Investigation of Near Shore Turbidity at Lake Tahoe

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SUMMARY

The spatial and temporal variability of turbidity in the near shore zone of Lake Tahoe was investigated using an instrumented boat to map the spatial distribution of turbidity. The highest turbidity values were in the lake adjacent to Tahoe Keys and exceeded the TRPA littoral zone turbidity threshold. Areas with persistently high turbidity occurred off South Lake Tahoe and Tahoe City. Areas with occasional high turbidity occurred off Incline Village and Kings Beach. Undeveloped areas such as Rubicon and Deadman Point consistently had low turbidity. There is a strong correlation between elevated turbidity near the shore and development on the shore. It is likely that most of the clarity loss near the shore is caused by processes that occur along a small percentage of the lakeshore.

INTRODUCTION

Lake Tahoe is well known for its exceptional clarity. Maintaining this clarity is important for aesthetic, economic, public health and ecological reasons. The clarity of Lake Tahoe is most apparent near the shore, which we call the near shore zone and define as the portion of the lake that has a depth less than 7.5 m, or is within 100 m of shore, which ever extends further from shore. The near shore zone is similar to the littoral zone, which is the portion of the lake where enough light reaches the bottom for macrophytes (rooted plants) to grow. At Lake Tahoe the littoral zone is the portion of the lake were the depth is less than about 30 m; this can be a zone a few tens of meters to several kilometers wide. Except for atmospheric deposition all the clarity degrading material such as nutrients and particles that enter the lake pass through the near shore zone, making the near shore zone a good place to search for undesirable inflows to the lake. The near shore zone is the portion of the lake first impacted by disturbances on shore because the material causing the adverse impact will have the greatest concentration near the source on shore. The near shore zone is also be the portion of the lake that responds first to local restoration activities, because it is more influenced by local changes than the center of the lake.

The Tahoe Research Group at the University of California, Davis, has been monitoring the clarity of Lake Tahoe using a secchi disk for 34 years. This measures the greatest depth at which a black and white 20 cm diameter disk is visible. These measurements cannot be made in most of the near shore zone because the water depths are not greater than the 20 to 25 m depth at which the secchi disk commonly fades from view. There has been a progressive decline in clarity as measured by the secchi depth during the last 34 years.

Another measure of clarity is turbidity, which is a quantitative measure of how much light is scattered by the particles in a water sample. High turbidity water is murky, low turbidity water is clear. Turbidity is expressed in Nephelometric Turbidity units (NTU), which are based on standard concentrations of formazin in water. At Lake Tahoe clarity is traditionally thought of in terms of secchi depth, which is easier to understand than turbidity. For example it is easier to understand the significance of being able to see a dinner plate 30 meters below the surface, than the turbidity is 0.1 NTU. However, secchi measurements cannot be done in shallow water and are time consuming. Turbidity can be measured in water of any depth and can be measured continuously from a moving boat; this makes turbidity well suited for investigating the spatial variability of water clarity in the near shore zone. Turbidity values at Lake Tahoe range from 0.06 NTU in the middle of the lake to greater than 4 NTU at Tahoe Keys. For reference filtered distilled water typically has a turbidity of 0.02 NTU and the EPA standard for drinking water is 0.5 NTU.

METHODS

For this project we primarily used two measurement systems, one for investigating spatial changes and the other for investigating temporal changes. The first system was on a moving boat and measured spatial changes in turbidity. The second system was fixed on a pier and measured the temporal variability of light attenuation. Light attenuation is a proxy measurement for turbidity.

Method 1: Spatial Measurements

The turbidity measurement system had a probe that extended in front of the boat. A submersible pump on the probe pumped water from a depth of ~1 m up to instruments on the boat. The water entered a glass tube (5 cm x 2 cm) in a Hach-2000 turbidity meter. The turbidity was determined by measuring the amount of light scattered at a 90-degree angle from an incoming light beam by water in the glass tube. The turbidity instrument was calibrated with formazin standards every three weeks, and with solid turbidity standards before and after each day of surveying. A computer read the voltage output of the turbidity meter. The computer also read the location of the boat from a global positioning system that has an accuracy of about 20 meters. The computer recorded the turbidity, time and boat location in a data file. This information was recorded every second, which corresponded to about one measurement for every 10 m of distance traveled. The computer also displayed a real time moving map that showed the track of the boat. The color of the boat track on the display was determined by the value of the turbidity at that location. The real time map display of turbidity and position allowed the operators to adjust the survey parameters in the field in response to areas of high turbidity.

On one survey a Turner 10-AU fluorometer was also used. After the water passed through the turbidity meter it entered the glass tube in the fluorometer. A monochromatic light shined on the water in the glass tube. Chlorophyll in the water fluoresced with a different wavelength of light. The amount of light fluoresced was proportional to the chlorophyll concentration in the water.

Surveys were repeated with a positioning accuracy of about 30 m. Typically the surveys were conducted 20-300 m offshore and the operator selected a distance that was free of obstacles such as buoys and boats. Under these conditions we operated at speeds of 15 to 20 kilometers an hour. Some surveys occurred within the obstacles at a slower speed. About 10% of each survey was immediately repeated. This was done by turning the boat around and repeating a portion of the survey. This was done occasionally when rapid changes in turbidity were observed. The survey data was processed to convert the recorded voltage and position values to meaningful units and files that are suitable for use by the geographic information system Arcview.

Method 2: Temporal Measurements

The second system measured the amount of light attenuation in the lake water over a 30 cm path. The instrument, a Hobilabs C-Beta, was lowered into the lake. A light source on the instrument shined a light beam to a light sensor located 30 cm away from the light source. The attenuation of

the light over the 30 cm path was expressed in units of % absorption/meter, or more commonly as 1/m. The optical design of the instrument reduced interference caused by sunlight.
The C-Beta had an internal data logger that allowed it to be moored at a fixed location and measure light attenuation at regular intervals. In this survey the light attenuation was measured every 20 minutes. This allowed a proxy for turbidity to be measured continuously at a fixed location without an operator. A rough empirical estimate of the relationship between turbidity and light attenuation was developed, but it should only be used to estimate changes in turbidity, not the absolute value of turbidity. With more effort a better relationship could be obtained.

SPATIAL SURVEY RESULTS

General Comments

The results of spatial surveys are displayed on maps that show the track of the boat in different colors. The color of the boat track is selected to represent a property of the water. For example, red indicates high turbidity, green indicates intermediate turbidity, and blue indicates low turbidity. The turbidity value assigned to the colors is different on different figures so small differences in turbidity relevant to the discussion can be displayed. With a few exceptions the surveys do not show how the turbidity changes perpendicular to the shore. When surveys where conducted away from the shore, the turbidity decreased with increasing distance from shore.

Short-term Variations

To investigate the short-term variability of turbidity several sets of surveys were carried out a few days to weeks apart. Figure 1 shows two surveys made of the lakeshore 11 days apart in September 2001. The high turbidity areas with large extent (more than 3 km in extent and greater than 0.2 NTU, shown as orange and red) in Emerald Bay and off Tahoe City and South Shore occur in both surveys. The moderate turbidity areas with smaller extent (less than 1 km in extent and between 0.16 and 0.25 NTU, shown as yellow and orange) such as Incline Village and Glenbrook change over the 11 days between the surveys. There was no precipitation during this time. During the period between the two surveys the Star Fire, a large fire about 30 km west of Lake Tahoe, filled the Tahoe Basin with thick smoke for about a week that at times reduced visibility to a few miles. There was not a lake wide change in turbidity associated with the influx of thick smoke that occurred between the two surveys.

