Application of an automatic event-controlled sampler for biological analysis and monitoring: studies on plume tracking in Milwaukee Harbor, Milwaukee, Wisconsin

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***Abstract*-An automatic remote-controlled sampling system for biological analysis and monitoring is presented and its functionality described. In order to test the automatic sampler's ability to reproduce standard manual sampling methods, several trials were performed. The automatic sampler allows event-triggered samplings. Time series of these events are presented and interpreted. Significant patterns of bacterial concentrations and sonde parameters are expected during heavy rainfall and CSO events. Comparison of samples from the automatic sampler and the manual samples collected at the south gap in Milwaukee Harbor showed the same results for samples analyzed the day of collection as for those that were stored at the bottom of the lake.**

I. INTRODUCTION

Urban stormwater and sewage overflows introduce large amounts of contaminants into the Great Lakes each year and are considered a major source of contamination of surface waters in the United States. Large volumes of stormwater generated during heavy precipitation can exceed a sewer's capacity, resulting in both stormwater and sanitary sewage being released into the lake as part of a combined sewer overflow (CSO). Sanitary sewer overflow (SSO) may also occur when separated sanitary sewers are inundated with large volumes of rainwater or in the event of mechanical failure. These events are of concern to public health because they have the potential of carrying disease-causing organisms including viruses and bacteria into lake water [5]. There is a need for improved long-term, continuous monitoring of Lake Michigan in order to study these important episodic events. The traditional method of studying CSO effects on the lake has been through ship-based water sampling carried out as close to the event in time as possible. This method has three significant drawbacks: 1) ship time is not always available when a CSO event occurs; 2) it is desirable to obtain samples during a CSO event and for a period of time afterward, an extremely difficult task given the event's unpredictability and the limited availability of ship time, cost, and personnel, and (3) weather conditions are not always favorable (e.g., cruises are cancelled due to rough seas). Thus, sampling often occurs at non-optimal times and for insufficient periods of time, resulting in an undersampling of the events. Adaptive sampling techniques [3, 6] applied to buoy-based sampling systems solve this problem by sensing local weather conditions and increasing the sampling rate when a CSO event is expected, such as when there is >5 cm of rain within 24 hours. The system obtains samples and measurements at the optimal time and at important flanking time periods. In this paper the first adaptive sampling experiments utilizing the WATER Institute's Great Lakes Urban Coastal Observing System (GLUCOS) are described with the aim of tracking bacterial loading and persistence in the lake caused by heavy rainfall and/or a CSO event.

With this intent, two experiments were performed in 2008. A McLane RAS-500 water sampler was deployed for about 30 days at a time just outside the south gap in the Milwaukee Harbor break wall, as can be seen in Fig. 1, starting on August 12 and again on September 29, at 8.7 m depth. The estuary leading to Lake Michigan is comprised of the junction of Milwaukee, Menomonee, and Kinnickinnic rivers and a channel conducting to the harbor, with approximately 150 CSO outfalls located on the estuary.

This project made use of sondes affixed to the anchor and to the spar float just below the surface. Sonde features were: conductivity, turbidity, pH, chlorophyll content, dissolved oxygen, temperature and depth. The adaptive sampler has 48 sample cylinders connected in parallel though manifolds each with a 500 ml bag. Each individual sample bag is connected in series and between the intake head and the exhaust. The pump draws water out of the flooded sample cylinders by creating a negative pressure gradient that pulls lake water through the intake and into the bag. The sampler was integrated into our existing Pioneer II buoy system. Low-level operation of its hardware is controlled by an integrated microcontroller (μC) running McLane's firmware.

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The µC provides a command line interface over RS-232 to allow for higher level control of the system. Custom software on the buoy's computer interacts with the McLane sampler to issue commands and keep track of its status, battery life and Milwaukee's watershed. When the average rainfall from at least six of these stations reads more than 0.51 cm within an hour a rain event is assumed. The software then sends an email/text message out to alert staff and contacts the buoy's computer to begin automatic sampling. This causes the buoy to take one liter samples every two hours until stopped by staff. In order to test the automatic sampler's ability to reproduce standard manual sampling methods several trials with both methods were performed. Samples were tested for *E. coli* and *Enterococci*. Results of comparative samples from the automatic sampler and the manual samples are compared to assess reliability of the sampler.

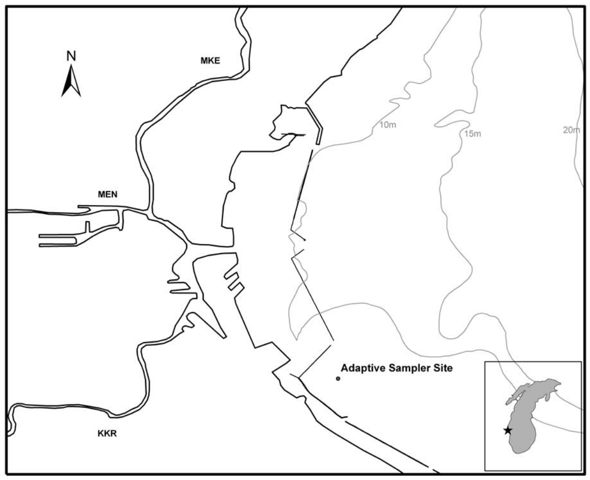

Figure 1. Study area in Lake Michigan near metropolitan Milwaukee. Approximately 150 CSO outfalls are located on the Milwaukee (MKE), Menomonee (MEN), and Kinnikinnick (KKR) rivers.

