Nearshore Water Quality Monitoring Buoy at Lake Tahoe

Brian Fitzgerald
Richard B. Susfalk
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January 2012

Prepared by
Desert Research Institute, Reno, NV

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1.0 INTRODUCTION

Lake Tahoe is a unique environment that has been designated an “Outstanding National Water Resource” by the U.S. Environmental Protection Agency because of its ecological assets, its scenic characteristics, and the recreational opportunities that it provides. Of particular concern to resource management agencies is the fact that optical clarity of Lake Tahoe has decreased significantly during the last four decades. This is largely the result of an accumulation of fine sediment particles in the lake from watershed runoff and atmospheric deposition (Byron and Goldman, 1986; Goldman et al., 1993; Jassby et al., 1999) and increased algal growth from greater nutrient inputs. Historically, research has been directed towards quantifying and understanding the sources of sediment and nutrient loads from watersheds, as well as the impacts that these pollutants have on mid-lake clarity. However, the processes that link on-shore nutrient and sediment sources with mid-lake clarity through the nearshore zone are not yet well understood (Reuter and Miller, 2000).

Nearshore clarity degradation is easily visible to visitors and residents because of its shallow depth and proximity to the shoreline. Maintaining an excellent nearshore environmental quality is critical for tourism, as the nearshore zone is where most visitors directly interact with the lake. Stakeholders may experience poor environmental conditions such as slippery rocks from periphyton growth, the clogging of marinas by milfoil, or water that has turned green in color.

The clarity of water in Lake Tahoe’s nearshore zone is an important issue as: 1) it is where most residents and visitors come close enough to the lake to observe its clarity; 2) all clarity reducing materials (i.e., nutrients and sediments), except for those entering by atmospheric deposition, must pass through the nearshore zone; and 3) the concentration of clarity-degrading constituents are greatest in the nearshore zone before subsequent dilution and mixing with cleaner mid-lake water. Additionally, the nearshore zone tends to respond quickly to changes in on-shore processes and disturbances, suggesting that it is the logical place to assess the impacts of localized on-shore events (e.g., variable stream flows, urban runoff events, BMP implementation, and watershed restoration activities).

Processes affecting Lake Tahoe’s nearshore environment are complex, as the nearshore supports abundant aquatic life and integrates inputs from on-shore activities (e.g., urban runoff) with the mixing of deeper lake waters. The ecological quality of the nearshore has also responded to anthropogenic activities, evidenced by changes in periphyton and the habitat for native fish species. New challenges to nearshore water quality are increasing with the colonization of the nearshore by invasive species such as Eurasian watermilfoil (*Myriophyllum spicatum*), largemouth bass (*Micropterus salmoides),* bluegill (*Lepomis macrochirus),* and Asian clam (*Corbicula fluminea*).

Historically, the nearshore environment has received less research and management attention than the pelagic lake zone, where long-term trends in clarity loss, increased algal productivity and pollutant loading have been evident. Without an effective and coordinated monitoring program, the response of the nearshore quality to the Tahoe Environmental Improvement Program (EIP) projects and Total Maximum Daily Load (TMDL) efforts, or the consequences of the establishment of invasive species will remain poorly understood. Previous investigations of nearshore water clarity have shown a distinct association between elevated nearshore turbidity and some developed areas (Taylor et al., 2004, Susfalk and Fitzgerald, 2011). This work quantified nearshore turbidity on both basin-wide and local (e.g., South Lake Tahoe) scales by employing lake perimeter surveys of turbidity and chlorophyll fluorescence. Nearshore turbidity was principally elevated during runoff associated with low-elevation snowmelt and precipitation events. In addition, the Tahoe Regional Planning Agency (TRPA) monitored water clarity through its Littoral Zone Turbidity Monitoring Program at several sites around the lake. This program, however, was not well suited for identifying trends in the nearshore zone as samples were taken offshore in 30 meter deep water may not necessarily reflect nearshore conditions, temporally or spatially. Both of these monitoring approaches provide a “snapshot” of nearshore conditions when trained personnel are out on the lake taking measurements. Neither has been successful in quantifying long-term trends because they only collected data several times throughout the year.

An alternative approach to monitoring the nearshore is to utilize an unattended buoy-based system. This approach provides the ability to collect near-continuous water clarity data at specific locations to observe short- and long-term trends. Among other uses, data from a buoy-based system could be used to: 1) support the development and/or monitoring of nearshore clarity thresholds, or a Total Maximum Daily Load (TMDL), which may contribute to nearshore water clarity; 2) assess the impact that restoration activities and/or BMPs have on water quality entering the lake; 3) provide data on how water-based activities such as marina dredging and/or boating impact the nearshore, either for research efforts or compliance, 4) improve our understanding of the importance of the nearshore zone through the development of mechanistic links between on-shore, nearshore, and mid-lake processes, and 5) facilitate interpretation of invasive species movement, growth, and durability for ecologists studying algae, crayfish, and warm-water fish . In 2008, the Nevada Division of State Lands (NDSL) previously funded the development of a buoy-based system to continuously monitor nearshore water quality parameters.

1.1 Previous Lake Tahoe Buoy Study

The objective of this proof-of-concept study was to demonstrate the deployment, operation, and cost of operating a nearshore monitoring platform. Specific issues related to deploying a nearshore buoy at Lake Tahoe included an unconventional sensor package capable of measuring Lake Tahoe's pristine water quality and aesthetic appearance, while requiring a small visual footprint.

In 2008, the buoy was located in Crystal Bay at Incline Village, NV, near the adjacent outfalls of Third Creek and Incline Creek. Results from the pilot study showed that near-shore water clarity declined in response to the delivery of suspended sediments, mobilized by snowmelt and rain events, from adjacent creeks (Susfalk et al., 2009). This decline was measured as increased turbidity and as decreased light transmission. Both clarity-measuring optical techniques were successful at quantifying these event-induced clarity reductions. There were some operational problems in 2008, such as: biofouling of sensors, destruction of wind sensors, and lack of depth-profiling, discussed further in Section 2.0. The buoy project presented here was conducted in 2010-2011 and addressed shortcomings of the initial project.

1.2 Purpose

Basin managers, through the Nearshore Agency Working Group (NAWG), are currently developing a framework by which to manage Lake Tahoe's nearshore zone. The U.S. Forest Service, through the Southern Nevada Public Land Management Act (SNPLMA) program, has also funded a Directed Action to assess current nearshore standards, to suggest scientifically-supportable standards and indicators, to develop a nearshore conceptual model, and to suggest a future monitoring plan. This is being conducted by researchers at the Desert Research Institute (DRI), the University of Nevada, Reno (UNR), and the University of California, Davis, collectively known as the Nearshore Science Team (NeST). First-hand knowledge of the challenges in developing and maintaining small nearshore monitoring buoys for long-term monitoring will contribute to these on-going efforts.

The main purpose of the 2010 buoy project was to address several practical questions pertaining to the construction, operation, maintenance, and usefulness of a nearshore water clarity buoy. Specifically, there were three main objectives:

1. Monitor environmental conditions for a full year. The previous, pilot study was only conducted from May to October 2008 and did not include a winter period that presents several additional operational challenges compared to summer operations.
2. Test a new, active anti-biofouling design. The pilot study found that biofouling was primarily a summertime issue, but that some sensors such as light transmissivity, were susceptible to biofouling within 7 to 10 days when using simple, passive anti-biofouling approaches.

3. Increase the ecological significance of monitoring through the addition of monitoring temperatures at several depths, and augmentation of the sample collection system so that water collected from several depths can be analyzed. The pilot study was limited to analysis of water at only one depth near the surface. Although these additions seem relatively simple, they significantly increased the complexity of buoy operations.

These objectives were addressed through modifications to and operation of the nearshore buoy placed in Lake Tahoe's nearshore zone between August 2010 and June 2011. Together, the previous 2008 pilot project and this 2010 project provide managers with more practical information that they can use to assess the feasibility of a long-term nearshore monitoring program, such as: 1) the costs associated with developing, deploying, and operating nearshore buoys under seasonal conditions; 2) the quality of data that can be expected in different seasons; 3) practical issues that affect year-around operation, and; 4) potential impacts and solutions to the biofouling "problem." Conducting these initial studies will provide important information to the NeST and NAWG groups in the development and implementation of a long-term monitoring program for the nearshore. These groups may choose to implement TMDL, standards, and indicators for water clarity parameters in the nearshore of Lake Tahoe, where this buoy technology may be implemented for monitoring in the future.

2.0 NEARSHORE MONITORING BUOY

The first consideration of this project was to address the problems that arose during the pilot deployment in 2008, including excessive biofouling, lack of depth profile measurements, and problems created by wind speed and wave action. For 2008, we expected a degree of biofouling based on the literature and field observation of substrates. Attempts to address the problem using a passive anti-biofouling system were somewhat successful (Susfalk et al., 2009). The next issue involved wind and wave action from strong storms damaging sensors such as the anemometer. Another issue during the 2008 study was recreational traffic disturbances; its location adjacent to both a boat ramp and swimming beach meant that curious swimmers and boating traffic may have unintentionally disturbed the buoy. The heavy nearby traffic could have stirred up substrate sediments and affected readings. Depth profiling of measurements would have enhanced the scientific utility of the buoy, improving understanding of mixing and layering of temperature and clarity-reducing materials.

To minimize costs, we chose to use the same buoy/flotation platform as developed for the 2008 deployment. Commercial buoy systems typically sold for marine use were originally thought to be too large for use in Lake Tahoe's nearshore zone, were cost-prohibitive, would attract too much attention from boaters, and would cause an unsightly visual impact from shore. In the intervening years, a couple of small, commercial buoy systems have been introduced for fresh water monitoring. These systems can also be cost-prohibitive, do not support a range of sensors that can be used for both ecological and water clarity measurements, and do not include sensors with the necessary specifications to assess Lake Tahoe's pristine water clarity. Although the 2008 version of the buoy was developed with ample space to mount sensors, the added infrastructure of the 2010 version made it difficult to mount and maintain all the equipment on this platform. Specific benefits in utilizing the existing buoy included:

Sensor types.

There was little or no opportunity to choose the sensors that were included in commercial multi-parameter probe sondes and buoys. For example, none of these systems included a light transmissometer, a sensor that has previously been shown to be superior for water clarity measurements in Lake Tahoe (Taylor et al., 2004). Pre-packaged commercial buoy systems are typically based on vendor proprietary data logging systems that may either not be capable of interfacing with or have enough capacity to support additional sensors.

Specification of the model and manufacturer of the on-board sensors.

Where possible, we wanted to use the same sensor manufacturers and models that had been used for previous and ongoing research in the Lake Tahoe Basin. The use of the alternative sensors would have needed to be individually evaluated for their use in Lake Tahoe. Lastly, the investigators already had most of the required sensors on-hand, thereby significantly reducing the cost devoted to purchasing new equipment.

Expandable data logging and telemetry systems.

The use of an expandable data logging system provided us with the ability to add telemetry that provided real-time access to the data as well as the ability to reprogram the buoy from the shoreline or office. The data loggers contained in commercial buoys tend to be much less flexible regarding the ability to make operational changes. In addition, remote telemetry was not a standard option on all the commercial systems.

2.1 Buoy Construction, Sensors, and Electronics

The buoy platform was based on a closed cell Softlite ionomer foam float (Gilman Corporation). An equipment cage for mounting the water clarity sensors was positioned underneath the float while an electronics compartment was mounted on top of the float (Figure 1). The cage and electronic compartment were constructed from aluminum alloy 6061 and welded together with a mig welder.

Figure 1. Structural portion of the buoy without sensors or sensor mounts.

The following sensors and equipment were installed on the buoy:

Light Transmissometer.

Light transmittance is an optical property that characterizes how much light is attenuated, or reduced, as it travels through water. Attenuation is caused by two inherent optical properties of water: the absorption and scattering of light. Absorption occurs when particles and dissolved material in the water absorb light. Scattering occurs when particles in water deflect light in a direction that is different from the incoming light. Transmissometers are a preferred “clarity” measurement as they are not influenced by changes in the natural lighting or surface conditions such as with Secchi depths and they do not suffer from the instrumentation issues that plague turbidimeters. Light transmittance is reported as the percentage of light that remains after the light has traveled a specified distance through water. A WETLabs (Philomath, OR) C-star Light Transmissometer was installed on the buoy.

Turbidimeter.

Turbidity measurements are a specific class of scattering measurements, expressed in nephelometric turbidity units (NTU). If done in accordance with EPA method 180.1, turbidity measurements must use white light (e.g., comprised of many colors of light) and the scattered light must be measured at 90^{o} to the incoming light beam. The EPA method is not used in submersible, battery-powered turbidimeters. Instead, these instruments typically use a single-color infrared diode (IRD) and measure scattering at greater angles, such as 140 to 160°. Model-specific differences in how turbidity is quantified result in differing sensitivities in several factors including the color of water, presence of infrared-absorbing dissolved matter, particle size, particle shape, and sediment concentration and composition. Therefore, caution must be utilized when comparing turbidity between two different meters, especially between bench top units that follow EPA 180.1 and submersible turbidimeters (Lewis et al., 2007). The inclusion of the turbidity measurement provides a direct comparison to in-stream turbidity measurements as well as being consistent with regulatory agencies that have historically used turbidity measurements in the shallow waters of Lake Tahoe. However, turbidity measurements are not necessarily well suited for Lake Tahoe clarity measurements; a result of the difficulty of obtaining reproducible measurements under the low, background conditions typical of the lake's pristine water clarity. One submersible DTS-12 turbidimeter (FTS Incorporated, Victoria, Canada) was installed on the buoy for this study, as opposed to the pilot study of 2008 that employed two turbidimeters.