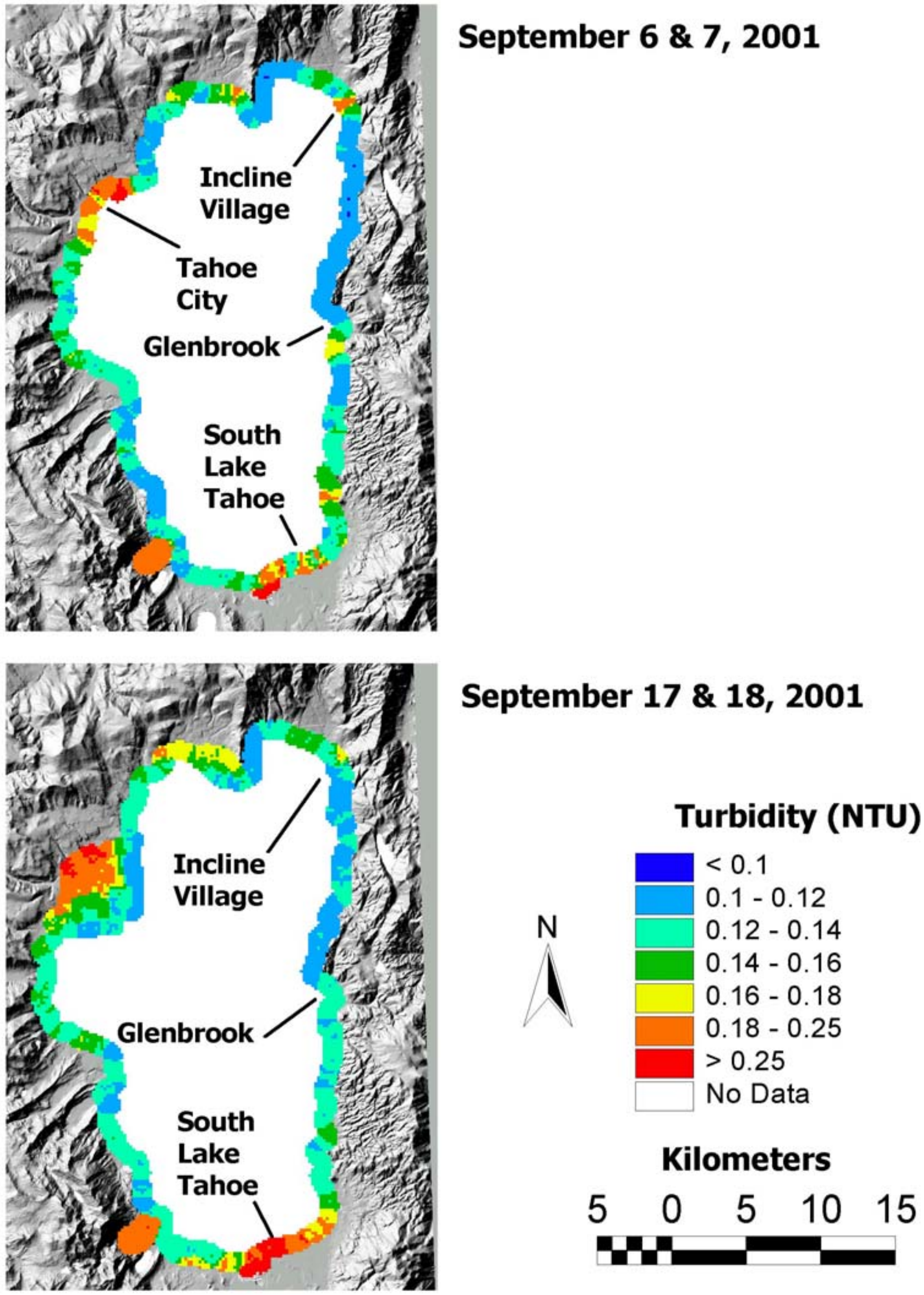

Figure 1. Results from two near shore turbidity surveys of the entire lake taken 11 days apart in September 2001.

A closer inspection of the area off Glenbrook (Figure 2) shows that on September 6, 2001, there was a zone of elevated turbidity (greater than 0.17 NTU, shown as yellow, orange and red) bounded to the south by low turbidity (less than 0.13 NTU, shown in blue). Eleven days later the elevated turbidity zone was gone. The cause of this minor and short duration increase in turbidity is not known. It is unlikely there was a change in surface inflows between these surveys because there was no precipitation and there is no stream outlet it the area. Upwelling of high turbidity water is a possible cause for this transient phenomenon.

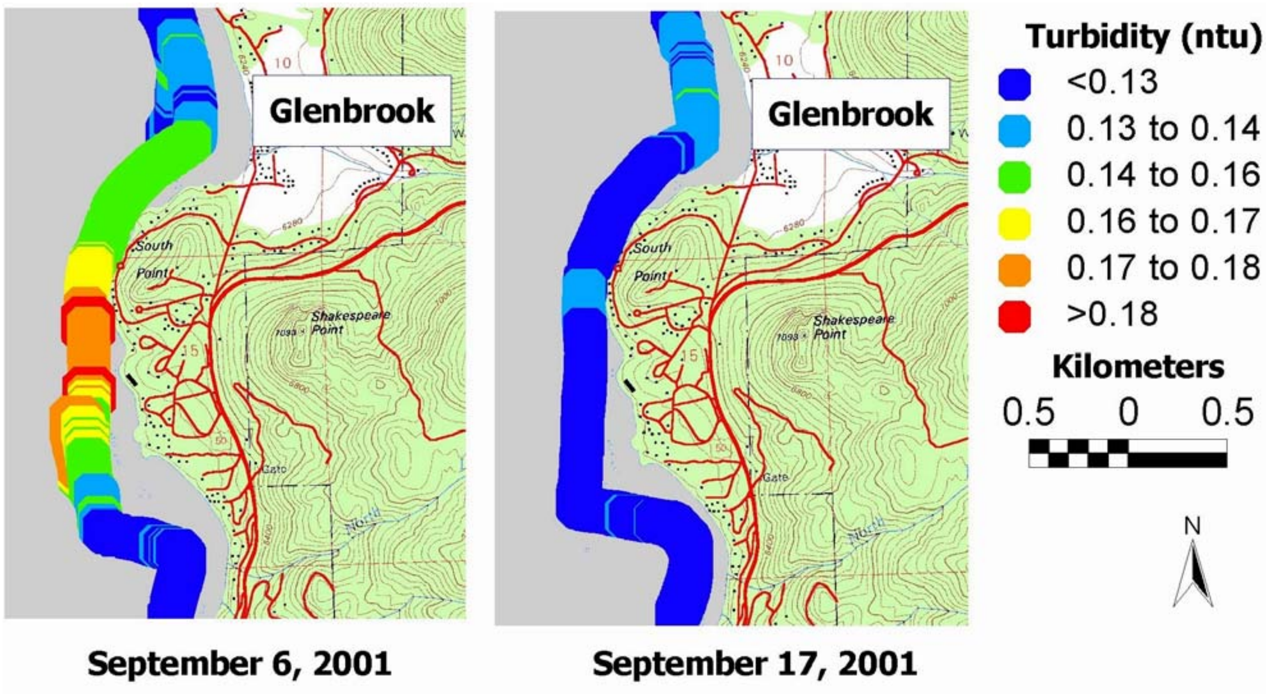

Figure 2. Detailed view of two near shore turbidity surveys off Glenbrook taken 11 days apart in September 2001.

A second example of short-term changes in turbidity is two surveys off Homewood on March 8 and 14, 2001 (Figure 3). From a lake wide perspective this is a low turbidity area. The lowest turbidities in this area are less than 0.07 NTU and the highest turbidity levels are around 0.11 to 0.13 NTU. There was only a small change (~0.03 NTU) close to shore between the two surveys. The area at the mouth of Homewood Creek, which runs through Homewood ski area, had the highest turbidities (0.10 to 0.13) during this period, however these values were still low relative to other locations along the lakeshore.