II. PLATFORM DESCRIPTION – HARDWARE

Components of the hardware

The following system components are presented from the bottom up as seen in Fig.2. More detailed drawings are presented in Fig.3.

A. Anchor and Frame

The anchor is a rebar-reinforced concrete block that has a dry weight of 318 kg, with a steel lifting plate and two exposed threaded rods on either end used to attach a mounting/protective frame to the anchor. The rectangular frame was built using 3.5 cm square steel tubing with holes drilled along its length for drainage and as attachment points. The frame protects a battery and an electronics module, both in cylindrical pressure housings, and a sonde sampling instrument. Horizontal steel rails are bolted to the frame, allowing the sonde and pressure housings to be mounted and secured to the anchor assembly. Rubber strips are used in-between hose clamps, the rails, and the pressure housings to prevent electrical contact and extend the life of sacrificial anodes. The threaded rods from the anchor pass through holes in two square pipe stubs welded to the frame and lock the frame to the anchor with steel nuts. The lifting plate passes between the two center instrument rails and completely supports the weight of the anchor when suspended.

B. Pressure Housings

1) Description of Pressure Housings: The electronics and battery pressure housings are 0.15 meter diameter aluminum cylinders, 0.635 and 0.71 meters long respectively, with two aluminum end-caps, all machined by the WATER Institute machine shop. The end-cap is a disk with a centered, extruded cylinder of a slightly smaller diameter than the inner diameter of the housing. On the contact surface an O-ring channel allows for a water tight fitting. The cap is held in place by several set screws catching in a second channel. The end caps are milled with different numbers and sizes of threaded holes depending on the function of the cap; making the pressure housings highly modular. The electronics and battery caps are then outfitted with the types of Teledyne Impulse bulkheads relevant to the project and sacrificial anodes are attached to the rear caps for corrosion protection.

2) Signal Conversion Can: The can is a small pressure cylinder holding a signal converter with an addressing feature (B&B Electronics, model 485DSS). The signal is converted from RS-232, which the sonde uses to communicate, to RS-422, which can be run long distances without signal attenuation. The addressing feature allows for multiple sondes to be daisy-chained along a series of RS-422 configured cables. One end cap has an RS-232 connector for the sonde, the other end cap has two RS-422 connectors for the multidrop network.

