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Crowley Lake, Mono County : nutrient loading and eutrophication

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Publication Date

2005-05-01

Crowley Lake, Mono County:
Nutrient Loading and Eutrophication

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LA 222 – Spring 2005
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Final Draft

ABSTRACT

After being classified as eutrophic by the Environmental Protection Agency in 1975, Crowley Lake has been the subject of studies and restoration efforts to manage the nutrient load and subsequent cyanobacterial blooms. Our research project used data from the Landsat satellite images to evaluate the restoration effort implemented in 2000 along Owens River to reduce nutrient loading to Crowley Lake. We focused on the presence of cyanobacteria blooms as an indicator of the eutrophic status and nutrient concentrations in the lake. The results showed strong evidence for continued algal growth on the lake's surface in 2002, two years after the remediation was completed, however the reflectance from the satellite data is not specific and could reflect the presence of macrophytes rather than surface algae. The size of the algal bloom in 2002 however was reduced from that observed via satellite in 2000. Additional data from other years is necessary to determine whether this is actually a trend or simply a result of aberrant climate or conditions unique to 2002.

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INTRODUCTION

Problem Statement

The occurrence of eutrophication and algal blooms in lakes and reservoirs has been increasing in the last 20 years (Anderson, Glibert et al. 2002). There are often anthropogenic causes that can be remediated through well-planned restoration projects. We chose to evaluate the efficacy of restoration work implemented in 2000 to address the eutrophic conditions in Crowley Lake. The growth of phytoplankton on the water surface is often a symptom of eutrophication. Our project relied on available satellite images, which can detect algal blooms due to their associated color. This type of monitoring with remotely sensed data can alleviate some of the time and cost normally required to monitor restoration efforts through collection and analysis of water samples.

Background

Crowley Lake or Long Valley Reservoir is located on the eastern slope of the Sierra Nevada in Mono County. Crowley Lake was created by the impoundment of the Upper Owens River in 1941 by the City of Los Angeles, and the Owens River remains the main tributary delivering half of the overall water budget to Crowley Lake. Four smaller tributaries (McGee, Hilton, Whiskey, and Crooked Creeks) also flow directly into the lake from the southwest, and Leighton Springs flows into the lake from the east (see Figure 1 in the Appendix).

The watershed is made up predominately of public lands administered by Inyo National Forest and the Bureau of Land

Management, while the City of Los Angeles owns the land immediately adjacent to the lake, which is used heavily for grazing, with other activities such as trout fishing and hiking taking place throughout the



watershed. Recreational usage in the watershed has also increased over the years, and nearby communities of Mammoth Lakes, McGee Creek, and Hilton Creek have seen increases in residential and commercial development. In addition to these human activities, natural releases from the adjacent springs have also led to high levels of nutrients transported into Crowley Lake. In 1975 the EPA's National Eutrophication Survey classified the lake as eutrophic and led attempts to manage and mitigate the impacts of eutrophication in the lake, especially when the lake constitutes 60% of the storage capacity for the Los Angeles Aqueduct system.

Eutrophication and Cyanobacteria

Eutrophication is the enrichment of an aquatic system from the addition of nutrients. It is typically caused by compounds containing phosphorus (P) and nitrogen (N). N and P are necessary for the growth of plant and animal life in the ecosystem, but elevations in their concentrations can cause some organisms to proliferate and disrupt the ecological integrity. The high levels of P and N give them a biological advantage and allow them to out compete other species thus decreasing the biodiversity (Chorus 2001). In Crowley Lake, the increases of N and P have favored the increase in growth of blue-green algae or cyanobacteria, which are normally associated with algal blooms.

While eutrophication can be a naturally occurring process in aging lakes and estuaries (Bianchi, Engelhaupt et al. 2000), nutrient loading to Crowley Lake comes from human activities such as cattle grazing and residential development, as well as the natural contribution of nearby springs. N and P loading to Crowley Lake is high and dominated by the Owens River which contributes 96% of the P and 79% of the N. McGee Creek also contributes 13% to overall N loading (Figure 2). The communities of Mammoth Lakes, McGee Creek, and Hilton Creek show little effect on in-stream nutrient concentrations entering Crowley Lake (Jellison and Dawson 2003). Nearly the entire phosphorus load entering through the Owens River is a result of large natural springs along the upper Owens River above East Portal and along Mammoth/Hot Creek from below US highway 395 to the lower end of the Hot Creek

thermal area. The nutrient loading has low N:P ratios, thus favoring the growth and development of cyanophyte (blue-green) blooms that are capable of nitrogen fixation. In an assessment of internal nutrient loading to Crowley Lake in 2003, the estimates of annual P loading are approximately equal to measured reservoir outflows. However, the export of N in the reservoir outflows is 3 to 4 times the measured inflows. The difference is presumably due to unmeasured inputs via nitrogen fixation by cyanobacteria (Jellison, Rose et al. 2003).

Human and Ecological Health Concerns

Cyanobacteria produce toxic compounds referred to collectively as cyanotoxins. There are many different cyanobacteria species and many different cyanotoxins. Not all cyanobacteria produce cyanotoxins, and many cyanobacteria produce multiple cyanotoxins. The most common toxin-producing cyanobacteria are *microcystis* spp., *anabaena* spp., *aphanizomenon* spp. and *nodularia* spp. The cyanotoxins they produce can be grouped into hepatotoxins (those that produce liver toxicity), neurotoxins (those that produce nervous system toxicity), and dermatotoxins (those that produce skin toxicity) as shown below in Table 1 (see Appendix).