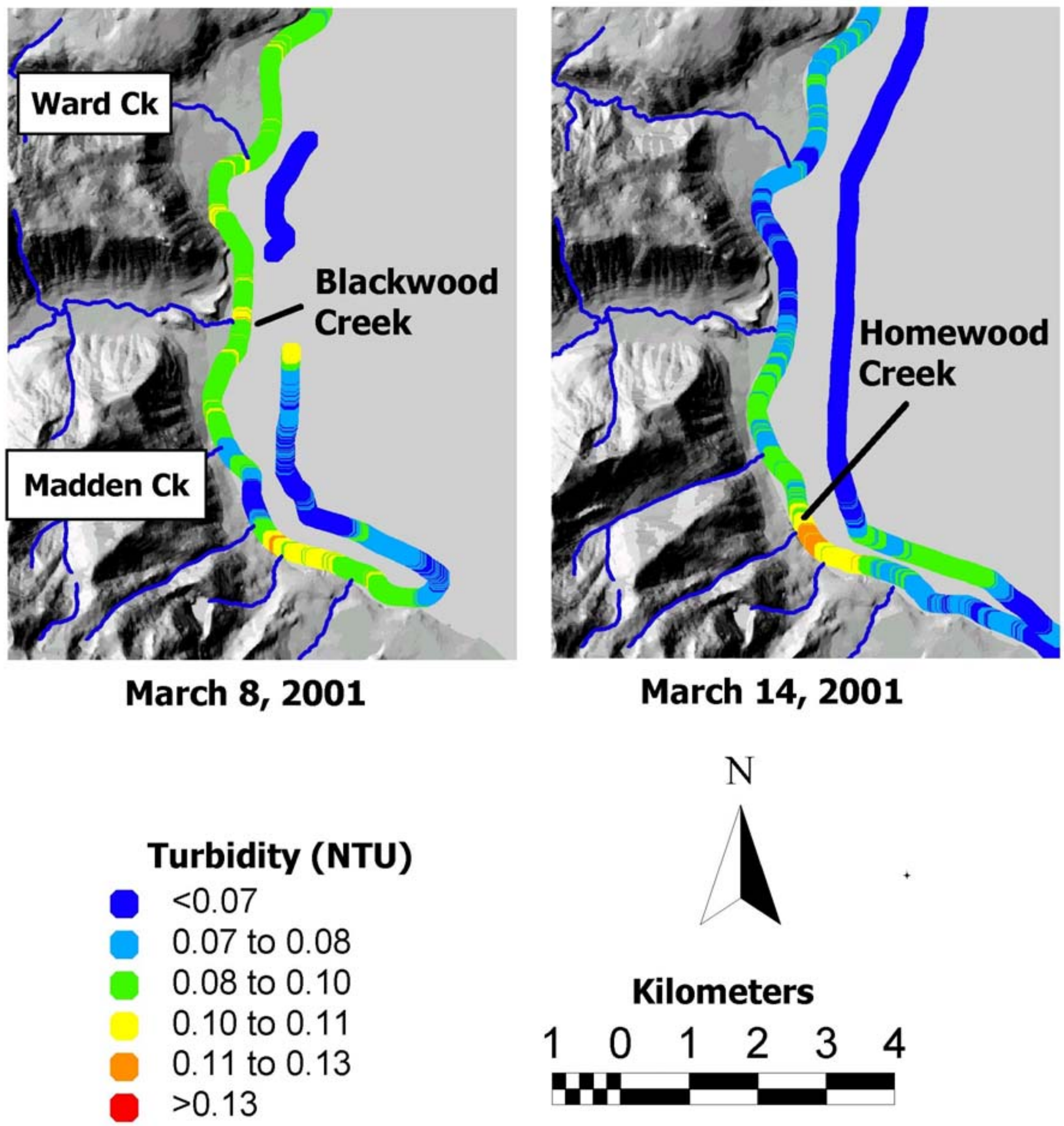

Figure 3. Turbidity surveys in McKinney Bay.

A third example of short-term changes in turbidity is four surveys off of Tahoe City conducted during March 2001 (Figure 4). Three of the four surveys showed elevated turbidities between the Tahoe City Marina and the outlet to the Truckee River (elevated to levels of 0.12 to 0.16 NTU above a background of less than 0.08 NTU). Two of three surveys also showed elevated turbidity in the vicinity of Star Harbor (elevated to levels of 0.1 to 0.16 NTU above a background of less than 0.08 NTU shown as dark blue). These features were also observed in August 2001 and are discussed later in this report.

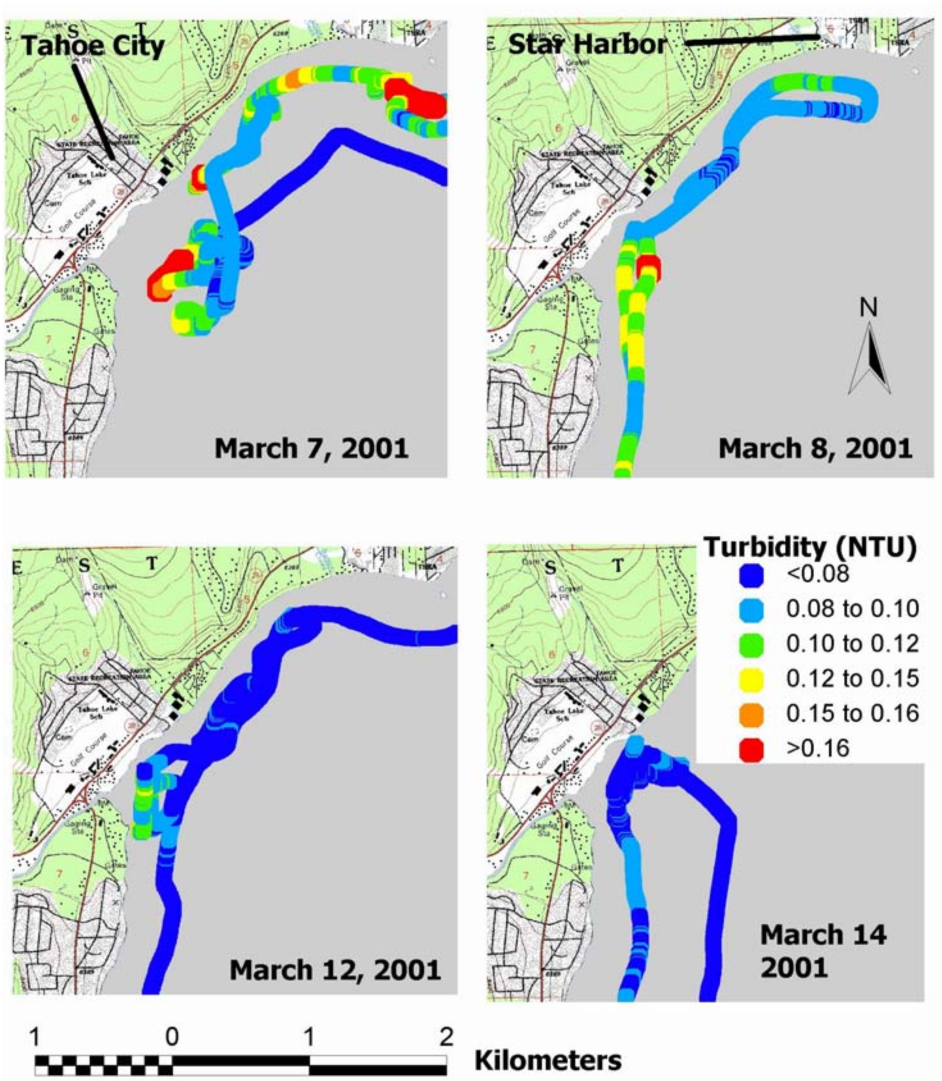

Figure 4: Turbidity surveys off Tahoe City in March

These examples show that areas of elevated turbidity with an extent of many kilometers can be persistent on time scales of weeks, but areas with elevated turbidity with an extent of less than a kilometer can change significantly in a few weeks. These examples highlight how repeated spatial turbidity surveys can identify areas with persistent elevated turbidities.

Seasonal Surveys
Surveys were made during different seasons to identify seasonal patterns in turbidity. Generally the seasonal surveys (Figure 5) were made during periods when the weather had been calm for several days preceding the survey. Precipitation occurred during the September 2001 and March 2002 surveys, and repeat measurements of parts of survey show the storms did not influence the turbidity.