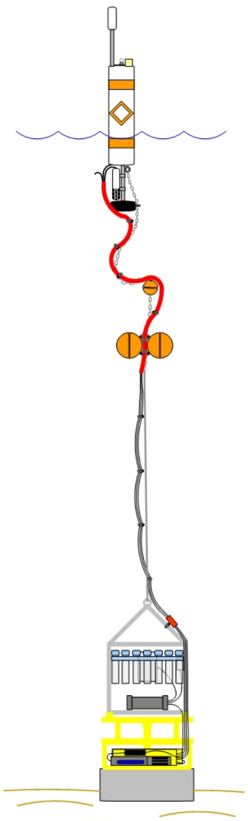

Figure 2. Adaptive sampler system hardware assembly

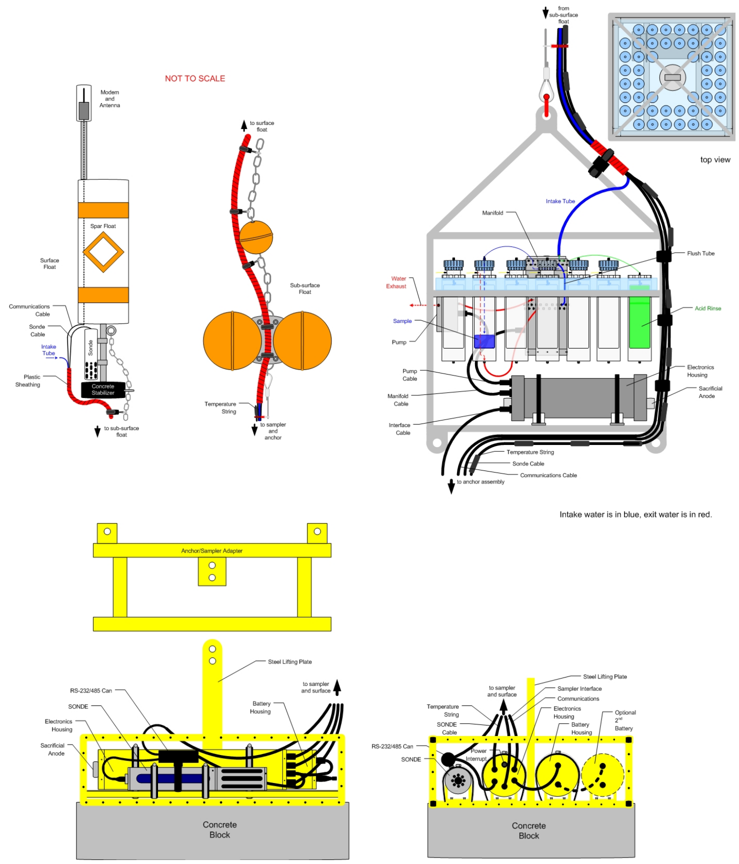

Figure 3. Component details

C. Frame Adapter

An adapter attaching the McLane sampler to the anchor frame allowed the two to be consolidated into one unit, making deployment easier. The adapter was made of square steel pipe with attachment points for the lifting plate of the anchor and the four eyelets on the bottom of the sampler frame. The rails rest on, and slot into the anchor frame, increasing stability.

D. McLane RAS-500 Water Sampler

The McLane RAS-500 water sampler, as seen in Fig. 2, works using a pressure gradient; by pumping water from plastic cylinders containing collapsed sample bags, it draws water through the intake hose and into a bag. The system is suspended in a cubical stainless steel cage with one mooring eye at each corner of the bottom side. On the top side the frame is a four-sided pyramid with a mooring eye at its apex. The in-line tension rating for the sampler cage is 2268 kg. The physical strain of the mooring is therefore confined to the lifting plate of the anchor, the frame adapter and the sampler cage; all designed to be load bearing.

E. Wire rope and Cable bundle

A 5.6 m long, 0.79 cm (5/16 inch) stainless steel wire rope with stainless steel thimbles on either end connects the sampler to a subsurface float. A cable bundle running along the wire rope is taped together, and connected to the wire rope with carabineers every few meters. Block & screw anchors are used periodically to support the weight of the cable bundle. In addition to the normal cabling opaque tygon tubing, used as an intake tube for the sampler, was included in the cable bundle. The finished cable bundle consisted of a communications cable to the RF modem, the RS-422 cable, a temperature sensor string (NexSens, model TS110) and the intake tube for the McLane sampler. The tubing used was opaque in order to curb biofouling of its interior by algae.

F. *Sub-surface float*

The sub-surface float is a pair of plastic 36 cm diameter spheres connected horizontally by a steel plate with steel attachment loops, as shown in Fig. 2. The sub-surface float is connected using shackles on its bottom to the wire rope's thimble and at the top to a steel chain. The chain connects the surface and sub-surface floats together. A small plastic spherical float halfway along the length of the chain creates a catenary to the surface float, reducing the amount of wave action transferred by the surface float to the sub-surface float. The cable is bundled in heavy plastic sheathing attached to the chain at intervals with lanyard carabineers.

G. *Surface float*

The surface float consists of a 36 cm diameter, 130 cm high spar buoy (Rolyan Buoys, model B1452) from which is suspended a cylindrical, concrete block encased in plastic on a steel pipe that runs lengthwise through the center of the float, as seen in Fig. 2. The block acts as ballast and counteracts wave action. The mooring chain from the sub-surface float passes through a steel hoop affixed to the concrete block and connects to a mooring eye welded to the pipe. This is to insure that the float will stay relatively upright when the chain is under tension. Drilled lengthwise through the spar buoy is a hole lined with a PVC tube that is capped and fitted with a water-tight connector on the bottom end. A cable runs up this hole to a smaller diameter PVC tube with its own connector which acts as an extensible mast for the communications pod. The RF modem and antenna are enclosed in a PVC capsule atop the smaller diameter PVC tube.

The surface float also has a removable sonde-holder attached to the center pipe above and below the mooring eye. The sonde cable and sampler intake hose terminate here. The holder is a large PVC tube with slats cut into it to allow water flow through the sonde basket and over the instrument probes. The intake hose is fitted with a large aperture filter to prevent debris from entering and obstructing the sample water intake.

Detailed Description of the McLane RAS-500 Water Sampler

Of the 49 cylinders on the sampler 48 have filters. Into the tops of the filters run small-diameter plastic tubing with a screw connector containing a small check valve. These intake tubes are connected to the central circular manifold, which has 50 unique positions. There is a position for each of the 49 cylinders and one that bypasses the cylinders and is used to flush the intake tube with ambient water in either direction.

After water passes through the filters evacuated sample bags attached to the bottom retain the water samples until retrieval. Here an important point must be made; the filter does not feed the sample cylinder, only the sample bag. Outside of the sample bag, the cylinder is filled with water that is exhausted to the outside creating suction that fills the bags, like lungs. The sample cylinders connect on the underside to tubes that run to a second manifold which acts exactly as the first but in reverse. The manifolds always move together and always mirror each other.