As indicated by the types of toxins, human exposure to cyanotoxins leads to symptoms of liver, neurological and skin toxicity. These include skin irritations, allergic responses, mucosa blistering, muscular and joint pains, gastroenteritis, pulmonary consolidation, liver and kidney damage and a range of neurological effects (e.g. tingling and dizziness) (Codd 2000).

The primary exposure pathway of concern is the contamination of drinking water. In Australia the consumption of drinking water from a dam containing *cylindrospermopsis raciborskii* resulted in the hospitalization of 140 children. In Brazil 88 deaths were reported when a cyanobacteria bloom in a newly flooded dam led to drinking water contamination (1999). Animal toxicity data shows that chronic low level exposure to cyanobacterial toxins may be a risk factor for cancers of the digestive system. This has been corroborated in human studies in which drinking surface water was associated with liver cancer incidence in rural China (Zhou, Yu et al. 2002). The World Health Organization set a provisional

drinking water guideline of 1.0 µg of microcystin-LR per liter (WHO 2004). Swimming and other recreational contact with cyanobacteria in water increases the likelihood of skin irritation and gastrointestinal symptoms (Pilotto, Douglas et al. 1997). Irrigation with water contaminated by cyanotoxins can lacerate the cells and aerosolizes the toxins which can then be inhaled. Such inhalation exposure may also occur in showers or saunas (Hoppu, Salmela et al. 2002).

Cyanobacteria proliferation is also detrimental for the aquatic life in a water body. Their presence reduces the dissolved oxygen levels and the amount of ambient light penetrating the surface and thereby affects both vegetation and fish. In addition to promoting increased algal growth, the high nutrient levels of eutrophic waters can also promote increased growth of nuisance aquatic plants. The toxins that affect humans also impact other organisms from zooplankton to large fish high up the food chain (Paerl, Fulton et al. 2001). Fish kills and alterations in the food web can be disastrous to the local ecosystem, eroding its ability to continue its natural beneficial services, which in turn may have economic impacts. In fact eutrophication is the dominant water quality problem in the U.S. as the cause 50% of the impaired lake area and 60% of the impaired river area (Smith, Tilman et al. 1999).

APPROACH AND METHODS

Original Remediation

As part of the EPA's National Eutrophication Survey, Crowley Lake was surveyed in 1975 and classified as eutrophic based on nutrients, dissolved oxygen, chlorophyll a, the phytoplankton community, and Secchi disk transparency (Jellison and Dawson 2003). In subsequent decades, many of the management issues and concerns have centered on mitigating the impacts of eutrophication of the lake. Management actions have included the use of copper sulfate to control blue-green algae populations that result in taste and odor problems and occasional fish kills, and aeration of dam outflows to mitigate the impact of low oxygen on downstream fisheries.

The purpose of the remediation project conducted in 2000 by the University of California's Sierra Nevada Aquatic Research Laboratory for the State Water Resources Control Board (Remediation Project)

was to restore a substantial length of Owens River immediately upstream of Crowley Lake. However, their main intention of the project was not necessarily to restore Crowley Lake to a non-eutrophic state. To do this, the Remediation Project implemented best management practices (BMPs) to reduce or prevent pollution from grazing, irrigation, recreation and physical habitat alteration. They evaluated the success of these measures (e.g. corridor fencing and livestock exclusion) through monitoring both before and after implementation (Jellison and Dawson 2003). Grazing, irrigation, and recreation are sources of nutrients and also the dominant land uses upstream of Crowley Lake, but the dominant source of Crowley Lake's high phosphorus concentrations are the natural springs along Owens River and Mammoth/Hot Creek. As such, the impact of the mitigation measures on the eutrophic conditions in Crowley Lake is expected to be minimal.

In the summer of 2000, the Remediation Project constructed approximately 4.4 km of riparian corridor fencing along both sides of the Owens River from Benton Crossing downstream to a point near Crowley Lake. The point where the river becomes the lake is difficult to determine because of the broad river channel and the large fluctuations in lake surface elevation. This section of river was the last remaining major tributary to Crowley Lake on LADWP land that was unfenced.

The Remediation Project also closed roads within the project area and parking was relocated outside to reduce human and vehicle impacts on the floodplain and the riverbanks. Public access was still allowed to the river through a variety of convenient access points constructed in the same location as historical access points. Additionally, exclusion and prescribed grazing were implemented on the same reach of the Owens River. Livestock were to be excluded for at least the first five years following the fencing. After that, the excluded area was to be evaluated in order to decide whether to reintroduce livestock on a limited use basis (Jellison and Dawson 2003).

A series of ditches directs water from the tributaries to irrigate many pastures in the Upper Owens River watershed. The return flow that then comes off the irrigated pasture and returns to the stream channel may pick up nutrients from the pasture and associated cow manure and return to the tributary nutrient rich. Ideally just enough water is turned out to balance the evapo-transpiration demand of the

pasture and result in no return flow. However, this requires careful attention and the ability to precisely meter the volume of water turned out. On Mammoth Creek through Chance Ranch the irrigation structures were constructed of wood and probably dated back to the early 1900s. These structures were not very adjustable and diversions could never be turned off completely. Therefore another remediation measure implemented during the summer of 2001 was the replacement of the three primary irrigation structures with new concrete structures.

