Development of a Real-Time Water Quality Buoy for the Fraser River Estuary

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Abstract - **An innovative project has been initiated to monitor water quality of the Fraser River Estuary as a joint initiative between Environment Canada and the British Columbia Ministry of Environment. Monitoring year-round, real-time, water quality and meteorological parameters in the Fraser River Estuary required a unique approach. Axys Technologies' experience in both the marine, meteorological, and water quality fields was critical to the development of this custom monitoring station.**

Station location and in-situ water sampling required a moored buoy platform. A Three Meter Oceanographic-Data-Acquisition-System (ODAS) buoy was selected. This platform is capable of surviving freshet conditions in the Fraser Estuary, and support the extensive sampling and monitoring equipment required for this project. The ODAS buoy was modified to include both standard meteorological and multi-parameter water quality sensors, as well as instrumentation needed to collect whole water samples and extract large volumes of water using Solid Phase Extraction (SPE) for the collection of Persistent Organic Pollutant (POP) samples. Monitoring requirements include scheduled continuous and biweekly sampling, along with the ability to distinguish tidally driven events to initiate sampling for organic contaminates.

Challenges include the maintenance requirements for each sensor to ensure optimied ongoing operation as well as the vulnerability of this buoy to both vessel traffic and floating debris. Future application development may include automatic data Quality Assurance/Quality Control (QA/QC) and compatibility with a proposed national network.

I. Introduction

Axys Technologies Inc. (Axys) is a Canadian company specializing in the design and manufacture of environmental data acquisition, processing and telemetry systems. We apply our extensive knowledge and experience in marine and freshwater ODAS buoy platforms to measuring oceanic and atmospheric parameters. Product experience encompass the design and manufacture of the INFILTREX™ high volume SPE water sampling instrument used for the collection of aqueous and particulate phase POP samples.

Practical considerations included the use of a demonstration buoy hull loaned to the project by Environment Canada – Meteorological Services as the platform into which the sensors and data collection payload would be integrated.

The starting point was to utilize standard buoy infrastructure used by the operational marine ODAS network to determine an ideal payload integration and deployment strategy. A project overview was conceptualized to incorporate a standard payload and sensor suite, with provisions to include the non-standard water quality elements. Of key importance in the design phase was provision for in-field servicing, ease of sample collection, verification of data quality, assurance of continuous power, and flexibility in communication media. Land-based water sampling technologies have been incorporated into this buoy to extend the traditional marine monitoring station capabilities.

Located on the Main Arm of the Fraser River Estuary, this buoy is to be part of an existing 39 station Federal-Provincial Water Quality Monitoring Network of in British Columbia. Designed to collect Whole Water and time-integrated high volume Solid Phase Extraction (SPE) only during fresh water periods, the samplers are not active in the presence of marine tidal water.

Standard meteorological and oceanographic sensors, along with real-time video imagery round complete the sensor suite of this marine meteorological in-situ data acquisition station. The acquired meteorological and additional photographic data are transmitted via cellular Code Division Multiple Access (CDMA) Internet Protocol (IP) modem for immediate viewing on a designated client website.

This buoy measures/collects the following parameters:

- Wind speed and Direction
- Air Temperature and Relative Humidity
- Barometric Pressure
- Conductivity, Temperature and Depth (CTD)
- Dissolved Oxygen (DO)
- Turbidity
- Surface Currents
- Water Depth
- High Volume SPE Water Sampler for POP's
- Whole Water Samples for standard water chemistry analysis (nutrients, metals, organics)

This complete suite of sensors, in addition to three type of telemetry, a control system and power management system

have been integrated into the compact footprint of the Three Meter foam ODAS buoy. Axys has taken a combination of commercial-off-the-shelf sensors and customized sampling equipment and put them under the control of an Axys Watchman500 (WM500) controller to integrate and automate sample collection and data distribution.

The In-situ Automated ODAS Water Quality station is capable of automatically collecting data that previously could only be gathered manually, requiring technical staff to be on-site at all times of the day or night to coordinate sampling during specific stages in the estuarine tidal cycle. This station will ensure:

- Real-time access to routine meteorological and water quality parameters;
- True-time integrated samples over longer periods;
- Better resource allocation of technical staff;
- Increased safety of technical staff not having to sample in poor weather and at night.