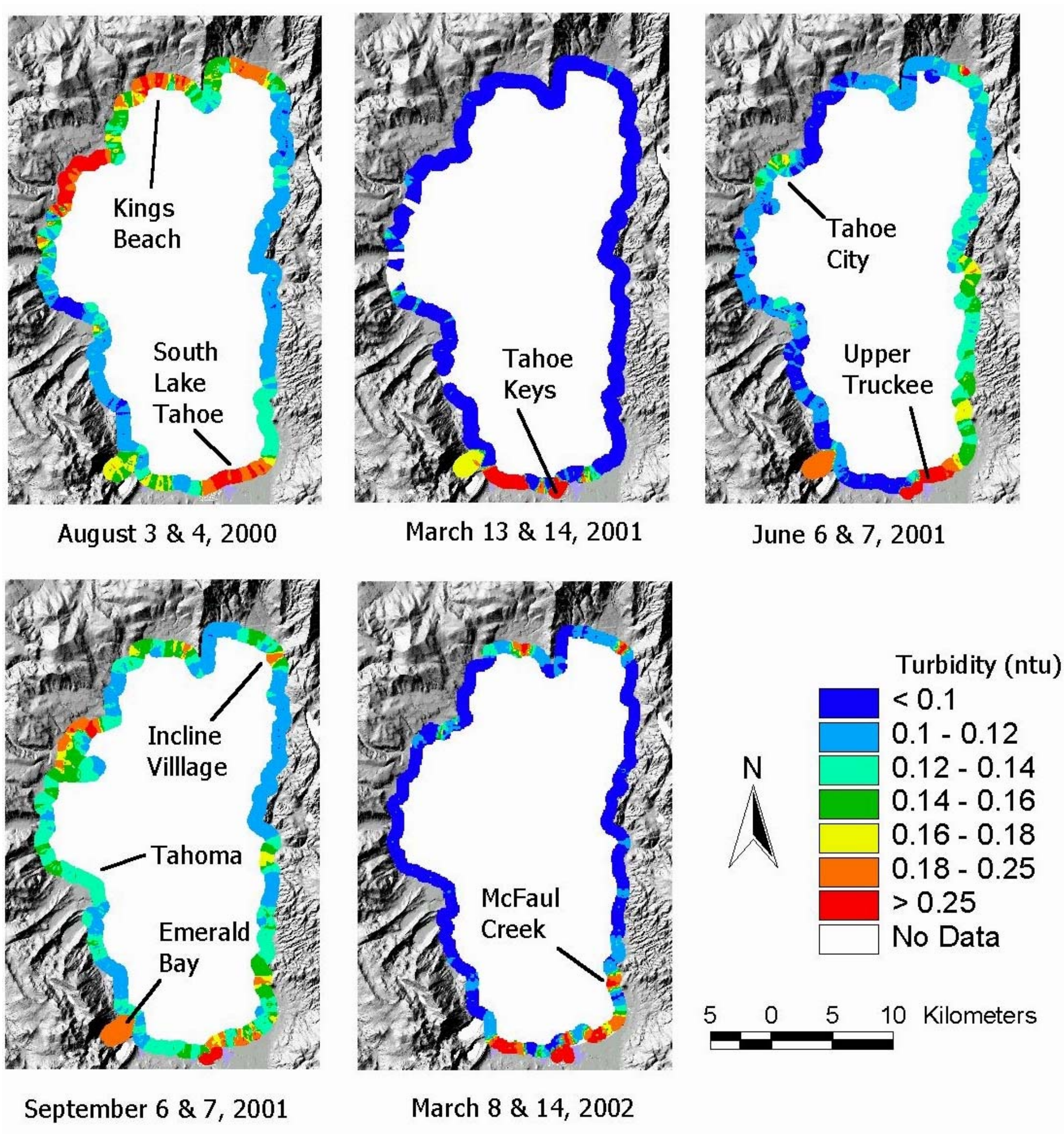

Figure 5. Results from near shore turbidity surveys around the entire lake in different seasons.

On August 3 and 4, 2000 there was high turbidity in both a relative and absolute sense (0.20 – 0.25 NTU) off the developed areas of Tahoe City, Kings Beach, Incline Village, and South Lake Tahoe. All of these areas have shallow water close to shore. However, the shallow areas off the southwest corner of the lake and off Tahoma, which are not heavily developed, do not have high turbidity. Hence, the high turbidity appears to be associated with developed areas and not with shallow water. Stream inflow of particles is negligible in August. In August the lake is warm, favoring algae growth. Algae growth early in the summer consumes the nutrients that accumulated in the lake during the winter and spring, so that in August there is not a supply of nutrients stored in the lake for algae to consume. Any algae growth in August is likely associated with an inflow of nutrients to the lake that is occurring in August, as opposed to consumption of nutrients that are stored in the lake from winter and spring. The high turbidity levels could be caused by boat traffic resuspending lake sediment, by the release of nutrients by lake sediment, or by nutrient rich groundwater inflows.

On March 13 and 14, 2001 a survey showed high turbidity centered at Tahoe Keys (greater than 1.0 NTU) and the Upper Truckee River outlet. This survey was taken during a warm spell when there was melting snow at lake level but the higher elevations where still frozen. The cold lake temperatures reduced algae growth and the main part of spring runoff had not yet occurred. The majority of the lake had a turbidity of less than 0.1 NTU, which is low relative to other seasons.

On June 6 and 7, 2001, a survey showed high turbidity (0.25 to 0.3 NTU) centered at South Lake Tahoe with a connected area of elevated turbidity (0.12 to 0.18 NTU) extending up the southeast shore. This survey was taken after spring runoff on the east side of the lake and during the last stages of spring runoff on the west side of the lake. The area of elevated turbidity along the southeast shore may be material that has driven along the shore from the South Lake Tahoe area by the prevailing winds. Moderate turbidity areas (0.12 to 0.18 NTU) with small spatial extent occurred off Glenbrook, Tahoe City and Incline Village.

On September 6 and 7, 2001, a survey showed high turbidity areas with a large extent (more than 2 km in extent and greater than 0.2 NTU) off Tahoe City and South Lake Tahoe. High turbidity areas were located off Kings Beach, Incline Village, Glenbrook and Round Hill but they had a smaller spatial extent.

On March 8 and 14, 2002 a survey showed several high turbidity areas with a large spatial extent along the south shore. Typically these areas were about 1 km in extent and had a turbidity of 0.25 to 0.3 NTU. There may be a strong correlation between turbidity and depth in this region during this season but we do not have enough data to determine if this is the case. Off Tahoe Keys there were locations in the lake with turbidity greater than 2 NTU. There were slightly elevated high turbidity areas with a small spatial extent (~500m in extent and 0.25- 0.3 NTU) off Kings Beach and Incline Village. There was an elevated turbidity area with a small extent (~500 m in extent and 0.25 to 0.3 NTU) off McFaul Creek, which also shows up in the September 2001 and August 2001. This creek was flowing when the survey was conducted. This survey was taken on two days. On March 8, the area from Tahoe City along the east shore to Tahoe Keys was surveyed. On March 14 the area from Tahoe City along the west shore to Tahoe Keys was surveyed. The day before each survey was made several inches on snow had fallen at lake level, which had not melted when the surveys were made.

These surveys indicate a close association between developed areas and elevated turbidity during the summer. Several interpretations of these data are possible. For example, summer surface inflows are probably not a factor in this association because summer surface inflows are small. Increased boat traffic around developed areas in the summer may resuspend lake sediments and increase the turbidity. Nutrients from developed areas may be entering the lake during the summer by groundwater inflow and enhancing algae populations. Nutrients from developed areas may also be entering the lake during the winter by surface and groundwater inflows and be stored in lake sediments. These stored nutrients may be released during the summer when the increased algae concentrations deplete the nutrients in the lake, creating a gradient in nutrient concentrations that draws nutrients out from storage in the sediments. With the available data it is not possible to definitely determine a cause for the spatial correlation of development and high summer turbidities.

Emerald Bay has consistently elevated turbidity values. This is likely caused by the limited exchange of water between the relatively shallow Emerald Bay and the deep water of the lake, the steep slopes with large road impacts around the bay, and the large inflow of surface water relative to the small and restricted area of the bay. These conditions make the water quality issues in Emerald Bay considerably different than other parts of Lake Tahoe.

Tahoe Keys/Upper Truckee River Outlet
The area around the outlet of the Upper Truckee River and the two entrances to the Tahoe Keys is discussed separately because the turbidity levels were an order of magnitude greater than any place else on the lake. Figure 6 shows the results from seasonal surveys at Tahoe Keys. At the scale of these figures, the track of the boat can be seen. The values of turbidity assigned to the colors are significantly greater than in the previous figures. In all cases when the boat entered the Tahoe Keys there was very high turbidity (greater than 0.5 NTU), in some cases the turbidity exceeded the 2-NTU maximum range of the measurement system. The two surveys in March 2001 and 2002 showed plumes of particularly high turbidity (values in excess of 2 NTU) in the lake. It is possible that during the late winter low elevation snow melt around the Tahoe Keys creates a flux of material from the Keys into the lake. The two summer surveys (August 8, 2000 and June 7, 2001) show that the highest turbidity areas are closer to the outlet of the Upper Truckee River than the entrances to Tahoe Keys. This suggests that during summer the Upper Truckee River or the Truckee Marsh is more of a problem than Tahoe Keys. More surveys, conducted in a grid pattern and during all seasons will be needed to characterize the spatial and temporal variability in this area so that the sources of turbidity degrading material can identified.