Remote Data

Although the remediation project made useful improvements in the watershed, they did not address the largest nutrient source (i.e. the natural springs). We therefore expected that eutrophic conditions and algal blooms would continue to be a problem at Crowley Lake. We evaluated the river restoration efforts to remediate nutrient loading and eutrophication of Crowley Lake by using remotely sensed data from Landsat Thematic Mapper (Landsat TM), Landsat ETM and Landsat 7. Several studies have used remotely sensed data (Kahru, Leppanen et al. 2000; Vincent, Xiaoming et al. 2003) to detect cyanobacteria in both freshwater and marine waters. These studies successfully used both Landsat and the Advanced Very High Resolution Radiometer (AVHRR) images for this purpose. These two types of satellite images differ in their spatial resolution and the detection instrument onboard the satellite. The use of Landsat's data is preferable in this project because of its higher spatial resolution of 30 square meters versus AVHRR's 1.1 square kilometer resolution. Higher spatial resolution will facilitate our ability to distinguish differences within the small footprint of Crowley Lake, which is approximately 4,000 x 8,000 meters.

We conducted our analysis using data from the California Spatial Information Library (<http://gis.ca.gov/>) and Earth Science Data Interface (<http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp>). Data for the path and row (Path 42, Row 34) that encompass Crowley Lake were available for 1989, 1999, 2000, 2001, and 2002. However, only the 1989, 2000 and 2002 data are from the summer when

blooms are most likely. The 1999 and 2001 data are from December and October when it is unlikely that blooms would occur.

Landsat 7 data and other satellite images measure how the earth's surface reflects solar radiation. Different materials on the earth's surface reflect differently. For example, rock reflects at different wavelengths than vegetation, and water without cyanobacteria surface blooms reflects differently than water with a bloom. The Landsat 7 system is designed to collect 7 bands or channels of reflected energy and one channel of emitted energy. This reflected energy is returned from the object unchanged with the angle of incidence equal to the angle of reflection. The wavelength reflected determines the color of an object. A plot of the collective interactive mechanisms (scattering, emittance, reflectance, and absorption) at wavelengths on the electromagnetic spectrum should result in a unique curve, or spectral signature, that is diagnostic of an object or a class of objects. A signature on such a graph can be defined as reflectance as a function of wavelength (Figure 3).

In the Kahru study (Kahru, Leppanen et al. 2000), Cyanobacteria were detected in the light reflectance range of 570 to 700 nanometers (nm). In the study conducted by Vincent (Vincent, Xiaoming et al. 2003), the use of phycocyanin, which is a blue accessory pigment attached to the photosynthetic membrane, and accounts for up to 20% of the proteins in cyanobacteria, reflected at 630 nm (Watras and Baker 1988). Therefore our analysis will focus on bands 2 and 3 of the Landsat data which corresponds to a wavelength of 525 to 605 nm and 630 to 690 nm. We choose to use all six bands (Landsat has 7 bands, but only 6 are of the same resolution) as input in the classification because of potential for some unique spectral property specific to cyanobacteria to be contained in the other bands. We hoped this might help to distinguish cyanobacteria and other surface algae from macrophytes. Using all seven bands, we made a composite image using a software program called PCI Geomatics (version 9.1) to conduct a supervised classification. Supervised classification is just one method for mapping different classes of material using remotely sensed data, but depends heavily on the cognition and skills of the image analyst. We relied on the reported reflectance of cyanobacteria in the literature to help ensure

proper classification, and this made it possible to visually color code pixels containing cyanobacteria based on their characteristic reflectance.

Field Data

The 2000 restoration project on the Owens River conducted a time series of riparian monitoring measurements before and after the project. The measurements they collected in 1994, 1996, and 1999 served as the baseline values. They measured channel cross section, landform, dominant vegetation type, bank angles, and bank undercut at thirty transect locations between Benton Crossing and Crowley Lake. They also measured elevations of each landform above the channel bed using a tripod, transit, and stadia rod. They then repeated these measurements in 2001, one year after construction of the corridor fencing.

In 2002 adjustments were made to the fencing, roads, and access points for the fencing below Benton Crossing. Three new large irrigation structures were constructed on Mammoth Creek to better regulate irrigation flows and prevent return irrigation flows from re-entering Mammoth Creek. The effectiveness of these measures has never been determined.

To assess nutrient loading to the lake and determine changes occurring across heavily grazed pastures, the remediation project sampled tributary inflows to Crowley Lake biweekly during the spring-summer period (May-September) and monthly the rest of the year. In addition, they sampled Mammoth Creek and the dam outflow. Table 2 lists the sampling locations. They also characterized the phytoplankton communities through microscopic identification and enumeration. They accomplished this using a 10 ml sample that had been allowed to settle for 24 hours in a 10 ml Hydro-Bios Utermohl chamber. A few drops of Lugol's Solution was added to aid in settling. The samples were analyzed on a Carl Zeiss inverted microscope at 160x magnification. Chlorophyll *a* concentrations were also used to characterize the phytoplankton.

