Center for Urban Environmental Research and Education
University of Maryland, Baltimore County

Preliminary Assessment of Real-Time Sensor Deployment in Baltimore Urban Watersheds

CUERE Technical Report 2011/001
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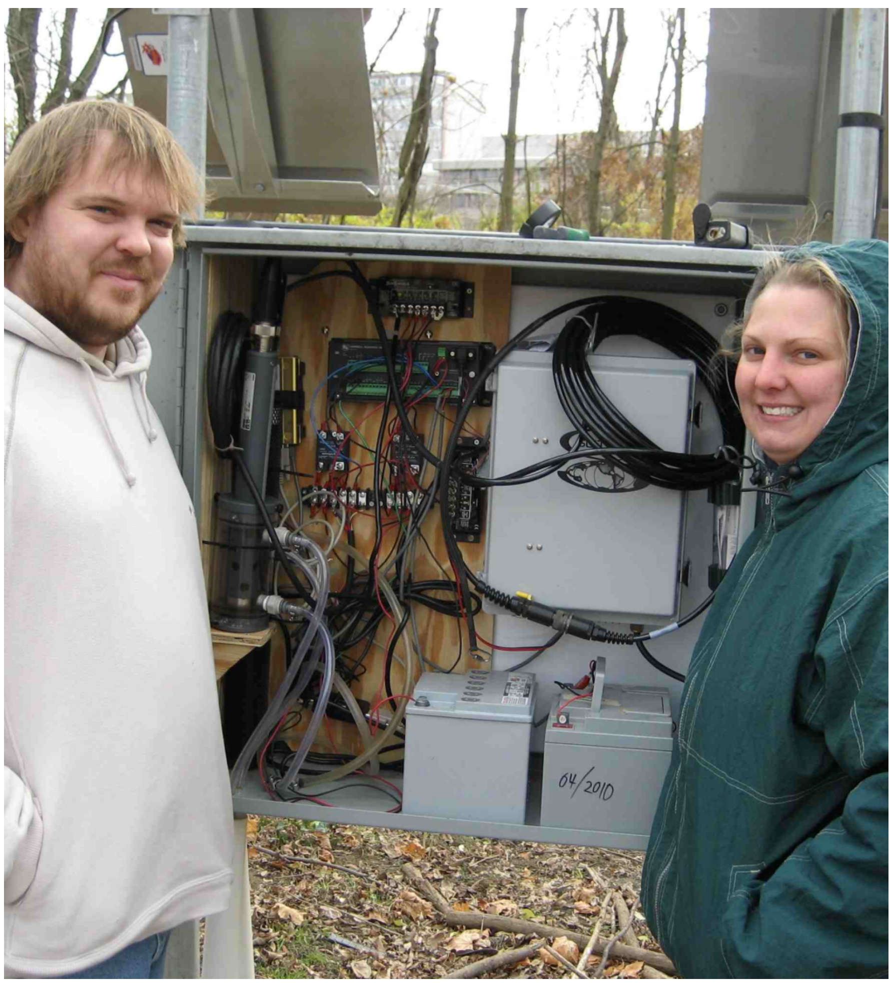

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ON THE COVER
Sensor station at DR4.

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Abstract

Real-time water quality sensors were deployed at six stream stations in Dead Run, Baltimore, MD beginning in Fall 2010. This report summarizes initial experiences, design variable considerations, and lessons learned from one year of deployment. Satlantic SUNA nitrate optical sensors and YSI 600-LS specific conductance and temperature sensors were placed in locked housings at USGS sites where water level data were already being recorded. Considerations for system hydraulics, power, data logging, communication systems, laboratory testing, field site construction, and troubleshooting tips are presented. Example data sets are shown and recommendations for system improvements are made. An itemization of all parts required for deployment is provided.

1. Introduction

1.1 Objectives

The purpose of this technical report is to document the steps undertaken to deploy real-time nitrate and conductivity sensors in selected watersheds of the Baltimore Ecosystem Study Long Term Ecological Research project (http://beslter.org). The sensor work was funded by National Science Foundation as part of the WATERS Testbed Phase 2 studies.

A long-term goal of this work is to quantify the travel time for solutes to travel through watersheds and predict how this is affected by variability in land use. The specific research questions addressed in this project include:

- How can sources, timing and fluxes of solutes from groundwater to surface water vary as a function of land use (ultra-urban, suburban, exurban, forest) and stream position (headwater vs downstream)?
- How do transport time scales and subsurface flowpaths vary with flow regime (base flow vs storms) and antecedent conditions?
- How can information from high frequency sensor deployment across a range of hydrologic conditions be used to “fill in the gaps” from our current weekly long-term monitoring to explain interannual changes in residence times and flushing of solutes?
- How well can a physically-based watershed flow and transport model represent solute transport behavior across a range of time scales?

This document focuses on our field deployment experiences in from October to December 2010 and March to December 2011, and includes sections on (1) overview and choice of sensors; (2) design considerations for hydraulics, power, data logging, wiring, communications, and data serving; (3) laboratory testing prior to field deployment; (4) field deployment steps, including troubleshooting; (5) discussion of example data sets; and (6) summary and recommendations.

1.2 Choice of sensors

Our choice of sensor brands and models is based on recommendations from colleagues associated with CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science, Inc., http://www.cuahsi.org), employees of the U.S. Geological Survey, and our prior experience with vendors.

We chose the Satlantic (http://www.satlantic.com) SUNA sensor for nitrate measurement based on positive experience with in-situ testing of the Satlantic ISUS sensor by University of Florida (W. Graham, personal communication, 2008) and U.S.

Geological Survey (Pellerin et al., 2009); the SUNA uses the same technology as the ISUS and came on the market for $10,000 less than the ISUS just as this project was in its formative stages. One potential concern with the Satlantic optical sensor technology is possible interference from turbidity, as will be discussed later in this report.

Sensors for robust specific conductance measurement have been on the market for many years; we chose the YSI 600LS (http://www.ysi.com) for conductivity/temperature measurement based on our long-term experience with YSI as a vendor of dependable equipment and on USGS recommendations. The ability to measure water level with this particular sensor makes it expensive; this feature was chosen so as to be able to use the sensors for future projects where water-level measurements are required at sites where such data is not already being collected.

Neither sensor has internal data logging capability; we made this choice owing to our intended external data logging system for these and other co-deployed sensors.

Both the SUNA and YSI 600 LS sensors are designed to be submerged in natural waters. However, owing to our location in an urban area, where both vandalism and damage by flash-flood storm debris can result in loss of sensors deployed directly in streams, we chose to secure the sensors in locked shelters in the floodplain adjacent to each stream location and to pump water to flow cells connected to the sensors. This choice made the logistics more complicated than would be required for direct sensor deployment in the streams.

1.3 Site description

This project uses the Baltimore Ecosystem Study (BES) LTER as an observational platform. The BES LTER, founded in 1998, is composed of the Baltimore metropolitan area (Anne Arundel, Baltimore, Carroll, Harford, and Howard Counties and Baltimore City, Maryland). The area contains an urban core as well as older urban and suburban residential areas, rapidly suburbanizing areas, and a suburban/rural fringe. Work to date has focused on delimiting the social, economic, and ecological patch structure of Baltimore, and documenting how the patches interact and how the patch structure has changed over time (Pickett et al. 2008). Long-term data sets quantify the fluxes of water, carbon, and nutrients through the urban water cycle and terrain. Weekly stream chemistry data (Cl^-, NO_3^-, total N, PO_4^{3-}, total P, SO_4^{2-}) have been collected for over 13 years at 11 sites; time series are available at http://beslter.org. These data have been used to quantify urban biogeochemical budgets and cycles (Groffman et al., 2004; Kaushal et al. 2008; Shields et al. 2008).

The USGS MD-DE-DC Water Science Center maintains a series of streamflow gaging stations at which the weekly BES chemistry samples are taken, and at which the sensors for this project were to be deployed. The work plan called for deployment at six nested suburban locations in year 1 of the project (Dead Run), and along a longitudinal urban-rural gradient of the BES main nested watersheds plus the forested reference watershed in year 2 of the project (Figure 1, Table 1). USGS streamflow gaging stations are located at all of these sites. This report addresses initial deployment in Dead Run and its subwatersheds.

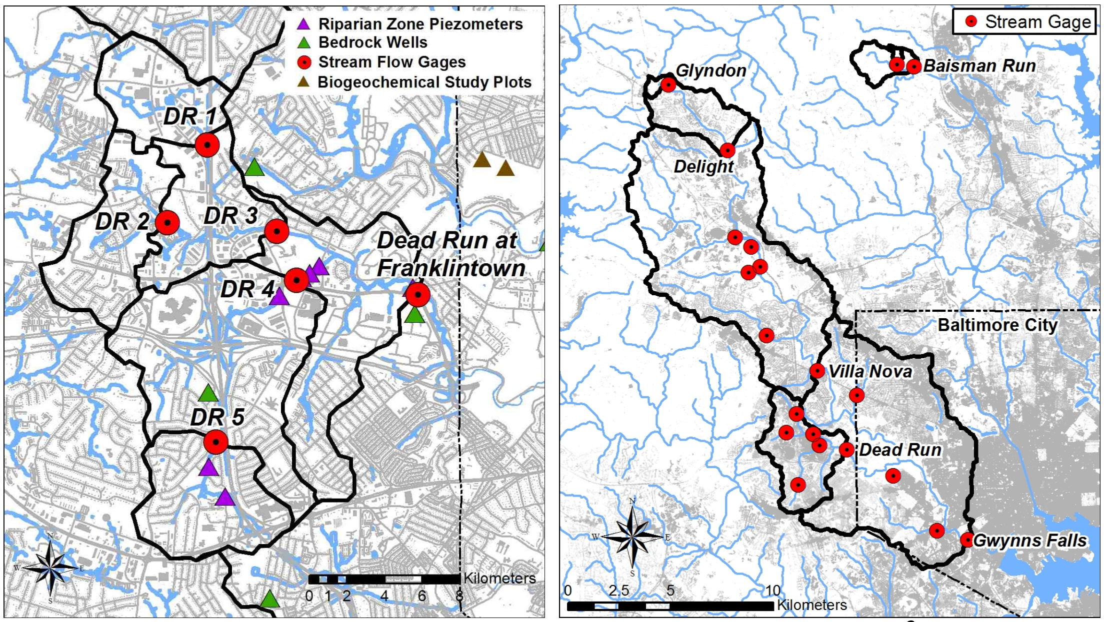

Figure 1. Study watersheds for sensor project. (a) Dead Run (14.1 km^2); (b) Gwynns Falls (171 km^2) and nested subwatersheds.

Table 1. Characteristics of study watersheds.

Name	Area (km^2)	Percent Impervious	Nested Within
Dead Run Sites			
DR Franklintown (DRKR)	14.1	45.0	
DR3	5.0	48.2	DRKR
DR4	6.2	49.8	DRKR
DR1	1.3	51.1	DR3
DR2	1.9	44.7	DR3
DR5	1.53	44.9	DR4
Gwynns Falls Longitudinal Sites			
Gwynns Falls at Carroll Park	171	30.3	
Villa Nova	84.5	21.1	Carroll Park
Delight	10.6	18.6	Villa Nova
Glyndon	0.7	21.1	Delight
Pond Branch[1]	0.4	0	Baisman Run

[1]Forested reference watershed

1.4 Timeframe of initial testing

Laboratory QA/QC chemical testing was carried out in spring of 2010; laboratory testing of wiring, hydraulics, and datalogger set-up was carried out in summer of 2010. Initial field deployments of 6 sensor stations were carried out in Dead Run from October 6 – December 6-7, 2010. The sensors were brought inside on December 6-7 due to concerns for pumping freezing water through the flow cells and potentially damaging them. The sensors were re-deployed in March 2011 and tested through December 2011, so as to be able to evaluate data over a period of four seasons.

2. Design

2.1 Overview

The design of our system is dictated in part by physical constraints of the field sites, as well as the need to utilize components already deployed at chosen sites. At five of our six sites (DR1 – DR5, Figure 1), painted steel junction boxes (30" x 30" x 12") have been deployed by USGS under a joint project with UMBC for the purpose of housing Accububble pressure transducers and data logging/communication equipment; we had access to these boxes for housing additional sensors. At one site (DR5), two raingages are also part of the station. At DR Franklintown, a similar setup was not available to us and therefore we deployed the nitrate and conductivity sensors in a separate enclosure (a 55-gallon drum) located at this site for other BES experiments. At all sites, we chose to install a bilge pump in the stream and pump water to the sensors. This configuration required sizing the pump and tubing to overcome head losses; trenching PVC pipe to enclose pump tubing and wiring between the stream and the sensor enclosure, and securing/protecting the pump in the stream. These steps are not needed for sites where the sensors can be installed directly in the stream.

An additional consideration in many of the design components is the frequency at which measurements are to be made. We did not want to consume energy by taking measurements too frequently during base flow when changes vary slowly over time; however, a main objective was to capture the behavior of storms, where measurements every 5 minutes are typical for urban systems. For the purpose of initial testing, we set the sensors to record measurements every 30 minutes. A feature of our system is that the dataloggers can be called via cellular modem to change this to a shorter period as desired. This option to change the recording interval on the fly will be implemented in future deployments; alternatively, this feature can be implemented by triggering sensor measurements with water level changes in stations where the sensors are co-deployed with pressure transducers.

Discussed in this section are considerations for system hydraulics (pump sizing, filtering), power, data logging, communication, wiring, and data serving that were utilized in our sensor deployments.

2.2 Hydraulics

2.2.1 Pump type

Bilge (submersible) pumps are commonly used in boating and are readily available, inexpensive, compact, and robust. They are designed to be cycled on and off often and to last without corrosion in sea water. Most bilge pumps are self-priming; if they are placed in water and switched on they will pump water without the need for manual priming (manually forcing water into the suction port). A self-priming bilge pump is appropriate for our application since unattended operation is required.

2.2.2 Pump sizing

For the water to reach the sensors, the pumps must overcome the elevation head and head losses due to friction. The elevation head remains constant at a site and is determined by measuring the required lift at a site. The frictional head losses are a function of fluid velocity, tubing diameter and length, and fluid physical properties (which depend on temperature). Additional losses due to tubing bends are a minor component of overall head loss.

2.2.2.1 Effect of battery voltage on flow rate

Since most pumps are overefficient or underefficient with respect to their rated flows, it is prudent to test a pump before deployment and observe its actual flow rate; this flow rate is used in calculating the friction losses and for determining whether the pump can overcome those losses.

4.5- and 6-amp Rule® bilge pumps were chosen for testing. The pumps are designed to be powered by 12 V batteries, but rated 12 V batteries can have a voltage potential up to 13.7 V when fully charged; 10.8 V is the recommended lower limit for a 12 V battery before being recharged. Flow rates at voltages ranging from 13.7 V to 12 V and at 10.8 V were therefore measured in the lab. Tests were performed using tap water at 19.5 ^{o}C.

The relationship between input power and measured flow rate for the two pumps evaluated is shown in Figure 2. This figure illustrates that as the voltage drops from around 12.5 V to 10.8 V, the flow rate decreases by approximately one third. The slope of the fitted line for the 4.5-amp pump is half that of the 6-amp pump; this shows that the flow rate of the 4.5-amp pump is less affected by a drop in voltage than the 6-amp pump. These ranges in flow rates need to be considered when deciding on which pump to use. The lower flow rate of the chosen pump should be used to conservatively determine the purge time needed between runs as discussed in Section 2.2.4. Table 2 lists the average flow rate observed for fully charged and low voltage conditions.

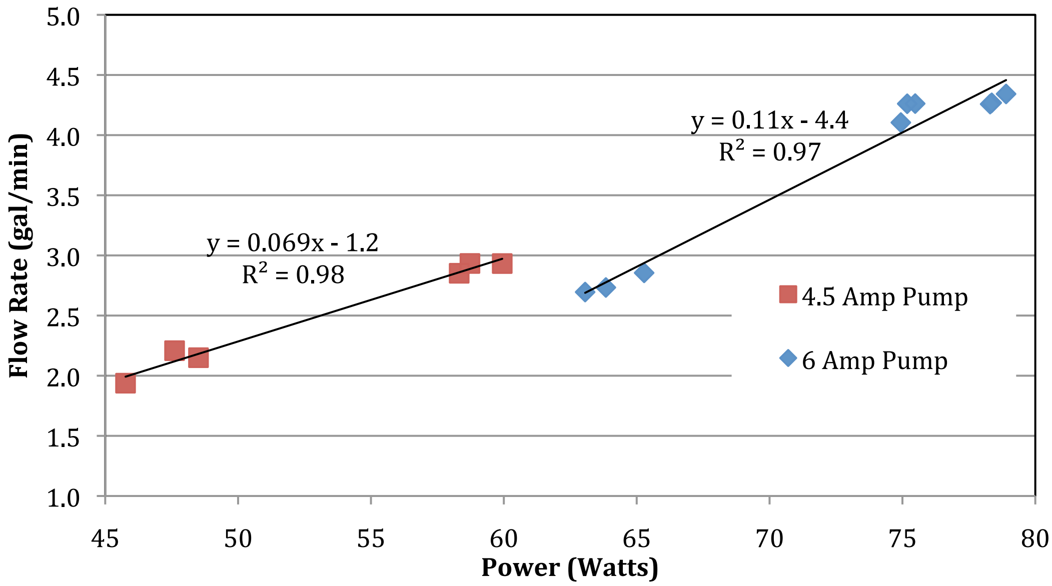

Figure 2. Pump flow rate dependence on battery voltage (power (watts) = voltage (volts)*current (amps)).

Table 2. Observed average pump flow rates with tap water at 19.5 °C.

Pump	Manufacturer's Specifications	Fully Charged Battery (13.7 V – 12 V)	Low Voltage Battery (10.8 V)
6 amp	8 gal/min	4.2 gal/min	2.8 gal/min
4.5 amp	4 gal/min	2.9 gal/min	2.1 gal/min

2.2.2.2 Calculation of friction losses

The Darcy-Weisbach equation can be used to determine frictional head losses:

$$h_L = f \frac{L}{D} \frac{V^2}{2g} \tag{1}$$

where

h_L is the head losses due to friction [L]
f is an empirical friction factor [-]
L is the length of the tubing [L]
D is the diameter of the tubing [L]
V is the average fluid velocity [L/t] = Q/A
Q is the volumetric flow rate [L^3/t]
A is the cross-sectional area of tubing [L^2] = $\pi D^2/4$
g is the acceleration due to gravity [L/t^2]

Frictional head losses are proportional to fluid velocity and tubing length and inversely proportional to tubing diameter. The friction factor, f, is a function of the Reynolds number and can be calculated using the Blasius equation:

$$f = 0.316\ \mathrm{Re}^{-0.25} \tag{2}$$

where Re is the Reynolds number

$$\mathrm{Re} = \frac{DV}{\upsilon} \tag{3}$$

and ν is the kinematic viscosity of the fluid [L^2/t].

