte biomass.

  In order to achieve using sediment sonar echo for vegetation prediction, the first work is to collect sediment sonar echo when the water is free of vegetation, which is used to define the base condition of sediment echo response.

  This base condition sediment sonar echo could then be compared against the relevant sediment echoes after macrophyte showing up in the water. The difference in sediment echo responses could be attributed to the appearance of macrophyte biomass in the water, i.e., the following mathematical equation could be established to predict the macrophyte biomass density using BioSonics sonar signals:

  $$X \propto f(E_i - E_b) \qquad \text{Eq.1}$$

  In Equation 1, X is the predicted macrophyte density for a specific river location (in g/m^2), E_i is the sonar echo strength measured for the same river location during anytime of the macrophyte growing season (in dB), while E_b is the sonar

echo strength measured for the same location when no macrophyte growth occurs in the river (in dB). In order to calculate X, the correlation function, *f,* needs to be derived at first. The next phase of the BioSonics study was already proposed to derive this function "f", so that a new X could be predicted when the measured E_i and E_b are available.

- Using water column echo strength change for vegetation interpretation

  The other significant variation of sonar signals occurs in the water column, when different levels of rooted vegetation exist. When vegetation is sparse or missing in the water, the echo strength for the water layer is uniformly low, since water is a poor substance for sonar echo reflection. On the other hand, when high amount of underwater macrophytes exist, the echogram for the water layer becomes noisy, because vegetation biomass is much stronger than water for reflecting sonar beams back to the BioSonics transducer. These noises are the footprint of biomass in the echogram and could be employed to interpret the distribution, size and shape of macrophyte in the water.

  Similar as using sediment sonar signals for biomass density calculation, the base condition sonar echoes for the water layer need to be characterized first during the time before the growing season of macrophyte. This base condition echogram establishes the background echo noises that are not related to macrophyte. Then, the new water column echograms after macrophyte's presence are to be acquired and compared against the base condition echogram, which could subsequently be applied to map and calculate the vegetation distribution and canopy sizes in the water.

Figure 20. BioSonics Sonar Echogram and Echo Amplitude for Ping 918

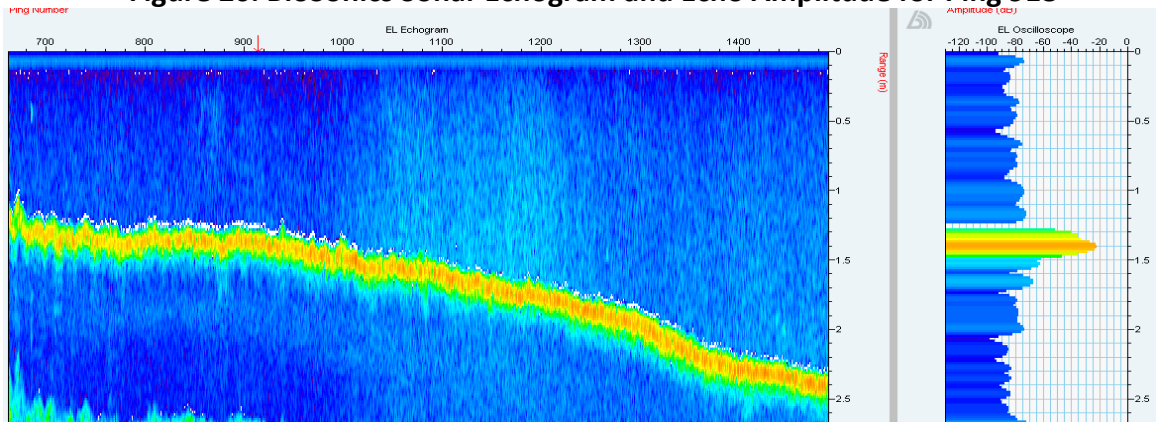
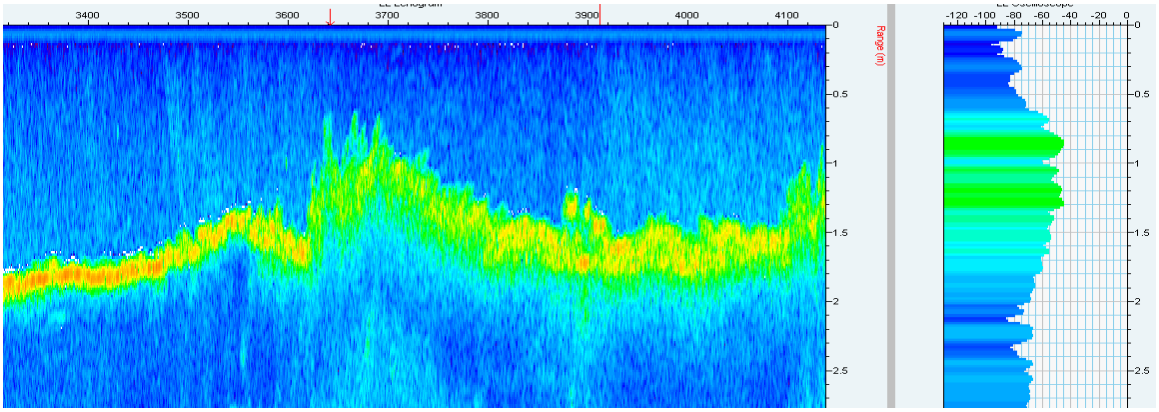


Figure 21. BioSonics Sonar Echogram and Echo Amplitude for Ping 3641



Bathymetry and Velocity Survey

Bathymetry and flow/velocity are the two closely related physical variables of a river channel. Bathymetry is the spatial geometry of a channel and determines how fast the upstream water passes through a cross section.

Channel bathymetry data is one of the key input data for a water quality model. However, collection of bathymetry data for a river channel is typically very expensive and time consuming. The historically available bathymetry data for the Bow River are limited to the urban areas where there is flood risk to human habitat. However, the bathymetry data for a rural reach are typically missing for the Bow River. Channel flow/velocity profiles are the key dataset for calibrating the responses of certain cross-section to different stages of upstream flow.

This BioSonics study was designed to couple the mapping of vegetation and sediment together with the survey of channel bathymetry and flow/velocity profile. The RTK transducer and SonTeck M9 were equipped together with the BioSonics Echosounder in an inflatable boat, which allows seamless and simultaneous collection of multimedia data from the same one field trip.

During the BioSonics study, three cross-sections within the study area were selected for detailed bathymetry measurement, which are shown in Figure 22. The bathymetry data from O'Connor study were used to derive a digital terrain model (DTM) for the surveyed reach, based on which the bathymetry profiles for the corresponding three cross-sections were derived. These cross-section profiles from the two studies were then compared against each other, and Figures 23 to 25 present the results of bathymetry comparison.

The bathymetry profiles from these two studies show, in general, similar trends of bottom elevation variation cross-sectional wise. However, the bathymetry deviations were observed along each of the three cross-sections, with the bottom elevation differences being as large as 1 m. Without another set of independent bathymetry data for this same reach, it is hard to determine which set of bathymetry data is a better representation of the actual channel profile for the selected cross-sections.

On the other hand, efforts were spent on understanding why the bathymetry deviations exist between the two studies. It was identified that the applied survey traces do not agree with each other between the two studies (Figure 22). The survey traces employed for the City's O'Conor work appear to be very detailed, however they lack spatial consistency. The traces are overcrowded in some area, but are less detailed or even absent in some other places, which would affect the bathymetry interpolation results for areas not covered by the survey traces. The survey traces from (Figure 22) the BioSonics study repeat exactly the selected cross-sections, and as such no interpolation was needed to derive the cross-section profile. As such, the comparison indicates that the cross-section profiles from BioSonics study is more likely representing the actual geometry profiles of the channel.

The flow velocity vector profile surveyed on Oct 15th of 2010 was presented in Figure 26. The average velocity is around the magnitude of 1 m/s for the range of surveyed reach.

The water current generally moved along the longitudinal direction of the channel from upstream to downstream, with less exchange of flows laterally. The water around the centre portion of the channel flowed much faster than the water near the bank. In general, the survey results of velocity vectors from the BioSonics study are justifiable and agree with the known ranges measured for the Bow River historically.