Ice cover in Crowley Lake disappears in April. They conducted sampling following ice-off, in late midsummer (May 31 and August 14 in 2000 and April 18 and August 15 in 2001), and following autumn turnover (November 9 in 2000 and November 7 in 2001). An additional final survey was

conducted on April 3, 2002 to allow an assessment of changes in the nutrient budget across two complete runoff years. They assessed the plankton community at five different stations (named: north, south, east, west and middle) at each of the sampling times. Table 3 (see Appendix) shows the different phytoplankton that they identified in Crowley Lake. Each species accounted for a different proportion of the overall biomass on the different sampling dates.

Cyanophyte blooms may have high spatial and temporal variability and the three lake-wide surveys conducted in 2000 and 2001 cannot be used to describe the relative frequency or magnitude of nuisance blooms. An assessment of this would likely require at least weekly sampling. Thus, while the seasonal chlorophyll concentration was similar to that described by Warner in 1965 (Warner 1965), they could not use the data to determine whether Crowley Lake had become significantly more eutrophic in this period.

We had hoped to make one visit to the site to look for the presence of toxin producing cyanobacteria using a handheld microscope capable of magnification at 40x, 100x and 400x. Because algal blooms are easily transported by wind and can concentrate together in small areas, we planned to sample 5 different sites spread over the lake as close to the original five sampling sites used to monitor the lake in 2000 and 2001 as possible. If cyanobacteria were visible with the handheld microscope, we planned to preserve samples with Lugol's iodine solution and quantify cell count per volume under another microscope in the laboratory. Figures 5 through 9 show images of the target cyanobacteria species. Unfortunately the winter weather conditions in Crowley Lake did not subside in time for us to do this during the course of this class. Continued forecasts for snow and rain through April and the start of May meant that field conditions would be inappropriate for cyanobacterial growth.

FINDINGS AND RESULTS

Results

The results of the image analysis are shown in the appendix. Figure 10 shows Crowley Lake in July 2000. The area classified as algal growth is highlighted in green. This classification allowed us to

select sites by tone and color within the image that appear to represent algal growth. The software then uses these sites to define a spectral response curve to find additional sites that also fall within the boundaries of this spectral signature. Figure 11 shows Crowley Lake in July 2000 viewed only with Bands 2 and 3. These two bands correspond to the wavelengths reported in the literature as those in which cyanobacteria reflect. The higher reflectance in the image is shown as lighter shades. We used an enhancement function to accentuate the variation in brightness within the lake. There are lighter portions surrounding the perimeter of the lake, the inlets and outlets of the rivers, as well as some areas in the middle of the lake. The red shading represents the areas classified using a supervised classification (i.e. the same as the green highlighted area in Figure 10) within the PCI Geomatics software. The red class overlies the lighter areas where reflectance in the red and green bands is greatest as would be expected from cyanobacteria or other algal growth. Since water has a low reflectance in bands 2 and 3, only some kind of macrophyte or lake vegetation growing on the surface or algal blooms could lead to this elevated reflectance.

Table 4 (see Appendix) shows a sample of the numerical brightness values corresponding to the areas classified as both algal and non-algal in the lake. Everything in the algal category reflects higher in bands 2 and 3. The spectral signature for the algal category had a mean brightness value of 51 for band 2 and a mean of 40 for band 3. The same spectral signature was used to classify the images from July 1989 and July 2002. The true color image and the bands 2 and 3 only image for July 1989 are shown in Figures 12 and 13 respectively. Zero pixels were identified with the classification on the July 1989 image. The image showing only bands 2 and 3 likewise has no real pale areas indicating high reflectance on the lake. This is an indication that the specific conditions (e.g. climate, etc.) did not favor strong algal blooms in 1989 even though we know that Crowley Lake was classified as eutrophic long before then. The true color image and the bands 2 and 3 only image for July 2002 are shown in Figures 14 and 15 respectively. The highlighted areas indicating estimated areas of algal growth are smaller than those in the 2000 images. This may indicate a reduction in nutrient load and concomitant decreases in algal growth, however weather patterns vary highly from year to year and thus additional years of data need to

be analyzed to verify whether a trend is occurring. The 1999 and 2001 images from winter months were classified, but as expected no areas could be categorized with the spectral signature of algal growth. Figures of these images were therefore not included in this report.

Sources of Error

In this study, the spatial resolution of the Landsat data may result in an overestimation of the presence of cyanobacteria. Even though the 30 meter resolution is high in comparison to the AVHRR, it still requires the assumption that an entire 30 square meter area has the same cover, when in reality a small coverage is able to result in the entire pixel being classified as one particular category such as algal growth. In addition, the spectral signature of cyanobacteria is not necessarily unique. Although it is distinct from the spectral signature of water, it is very similar to that of other chlorophyll containing plants or organisms. Therefore, while our remote images indicate the presence of something that may be blue-green algae, we cannot be sure without field data to confirm it. Although we know that cyanobacteria reflect in bands 2 and 3, we used all six bands as input in the classification because of our concern that we are picking up the reflectance of some macrophyte in the lake. Our separate classification that used only bands 2 and 3 as the input channels from the July 2000 image is highlighted in green (Figure 16). In addition to the area within the lake classified in the first method with all six bands, this classification with only bands 2 and 3 also included vegetated areas in the surrounding area. Thus it appears that there is some information in the other 4 bands that somehow distinguishes things on the lake that reflect in Bands 2 and 3 from leafy vegetation in other places, but we are uncertain whether this unknown factor is due to the presence of algae.