The head lift and length of tubing required at each of the six Dead Run stations is shown in Table 3. We calculated the frictional head losses for at 0˚C and 30 ˚C, and at fully-charged and low-voltage conditions for both pumps (Appendix A).

Table 3. Head lift and tubing length at each station.

Station	**Head lift required (ft)**	**Tubing length required (ft)**
DRKR	9.0	21
DR1	9.8	18
DR2	8.0	45
DR3	7.3	19
DR4	7.4	36
DR5	9.2	26

Both pumps are rated by the manufacturer as being able to overcome 32 ft of total head loss (elevation head (lift), head losses due to friction, and minor losses), at their rated orifice openings. The 6-amp pump has an orifice opening of 0.75 in (outer diameter); the 4.5-amp pump has an orifice opening of 0.5 in (outer diameter). Since the length of the tubing and the lift at each site are fixed, the tubing diameter becomes the main design variable affecting calculation of total head to be overcome, through friction loss. This is illustrated for DR2 in Figure 3.

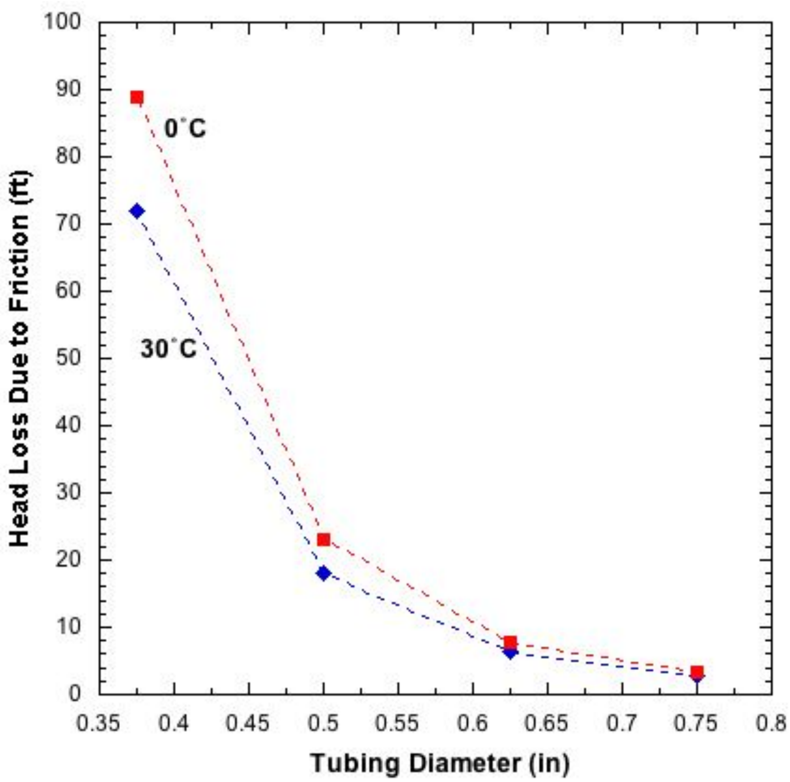

Figure 3. Effect of tubing diameter and temperature on friction loss at DR2 for the 6-amp Rule® pump.

We initially chose 3/8-in-ID tubing for the 4.5-amp pump because this is the tubing size that fits the intake ports of the sensor flow cells. However, we subsequently increased the tubing diameter to 0.5-in ID in order to reduce the head loss due to friction using this pump. The tubing can be reduced to 3/8-in ID tubing using barb fittings close to the flow cell intake ports.

The calculations in Appendix A and the DR2 example shown in Figure 3 also illustrate the effect of fluid viscosity (due to changes in temperature) on head loss: the effect becomes apparent for smaller tubing. This range of temperatures (0˚C – 30˚C) is expected over the range of seasons when the sensors will be deployed.

2.2.2.3 Considerations of maximum flow rate

Although a powerful enough pump must be used to overcome head lift and friction losses, there is a limit on the maximum flow rate that can be used in our system owing to the design of the YSI flow cell. The YSI flow cell is not directly attached to the sensor. The sensor sits inside the flow cell, which is not sealed (i.e., it is open to the atmosphere). The flow cell fills with water through an inflow port near the bottom; the outflow port is near the top of the flow cell. If the flow rate exceeds the capacity of outflow port, the water will leak out of the top of the flow cell. YSI states that the maximum flow rate that the flow cell can accommodate is 5 gallons per minute. Since the flow line is split in half before reaching the YSI, this means that a pump flow rate greater than 10 gal/min should not be used.

2.2.2.4 Pump service life

Bilge pumps have a finite life expectancy. Over time the internal impeller becomes worn. This causes the system to cavitate and allows bubbles in the water line, which can lead to errors with the SUNA nitrate measurement. In addition, the brushes on the internal motor become worn down more quickly as the frequency of cycling the pumps on and off increases.

The Rule® pump has a plastic impeller. The Rule® pump manufacturer specifications state the pump has an expected service life of approximately 100 hours, or about 60 days for our application (i.e., with the pump running for roughly 2 minutes during every half hour sampling interval). However, we found that the Rule® pumps were reliable for only about 40 days in most cases, but did last up to 60 days at some sites. Indications that the pumps are beginning to break down are that (1) they fail to self-prime and (2) they pump with air bubbles in the water line.

Wale® makes a 3.5-A pump with a stainless steel impeller that has an expected service life of approximately 400 hours (250 days for our application). We have deployed these pumps as an alternative to the Rule® pumps to test their durability. Of the 6 Wale® pumps initially installed, one pump stopped working after 30 days. Another pump needed to be replaced after 50 days because it was having difficulty self-priming. Others have lasted for 150 days without any problems.

2.2.3 Y configuration and location of sensors

The water entering the protective enclosure via tubing (from the pump) is split between the SUNA and YSI using a Y connection so that the sensors are taking readings of the same water sample (the YSI takes one reading whereas the SUNA takes multiple readings and averages them). Because the YSI flow cell is open to the atmosphere, the top of the flow cell must be placed above all parts that contain water (above all tubing and above the SUNA flow cell). If it is lower than these components, it will be at a higher pressure and will leak from the top regardless of the flow rate.

It is also important to make sure that the outflow tubing does not become crimped or clogged. If this happens, backpressure can result, causing the YSI flow cell to leak from the top.

2.2.4 Filtering

Due to the potential for turbidity interference with the SUNA reading, USGS (Brian Pellerin, personal communication, July 2010) recommended filtering the water in-line before the sensors. Our testing of the USGS-recommended filter system (see parts list in Appendix B) resulted in identification of two problems: (1) increased head drop due to resistance to flow, and (2) significant flushing time required to purge the filter housing.

Because the filter consists of a fine (0.2 micron) mesh, it greatly reduces the flow rate of the system, since the filter provides resistance to flow. To compensate for this effect, a larger pump would be required to maintain a desired flow rate, which would draw more power.

The volume of the recommended filter was 1.8 liters. A concern with using such a large filter is that water would be stored in the filter between runs. This water would need to be fully purged for a subsequent trial, to obtain a water quality value that was not averaged with water from the previous trial. Laboratory trials using water spiked with known concentrations of NaCl showed that it took between 4 and 5 minutes of pumping time to completely purge the filter. For this reason, the filter apparatus was not used during the field trial.

2.2.5 Determination of on/off time for pump and sensors

Operational characteristics and requirements of the sensors, as well as sampling requirements at the site, need to be factored into determining the pumping cycle required. We noted above that for the first test deployment, we wanted to take measurements every 30 minutes. We chose to turn the pump on before each measurement, as opposed to leaving the pump running continuously. Running the pump continuously is certainly feasible and would need to be taken into account in calculating the power budget.

The YSI is always on; it has standby and data acquisition modes. When the datalogger sends a signal to excite the YSI, it switches from standby to data acquisition mode and instantly takes a reading of the parameters chosen during setup of the sensors (for our case, specific conductance and temperature). Once the reading is taken, it is sent to the datalogger and stored. Multiple readings can be taken if desired; this is specified through programming of the datalogger.

The SUNA is either on or off; there is no standby. When the datalogger sends a signal to excite the SUNA to turn it on, the SUNA takes one measurement every 2 seconds. The measurements are averaged over the total measurement interval and that value is sent to the datalogger. No warm-up is needed unless the SUNA will be running for minutes at a time. Running the SUNA for 15 seconds to obtain about 6 light samples is sufficient, (the first three seconds are for taking a dark frame sample) according to Satlantic (Geoff MacIntyre, personal communication, June 2011).

When the pump is turned off, water will drain out of the flow cells and tubing system by gravity. Owing to the design of the YSI flow cell, some water will remain in the bottom of the flow cell between runs (the lower port is located above the bottom of the flow cell). Lab testing showed that one minute of pumping was adequate to purge the YSI flow cell at the beginning of a subsequent run.

When the pump is activated it only takes a few seconds for water the reach the sensors from the stream, so this factor is negligible in the determination of the system timing.

Since the YSI flow cell must be purged, the system begins by running the pump for 50 seconds. After this purging time an excitation signal is sent to the YSI and SUNA to take readings. Since the SUNA takes longer than the YSI to obtain a reading, the excitation channels remain on for both sensors until the datalogger obtains a data value from the SUNA. Once this occurs the excitation channels for the sensors are turned off; the YSI goes back to standby mode and the SUNA shuts off. The pump is also shut down at this time.

The SUNA will always attempt to take readings when powered on. If the SUNA cannot obtain an accurate reading for any reason, various error codes will be sent to the datalogger. The datalogger interprets this error code as a data value and will shut down the system.

The series and order of events required for system operation are summarized in Figure 4.

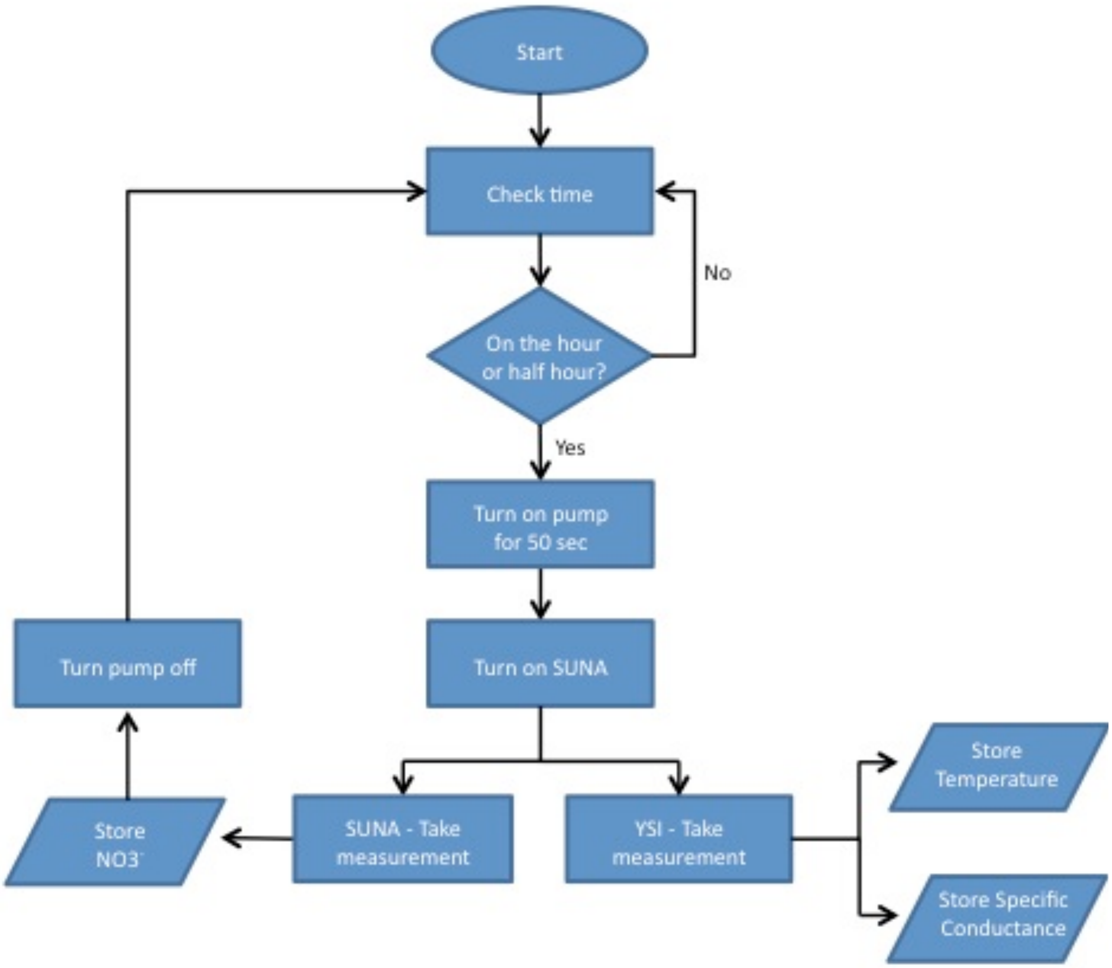

Figure 4. Sequence of events required for taking sensor measurements and storing the results.

2.3 Power

2.3.1 Battery sizing

The first requirement for any power budget is to determine what the current draw is of all pieces of equipment. These requirements can be determined from manufacturer documentation. The current drawn for our sensor components is listed in Table 4.

Table 4. Current drawn for sensor station components.

Device	Current drawn (amps)
Rule Pump	4.5 or 6
Wale Pump	3.5
SUNA	0.63
YSI	< 0.001
CR10X datalogger	< 0.001 (quiescent) to 0.46 (processing)

Our field logistics did not include the option for AC power supply; in all cases DC via 12V batteries was the best option available. In order to avoid having to continuously swap out batteries, our system was designed to charge the batteries in-situ from solar panels.

Owing to the significant current draw from the bilge pumps (3.5, 4.5, or 6 amps depending on the pump chosen), we chose to run the pump from one 12V battery and all sensors and datalogger from a second 12V battery, with each battery charged by a dedicated solar panel.

The size of each 12V battery was chosen so as to maximize the amp-hour rating, while allowing the battery to fit inside the existing enclosures and be portable such that it could be carried by project personnel from a field vehicle to the site over uneven terrain. We chose 40 amp-hour gel batteries by MK (see parts list, Appendix B), each of which weighs 32 pounds and measures 7.75" L x 6.63" W x 6.88" H.

Because one site was initially powered exclusively by batteries, we show (Table 5) calculation of how long one battery will last, for the 6-amp pump (6.7 days).

For cases where the batteries are charged in the lab for swap-out, this requires the additional expense of two extra batteries plus two battery chargers (see Appendix B). This cost plus the time/labor required for changing out batteries should be considered when weighing against the option for solar panel purchase and installation for battery recharge.

Table 5. Calculation of battery replacement schedule.

The required battery capacity is calculated as follows. Since the battery should not be discharged battery past 80% full-charge capacity, the capacity is scaled by 80%. (80% is a convention used by the battery industry to account for tolerance errors of the connected devices' power ratings.)

C = A*T/0.8
where
C = required battery capacity (amp-hrs)
A = amps
T = time in use (hours)

In our case we wanted to turn the 6-amp pump on for 60 sec, 48 times per day:

C = [6 amps * 60 sec*(1 hr/3600 sec)*(48 measurements/day)]/0.8
= [6 amps* 0.80 hr/day]/0.8
= 6.0 amp-hours/day

A 40 amp-hour battery will therefore last for

40 amp-hrs/(6 amp-hrs/day) = 6.7 days

before needing replacement.

When fully charged, battery voltage will be greater than or equal to 12.6V. If the battery charge is allowed to fall below 12V, it must be recharged to a minimum voltage of 12.6V. Battery charge should never be allowed to fall below 11V. Falling below this can adversely affect the battery's ability to subsequently charge.

2.3.2 Solar panel sizing

Solar panels are available for recharging 12V batteries. There are a number of factors involved in sizing a solar panel for this purpose, including wattage required by the equipment, number of hours of daylight available, battery size, and rate of battery drawdown. A useful tutorial and an interactive calculator for determining number and sizes of solar panels required are available at batterystuff.com:

http://www.batterystuff.com/solar-calculator.html
http://www.batterystuff.com/tutorial-solar-calculator.html

This software allows calculation of numbers and sizes of solar panels for a given application.

For the example of our 6-amp pump and 12V, 40 amp-hour battery, the batterystuff.com materials were used to determine that one 30-watt solar panel would be adequate for running the pump for 1 minute, 48 times per day. The details used in the solar calculator are provided in Table 6. This choice allows for our anticipated increase in sampling frequency during storms, which would increase the number of hours per day of pump usage.

For our other sensors powered by the second 12V battery, we determined that a 10-watt panel was adequate.

Table 6. Sizing of solar panel using http://www.batterystuff.com/solar-calculator.html

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Input data
DC Pump wattage = 12V * 6 amps = 72 watts
Usage per day: 0.8 hours (1 minute, 48 times per day)
System voltage: 12 V
Backup days of power required: 1
Battery amp rating: 40 amp-hours
Sunlight hours per day: 8
Select panel size: 30 watts

Output
Number of panels needed (calculated): 1

2.3.3 Use of relays

Relays are essentially switches, used to connect the datalogger to equipment when on and off modes are desired. We used relays for the pump and the SUNA; otherwise they would be in the continuous “on” mode, once powered up. This enabled us to (1) conserve power; (2) keep the batteries and solar panels needed to reasonable sizes; and (3) conserve the SUNA lamp, which has a finite specified life.

Various types of relays are available; for this application solid-state relays were chosen. Solid-state relays are ideal for our application because they allow a low input signal (from the datalogger) to activate a much higher voltage potential (used for the bilge pump and sensors).

Most solid state relays work in the same way, using four ports, connected to the input signal device (datalogger) and device to be used and the device's power supply. For our relays,

Port 1 connects to the power input of the device to be turned on and off (the bilge pump and SUNA).
Port 2 connects to the power supply for that device, which is the battery positive (or the load positive on the SunSaver if a solar panel is used).
Port 3 is the input excitation port; this is connected to the datalogger (or any device that triggers the system to turn on).
Port 4 connects to the common ground.

An excitation signal is sent to Port 3 at a time specified in the datalogger. This allows the power supply at Port 2 to power the device connected to Port 1. When the signal is removed from Port 3 the power supply from Port 2 is no longer connected to Port 1 and the device shuts off.

The typical labeling of each port is the convention used here. Labeling varies by manufacturer, and may differ for various countries.