Figure 22. Comparison of Bathymetry Survey Traces between BioSonics Study (Red Colored) and O'Connor Study (Yellow Colored)

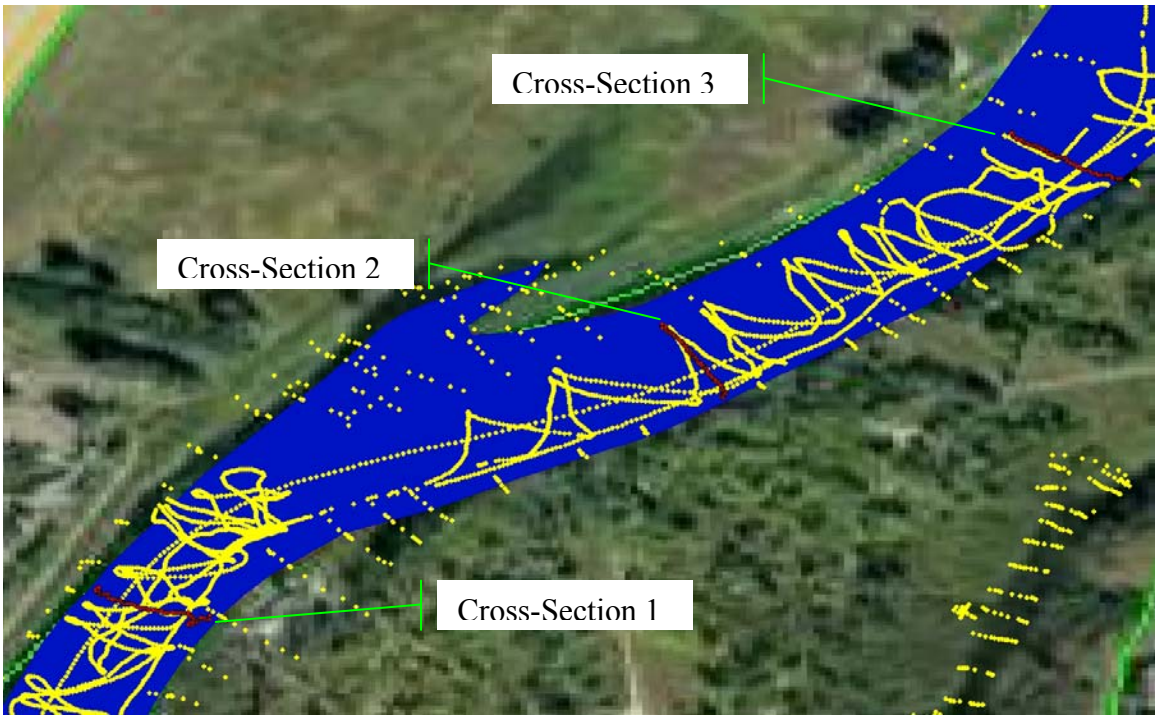


Figure 23. Comparison of Bathymetry Profiles Measured from BioSonics Study and O'Connor Study: Cross-section 1

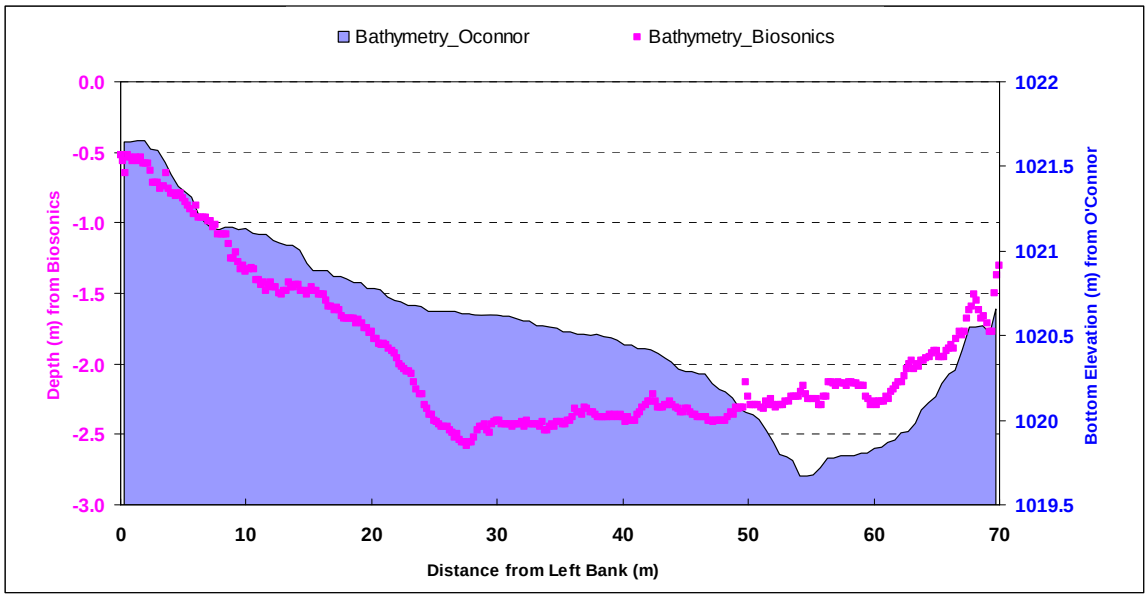


Figure 24. Comparison of Bathymetry Profiles Measured from BioSonics Study and O'Connor Study: Cross-section 2

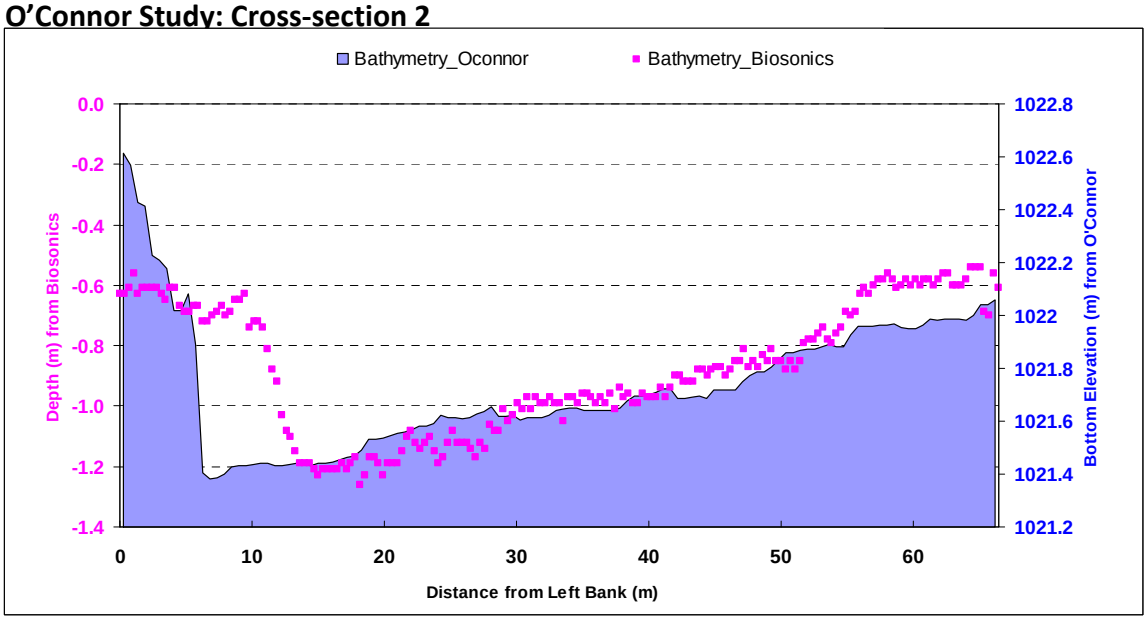


Figure 25. Comparison of Bathymetry Profiles Measured from BioSonics Study and O'Connor Study: Cross-section 3