Another source of error in this study is the limited satellite coverage, and the limited time frame we were able to analyze given the available data. We know that the presence of cyanobacteria is most prevalent during the warmer season (May through September), but the remotely sensed data we were able to obtain from this time of the year was only available for the years 1989, 2000, and 2002. The data for

1999 and 2001 was collected in December and October. Additional data is available for purchase, but the price far exceeded the budget of this study.

Our on-site sampling of water from Crowley Lake took place on May 1 and may therefore not be appropriate for comparison with the July satellite data. Our selection of sampling sites on the lake may have been inadequate, and our single visit is extremely limiting given the high temporal and spatial variability of algal growth.

Finally some species of cyanobacteria do not float on the surface of the water, but are able to survive several feet below the surface. If algal species in Crowley Lake are of this type then they would be more difficult to detect with satellite data. This poses another source of error to our analysis using satellite data.

CONCLUSIONS

The satellite images from July 2000 and July 2002 both show strong evidence for algal growth as discussed above in the results. In addition to algae, there are a few other things in lake water that could elevate the reflectance in bands 2 and 3. For example some kind of lake vegetation or other chlorophyll containing organism would also reflect at the same wavelength. Therefore the interpretation of this data is not definitive without field data from the same dates to ground truth it. Nonetheless it strongly indicates the possibility that the eutrophic conditions and algal blooms typical of Crowley Lake prior to the 2000 remediation still persisted in 2002 although their prevalence seems to be slightly diminished. Ideally we would have liked to review similar satellite data from July of 2001, 2003, and 2004 to look for evidence of a trend in this decline. With only one post-remediation dataset, it is difficult to know whether these observations represent a real decline in nutrient load or whether they are simply the result of particular aberrant weather patterns during 2002. If our interpretation of the presence of algal blooms is indeed accurate, than the nutrient load has not been altered substantially between 2000 and 2002.

Since we were not able to conduct our field visit as planned, this analysis is really lacking the ground-truthing of actual site data to compare with the satellite data.

There are several factors that may explain the continued growth of algal species in Lake Crowley and its continuing problems of high nutrient load and eutrophic conditions. First, although Owens River is the dominant source of nutrients to Crowley Lake, natural springs contribute the majority of these nutrients to the watershed rather than agriculture or grazing activities that were addressed in the remediation. Second, the remediation consisted only of adding riparian fencing to a relatively small fraction of Owens River. The rest of the river already had riparian fencing thus the total impact of the remediation might not be expected to change the overall nutrient load substantially. Finally, it is important to realize that there may be large time lags between the implementation of measures to reduce external nutrient inputs to lakes and an actual reduction due to the time required to flush phosphorus out of the water body and to establish a new sediment-water equilibrium. Often the phosphate storage capacity of anoxic sediments typical in hypertrophic waters is quite substantial and can continue to release phosphorus for many years after external inputs have been minimized. As many as 10 years may be necessary between the implementation of a restoration measure that substantially decreases inputs, and visible success in terms of reduction of phytoplankton biomass and cyanobacterial blooms (Chorus and Bartram 1999).

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APPENDIX



Figure 1: Crowley Lake and Watershed (shown in red)

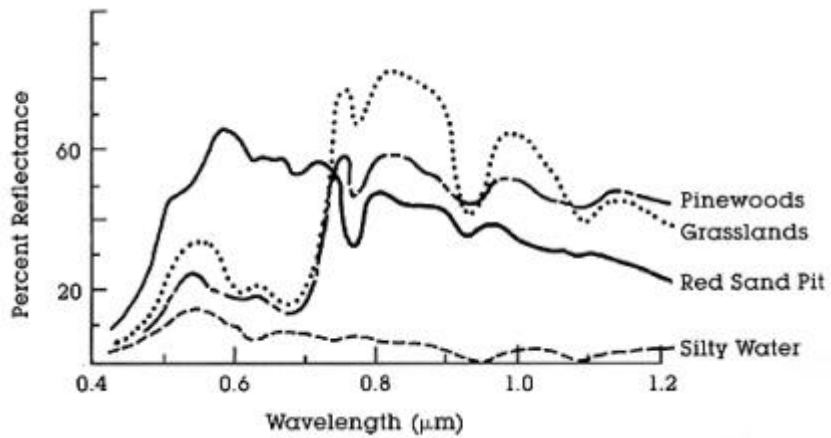
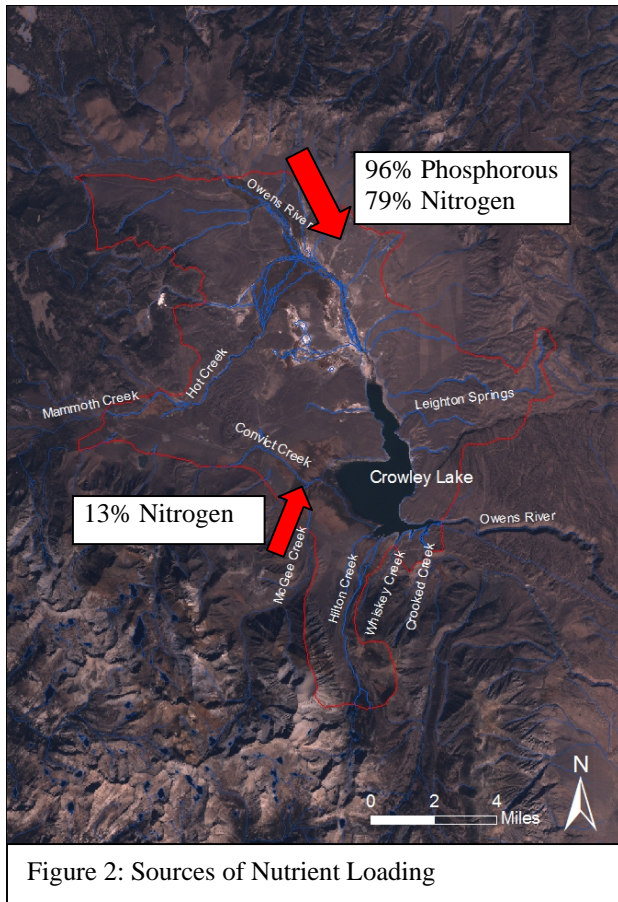