Relative Chlorophyll Fluorescence.

Fluorescence is an inherent optical property of water that occurs when water is illuminated with light of one color and then emits, or fluoresces, light of a different color. Fluorescence can be used to measure the concentration of chlorophyll in the water. To determine the relative chlorophyll concentration in a water sample, the sample is illuminated with blue light and the amount of red light that is emitted, which is proportional to the amount of chlorophyll in the water, is measured. The relationship between the amount of fluorescence and the chlorophyll concentration partially depends on the algal species that contains the chlorophyll. Fluorescence was measured using a WETLabs Chlorophyll Fluorescence WETSTAR. However, the internal cuvette was shattered early on in the 2008 project during a storm, submerging the internal electronics and destroying the sensor. For 2010, we purchased a new WETSTAR.

Global Positioning Satellite (GPS) Receiver.

A Garmin GPS16-HVS was installed in order to provide the latitude and longitude coordinates of the buoy. This was included so that the buoy's location could be determined through telemetry if it broke free of its moorings. An alarm warning feature was established in the datalogger program that would alert personnel of any significant changes in the location of the buoy.

Water Temperature.

Water temperature was measured by a string of thermocouples at 0.23, 0.46, and 0.92 meters below the water surface. Temperature was also measured by an integrated sensor within the DTS-12 turbidity sensor, at approximately 0.46 meters depth.

Data Logging and Telemetry.

A CR1000 (Campbell Scientific, Logan, UT) was used to operate the buoy and record data. The buoy was outfitted with a 900 Mhz RF400 (Campbell Scientific) radio, and a Raven cellular modem (AirLink, Fremont, CA) for telemetry. The 900 Mhz radio was used primarily for shore-to-buoy communications during maintenance whereas the cellular modem was used for the automated transfer of data back to DRI's data servers as often as once per hour.

2.1.1 Water Clarity Measurements

Water clarity was assessed using both a light transmissometer and a turbidimeter. The transmissometer measured both the absorption and scattering of visible light in the blue wavelength as light traveled through a straight line (0°) in the water. Units were reported as the percentage of light that remains after absorption and scattering. Therefore, light transmission decreased as water clarity became degraded. Previous work by Taylor et al. (2004) has indicated that there appears to be a straightforward relationship between light transmission and clarity as measured by Secchi depth.

Turbidity will increase as water clarity becomes degraded and the relationship between turbidity and Secchi depth appears to be non-linear (Susfalk et al., 2009). Furthermore, Susfalk et al found turbidity to be relatively insensitive to the degradation of excellent water clarity (turbidity <1 NTU) compared to light transmission. Light transmission was a better surrogate for water clarity as it measures both light adsorption and scattering within a visible wavelength and has a more linear relationship with Secchi depth

2.2 Assembly and Other Improvements from Pilot Study.

There were special considerations for space while arranging the buoy instruments on the 2010 version of the buoy to fulfill the new depth profiling and anti-biofouling objectives. Total battery capacity was increased from one large battery of 26 amp-hours to four smaller batteries of 52 amp-hours in order to equally distribute their weight and to fit into the existing aluminum electronics enclosure on top of the buoy (discussed further in section 2.2.3). New solenoid valves, rigid-walled bladders, and a second pump were added to the underwater cage in order to enable multi-depth sampling and for the biofouling treatment system. Any future buoy deployments should allow for expanded underwater cage space for these new functionalities, as this configuration provided minimal space for configuring and maintaining the sensors. In a cost-saving measure, automotive solenoid valves were chosen and encased in silicone for waterproofing.

2.2.1 Datalogger program and function

The datalogger program used to control buoy functions was modified significantly from the pilot study. There were changes to the pumping system to enable the two pumps and opening/closing cycle of solenoid valves for the biofouling treatment. The sampling schedule was changed occasionally while deployed to either conduct experiments, improve operations, and/or to improve the quality of data that was being collected. An AC/DC relay power control device, SDM-CD16AC (Campbell Scientific) was added for the 2010 study, and was required to control all power to the solenoids and the pumps. This necessitated expanded programming subroutines to control the added functionality.

2.2.2 Anti-biofouling approaches and biofouling quantification

Water clarity sensors were installed on the buoy either as an "external" sensor that measured the bulk water column or as an "internal" sensor that required water to be passed through a cuvette or internal chamber. The turbidimeter and thermocouple-based water temperature sensors were external while light transmissometer and chlorophyll fluorescence sensors were internal (Figure 2). Water was pushed through the internal sensors by a pump that was driven by a relay operated by the data logging system.

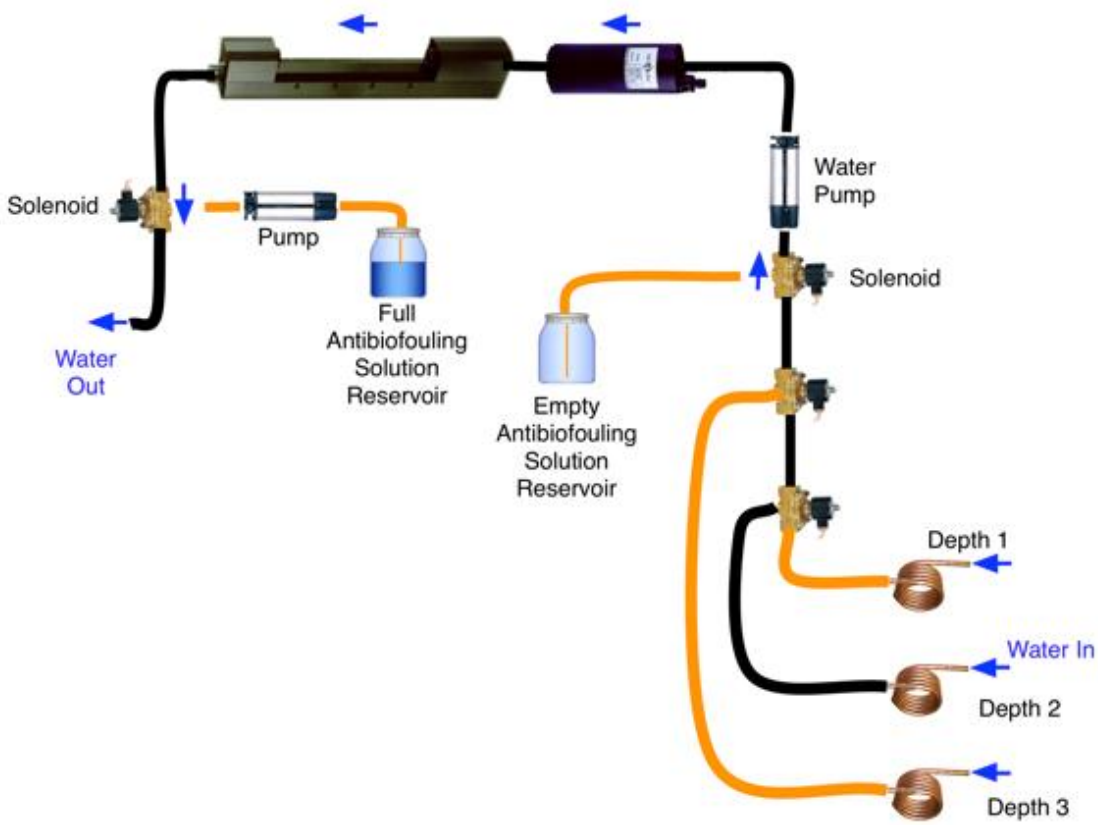


Figure 2. Schematic of "internal" water quality sensors on the buoy. Turbidity and water temperature (not shown) sensors were open to the lake whereas all others were part of a closed system requiring a pump to push water through the system.

Over time, the colonization of biological organisms naturally obscures the light transmissometer, turbidimeter, and chlorophyll fluorescence sensors' optics and degrades sensor data. The minimization of biofouling is critical to the cost-efficiency of buoy deployment as it reduces the number of costly trips needed to physically clean the sensors' optics. The 2008 pilot buoy study found that physical wiping of external sensor windows was effective at eliminating biofouling automatically for the DTS-12 turbidimeter. However, sensors that utilized cuvettes or internal sensor windows, such as the light transmissometer and chlorophyll fluorescence sensors, were susceptible to biofouling between routine maintenance trips. For example, during the 2008 study, copper tubing was used as flow-through plumbing that acted as a passive biocide for the internal sensors. These sensors still experienced biofouling within 7 to 10 days during late summer. Compare this to an external turbidimeter whose wiper was intentionally disabled, which then became biofouled within hours. Although several common chemical anti-biofouling approaches exist (e.g., tributyl tin waxes and aerosol sprays, antifungal agents, halide tablets, Alconox, copper tubing and paints, and cayenne pepper) they are not generally suitable for Lake Tahoe's pristine waters.

To reduce the impacts of biofouling of the internal sensors, the 2010 version of the buoy added an anti-biofouling solution contained in rigid-walled reservoirs (Figure 2), or bladders. This system was designed so that the anti-biofouling solution would be captured and reused during each successive cleaning cycle. The bladders were then recharged with fresh anti-biofouling solution during routine maintenance trips. The two bladders were installed near the inlet and outlet of the sample system. When a cleaning cycle was activated, solenoid valves closed off the sample intake line and pumped anti-biofouling solution from the storage bladder through the sample line and sensor cuvettes to a terminal bladder. Then, the pump reversed and returned the anti-biofouling solution to the storage bladder at the end of the cleaning cycle. Cleaning cycles were initiated by the datalogger once per week during the winter and spring, once per day during the summer and fall, or manually when needed. The anti-biofouling solution consisted of commonly available halide tablets that are normally used to sanitize water in hot tubs. A small amount of anti-biofouling solution was diluted with lake water already present in the tubing and released to the lake at the start and end of each cleaning cycle. However, the dose of anti-biofouling solution was estimated to be equivalent to the release of a few milliliters of swimming pool water into the lake during any given week.

2.2.3 Power constraints

One of the largest constraints for long-term deployment of the buoy was the potential to run out of battery power, particularly during periods of cloud cover over the winter. The relatively small size of the buoy precluded the use of large-capacity battery systems to supply power. During summertime conditions, the pilot study estimated that the buoy had an approximately 8-day power reserve when taking measurements at relatively rapidly intervals. For this project, the battery capacity was increased from one battery to four batteries, in series. In order to provide a sufficient power recharge to the batteries for the sensors, datalogger, pump, solenoids, and telemetry systems, a 30-Watt unbreakable solar panel was secured to the top surface of the equipment housing. However, a potential need was anticipated during the winter months to conserve power by minimizing nighttime operations and using the anti-biofouling system infrequently. Not only are there fewer daylight hours to recharge the batteries during winter, but colder winter temperatures reduce their capacity to hold a charge. Turbidity was measured as frequently as every 15 minutes with no adverse power drain. The largest power draw on the system was the pump, which needed to be on for an extended time to be able to sample water from multiple depths and during the anti-biofouling cleaning cycles. At peak power expenditure, the pump system was activated for two minutes as frequently as every 15 minutes. The next largest power consumption was the telemetry system, which was configured to turn on only for a limited number of hours during the daylight and only if there was sufficient battery charge.

2.2.4 Anemometers

The 2008 pilot study buoy utilized wind speed and direction measurements to assess the impact of waves and buoy movement on sensor performance. These sensors were not included during this deployment, as they were critically damaged by substantial winds and wave action twice during the pilot study and are expensive to replace. For 2010, meteorological data was collected from nearby weather stations to provide gross weather conditions. As this project was not designed to assess the impact of weather on nearshore clarity, this was deemed an acceptable concession. Buoy-based measurements would be required if this were an objective because of the highly-variable and localized nature of wind.

3.0 DEPLOYMENT

3.1 Location and Logistics

The buoy was deployed for five different periods of time and/or locations between August 12, 2010 and June 2, 2011 (Figure 3 and Table 1). Each deployment location and duration was selected for one of two reasons: 1) ease of access, or 2) to strategically answer a specific operational question.