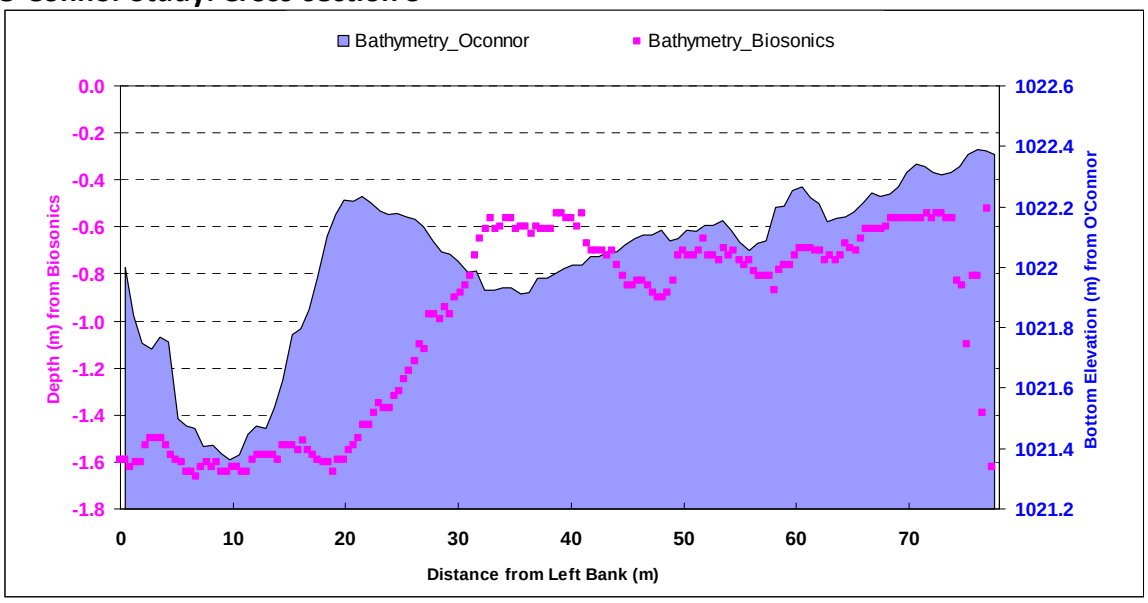
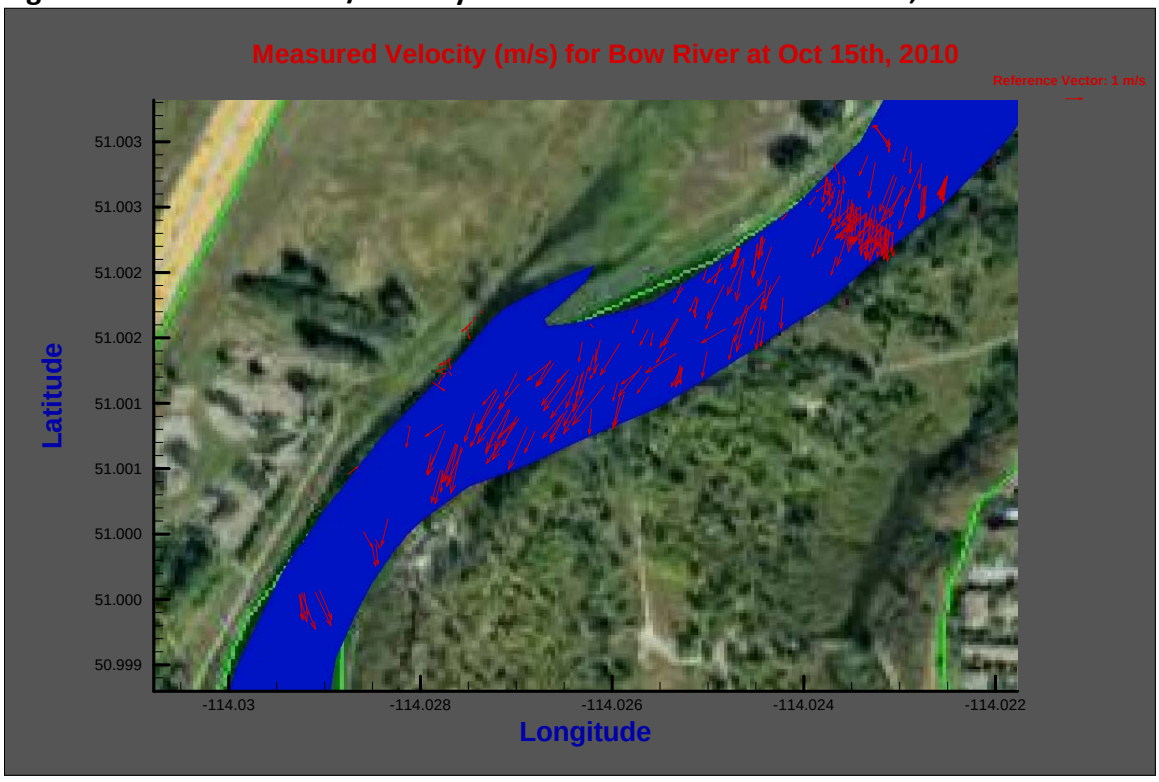


Figure 26. Measured Flow/Velocity Profiles for Bow River at Oct 15th, 2010



Water Quality Ground-truth Study

Conventional Parameters

The monitoring results for the conventional water quality parameters (temperature, DO, pH, conductivity and TDS) and flow/velocity are compiled and summarized in Table 3. The results show some spatial variation in concentrations between right and left banks and along the river reach.

The temperature at the left bank was often greater than right bank at all three sites during trip 1. The spatial difference in temperature could be attributed to the combined effect of ambient water temperature and wastewater effluent temperature. Ambient water was warmer than wastewater effluent during the time of trip 1 (July), which resulted in slightly cooler condition along right shore line of the Bow River. During trip 2 and 3 the opposite seems to be the case; the ambient water is cooler than that of the wastewater, so elevated temperatures appear on the right bank. The ambient water temperature was expected to be lower than wastewater effluent temperature at that time of the year, therefore, the higher water temperature observed at the right bank reflected the impact of the wastewater effluent.

Table 3: Conventional Parameter Monitoring Results

Site	Trip	Temperature		Dissolved Oxygen		Dissolved Oxygen		pH		Conductivity		Total Dissolved Solids		Point Velocity	
		°C		mg/L		% Saturation		pH unit		us/cm		mg/L		m/s	
		R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	Trip1	16.9	18.6	9.4	10	**nd**	119	7.8	8.6	407	281	264	182	0.006	0.03
	Trip 2	14.6	14.3	8.6	9.8	95	107	7.5	8.4	428	293	279	190	-0.041	0
	Trip 3	11.8	**8.4**	9.7	13.8	89	118	7.7	8.5	613	318	399	207	0.005	0.04
2	Trip1	17.9	18.1	12	10.3	142	121	8	8.6	387	280	251	182	0.1	0.95
	Trip 2	16.7	**14.1**	8.7	9.7	101	105	7.9	8.4	554	292	360	190	0.04	0.78
	Trip 3	12.7	**7.2**	9.4	13.6	89	113	7.5	8.5	675	315	440	205	0.23	0.8
3	Trip1	18.2	18.5	9.6	10	114	119	7.5	8.6	540	281	351	182	0.29	nd
	Trip 2	16.7	**14.2**	8.9	9.3	103	102	7.4	8.4	357	292	357	190	0.15	nd
	Trip 3	12.8	**7.4**	10.8	13.9	104	115	7.2	8.5	707	314	459	204	0.33	0.51

Table 3 also indicates that the left bank dissolved oxygen concentrations were generally greater than the right bank DO concentrations. The lower DO along the right bank is somewhat surprising because the macrophyte densities measured along that bank were much higher than on the left bank. Higher concentration of DO would be expected to occur due to the active photosynthesis effect around the time of sampling. Low DO concentration in the WWTP effluent combined with high nutrient concentrations could have caused significant DO reduction along the right bank. Higher observed nitrate-nitrite concentration at the right bank compared to the left bank also supports this assumption. In addition, the velocity along the left bank was higher than that along the right bank, so re-aeration could be another reason for higher DO values along the left bank. It is also suspected that some other DO sinks exist along the right bank, such as sediment oxygen demands, which should be investigated in the future.

The measured pH values at the right bank were consistently lower than the left bank values. The pH values measured along the left bank are similar to the conditions that were measured for the upstream ambient water of the Bow River, so the lower observed pH values for the right bank is likely also the result of the effluent from the WWTP. Similarly, the consistently higher total dissolved solid (TDS) concentrations and conductivities at the right bank compared to the left bank also indicate the influence of wastewater discharge, which is expected to have higher TDS concentrations.

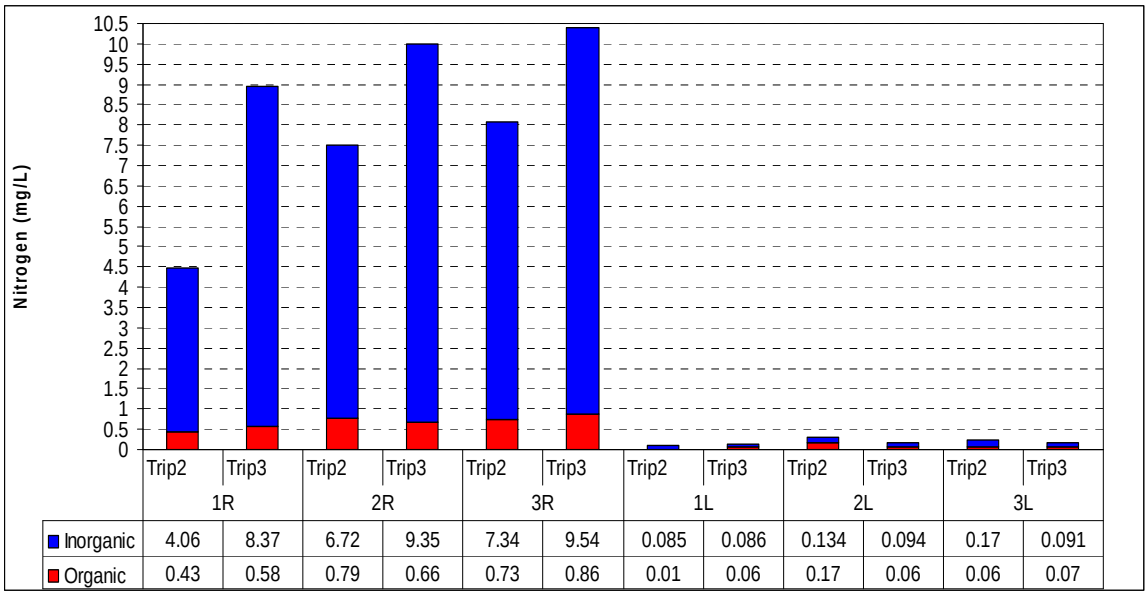
Nutrients in Water

Nitrogen

The total nitrogen (TN) concentration is the sum of inorganic and organic nitrogen, and is observed to be significantly higher on the right bank than on the left bank (Figure 27). Figure 27 also shows a decrease in TN concentrations along right bank with the increase in distance from the WWTP. The higher right bank TN concentration and reduction in TN concentration along the river are due to the effect of wastewater discharge apparently. The inorganic nitrogen appears to be the major contributor of the differences in TN between the two banks, because the organic nitrogen concentrations did not fluctuate as much for both banks.