2.4 Data logging

Our choice of datalogger was dictated by those already in place for other projects at the chosen sensor sites. We operate a set of streamflow gages in cooperation with the USGS MD-DE-DC Water Science Center. In order for water level data from these stations to be transmitted via Raven cellular modem to the USGS office and ingested into the USGS data management system, that office currently requires use of Campbell Scientific CR10X dataloggers for compatibility with its existing system. Since our nitrate and conductivity sensors are co-located at stations where these dataloggers are already in place, we chose to use the CR10X sensors for this project. This model of datalogger has been "retired" from Campbell Scientific but is available to us for rental from the USGS Hydrologic Instrumentation Facility. If we were conducting the project without this constraint, we would recommend use of the CR1000 datalogger, which is currently available from Campbell Scientific.

A datalogger program is needed to turn on the pump and the SUNA sensor and record sensor measurements of nitrate, specific conductance, and temperature. Since we have Accububble pressure transducers co-located at most stations, plus two precipitation gages at one station, our program has options for recording these data as well.

The datalogger program written for and utilized in this project is given in Appendix C and annotated to aid the reader in interpretation. The user manual providing the syntax for CR10X programming can be downloaded from http://www.campbellsci.com/documents/manuals/cr10x.pdf.

2.5 Communication

2.5.1 Raven set up and programming

Wireless cellular modems (RavenXTG Sierra Wireless Cellular Modems) were chosen as the telemetry for the sensor system. In order to remotely access data via the wireless modem, a SIM card with an assigned phone number and an assigned static IP address was purchased, installed in the wireless modem, and activated. After speaking with an account representative from AT&T we determined that 3072 KB of data usage would be a sufficient amount for transmitting the sensor data. (This estimate includes transmission of stage data at these sites, where stage data are collected every 5 minutes). SIM cards can be purchased and delivered without being activated. Activation at a later date such as the day before deployment is recommended to avoid paying for the service before it is being used.

Detailed instructions for installing SIM cards, programming the modems, establishing a connection, performing data download, and troubleshooting can be obtained from the Campbell Scientific, Inc. Instruction Manual RavenXTG Sierra Wireless Cellular Modem (Campbell Scientific Inc., 2006). Key steps are summarized here.

Once SIM cards have been purchased, installed in the modem, and activated, the modems can be programmed using AceManager software. AceManager can be downloaded from the Sierra Wireless Airlink Solutions website (http://www.sierrawireless.com/support/). A template file, Raven GPRS/EDGE Template 9600, which configures the modem to be compatible with the Campbell Scientific CR10X datalogger, can be downloaded from the Campbell Scientific website (http://www.campbellsci.com/downloads).

Programming the wireless modem requires that it be connected to a PC using a RS-232 cable. The modem must be powered with a 12 V battery and connected to a cellular antenna. When everything is set up correctly and the modem is being powered, AceManager can be opened, and the modem can be accessed by clicking on “connect” and selecting PPP and the COM port that the modem is connected to. After a connection has been established, the template file can be loaded and “write” must be clicked on to upload the file to the modem. When the template has been loaded, the Device Port value under the “Misc” group should be 3001. (3001 becomes the assigned port number as referred in the next paragraph in the discussion of LoggerNet. If no IP address or the wrong IP address is shown in the Status window, then the user should go to the Misc group and enter the static IP address in the "Force static IP value".) The phone number for the SIM card is entered under the "new value" cell for phone number. Next, AT Verbose Mode should be set to 0-numeric when using CR10X dataloggers. Then, under "Cellular window", APN is set to I2GOLD. Once all these values are entered, "write" can be clicked again to program these changes to the modem. When the modem is finished being programmed, "disconnect" can be chosen to end the session.

2.5.2 Base station communication with datalogger

Campbell Scientific dataloggers can be set up and configured using the Campbell Scientific program LoggerNet. The connection type selected for communication with the datalogger should be "IP Port connection". The internet IP address is the assigned static IP address of the SIM card plus the port number. Per the discussion above, the assigned port number becomes 3001 after the Campbell Scientific template has been loaded and programmed into the modem.

A dedicated computer in a central location is recommended for connecting to the sites and downloading data. This ensures that the downloading of data is not interrupted by other uses of the computer. We also recommend that the computer be connected to an uninterruptible power supply (UPS) to protect against power outages that could cause interruption of data streaming. The computer must remain turned on and LoggerNet must remain open in order to connect to a modem and download data. Using LoggerNet, a data collection schedule is enabled from this central computer. We suggest that the status monitor window remain open. This allows data downloading to occur and also allows all the networks that have been setup in LoggerNet to be easily monitored. Additional details can be viewed using the Log Tool. For our sensors, LoggerNet is set up to connect and download data from the CR10Xs every hour.

2.5.3 Data archiving and serving

Once the data is downloaded using LoggerNet, it is then transferred to the CUAHSI (Consortium of Universities for the Advancement of Hydrologic Sciences Inc.) Observations Data Model (ODM) (http://his.cuahsi.org/odmdatabases.html) and made available for publication using CUAHSI WaterML Web Services (http://his.cuahsi.org/wofws.html). A number of different software components are used to format and transfer the data to the ODM and publish the data from the WaterML Web Service on the web. A workflow showing the connected software components is depicted in Figure 5.

The data from LoggerNet must first be transformed into a format that can be ingested into the ODM because the CR10X datalogger does not produce a time stamp that conforms to the date/time data type in the ODM. A Python script is used to convert the

CR10X time stamp to the database-readable format YYYY-MM-DD HH:MM:SS. The Python script runs hourly, 15 minutes after the LoggerNet download.

The CUAHSI Streaming Data Loader (SDL) (http://his.cuahsi.org/odmsdl.html) is used to automatically upload data into the ODM. The SDL is a GUI-based program that allows one to automatically load data into the ODM. The SDL is configured by entering the appropriate site and parameter information and mapping the proper site to each data file and the parameter to a column within the data file. The SDL is set to run as a scheduled task on the dedicated computer with an hourly time interval 15 minutes after the Python script. The data is uploaded into an ODM database on the Hydrologic Information System (HIS) server at UMBC (his09.umbc.edu).

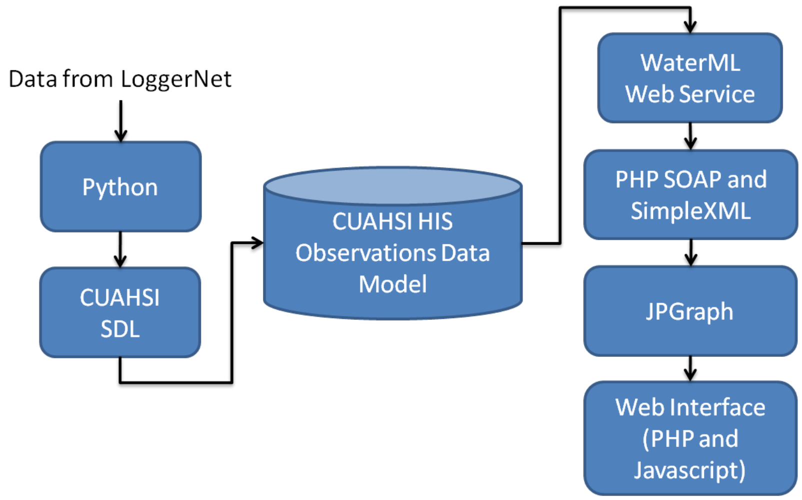
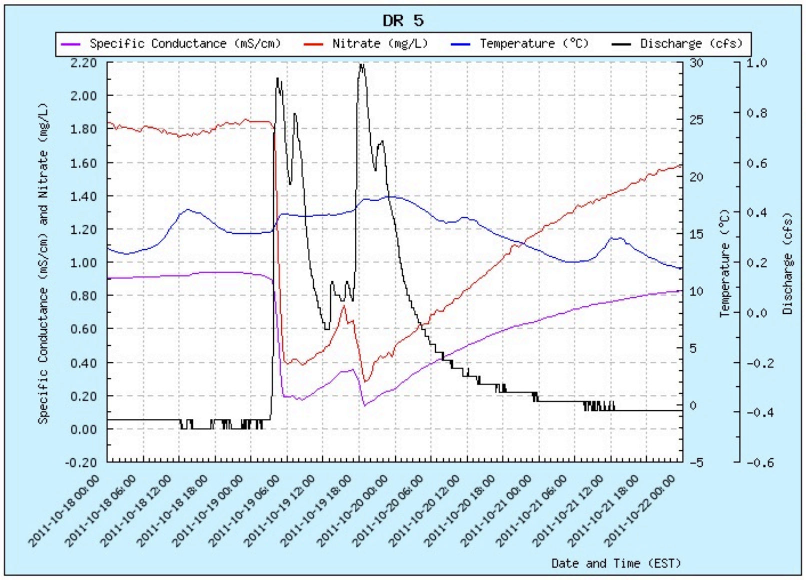


Figure 5. System architecture for serving nitrate sensor data.

The ODM database is configured with WaterML web services. The web services expose a number of methods that allow for programmatic access to the data stored in the ODM using the Simple Object Access Protocol (SOAP). The methods include GetSites which returns the site information contained in the ODM, GetSiteInfo which returns metadata about each site, GetVariableInfo which returns information about variables collected at a site, and GetValues which returns the data for each variable.

The web service definition language (WSDL) address for the nitrate database is located at (http://his09.umbc.edu/BaltNitrate/cuahsi_1_1.asmx?WSDL). The web service is called by a SOAP client developed using PHP. The client uses PHP SOAP and Simple XML to call the web service methods and parse the SOAP response. The data is then displayed through a web interface developed using PHP and javascript as shown in Figure 6.

UMBC Sensor Project*



Choose the site: DR 5

View data beginning with October 18 2011 and ending with October 21 2011 Update Graph

DR 5

Date and Time (EST)	Specific Conductance (mS/cm)	Date and Time (EST)	Nitrate (mg/L)	Date and Time (EST)	Temperature (°C)
October 18, 2011 00:02:00	0.91	October 18, 2011 00:02:00	1.84	October 18, 2011 00:02:00	13.70
October 18, 2011 00:32:00	0.91	October 18, 2011 00:32:00	1.84	October 18, 2011 00:32:00	13.62
October 18, 2011 01:02:00	0.91	October 18, 2011 01:02:00	1.83	October 18, 2011 01:02:00	13.52
October 18, 2011 01:32:00	0.91	October 18, 2011 01:32:00	1.80	October 18, 2011 01:32:00	13.44
October 18, 2011 02:02:00	0.91	October 18, 2011 02:02:00	1.82	October 18, 2011 02:02:00	13.35
October 18, 2011 02:32:00	0.91	October 18, 2011 02:32:00	1.81	October 18, 2011 02:32:00	13.28

DR 5

Date and Time (EST)	Stage (ft)	Discharge (cfs)
October 18, 2011 00:00:00	0.450	0.372
October 18, 2011 00:05:00	0.450	0.372
October 18, 2011 00:10:00	0.450	0.372
October 18, 2011 00:15:00	0.450	0.372
October 18, 2011 00:20:00	0.450	0.372
October 18, 2011 00:25:00	0.450	0.372
October 18, 2011 00:30:00	0.450	0.372

Site Information

Site ID	DR 5 (DR5); USGS Site ID 01589312
Location	39°17'45.2"N, 76°44'38.7"W, Baltimore County, Hydrologic Unit 02060003, on right bank at upstream side of culvert on Black Friars Road, 1.1 mi north of Catonsville, 1.7 mi southwest of Woodlawn, and 1.8 mi west of Baltimore City
Period of Record	November 2010 to present
Remarks	Records for this station are managed by the Center for Urban Environmental Research and Education, University of Maryland Baltimore County. For any inquiries or to report malfunctions regarding the sensors, contact Julia Miller (julia@umbc.edu).
Funding	Funding for the operation of this station is provided by National Science Foundation.
Web Design	Roxanne Sanderson, UMBC

* Conducted in partnership with USGS and the Baltimore Ecosystem Study.

Figure 6. Sensor data visualization website.

Upon navigating to the web interface, a graph automatically displays specific conductance, nitrate, temperature, and discharge data for the DRKR (DR Franklintown) watershed. Dropdown boxes to the right of the graph allow one to change the site (e.g., DR5 in Figure 6) and the number of days visible on the graph. Data from the graph are displayed in a table below the graph. At the bottom of the page, site information includes site ID, location and contact information.

2.6 Wiring

The wiring of the sensors, batteries, and solar panels to the datalogger is shown in Figure 7.

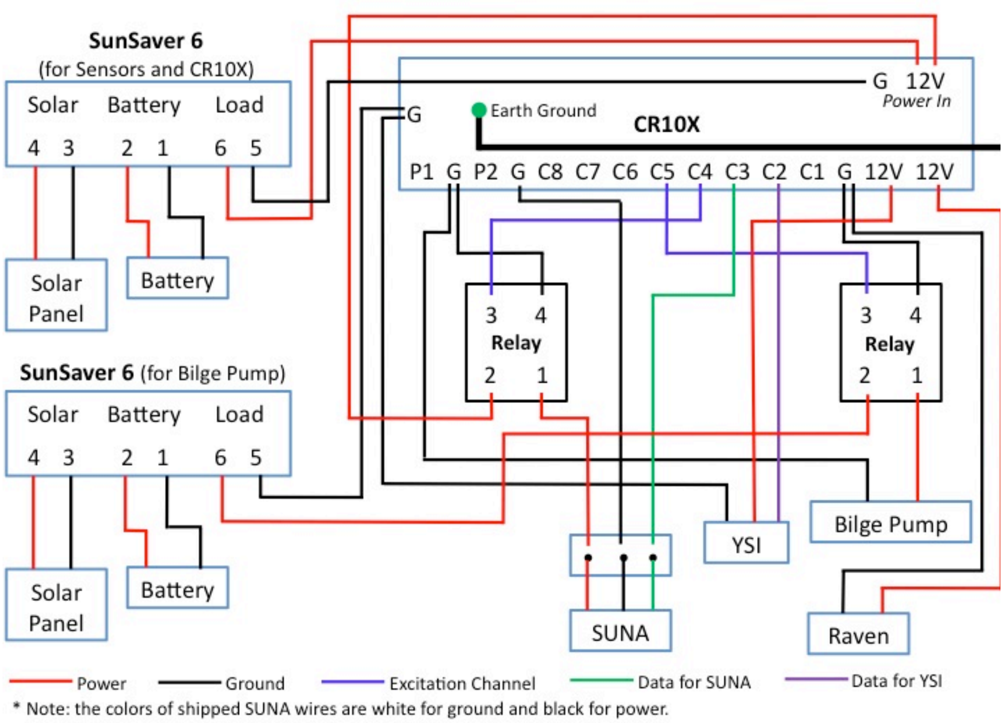


Figure 7. Wiring diagram for sensors.

The solar panels and batteries are connected to the SunSavers, which have ports labeled for each. One SunSaver can be used for the datalogger and sensors, and the other SunSaver for the pump. The 12V power in and the ground on the datalogger connects to the load terminals on the one SunSaver.

Two relays are used, one for the SUNA and one for the bilge pump. Port 2 on the relay for the bilge pump connects to positive load on one SunSaver. The bilge pump ground connects to the negative port on the same SunSaver. The power wire on the bilge pump connects to Port 2 on the bilge pump relay. Port 3 on the pump relay is connected to channel C5 on the datalogger.

On the relay used for the SUNA, Port 1 connects to the power (black wire) of the SUNA pigtail. Port 2 on this relay connects to the 12V power in on the datalogger. Port 3 connects to C4 on the datalogger. For both relays Port 4 connects to ground.

There are two 12V channels on the bottom right of the datalogger. The power on the YSI and Raven can connect to either of these channels, and the ground for each can connect to any ground. The data channel (purple wire) on the YSI connects to channel C2 on the datalogger

The data channel (green wire) on the SUNA pigtail connects to channel C3 on the datalogger. We used a wiring terminal to help support the SUNA wires. The wires on the SUNA pigtail are a higher gage (smaller wire) than those used by the other components. We connected the wires on the SUNA to a terminal as a junction and then ran wire from the terminal to the intended ports on the relay and datalogger. This enabled us to position the terminal and SUNA wires so that there would not be as much physical stress placed on the small-diameter wires. These terminal strips are typically sold with 4, 6 or 8 channels. More of these terminals can be used if desired to organize the wires.

16-gage wire was used for the miscellaneous wiring needed for the system. Spade terminals were also used to connect wires to the relays and SunSavers and terminal.

An earth ground must be connected to the datalogger, which is the labeled slot on the bottom right for the CR10X. Typically 8 to 10 gage wire is used. The wire is run to a copper grounding rod hammered into the soil near the instrument enclosure. The wire is connected to the grounding rod with a copper grounding clamp. The ground wires of the various components can be connected to any channel labeled G on the CR10X such that they all connect to the common ground. However, the Load ground (Port 5) on the SunSaver, used for the CR10X, should be connected to the ground channel associated with (adjacent to) the 12V power in on the top right of the datalogger.

A summary of the wiring connections is provided in Table 7.

Table 7. Summary of wiring connections for CR10X and sensor set-up.

CR10X

- 12V Power In – 6 (load positive) on SunSaver6 for sensors and CR10X
- 12V Power In – 2 on relay for sensors and CR10X
- G on Power In – 5 (load negative) on SunSaver6 for sensors and CR10X
- C2 – Purple wire on YSI data transmission cable
- C3 – Green wire on SUNA pig tail cable
- C4 – 3 on relay for sensors and CR10X
- C5 – 3 on relay for bilge pump
- 12V – Red wire for RavenXT wireless modem
- 12V – Red wire on YSI data transmission cable

YSI – Data transmission cable

- Purple (data) – C2 on CR10X
- Red (power) – 12V on CR10X
- Black (ground) – G on CR10X

SUNA – Pig tail cable

- Green (data) – C3 on CR10X
- Black (power) – 1 on SUNA relay
- White (ground) – G on CR10X

RavenXT wireless modem

- Red wire – 12V on CR10X
- Black wire – G on CR10X

Relay for SUNA and CR10X

- 1 – SUNA pig tail black (power)
- 2 – 12V Power In on CR10X
- 3 – C4 on CR10X
- 4 – G on CR10X

Relay for bilge pump

- 1 – Positive on bilge pump
- 2 – 6 (load positive) on SunSaver6
- 3 – C5 on CR10X
- 4 – G on CR10X

Battery for sensors and CR10X

- Positive – 2 (battery positive) on SunSaver 6 for sensors
- Negative – 1 (battery negative) on SunSaver 6 for sensors

Battery for bilge pump

- Positive – 2 (battery positive) on SunSaver 6 for bilge pump
- Negative – 1 (battery negative) on SunSaver 6 for bilge pump

Solar Panel for sensors and CR10X

- Positive – 4 (solar panel positive) on SunSaver 6 for sensors
- Negative – 3 (solar panel negative) on SunSaver 6 for sensors

Solar panel for bilge pump

- Positive – 4 (solar panel positive) on SunSaver 6 for bilge pump
- Negative – 5 (solar panel negative) on SunSaver 6 for bilge pump

SunSaver 6 for sensors and CR10X

- 1 – Battery (for sensors and CR10X) negative
- 2 – Battery (for sensors and CR10X) positive
- 3 – Solar panel (for sensors and CR10X) negative
- 4 – Solar panel (for Sensors and CR10X) positive
- 5 – G Power In on CR10X
- 6 – 12V Power In on CR10X

SunSaver 6 for bilge pump

- 1 – Battery (for bilge pump) negative
- 2 – Battery (for bilge pump) positive
- 3 – Solar panel (for bilge pump) negative
- 4 – Solar panel (for bilge pump) positive
- 5 – G on CR10X
- 6 – 2 on relay for bilge pump

2.7 Parts chart – costs and itemization

An itemization of all components used to build a sensor station (excluding tools) is provided in Appendix B.