The first deployment location was at the north end of Marla Bay, where the Marla Bay Marina and manager, Scott Smith, granted easy boat ramp access and an anchor to affix the buoy. It was positioned on a navigation marker buoy anchor on August 12, 2010. There was an unexplained period of data loss, beginning on the morning of September 29, 2010. Upon field examination, water was found inside the datalogger housing. A new datalogger

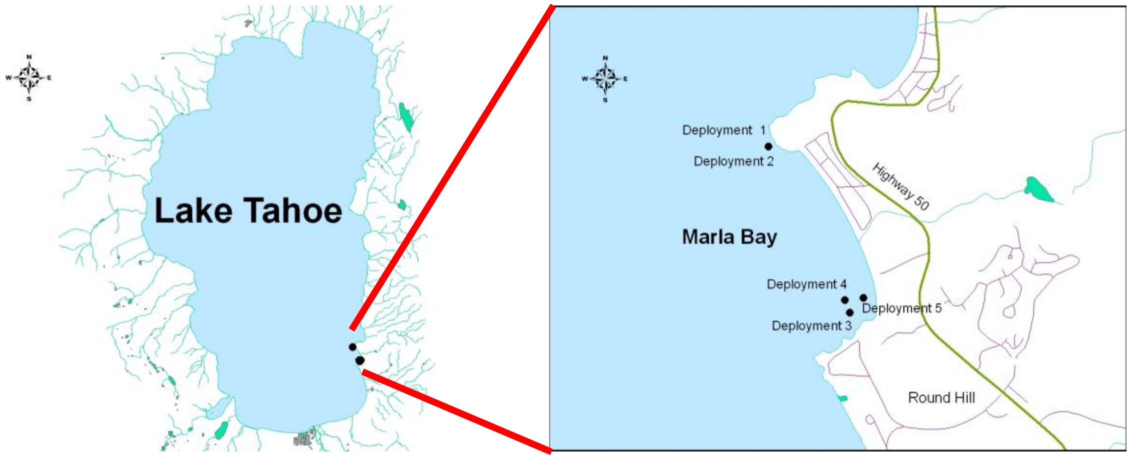


Figure 3. Map of deployment locations.

Table 1. Shows the five deployment locations and durations. The rationale for removing the buoy from a particular deployment is also given. GPS coordinates are in WGS84 datum.

Deployment	Latitude	Longitude	Estimated Water Depth	Date Start	Date End	Location	Reason Removed
1	39.0002	-119.9611	6 meters	12Aug2010	29Sep2010	Marla Bay Marina	Water Ingress
2	39.0002	-119.9611	6 meters	06Oct2010	15Oct2010	Marla Bay Marina	Moved to clam beds
3	38.9894	-119.9550	5 meters	15Oct2010	26Oct2010	Round Hill Pines Marina	Water Ingress
4	38.9902	-119.9554	4.5 meters	01Nov2010	02Dec2010	Round Hill Pines Marina	Power Failure
5	38.9903	-119.9538	3.5 meters	22Mar2011	02Jun2011	Round Hill Pines Marina	End of Study

housing enclosure was installed to prevent water ingress into the electronics enclosure; and, a replacement datalogger was installed for the damaged one. A real-time temperature/relative humidity sensor (HMP45C, Campbell Scientific, Logan UT) was installed within the equipment housing to enable tracking of water content. For the second deployment, the buoy was placed at the same Marla Bay Marina location on October 6, 2010. The buoy was moved to a location off of Round Hill Pines Marina, with permission from manager Frank Forvilly, on October 15, 2010, for the third deployment. This move was to support background clarity data acquisition during the tarpaulin removal as part of an Asian clam tarpaulin mitigation study (Wittman et al, 2012). A period of data loss, which ended the third deployment, was a result of excessive moisture buildup within the housing unit that resulted in the system shutting itself down. This moisture buildup was caused by water infiltration during a storm on October 24, 2010, the first large event after the replacement of the equipment housing. The junction box orifice where the sensor wires pass through the equipment housing was isolated as the cause and repaired.

For the fourth deployment, the buoy was placed on the opposite side of the Round Hill Pines navigation channel. The data logger program was altered on November 16, 2010, to reduce the buoy's power draw in order to prepare it for wintertime operations. The cellular modem went from being powered all the time to just being powered between the daylight hours of 8 am to 5 pm. The sampling frequency for the C-star (light transmissivity) and wet-star (relative chlorophyll) sensors was reduced from every hour to every two hours. This was done primarily to reduce the power needed to run the solenoids and water pumps required by these sensors. Likewise, the frequency of the sensor cleaning cycle was adjusted from daily to weekly because of the need to run the pumps for an extended period of time. Water temperature and turbidity remained on a 15-minute interval data collection frequency because these sensors have a low power requirement.

The buoy was placed at a centralized and easily accessible anchor within the Round Hill Pines Marina for the fifth deployment on March 22, 2011. Excessive wind storms in spring 2011 precluded easy canoe-based maintenance. The cellular modem continued to be powered only between 8 am and 5 pm. The sampling frequency for the C-star (light transmissivity) and wet-star (relative chlorophyll) sensors was *further* reduced from every two hours to once per day at noon. This was done primarily to reduce the power draw of the solenoids and water pumps required by these sensors. Compared to the 2008 version of the buoy, this 2010 configuration required substantially more power to operate the sampling pump while water was being collected at multiple water depths and to operate the four additional solenoids required for this sampling approach.

The movement of the buoy from one location to another did not appear to complicate results of the study. A potential confounding factor could be the depth of water, which would lead to decreased water clarity, as wind-driven sediment resuspension in shallower waters. Several studies have found that wind speeds of 5 meters sec^{-1} are able to resuspend substrate sediments of varying size classifications from depths of up to 4 meters (Cozar 2005, Gabrielson 1985).

The frequency of the cleaning cycle continued as once per week because of the long duration and power requirements of pumping needed for cleaning. The cleaning cycle frequency could have been increased in the spring if excessive biofouling were observed. This is possible as battery performance will increase in the spring and summer due to higher ambient air and water temperatures and the increased charging rate from sun position and a greater frequency of cloudless days. Water temperature and turbidity remained on a 15-minute interval data collection frequency because of their low power usage.

On April 16^{th} sampling for the C-star (light transmissivity) and WETSTAR (relative chlorophyll) became sporadic. The sampling frequency for the C-star and wet-star sensors was remotely increased to three times per day at 10 am, noon, and 2 pm to achieve better sampling resolution and troubleshooting capability. A field visit to investigate was judged to be unnecessary given budget constraints. Upon removal of the buoy on June 2, 2011, the problem was determined to be a loose power cable connection from the CR1000 datalogger to the SDM-CD16AC module that turned sensors, solenoids, and the water pump on and off.

The connection may have been poorly secured at deployment, or become loosed through repeated bouncing from wave action. The cable was connected sufficiently enough to power the cellular modem, C-star and wet-star sensors intermittently at the interval called for by the software program. That the physical connection was occasionally intact at the same time as the triggering of sensor sampling was fortuitous.

3.2 Power Failure

Beginning on November 18, 2010, the buoy exhibited an uncharacteristic increase in power use as evidenced by the large decrease in battery voltage at night when the system could no longer rely on solar panel inputs (See Figure 4). By December 2, 2010, the battery voltage was less than 8.5 volts and could no longer support the electronics package. The buoy was left in the water to assess if a series of subsequent sunny days could supply enough solar power to revive the buoy. After no communication for three days the buoy was removed from the water to assess the failure and conduct repairs, ending the fourth deployment.

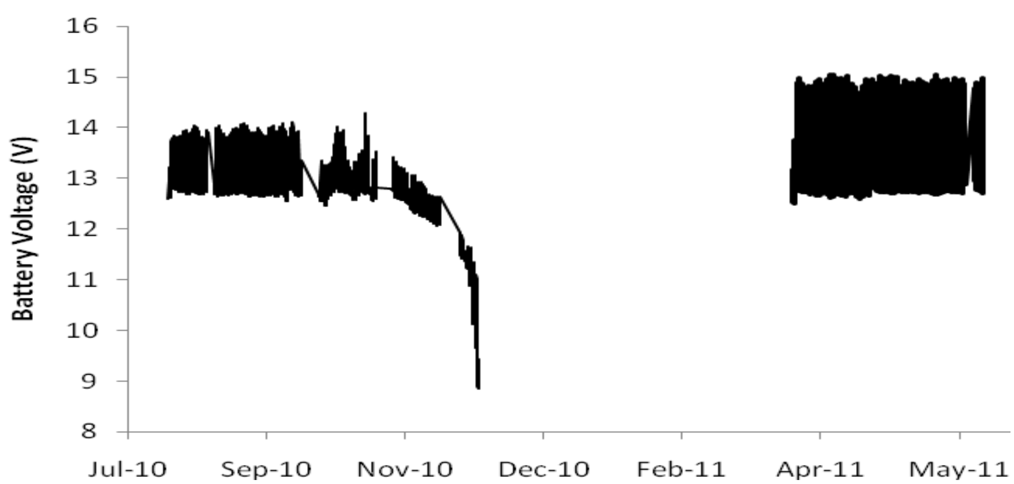


Figure 4. Average hourly battery voltage.

Potential causes for these power issues on the buoy would be either too much drain, or not enough solar recharge. We postulated that the root cause of this power issue was: 1) the rate of power recharge, i.e., the new solar panel, solar regulator, and battery configuration, or 2) the drawdown of power from overuse of the high power-draw cellular modem or pumps. To assess the drawdown of the new solenoid driven pumping and cleaning systems, testing occurred in the laboratory of DRI; while testing of the recharge systems was conducted in DRI’s parking lot to ascertain the solar panel charging capacity and battery recovery. Testing of the two systems, drawdown and recharge, did not reveal any deficiencies. Not until after this indeterminate testing and the logger and power control device systems were re-wired did we discover a short in one of the four solenoids, which would have slowly drained the system of power while the solenoid was fully submerged in water over the course of a few days. It was concluded that this electrical short was the sole cause of the power issues during the fourth deployment. The buoy was fixed and redeployed to Round Hill Pines on March 22, 2011, for the fifth deployment.

3.3 Light Transmissometer Sampling Issues

The light transmissometer sensor experienced a slow equilibration to baseline readings each time it was cleaned and/or deployed, even though the sample lines were completely purged of air when the buoy is put in to place (Figure 5). Upon each of the five separate deployments of the buoy, the light transmissometer showed variability in its baseline reading, i.e., the maximum transmittance of light for a deployment period was significantly different, ranging from 3300 to 4400mV. Natural causes, like real clarity degradation, were deemed to not be the cause as there was not a similar in situ response with either the turbidimeter nor chlorophyll meter. In addition, other studies on Lake Tahoe employing the same instruments did not observe such baseline shifts (Taylor et al., 2004, Susfalk et al., 2009). The equilibration problem resolved itself within 12 to 48 hours after being deployed.

It was suggested by the manufacturer of the instrument, WETLabs Inc, that very small air bubbles stuck to the walls of the sample cell by surface tension may cause refraction of the passing light beam, affecting the readings. A potential reason that the Taylor et al. (2004) and Susfalk et al. (2009) studies were not similarly impacted was because vibrations present on the Research Vessel Mount Rose may have helped to dissipate air bubbles. Alternatively, the light transmissometer on the boat was placed in warmer water before sampling began, allowing for air bubbles to overcome surface tension. The baseline and equilibration problems were not seen in 2008, potentially, because the buoy was not removed from the water for the entire study period. For 2010, the problem occurred despite careful purging of the sample lines of air, while the intake was submerged in the lake at the time of each deployment. It was hypothesized that flushing a surfactant through the system may clean the light transmissometer cell of any residual bubbles. This theory was not tested *in situ* and would be essential prior to another buoy deployment to prevent these baseline shifts. Surfactant could be pumped through the plumbing system as part of the purging process at the beginning of each deployment. Another solution may be to calibrate the light transmissometer to a known, ultra-clear medium such as deionized water at the outset of each deployment.

3.4 Changing Objectives

Over the course of the intended deployment period of one full year, many interruptions presented themselves. These issues, described in detail above, precluded deployment for the full 12-month period. With each issue that arose, the costs of maintenance increased. The initial goals of observing environmental conditions in one location were necessarily changed. The movements of the buoy between deployments and issues described, though, did not complicate the overall goals and objectives of the study and the interpretation thereof. The original objectives were still incorporated and assessed, as well as could be expected under the circumstances.