Total Kjedahl nitrogen (TKN), which is a measure of organic nitrogen and ammonia, shows mixed spatial variations across and along the river channel. Higher concentrations of TKN were observed along the right bank, similar as TN. The TKN concentrations on the right bank also increased as the distance from the WWTP decreases (Figure 28). Similar to TN and TKN, ammonia concentrations are significantly higher along the right bank than the left bank. However, all observed ammonia concentrations are below the EPA guideline of 0.2mg/L for the protection of aquatic life.

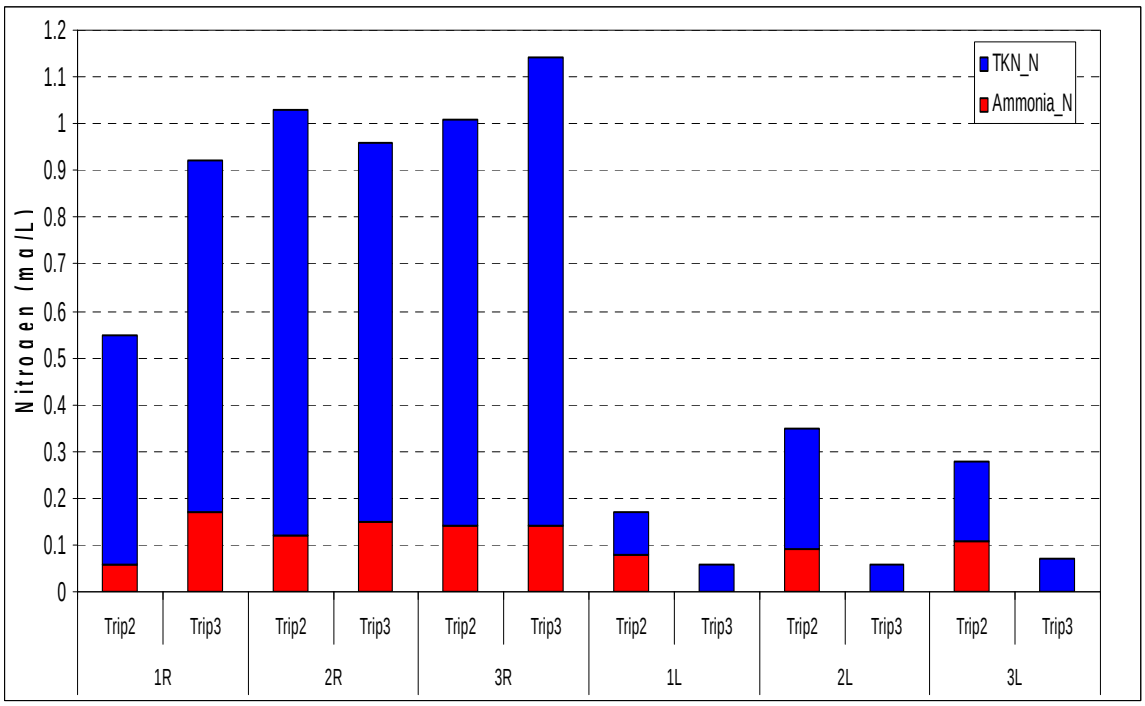
Figure 27. Observed Organic and Inorganic Nitrogen*



	1R		2R		3R		1L		2L		3L	
Inorganic	4.06	8.37	6.72	9.35	7.34	9.54	0.085	0.086	0.134	0.094	0.17	0.091
Organic	0.43	0.58	0.79	0.66	0.73	0.86	0.01	0.06	0.17	0.06	0.06	0.07

* The concentration of organic and inorganic nitrogen, in water samples collected from the Bow River in trip 2 (Sept 15) and trip 3 (Oct 14) of the Bow River Pilot Study. 1-3 represent the transect where the sample was taken, R (right bank) and L (left bank). Missing values are non-detects.

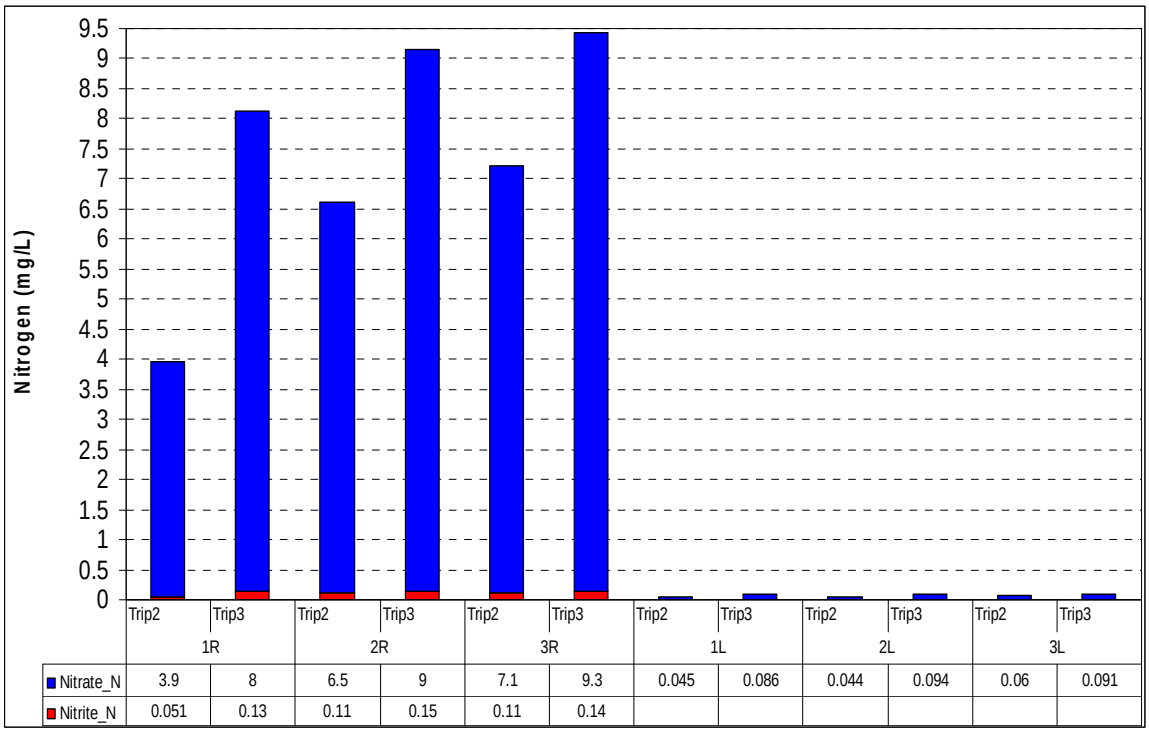
Figure 28. Observed Ammonia and Total Kjeldahl Nitrogen*



* The concentration of ammonia (NH3-N) and organic N as total kjeldahl nitrogen (TKN) in water samples collected from the Bow River in trip 2 (Sept 15) and trip 3 (Oct 14) of the Bow River Pilot Study. 1-3 represent the transect where the sample was taken, R (right bank) and L (left bank). Missing values are non-detects.

Nitrate and nitrite, the other two inorganic forms of nitrogen, display the similar spatial trends as TN, TKN and ammonia (Figure 29). The concentrations were significantly higher along the right bank than the left bank. All water samples collected from the right bank were above the BRBC water quality objective of 1.5mg/L (BRBC, 2008).

Figure 29. Observed Nitrate and Nitrite Nitrogen*



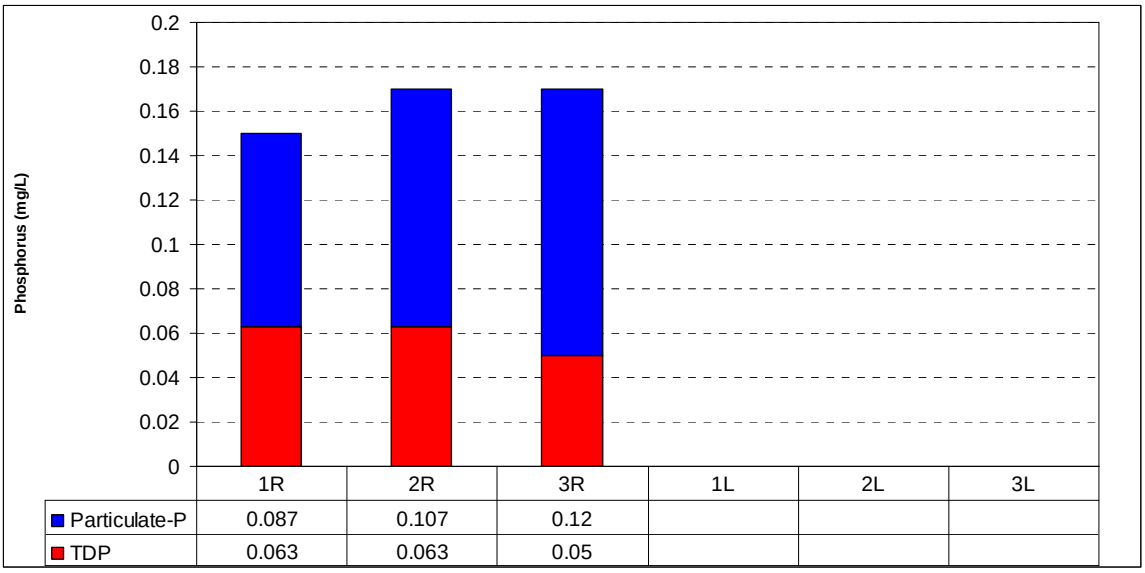
	Trip2	Trip3	Trip2	Trip3	Trip2	Trip3	Trip2	Trip3	Trip2	Trip3	Trip2	Trip3
	1R		2R		3R		1L		2L		3L	
Nitrate_N	3.9	8	6.5	9	7.1	9.3	0.045	0.086	0.044	0.094	0.06	0.091
Nitrite_N	0.051	0.13	0.11	0.15	0.11	0.14						

* The concentration of NO2-NO3-N (mg/L) in water samples collected from the Bow River in trip 2 (Sept 15) and trip 3 (Oct 14) of the Bow River Pilot Study. 1-3 represent the transect where the sample was taken, R (right bank) and L (left bank). Missing values are non-detects.