The downstream side of the second valve is then connected to the pump which exhausts to the ambient water. Underneath the downstream manifold the central assembly also contains the motor used to position the valves. The 49th cylinder (labeled A) is meant to contain a sample bag containing an acid solution for the purpose of sterilizing the intake tube to prevent contamination of samples.

In summary, the sampler is comprised of two separate water handling systems which can both be opened to the outside but not to each other. The intake system consists of an intake hose, an upper manifold and the sample bags themselves. The back-end system functions by drawing water from the flooded cylinders in which the evacuated bags reside and exhausting it. Exhaust can be directed by attaching a tube to the pump exhaust.

The pressure housing contains both an on-board control electronics stack, and the batteries that run the pump and manifold assembly with a backup 9-volt battery for the electronics. The pressure housing is rating for 5500 m and both of its end caps have attached sacrificial anodes. The bulkhead connectors connect power cables to the manifold and pump motors and a communications cable to the electronics module of the Pioneer system.

Testing

Due to sample volume inconsistencies several pump precision tests were run in and out of a laboratory test tank. It was originally thought that the sampler leaked air into its intake water when outside of the test tank. It was assumed that it was leaking while submerged as well, but that the evidence was being lost due to the inability to distinguish leaked water from sample water. Dye was injected around the manifolds in attempt to visualize any water leaking in from the outside. The results were ambiguous because the dye was not at sufficient concentration in the samples to affect the color.

A second test was performed in which a known volume of water was pumped into a sample bag and then measured. Care was taken to evacuate the sample bags completely before the test so that an air leak would manifest itself. A lesser volume than was commanded was pumped into a sample bag when the sampler was outside the tank but the bag did not fill with air indicating that the leak was on the non-sample side of the system and therefore irrelevant if the sample volume could be adjusted. It was realized, however, that when tested in air the sample volume discrepancy was most likely due to the pressure equalization valve on the cylinder not being meant to equalize two fluids of such different viscosities as water and air. When submerged the combined volumes were equal to the starting volume. Endurance testing saw consistent performance over several days of constant pumping. The entire assembled buoy was tested later, also for several days, with no problems.

The 250 USD proprietary battery was replicated with off the shelf C-cells after it exploded shortly after being deployed for the first time. There have been no problems since. The explosion was most likely due to exposure to moisture in the testing process and/or age. The sampler's controller stack sustained same corrosion damage but was repaired by rebuilding the damaged traces.

Detailed Description of Sondes

The YSI model 6600 EDS V2 sonde is a multi-parameter water-testing instrument with on-board batteries and memory which can transmit real-time information via a RS-232 cable. The specific variables being tested can be changed by switching out probes with room for a total of six. Normally, the parameters relevant for WATER Institute scientists are: conductivity, turbidity, pH, chlorophyll content, dissolved oxygen, temperature and depth. The last two parameters are native to the sonde and cannot be removed but they can be turned off if desired. Also recorded is the date and time of each sample. Through the connection to the electronics module data is logged and saved as tar files along with water column temperature data from the temperature string and periodically relayed back to servers on land. Each of the probes is calibrated using standard solutions of known values for one or two point calibration. They are as follows: (a) conductivity: 717 μmho/cm (KCl); (b) turbidity: 0 NTU (tap water), 100 NTU (standard solution); (c) pH: 7.02 (standard solution), 10.01 (standard solution); (d) dissolved oxygen: water saturated air, using atmospheric pressure corrected for elevation normalization error; (e) depth: can be set, works off pressure; and (f) temperature: cannot be set. If the sonde passes the calibration tests successfully it is approved for use.

Electronics module

The electronics consists of several terminal strips, a TS-7260 board running Linux, a PC-104 TS-SER4 four-serial-port board for instrument connections, a One-wire to serial adapter for the thermistor string connection and a custom power regulating and humidity sensing board. The sampler and sonde connections are directly to the TS-SER4 board and the thermistor string is first routed through its one wire adapter before being attached to the TS-SER4. The radio is connected to the TS-7260 and the power is first run through the power regulating board before supplying it. The SER4 is run off the 7260 via a PC-104 bus. Both the radio and sonde connections use RS-485 standard while the sampler and the thermistor use RS-232.

III. PLATFORM DESCRIPTION - SOFTWARE

A basic Pioneer II buoy system is used as the main control platform [4]. The water sampler is controlled through a command line interface over RS-232. The buoy's computer then commands the McLane μC through custom software permitting automatic control of the sampler through a simple API (Application Programmer Interface).

To take a one liter sample, the intake tube must first be flushed of any standing water. This requires the sampler to change its manifold to port zero to allow water to bypass the sample containers and pump twice the volume of water in the intake tube out. Whenever pumping is initiated by the buoy's computer it creates a lock file to prevent another program or another instance of itself from interrupting the pumping. This happens over two commands as the sample volume limit is 500 ml and the intake tube has a volume of 411 ml. Second, the sampler must move the manifold port to the next free sample bag; this is tracked by the buoy computer. If the sample number is greater than 48, the program exits immediately, as the max capacity has been reached. Otherwise, a command to pump 500 ml into that bag is issued; the manifold port is incremented by one and the process is repeated for the next sample bag, as shown in Fig. 4.