This complex project required the development of custom device handlers to control and operate:

- whole water sampling, integrating with the associated refrigeration controls (pump activation, relay control).
- feedback control algorithms for the operation of the INFILTREX (flow regulation, volume measurement, pressure monitoring and valve operation).
- event-driven sampling algorithms based on sensor threshold values and conditional timing statements.
- IP camera imagery control, IP modem integration, AIS telemetry, depth sounder and Water quality sondes.
- integration of a large capacity solar power array and an underwater current generator into the ODAS buoy power management system.
- system integration and operational procedure development.

II. Operational Considerations

Important design considerations with respect to the station location are river currents, tides and marine vessel traffic. The ODAS buoy hull and the different sensor suites integrated into this In-situ Automated ODAS Water Quality station have service requirements that need to be followed to ensure optimal performance and the high-quality of data output.

A. Location

The buoy will be deployed on the Main Arm of the Fraser River Estuary, which contains approximately 85% of the river discharge [1]. The deployment location experiences marine estuarine conditions over the various tidal stages except during peak freshet conditions. Hazards to this ODAS station will include:

- Extreme currents, documented at greater than two knots downriver flow on the surface with a one knot upstream flow at a depth around 6m [2];
- Large woody debris (including full trees with root balls);
- Constant commercial marine traffic to various industrial facilities upstream of the site.

B. Maintenance

The three meter foam hull ODAS buoy with aluminum superstructure is a new demonstration hull design being evaluated by Environment Canada for use in its operational Marine ODAS network. The ODAS hull and primary solar power system require very little annual maintenance, with major service accomplished on a four-year cycle. The underwater power generator is a new element with no previous service history; thus annual servicing will be completed on an as-needed basis during the annual mooring inspection. The standard meteorological sensor suite installed on the buoy requires servicing on an annual basis.

The ODAS buoy is fitted with a number of water quality monitoring sensors (dissolved oxygen and PH sensors) that require bi-monthly to monthly maintenance. As well, the whole water samples and SPE columns and filters will need to be collected regularly and sent to the lab for analysis. The 12 VDC refrigeration chamber for the Whole Water sample is powered from a separate battery, which is exchanged at sample recovery.

As with all equipment in a marine environment, the buoy will experience biofouling and corrosion issues, addressed by annual maintenance to remove marine growth and replace the sacrificial anodes.

III. Platform Design

A. ODAS Buoy

The buoy hull provided by Environment Canada - Meteorological Services of Canada, is a Three Meter Gilman

Foam Float with an aluminum superstructure and steel substructure based on the original National Data Buoy Centre Value Engineered (VE) Three Meter Discus Buoy design (dated 2003). The aluminum payload and mast were constructed at the Victoria Coast Guard Facility's Blacksmith shop.

B. Moon pool

The foam hull was customized to accept a standard Axys 10" diameter polyethylene Moon Pool tube welded into place. A standard Axys instrument rack is secured to the top flange on the moon pool to enable in-field servicing of the water quality sensors. The moon pool has no direct connection to the interior compartment ensuring there is no possibility of water entering the hull. Sensors and instruments are mounted in a modular cage assembly of variable length, based on the size and number of instruments as well as the desired location of the sensors below the waterline. The cage is lowered into the moon pool and bolted down to the upper flange. Cables connect the instruments to the WM500 data logger inside the buoy via an external cableway bulkhead utilizing compression glands to maintain watertight integrity.

C. Advanced Water sampling Enclosure (AWSE)

A custom designed module was engineered to contain two separately controlled sampling devices; the refrigerated whole water sampler and the INFILTREX SPE sampler. This custom module consists of an externally mounted aluminum environmental housing fastened onto the lower mast on the buoy. The module enclose features easy access to all internal components and serviceable items via a full-size, hinged, gasketed door panel, and reinforced/secure attachment points for all internal components for sustained operation in a dynamic environment. Waterproof electrical connectors and compression glands for water lines and drainage keep the module watertight while allowing any excess sample water to escape All internal elements are modularized with quick disconnect connectors to allow for quick field servicing through on-site module replacement if required.

The custom designed module is oriented relative to the central buoy area to allow easy user access for field technicians when performing regular servicing and maintenance.