Phosphorus

A spatial difference was observed for total phosphorus (TP) concentration which includes dissolved and particulate forms of P measured both at the right and the left bank. TP was much higher on the right bank, but typically not observable on the left bank (below detection limit, Figure 30). All of the observed TP concentrations along the right bank were above the BRBC objective of 0.028mg/L (BRBC, 2008). The TP concentrations had a slight increase moving upstream toward the WWTP from transect 1 to transect 3.

Figure 30. Observed Total Dissolved and Particulate Phosphorus

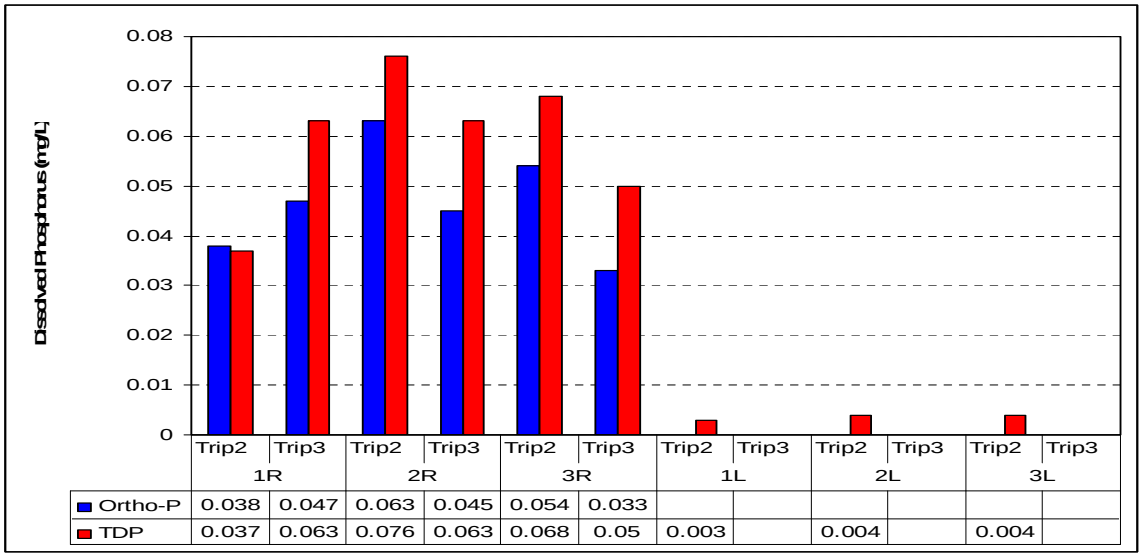


* The concentration of total phosphorus (TP) represented by total dissolved phosphorus (TDP) and particulate phosphorus in water samples collected from the Bow River in trip 3 of the Bow River Pilot Study. 1-3 represent the transect the sample was taken, R (right bank) and L (left bank). Missing values are non-detects.

Total dissolved phosphorus (TDP), including both dissolved inorganic and organic components of phosphorus, had a significant difference in concentration along the right versus the left bank (Figure 31). Along the right bank the TDP concentrations were all above the relevant objective of 0.015mg/L, set by the BRBC (BRBC 2008), whereas along the left bank the TDP was marginally above the detection limit (0.003mg/L).

Orthophosphate, PO_4–P, which is the most readily bioavailable form of P, was the major component of TDP along the right bank, whereas dissolved organic phosphorus was the major component of the TDP along the left bank. Aside from the most downstream site on the RDB (1R), TDP displayed a temporal decrease and was below the detection limit for all sites LDB on the third trip.

Figure 31. Observed Total Dissolved Phosphorus and Ortho-phosphate



* The concentration of total dissolved phosphorus (TDP) and ortho-phosphate in water samples collected from the Bow River in trip 2 (Sept 15) and trip 3 (Oct 14) of the Bow River Pilot Study. 1-3 represent the transect the sample was taken, R (right bank) and L (left bank). Missing values are non-detects.

Vegetation

Macrophyte

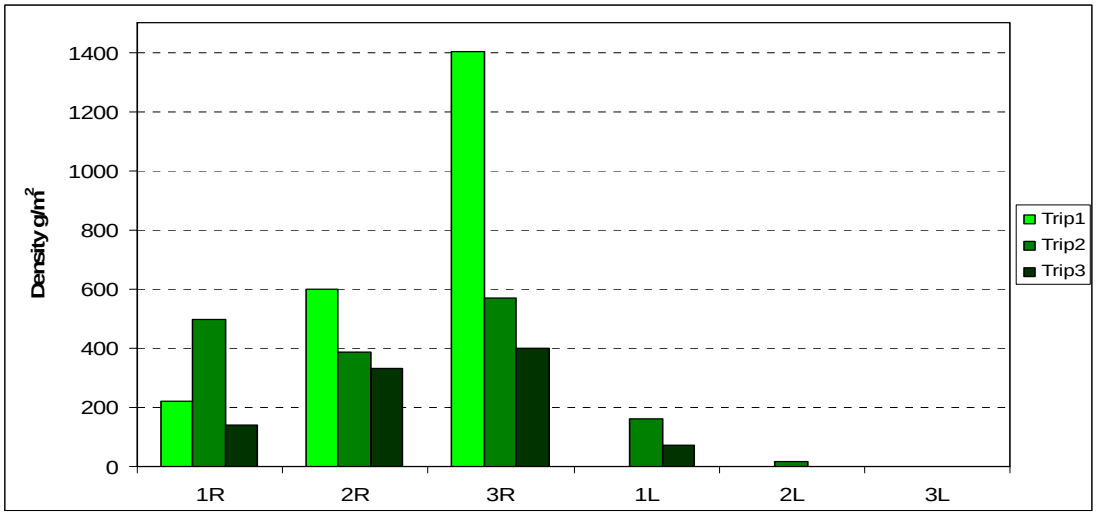
The average macrophyte biomass displayed similar spatial trends as nutrients in water. The right bank had an average macrophyte density of 502 g/m^2 (n=18, "n" is number of sample) and displayed higher biomass abundance close to WWTP and reduced biomass abundance away from the WWTP.

On the other hand, the left bank had an average density of 28 g/m^2 (n=18) and displayed longitudinal trends opposite to the right bank (Figure 32). The spatial trend observed in the macrophytes indicates that increased growth of macrophyte is likely a result of the nutrient rich discharge plumes from the WWTP as previously observed on the Bow and South Saskatchewan River (Carr & Chambers, 1998; Sosiak, 2002). Site 1L, the only site that had macrophyte growth on the left bank, was in a depositional area with river bed comprised of silt and sand and low flow velocity. In contrast, the sites upstream on the left bank river beds were made of coarse materials and experienced typically higher flow velocities. Therefore, velocity and sediment composition could limit the establishment of macrophytes along the left bank (Madsen *et al*, 2001; Sosiak, 2002).

When macrophyte beds are formed, growth will typically occur in the direction where physical disturbance is less. Usually, the beds will elongate downstream with the upstream boundary remaining close to the initial colonization point (Sand-Jense & Borum, 1990). In the current study, this longitudinal trend was observed along the right bank. From trip 1 to trip 2, the patches of macrophytes along the right bank began to merge together to form one dense bed, but the most upstream boundary of the bed remained similar.

The temporal variation in macrophyte density follows a typical seasonal growth curve, with an increase in density throughout the summer to a peak density in September (Sosiak, 2002) and then a decrease in density as aquatic plants senesce in October. However, the peak densities obtained for sites 2R and 3R were during July instead of in September, which could be a result of the particular species dominating in that cross-section.