The software on the buoy for controlling the samples consists of multiple small programs written in C-Kermit (The Kermit Project, Columbia University, New York, NY). One of these scripts is run by the buoy's cron[2] daemon every five minutes. This program checks a specified location on the file system for two types of 'flag' files. Flag files are empty files used for signaling events to programs. The first type of flag file, hence forth referred to as the "manual-sample", flag will initiate one sample and then be removed by the program once the sample has completed. The second type of flag file, hence forth referred to as the "auto-sample", flag will initiate a sample every two hours until the capacity of the sampler is reached or until stopped remotely by staff.

To accurately determine if a rain event is occurring can be difficult. Original plans called for software on board the buoy to identify a rain event's signature. This signature was to be based on real time environmental parameters gathered with the sondes. However, after reviewing historical sonde data recorded during previous rain events, we concluded that there would be too many possible false positives introduced as a result.

Therefore, another method was employed. Custom software written in PHP is scheduled to run every 30 minutes by the server's cron daemon. This program automatically queries the available rainfall gauges from the MMSD's website [2] that are within Milwaukee's watershed. If the average rainfall from at least six of these stations reads more than 0.51 cm within an hour, a rain event is assumed. The software then sends an e-mail or text message to alert staff and contact the buoy's computer to create an

[2] cron is the name of program that enables unix users to execute command or scripts (groups of commands) automatically at a specified time/date.

“auto-sample” flag file for the buoy's software. This will cause the buoy to take one liter samples every two hours until stopped by staff.

In addition to automatic methods, it is often necessary to trigger a sample manually in order to produce control samples for comparison. Thus, an alternate method for triggering a sample on demand is available. This feature is accessed online through a web interface. This is accomplished with another small PHP program that provides a simple “trigger sample” button. When clicked it causes the program to contact the buoy and create a manual-flag file which initiates a single sample.

Communication to shore is handled by a 900 MHz radio modem (model Digi 9XTend, MaxStream, Lindon, UT) that is mounted in a waterproof container on top of the spar buoy. The buoy communicates with the shore station located on top of a tall building on the Milwaukee lakefront, Cudahy Tower. The shore station links its 900 MHz radio modem to an Ethernet-connected serial device server (model NPort 5110, MOXA, Brea, CA), ultimately connecting the buoy in the lake to the WATER Institute staff through the Internet. The software and communications architecture of the Pioneer II system is described more in depth in [4].