Figure 3: Spectral signatures of different objects. Source: Landsat 7 handbook



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Figure 5: *Anabaena flos-aquae*, Gull Bay, Upper Saranac Lake, NY, 6/12/93, 33X



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Figure 8: rafted *Aphanizomenon* & *Anabaena* 320X
8/18/86 Moore Res north, Littleton NH



Figure 6: *Anabaena flos-aquae*

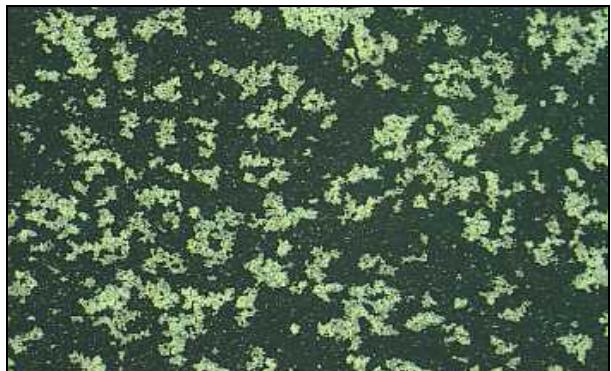


Figure 9: A close-up of cyanobacteria bloom in Lake Sammamish, King County, Washington

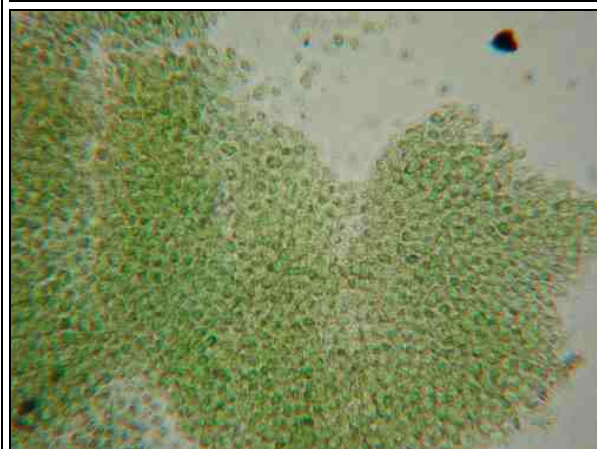
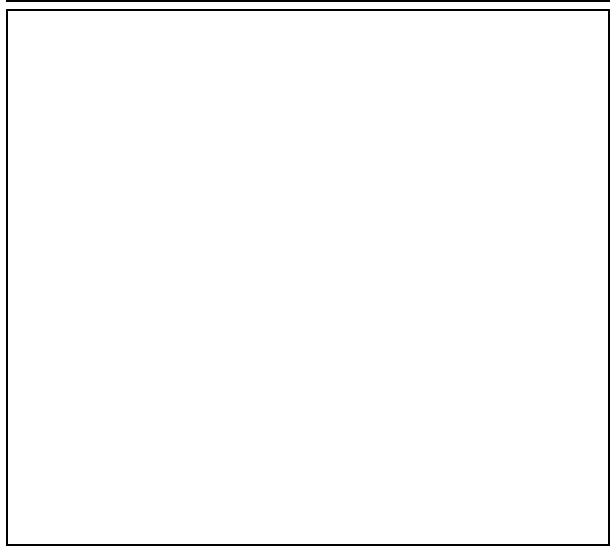


Figure 7: *Microcystis aerogenosa*. 100X Source:
Purdue University Biology Department