3. Laboratory testing

Two activities comprised laboratory testing: (1) chemical analyses to compare ion chromatography with the SUNA and identify possible interferences with the sensor (memory effects, temperature, colored DOC, turbidity); and (2) a dry run of the hydraulics, wiring, data logging, and communication systems, to ensure that all items were working properly in advance of deployment.

3.1 Chemical QA/QC

The weekly stream chemistry sampling that has proceeded for 13 years in the Baltimore Ecosystem Study employs ion chromatography for anion water quality analysis. In order to evaluate whether the optical nitrate sensor will provide acceptable quality data as compared to the IC analysis, we ran a series of laboratory tests to evaluate the IC versus the SUNA for (1) three trials of 7 concentrations of nitrate standards (Figure 8); (2) temperature effects (Figure 9); (3) effects of dissolved organic carbon from humic substances (Figure 10); and (4) effects of turbidity. In addition, we analyzed samples (Figure 11) taken from field sites where the sensors are to be deployed, and established a correlation between specific conductance and chloride for use in subsequent analysis (Figure 12).

The purpose of the three trials using nitrate standards shown in Figure 8 was to test for memory effects in the sensor. Each sequence was composed of low-concentration nitrate standards, followed by higher concentrations, then low again. In all cases the concentrations ranged from 0.01 mg/L to 10 mg/L. The results show good agreement between IC and SUNA measurement of the standards.

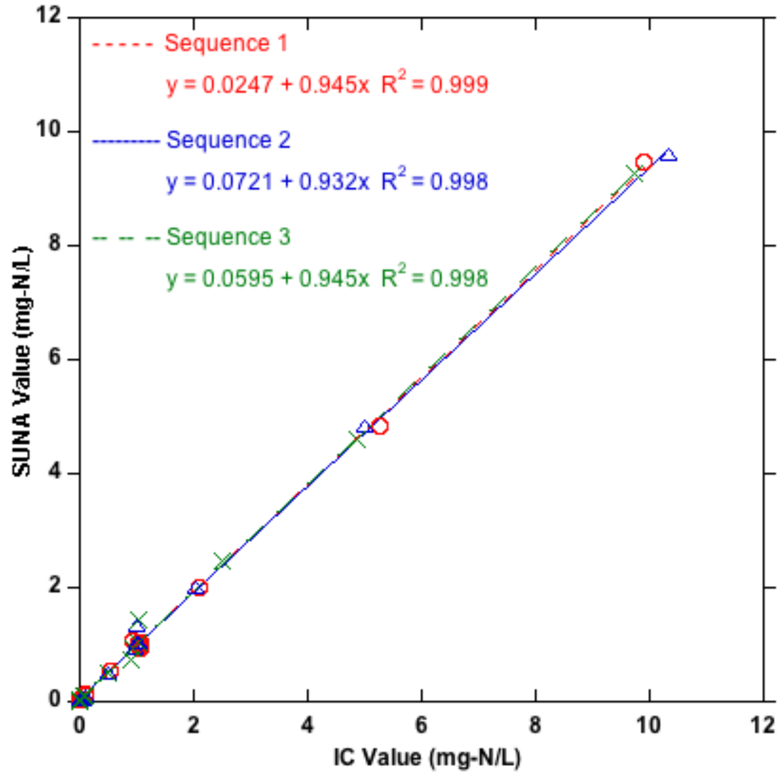


Figure 8. SUNA vs IC for several nitrate standards (low-high sequences).

To test for ambient temperature effects that would be expected for the SUNA under field conditions, the sensor was placed in a freezer at -15˚C and in an incubator at 6˚C, 20˚C, and 40˚C. SUNA measurements of four nitrate standards (0.01, 0.1, 1 and 10 mg/L) were compared to those run on the IC at room temperature, as would be the case for samples brought back to the lab. The results (Figure 9) indicate that temperature had little effect on the sensor nitrate readings compared to analyzing the samples at room temperature using the IC.

Because the SUNA is an optical probe, it was desirable to determine whether there could be any interference from either color (due to dissolved organic carbon (DOC) from humic substances) or turbidity. Concerns had been raised by other groups (U. Florida, USGS) that both of these could possibly interfere with SUNA nitrate measurements.

The DOC of waters in our system typically does not exceed 15 mg/L. We used International Humic Substances Society (IHSS) Suwanee River Fulvic Acid standards to prepare various controlled concentrations of DOC, ranging from 0.1 to 15 mg/L and formulated a matrix of mixtures with nitrate standards, ranging from 0 to 10 mg-N/L. The results in Figure 10 indicate that this range of DOC from humic substances had little effect on nitrate concentrations measured with the SUNA vs the IC.

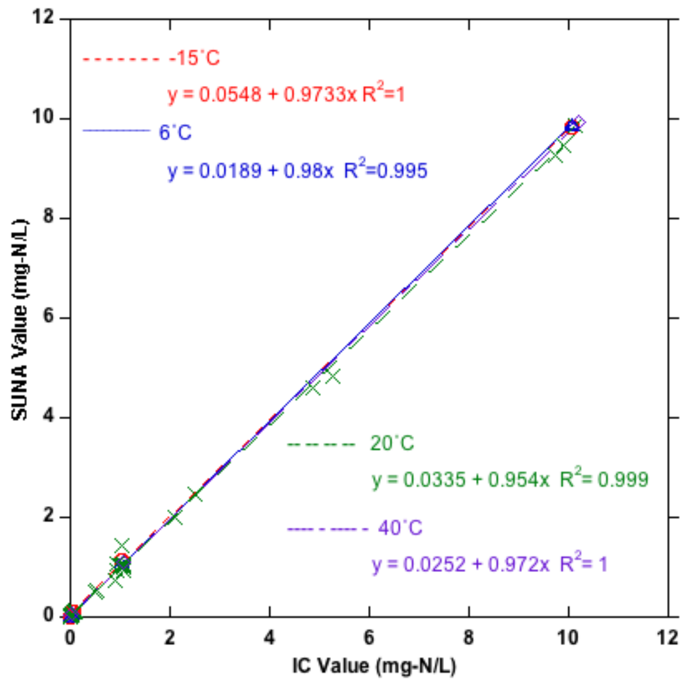


Figure 9. Temperature effects on nitrate measurement.

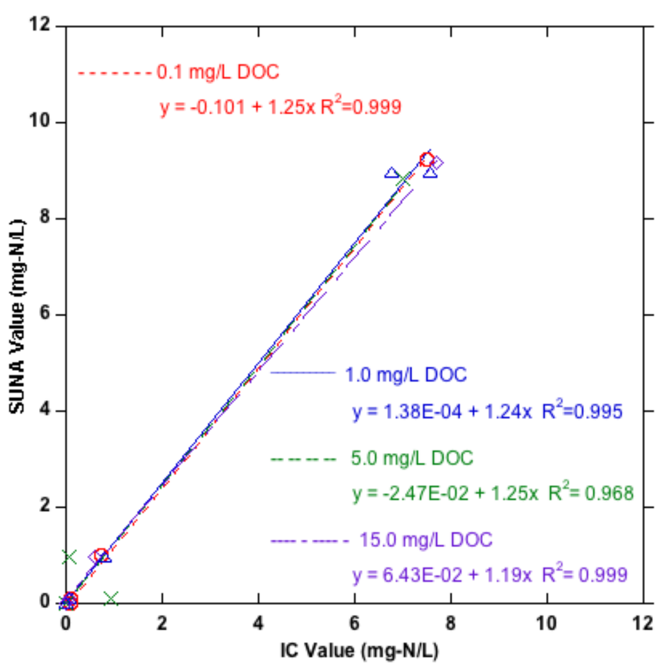


Figure 10. Effects of DOC from humic substances on nitrate measurement.

To evaluate the effects of turbidity, we prepared solutions encompassing a broad range of NTU values using titanium dioxide and measured the turbidity of the solutions using a YSI optical turbidity sensor. These results were used to generate a calibration curve of titanium dioxide concentration vs turbidity. We then chose four levels of turbidity and nine nitrate standards to make mixtures and measure with both the IC and the SUNA sensor. The SUNA was able to measure nitrate concentrations in mixtures up to 250 NTU. Above 250 NTU, the SUNA gave a recording of "NAN". The percent error between the two sets of readings (IC and SUNA) for turbidity less than or equal to 250 NTU was significant, especially for low nitrate concentrations (1 - 2 mg/L), which are relevant for our systems. These findings suggest the need for in-line field filtering to remove turbidity, which is consistent with recommendations made by USGS (Brian Pellerin, personal communication, 2010).

Other researchers have evaluated the effects turbidity on the SUNA readings using methods that are a variation on the above. Satlantic obtained SUNA readings up to ~450 NTU of turbidity made from solutions of Arizona Road Dust (Geoff MacIntyre, personal communication, 2011); USGS obtained similar results using a silt/loam IHSS standard (Brian Pellerin, personal communication, 2011). The next generation SUNA, to be released in early 2012, is designed to operate in extremely turbid environments (> 1500 NTU is the goal) to overcome the problems with turbidity interference on nitrate readings (Geoff MacIntyre, personal communication, December 2011).

The final phase of laboratory testing included an initial round of measurement of stream samples at the sensor test sites taken manually under base flow conditions, using the IC and the SUNA on samples in the laboratory (Figure 11). With the exception of one point, results for nitrate concentration using both methods show good agreement.

A correlation between specific conductance and chloride for samples taken at DRKR is shown in Figure 12. This information was required for mathematical analysis being conducted for this project (e.g., VerHoef et al., 2011).

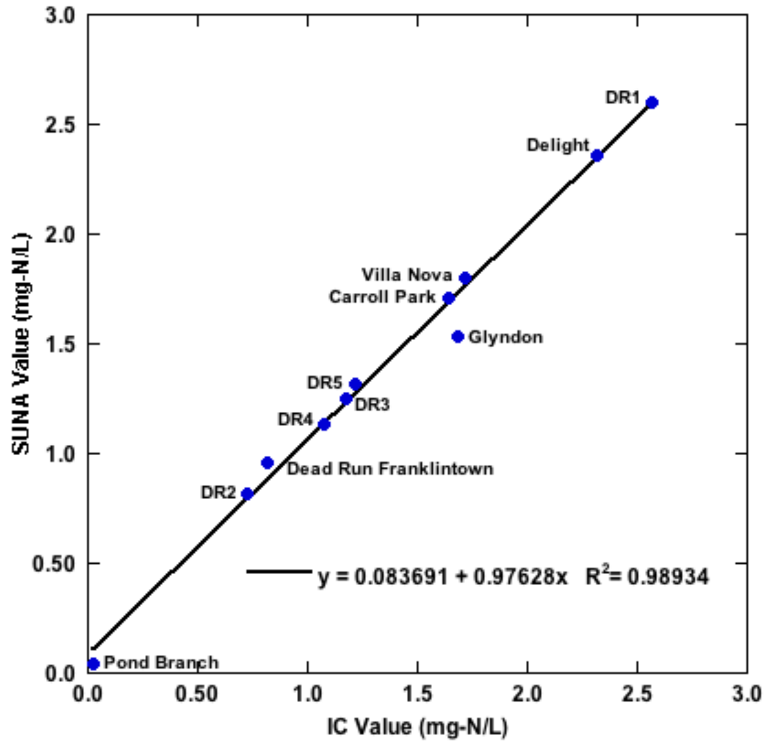


Figure 11. Measurements of base-flow nitrate concentrations from grab samples taken at station locations and analyzed in the laboratory using the SUNA and ion chromatography.

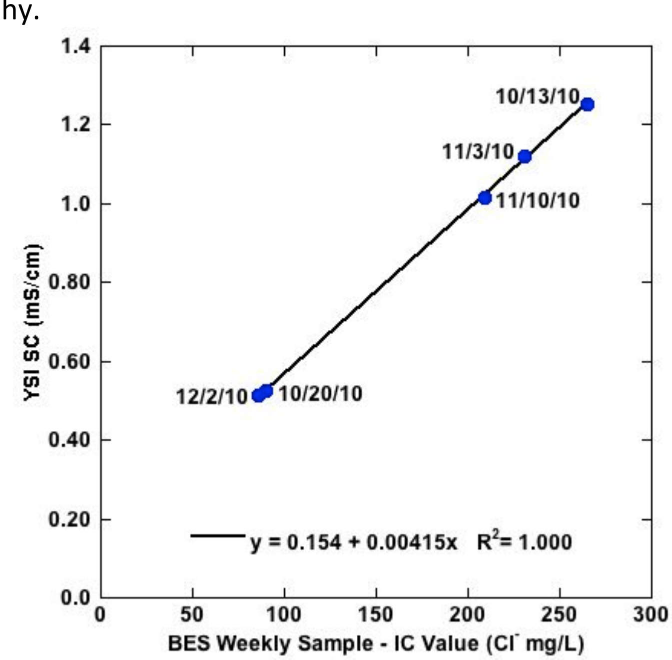


Figure 12. Correlation between specific conductance (measured using the YSI sensor) and chloride (measured using ion chromatography), for stream samples taken at Dead Run Franklintown.

3.2 Testing hydraulics, wiring, datalogger programming

Before deployment, the entire system should be set up in the lab and tested. This enables the user to check that the sensors are configured with the correct settings, proper power is being supplied to the system, and that datalogger is programmed correctly to turn the pump and sensors on/off to take sensor readings at correct times.

3.2.1 Sensors

The SUNA should be set to the SDI-12 mode via a PC and Satlantic SUNACom software so it can communicate with the datalogger. The YSI should be set up to record specific conductance and temperature only. If any other measurements are set up to be recorded, they will overwrite the specific conductance and temperature data strings in the datalogger. If the system is run with deionized water, the YSI should report a specific conductance measurement near 0 mS/cm and the SUNA should report a nitrate concentration slightly above 0. (Even if there is no nitrate in a sample the output will never be 0 (integer); it will always be a small real number regardless of the units being used.)

The YSI should be calibrated for specific conductance. This can be done using the EcoWatch software with specific conductance solutions supplied by YSI. The SUNA does not require initial calibration, as this is done in the factory. Update calibrations must be performed with deionized water as described in Section 4.3.7.

3.2.2 Hydraulics

Testing in the lab will also reveal whether there are any leaks in the system. Leaks in the flow cells could result from (1) manufacturing defect, (2) excess pressure in the flow tubing due to unintended kinks, or (3) a flow rate that is too high for the YSI flow cell. If there is a kink in the tubing or if the flow rate is too high, the YSI flow cell will leak from the top. The flow rate should be tested with the system fully wired as shown in Figure 7. The flow rate is higher when the bilge pump is triggered from the relay than when it is connected directly to a battery. This is because the relay is getting power from both the battery and the datalogger when it is active.

The lab testing can also provide a check as to whether the pump is sized correctly to overcome the calculated/expected head losses. We did this by looping the plastic tubing over a pipe near the lab ceiling to simulate the height of the lift and length required in the field.

As mentioned in Section 2.2.4, testing the recommended filtering system in the laboratory before going to the time and expense of field deployment led us to identify problems (hydraulics) unrelated to turbidity removal.

3.2.3 Wiring and datalogger

These components should be set up exactly as intended for the field, to ensure that the system is error-free.

4. Field deployment

4.1 Construction

4.1.1 Enclosures

At 5 of our 6 stations, 30" x 30" x 12" metal junction boxes by Hoffman Inc. had previously been deployed by USGS for the purpose of housing Accububble pressure transducers. 12V batteries rest on the bottom of the box. We lined the interior sides and back of each box with pieces of ¼-in thick plywood so as to be able to mount the sensors, Raven, datalogger, and SunSaver on the inner faces of the box (Figure 13).

Figure 13. Interior of Hoffman box.

Two holes were drilled in the bottom of each box to allow placement of the inflow and outflow vinyl tubing from the sensors. The outflow tubing is shielded by a 1.5-in PVC pipe running vertically downward from the box and then horizontally (trenched and buried) to direct the outflow water away from the sensor station and onto the ground downstream of the pump intake. Holes are also needed in the Hoffman box for the Raven antenna, the grounding wire, and the solar panel wires. Foam sealant was used around all holes to keep moisture out to the extent possible.

At the one station where a Hoffman box was not available, we chose to use a 55-gallon drum as the sensor enclosure (Figure 14). The drum is bolted to part of the wingwall of a bridge culvert; the top is removable (and lockable) and a sensor package can be slid into this enclosure. This had previously been designed to hold an ISCO sampler for use in another project (Ken Belt, USFS, personal communication, 2010). For this set-up, we designed a cage made out of galvanized steel strips bolted together and further reinforced with a piece of plywood along one side (Figure 15). The sensors are mounted in the interior of the cage using zip ties and bolts; the Raven, datalogger, and SunSaver control panel are mounted onto the plywood facing outward for ease of access. The only constraints on the size of the cage are the circumference and height of the drum, as well as the need to fit two 12V batteries into the enclosure.

Figure 14. 55-gallon drum that can be used as an enclosure for the sensor package (a) with lid off; (b) secured.

Figure 15. Cage constructed to hold sensor package inside 55-gallon drum.

4.1.2 Trenching and pipe deployment

In order to protect the bilge pump (deployed in the stream) and the Tygon tubing connecting the pump to the sensors (located in the housing on the stream bank), the pump and tubing system were enclosed in a length of connected PVC pipe pieces. The PVC pipe system was then buried in a channel trenched in the soil so as to conceal and protect the pipe.

The bilge pump was housed in 2" ID (inner diameter) PVC pipe. Four rows of ½" holes were drilled along an upper half-circumference of one end of the 2" PVC pipe segment to allow for water flow into the pipe and contact the bilge pump intake. A lower portion of the pipe circumference was left unperforated (so as to avoid sucking in sediment when the pump was active) and placed against the streambed.

The 2" pipe containing the pump was attached to 1-½"PVC pipe containing the Tygon tubing. These were connected using a series of small pieces such that the 2" end housing the bilge pump could be screwed on and off (Figure 16) for the bilge pump to be easily accessed for maintenance or troubleshooting.