D. Station Power

Initial design power calculations showed an average of 10 Ah/day requirement based on an hourly sampling regime. Because of the high power demand of this system along with 24/7 operations over multiyear deployments without primary battery replacements, a unique power system was developed combining rechargeable batteries with power generation from multiple sources, including:

- 8 x 100Ah 12V Batteries for a total of 800Ah reserve capacity
- 6 x 55 Watt Solar Panels
- Underwater Power Generator UW100 can generate up to 2.4kWh per day

Power is managed through an Axys power distribution module inside the well of the buoy. This is a temperature-compensated, fused system to control the charge/discharge cycle of the system. System voltages and current charge/discharge levels are included in the buoy status transmissions.

A separate 100Ah 12V battery has been mounted in the AWSE enclosure to power the refrigeration and peristaltic pump for the whole water sampling. This battery is exclusive of the buoy's power network and is intended to be replaced/recharged as part of the sample collection process.

E. Mooring and Anchor

Discussions with the regional Canadian Coast Guard personnel who are responsible for maintaining the Fraser River Navigation buoys, recommend that this buoy be moored with 36m all-chain mooring and 3ton serrated steel anchor for the selected deployment location, which has a maximum depth of 13m.

An all-chain mooring typically has a lifespan of 2-3 years. Other advantages are: simple design, very rugged, resistant to damage by marine traffic, and is considered a standard mooring type by the navigation buoy tender vessels that would be maintaining the buoy. The buoy will have a small watch circle as required by the heavy commercial vessel traffic and limited sea room.

F. ODAS Station Visibility

To ensure the ODAS buoy is compliant to IALA regulations, it has been fitted with a 3-mile visible LED navigation light displaying the Amber Gp Fl 4 (20) flash sequence and a Firdell Blipper radar reflector. Another advanced feature on this buoy to increase awareness of this station to marine operators is the incorporation of an Automatic Identifications System (AIS) transmitter. This device will transmit a unique platform ID along with buoy's GPS location and basic weather information. New shipping regulations are requiring vessels to receive this AIS data onto their navigation systems.

IV. Payload

A. Data Acquisition, Processing and Control

The WM500 is the key component of this data acquisition system. The WM500 has a modular design that allows for future system reconfiguration. It allows for two-way communication

and diagnostics enabling the user to remotely manage and configure the system.

The WM500 controls the data acquisition, processing and telemetry in real-time. This includes configurable sample rate, report rate and sample period as well as remote diagnostics and configuration for hardware settings and software upload. Every hardware node or module in the WM500 has an on-board WM500 application that provides the infrastructure needed to perform sensor configuration, diagnostics, data acquisition, in field firmware updates and many other functions

A single complete WM500 hardware module is called a node. A system can have one or more nodes (node and module are interchangeable terms). Once a module is physically placed in the system with other modules it is assigned a unique node identity within the system, which is stored on the node microprocessor along with the on-board WM500 application.

The WM500 System is collection of nodes, with common hardware that cooperates on a multiple access communication bus to gather and process data, under the control of a designated primary module, which forms the internal communications link. This Primary Node can query and configure any secondary module or directly communicate with any of the sensors using internal system communication protocols.

The basic elements of this specific WM500 are as follows:

- **Primary Node (Node 1):** The Primary Node controls all other nodes in the system. It is responsible for network time synchronization, data collection and formatting data messages for output, in addition to other node functions. The Primary Node controls:
  - System Sampling (flood sensor, light status, current and voltage reporting)
  - Telemetry
    - CDMA EVDO modem - Air Link
    - Inmarsat D+- DMR 200
    - AIS- ATONIS
  - Whole Water Sampler/Refrigeration- Custom EC
  - Air Temperature and Relative Humidity – Rotronics Hygroclip
  - Wind Speed and Direction– RM Young 1503
  - GPS- Inmarsat D+ and Atonis AIS
  - Format NMEA data messages to be transmitted.

- **Secondary Node (Node 2):** The Secondary Node are managed by the Primary Node. These have all of the capabilities of the Primary Node with the exception of the capability to create and send data messages. This node controls:
  - IP Camera- Stardot Netcam XL
  - Water Quality -YSI6600 ADV (CTD/DO/Turbidity/Current)
  - Depth Sensor- AirMar
  - POP sampler- Axys INFILTREX™ 300L
  - Barometric Pressure- Vaisala PTB101B
  - Buoy Reference Compass Heading- KVH C-100
  - Flood Sensor – AXYS

- All data will be logged on-board the buoy and stored on a 1 GB compact flash card.