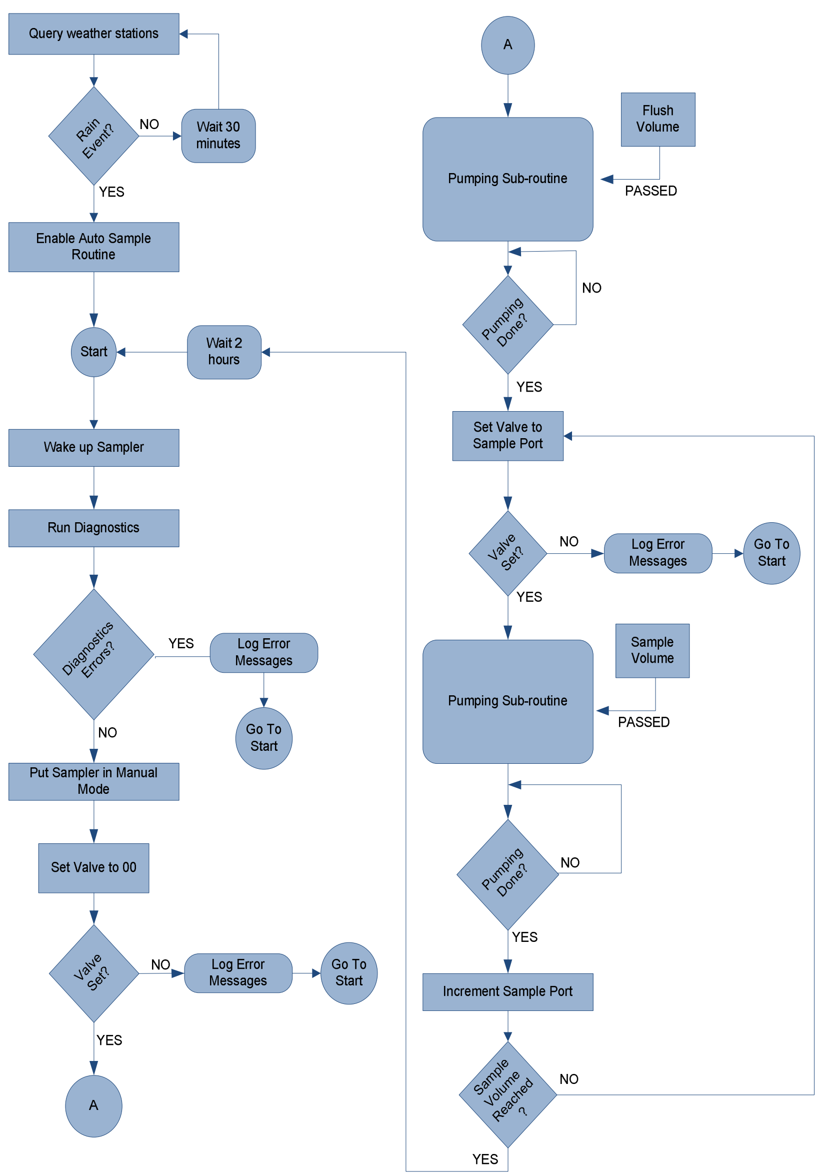

Figure 4. Flow chart of the algorithm for command line control of the sampler

IV. DEPLOYMENT AND RECOVERY OF THE ADAPTIVE SAMPLER

As per the McLane manual, prior to deployment every tube must be primed with water and the sample cylinders must be flooded. The sample bags must also be evacuated and connected. Typically this is done before deployment with the exception of priming the intake tube, which is flushed in reverse immediately after deployment. For the intake tubes between the first manifold and the cylinders de-ionized water is used because any water in those tubes will inevitably end up in the samples. The volume is small, however, and doesn't significantly dilute the sample. When recovering the adaptive sampler, two important things had to be taken into consideration: (1) the only water in the sample bag was the water taken during the sampling period and (2) the samples had to be chilled quickly to preserve the bacteria.

Immediately after pulling the sampler out of the water, a hose was used to spray off the algae (see Fig. 5) before it dried on to the sampler. Algae were a concern because it not only would get in the way of working, but also, the more algae there was on the system, the greater the chance of some of it contaminating a sample. After the sampler was cleaned, it was taken apart as quickly as possible to preserve the samples. For each bag, the top valve had to be closed before detaching the sample bag from the system to prevent contamination. Each bag was numbered to correspond to the cylinder from which it was taken. The samples were then put into a slot with the corresponding number in a cooler filled with ice and water. The samples were kept at about 4°C until they were filtered for bacteria.

Figure 5. Bottom assembly post-recovery on Neeskay deck. Note algae growth.

V. MICROBIOLOGICAL AND PHYSICAL ANALYSIS

Microbiological analysis

During the first deployment, fourteen samples were collected in duplicate (two one-liter-samples taken at each sample time) by the adaptive sampler. Five samples were collected manually at the same time that the adaptive sampler was activated for a comparison study. Manual samples and samples from the adaptive sampler were tested for *E. coli* and *Enterococci*, according to EPA Methods [8, 9]. Bacteria density was expressed in Colony Forming Unit (CFU) per 100 ml of sample. Bacteria counts were 8 CFU/100ml or less for all samples. During the second deployment, thirteen samples were collected in triplicate (three one-liter-samples taken at each sample time) by the adaptive sampler. Two samples were collected manually for validation of the system.

Again, manual samples and samples from the adaptive sampler were tested for *E. coli* and *Enterococci*. Bacteria counts were 19 CFU/100ml or less for all samples. The validation showed the same results for samples analyzed the day of collection as for those that were stored at the bottom of the lake. The average amount of time that the samples were kept on the bottom of the lake was 30 days.

Physical analysis

Sonde parameters, such as temperature, conductivity, pH, dissolved oxygen, and turbidity are very important to help track bacterial loadings into the lake. However, these parameters are affected by other phenomenon in the lake and not only by bacterial loading. Therefore, sonde parameters should be cross-correlated with bacteria density and not evaluated separately. Because very low bacteria counts were detected during the two deployments of the adaptive sampler, cross-correlation was not possible to be performed. However, time-series of all parameters are discussed here to show trends of parameters and differences of top and bottom sondes due to different environments. In addition, knowledge of the status and fluctuation of parameters in the water column is extremely important for detection and interpretation of pollution signature.

A. Temperature

During the first deployment, the temperature for both sondes remained relatively constant throughout the period, with the exception of two instances of major decrease, particularly seen in the bottom sonde. The first temperature drop was no more than 5ºC and occurred on August 23rd and lasted until late morning on the 24th. The next major drop in temperature was much more drastic and occurred about a week later, starting on the 30th. This drop in temperature goes from 19.51˚C to 9.7˚C for the bottom sonde in the space of two days, as can be seen in Fig. 6. The top sonde only drops a few degrees in this period. By the end of the deployment both sondes stabilize around 20ºC.

During the second deployment, as expected, the temperature steadily dropped with time for both sondes (September-November). In the graph there are some large down-ward spikes for both sondes, this occurs because some data has been filtered out and there is a several day gap (from 10/9/2008 to 10/21/2008) that has been filtered out, where the temperature decline is almost -3ºC.