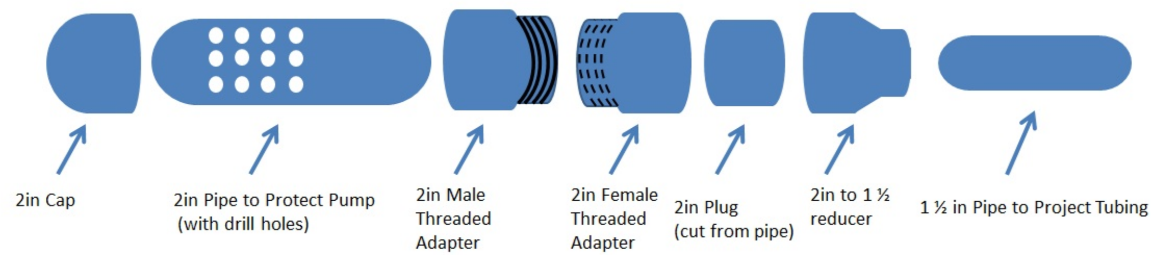


Figure 16. Schematic of PVC pipe pieces used to protect pump and pump tubing.

A 2" male threaded adapter is pressure-connected to the 2" PVC piece using PVC cement. This can then be connected to the 2" female threaded adapter, which needs to be reduced to fit the 1-½" pipe containing the plastic tubing. The 2" female adapter and the 2"-to-1 ½" reducer cannot directly be connected since they have the same inner and outer diameters, but they can be connected via a 2" plug. The 2" pipe, 2" male threaded adapter, and a 2" cap to seal the pipe comprise the bilge pump housing assembly, which can be screwed on and off. The 2" female adapter, 2" plug, 2" to 1-½" reducer and 1-½" pipe are all glued together and remain stationary at the site.

We have experienced that the PVC can break apart at the connection between the 1-½" pipe and the 2" to 1-½" coupler connection (shown in Figure 16), during flashy storms. As an added measure of security we added a self-tapping set screw to the 1-½" pipe and the 2" to 1-½" coupler connection to aid in preventing the connection from breaking apart.

Before any trenching or pipe fitting, we first determined the best location for the bilge pump to be placed in the stream. We wanted the pumps to be as close to the enclosures as possible, but placed in flowing water (not pools) and such that they could be protected in a storm (i.e., braced with rebar and rocks). These also needed to be placed in locations where the perforated pipe would be submerged during low flow conditions, which may be as shallow as 3 or 4 inches in urban streams. Typically the best locations were 2 or 3 feet from the bank. At DR Franklinton and DR5, concrete aprons were present in the streams and the PVC pump housings could be butted up against the aprons and held in place by rebar (Figure 17). At DR3 and DR4, the PVC runs along galvanized pipe that was previously deployed by USGS to protect the Accububble pressure transducer. The PVC was secured to the pipe with wire ties. A large tree with an exposed root system near the bank is present at DR1; we placed the PVC pipe through this root system for support. At DR2 the stream is narrow near the testing location; here we dug into the bank and used the earth as a support for the PVC.

Figure 17. Pump housing deployment at DR Franklintown.

Once the housing location is determined, a mock setup should be carried out by laying out the entire length of pipe, from the bilge pump housing to the enclosure. Once the desired path is determined, trenching can begin. It is important to trench *before* cutting or connecting the piping because the path may turn out to be obstructed by large roots or concrete foundations.

After the trenching is completed, the pipe segments can be fit together. The first step is to attach the adapters and reducer as shown in Figure 16 to build the pump housing. Then the bilge pump can be connected to the plastic tubing (secured with a hose clamp) and placed inside of the PVC housing. The pipe can then be assembled starting from the 2" to 1-½" reducer and ending at the sensor enclosure. The plastic tubing and pump wires can be fed through each piece of PVC as work progresses. All PVC connections should be cleaned with PVC primer and glued with PVC cement. A hacksaw can be used to cut all pieces to desired lengths, and elbows can be used to conform to the topography as needed. The pumps do have a finite lifetime so one connection in the PVC should remain unglued to access the wires. It is helpful to have a splice in the wires near this unglued connection for ease of changing the pumps.

As shown in Figure 17 a cap can be fit over the end of the PVC bilge pump housing. This cap should not be glued so that it can be easily removed.

A fine copper mesh can be wrapped around the perforated 2” PVC to act as a biocide and filter. A “cage” can be built in front of the PVC intake as a barrier against leaves and other debris and trash. The copper mesh and cage are described in more detail in Section 4.2.4.

4.1.3 Tubing considerations

Tygon tubing was used to connect the pump to the sensors, because it is flexible and resists kinking and breakage. In several cases we used vinyl tubing as a substitute, and this proved to be harder to work with. All tubing that is pressure-attached to barb fittings should be secured with small hose clamps for extra security.

While Tygon tubing is flexible and resists kinking and breakage, it will show signs of biofouling over time, as will most plastic tubing. As an alternative, food-grade tubing, which is more resistant to biofouling, can be used; however, food-grade tubing is stiff and difficult to run through the PVC pipe from the pump to the enclosure. Copper pipe could be used to supply water to the sensors; however, this could also be difficult to run from the pump to the enclosure. The choice of tubing should be made based on site accessibility with the understanding that anything other than copper or food-grade plastic will show biofouling over time.

A Y-connection can be used to split the water equally from the inlet tube to both sensors. The Y split should be placed near the bottom of the box enclosure. Once the Y-connection is in place, the tubing can be cut to length from each sensor to the Y connector.

4.1.4 Solar panel deployment

One 30-watt, unbreakable solar panel, manufactured by Power Up Solar, was deployed at all locations for the purpose of powering the bilge pump via a 12V battery. One 30-watt solar panel was already in place at each station to power the Accububble pressure transducer, as well as the datalogger and sensors. A mounting bracket for the 30W panel allows the solar panel to be mounted against a wall, horizontally or vertically, or attached to a pole. The bracket also allows the panel to be tilted with a range of motion of almost 90^{o}.

We mounted the solar panels to existing galvanized steel poles previously deployed by USGS to hold satellite data communication antennas. The panels were attached to the pole using two stainless steel hose clamps that could accommodate a 2” pipe. Our goal was to mount the solar panels high enough to minimize the potential for vandalism. At two of our stations, the existing poles had to be extended, which was accomplished by attaching a section of 2" pipe to the top of the existing pipe using a coupler. The coupler contained all female threads and was screwed to the top of the existing pipe (which was already male threaded). The extension pipe was then threaded into the top of the coupler.

In cases where a new pole is needed, a hole needs to be excavated at least 2 ft deep and filled with fast drying concrete (e.g., Sakrete (50 lb)), in which a 10-ft, 2-in galvanized steel pole can be placed.

At one site, our solar panels needed to be mounted against a bridge. To do this, masonry wedge anchor bolts were set in the face of the bridge by drilling a 1-½" deep hole, the same diameter as the bolts to be used, and hammering to wedge the ends of the bolt into the holes. Four bolts were used to mount two U brackets, spaced vertically such that 2-inch galvanized pipe could be slid through them. A horizontal bolt in the U brace was tightened to hold the galvanized pipe in place.

All solar panels were positioned to face south and to match the tilt of the solar panels already deployed at the sites by USGS.

4.1.5 Wiring

Before inserting the bilge pump into the PVC housing, the existing power and ground wires on the pump need to be extended to the sensor enclosure. After trenching, 16-gage wire can be run from the pump to the enclosure and then cut, leaving some excess. This wire can then be then spliced to the pump wires by stripping the end of each wire and connecting them using a wire nut. Since water may reach this spliced connection, it should be sealed; this can be done by wrapping the wire nut with electrical tape, covering with heat shrink (a material that shrinks and makes a tight seal when heated), and wrapping once more in electrical tape to ensure the ends of the heat- shrink-wrapping are sealed. Since the pumps have a finite lifetime, it is advisable to make a splice in the wires somewhere near an easy access connection in the PVC.

The overall wiring diagram utilized in the enclosure is shown and discussed in Section 2.6. As mentioned in that section, 16-gage wire was used to connect all components. Red wire was used as power (positive), black was used as ground (negative), and blue was used as excitation channel or data transmission wire.

In terms of wiring order, this is somewhat arbitrary, but we found that the following order worked well for our set-up: (1) connections between the relays and datalogger; (2) connection of the bilge pump and SUNA to the relays; (3) connection of the YSI and other SUNA wires to the datalogger; and (4) connection of the Raven to the datalogger.

The SunSaver solar controllers should be connected last. Per the SunSaver manual, the battery should first be connected to the SunSaver, followed by the solar panel wires and lastly the load. Each port is labeled on the SunSaver 6. It is important to not touch any exposed wires together other than the following: (1) Ground wires can touch and multiple wires can go in the same ground port on the datalogger. (2) The YSI power and Raven power can go in the same 12V port or in separate 12V ports on the bottom right of the datalogger. (3) The positive load for the SunSaver and relay port 2 on the SunSaver and relay used for the datalogger and touch and go in the same 12V power in port on the top right of the datalogger. These connections are all shown in Figure 7.

It is important to note that the wire connected to Port 1 on the relay should NOT be disconnected or reconnected if the system is supposed to be running; this action can short out the relay and leave it stuck “on” (whatever is connected to the relay will remain on).

An 8-gage wire was used for the earth ground. The wire was run to the copper grounding rod that was set near the enclosures.

4.1.6 Grounding rod

One-half-inch diameter, 8-ft copper rod can be used as a ground. The rod can be hammered into the ground using a post driver until about 2 ft of rod remains exposed, followed by a sledge hammer to finish the job. Approximately 2 inches of rod should be left exposed. The 8-gage ground wire is attached the near the top of the exposed rod with a copper grounding rod clamp. It is important to put the clamp on the rod before it is set in the ground, because the tip of the malleable rod will be rendered flatter and slightly larger in diameter from hits by the post driver and sledge hammer, rendering it infeasible to slip on the tightly-fitting clamp afterwards. The rod should be installed near the enclosure and can be covered with small rocks for camouflage.

4.2 Troubleshooting sensors

After our sensor stations were deployed, we ran into a number of problems that took a bit of time to identify and remedy. We hope that by providing some “lessons learned” in what can go wrong, others can more quickly resolve the same problems.

4.2.1 Blockage of SUNA optical path

At our first deployment (DR Franklintown) we recorded a highly fluctuating nitrate signal. We had assumed that this was a natural fluctuation. Our second deployment showed a much more smoothly varying nitrate signal, which led us to suspect that something was wrong with the Franklintown deployment.

Investigating the SUNA at DR Franklintown revealed that there was a broken O-ring partly blocking the path of the optical sensor. The SUNA flow-through cell contains two small O-rings that fit in circular grooves on the top and bottom of flow cell. These O-rings provide a tight interference fit but do not fit well and often break when the flow cell is inserted into the SUNA. Once we realized that these could break upon flow-cell insertion, we took greater care to ensure that the O-rings were not flopping out of the grooves designed to hold them. We found that it takes a great deal of finesse to get the flow cell into the SUNA without breaking these O-rings; wetting the O-rings before inserting the flow cell helps to make insertion easier. Even if the flow cell is inserted without the O-rings breaking, they frequently break when the flow cell is removed. Satlantic subsequently provided us with better-fitting O-rings, but precaution with inserting them is still advised. Mechanical modifications to the O-ring grooves in the flow cells have reportedly improved the design (Geoff MacIntyre, personal communication, 2011).

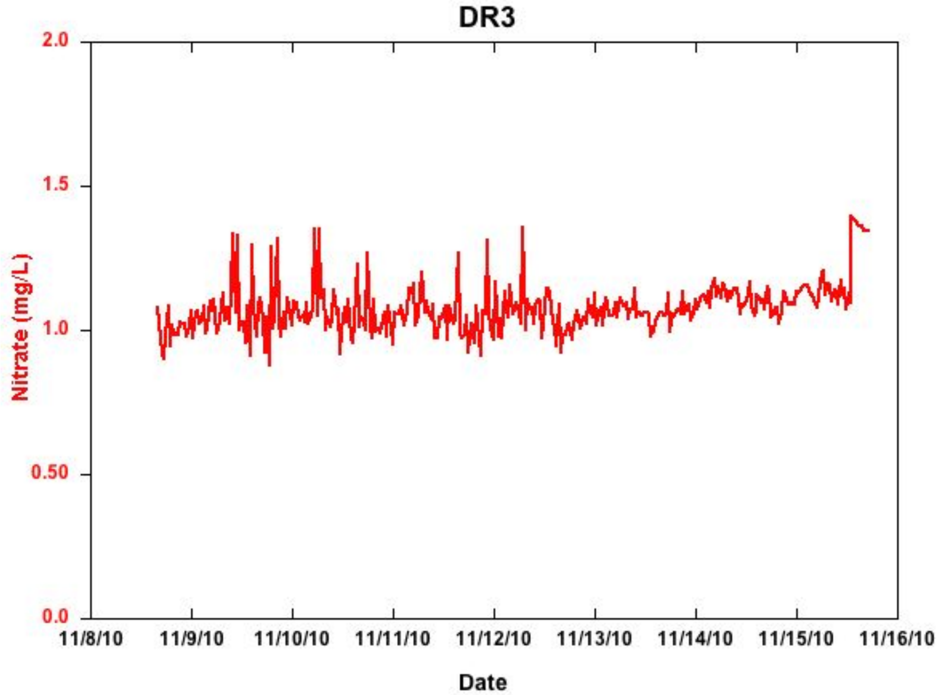
This problem can be identified most easily by inspection of a graph of the streamed sensor data. Figure 18, an example from DR3, shows that the diurnal nitrate signal is difficult to discern when interference is present, but clearly observable when the interference has been removed.

This problem can be confirmed by evaluating the SUNA spectra using the SUNACom software with the sensor connected to a PC (Figure 19). If the spectra output show noise in the signal as in Figure 19a, this is an indication that there is debris in the optical path that is not being flushed out during runs; one likely cause of this behavior is a broken O-ring. If the spectra output is good, the data should plot as a smoothly varying curve as a function of time as shown in Figure 19b.

Figure 19a shows that when there is a blockage of the optical path, the light counts are on the order of 1000 to 2000. When light is passing through the water sample there should be a peak near or over 40,000 light counts as shown in Figure 19b. Anything below 10,000 counts means that adequate light is not passing through the water. This could also be caused by high turbidity.

4.2.2 Pump under/over sizing

Pumps are purchased with a specified nominal flow rate, e.g., 8 gal/min. As discussed in Section 2.2.2.2 and shown in Table 2, the observed flow rate is less than specified and can vary with battery charge. Also, the rated head loss that can be overcome with the pump will depart from manufacturer’s specifications if a tubing size smaller than the pump outlet orifice is used. As shown in Appendix A and Figure 3, swings in temperature will affect viscosity of the water, which in turn increases the head loss as the temperature drops, or decreases the head loss as the temperature increases. This effect is significant for smaller-diameter tubing.



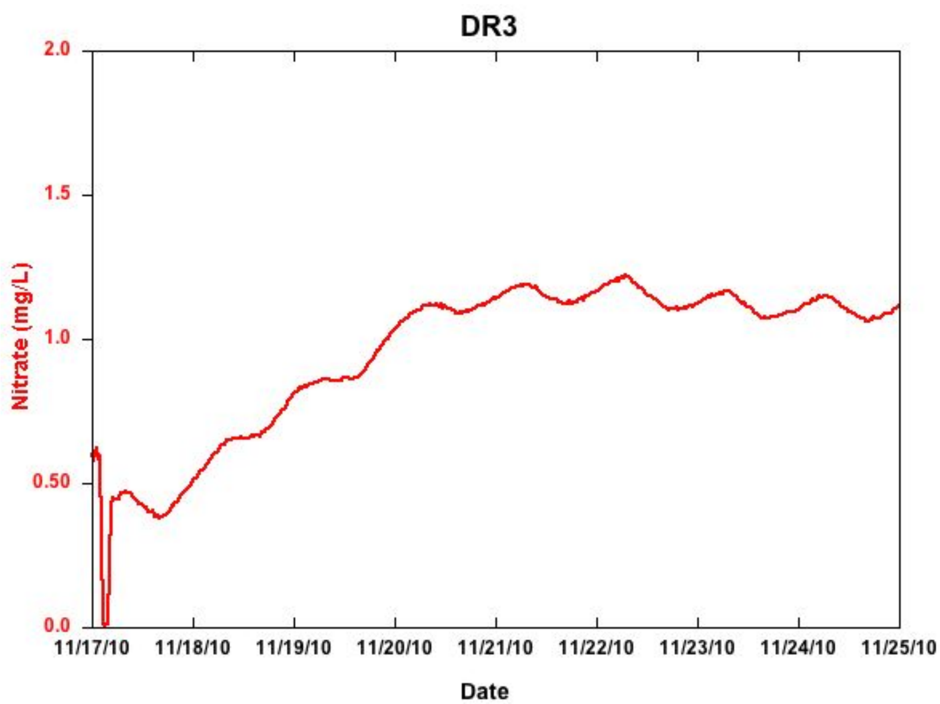
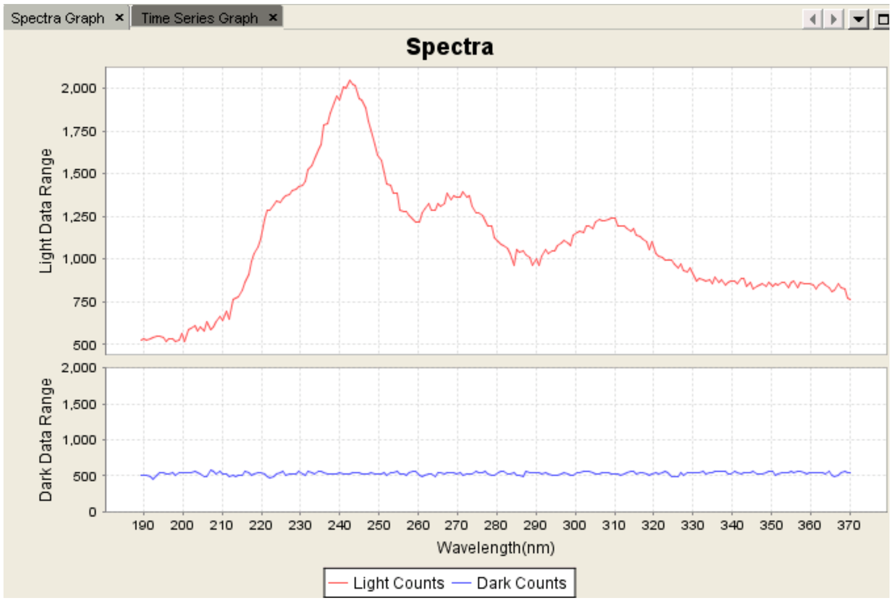


Figure 18. Example field data illustrating that (a) the optical path being blocked by broken O-ring (top figure); (b) the sensor is working correctly (bottom figure).