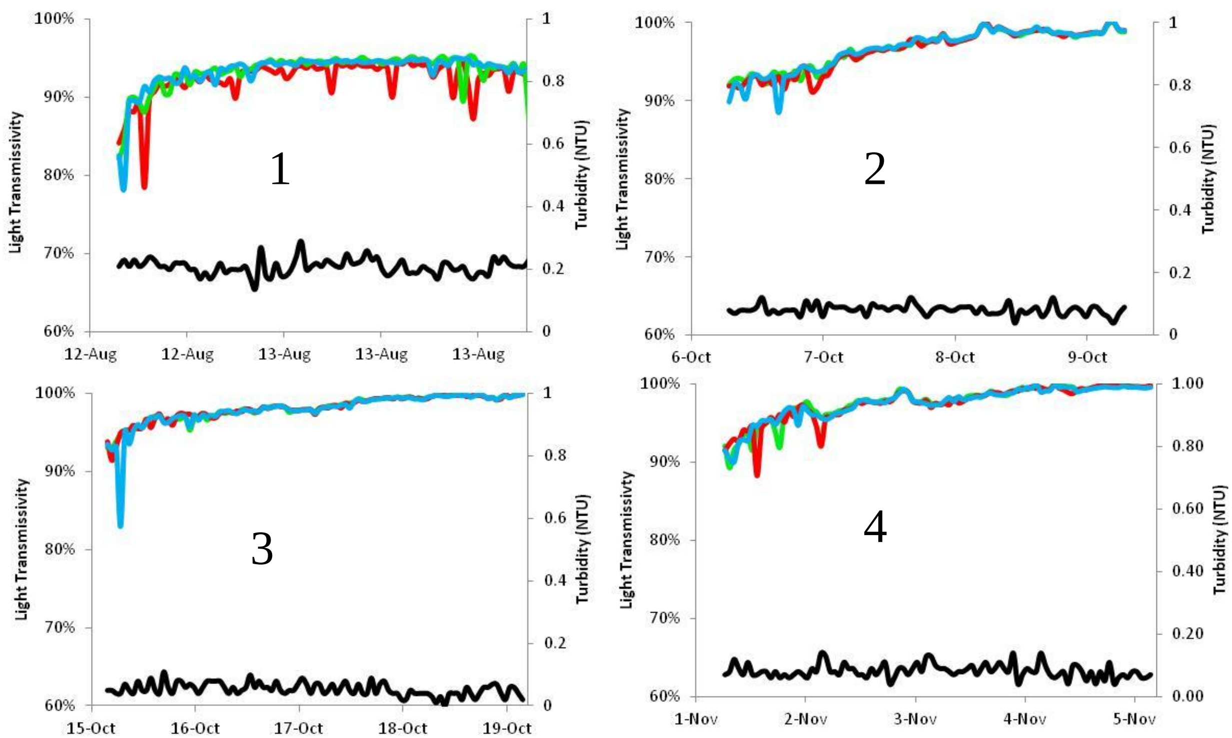


Figure 5. Comparison of observed turbidity and light transmissivity at the outset of each deployment period. Number labels refer to deployment number (Table 1). Black lines are turbidity; blue lines are 0.23 meter depth light transmissivity; green lines are 0.46 meter depth light transmissivity; red lines are 0.92 meter depth light transmissivity. Turbidity data presented are average hourly data and light transmissivity are raw hourly measurements. Note that deployment 5 is not included because the sampling interval was only once per day for light transmissivity at that time.

4.0 RESULTS

4.1 Turbidity and Light Transmissometer Results

The findings for turbidity and light transmission in 2010 at Marla Bay were similar to those for the 2008 pilot study in Incline Village. When compared to the pilot study, daily average turbidity was lower (0.25 versus 0.47 NTU) and daily average light transmissivity was higher (95.4% versus 91.0%). The location of the pilot project at the outfalls of Third and Incline Creeks greatly affected readings. As expected, higher clarity was found in Marla Bay, which has no significant direct runoff sources.

The full data set for the 2010 study are presented in Figure 6. During the fall season, only modest fluctuations are noted in both turbidity and light transmissivity. In the spring, more variability is observed in both of these water quality parameters. The sampling interval for light transmissivity was only three times per day in March & April, then once per day in May and June, which may contribute to the irregularity of results. The turbidity during this spring sampling had similar fluctuation, which indicates real water clarity loss. These observations are explored in greater detail in the deployment graphs and event graphs later in this chapter.

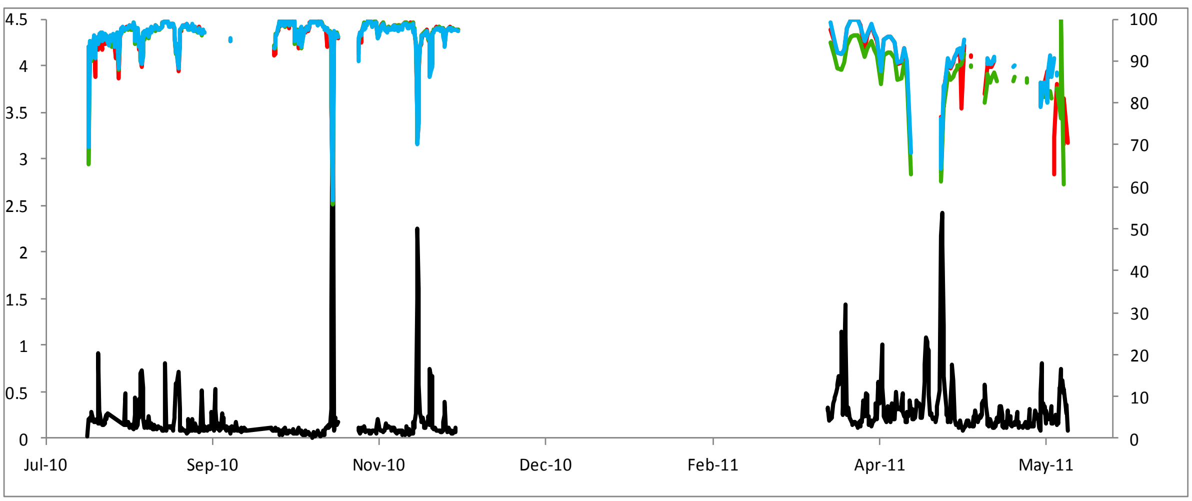
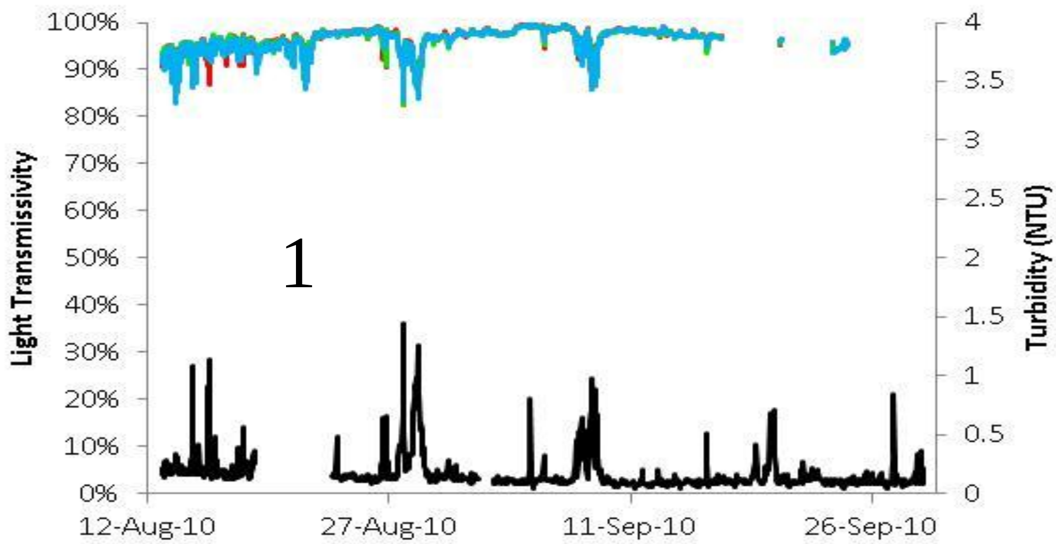


Figure 6. Comparison of observed turbidity and light transmissivity for the period of record, August 2010- June 2011. Black line is turbidity. Blue, green, and red lines are 0.23, 0.46, and 0.92 meter depth light transmissivity, respectively. Turbidity data and light transmissivity are 6-hour average measurements.

Over the five deployments, turbidity and light transmission both mirrored changes in water clarity (Figure 7). Daily minimum turbidity levels were approximately 0.15 to 0.35 NTU during the snowmelt season (deployment 5), or two or more times greater than that of background measurements (0.06 NTU) conducted in late summer. Average daily values of greater than 0.5 NTU were not uncommon during snowmelt, with instantaneous measurements of up to approximately 2.2 NTU. The Marla Bay area was chosen as a location for the project because of its proximity to large Asian clam beds. Asian clam deterrent tarps had been in place and would be removed during the course of the buoy deployment by Wittman et al (2012), providing an opportunity to observe water quality before, during, and after the disturbance (Section 5.1.3). Turbidity measurements were deemed to not be significantly impacted by runoff. The only tributary to Marla Bay is

McFaul Creek, which has low discharge (Taylor, 2002), and the buoy was not placed near that creek outfall to the lake for any of its deployments. Runoff monitoring was not an objective of this study, as it was during the first pilot project.



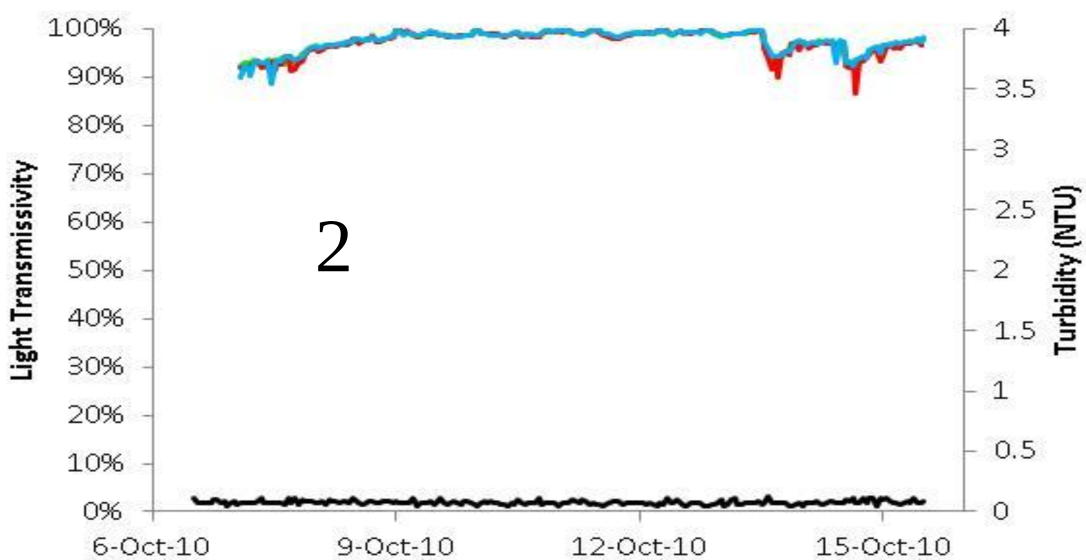


Figure 7. Comparison of observed turbidity and light transmissivity between August 12, 2010 and June 2, 2011. Each graph represents one deployment period. Graph "1" is deployment 1, graph "2" is deployment 2, etc. Black lines are turbidity, blue lines are 0.23 meter depth light transmissivity, green lines are 0.46 meter depth light transmissivity; red lines are 0.92 meter depth light transmissivity. Turbidity data presented are average hourly data and light transmissivity are raw hourly measurements. Note that the turbidity scale on secondary y-axis in graph 3 is twice that of the other graphs.

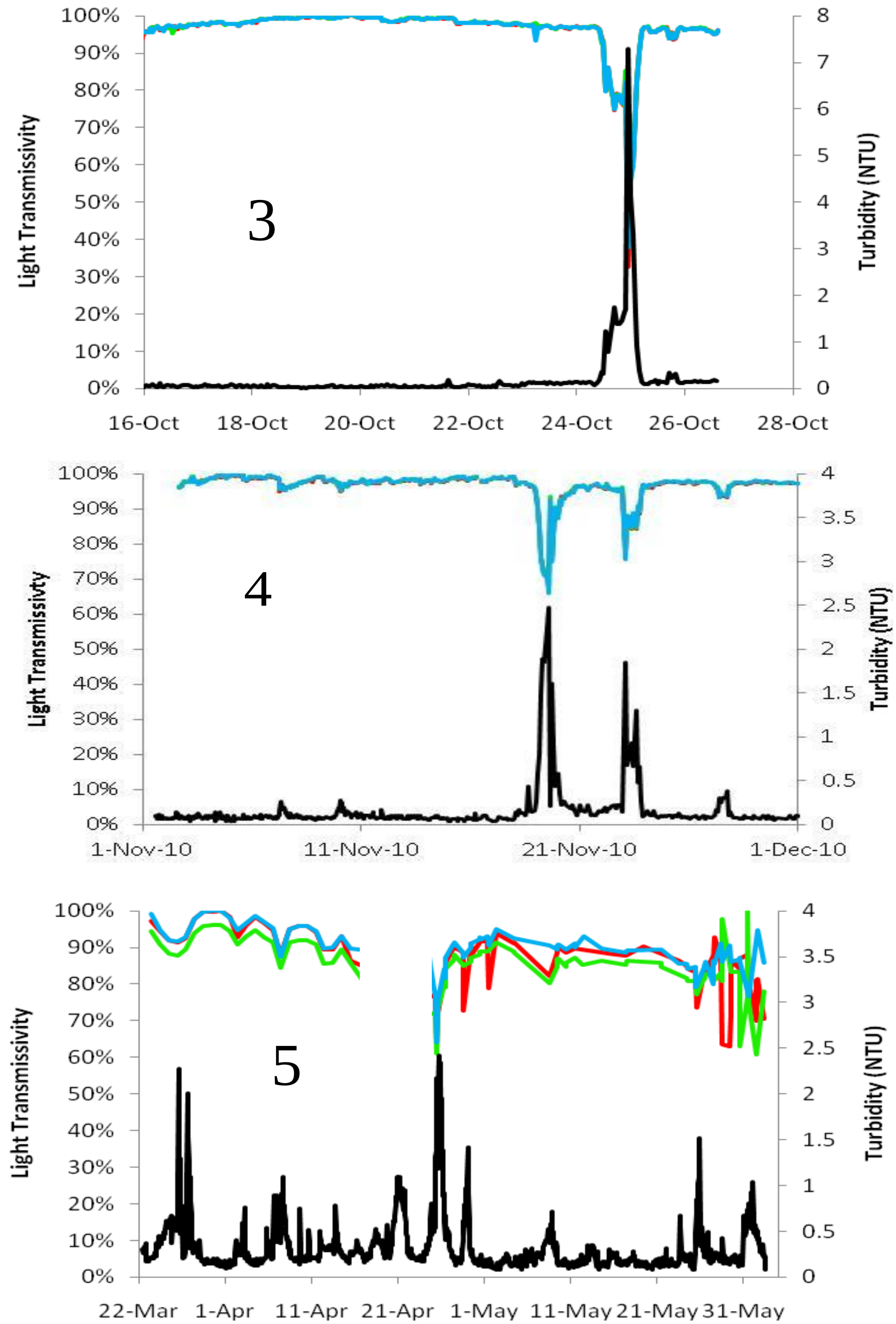


Figure 7. Comparison of observed turbidity and light transmissivity between March 22, 2010 and June 2, 2011 (continued).