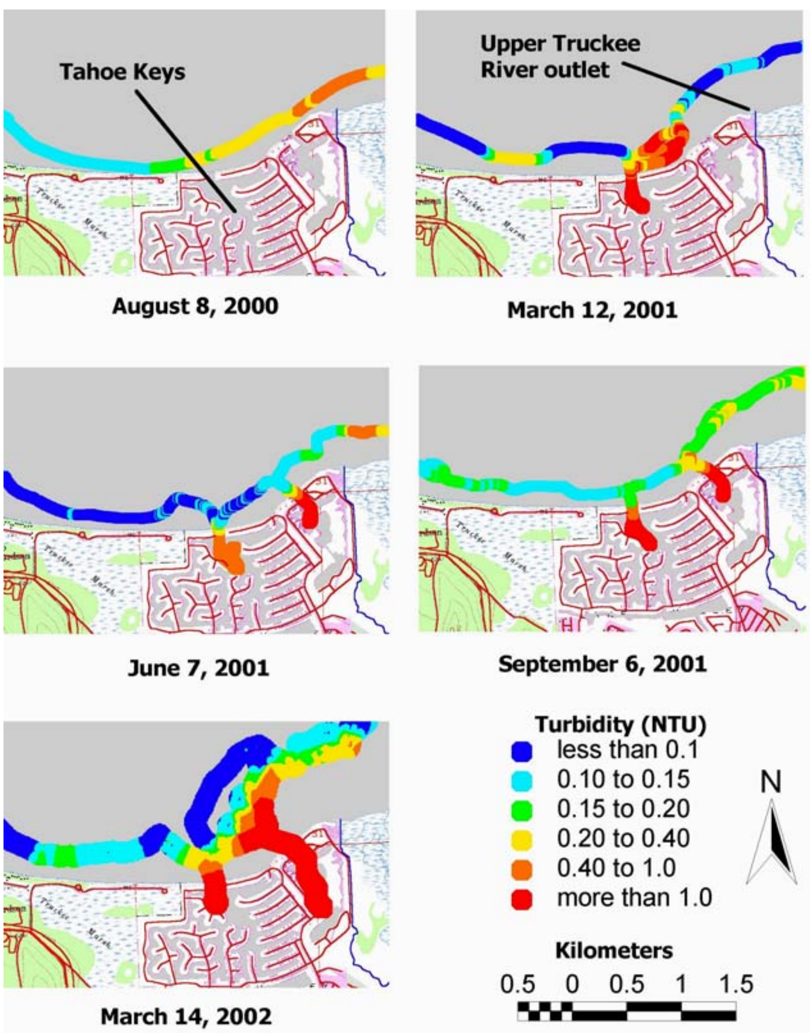

Figure 6. Results from near shore turbidity surveys around Tahoe Keys in different seasons.

Surveys Associated with Short Term Hydrologic Disturbances

We had two opportunities to measure turbidity before and after hydrologic disturbances, allowing us to determine the influence of the disturbances on turbidity. These results are presented in maps that show the difference between the turbidity values observed on different dates. Areas were the turbidity increased after the disturbances are shown in red. Areas were the turbidity did not change are shown in green. Areas were the turbidity decreased are shown in blue. For an area to be included in these surveys the survey tracks from before and after the storm had to be within 50 m of each other.

The first opportunity to measure the influence of a hydrologic disturbance on turbidity was associated with a summer thunderstorm. A survey had been conducted on August 3, 2001. In the afternoon of August 4, 2001, there was an intense thunderstorm producing 1.3 cm of rain in 12 minutes at the Thunderbird Lodge. This storm was accompanied by large amounts of overland flow, displacement of forest litter, and erosion and mobilization of the Highway 28 shoulder along the east side of the lake. On the morning of August 5, 2001, a second survey was conducted. Figure 7 shows the turbidity difference between the two surveys. The magnitude of the turbidity changes was very small and changes only occurred within a 100 meters of the discharge from Third and Incline creeks, and at the outlet of an unnamed drainage 200 m east of the Thunderbird Lodge. An even smaller increase was observed at Marlette creek. This result is only from one event, but it suggests that summer thunderstorms only contribute minor amounts of inorganic particles that imediately increase the turbidity. These surveys do not shed any light on the issue of if storm related inorganic material is transporting nutrients to the lake that promote algal growth and increase the turbidity at a later time.

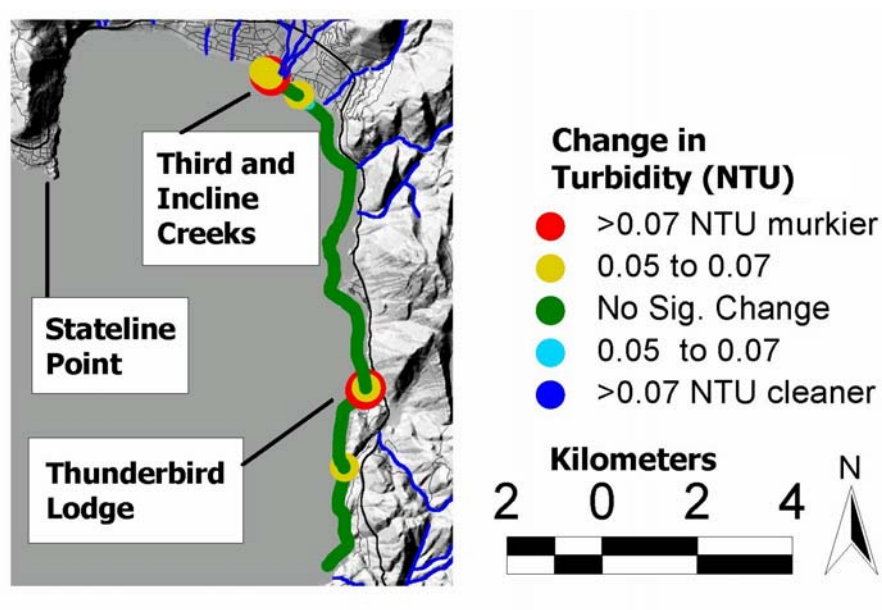

Figure 7. Change in near shore turbidity after an intense August thundershower.

The second opportunity to measure the influence of a hydrologic disturbance on turbidity was in September 2001. A turbidity survey was conducted on September 3, 2001. For the next three days there were high winds from the southwest and wave heights in the Incline Village area reached 0.7 meters. There was no precipitation during this time. A turbidity survey was conducted on September 7 and the difference between the two surveys is shown in Figure 8. The turbidity difference is very small, and only occurs within less than 100 m of the discharge from Third and Incline creeks. It is suspected that the increase in turbidity is caused by the resuspension of fine sediments associated with previous discharges from the creeks. This result suggests that moderate wave action along the northeast shore does not suspend enough particles to directly increase the turbidity 100 m off shore. These surveys do shed any light on the issue of if storm related inorganic material is transporting nutrients to the lake that promote algal growth and increase the turbidity at a later time.