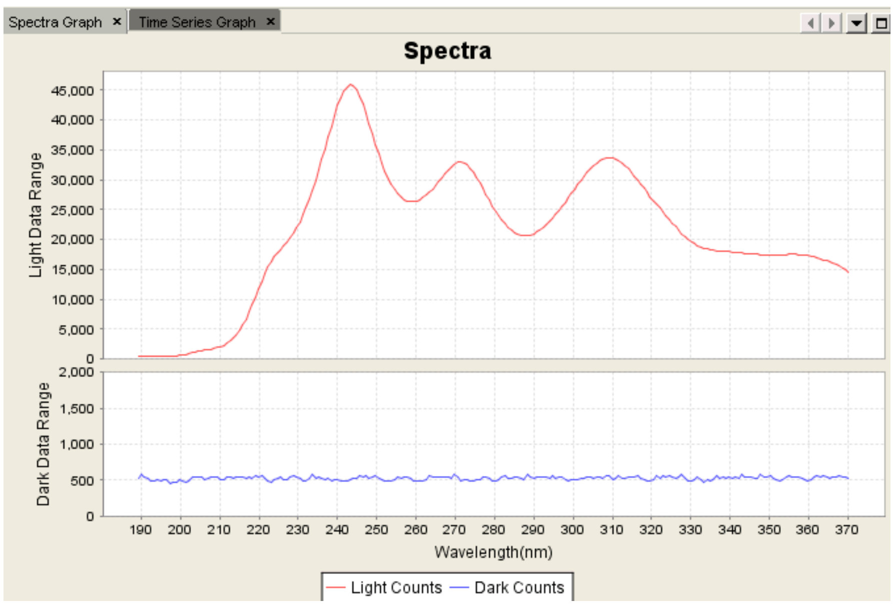


Figure 19. SUNA spectra illustrating that (a) the optical path is being blocked by a broken O-ring (top figure); (b) the sensor is working correctly (bottom figure).

If the head losses are too great to be overcome by the pump, water will not reach the flow cell. A pump that appears to be working well during warm weather may fail if the temperature drops significantly, and smaller tubing is being used, because the head loss due to friction increases significantly.

On the other hand, a pump must not be oversized owing to the potential for leaks out of the top of the YSI flow cell, as discussed in Section 2.2.2.

If water is not reaching the flow cells due to problems with either pumping water in or draining water out, the flow cells will be attempting to record an air measurement. The values being recorded will drop suddenly. The SUNA will show a low positive or negative value (order +/- 0.001 mg/L); the YSI will show a low positive value (order 0.001 mS/cm).

4.2.3 Tubing kinks

Kinking of the tubing can cause pressure buildup in the lines. This pressure can force water out the top of the YSI flow cell or stress the tubing at the inflow or outflow ports on the flow cell. To guard against the latter problem, all tubing should be secured to ports with hose clamps.

An additional consideration of the tubing set up is that the water must be free to drain away from the flow cells. Therefore the exit end of the plastic tubing must be kept free of debris/soil.

4.2.4 Leaf, trash, and periphyton clogs

Based on our experience with leaf debris and dead crayfish clogging the ½-inch open holes in the perforated pipe, we covered the pipe holes with netting material, held in place using wire ties. This also prevented larger sediment particles from entering the pump housing chamber.

We chose woven copper mesh cloth as the netting material, because in addition to working as a sediment filter, the copper acts as a biocide to deter periphyton growth. Periphyton is a mixture of algae, bacteria and detritus and appears as brown specks clinging to the pipe. The periphyton growth can be fast and thick and actually can impede water flow into the perforated holes if the employed netting does not have biocidal properties.

Copper mesh cloth is flexible and can be easily wrapped around the end of the 2” PVC that protects the pump housing. We have found that a fine mesh of 100 x 100, 0.0045” wide diameter and 0.006” width opening has been effective in keeping sediment out of the PVC and does not restrict water flow. As a precaution to protect the pumps from sediment or other small debris, we also wrapped copper mesh around the pump intake. The copper mesh needs to be replaced approximately every 6 months, as fine holes can be punched into it from passing storm debris.

Even after placement of netting over the perforated holes, we still had problems with decaying leaves and trash (mainly plastic bags) getting sucked tightly against the intake holes by the pump, causing the water intake to drop and the sensors to fail to record a reading. We were able to rectify this problem by using a combination of two methods: (1) building rock barriers in front of the pump housing, and (2) making a cage upstream of the pump housing using plastic deer fencing (Figure 20).

Figure 20. Example protective cage made of deer fencing and rebar.

The rock barriers can divert leaves away from the pump housing while still allowing for water to enter it. Determining the optimal arrangement is a trial and error process. We found that after storm events the rocks often moved and a new barrier had to be built.

A deer-fencing cage can be built with 2-ft rebar spaced about 1.5 to 2 ft apart, driven into the streambed until the rebar is about 10" above the water level at baseflow. The deer fencing can be pulled tightly against the rebar and attached with zip ties. Rebar can also be also laid against the streambed and attached to the deer fences to prevent debris from flowing under the cage. If the cage is built near a stage measuring device, such as a pressure transducer, it must be ensured that as the cage collects debris, the water level does not back up such that stage measurements are erroneously increased.

As with pumping sizing problems identified in the previous section, if water does not reach the flow cells owing to problems with clogs of the pump intake, the sensors will not receive water and therefore will not record water quality. One sign of a pump intake clog is that sensors for nitrate and specific conductance both go toward zero, but the temperature continues to be recorded by the YSI. The data being recorded represent air temperature.

4.2.5 Batteries dying, solar controller and datalogger problems

We had several instances where it appeared that a solar panel was not properly charging a battery at a site where the solar panel had been installed for several years We believe that this was a problem with the SunSaver controller shorting out. The SunSaver is very unforgiving and if wires cross on the panel and short out the system the SunSaver will no longer be able to charge the battery. We believe this may have happened and gone unnoticed. There is a green LED light labeled "charging" on the SunSaver; this light is on if a battery is connected to the SunSaver and light is reaching the solar panel. However, apparently this light also may be on when the battery may not actually be charging, if the SunSaver has been shorted out. We confirmed this using a SunSaver we knew had shorted out and was no longer able to charge a battery, i.e., its LED green charging light was green even though it was not functioning.

Some SunSavers are made with a red LED light that indicates they have a low voltage disconnect. This means that if the battery goes below a specific voltage (11.5 V with the SunSaver 6), the load is disconnected from the battery. The system will engage the load again once the voltage reaches 12.6 V. This system is intended to preserve battery life; if a battery goes well below this 11.5 V cutoff it could lose its capacity to hold a charge. If a site visit shows a battery is near 11.5 V and the pumps have not been running, it most likely means the low voltage disconnect has been tripped and the battery should be replaced. To bypass this low voltage cutoff, the wires that should be connected to the load on the SunSaver (Port 2 on the relay and the ground wire) can be connected directly to the battery.

Technical support documents for Morningstar SunSaver can be downloaded from http://www.morningstarcorp.com/en/support/product.cfm?ProductId=4

If the batteries are charged and the solar controller seems to be in working order and the system is still not running, the datalogger may need to be reset. This can be accomplished by unplugging and re-plugging in the power to the datalogger.

4.2.6 Ice

Ice can cause two problems with the sensors the way we have them deployed (out of the stream and in housings): (1) water freezing in the tubing between runs; and (2) ice particles moving through the system during runs that could potentially damage the sensors by torquing the flow cell parts. The water in the pump could also freeze thereby not allowing for any water to be pumped to the sensors. Owing to the desire to avoid these problems, we removed the sensors from the field sites when air temperatures started to fall significantly below freezing, i.e., in early December.

4.2.7 Interpretation of error codes and erroneous data values

CR10X recording of 0 for SUNA nitrate value

When light is unable to get through the optical path of the water sample and reach the detector, the second-generation (black casing) SUNA generates an alpha string of “NAN” which the CR10X datalogger records as a zero (integer). The reasons that this error could occur include (1) the water may be excessively turbid; (2) an air bubble could be stuck in the flow cell; or (3) or the SUNA lamp may not be not working. The zero recorded by the datalogger does not mean a zero value of nitrate – in fact the SUNA cannot produce a zero integer value for a nitrate measurement.

CR10X recording of 6999 for SUNA nitrate value

For the first generation SUNA (stainless steel casing), this error (as discussed above) is represented as repeating digits of 9 (999999…). The CR10X datalogger can be set to high or low resolution. This refers to the highest value the datalogger can store. In low resolution the datalogger can store a value up to 6999. If a value of 6999 or larger is sent to the datalogger and it is in low resolution, it will record 6999. A 99999 string is larger than 6999 and therefore it will be recorded as 6999.

A value of 6999 will also be recorded if more than 4 digits are sent as a data string while the datalogger is in low resolution.

CR10X recording of 99999 for SUNA nitrate value

If the CR10X datalogger is set to high resolution and this error occurs (SUNA sending a 99999) a value of 99999... will be recorded.

Low magnitude or negative nitrate values

A low value or negative value in the SUNA output during base flow, such as +/-0.003 mg/L of nitrate, means that there is no nitrate in the sample. In our case, since we know that our streams all contain significant concentrations of nitrate, a low or negative value likely means that there is no water going past the sensor, i.e., the pump is not adequately supplying water to the sensors, or there is a blockage in the water line.

4.2.8 Testing pumps

Many times when a sensor is not collecting accurate data, this is due to the pump not supplying water to the sensor. To quickly check whether the pump is working properly, the positive wire on the pump connected to Port 1 on the relay can be removed and touched to the positive terminal on the battery (the relay and battery designated for the pump), when the pump is not running. Since the system has a common ground, once the pump wire touches the positive battery terminal, the pump should activate and water should run into the enclosure. If this does not happen, one of the following may be a occurring: (1) there is an issue with the pump due to low batteries; (2) the pump is not priming; or (3) the PVC pipe is clogged with debris.

Care should be taken with this procedure, because as mentioned in Section 4.1.5, if the positive pump wire attached to Port 1 is disconnected or reconnected while the system is running, the relay will short out. The relay will no longer act as switch to turn the pump on or off, and the pump will remain on.

4.2.9 Priming pumps

If either the Rule® or Wale® pump sits in the PVC without water for more than one pumping cycle, due to abnormally low base flow or some type of clogging of the PVC, the pump must be re-primed. The Rule® pump seems to re-prime more easily. For the Rule® pumps, while the pump is running, water can be forced by hand into the perforated PVC and the pump will prime and begin to work.

When re-priming the Wale® pumps, the 2” PVC must be removed to expose the pump, and the plastic tubing must be removed from the pump’s outlet port. The pump can then be submerged and turned on. Once water is forced into the inflow port and the pump is primed it can then be shut off and the plastic tubing can be reattached to the outflow port.

If the 2-inch PVC is removed for cleaning or troubleshooting, and the Wale® is removed from the water, it typically needs to be re-primed before it will run properly again. This does not seem an issue with the Rule® pumps, as long as they are not turned on while they are out of the water.

4.2.10 Relay shorting

If the pump continues to run regardless of the time on the CR10-X, the relay may have shorted out and need replacing. This can happen if the wire connected to Port 1 on the relay is disconnected or reconnected while the system is supposed to be running.

4.2.11 Backflow bubbles

At one site, our pumps would not self-prime between runs regardless of the pump used. We observed bubbles were coming out of the pump after the pump shut off and water back flowed from the sensors. We identified that air was being pulled into the outflow of the SUNA and YSI outflow tubes from the backflow process. To fix this problem, the outflow tubes were extended into the stream, downstream of the pump so that they were submerged and that water, instead of air, was pulled back into the plastic tubing.

4.3 Maintenance

4.3.1 Power

If solar panels are not installed at each location, the batteries need to be replaced on a calculated schedule. This can be done right before the programmed pump switch-on time to make sure the system turns on when it is supposed to after installation of a new battery.

4.3.2 Tubing

At each trip to the site the tubes in the enclosure and the outflow tubes should be checked to make sure they are not crimped or becoming clogged. Plastic tubing will biofoul over time and should be monitored and cleaned or replaced when needed.

4.3.3 Pump replacement

To replace a pump, the splice that connects the power wires of the pump to the wires leading to the battery needs to be exposed and taken apart. Since these wires are all inside the PVC, the easiest way to splice in the new pump is to make the splice near an unglued connection in the PVC, for example at the male and female threaded adaptors (Figure 16). Further, there also needs to be extra wire left near the pump battery to allow the pump and wires to be pulled until the existing splice is visible and out of the water. Once the existing splice is exposed and out of the water the old pump can be disconnected from the wires leading to the battery and the new pump can be spliced to these wires. Before closing the PVC connection, it is good practice to check to make sure that the new pump runs correctly with the newly spliced wires.

4.3.4 Cleaning solar panels

As the solar panels become dirty, their photocells collect fewer photons and their efficiency becomes reduced. Solar panels should be cleaned with water or glass cleaner every few months, and more often when they are more susceptible to becoming dirty such as in late spring when pollen counts are high.

4.3.5 Cleaning sensors

The YSI and SUNA sensors and flow cells should be cleaned routinely. Since the YSI flow cell retains some water between runs, a film will grow over time on the bottom of the flow cell. This can be removed with a flexible brush. Bathroom cleaner such as Scrubbing Bubbles can also be used in the YSI flow cell (Matthew Longfield, YSI, personal communication, December 6, 2010). The SUNA is more delicate and the flow cell and optical paths should be cleaned with Q-tips and isopropyl alcohol.

4.3.6 Site check after storms

We have noticed that the flow cell and optical path on the SUNA appear to be dirty after a storm, regardless of the time elapsed since previous cleaning; this is most likely due to higher turbidity during storm events. Therefore we recommend that the SUNA be cleaned after storms.

Subsequent to recession of storm flow, the 2-inch PVC at some sites becomes covered with sediment. While the PVC may still fill with water and the pump may still be supplying water, the sediment needs to be removed after storm events. Over time sediment can get into the pump, and although the pump may be working with the PVC covered in sediment, eventually it will be unable to suck in more water. In cases like this the SUNA will usually read 0 even though the YSI is working properly.

We have experienced that the PVC end can become dislodged during storms. In one instance, the pump was still in the water and data were still being collected, so unless a site visit was performed after a storm, we would not have known that the PVC was missing.

4.3.7 SUNA calibration

Over time the lamp in the SUNA may drift slightly. Every 4 to 6 months the SUNA should be calibrated, which can be accomplished using SUNACom. The method is described in the SUNACom section of the SUNA Owner's Manual, and is summarized here.

The flow cell should be removed and the optical path should be cleaned thoroughly with a Q-tip and isopropyl alcohol. Plastic food wrap should be tightly wrapped around the SUNA near the slit for the optical path. The SUNA should be placed on a flat surface with the optical path slit facing up. A hole is then poked in the plastic wrap and the slit filled with deionized water, making sure there are no bubbles on the SUNA's surfaces. The SUNA must be connected to a computer and SUNACom opened. The SUNA must be set to the RS-232 (full binary or full ASCII) mode, not SDI-12 mode. On the main SUNACom Dashboard Window "Update Calibration" should be clicked and then the prompts followed. When completed, a graph will appear that shows the percent error at each wavelength between the new and previous calibration. If there are wavelength(s) with high error, the plastic wrap can be removed and the process repeated. If both calibrations were performed correctly, this second calibration update should show little error.

4.4 Field installation of Ravens

The magnetic “hockey puck” antenna is mounted on top of the junction box and its cable threaded through the hole in the bottom of the box.

The power cord is connected to the modem and its black wire is inserted into any G slot (ground) of the CR10X that is located the lower right corner of the panel and the red wire into the 12V CR10X slot directly next to the G slot. The modem is connected to the interface using the 10873 serial cable (RS-232). The interface is connected to the CR10X using the SC12 cable. This is illustrated by the figure on page 6 of the instruction manual (Campbell Scientific Inc., 2006).

The indicator lights on the modem should be checked. The power light and network light should be a solid green. A solid signal light indicates a strong signal, whereas a flashing light indicates a weaker signal. In order to transmit data the signal must be greater than -90dBm. The network connection and signal strength of the modem can be checked using AceManager, either by directly connecting to the modem with a RS-232 cable or if an internet connection is available by connecting using the IP address under the UDP connection.

5. Example data sets

Despite the complexities of setting up, securing, and maintaining the sensor system, we have obtained high-frequency data that are not observable from weekly grab sampling. Just from the initial application for two months in one season, we were able to observe behavior of a number of phenomena, some expected and some novel.

Figure 21 shows the benefit of deploying multiple sensors simultaneously. The example plot is from DR3 following storm recovery. This graph demonstrates the well-known synchronization of high diurnal nitrate concentrations at low temperatures and vice versa. The “recovery” of the strength of the diurnal nitrate signal following a storm is also apparent from this plot. The data also illustrate the relationship between nitrate and specific conductance. Specific conductance encompasses solutes that are both conservative/biologically nonreactive as well as those that may be influenced by biotic activity such as nitrate. The specific conductance data display a temporal pattern that mimics the nitrate data, indicating the diurnal influence of the biotic portion of specific conductance on the recorded signal.

Figure 22 shows observations recorded by the sensors during base flow and storms during our initial deployment at Franklintown (DRKR). The nitrate signal is erratic, because these observations were recorded before we discovered and fixed the problem with the broken O-rings blocking the path of the optical sensor. Diurnal variation in stream temperature is apparent, as are slight increases in temperature during initial storm runoff, even as seasonal daily mean temperatures have started to drop as fall season progresses.   This plot also demonstrates the classic behavior of base flow constituent concentrations being diluted from storm runoff. A two-end-member mixing model can be applied to the specific conductance data to calculate percent “old water” of the total stormflow. For these data sets, such a calculation yielded old water as being 21% and 46% of the total storm flow for the two storms, respectively. Alternative conceptual models for mixing can be applied to the data as desired.