It should also be noted that the internal sensor data for deployment 5 is irregular and blocky because of the extended sampling interval. The perceived benefits to power savings did not outweigh the costs to data collection and interpretation by sampling once per day for this study. Later, in April, sampling of light transmissivity and relative chlorophyll was conducted three times per day during the daylight hours. This schedule may provide insight towards both long-term baseline reference clarity data, but also observe shorter-term hydrologic events that would be missed with once-per-day sampling. Light transmissivity and relative chlorophyll samples should be taken once per hour if the intent is monitoring of short-term hydrologic events. Alternatively, this once-per-hour sampling scheme could be rotated through the three depths, so that each depth is sampled every three hours for a total of three or four samples per day, if needed. If the goal of buoy monitoring of the nearshore is long-term threshold exceedances and management thereof, then once-per-day sampling may suffice.

The water temperature results for the period of record are shown in Figure 8. The upper and lower thermocouples are not shown in this long-term graph, as they provide little added information. The depth profile of temperatures provided more distinctive opportunity for interpretation of short-term changes in air versus water temperature (Section 4.2.2). Water temperature changed from a daily average high of 19.7 °C on August 18, 2010, to a daily average low of 2.7 °C on March 25, 2011.

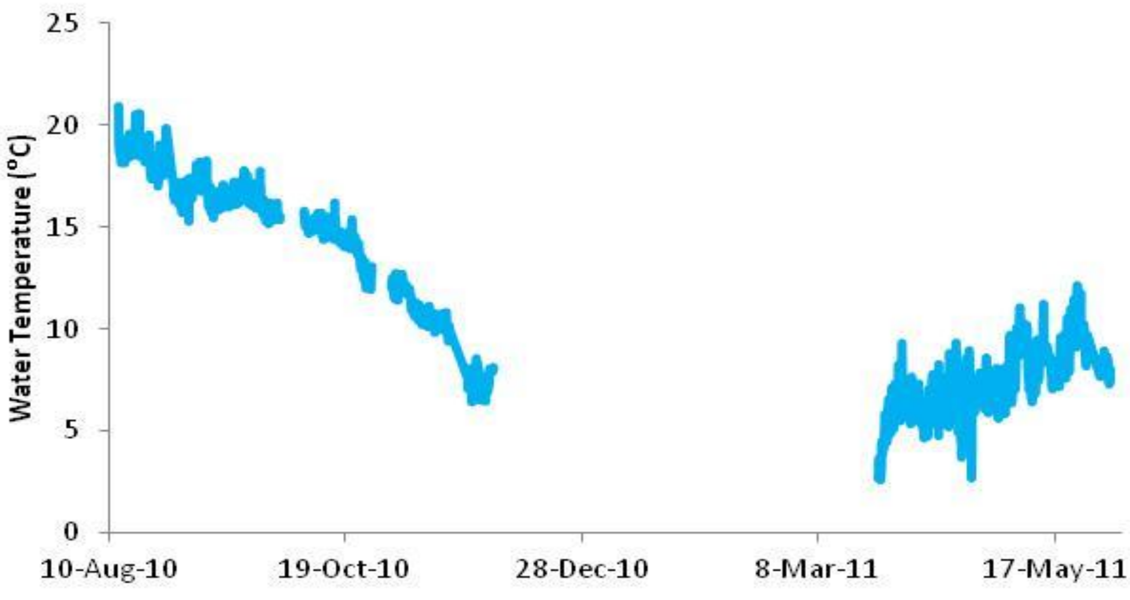


Figure 8. Temperature for the period of record, between August 12, 2010 and June 2, 2011. Only the middle depth (0.46 meters below water surface) is shown, but deviation from upper (0.23 meters) and lower (0.92 meters) depths over this scale were negligible.

4.1.1 Nearshore clarity events

There were eight significant nearshore clarity reducing events during the study period (Figures 9a through 9d). These events were largely unexplained phenomena, as one of the probable causes, wind, was not directly measured at or near the buoy location. Events were chosen based on a finding of turbidity above 1 NTU, which meant that clarity loss was an order of magnitude above normal, baseline readings.

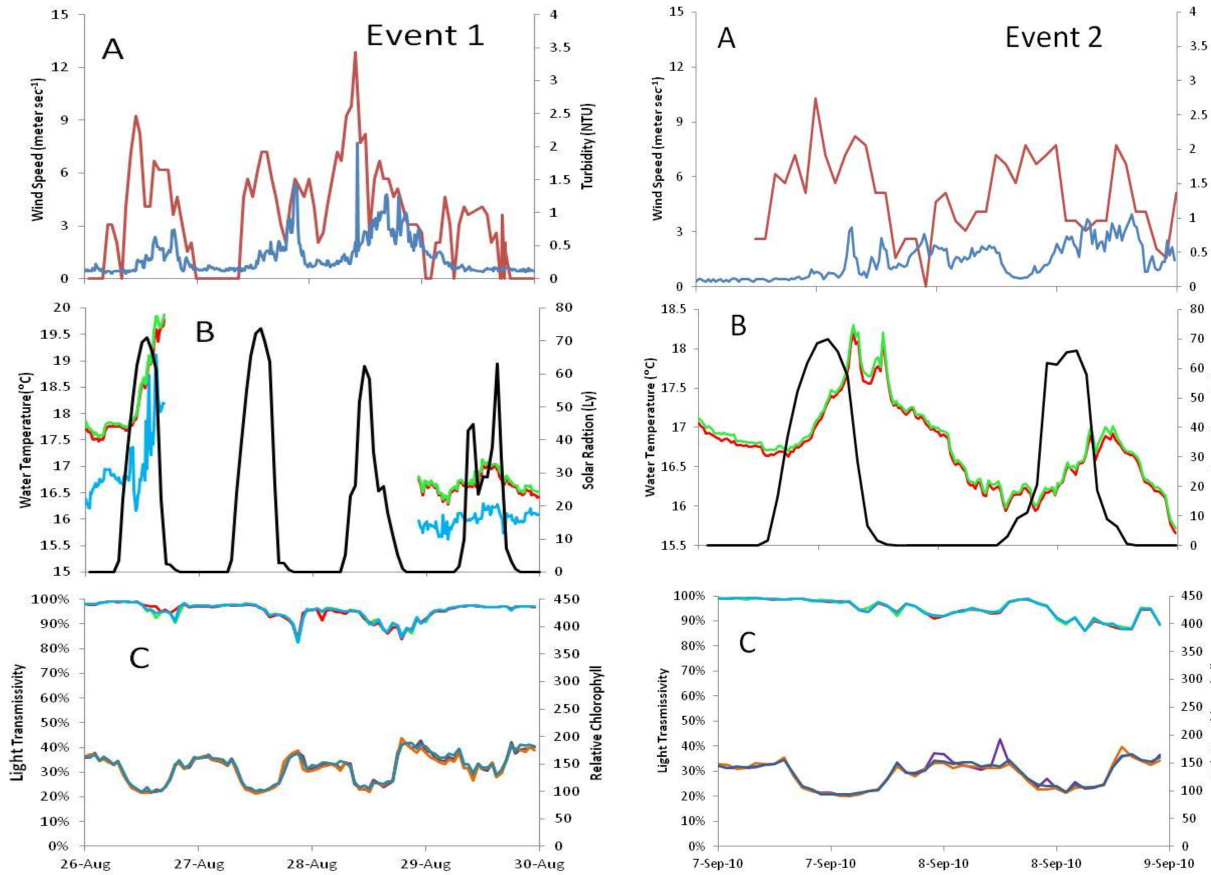


Figure 9a Events 1 and 2. For "A"graphs: Turbidity (dark blue) and wind speed (purple). For "B" graphs: Water temperature profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters) and, solar radiation (black), comparison. For "C" graphs: Light transmissivity profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters), and Chlorophyll profile, navy blue = shallow (0.23 meters), purple = middle (0.46 meters), orange = deep (0.92 meters). All values are reported as hourly averages.

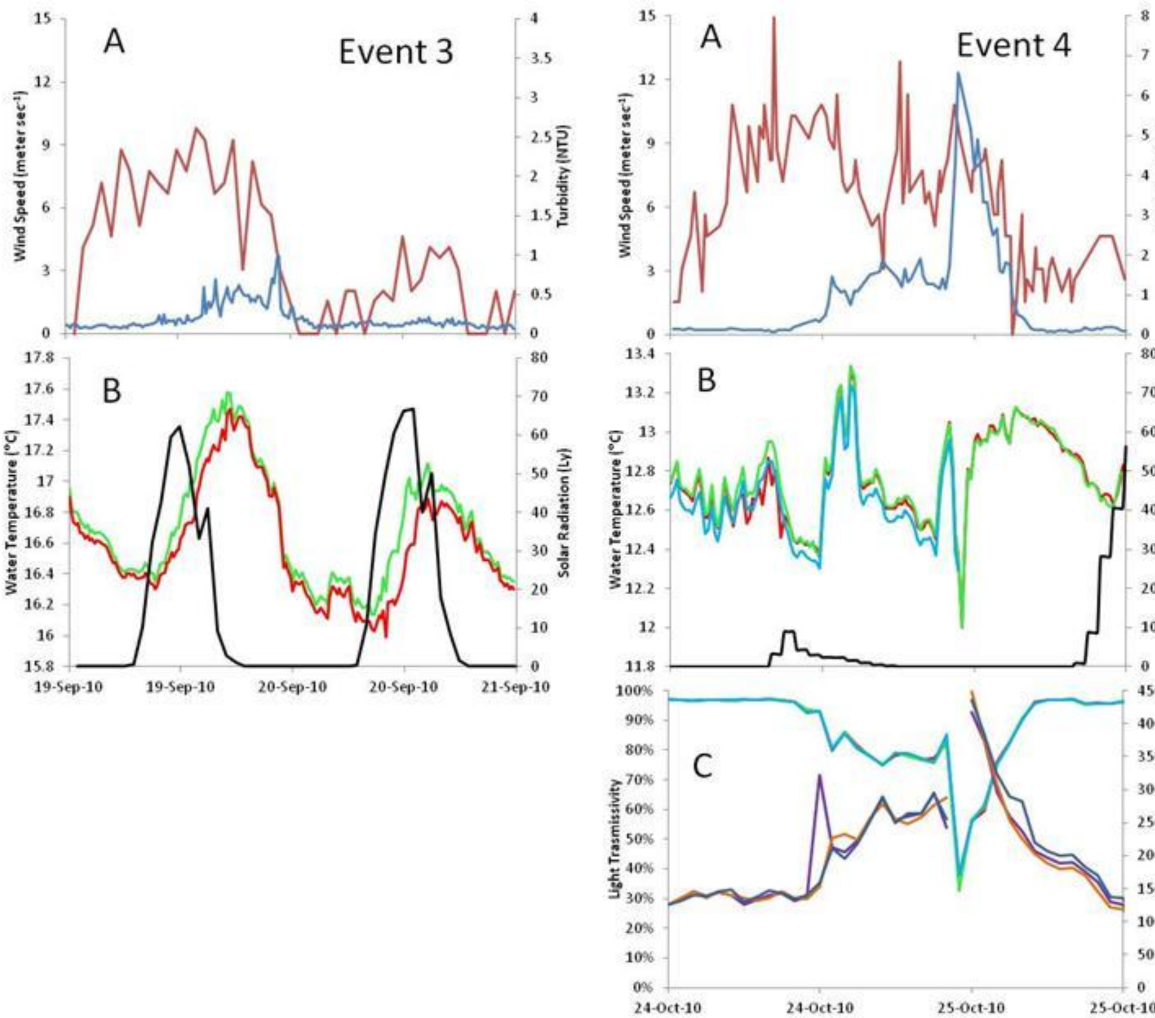


Figure 9b. Events 3 and 4. For "A"graphs: Turbidity (dark blue) and wind speed (purple). For "B" graphs: Water temperature profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters) and, solar radiation (black), comparison. For "C" graphs: Light transmissivity profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters), and Chlorophyll profile, navy blue = shallow (0.23 meters), purple = middle (0.46 meters), orange = deep (0.92 meters). All values are reported as hourly averages.