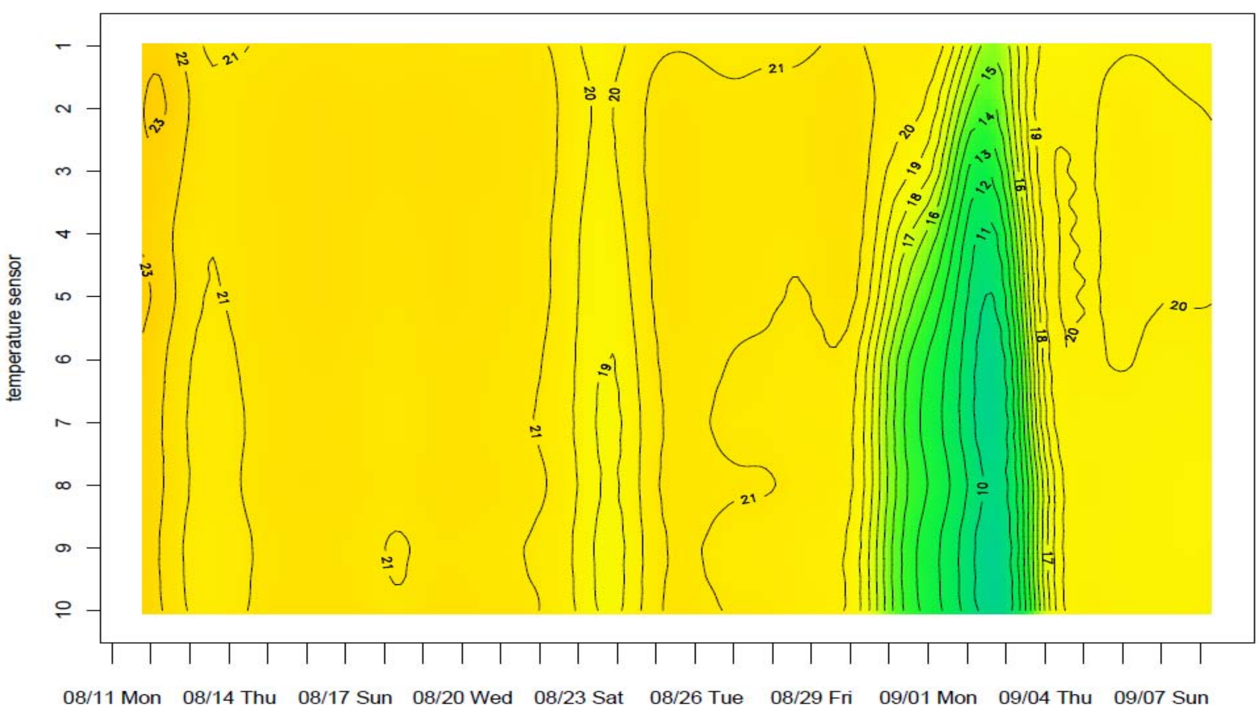

Figure 6. Temperature profile vs. time for the adaptive sampler. Data is from the first deployment. The temperature sensors are spaced one meter apart, sensor #1 is uppermost, about three meters below the surface.

B. Conductivity

During the first deployment, conductivity for both sondes remained, for the most part, between 275 and 350 µS/cm. During the second deployment (Fig. 7), the patterns between the top and bottom sondes were very similar for conductivity, but with the top sonde slightly lower than the bottom sonde, maybe due to higher presence of sediments on the bottom of the lake and no significant resuspension event. The largest spike for both of the sondes happened on October 21st, early in the morning. Conductivity for both sondes jumped nearly 30 µS/cm from where they had been on October 9th. They then both stabilized at about 320 µS/cm until the end of the deployment.

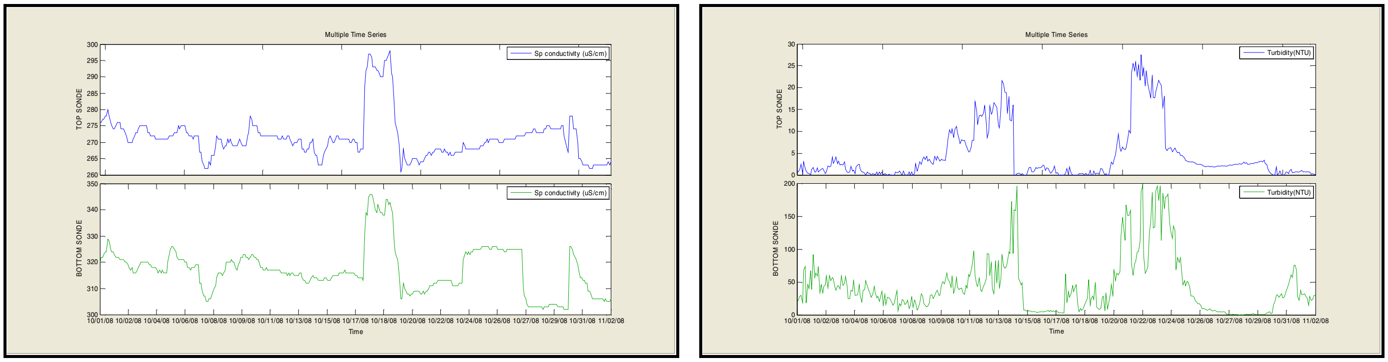

Figure 7. Specific conductivity plots in µS/cm (left) and turbidity plots in NTU (right) for the second deployment, top and bottom sondes in respective positions.