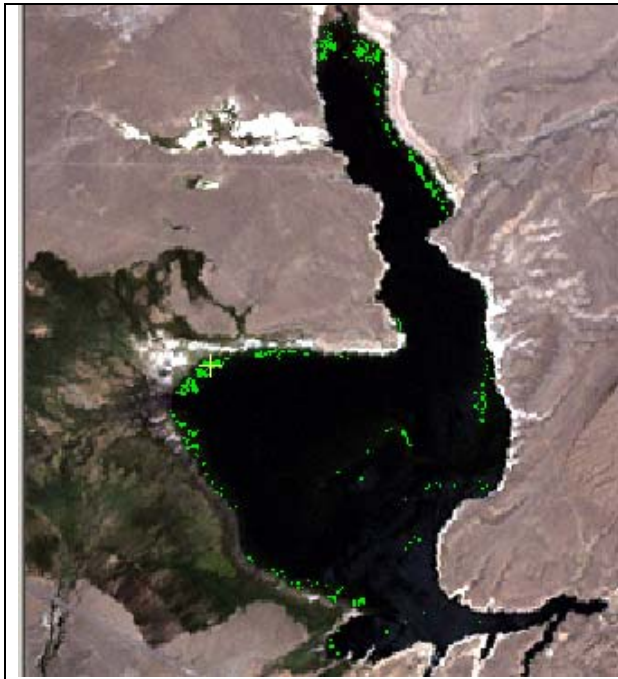


Figure 10: July 2000

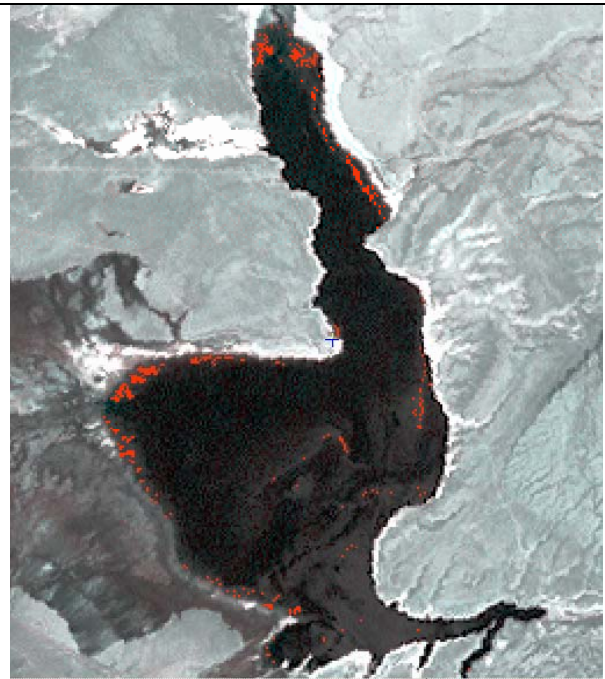


Figure 11: July 2000



Figure 12: July 1989

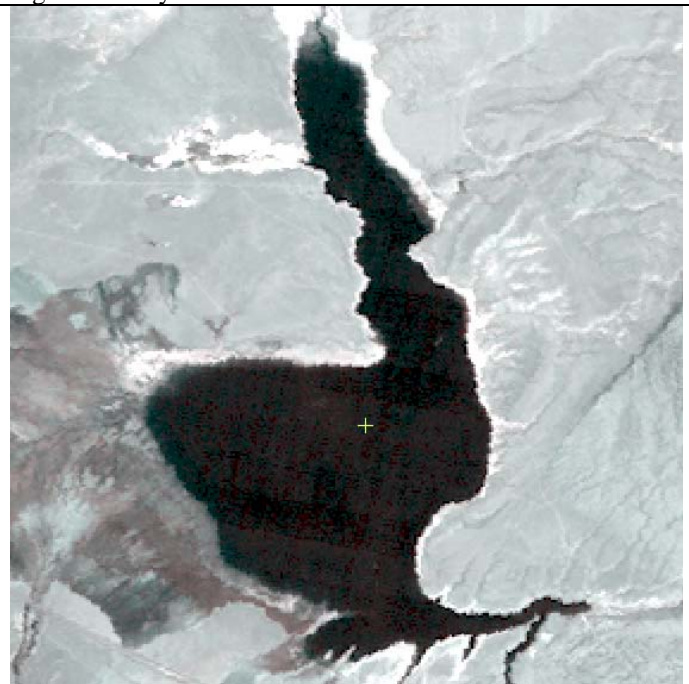


Figure 13: July 1989

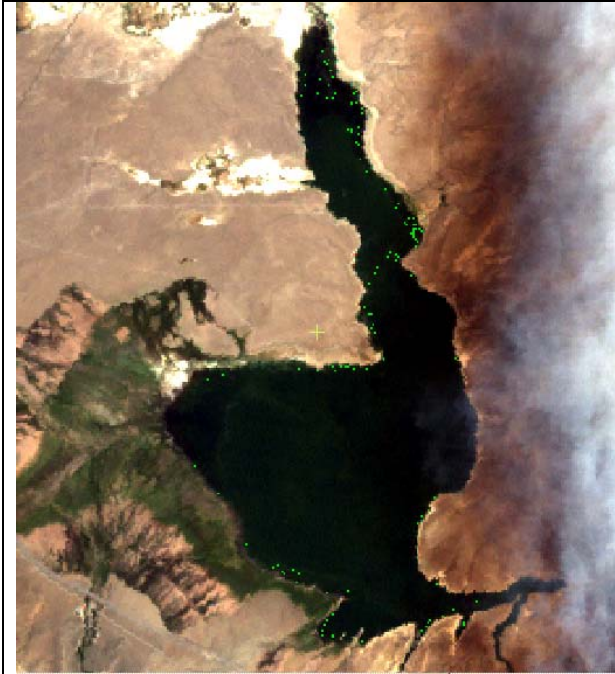


Figure 14: July 2002

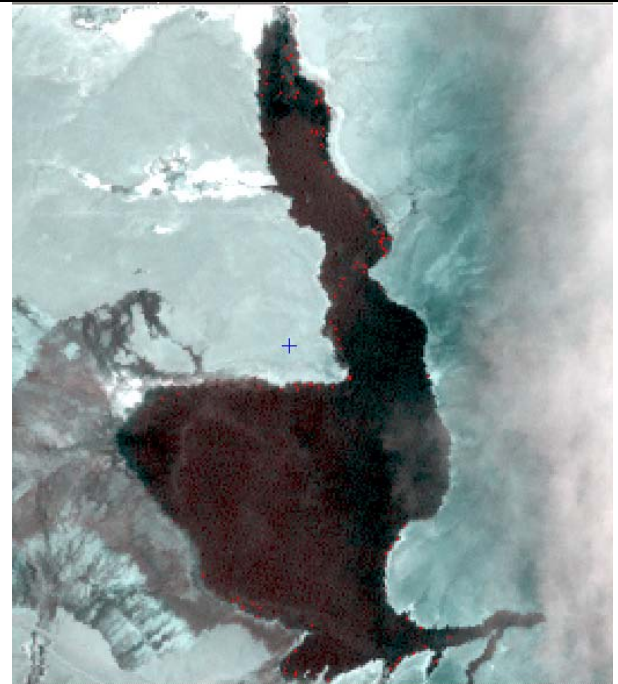


Figure 15: July 2002

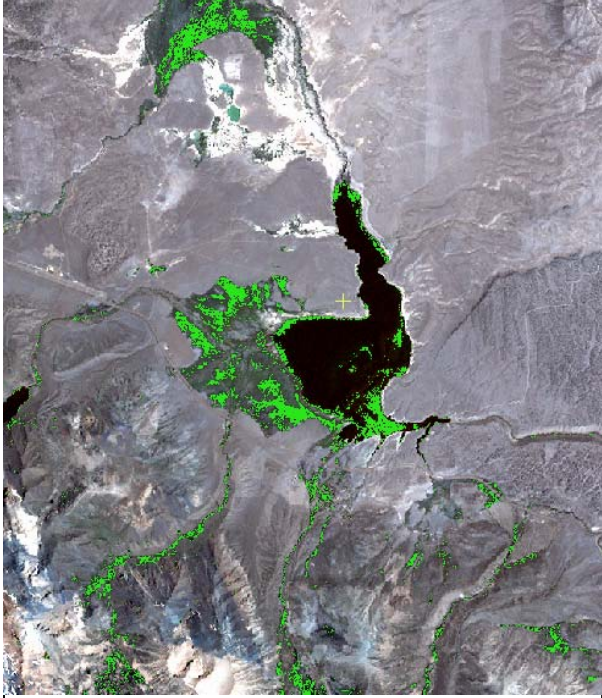


Figure 16: Supervised classification using Bands 2 and 3.

Table 1	
Type of Toxin	Toxin Name
Hepatotoxin	microcystin
	Nodularin
Neurotoxin	Anatoxin-a
	Anatoxin-a(s)
	Saxitoxin
Dermatoxin	aplysiatoxin

Table 2: Sampling Locations of Nutrient Load Assessment	
Stream	Sampling Location
Owens River	Where it enters the lake
Hilton Creek	Adjacent to the lake
Mammoth Creek	Just below Highway US395
McGee Creek	Just below Highway US395
Whisky Creek	Just below Highway US395
Crooked Creek	Just below Highway US395
Convict Creek	1 km above US395