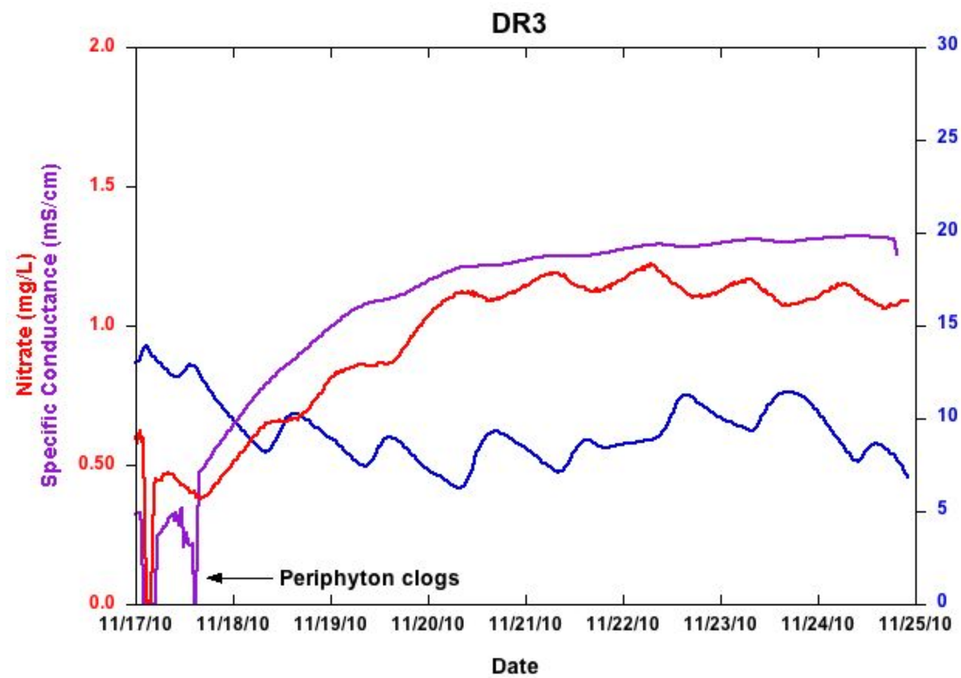


Figure 21. Nitrate, specific conductance, and temperature data recorded every 30 minutes at DR3.

Figure 23 illustrates a number of features of the nitrate signal behavior for one week at all six stations when all stations were functional and after the problem with the O-rings had been resolved. The diurnal signal is apparent at all stations, and is most pronounced at DR1. Mean nitrate concentrations at DR1 and DR5, two first-order watersheds, are about double those of the other stations, including DR2, which is also a first-order watershed of approximately the same size as DR1 and DR5. The observed behavior of the nested watersheds reveals interesting behavior that is not just a function of scale, but rather is likely also a function of land use and land cover. Figure 23 also illustrates the washout of the diurnal signal during storm recovery. Previously discussed problems with periphyton clogs of the pump intakes are also shown by Figures 21, 22, and 23.

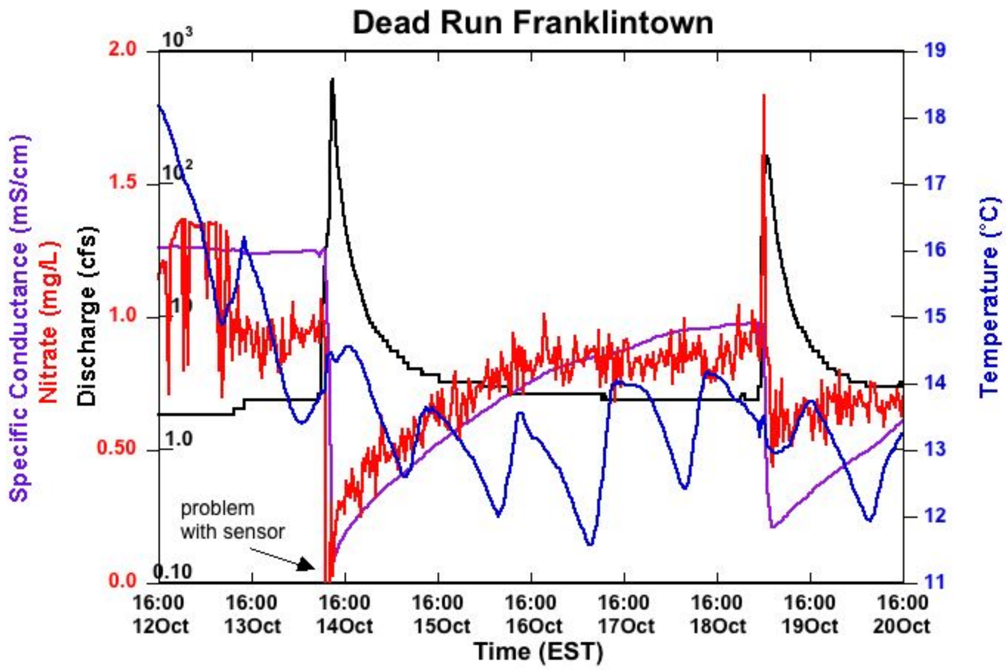


Figure 22. Observations of stream flow, temperature, nitrate, and specific conductance at DRKR measured every 30 minutes during base flow and storms, October 2010.

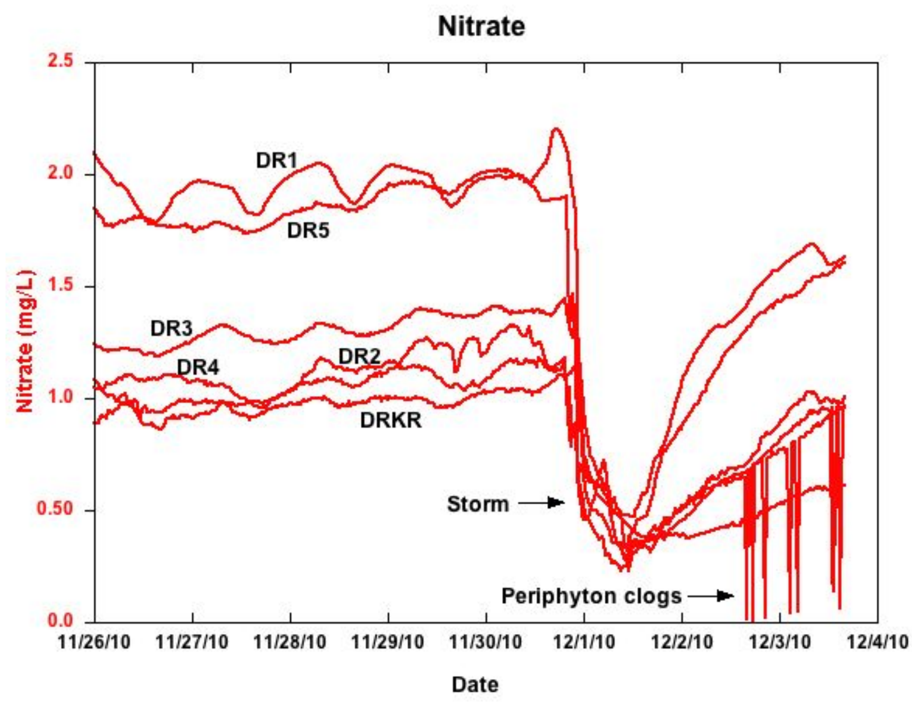


Figure 23. Nested watershed behavior of nitrate concentrations measured every 30 minutes, under base flow conditions and during a storm.

Ongoing work is being undertaken to tie observations into a physically-based mathematical model to incorporate other spatial data (vegetation, impervious cover, slopes) and to deploy additional sensors (e.g., oxygen) at the sites in an effort to elucidate function and stream metabolism in these nested urban watersheds. We will also be examining system behavior as a function of season and capturing the finer temporal scale behavior of storms as we change the frequency of data collection.

6. Summary and recommendations

We deployed Satlantic SUNA nitrate and YSI conductivity/temperature sensors in a nested watershed design for an initial test period (October - December 2010 and March-December 2011) in Baltimore, MD to obtain high-frequency stream water quality data. Because our stations are located in an urban area, we chose to secure the sensors in locked boxes out of the stream and to pump water to them, as opposed to placing the sensors directly in the stream.

The sensors worked well in terms of continuous function and we were pleased with the service provided by the vendors to help us in troubleshooting. Addressing the issue of the need to carry out in-line filtering to remove turbidity to obtain robust nitrate measurements comparable to laboratory IC readings is an ongoing effort that we hope to resolve in the future.

The biggest learning curve for our group was design, installation, and managing of the peripherals to obtain the data in an unattended manner. The deployment required background or acquired knowledge in fluid mechanics, electronics, computer programming, data communication systems, information management, aquatic ecology, and biogeochemistry, and significant "know-how" with field deployments. We could not have completed this effort without a team approach to cover the required knowledge base.

Although the solar panels and transmitting of data by cellular modem added significantly to the cost of deployment, we would not be able to keep the system running otherwise. We cannot stress enough how important it is to continually look at the data remotely – not looking at the numbers, but rather graphing the data – to ensure that the system is working as intended. The solar panel recharging of the batteries saves on labor and worry of swapping out batteries on a schedule. The system hydraulics presented the greatest challenge, namely with the pump intake clogging owing to various types of biological matter and trash as well as the limited lifespan of the pumps.

We stress that groups wanting to try to do sensor deployments must go into this endeavor with a full understanding of the complexities to be encountered and expenses involved. We hope that this report can help guide users in such an undertaking.

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Appendix A. Calculated head losses ($H = h_L + \Delta z$) for 4.5 A and 6 A pumps at 0˚C and 30˚C using Equations (1) – (3) for flow rates observed at 12 V and 10.8 V.

Station	Tubing Length (ft)	Required Lift Δz (ft)
DRKR	21	9.0
DR1	18	9.8
DR2	45	8.0
DR3	19	7.3
DR4	36	7.4
DR5	26	9.2

0˚C, 6 amp pump

	D = 3/4 in				D = 5/8 in				D = 1/2 in				D = 3/8 in			
	12 V		10.8 V		12 V		10.8 V		12 V		10.8 V		12 V		10.8 V	
Station	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)
DRKR	1.5	11	0.76	9.8	3.7	13	1.8	11	11	20	5.2	14	41	50	20	29
DR1	1.3	11	0.65	10	3.1	13	1.5	11	9.0	19	4.4	14	35	45	17	27
DR2	3.3	11	1.6	9.6	7.8	16	3.9	12	23	31	11	19	89	97	44	52
DR3	1.4	8.7	0.68	8.0	3.3	11	1.6	8.9	9.5	17	4.7	12	37	45	18	26
DR4	2.6	10	1.3	8.7	6.3	14	3.1	10	18	25	8.9	16	71	78	35	42
DR5	1.9	11	0.94	10	4.5	14	2.2	11	13	22	6.4	16	51	60	25	34

30˚C, 6 amp pump

	D = 3/4 in				D = 5/8 in				D = 1/2 in				D = 3/8 in			
	12 V		10.8 V		12 V		10.8 V		12 V		10.8 V		12 V		10.8 V	
Station	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)	h_L(ft)	H (ft)
DRKR	1.3	10	0.62	9.6	3.0	12	1.5	10	8.6	18	4.2	13	34	43	17	26
DR1	1.1	11	0.53	10	2.6	12	1.3	11	7.4	17	3.6	13	29	39	14	24
DR2	2.7	11	1.3	9.3	6.4	14	3.1	11	18	26	9.1	17	72	80	36	44
DR3	1.1	8.4	0.56	7.9	2.7	10	1.3	8.6	7.8	15	3.8	11	31	38	15	22
DR4	2.2	9.6	1.1	8.5	5.1	13	2.5	10	15	22	7.3	15	58	65	29	36
DR5	1.6	11	0.77	10	3.7	13	1.8	11	11	20	5.3	14	42	51	21	30

0˚C, 4.5 amp pump

	D = 1/2 in				D = 3/8 in			
	12 V		10.8 V		12 V		10.8 V	
Station	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**
DRKR	5.5	15	3.1	12	22	31	12	21
DR1	4.7	15	2.7	12	19	28	11	20
DR2	12	20	6.7	15	46	54	26	34
DR3	5.0	12	2.8	10	20	27	11	18
DR4	9.5	17	5.4	13	37	45	21	28
DR5	6.8	16	3.9	13	27	36	15	24

30˚C, 4.5 amp pump

	D = 1/2 in				D = 3/8 in			
	12 V		10.8 V		12 V		10.8 V	
Station	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**	**h_L(ft)**	**H (ft)**
DRKR	4.5	14	2.6	12	18	27	10	19
DR1	3.9	14	2.2	12	15	25	9	18
DR2	9.7	18	5.5	13	38	46	22	30
DR3	4.1	11	2.3	9.6	16	23	9	16
DR4	7.7	15	4.4	12	30	38	17	25
DR5	5.6	15	3.2	12	22	31	12	22

Appendix B. Parts list

Item	Brand and Model	Part number	Vendor	Cost
Sensors				
SUNA	Satlantic		Satlantic	$18,000.00
SUNA flow cell	Satlantic		Satlantic	$350.00
SUNA power/telemetry cable (8 pin pigtail)	Satlantic		Satlantic	$225.00
SUNA carrying case	Satlantic		Satlantic	$250.00
YSI 600LS BCR-C-T-SV	YSI	600-12	YSI	$1,667.25
YSI 600 flow cell	YSI	696	YSI	$295.00
Vented cable, 25 ft	YSI	6191	YSI	$576.00
Adapter, DB-9/MS-8/Power	YSI	6095	YSI	$157.50
Adapter, Power, Flying Lead	YSI	6100	YSI	$76.50
Adapter, Field, Flying Lead	YSI	6096	YSI	$76.50
Conductivity calibration solution	YSI	60907	YSI	$122.00
Power				
30 Watt lightweight unbreakable solar panel		BSP3012-LSS	batterystuff.com	$260.00
10 Watt lightweight unbreakable solar panel		BSP1012-LSS	batterystuff.com	$108.00
Mounting bracket for 30 Watt panel		30LTHPM	batterystuff.com	$72.00
Mounting bracket for 10 Watt panel		10LTHPM	PowerUp	$35.69
Solar charge controller, 12V 6 amp	SunSaver	SS6-12V	batterystuff.com	$44.00
12 V 40 amp-hr gel battery	MK	M40SLDG	batterystuff.com	$189.00
Battery charger	Professional series 12 V 10 A 3 stage charger	INTPS1210	batterystuff.com	$159.00
Communication				
Raven XT	GPRS Modem G2263-CD	364188	Tessco	$292.50
Raven antenna - Dual band cellular/PCS antenna, magnetic mount.		AP85/18-M-S2	AntennaPlus	$90.00
Mounting bracket for Raven XT	Sierra Wireless part 100-170-1013	324142	Tessco	$20.00
Monthly phone service			AT&T	$15.00
Cable for modem connection-- CS I/O to 9 pin RS 232 DCE interface	Campbell Scientific	SC932A	Campbell Scientific	$88.31

Wiring				
CR10X modem, monthly rental	Campbell Scientific		USGS	$33.00
Relay, Solid state	CRYDOM D1D12	1DTL7	Grainger	$86.00
Double row terminal block, 4 POS 1		296-187	Home Depot	$4.97
Double row terminal block, 6 POS 1		296-748	Home Depot	$5.97
Wire connectors: 22-18 AWG Spade vinyl, Stud 8-10 100		299-850	Home Depot	$6.99
Wire, black, 16 AWG, 24 ft		710-914	Home Depot	$4.69
Wire, red, 16 AWG, 24 ft		710-797	Home Depot	$4.69
Wire, blue 16 AWG, 24 ft		710-900	Home Depot	$4.69
Electrical tape, 3/4" x 30 ft		225-835	Home Depot	$1.97
Heat-shrink tubing, 3/8" - 3/16"		542-415	Home Depot	$1.95
Heat-shrink tubing, 1/2" - 1/4"		542-458	Home Depot	$1.95
Aim-n-flame II		233-989	Home Depot	$2.78
Hydraulics				
12V Submersible Pump, 6 amp		P-Congo	Backwoods Solar Electric Systems Inc	$98.00
12V Submersible Pump, 5 amp		P-Amazon	Backwoods Solar Electric Systems Inc	$72.00
12V GP In-line water pump, 5 amp		GP1692	Global Water Supply	$68.00
Tygon tubing, 3/8 in, 50 ft, clear		2DCA3	Grainger	$123.00
Vinyl tubing, 1/2" OD, 3/8" ID x 10 ft		702-229	Home Depot	$4.15
Filter housing, 3/4" #12 222 Opaque w/ double plugs		PL-150512	Mar Cor Purification	$198.37
O ring for filter housing			Mar Cor Purification	$0.00
Mounting bracket, MC-1 Kit		285-81-005	Mar Cor Purification	$9.77
Filter, FP-02-10-A PP Pleated/12CS		276-13-501	Mar Cor Purification	$49.00
Couplings, 3/8" barb, 10 pack		3XUY7	Grainger	$3.56
Y connectors - Barbed Y, 3/8", 10 pack		3XVY2	Grainger	$23.60
Hose clamps, #006 SS clamp, 3/8" x 7/8" dia, 10 pack		602-044	Home Depot	$7.00
Hose clamps, #036 SS clamp, 1-3/4" x 2-3/4" dia, 10 pack		602-048	Home Depot	$9.70

Enclosure				
Hoffman box, 30" x 30"x 12"	Hinge cover, medium, Type 3R (contractor)	A30R3012 HCR	Hoffman http://www.hoffmanonline.com	$753.60
Grounding rod, copper 5/8" x 8 ft		687-685	Home Depot	$8.97
Grounding rod wire, 8 stranded THHN green, 10 ft		799-637	Home Depot	$4.50
Grounding rod clamp, 1/2" bronze		293-795	Home Depot	$2.00
Galvanized pipe: 2" EMT conduit x 10'		580-031	Home Depot	$13.96
Concrete, Fast Set Sakrete 50 lb		370-328	Home Depot	$4.98
Padlock, High security		7102002	USGS HIF	$11.00
Great Stuff, Gaps & Cracks, 16 oz		507-765	Home Depot	$3.98
Construction materials				
PVC pipe material 1-1/2" x 10' PVC40 PE solidcore pipe		193-844	Home Depot	$3.73
Cap, 2" slip		232-777	Home Depot	$0.98
Elbows, 1-1/2" PVC 90° SXS		294-101	Home Depot	$1.21
Elbows, 1-1/2" PVC 90° long sweep		189-502	Home Depot	$1.98
Elbows, 1-1/2", PVC 22.5° HXH		641-344	Home Depot	$1.36
2" x 1-1/2" DWV reducer/increaser HXH		472-476	Home Depot	$1.21
2" DWV female adapter HXFPT		189-170	Home Depot	$1.66
2" DWV male adapter HXMPT		189-138	Home Depot	$1.27
2" x 2' PVC-PW/DWV SCH40 pipe		276-902	Home Depot	$3.36
PVC primer, 8 oz		391-417	Home Depot	$4.73
PVC cement, 8 oz		543-570	Home Depot	$5.64
Zip ties				
14" natural cable tie 10 pk		295-455	Home Depot	$1.69
200 PC garden cable tie tube		777-609	Home Depot	$4.99
Copper screening (100 mesh)	12"x12" sheet of 100 x 100 copper mesh	9224T87	McMaster Carr	$9.05
Rebar, 1/2" x 4 ft		274-356	Home Depot	$2.65
Cage				
Plywood, 15/32" or 1/2", 2 ft x 2 ft		300-888	Home Depot	$5.41
Flat slotted galvanized metal, xx ft?			Home Depot	$6.51

Angle slotted galvanized metal, xx ft		Home Depot	$9.43
Hex nuts, 3/8 "	655-449	Home Depot	$0.11
Hex bolts, 3/8"		Home Depot	$0.18
Cut washers, 3/8"	655-570	Home Depot	$0.13
Plywood, 15/32" or /2", 2 ft x 4 ft	300-896	Home Depot	$9.72
Wood screws for attaching relays, ravens to plywood: FH-PH 6 x 3/4"	251-356	Home Depot	$3.77
Wood screws for attaching terminal connectors to plywood: FH-PH 6 x 1"	251-380	Home Depot	$3.97
Shims, pack	879-282	Home Depot	$1.35

Appendix C. Program for CR10X datalogger.