Figure 32. Average Macrophyte Dry Weight (g/m2)



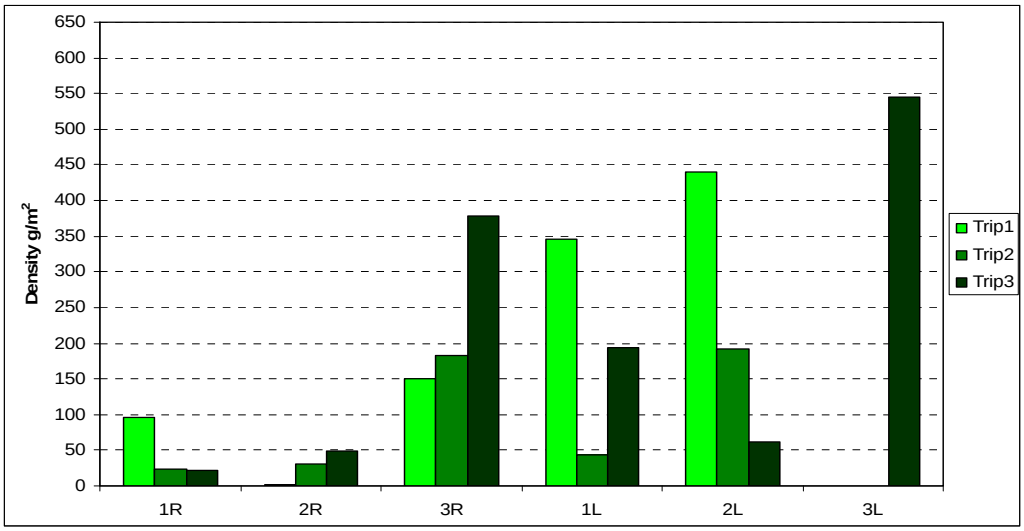
* The average macrophyte dry weight density (g/m2) measured over three trips, July, Sept, and Oct, during the Bow River Pilot Study. 1-3 represent the transect number the sample was collected, R is right downstream bank and L is left downstream bank.

Periphyton

Periphyton density displayed the opposite spatial trend to that of macrophyte density; however the difference in densities across the banks was not as dramatic. (Figure 33). The left bank had greater densities overall (average density =275 g/m^2, n= 11) than the right bank (average density =101 g/m^2, n=11). Site 3L, the most upstream site on the left bank was not sampled for periphyton during the first two trips due to high water levels and therefore was moved slightly downstream during the third trip in order to get a measurable sample.

Competition from macrophyte could limit periphyton growth through both shading and nutrient availability. The decrease in periphyton from trip 1 to trip 2 could be due to the limited availability of light caused by significant increase in macrophyte density. Over time as the macrophytes senesce, they release nutrients back to the water column. The increase in periphyton density from trip 2 to trip 3 in most cases could be due to the more availability of nutrients in water columns and less shading from the macrophyte beds.

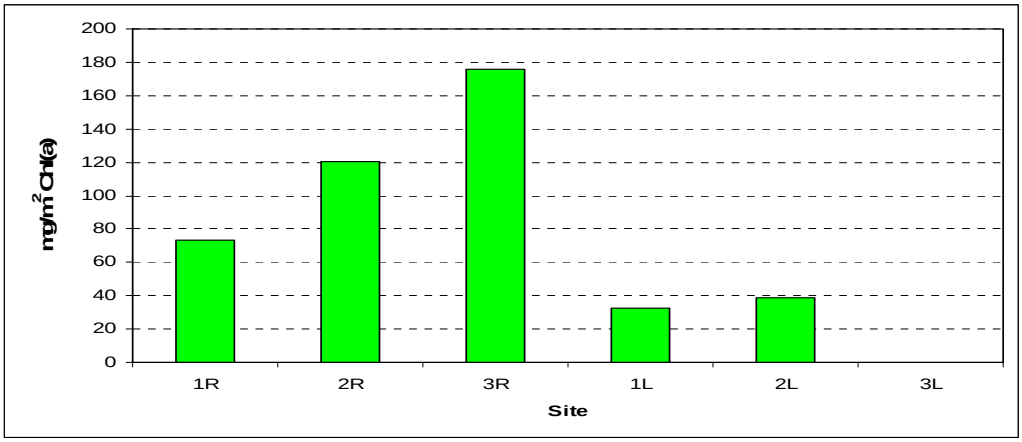
Figure 33. Average Periphyton Dry Weight (g/m2)



* The average periphyton dry weight density (g/m2) measured over three trips, July, Sept, and Oct, during the Bow River Pilot Study. 1-3 represent the transect number the sample was collected, R is right downstream bank and L is left downstream bank.

However, if looking at the Chlorapyll-a values for periphyton, the periphyton on the right bank have appreciably more Chlorophyll a in their tissue with the periphyton from site 3R containing the highest amount (Figure 34), which is potentially why site 3R had a high density of periphyton regardless of the high density of macrophyte. The chla and density variability may be a result of species variation from the right and left bank. The differences observed in the algal species present can be indicative of differences in the environment: on the right bank more filamentous green type algae appeared to dominate, whereas on the left bank calcareous slimy type algae were more popular (Figure 35). Previous studies have also shown that chlorophyll *a* can increase with no increase in biomass as a result of NO_3 enrichment in ambient water (Stelzer & Lamberti, 2001).

Figure 34. Chlorophyll *a* in Periphyton Tissue*



* The Chlorophyll a concentration in measured in periphyton tissue during trip 2 (Sept) of the Bow River Pilot Study. 1-3 represent the transect number the sample was collected, R is right downstream bank and L is left downstream bank.

Figure 35. Periphyton Photos and Site 3 on the Right Bank (Trip 2)

(a) Left Bank of Site 2 (b) Right Bank of Site 3

Tissue Nutrient and Stoichiometry

Table 4 presents carbon, nitrogen and phosphorus content from the composite samples of macrophyte and periphyton that were sampled for tissue analysis.

Table 4: Stiochiometry of C, N, and P in Macrophyte and Periphyton Tissues

Site	Macrophyte						Periphyton					
	%C	%N	%P	C:N	C:P	N:P	%C	%N	%P	C:N	C:P	N:P
1R	29	3.4	0.074	9	392	46	3.6	0.5	0.065	7	55	7
2R	26	2.6	0.047	10	553	55	9.8	1.7	0.09	6	109	19
3R	33	3.3	0.046	10	717	72	16	3.5	0.136	5	118	26
1L	25	2.0	0.023	13	1087	87	4.9	0.5	0.186	10	26	3
2L	-	-	-	-	-	-	6.3	0.6	0.018	11	350	33
3L	-	-	-	-	-	-	-	-	-	-	-	-

There does not appear to be much difference in the %C for tissues collected from macrophytes along the right bank versus tissues collected from the left bank.

The C concentration in macrophyte tissue is often more related to the structure of the plant (Duarte, 1992) thus, a similar concentration in the samples is not surprising as similar species were observed on the two banks of the river and composite samples of the macrophytes were used for tissue analysis, with the exception of site 1L. So, more variation may be present if the individual species rather than composite samples are compared (Gerloff & Krombholz, 1966; Demars & Edwards, 2007).

The % N and % P in Table 4 show higher level of nutrients in the macrophyte tissues collected from the right bank compared to the tissues collected on the left bank. This indicates that the macrophytes from the right bank are capable of uptaking and storing elevated levels of nutrients from the water directly influenced by the WWTP plumes.

However, all the P% of the collected macrophyte tissues were below 0.13%, which was reported as the critical threshold of tissue P for vegetation (Gerloff & Krombholz, 1966). The lower levels of % P for the samples from this study indicate higher likelihood of P limitation of the local macrophyte species, especially for these species from the left bank (*Potamogeton crispus*).

The N contents of the collected macrophyte tissues from both banks were all above the critical threshold of 1.3% of N in macrophyte, which indicates that N may not be related to limiting factor of macrophyte growth. Further, the high N:P ratios (46:1-87:1) also indicate a tendency toward P limitation for this local reach.

Unlike the Macrophyte tissues, there was more variation of % C in the periphyton tissues, which could be indicative of species differences across the left and right bank and longitudinally (Stezler & Lamberti, 2001; Cross et al, 2005). Further the %C in macrophyte tissue was significantly higher than that measured in the periphyton tissues which is probably a result of the higher content of cellulose in the macrophytes (Duarte, 1992)

The N:P ratio was much smaller in periphyton tissue (3:1-33:1) than macrophyte tissue (46:1-87:1). The sampling sites in transect 1 (1R & 1L) had N:P ratios for periphyton that are below both the Redfield ratio 16:1 and the Vallentyne's critical N:P ratio of 7:1 for biomass. These indicate that those periphyton species tend to be more limited by N than P. Further, the % N in all of the periphyton samples was below the critical threshold of 4.0% presented by Gerloff and Skoog (Gerloff and Skoog, 1957), which further indicates a higher possibility of N limitation for periphyton.

Table 5 compares the averaged N:C and P:C ratios measured from the periphyton and macrophyte tissue samples within the reach, against the values that are currently used in the BRWQM model. Although there are some variations, the values from both sources all show that the ratio of nitrogen and phosphorus to carbon in macrophytes is much lower than in periphyton. This implies that nitrogen and phosphorus requirement is less for macrophytes than for periphyton (Sand-Jensen & Borum, 1991).

Table 5. Comparison of Monitored N:C & P:C Ratios And BRWQM Applied Values

Tissue ratios	Marophyte measured	model value	Periphyton measured	model value
N:C	0.099	0.066	0.145	0.25
P:C	0.002	0.009	0.021	0.025

Community Composition

Three dominant species of macrophytes were found in the local reach from this field study, which are:

- *Potamogeton vaginatis* (Figure 36);
- *Potomogeton crispus* (Figure 37), and;
- *Veronica anagallis-aquatica* (Figure 38).

Potamogeton vaginatis, large sheathed pondweed and *Potamogetan crispus*, curly leaved pondweed, have been previously identified along the Bow River (Sosiak, 2002) and were found throughout the study reach.