C. pH

During the first deployment, the pH for the bottom sonde was absent from all records, leaving only the top sonde. The pH for the top sonde remained mostly in the 8.1 to 8.5 range. There were few spikes in the data. The pH jumped up from 8.36 on August 13th at 10:05am to 8.51 at 4:55pm on August 14th. The next major spike was a decrease which happened on August 27th. The pH started at 8.33 at 8:50am on the 27th, then decreased to 8.08 at 7:25pm. It then gradually increased over the next day and got back to 8.3 during the late afternoon of the 28th.

During the second deployment, the pH levels for the top and bottom sondes did not follow the same patterns as one another; the top sonde remained relatively steady throughout the experiment period, while the bottom sonde tended to fluctuate. The bottom sonde changed frequently, ranging from 6.95 on October 23rd at 10:45am to 8.72 the same day, an hour later. Overall, the pH for the bottom sonde decreased with time, while pH increased slightly for the sonde near the water's surface. This pH fluctuation on the bottom sonde may be due to flow of sediments on the bottom of the lake, but not related to pollution discharge.

D. DO sat

The dissolved oxygen for the top sonde remained relatively stable; most data points were above 90% and below 110%, with the outliers only straying a few percentage points away from this range. However, the bottom sonde had a greater range with two downward spikes throughout the sample period. This behavior may have been due to probe failure. At the beginning of the second deployment the DO steadily decreased for both sondes, with the top sonde having a higher percentage than the bottom. There were some large spikes, particularly with the bottom sonde, with the largest occurring close to the end of the experiment. The first spike started mid-day on October 8th and lasted a couple hours before stabilizing at a lower percentage than it had been previous to the 8th. The DO then increased slowly to 100 late October 23rd, then dropped again to 93.2 several hours later on the 24th (data was filtered, 10/23, 19:15 and 10/24, 6:31 are next to each other after data filtering.) The percentage stays in the mid to upper 80's until it spikes up to almost 100 on November 2nd, where it stabilized until the end of the experiment. Overall, the top sonde remained fairly stable. There was one sharp decrease the morning of October 25th, then a significant jump on November 2nd, very similar to the bottom sonde. However, since the data is filtered the 25th and the 2nd are next to each other, the week between them is missing, so it is unclear as to whether this is a significant jump or not. The DO results follow similar trend of the pH, possibly indicating the flow of sediments on the bottom of the lake.

E. Turbidity

Turbidity for the top sonde was very stable during the first deployment, varying from 0 to 10 NTU. However, turbidity for the bottom sonde showed more variability during the same time of deployment, varying from 20 NTU to 200NTU. For the second deployment (Fig. 7), turbidity for the top sonde remained relatively constant, with only two major spikes throughout the sample period. However, the turbidity for the bottom sonde was variable, ranging from 0 to 196 NTU. Despite the variability, there were only two drastic spikes throughout the sample period. The first spike started as a gradual increase for both sondes, starting early in the morning on October 7th, reaching a maximum the same day at 7:45pm for the top sonde and then almost 24 hours later for the bottom sonde. The turbidity measured by both sondes decreased to between 0 and 10 NTU until October 21st when the bottom sonde increased to 62.5 NTU, while the top sonde remained close to 0. Both sondes began to record an increase in turbidity on the 22nd, with the top sonde increasing and then staying relatively stable (not jumping more than 7 NTU at one time) while the bottom sonde continuously alternated between extreme highs and middle ranges, at some points jumping as much as 100 NTU at a time. On October 24th, both sondes decreased and remained in the 0 to 10 NTU range until November 2nd when the bottom sonde jumped up to 30 NTU and remained in the 20 to 75 NTU range until the end of the experiment.

VI. CONCLUSIONS

Preliminary results of comparative samples from the automatic sampler and the manual samples were very similar. Our trial runs were performed under baseflow conditions and bacteria counts were consistently very low (less than 20 CFU/100 ml). Through historical data, it is known that the south gap is a good site for plume tracking in Milwaukee harbor during rainfall events. Future validation studies may be conducted on the same site during wet weather sampling. Overall, the adaptive sampling strategy will be used during heavy rains and CSO events to track bacterial loading and persistence in Lake Michigan and we expect to determine significant patterns through time series analysis of bacterial concentrations and sonde parameters.

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