The WM500 application is compiled with a collection of 'device handlers' to suit this set of sensors. When the device handlers are compiled into the application it is 'installed'. Device handlers are designed to provide the required functionality while minimizing the size of the compiled application.

B. SENSORS

This buoy is fitted with an extensive suite of sensors that include:

- Anemometer – RM Young 1503
- Buoy Heading Compass Reference– KVH C100
- Air Temperature and Relative Humidity – Rotronics Hygroclip
- Water Quality- CTD/DO/Turbidity/Current – YSI6600ADV
- POP - high volume water sampling – Axys INFILTREX™ 300L
- Whole Water/Refrigeration – Custom EC
- Barometric Pressure – PTB101B
- Flood Sensor – Axys
- Power – voltage and current monitoring- Axys

C. SAMPLING LOGIC

The following diagrams show the timing and sequence of events that occur during sampling and data transmission. Although the timing is completely configurable, be aware that the parameters are interrelated, and a thorough understanding of these relationships is required for effective timing modifications.

Node 1 (minutes are listed along the top row)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
System Sampling (10 min)														
Air Link CDMA (11 min)														
Whole Water														
Sends message to camera every 10 min with one min offset														
Air Temperature, Wind Speed and Direction, AIS GPS – 10 min sampling interval and duration														
AIS Transmits every 2 min with previous data interval's data														

- System Sampling includes: flood sensor, light status, current and system voltage
- Whole Water sampling is for one minute and event driven. 5 min offset

Node 2 (minutes are listed along the top row)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Camera on for 10 min off set by 15s • 1 picture taken every min between 8am and 8pm														
Water Quality														
					Depth sensor (5 min)									
					INFILTREX™ (5 min) • event driven									
Atmospheric Pressure and Compass - 10 min sampling interval and duration														
Flood sensor – 1 minute average at end of period.														

- Water quality sensor is on for 2 min at the start of the sample interval. This data is used for driving other conditional event sampling regimes.

The WM500 will time-sync via the Inmarsat D+ GPS time once per day. A Watchcircle check runs once per sample cycle to validate the buoy's position. If the buoy is outside the designated Watchcircle boundaries, an off-position error flag will added to the buoy status transmission data.

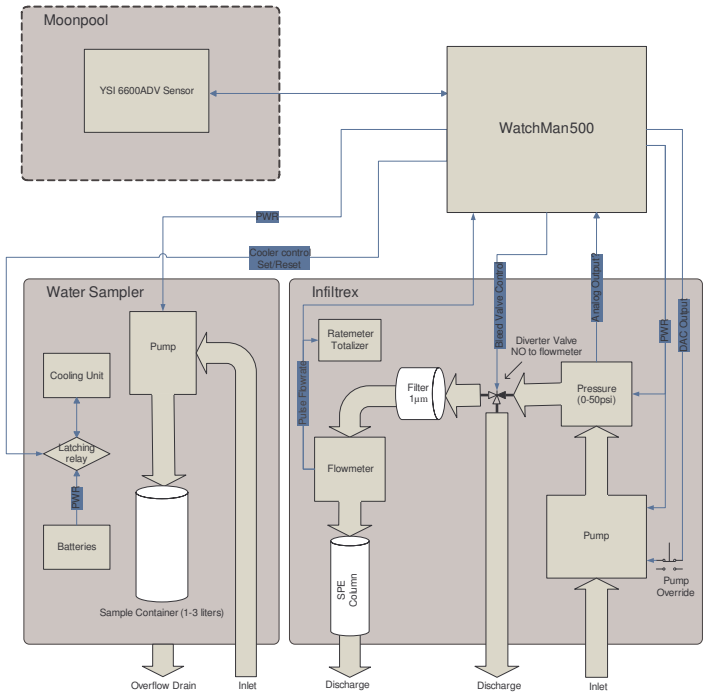
All the data will be displayed on a custom website.

D. INFILTREX™ 300L

The INFILTREX 300L™ high volume SPE water sampler has been developed by Axys for the sampling of trace amounts of POP for both dissolved and suspended phase samples.

This 12 VDC system has been modified for autonomous operation under the control of the WM500 to provide a regulated flow control and total volume accumulation data. Specific sampling requirements require pre-sample flushing/priming of inlet lines requiring an integrated solenoid valve to divert the flow path. The design incorporated both digital and analog pressure monitoring sensors to monitor system condition both remotely and on the buoy. The INFILTREX can be activated manually, using a manual pump control and backup rate meter/totalizer, which allows for easy operation and service by field technicians.