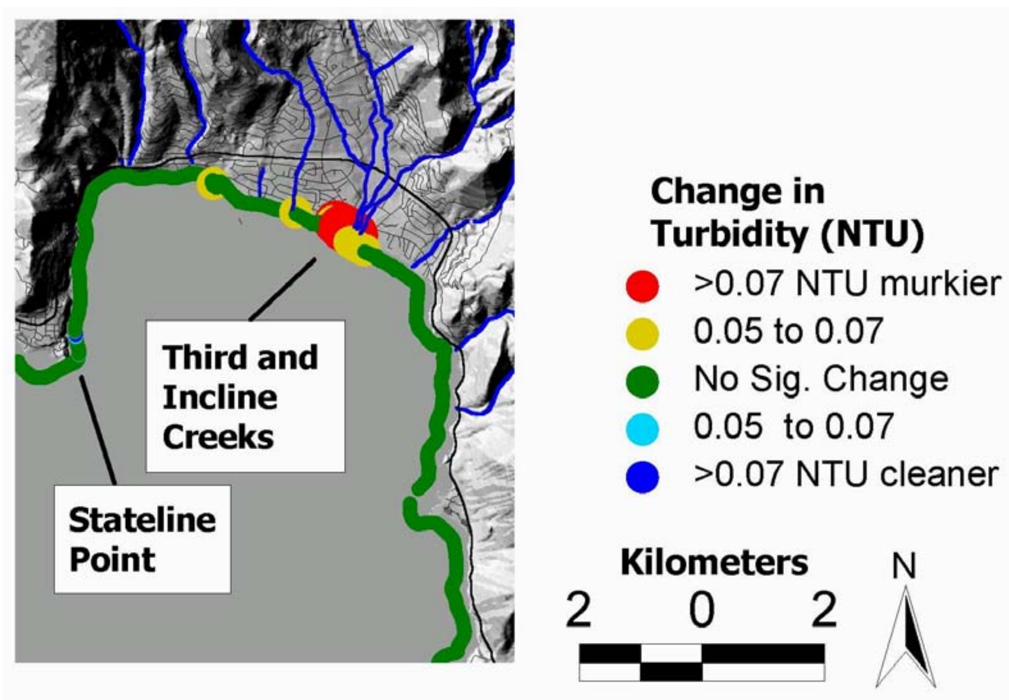

Figure 8. Change in near shore turbidity after three days of high winds and no precipitation in September 2001.

Tahoe City Surveys

On September 16, 2001, a survey was conducted in a grid pattern off of Tahoe City. For this survey we used the turbidity instrument and a fluorometer. The voltage output of the fluorometer is proportional to the chlorophyll concentration. To convert the voltage output of the fluorometer to chlorophyll concentration, water samples have to be collected and filtered, and the filters analyzed for chlorophyll. In this project we only report relative concentrations of chlorophyll. The chlorophyll concentration is of interest because it is an indication of the abundance of algae. The survey (Figure 9) identified two areas that both had high turbidity and chlorophyll concentrations, one off Tahoe City and one near Burton Creek. Each area extended for about a 1 km along the shore. These are the same areas that had elevated turbidities in March 2001 (see Figure 4).

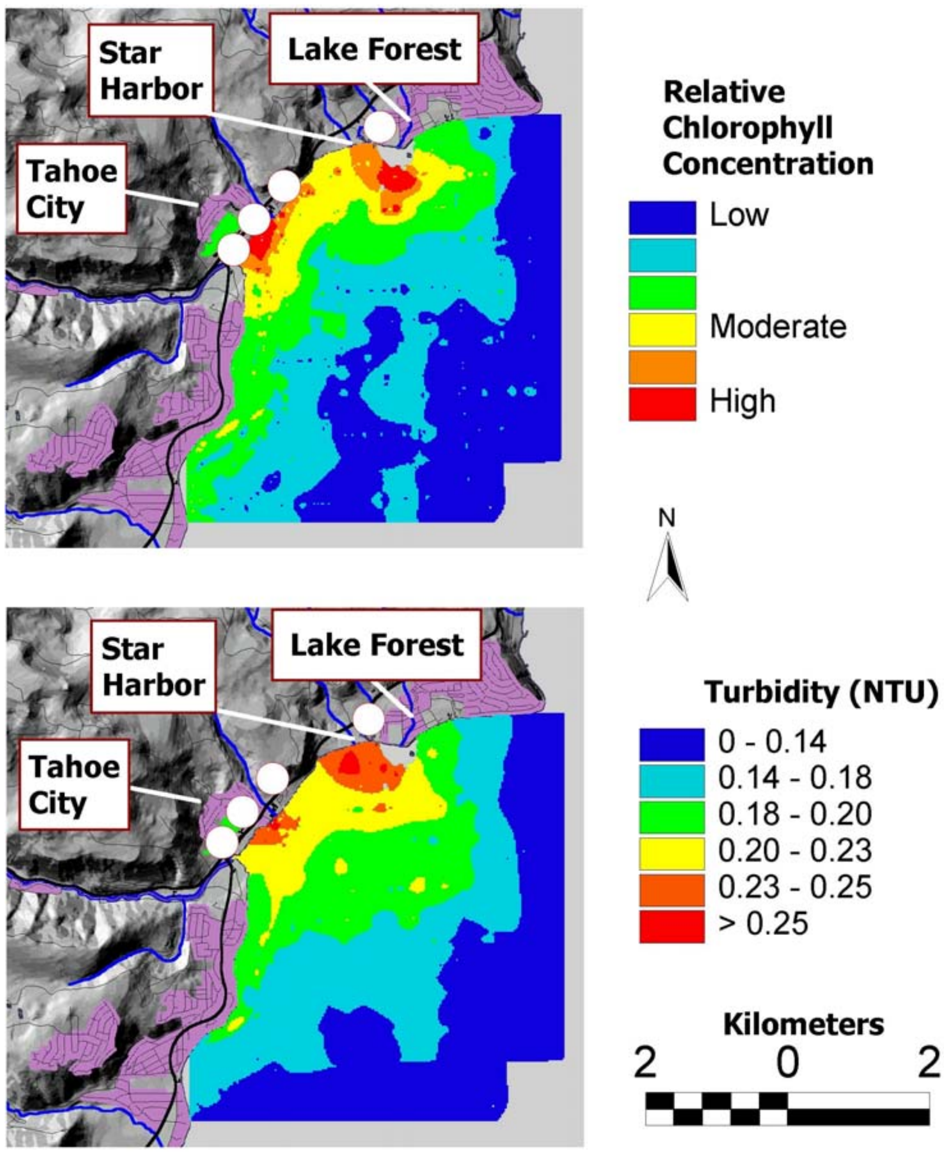

Figure 9. Maps of turbidity and relative chlorophyll concentration off Tahoe City and Lake Forest in September 2001. The purple areas onshore are developed areas and roads are shown as black lines. The green area onshore is a golf course. The white circles are sewage pumping stations.

On June 2, 2001, three months before these surveys were made, teams of volunteers organized by the Citizen Monitoring Working Group of the Lake Tahoe Environmental Education Coalition collected water samples at 44 locations around the basin. The samples were analyzed for many parameters including fecal coliform that is commonly found in the feces of warm-blooded animals. The highest concentration of fecal coliform (706 CFU/100 ml) was observed in Hatchery Creek at Star Harbor (Segale, personal communication, 2001). This fecal coliform value is almost two times greater than at any other site and about ten times greater than the average for all the sites. Repeat fecal coliform measurements in July 2001, and August 2001, did not have elevated values. It is tempting to speculate that groundwater transport of sewer exfiltration may have increased the flux of nutrients to the lake in these areas, however the data are too limited to draw this conclusion.

With the available information it is not possible to determine what caused the high turbidity areas off Tahoe City. The turbidity and chlorophyll surveys show a high degree of spatial correlation, however it is not possible to determine if high levels of algae are the leading cause of the high turbidity, or if inorganic material is the main cause of the increased turbidity and the algae is also elevated because of an increase in nutrients associated with the inorganic material. It is unlikely the increases in turbidity and chlorophyll were caused by atmospheric deposition because their spatial extent is much smaller than would be associated with atmospheric deposition patterns. It is also unlikely they were associated with an inflow of nutrients by surface water because the creeks were dry this late in the summer and many creeks with greater flows did not have high turbidity areas associated with them.

It is possible the high turbidity areas were caused by the resuspension of lake sediments by heavy boating traffic in these areas. It is also possible the high turbidity areas were caused by the release of nutrients stored in lake sediments that enhanced late summer algae growth in these areas. These stored nutrients may have been deposited during periods of greater stream flow with nutrient rich water from urban runoff. Limnology factors such as the characteristics of the bottom, and wind and water currents may also make these locations more favorable for algal growth. It is also possible that the high turbidity areas were caused by the inflow of nutrient rich groundwater that enhances algae populations in these areas. The close spatial correspondence of the areas with elevated turbidity and algae, sewer pumping stations, and the one high fecal coliform value, suggest sewer exfiltration leading to discharges of nutrient rich groundwater as a possible cause. Other possible sources of nutrient rich groundwater include soil disturbance and fertilizer use. We stress that sewer exfiltration is only one possibility. Additional work to determine the relative concentrations of inorganic and organic particles in the lake, and possible groundwater sampling, will be required to resolve this.