Table 3: Phytoplankton genera identified in Crowley Lake during the period May 31, 2000 to April 3, 2002.	
PHYLUM	GENERA
CYANOPHYTA (blue-green algae)	<i>Oscillatoria, Lyngbya, Coelosphaerium, Anabaena, Gloeotrichia, Aphanothece, Microcystis, Aphanizomenon, Merismopedia</i>
PYRRHOPHYTA (dinoflagellates)	<i>Ceratium, Gymnodinium</i>
CHRYSOPHYTA Sub-Phylum Bacillariophyceae (diatoms)	<i>Stephanodiscus, Asterionella, Fragilaria, Melosira, Synedra, Rhoicosphenia, Cocconeis, Navicula, Gomphonema, Nitzschia, Anomoeoneis, Cymbella, Pinnularia, Gyrosigma</i>
CHRYSOPHYTA Sub-Phylum Chrysophyceae	<i>Dinobryon, Mallomonas, Uroglena</i>
CHLOROPHYTA (green algae)	<i>Eudorina, Pediastrum, Volvox, Staurastrum, Cosmarium, Pandorina, Closterium, Crucigenia, Phacotus, Sphaerocystis, Oocystis, Schroederia</i>
CRYPTOPHYTA	<i>Rhodomonas, Cryptomonas</i>

Table 4: Numerical Brightness for Bands 2 and 3									
Band	Algal				Non-Algal				
	2	50	51	49	46	41	36	39	41
3	40	41	37	47	27	27	29	25	