The INFILTREX will only be collecting samples when conductivity readings are below 1000µs/cm (that is fresh water). When this condition is met, the WM500 will energize the solenoid valve to open the purge line path, and the pump is activated at a preset voltage to fill the inlet tubing line for a set period of time. The motor is then switched off, and the solenoid valve is de-energized, which switches the flow path to the sample line.



The pump is then powered at a preset voltage level to get an initial flow rate reading, after which flow is controlled via a feedback loop to maintain flow to within 10% of the programmed rates (~100mls/min). During sampling the line pressure is monitored at 1 Hz, with error flags being raised when pressures exceed 20 PSI. As well, if system flow rates cannot be maintained, the INFILTREX is shut down and an error message transmitted.

This station will be collecting samples to analyzed for POP which include: PCB's, nonyl-phenol, stepils, PAH's, and PBDE's -brominated diphenal ethers.

E. WHOLE WATER SAMPLING (DESIGNED BY ENVIRONMENT CANADA)

Axys has integrated a custom-built refrigerated, Whole Water sampling apparatus to be controlled by Node 1 of the WM500 through an external relay control box. If programmed conditions are met; in this case the data values for the conductivity set point fall into a preconfigured range; the peristaltic pump will be activated five minutes into the sampling cycle for a one minute duration. Once sampling has been initiated, the power to the refrigeration chamber is activated from the external battery. This battery will need to be changed/replaced each service trip.

With this system there is no flow control; the pump is activated at a manually set rate for a specific period of time. If the sample bottles are full, they will overflow into the refrigeration unit and exit via the refrigeration unit's drainage system.

This station will be collecting samples to analyzed for the following compounds: glyphosate, acid extractable herbicides (AEH), current use pesticides, pharmaceuticalsand personal care products.

F. Telemetry

This ODAS station deployment location is situated in an urban environment with access to wireless broadband communications networks. The primary telemetry for the station is CDMA EVDO direct IP with full duplex capability to allow for remote configuration, firmware upgrading, and diagnostics on the buoy through a remote terminal connection. The system will be linked to a remote server running the Axys Data Management Software (DMS), which will interface to a sequel server database. This data will be incorporated by the client into a station-specific website to allow public viewing of the near real-time data. The web camera is under control of the WM500, however the output of the camera is directly connected to the CDMA modem via a network cable.

Auxiliary telemetry consists of a low bandwidth Inmarsat D+ satellite transmitter. When activated, this transmitter provides a backup data conduit for basic meterological and station status information. The Inmarsat D+ system can either be polled remotely as part of the station position monitoring or be set to automatically send station position alarm status messages if specific conditions are met.

A Class B UAIS transponder has been integrated into the WM500 system to allow transmission of message 8 and 21 data. The marine band VHF transmission will be received by vessels equipped with an AIS receiver and the appropriate navigation GUI, which will display the station ID, position, meteorological information, and current information.

V. Summary

The integration of multiple custom sampling apparatus with traditional environmental monitoring sensor suites, in conjunction with complex sampling algorithms on a buoy has been accomplished using the advanced WM500 controller. Using wideband telemetry, the WM500 has provided unprecedented station control in terms of remote command and control capabilities, along with real-time data access.

The operation of this station will offer scientists a new dimension in the monitoring of contaminant transport from the Fraser River and enable more detailed data for input into the overall Georgia Basin contaminant transport models. Additionally real-time access to routine water quality parameters coupled to meteorological and river flow data will enhance the overall understanding of the environmental dynamics and which can be used to support other EC sampling initiatives. The knowledge enhancements offered by the new station are coupled with staff allocation savings and a mitigation of staff Health and Safety issues.

Development of this complex platform took longer than anticipated owing to coordination through multiple agencies, and with technical issues. Operation of the new buoy power system over a long-term deployment has yet to be assessed.

At this point overall program benefits have not been tabulated because is still in its nascent stages. Initial results are encouraging.

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VI. References

[1] Overview Report “Ambient Water Quality Assessment and Objectives for the Fraser River Sub-Basin from Kanaka Creek to the Mouth.”

[2] E. Thomson, “Oceanography of the British Columbia Coast,” Canadian Special Publication of Fisheries and Aquatic Sciences 56.