This program was written by Bill Davies of USGS and modified by Julia Miller and Jason VerHoef of UMBC. The program is intended for use with some or all of the sensors listed to the left.

This list shows the channels on the CR10x for the various sensors.

```
;{CR10X}
;William J Davies, USGS
;09/03/10
;
;wiring:
;P1  Rain Gage 1
;P2  Rain Gage 2
;C1  Stage SDI-12
;C2  YSI SDI-12
;C3  Suna SDI-12
;C4  Suna Control
;C5  Pump Control

;Subroutines:
;1  subroutine to turn on pump, turn on Suna, measure Suna, measure YSI
;   turn off pump, turn off Suna
;2  Measure stage
```

There are two main subroutines in the program.

Array ID 300 is assigned to the Accububble; 200 is for the YSI; and SUNA; 100 is for the tipping bucket rain gage.

```
;Data Output
;Array ID 300 (****Julia and Mike switch on 9/27/10)
;Day of the year
;time
;stage
;Battery Voltage

;Array ID 200
;Day of the year
;time
;temperature
;SC
;Nitrate (mg/L)

;Array ID 100 (****Julia and Mike switched on 9/27/10 so all rain gauge data had an
Array ID of 100)
;year
;day
;time (hhmm)
;time (sec)
;Rain gage 1 (tips)
;Rain gage 2 (tips)
```

```
*Table 1 Program
 01: 2        Execution Interval (seconds)
;**** On 9/29/10 changed execution interval was 30 seconds change to 2 seconds since
this is what the current rain gauge program has
;If flag 1 is low, reset everything to defaults
;This will set default values if there is a temp power
loss.
1:  If Flag/Port (P91)
 1: 21       Do if Flag 1 is Low
 2: 9        Call Subroutine 9
```

01 is the execution interval command; 2 seconds is the recording interval for precipitation. We expect to get no more than 1 tip in 2 seconds – this serves as a flag for QA/QC.

```
2:  Batt Voltage (P10) ;measure battery volts
 1: 3        Loc [ Batt_Volt ]
;**** On 9/29/10 changed multiplier from 1 to .01 since this is how it is in the old
program
3:  Pulse (P3) ;Read rain gages
 1: 2        Reps
 2: 1        Pulse Channel 1
 3: 2        Switch Closure, All Counts
 4: 22       Loc [ Rain_1    ]
 5: .01      Multiplier
 6: 0.0      Offset
```

For the rain gage, the multiplier (slope) chosen is 0.01, referring to 1 tip = 0.01 inches of rainfall. The offset is the y intercept, which is zero for our case.

```
;sum the 2 rain gages so when we do the <> comparison
;we see if either gage tipped. I'm always nervous about doing
;= or <> comparisons with floating point numbers so leave rain as
;integer (tips). Multiply by .01 before storage
4:  Z=X+Y (P33)
 1: 22       X Loc [ Rain_1    ]
 2: 23       Y Loc [ Rain_2    ]
 3: 24       Z Loc [ Rain_Sum  ]

5:  If (X<=>F) (P89)
 1: 24       X Loc [ Rain_Sum  ]
 2: 2        <>
 3: 0        F
 4: 30       Then Do
;*******On 9/29/10 took out P37 which Bill had because other program did not have
this
    6:  Do (P86)
     1: 10       Set Output Flag High (Flag 0)
;******On 9/27/10 Julia changed Array ID here to 100 was previously 300
    7:  Set Active Storage Area (P80)^5717
```

This sums the values of precipitation at the two rain gages. If either rain gage has tipped, the value is recorded. This avoids recording zeros for periods of no rain.

1: 1   Final Storage Area 1
2: 100   Array ID

8: Real Time (P77)^2212
1: 1111   Year,Day,Hour/Minute,Seconds (midnight = 0000)

9: Sample (P70)^31631
1: 2   Reps
2: 22   Loc [Rain_1   ]

> "reps" refers to the number of rain gages for which to carry out the same commands, in this case 2.

10: End (P95)

;Measure stage and record every 5 min
;*****On 9/27/10 Julia changed to every 5 minutes was every 15
11: If time is (P92)
1: 0   Minutes (Seconds --) into a
2: 5   Interval (same units as above)
3: 2   Call Subroutine 2

> This is an instruction to record the stage at zero (defined as on the hour) and every 5 minutes using subroutine 2.

;Measure Suna every 30 minutes, on the hour and half hour. We can change this code later to allow changing
;the measurement interval without having to re-program
12: If time is (P92)
1: 0   Minutes (Seconds --) into a
2: 30   Interval (same units as above)
3: 1   Call Subroutine 1

> This is an instruction to record SUNA data at 0 (start) and 30 minutes after 0. This can be changed remotely as desired.

;*** Julia added on 9/39/10 taken from Bill's program Rain_SDI_V3
;totalize tips on rain gage 1
;From my understanding this is just so tips can be read when connected to the datalogger without downloading data
13: Z=X+Y (P33)
1: 25   X Loc [Rain_tot1]
2: 22   Y Loc [Rain_1   ]
3: 25   Z Loc [Rain_tot1]

; totalize tips on rain gage 2
14: Z=X+Y (P33)
1: 26   X Loc [Rain_tot2]
2: 23   Y Loc [Rain_2   ]
3: 26   Z Loc [Rain_tot2]

```
*Table 2 Program
 02: 0.0000    Execution Interval (seconds)

*Table 3 Subroutines

1:  Beginning of Subroutine (P85)
 1: 1       Subroutine 1
;Subroutine to turn on Suna, pause Sna_secON seconds,
;turn on pump, pause Pmp_secON seconds,
;take a measurement and then turn off pump and Suna.
;Suna is on for (Sna_secON + Pmp_secON) seconds
;Pump is on for Pmp_secON seconds.

   2:  Z=F x 10^n (P30) ;Zero Suna counter
    1: 0       F
    2: 00      n, Exponent of 10
    3: 17      Z Loc [ Sna_count ]

   3:  Z=F x 10^n (P30) ;Zero pump counter
    1: 0       F
    2: 00      n, Exponent of 10
    3: 20      Z Loc [ Pmp_count ]


   4:  Set Port(s) (P20) ;Turn pump ON
    1: 9991    C8..C5 = nc/nc/nc/high
    2: 9999    C4..C1 = nc/nc/nc/nc

;This loop executes once per second. It exits when Pmp_count >= Pmp_secON
   5:  Beginning of Loop (P87) ;Delay to run pump before taking measurement
    1: 0       Delay
    2: 0       Loop Count

      6:  Excitation with Delay (P22)
       1: 1       Ex Channel
       2: 0       Delay W/Ex (0.01 sec units)
       3: 100     Delay After Ex (0.01 sec units)
       4: 0       mV Excitation

      7:  Z=Z+1 (P32)
       1: 20      Z Loc [ Pmp_count ]
```

17 is the location we chose for the SUNA elapsed time (count); 20 is the location for the pump elapsed time (count).

C5 is the channel location for the relay that drives the pump.

The datalogger programming requires a finite delay to be specified for the excitation channel to become active. The pump stays on for a specified amount of time before SUNA is switched on.

```
 8:  If (X<=>Y) (P88)
  1: 20       X Loc [ Pmp_count ]
  2: 3        >=
  3: 19       Y Loc [ Pmp_secON ]
  4: 31       Exit Loop if True

9:  End (P95)

10:  Set Port(s) (P20) ;Turn Suna ON
 1: 9999    C8..C5 = nc/nc/nc/nc
 2: 1999    C4..C1 = high/nc/nc/nc
```

nc=no change to c5 (pump stays on); c4 is the channel where the relay is connected that turns on the SUNA.

```
;This loop executes once per second. It exits when Sna_count >= Sna_secON
 11:  Beginning of Loop (P87)
  1: 0       Delay
  2: 0       Loop Count
```

Again a delay is required to turn on the SUNA.

```
   12:  Excitation with Delay (P22)
    1: 1       Ex Channel
    2: 0       Delay W/Ex (0.01 sec units)
    3: 100     Delay After Ex (0.01 sec units)
    4: 0       mV Excitation

   13:  Z=Z+1 (P32)
    1: 17      Z Loc [ Sna_count ]


   14:  If (X<=>Y) (P88)
    1: 17      X Loc [ Sna_count ]
    2: 3       >=
    3: 16      Y Loc [ Sna_secON ]
    4: 31      Exit Loop if True

 15:  End (P95)


 ;set default values to -7 (if no comms first val is -6999)
 16:  Beginning of Loop (P87)
  1: 0       Delay
  2: 3       Loop Count

   17:  Z=F x 10^n (P30)
    1: -7      F
```

-7 is a flag set to mean no communication between SUNA and datalogger. The default value is -6999; we changed this to -7.

```
      2: 0       n, Exponent of 10
      3: 12    -- Z Loc [ Sna_N_mgL ]

   18:  End (P95)

;Measure Suna - returns NO3 in micro moles, NO3 mg/L,
   ;Avg Spectrum, Dark frame value
   19:  SDI-12 Recorder (P105)
    1: 0       SDI-12 Address
    2: 0       Start Measurement (aM!)
    3: 3       Port
    4: 11       Loc [ Sna_N_mM  ]
    5: 1.0      Multiplier
    6: 0.0      Offset
```

0 is the SDI address for the SUNA; the SUNA measures 4 parameters starting with NO3 in micromoles.

```
;Measure YSI
   20:  Z=F x 10^n (P30) ;Set SC to default value of -7
    1: -7       F
    2: 00       n, Exponent of 10
    3: 8       Z Loc [ YSI_SC    ]
```

-7 again is the flag for no communication.

```
   21:  SDI-12 Recorder (P105)
    1: 0       SDI-12 Address
    2: 0       Start Measurement (aM!)
    3: 2       Port
    4: 7       Loc [ YSI_Temp  ]
    5: 1.0      Multiplier
    6: 0.0      Offset
```

0 is the SDI address for the YSI; YSI measures 2 parameters starting temperature (we only selected these 2 parameters within YSI Ecowatch).

```
   22:  If (X<=>F) (P89) ;if no coms from YSI set Temp to -7 default value
    1: 7       X Loc [ YSI_Temp  ]
    2: 4       <
    3: -100     F
    4: 30       Then Do

      23:  Z=F x 10^n (P30)
       1: -7       F
       2: 00       n, Exponent of 10
       3: 7       Z Loc [ YSI_Temp  ]

   24:  End (P95)
```

```
;Turn OFF Suna and Pump
   25:  Set Port(s) (P20) ;Turn Pump and Suna OFF
    1: 9990     C8..C5 = nc/nc/nc/low
    2: 0999     C4..C1 = low/nc/nc/nc

;Store Suna and YSI Data
   26:  Do (P86)
    1: 10       Set Output Flag High (Flag 0)

   27:  Set Active Storage Area (P80)^31535
    1: 1        Final Storage Area 1
    2: 200   -- Array ID
;***** On 9/27/10 Julia changed time to include year
;******** On10/08/10 Jason changed to allow SUNA to be high resolution
   28:  Real Time (P77)^311
    1: 1110     Year,Day,Hour/Minute (midnight = 0000)

   29:  Sample (P70)^7133
    1: 1        Reps
    2: 7        Loc [ YSI_Temp  ]

   30:  Resolution (P78)
    1: 1        High Resolution

   31:  Sample (P70)^2817
    1: 1        Reps
    2: 8        Loc [ YSI_SC    ]

   32:  Sample (P70)^9486
    1: 1        Reps
    2: 12       Loc [ Sna_N_mgL ]

   33:  Do (P86)
    1: 20       Set Output Flag Low (Flag 0)

34:  End (P95) ;End Subroutine


35:  Beginning of Subroutine (P85)
 1: 2        Subroutine 2
    ;subroutine to measure the stage and YSI

;measure stage
```

C5 and C4 are now both changed to low to turn off pump and SUNA.

Temp is stored at low resolution (default);

SC is stored at high resolution but this is not necessary.

Of the SUNA data collected, only NO3 mg/L is stored.

36: SDI-12 Recorder (P105) ;measure accububbler stage
 1: 0   SDI-12 Address
 2: 0   Start Measurement (aM!)
 3: 1   Port
 4: 4   Loc [Abb_stage]
 5: 1.0   Multiplier
 6: 0.0   Offset

;save stage
37: Do (P86)
 1: 10   Set Output Flag High (Flag 0)
;*****Julia changed array ID from 100 to 300 here on 9/27/10 so the rain gauge data could use the array id 100
38: Set Active Storage Area (P80)^22962
 1: 1   Final Storage Area 1
 2: 300   Array ID
;*****On 9/27/10 Julia changed time to include year
39: Real Time (P77)^26036
 1: 1110   Year,Day,Hour/Minute (midnight = 0000)

40: Sample (P70)^28326
 1: 1   Reps
 2: 4   Loc [Abb_stage]

41: Sample (P70)^25135
 1: 1   Reps
 2: 3   Loc [Batt_Volt]

42: Do (P86)
 1: 20   Set Output Flag Low (Flag 0)

43: End (P95) ;End Subroutine

44: Beginning of Subroutine (P85) ;
1: 9   Subroutine 9
;subroutine to load default values

45: Do (P86)
 1: 11   Set Flag 1 High

46: Z=F x 10^n (P30) ;default station ID

```
    1: 9000     F
    2: 00       n, Exponent of 10
    3: 1        Z Loc [ Sta_ID    ]

   ;Default Suna warmup time is number of seconds in Sna_secON + the number of
seconds
   ;in the pump warm up time variable (Pmp_secON)
   ;So the total on time for the suna before a measurement is (Sna_secON +
Pmp_secON) seconds
   47:  Z=F x 10^n (P30)
    1: 15       F
    2: 00       n, Exponent of 10
    3: 16       Z Loc [ Sna_secON ]

   ;Pump warm up time in seconds******Jason changed F to 50s
   48:  Z=F x 10^n (P30) ;Default pump purge time in seconds
    1: 50       F
    2: 00       n, Exponent of 10
    3: 19       Z Loc [ Pmp_secON ]

   49:  Set Port(s) (P20)
    1: 9997     C8..C5 = nc/nc/nc/output
    2: 7999     C4..C1 = output/nc/nc/nc
```

This command outputs the voltage to turn the relays on.

```
50:  End (P95) ;End Subroutine


51:  Beginning of Subroutine (P85)
 1: 98       Subroutine 98
;***** Julia added on 9/30/0
;subroutine to do the SDI-12 sensor thing as Bill says in Rain_SDI_V3
;Has to be subroutine 98
;Basically allows tips to be seen when connected to the datalogger without downloading
data

   52:  SDI-12 Sensor (P106)
    1: 1        SDI-12 Address
    2: 0204     Time/Values
    3: 27       Loc [ Rain_sdi1 ]
;put rain totals into locations for SDI-12 output

   53:  Z=X (P31)
    1: 25       X Loc [ Rain_tot1 ]
```

```
 2: 27      Z Loc [ Rain_sdi1 ]

54:  Z=X+Y (P33)
 1: 25      X Loc [ Rain_tot1 ]
 2: 29      Y Loc [ RnSDITot1 ]
 3: 29      Z Loc [ RnSDITot1 ]

55:  Z=X (P31)
 1: 26      X Loc [ Rain_tot2 ]
 2: 28      Z Loc [ Rain_sdi2 ]

56:  Z=X+Y (P33)
 1: 26      X Loc [ Rain_tot2 ]
 2: 30      Y Loc [ RnSDITot2 ]
 3: 30      Z Loc [ RnSDITot2 ]

;rezero totalizers

57:  Z=F x 10^n (P30)
 1: 0.0     F
 2: 00      n, Exponent of 10
 3: 25      Z Loc [ Rain_tot1 ]

58:  Z=F x 10^n (P30)
 1: 0.0     F
 2: 00      n, Exponent of 10
 3: 26      Z Loc [ Rain_tot2 ]

59:  End (P95)


End Program

-Input Locations-
1 Sta_ID    1 0 1
2 Version   0 0 0
3 Batt_Volt 1 1 1
4 Abb_stage 1 1 1
5 Abb_units 0 0 0
6 _________ 0 0 0
7 YSI_Temp  1 2 2
8 YSI_SC    1 1 1
9 YSI_Stage 1 0 0
```

10 __________ 0 0 0
11 Sna_N_mM 1 0 1
12 Sna_N_mgL 1 1 1
13 Sna_avg_S 0 0 0
14 Sna_dark 0 0 0
15 __________ 1 0 0
16 Sna_secON 1 1 1
17 Sna_count 1 1 2
18 __________ 0 0 0
19 Pmp_secON 1 1 1
20 Pmp_count 1 1 2
21 __________ 0 0 0
22 Rain_1   5 3 1
23 Rain_2   17 3 1
24 Rain_Sum 1 1 1
25 Rain_tot1 1 3 2
26 Rain_tot2 1 3 2
27 Rain_sdi1 1 1 1
28 Rain_sdi2 1 0 1
29 RnSDITot1 1 1 1
30 RnSDITot2 1 1 1
31 __________ 0 0 0
32 __________ 0 0 0
33 __________ 0 0 0
34 __________ 0 0 0
35 __________ 0 0 0
36 __________ 0 0 0
37 __________ 0 0 0
38 __________ 0 0 0
39 __________ 0 0 0
40 __________ 0 0 0
41 __________ 0 0 0
-Program Security-
0000
0000
0000
-Mode 4-
-Final Storage Area 2-
0
-CR10X ID-
0
-CR10X Power Up-
3

-CR10X Compile Setting-
3
-CR10X RS-232 Setting-
-1
-DLD File Labels-
0
-Final Storage Labels-
0,100,5717
1,Year_RTM,2212
1,Day_RTM
1,Hour_Minute_RTM
1,Seconds_RTM
2,Rain_1~22,31631
2,Rain_2~23
3,200,31535
4,Year_RTM,311
4,Day_RTM
4,Hour_Minute_RTM
5,YSI_Temp~7,7133
6,YSI_SC~8,2817
7,Sna_N_mgL~12,9486
8,300,22962
9,Year_RTM,26036
9,Day_RTM
9,Hour_Minute_RTM
10,Abb_stage~4,28326
11,Batt_Volt~3,25135