CONTINUOUS LIGHT ATTENUATION STUDIES

An instrument that measures the attenuation of light passing through the lake water was deployed at Homewood. The instrument (described in the methods section) was mounted on a private pier ~1 m below the surface, 1.0 meters above the bottom, and 15 m from shore. It had to be cleaned once a week to keep the optics free from biological material that would otherwise adversely influence the measurement. The intention of this deployment was to obtain a continuous proxy turbidity record at a fixed location as a check on the occasional spatial surveys made with the boat mounted turbidity measurement system. The need for two different types of instruments, each measuring different properties, arises because the turbidity instrumentation required for the low turbidity levels in Lake Tahoe requires too much maintenance for unattended operation, and the light attenuation instrument available to us was not suitable for deployment from a moving boat. We are trying to obtain a light attenuation instrument that can be used on a moving boat simultaneously with the turbidity instrument.

To use light attenuation as a proxy for turbidity it is necessary to develop an empirical relationship between the two measurements. This relationship will depend on the optical characteristics of the particles and water. For example, different mixtures of inorganic particles and algae, or different types of algae, will alter the relationship between light attenuation and turbidity. We developed a rough empirical relationship between light attenuation and turbidity by making simultaneous measurements of light attenuation and turbidity in different parts of the lake that had different levels of turbidity. We do not show this relationship because we are concerned that the light attenuation instrument may not have been properly calibrated. This would make the relationship unsuitable for use with another instrument that was correctly calibrated. Originally we had hoped to use measurements of light attenuation from the moored instrument to verify temporal changes observed with the boat mounted turbidity system. However after considering the calibration methods of the light attenuation and turbidity instruments, and the empirical and rough nature of the relationship between turbidity and light attenuation, we concluded the spatial turbidity measurements were more dependable than the estimation of the turbidity from the light attenuation measurements.

The record of estimated turbidity (Figure 10) is dominated by a daily cycle with amplitude of 0.05 NTU. It is not known if this cycle is an instrument artifact caused by increased ambient light levels during the day, or if it is a change in the optical properties of the water associated with daily changes in biological activity or wind stirring of sediments. There are several instances where storms briefly elevated the light attenuation. This is expected because of the shallow water depth were the instrument was moored. The multi day tends of the data collected at night, shown in red in figure 10, are considered to be real changes in turbidity. No attempt was made to record weather or other lake conditions to determine the causes of these variations because this project intended to use the light attenuation instrument only as a check on the boat mounted turbidity system.

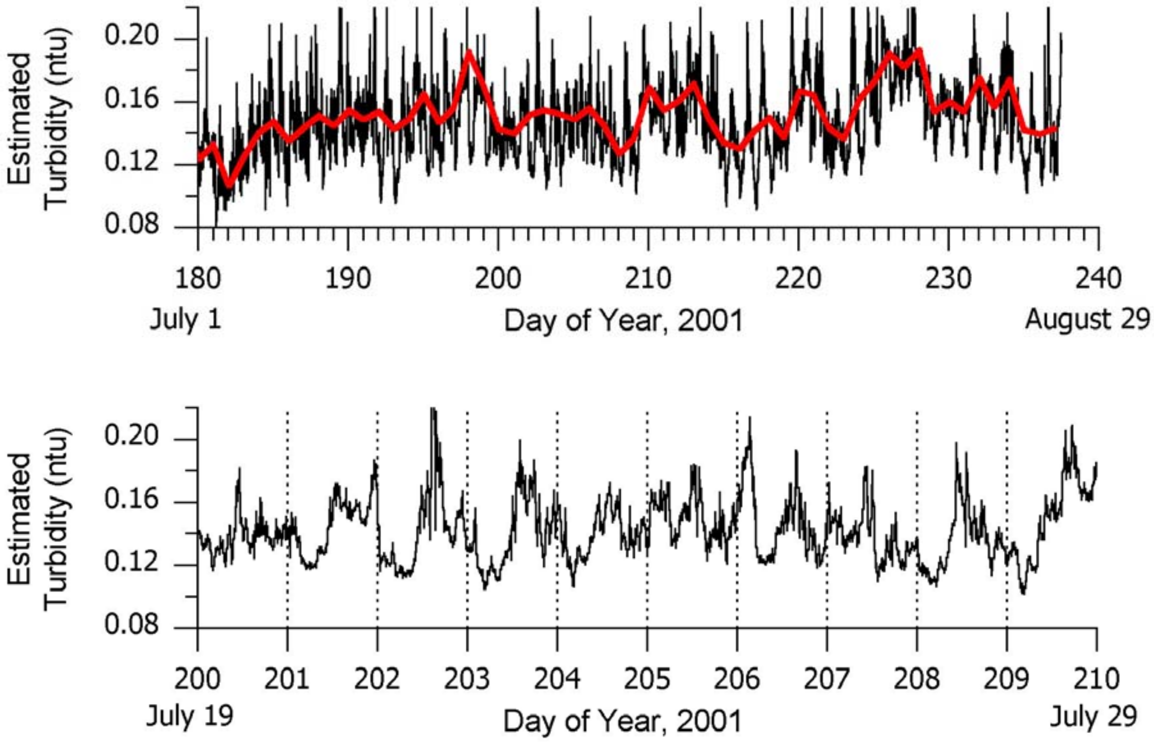

Figure 10. Estimated turbidity derived from light attenuation measurements with the C-Beta. The red line is the average value during the night. The lower graph is a detailed view of a portion of the upper graph so that the daily variation can be observed. The daily variation may be an instrument artifact caused by sunlight.

The continuously recording light attenuation instrument was not useful as a check on the boat turbidity system because the temporal changes were small relative to the uncertainty of the relationship between light attenuation and turbidity, and because of concerns about the ability of the instrument to resolve small changes in light attenuation in the presence of sunlight. In lake light attenuation instruments may be suitable for long term monitoring at a fixed location if the issue of the possible influence by sun light and the need for frequent cleaning can be resolved. The use of light attenuation instruments to continuously monitor clarity at Lake Tahoe is promising but it will require more development of the field methods.

RELEVANCE TO LONG TERM MONITORING OF LAKE CLARITY

To determine if the Environmental Improvement Projects being conducted around the basin are restoring lake clarity, it is desirable to determine how the near shore clarity is changing over time. This project has shown that near shore clarity, as measured by turbidity and light attenuation, has significant spatial and temporally variability.

An effective monitoring program should be able to determine how the clarity is changing over time at a specific location. (i.e. In the last 5 years has the clarity in summer at a monitoring buoy offshore of Tahoe City increased or decreased?) The best way to do this is with a clarity measurement made several times a day. This will allow seasonal averages to be obtained that are not based on conditions that occurred on a single day. An effective monitoring program should also determine how the spatial patterns of clarity are changing over time. (i.e. In the last 5 years has the size of the low clarity area off Tahoe City gotten bigger or smaller?) The best way to do this is with periodic spatial surveys of clarity.

Light attenuation measurements may be a useful long-term monitoring tool at Lake Tahoe. Light attenuation instruments can be deployed in the water for continuous unattended measurements or deployed on a moving boat. Instruments from different manufactures have a similar design and it is likely that instruments with similar optical responses will still be available several decades from now.

Turbidity measurements are also suitable for long term monitoring programs because instruments with similar characteristics are likely to be available many decades from now and because the measurements can be made from a moving boat in shallow water. However, it is difficult to continuously measure turbidity in the clean water of Lake Tahoe with an unattended instrument because a pump is required to move water into the sample cell. Turbidity instruments that have an open water design which do not require a pump will not respond to the small changes in turbidity in the low turbidity waters of Lake Tahoe. Light attenuation instruments have the advantage over turbidity instruments that they do not require a pump to move water into a sample cell and hence are simpler to deploy for unattended measurements in the low turbidity water of Lake Tahoe.

A less desirable approach is light scattering instruments. Light scattering instruments cannot be deployed in shallow water because they are influenced by light scattering off the bottom. Light scattering instruments are designed with different scattering angles and it may not be possible to obtain light scattering instruments with similar optical characteristics over the many decades of a long term monitoring program.