P.crispus is an invasive species that is able to establish in cold waters and tolerates a broad range of ecological conditions (Capers et al, 2005). This species typically reproduces by turions which remain dormant until the water cools in the fall, grow slowly throughout the winter, flower in the spring, and die back in the summer (Nichols & Shaw, 1986).

Veronica anagallis-aquatica, water speedwell, had not been previously identified on the Bow River, but is not considered to be an invasive species to North America. V.anagallis-aquatica is considered an amphibious species which can occur on land along wet areas or in water with emerged or totally submerged leaves, and thus has morphological and photosynthetic rate adaptations to survive different flow regimes (Torres Boeger & Poulson, 2002). The plants that were found in the faster flow were totally submerged with shorter stems and had broader almost lettuce-like leaves, whereas the emergent plants found in the slow and shallow water had longer stems and more lanceollate leaves.

Figure 36. *Potamogetan Vaginatis*

Figure 37. Potamogetan crispus

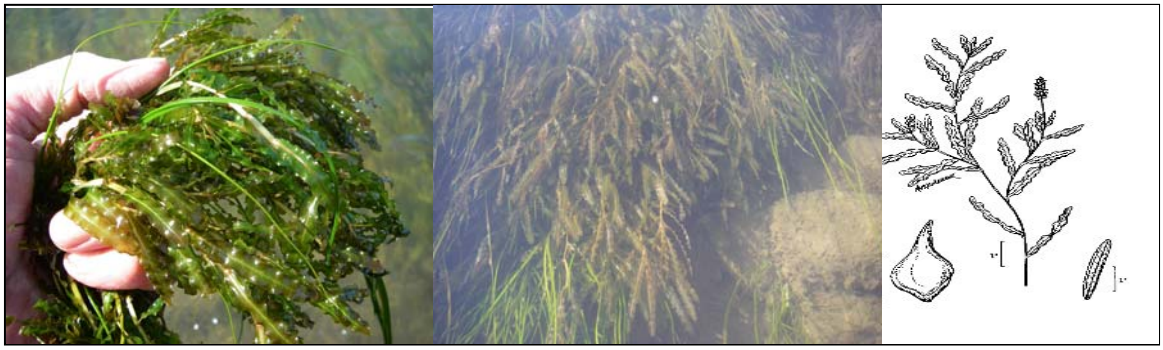


Figure 38. Veronica anagalis

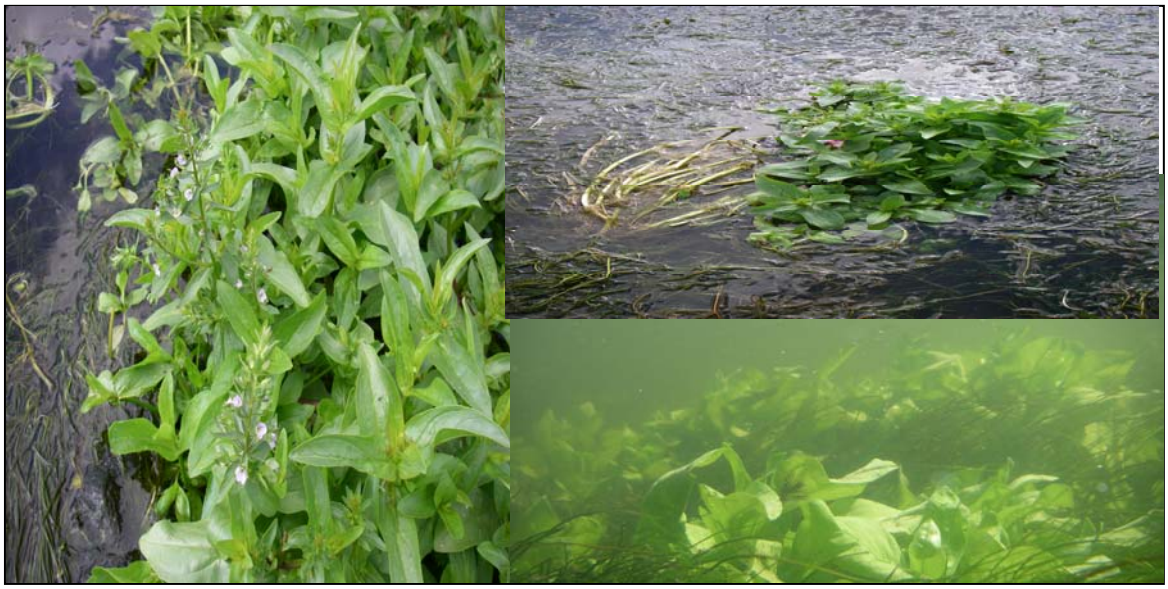
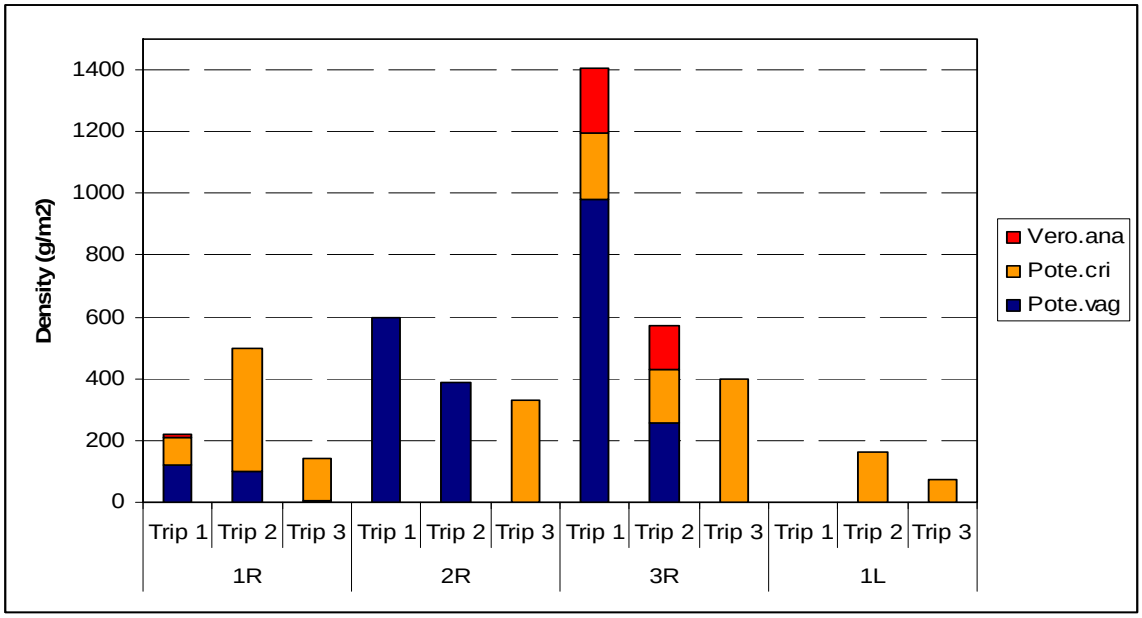


Figure 39 depicts the changes in the percent coverage of the three dominant species observed during the three trips. P.vaginatus dominated the macrophyte beds during the first trip, while P.crispus dominated all of sites during the third trip. The P.crispus in this reach did not seem to die off in the early summer as expected. This may be because, unlike P. vaginatis which was uprooted in the fall, P.crispus remained rooted. Also the P.vaginatis seemed to be predominately in the deeper waters that were not accessible for quadrat sampling in the later trips.

In trips one and two, Veronica was observed in the channel along the right bank only, with the highest density recorded in the site closest to the WWTP (3R) and was mainly found on the bank in trip 3.

There was much variability within the transects and the species composition shown is an average of what was found within the two quadrat samples that were taken at each site and may not be entirely representative of the entire site. Further, the samples collected were from wade able areas with a maximum depth of 80cm, so the species coverage measured does not necessarily represent the coverage further downstream.

Figure 39. Composition of Dominating Macrophytes during Different Field Trips



* The average dry weight density (g/m2) for Potamogeton vaginatis, Potomageton crispus and Veronica anagalis aquatica calculated from the total macrophyte weight and % coverage, measured over three trips, July, Sept, and Oct, during the Bow River Pilot Study. 1-3 represent the transect number the sample was collected, R is right downstream bank and L is left downstream bank.

Sediment

Particle Sizes

The sediment samples were taken from both the depositional areas along the right (2R) and the left bank (1L) where similar velocities were recorded. As such, there is not much difference in the particle sizes for the sediments from the two sites, but the right bank contains slightly higher percentage of finer (<0.075mm) materials (Table 6).