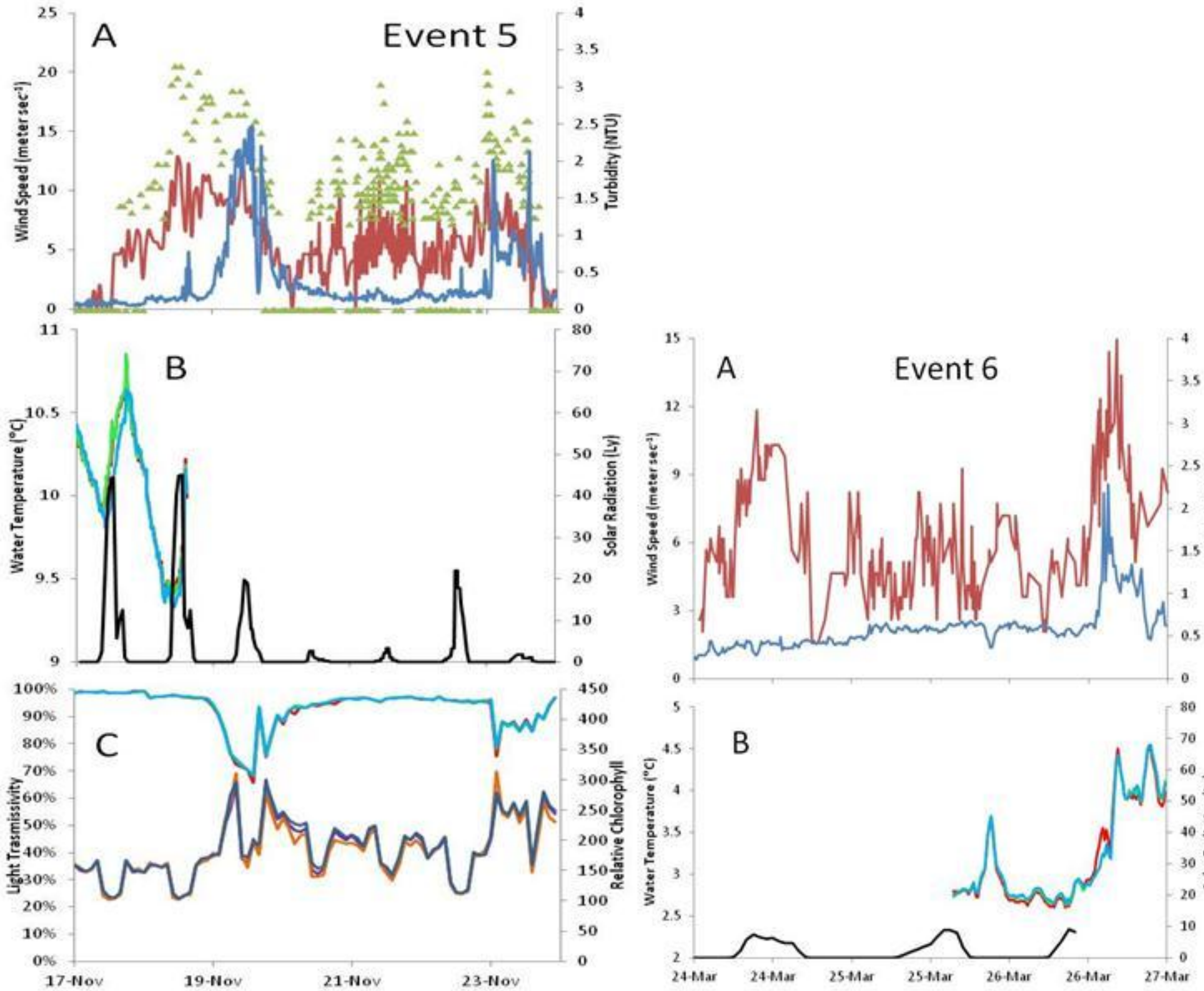


Figure 9c. Events 5 and 6. For "A"graphs: Turbidity (dark blue) and wind speed (purple). Olive triangles are wind gust speed. For "B" graphs: Water temperature profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters) and, solar radiation (black), comparison. For "C" graphs: Light transmissivity profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters), and Chlorophyll profile, navy blue = shallow (0.23 meters), purple = middle (0.46 meters), orange = deep (0.92 meters). All values are reported as hourly averages.

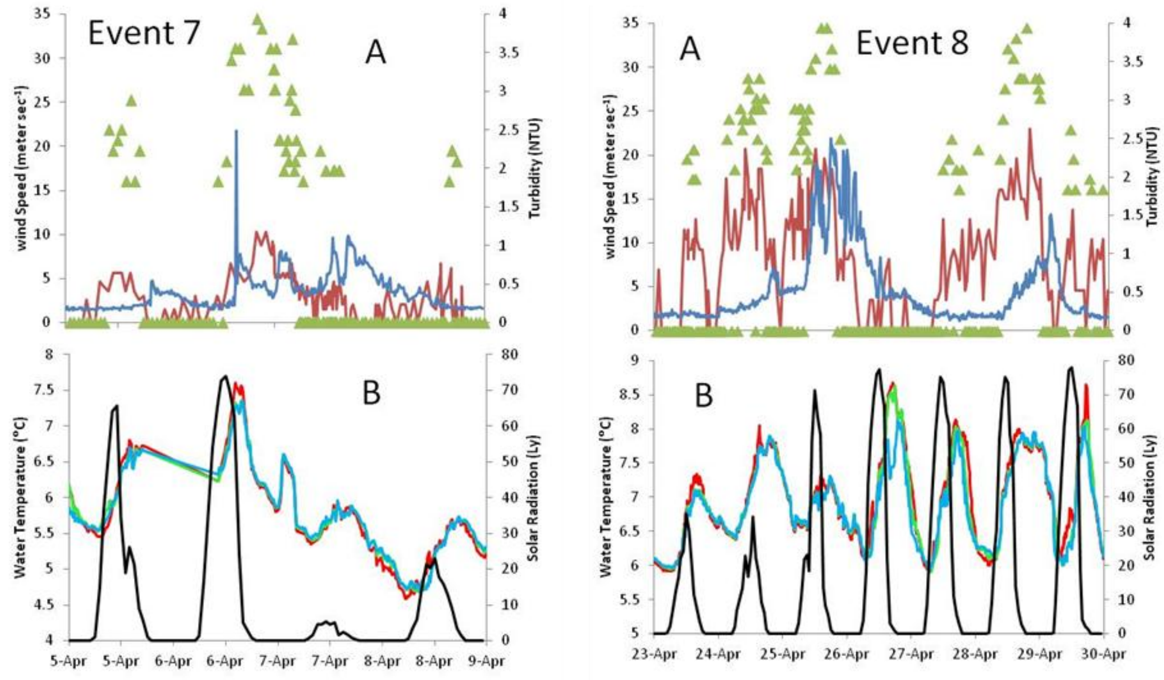


Figure 9d. Events 7 and 8. For "A"graphs: Turbidity (dark blue) and wind speed (purple). Olive triangles are wind gust speed. For "B" graphs: Water temperature profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters) and, solar radiation (black), comparison. All values are reported as hourly averages.

In the 2008 study, there was considerable disruption of turbidity data attributed to bubbles entrained in the water column by the significant wave action of storms. In order to provide context for changes in the water column, environmental conditions in the atmosphere needed to be examined. Some gross relationship was expected between air temperatures and water temperatures, and wind speed and turbidity. Weather data were taken from Zephyr Cove station (Nevada Department of Transportation, NV13**).** Data collected included: wind speed, wind direction, air temperature, humidity, precipitation, conditions, and dew point. Solar radiation was unavailable at the Zephyr Cove station, so those data were taken from the Meyers, California Remote Automated Weather Station (RAWS) station.

An analysis of wind speed versus turbidity of these events suggested that wind may be a real cause of loss in clarity (Table 2). Statistical relationships between wind speed and turbidity showed relevant correlation for 6 of the 8 events analyzed, with an offset shift of minus six hours for turbidity data. However, the only way to truly ascertain these relationships would be through buoy-based wind measurements. This was not done during this project as a cost-saving measure and because this type of analysis was not an objective of this project.

Table 2. Statistical analysis of wind speed versus turbidity for entirety of the eight events. There was an offset shift of six hours between the two data: turbidity minus six hours.

Event	Multiple R	P-value	Maximum wind speed (miles hour^{-1})	Maximum Turbidity (NTU)	Minimum Transmissivity (percent)
1	0.63	<0.05	28	2.06	82
2	0.08	0.63	23	1.05	86
3	0.60	<0.05	22	0.99	na
4	0.51	<0.05	33	6.58	32
5	0.48	<0.05	29	2.48	68
6	0.06	0.65	33	2.28	na
7	0.27	<0.05	23	2.49	na
8	0.47	<0.05	23	2.5	na

For the period of record, the highest instantaneous turbidity was observed during Event 4 on October 24, 2010 at 6.58 NTU. This corresponded to a light transmissivity value of 37 percent. This implicitly means that light transmission will reach a maximum obscuration at approximately 10.5 NTU. Therefore, light transmissivity should not be considered useful for short-term, high-turbidity nearshore events.

Back and forth buoy movement during wind events may have been the source of bubbles entrained in the water column, affecting turbidity readings. Each turbidity reading reported by the sensor was comprised of an estimated average of 100 readings taken over 10 seconds. To improve instantaneous turbidity readings, the best systematic estimator (BES) of turbidity was utilized rather than a straight arithmetic mean. This approach was chosen because it reduced the impact of spurious high and low readings but also provided some weight to values on either side of the mean. Large standard deviations did not always indicate wind events or unusual turbidity values. The variance term reported by the turbidimeter did not show any significant correlation with wind speed (R^2 <0.005), so was not incorporated in the event graphs. Occasionally, during storms, the turbidity variance became elevated to a large value and may have been a result of wind-energy reaching some threshold, which resuspended bottom sediments or created enough bubble splashing to affect readings. For example, during Event 5, turbidity variance was highly elevated when wind speeds were above 10 m s^{-1} and wind gusts were near 20 m s^{-1} (Figure 10). The turbidity variance was typically highest at the beginning of an event, which may correspond to air bubbles from high-gust wind action. In some of the events considered, wind speed appears to elevate turbidity, but not in all cases. Without wind speed and direction measurements on or immediately proximate to the buoy location, it is difficult to determine cause and effect of this phenomenon. Future buoy deployments should incorporate an anemometer at or near the buoy deployment location.

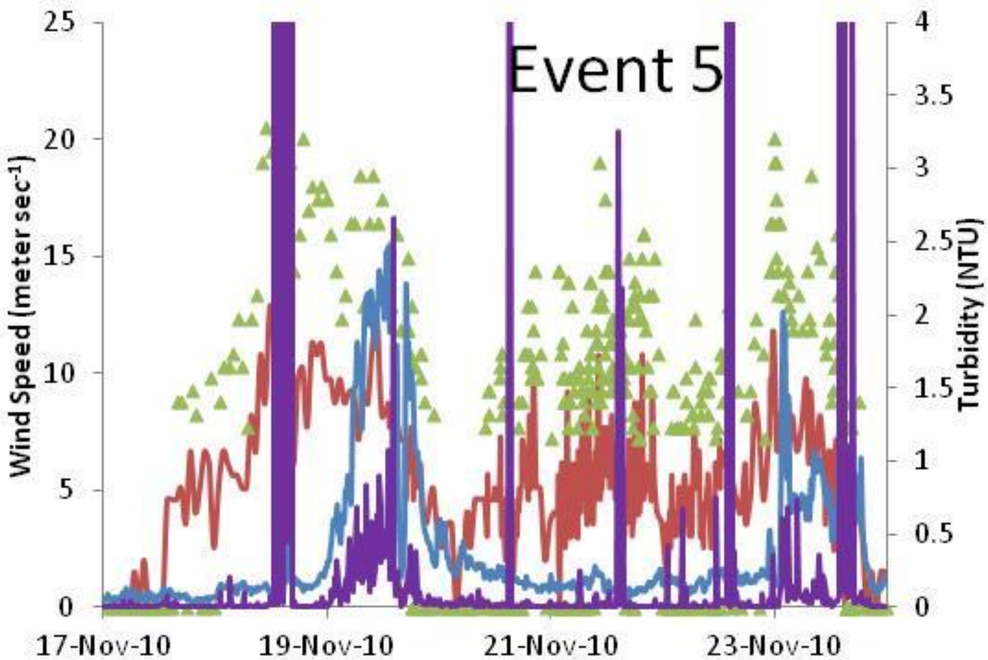


Figure 10. Event 5. Turbidity (dark blue) and wind speed (red). Olive triangles are wind gust speed. Purple line is variance of turbidity (in NTU).