Secchi disk measurements are not well suited for monitoring the near shore zone because the water is frequently too shallow to make a measurement. Another method to monitor the optical properties of water is the light extinction coefficent. This is a measure of the attenuation of natural light with depth. This measurement is influenced by environmental conditions such as waves, clouds and sun angle because natural light is used instead of a controlled light source. This method is not suitable for long term monitoring of clarity because it is dependent on environmental conditions that are not related to clarity.

At this time we do not have enough experience to suggest an optimal program for monitoring near shore water clarity. However a long term monitoring program should have a combination of spatial and temporal measurements utilizing methods that are efficient and that will be consistent over many decades. We hope to address the issue of an optimal monitoring program for near shore clarity in a future project.

RELEVANCE TO TRPA TURBIDITY MONITORING PROGRAM AND WATER QUALITY THRESHOLD

The Tahoe Regional Planning Agency (TRPA) has set environmental thresholds for the Tahoe Basin. This project is relevant to one of these thresholds. The only TRPA water quality threshold for near shore waters is the littoral zone turbidity threshold (TRPA threshold WQ-1). The TRPA program for monitoring compliance with this program consists of 9 sample sites in water 25 ft deep (Figure 11) (Whitney, 2002, Personal Communication). These sites range from tens to hundreds of meters offshore. Discrete samples are collected four times a year from depths of 5, 10, 15, 20, 25 ft. The small number of sample sites cannot delineate high turbidity areas like the ones associated with Tahoe Keys and Tahoe City and do not monitor the undeveloped sections of the shore that have the greatest clarity. The infrequent measurements will make it difficult, and maybe impossible, to determine temporal trends.

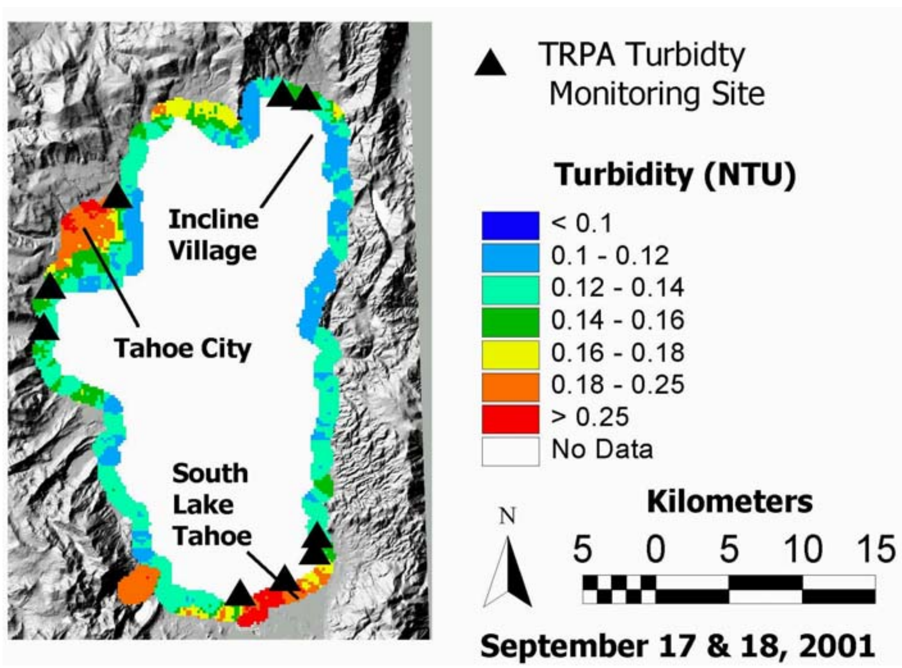

Figure 11. Location of TRPA turbidity monitoring sites and near shore turbidity on September 17 and 18, 2001.

The TRPA turbidity threshold for the littoral zone is 1 NTU in areas not influenced by streams and 3 NTU in areas influenced by streams. This 1 NTU threshold is a factor of 10 times greater than existing conditions off undeveloped areas and a factor of 4 times greater than existing conditions in the most turbid areas of the lake excluding Tahoe Keys. For reference the turbidity of the entire near shore zone would be similar to the turbidity of the Tahoe Keys marina in June before the TRPA threshold was exceeded. The secchi disk depth along the entire shore would be less than ~4 m before the TRPA turbidity threshold was exceeded.

The TRPA littoral turbidity threshold is the only TRPA water quality threshold that is being met. This is because the turbidity threshold is set at a level much greater than ambient conditions and the tight environmental standards of the other thresholds. TRPA staff is aware of the limitations of the current turbidity threshold and monitoring program and is proceeding along a path that may lead to changing the threshold and monitoring program when all the thresholds are reviewed in 2004.

Other indicators of water clarity are also used in Lake Tahoe. One of these is Secchi depth, which is the greatest depth that a black and white disk 20 cm in diameter, can be observed. Another is vertical extension coefficient, which is a measure of the rate that light intensity decreases with depth. Both of these measurements use natural sunlight that passes through the lake surface. The measurements are dependent on the angle of the sun above the horizon, cloud cover and the roughness of the water surface. These methods also require water that is deeper than most of the areas studied in this project. These methods are influenced by conditions over a range of depths as opposed to the turbidity measurement, which is only influenced by conditions at a single depth. It will be possible to develop an approximate empirical relationship between turbidity measured near the surface and the Secchi depth, and this will be done in future projects.

CONCLUSIONS AND HYPOTHESES

This was the first project to conduct detailed studies of the spatial variability of near shore turbidity at Lake Tahoe and hence when the project was developed it was not clear how useful spatial turbidity surveys would be. The project was designed with a broad focus instead of targeting specific issues. This section is divided into conclusions that are well supported by data, and hypotheses that are suggested by the data but not proven.

Conclusions

●There is a large spatial and temporal variability in near shore turbidity. A general pattern is that turbidity is greater during the summer than during the winter. The areas with consistently high turbidity are South Lake Tahoe, Tahoe Keys, and Tahoe City. Kings Beach and Incline Village have high turbidity too, but to a lesser degree. The Tahoe Keys and adjacent lake waters consistently have the highest turbidity and are occasionally greater than the TRPA WQ-1 threshold.

● Emerald Bay consistently has an elevated turbidity. The steep watershed, significant lands disturbance imediately adjacent to the bay due to road construction and avalanche activity, shallow depths and major stream inflow with restricted mixing with deep lake water, make this a unique area.

●Turbidity values are greatest near the shore. If the near shore clarity issue is resolved, the mid-lake clarity issue may also be resolved. However, it maybe possible to have acceptable mid-lake clarity and still have poor clarity near the shore.

●Although atmospheric deposition of nutrients may contribute to a lake wide decline in clarity, it occurs over too large an area to explain the small size of the areas with elevated turbidity. Hence, most of the near shore clarity loss is caused by neighborhood scale local problems.

●The TRPA turbidity monitoring program does not provide an effective means of locating problem areas and does not provide a way to measure changes over long time periods.

●The TRPA littoral zone turbidity threshold (WQ-1) does not provide a level of environmental protection that is consistent with the other TRPA thresholds and may not be consistent with the community's expectations.

Hypotheses

●Groundwater inflow of nutrients may be enhancing algae growth in some areas. The nutrient source may be sewer exfiltration, soil disturbance or fertilizer use.

●Summer thunderstorms and moderate waves may not have a significant short term impact on near shore turbidity.

●Most of the clarity problem may be the result of what is occurring along a small percentage of the shoreline.

RECOMMENDATIONS

●Information on the spatial and temporal variability of turbidity and light attenuation should be collected so that an informed discussion of the TRPA littoral zone turbidity threshold (TRPA water quality threshold WQ-1) can occur before the thresholds are reviewed in 2004.

●An effective near shore clarity monitoring program should be developed that will observe spatial and temporal variations in clarity. The program should monitor the entire lakeshore and portions of the mid-lake, but also have special emphasis on areas known to have low clarity. The program should be constructed so that changes that occur gradually over several decades can be documented.

●Spatial surveys should be conducted to identify sections of the lakeshore that are associated with high turbidity areas. These surveys should be conducted in different seasons because different areas will respond differently during different seasons.

●A program should be developed to identify the relative extent that algae and inorganic particles are responsible for increasing the turbidity. It should be anticipated that high turbidity has different causes in different areas and different seasons. This will require examination of the particles and cannot be done with just the methods presented here.

CONTACT INFORMATION

The data and figures in this report, and the report itself, are available on the web at: http://www.tahoenearshore.dri.edu

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