Table 6. Physical Characteristics of Sediment Sample

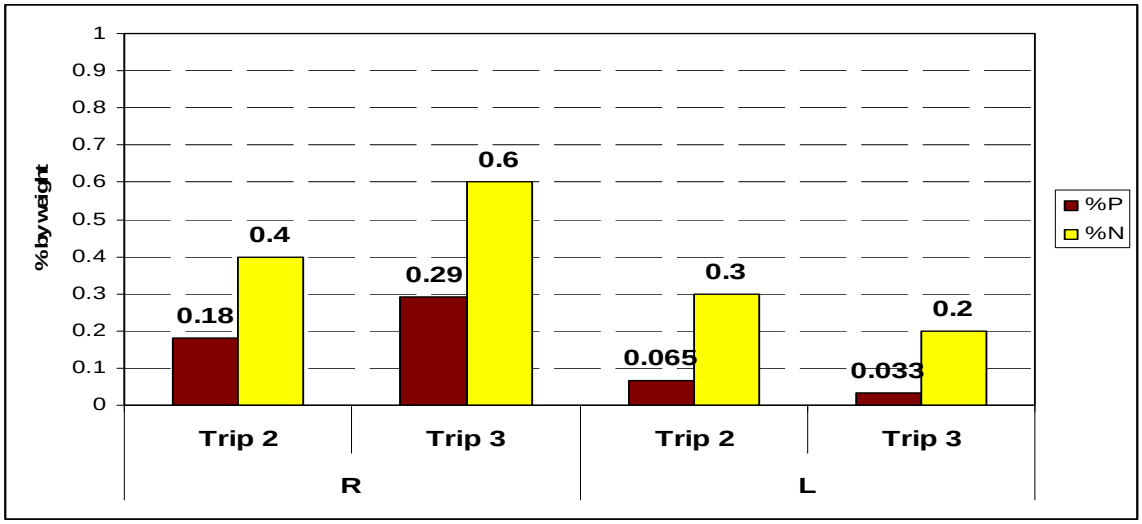
Physical Properties	Right Bank	Left Bank
Moisture %	63	51
Sieve-Pan %	73	66
Sieve-#200 (>0.075mm)%	27	34
Grain size	Fine	Fine

Nutrients

There was a spatial difference in the concentrations of nutrients obtained from the sediment samples between the right and left bank. The sediment samples on the right bank had higher percentage of both P and N compared to the left bank (Figure 40). There was also a measured difference over time for the right bank versus the left bank where both P and N increased from trip two to trip three on the right bank but decreased on the left bank.

The spatial differences of sediment nutrient levels correspond closely to the variations of nutrients in the water column, and the macrophyte density, i.e., higher sediment nutrient levels were found along the right bank where higher levels of nutrients and macrophyte in the water column were observed. The increase in the nutrient concentration in the sediment along the right bank from trip two to trip three may be a result of the macrophytes, because as macrophytes die they take up less nutrients and the dead plant material returns nutrients back to the sediment, which is why the same temporal increase was not observed along the left bank where there were no macrophytes.

Figure 40. Nutrients in Sediment Samples



* The stiochiometry of N and P in sediment composite samples collected during trip 2 (Aug 31, 2010) of the Bow River Pilot Study. R represents right bank and L represents left bank.

SECTION 5: CONCLUSIONS

The following conclusions from this phase of the study are summarized below:

BioSonics Survey

- BioSonics Echosounder was validated in the field to be able to be integrated with other instruments for seamless and simultaneous mapping of vegetation, sediment, flow/velocity, and channel bathymetry under a shallow riverine system, such as the Bow River;

- The field crews identified several key operating solutions for BioSonics under a shallow riverine environment that included configuring the instrument and designing the voyage traces for a BioSonics survey;

- A Visual Basic program was successfully developed to decode the binary formatted BioSonics sonar echoes;

- BioSonics sonar signals were qualitatively validated by the images and video clips taken by the underwater camera that they could be potentially applied to predict macrophyte density and size; however, more detailed field works are required to build the correlation equation between BioSonics sonar and macrophyte;

Water Quality Ground-truth Study

- There is definite difference in nutrient concentration of surface water as a result of WWTP.

- There is definite difference in macrophyte density as a result of WWTP.

- Predicting nutrient enrichment effect on vegetation from stream water alone may have limitations as macrophytes obtain much of required nutrients from sediment so macrophyte nutrient limitation may be more dependent on the sediment concentrations.

- Macrophyte density may not be the only thing to consider when understanding DO balance.

- Competition exists between macrophytes and periphyton so in order to coexits there may be different nutrient requirements and adaptations for the species.

- Periphyton community structure may be more important to look at than simply biomass.

SECTION 6: RECOMMENDATIONS

The follow suggestions are recommended to be considered in the 2011's BioSonics study and it ground truth water quality monitoring:

BioSonics Survey

- It is recommended that the next phase of work should focus on establishing algorithms to associate BioSonics echogram with macrophyte biomass density, canopy size, and plant length;
- In order to achieve the above goal, a manual sampling procedure of off-shore macrophyte biomass should be developed;
- The underwater camera has turned out to be a valuable tool for being used as a qualitative validation of BioSonics signals, however, the air bubble issues in the images from these video clips should be resolved in order to make the best use of these images;
- It is suggested that the BioSonics field study should be launched before the growing season of rooted plants, in order to collect the sonar echograms reflecting the base underwater conditions for both water and sediment layer. Another three rounds of survey are also suggested to be performed in different growing seasons of 2011, one in late of June, one during the middle of August, and the last one in late of October.
- It is also suggested that the BioSonics survey should be expanded to include all the major wastewater treatment plants by the City of Calgary, i.e., the Bonnybrook, the Fish Creek, and the Pine Creek plants;

Water Quality Ground-truth Study

- Sample individual species for tissue analysis as variance in plant tissue may be species related;
- Include BOD, sediment oxygen demand (SOD) into the sampling list;
- Further exploration of nutrient ratios in macrophyte and periphyton along different locations of the river.

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APPENDIX A.

Field Photos

Site photos

Trip 1:

1L looking across

1L looking upstream

1L looking upstream

1R looking across

1R looking downstream

1R looking upstream

2L looking across

2L looking downstream

2L looking upstream

2R looking across

2R looking downstream

2R looking upstream

3L looking across

3L looking downstream

3L looking upstream

3R Macrophyte sampling

3R looking upstream

3R looking downstream

Trip 2:

1L Potemogeton crispus bed

1L periphyton on rocks

1R macrophyte bed

2L looking downstream

2L substrate

2R looking across

2R water surface

3L bottom view

3R looking upstream

3R water surface

Trip 3:

1L looking downstream

1L periphyton

1R Potemogeton vaginatis

1R surface looking upstream

2L periphyton on substrate

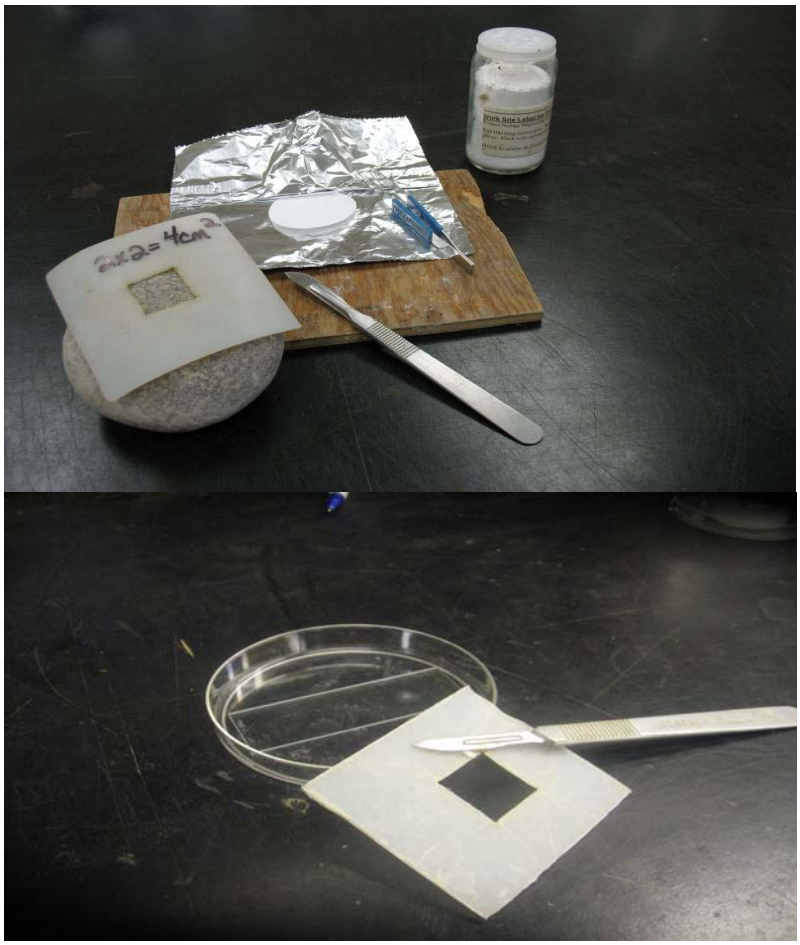
3L looking downstream

3L substrate

3R periphyton

3R underwater

Equipment:



Periphyton sampling equipment

YSI multiprobe data sonde for pH, conductivity, TDS, Temperature & D.O

Light meter for measuring light penetration (PAR)

Sampling quadrat

APPENDIX B.

Substrate and Density Categories

Table B1: Substrate and Density Categories

Substrate Categories	Size	Percent Coverage Categories
Boulders	>256mm	Absent 0%
Cobbles	64-256mm	Sparse 1-30%
Course Gravel	16-64mm	Moderate 30-60%
Fine Gravel	2-16mm	Dense 60-100%
Silt & Sand	<2mm	