4.2.2 Temperature profile

The temperature profile can be more easily viewed in the event figures (Figure 9, events 1 through 8) than in the long-term period of record graphs (Figure 7). During the fall and winter, the shallowest temperature (light blue) is colder than the deeper two temperatures. The cold air above resulted in lower water temperatures at the surface than temperatures seen at the 0.92 meter depth thermocouple (red). Then, the colder air temperatures were driven down the water column. The concept of diel temperature cycles reinforces this observation because the amplitude of the shallowest temperature cycle is greater and responds to changes in air temperature before the lower two water temperatures. In Figure 11, there is good definition of a diel temperature swing, whereby the sinusoidal curve of daily air temperature and solar radiation drive warmer air temperatures vertically down the water column during the day and cold air down in to the water column at night. In addition, the temperature profile reveals good mixing during strong wind events, as in event 8, where the temperatures are more uniform when winds are strongest and more divergent when winds are weakest. This type of information, when considered in conjunction with turbidity and light transmission data, could be useful in quantifying the impacts of wind-driven lake sediment resuspension towards lake clarity.

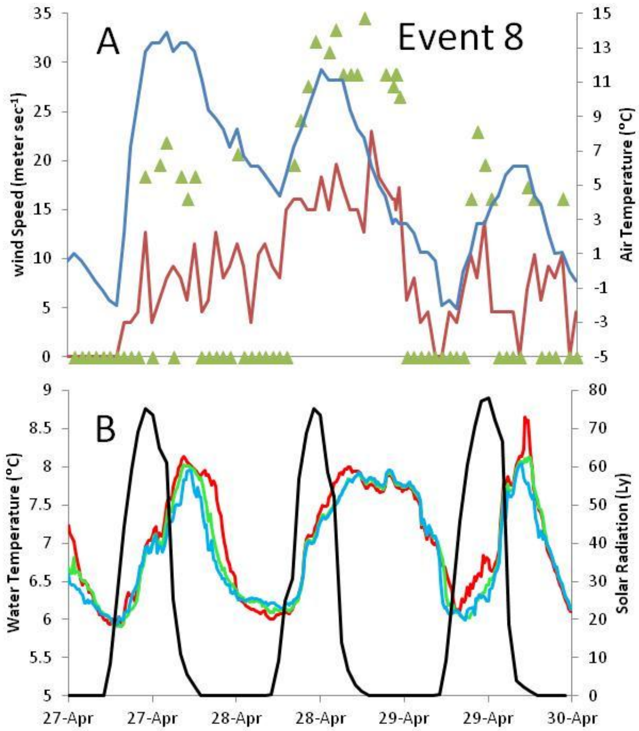


Figure 11. The end of Event 8, April 27, 2011 to April 30, 2011. For "A" graph: Wind speed is red, olive triangles are wind gust speed, the blue line is air temperature. For "B" graph: Water temperature profile, light blue = shallow (0.23 meters), green = middle (0.46 meters), red = deep (0.92 meters) and, solar radiation (black), comparison. All values are reported as hourly averages.

5.0 DISCUSSION

5.1. Water Clarity Measurements

Concerns raised in previous studies (Taylor et al., 2004, Susfalk et al., 2009) related to the use of turbidity in assessing seasonal and long-term changes at the highest levels of water clarity included: 1) turbidity was not a very sensitive measurement during background conditions when the number of suspended particles in the water column was low. Under these conditions, typically less than 2 NTU, other clarity-reducing factors such as absorption from dissolved organic matter can have a greater relative importance to overall water clarity; 2) repeatable turbidity measurements were difficult to achieve at low turbidity values because minor scratches on the cuvette window affect the low-end of the scale more so than at higher values; and 3) turbidity of the same water sample can be different depending on the model of turbidimeter and the sensitivities that each model has to particle shape, size, and composition. For threshold management, this means that turbidimeters used at Lake Tahoe must be standardized, preferably by using the same sensor model and unified calibration procedures.

Results from 2010 showed better low-end, baseline stability in turbidity measurements. A potential reason for the difference was that instrument used in 2010 was a newer model than that used in 2008. Another reason that the baseline readings could have been lower this round was that the instrument had recently been factory calibrated before deployment, perhaps resulting in better optical stability. The deployment location, also, may have influenced turbidity readings: 1) the buoy was placed in deeper water in 2010 (3.5 - 6 meters) than 2008 (2 – 4 meters), which would dampen the effects of resuspension, 2) there was less recreational activity in Marla Bay than Crystal Bay, 3) Marla Bay has less significant, proximate stream runoff, and 4) the sensor was lower in the water column than in 2008, which may have limited the influence of air bubbles affecting readings. These findings mean turbidity may not be the correct measurement if small changes in clarity occur, or absolute turbidities of less than 2 NTU are of concern.

In recent years, technological advances have allowed for the development of turbidimeters that utilize lasers to measure water clarity. These laser turbidimeters measure over a range of 0.0 to 5.0 NTU with resolution as low as 0.0003 NTU (Hach Co., Loveland, CO). As costs come down on these types of turbidimeters, they may warrant an investigation of their usefulness at Lake Tahoe. Currently, these laser turbidimeters cost on the order of $4,400-$5,700 versus a light transmissometer that costs approximately $5,800.

5.1.1 Important issues for winter operation of the buoy

Initial battery performance was good, as evidenced by the initial flat slope in battery voltage (Figure 4). After a solenoid short in late November 2010, however, battery power dropped below 8.5 volts and the station failed. While these power losses were unexpected, they provided learning experiences and pointed to specific issues that can be improved upon for future deployments.

There were foreseen issues of running out of battery power as a result of the lower solar recharge rates from: 1) lower sun angles, 2) increased number of cloudy days, and 3) the lower capacity of batteries to retain a charge under colder conditions. These were addressed at the outset of the project by increasing the size of the battery (capacity) and increasing the size of the solar panel from 10-Watts to 30-Watts over that of the pilot project. Also, by reducing the frequency of use of power-draining systems like the pumps and solenoids, power was conserved. This was achieved by reducing the interval at which measurements were made (over the course of the year-long deployment) from every 15 minutes to 1 to 3 times per day and limiting telemetry communications to daytime hours. Based on these findings, the current infrastructure configuration and operational methods of the buoy support wintertime operations. However, power requirements need to be reassessed if operations, sensor package, or sampling intervals are substantially changed.

The data quality was affected by the lengthened sampling interval during deployment 5. For chlorophyll and light transmissivity, the sampling interval was initially set to once per day for deployment 5, which significantly reduced data resolution for these parameters. For each of the previous four deployments, these parameters were measured at a higher frequency, ranging from 15 minutes to one-hour intervals. This higher frequency sampling is necessary to adequately assess short-term changes. If the goal of long-term monitoring is to define baseline nearshore conditions, then a once-per-day sampling scheme may suffice. One result of longer sampling intervals is shown by comparing event 8 (Figure 9) and deployment 5 (Figure 6), in which it occurred. The longer date range of the full spring period results in smoother data trends, whereas the shorter event date range shows blocky, irregular curves. Lower sampling rates may miss short-term events in the nearshore, where stream runoff or storms may affect water clarity for periods of less than 24 hours. In the summertime, sampling frequency can be increased because there is more power recharge. Also, sample timing can be shifted in to the daylight hours when recharge is sustained. For nearshore threshold management, the benefits of sampling three or more times per day may outweigh the benefits of power preservation of less frequent sampling. For the buoy, a sampling interval for the internal sensors of once every two hours is suggested to accommodate power considerations and statistical significance for short-term events. Alternatively, sampling once per hour, which rotated through three different water depths, would combine depth-integrated sampling while allowing for power and resolution considerations. Even though each reported turbidity data point is an average of up to 100 consecutive readings, multiple discreet measurements will be beneficial for statistical analysis of long-term trends.

5.1.2 Effectiveness of anti-biofouling approach

The implemented system in 2010 for eliminating biofouling of the light transmissometer and chlorophyll sensors by using a dual bladder system filled with a liquid solution of anti-biofouling compounds worked well. There was no discernible level of biofouling to the internal sensors. The pump and solenoid active anti-biofouling system required minimal maintenance, as the halide biocide fluid did not lose efficacy or significant volume over time. These results indicated that the cleaning cycle frequency can be reduced in winter to give lower power requirements, as biofouling does not readily occur at that time. Cleaning frequency is then increased in summer as the air and water warms, which improves battery performance, and increased sunlight recharges the batteries through the solar panel. Considering the poor anti-biofouling results from the pilot study and the amount of periphyton attached to the undercarriage of the buoy upon removal in June 2011 (Figure 12) the new configuration using an active anti-biofouling approach can be considered successful.

Figure 12. The buoy upon removal on June 2, 2011 showing the amount of algae growth on the aluminum infrastructure. Upright, at the right side of the photo, are the internal sample intake lines, which would hang down in to the water column during normal operation.

5.1.3 Nearshore clarity during Asian clam tarpaulin removal

In the first week of November 2010, the University of California, Davis TERC team removed a tarp from the substrate designed to inhibit Asian clam growth (Wittman et al, 2012). The buoy was placed at the anchor closest to the tarp removal area at the beginning of the fourth deployment on November 1, 2010. The buoy was approximately 200 meters away from the tarps at this time. Although the equilibration of the light transmissometer at the beginning of this deployment occurred at the same time as the tarp removal, small changes in water clarity were observed (Figure 13). The red line shows the 0.92 meter depth light transmissivity, which clearly spikes to less than the middle (0.46m) and upper (0.23m) depth intervals. The clarity reduction for this event was not consistent with timing or depth, as there was a different amount of response at each depth. In addition, the travel time of a potential disturbance from the Asian clam tarps to the buoy location is unknown. Each of the spikes in clarity loss occurs over a period of 3 to 6 hours, lending credence to their interpretation as real phenomena not false readings. That the turbidimeter does not indicate a clarity reducing response may mean that it was not sensitive enough to respond to the modest clarity disturbance. Other nearshore clarity reducing events commonly showed light transmission below 90% during events. The spikes in reduced light transmission are real, if small and short-lived.

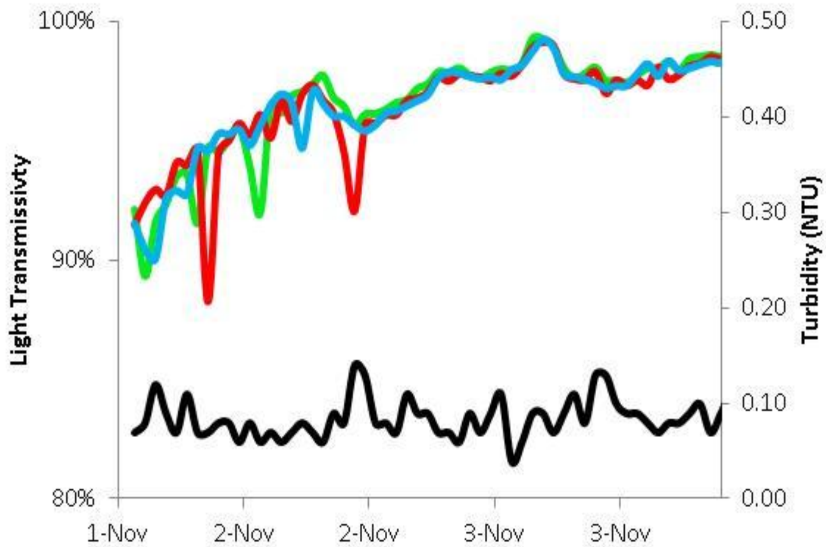


Figure 13. Details of equilibration shift at the beginning of deployment 4, corresponding to the time period of the removal of Asian clam deterrent tarps. Black line is turbidity, blue line is 0.23 meter depth light transmissivity, green line is 0.46 meter depth light transmissivity; red line is 0.92 meter depth light transmissivity.

5.1.4 Profiling and sample collection by depth

Depth profiling of light-transmissivity, chlorophyll and water temperature provided information about mixing and layer stratification to a depth of 0.92 meters. For water temperature, measurements showed important mixing events with wind and sun (Figure 11). The issues that arose because of the added depth profiling of internal sensors included: solenoid shorts, battery drawdown, and baseline shifts. Yet, these issues have been addressed during this study and strengthen the buoy for future deployments. The findings of light transmissivity response at different depths for the Asian clam tarp removal should not be discounted. But, if the buoy is to be used for long-term threshold monitoring, measurements at only one depth would be recommended based on these findings because the difference was relatively small over the long-term and do not justify the higher costs and complexity of the depth sampling system. If the buoy is to be placed in high traffic recreational areas or near creek outfalls to monitor high-impact events, then depth profiling should be used. Temperature profiling is scientifically relevant and can be achieved at minimal cost, so should be retained.

5.1.5 Solenoid electrical short

This project employed four solenoid valves, which were installed as part of the anti-biofouling and multiple-depth sampling system. Two solenoids were used to direct the flow of water from one of three different depth intake lines. The remaining two solenoids opened and closed during the cleaning cycle to separate the sample intake lines from the anti-biofouling fluid. The anti-biofouling fluid was pumped through the sample cells of the light transmissometer and chlorophyll meters.

The end of the third deployment was forced by a failure of the electrical system (See Section 3.1). Automotive solenoid valves were used for this project as a cost-saving measure, as submersible marine-type solenoids are one or two orders of magnitude more expensive. The silicone used to waterproof the solenoids was applied in layers with a caulk gun, which worked well for a majority of the deployment period. Doing a good job of encasing the solenoids in silicone is imperative. As an alternative, the automotive solenoids could be potted in liquid rubber that will solidify and create complete protection against water.

5.2 Suggestions for Improving Buoy Operations

Adding sensors to determine correlation between ultraviolet light and the growth rate, and the pervasiveness of invasive species would be advisable. Primarily a summertime issue, growth rates of periphyton algae may be tied to the amount of ultraviolet light that is incident at the substrate level. *Spirogyra, Zygnema, Mougeotia, Cladophora* have been found in clumps or masses rolling over the bottom sediments. These filamentous greens also grow attached to the limited fixed substrate in the nearshore including submerged macrophytes. Long-term nearshore water quality measurements would provide a good reference for possible interpretation of invasive species movement, growth, and durability. The information gathered will be of use to ecological researchers at the University of Nevada, Reno, who are studying invasive crayfish and periphyton.

The buoy was located in Marla Bay near the large Asian clam beds of Nevada Beach for this project. There are few on-shore discharges to Lake Tahoe in this bay, yet there were significant increases in turbidity that have tentatively been ascribed to wind-driven resuspension. Determining the wind-driven re-suspension of substrate sediments, beach erosion, or transport from other areas on water clarity would help assess the impacts that weather has on nearshore clarity. The results of tentative correlation, found in Table 2, between turbidity and high-wind weather events call for further investigation.

5.2.1 Potential Uses of Buoy for monitoring purposes.

A buoy-based system provides the ability to continuously monitor near-shore water clarity, a deficiency in existing short- and/or long-term nearshore monitoring programs. A temporally explicit data set provides the opportunity for trend analysis, including approaches such as exceedance curves. Therefore, the use of buoys provides one avenue for basin managers to address spatial differences in the nearshore. Buoys could be placed at multiple sites or different regions of the lake (e.g., pristine versus urbanized, Upper Truckee River versus urban runoff outfalls). Consider these potential uses of a buoy monitoring system:

1) Single buoy deployment. Increase ecological significance of monitoring through the addition of monitoring temperatures at several depths, and augmentation of the sample collection system so that water collected from several depths can be analyzed. One deployed buoy would not provide enough spatial significance to give data with statistical significance. A potential use of deploying just one buoy would be to move the buoy around to areas of interest, e.g.—place it at the mouth of the Upper Truckee River during the snowmelt runoff period and then move the buoy to a background clarity area for the fall/winter, such as off Sand Harbor. The associated costs would not be negligible, as the buoy platform itself is in need retrofitting and moving the buoy would require the use of a boat, which also is not insignificant. Total estimated cost for one year-round buoy deployment: $65,000.

2) Two to four buoys. The patchwork nature of previous nearshore studies has posed challenges to interpreting on-going changes in Lake Tahoe's nearshore ecology and water quality. There is a need for year-round measurements of one of the more consistently clear nearshore areas of Lake Tahoe, especially as pertains to background conditions before or during algae influx. Total estimated cost for each buoy more than one, year-round buoy deployment: $35,000.

Combination of monitoring platforms

1) Buoys & Boat. To include (1) deployment of a network of near-shore monitoring buoys placed at strategic locations around the lake; and (2) a regular program of periodic lakeshore measurements and sampling around the near-shore zone conducted by boat. This combination of temporally continuous sampling (buoys) and spatially continuous sampling (jet boat) would give a comprehensive view of nearshore water clarity changes. Total estimated cost for each year-round buoy deployment: $35,000 each, and jet boat full-lake monitoring: $5,000 per sampling trip.

6.0 SUMMARY AND RECOMMENDATIONS

Since 2001, nearshore clarity has been assessed using a "snapshot" approach. Although these surveys provided the nearshore clarity conditions the day they were taken, they have not been suitable for long-term trend analysis because of a lack of data between surveys. In 2008, NDSL funded a nearshore buoy project whose goal was the proof of concept of measuring the ultra-clear waters of Lake Tahoe with a custom-built modular sensor system. In 2010, the buoy was reconfigured to add a new anti-biofouling approach and measure parameters at depth. Specifically:

1. Monitor environmental conditions for a full year.

   A buoy-based system provides the ability to continuously monitor nearshore water clarity. A temporally explicit data set provides the opportunity for trend analysis, including approaches such as exceedance curves. The pilot study was only conducted from May to October 2008 and did not include a winter period that presents several additional operational challenges. The issue of maintaining sufficient battery power was addressed by increasing the size of the battery and solar panel, and reducing the frequency at which power-draining subsystems were operated. On-board power consumption was not found to be an issue during the summer. However, operation during winter required increased battery capacity and/or a reduction in power consumption obtainable through altering the frequency of monitoring and telemetry connections. Routine maintenance and sensor cleaning were easily accomplished by field personnel using a canoe or dinghy throughout the year, as there was immediate access to the buoy by boat ramp. However, this ease of access may not be true at other locations around the lake for future deployments.

2. Test a new anti-biofouling design.

   The pilot study found that biofouling was primarily a summertime issue, but that some sensors, such as light transmissivity, were susceptible to biofouling in 7 to 10 days using simple and passive anti-biofouling approaches. A new, active, closed system approach using an anti-biofouling solution was implemented. This approach was deemed successful despite a solenoid failure in December 2010. Biofouling of the light transmissometer and chlorophyll meters were controlled with halide anti-biofouling treatments once per week, and resulted in undetectable biofouling. Biofouling did not appear to impair turbidity readings as long as the sensor’s wiping mechanism was activated prior to each measurement. Biofouling was not observed while deployed during the colder water temperatures of November through April 2010.

3. Increase the ecological significance of monitoring.

   This was accomplished by the addition of profiling water temperatures at several depths, as well as an augmentation of the sample collection system so that water could be gathered from several depths for clarity measurements. Turbidity is useful for monitoring high-impact or runoff events that can affect invasive and endemic species movement and growth. Light transmission is preferred for monitoring the clarity of Lake Tahoe’s ultra-oligitrophic waters and background conditions because of its higher resolution and sensitivity. Transmissometers provide stable readings under non-degraded background conditions, are sensitive to small changes in water clarity, and measure both absorption and scattering. Light transmission and relative chlorophyll sensors required additional infrastructure and power considerations. These parameters, though, did not see much variability with depth in the deeper waters of Marla Bay and were deemed as not cost-effective for this particular deployment. If the buoy were placed at the outfall of a stream, more changes with depth would be expected. In addition, the depth-profiling of temperature was cost-effective and showed expected changes, driven by air temperature, solar radiation, and wind. Future deployments could profile temperatures down to the substrate level to provide information for invasive species studies.

6.1 Recommendations

Specific recommendations in construction and operation of a nearshore buoy include:

- A nearshore monitoring buoy is highly recommended for inclusion in any long-term monitoring plan. However, the deployment of four or more buoys may be necessary to reduce costs through economies of scale. The relatively inexpensive cost for a temporally consistent data set would be invaluable to the determination of water clarity improvement efforts. If the goal of best management practices and/or implementation of new nearshore clarity metrics is to improve the health of the ecosystem, the enjoyment of stakeholders, and the economy of the basin, then continuous monitoring is essential. The most reliable method of determining cause and effect of TMDL regulations and/or new thresholds is to monitor directly, in real-time the constituent of concern, water clarity.
- Water temperature should be measured and profiled at depth. Wind events cause mixing that can affect the types of particles suspended in the water column. Changes in water temperature with depth provided evidence of when significant mixing had occurred. The 2008 pilot study also noted that temperature changes could detect the influence of rain or snowmelt-fed creeks on the nearshore zone.
- The location of the buoy should be relatively close to shore, located in approximately two to four meters of water. Short-term deployments could be located in shallower water, given that the water depth did not drop below 1 meter to accommodate depth profiling equipment. Multiple buoys could be used to assess spatial changes around the lake. This study observed unaccounted for turbidity increases; which may have been a potential correlation of sediment resuspension and wind. Sediment resuspension may be significant source of nearshore clarity loss, but causality was not definitively determined. If the goal of monitoring is baseline/regional measurements this approach would not be successful. But, if the goal is to observe short-term, localized threshold exceedances, this would be the preferred method.
- Anti-biofouling measures are imperative. For the internal sensors, light transmissometer and chlorophyll, both passive and active cleaning systems were tested. The active system employed in 2010 achieved good anti-biofouling results. These measures helped to minimize sensor drift. Submersible sensors must include a wiper to eliminate biofouling.
- The baseline shifts and equilibration of the light transmissometer revealed problems

with their long-term field deployment. Surfactant treatment schedules should be implemented to minimize sensor equilibration problems that arise at the outset of a deployment. A solution to the baseline shift problem would be to calibrate the light transmissometer with deionized water and clean the lenses on a more frequent basis.

- Develop specific procedures and guidelines for collecting and analyzing data to support nearshore management objectives. The modular construction and flexible operation systems of the buoy allow for the monitoring of most water quality parameters. Measurement types, schedules, and purpose can each be manipulated toward management ends.
- Expand the functionality of the buoy by incorporating ultra-violet light sensors. These sensors could be placed at water surface and at the substrate level to inform ecologists about different environmental conditions that facilitate invasive species encroachment.

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8.0 REFERENCES

Byron, E.R. and C.R. Goldman. 1986. A technical summary of changing water quality in Lake Tahoe: The first five years of the Lake Tahoe Interagency Monitoring Program. Tahoe Research Group Institute of Ecology. University of California, Davis. 62pp.

Cozar, A., J.A. Galvez, V. Hull, C.M. Garcıa, S.A. Loiselle. 2005. Sediment resuspension by wind in a shallow lake of Esteros del Iber´a (Argentina): a model based on turbidimetry. *Ecological Modelling* 186: 63–76

Gabrielson, J.O., R. J. Lukatelichb. 1985. Wind-related Resuspension of Sediments in the Peel-Harvey Estuarine System. *Estuarine, Coastal and Shelf Science* 20: 135-145.

Goldman, C.R., A.D. Jassby, and S.H. Hackley. 1993. Decadal, interannual, and seasonal variability in enrichment bioassays at Lake Tahoe, California-Nevada, U.S.A. Can. *J. Aquat. Sci.* 50: 1489-1496.

Jassby, A.D., C.R. Goldman, J.E. Reuter, and R.C. Richards. 1999. Origins and scale-dependence of temporal variability in the transparency of Lake Tahoe, California-Nevada (USA). *Limnol. Oceanogr.* 44(2): 282-294.

Lewis, J., Eads, R., and R. Kein. 2007. Comparison of Turbidity Data Collected with Different Instruments. USFS. [URL: http://www.fs.fed.us/psw/topics/water/tts/Tprobe%20final%20report.pdf] Accessed 2/5/09.

Reuter, J.E. and W.W. Miller. 2000. Aquatic Resources, Water Quality, and Limnology of Lake Tahoe and Its Upland Watershed. *In:* Lake Tahoe Watershed Assessment: Volume 1. (Eds) D.D. Murphy and C.M.

Susfalk, R., A. Heyvaert, T. Mihevc, B. Fitzgerald, K. Taylor. 2009. Linking On-Shore and Near-Shore Processes : Near-Shore Water Quality Monitoring Buoy at Lake Tahoe. Prepared by Desert Research Institute Division of Hydrologic Sciences for Nevada Division of State Lands.

Susfalk, R.B. and B. Fitzgerald. 2011. Influence of Urban Runoff on Nearshore Water Quality at Lake Tahoe. In "Predicting and Managing Changes in Near-Shore Water Quality – SNPLMA Round 7 Final Report " (S.G. Schladow et. al.)

Taylor, K. 2002. Investigation of Near Shore Turbidity at Lake Tahoe. Desert Research Institute Division of Hydrologic Sciences Publication No. 41179. [URL: http://www.dri.edu/images/stories/research/programs/tahoe-nearshore-water/final02-10.pdf] Accessed 1/13/12.

Taylor, K., R. Susfalk, M. Shanafield, and G. Schladow. 2004. Nearshore Clarity at Lake Tahoe: Status and Causes of Reduction. Desert Research Institute Division of Hydrologic Sciences Publication No. 41193. [URL: http://www.dri.edu/images/stories/research/programs/tahoe-nearshore-water/DRIReport41193.pdf] Accessed 1/13/12.

Wittmann, M.E., S.Chandra, J.E. Reuter, S.G. Schladow, B.C. Allen and K.J. Webb. 2012. The Control of an Invasive Bivalve, Corbicula fluminea, Using Gas Impermeable Benthic Barriers in a Large Natural Lake. Environmental Management. DOI 10.1007/s00267-012-9850-5.