Appendix 2 - Case Study: The importance of considering scale in lake treatment

Upper Klamath Lake and Agency Lake are two closely associated lakes in Southern Oregon. In fact, as a result of The Nature Conservancy breaching the levees last October 30 (2007), there is more connection between these two water bodies. Both of these lakes are shallow (average depth 4.2 meters) and hyper-eutrophic . According to the Atlas of Oregon Lakes (Johnson et al 1985) Upper Klamath Lake is the largest (by area) lake in Oregon with an area of almost 25000 hectares (62000 acres). The drainage basin is 9415 km^2 (3810 square miles) and includes Crater Lake to the north and the Klamath and Sycan marshes to the northeast.

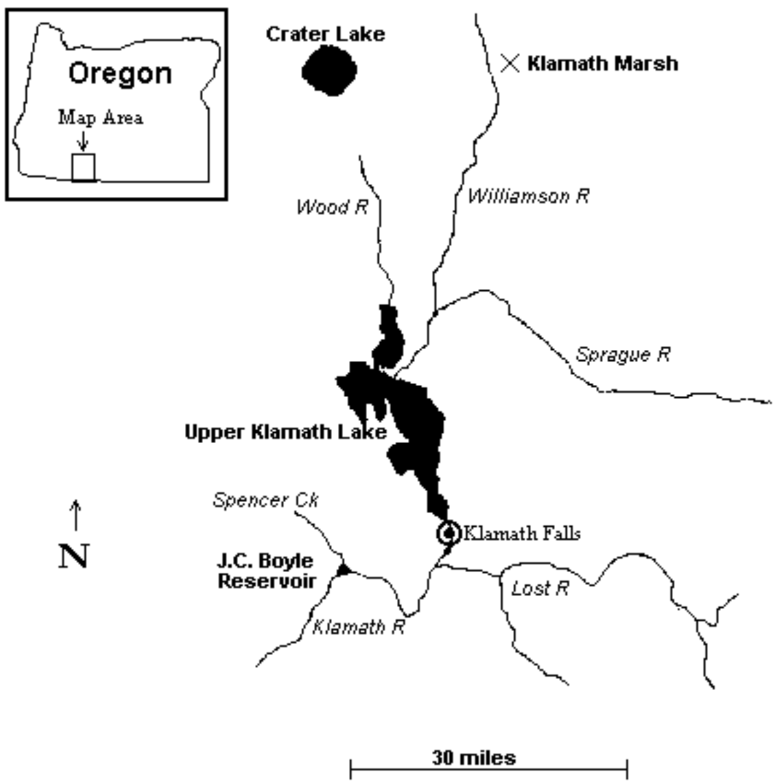


Figure app2-1. Location of Upper Klamath and Agency Lakes.

The water in these lakes is a valuable natural resource that is being shared by many people for many purposes. The general goal of the natural resource managers, citizens and scientists working in this area should be to understand this resource well enough to turn it into a sustainable resource that will maintain the freedom of choice for how the water and land are used by future generations. To do this, our society needs to meet two objectives; first we need to improve the current health of the lake (assuming that we don't want to pass a impoverished resource with few choices on to future users) and second we need to devise a plan to use the resource in a way that avoids "traps". A trap is a situation that is easier to get into than to get back out, i.e. changes in state that is not easily or readily reversible. These two objectives are necessary conditions for creating a sustainable resource but still may not be sufficient to guarantee in any sense that the lake health and natural capital services will be sustainable.

In the grand context of these social, economic and scientific objectives for lakes, our group's research goals were much narrower. We wanted to help understand the immediate causes and mechanisms that lead to blooms of the cyanobacterial species *Aphanizomenon Flos-Aquae* (AFA), examine several existing hypotheses for the control of these blooms by either P interception or humic-rich marsh waters. An important part of the project for us was to provide this information in a context that will help manage these lakes for water quality and fish survival. Our research project is problem based, rather than curiosity based (Norton 2005). The situation in the lakes is that there is too much algae at some time that leads to decreased water quality and when the algal bloom crashes, the oxygen depletion is so severe that it leads to fish kills of the endangered suckers. This situation is a "problem" because we prefer cleaner water and we prefer to maintain the biodiversity of fish in the basin. Thus our problem-based approach reflects the values that society has for the uses of the lake.

Water quality and quantity is a "wicked" problem

Although a list of problems with Upper Klamath and Agency Lakes is standard (high nutrients, high chlorophyll, extreme alga growth, bloom crashes that lead to anoxia, disruption or death to endangered sucker populations), not everyone values the water in the same way. Of the major types of problems we usually deal with (simple, common pool resources, information and wicked), the water resources in this basin are definitely a "wicked problem" which have the following characteristics:

- people put different values on the outcome of having cleaner lake water
- as we develop more understanding of the lake system, some people's values change
- the problem is exacerbated by its history in which more water was promised than is available during many years
- there is a broad range of important space and time scales from the entire basin to individual bays in the lake and from days to decades

Figure app2-2. Harvester machine for skimming AFA off the surface of UKL. An obvious example that not everyone wants to have lower algal concentrations in the lake.

The best way to address a wicked problem is to employ the three principles of adaptive manage that have been described by Norton (2005) (table 5). This approach is suited for complex ecosystem management situations because it demands local evidence and experience to be primary sources of information and puts this into context using multiple scales. Addressing multiple scales forces managers to use a variety of techniques to address those different scales.

Table 1: Three major tenets of adaptive management (Norton 2005)

Experimentalism	emphasize experimental approaches that guide taking actions (including research and management) that will reduce the uncertainty in the future
Multiscalar analysis	use models and approaches that span time and space scales
Place sensitivity	adopt the local place, including natural resource and the people using it, as the perspective from which multiscalar management orients

Hypotheses for control of water quality

There are three active hypotheses that address the control of algal blooms in these two lakes; phosphorus limitation and two versions of the "limno-humic" hypothesis. All of these hypotheses follow from the problem narratives for these lakes (Table 6) which all start with land use changes that include farming and creating levees in the lake. These three narratives were considered in examining the algal response and attempting to devise measurements and/or manipulations that would help us discriminate between these possible mechanisms. An important point is that the underlying hypothesized causes would be operating at different scales and remediation or lake restoration by re-establishing this control would be both at different time and different space scales.

Table 2. Narratives for the problem of too much algae in Upper Klamath Lake and Agency Lake. The three narratives describe how phosphorus, humics blocking light, or humics as inhibitory agents may have controlled the algal population before changes in the basin and lake. The P control narrative is on a longer scale than both the humic narratives.

P control	**Humics – light**	**Humics- inhibition**
land use changes		
More non-point sources for P	Less marsh connected to the lake	
Increase in external loading	Less humic material into lake	
Initial algal growth	Higher transparency (without humics) allows faster algal growth	Lower inhibition by humics allows faster algal growth
Positive feedback cycles with internal loading of P from sediments	Colony growth in spring outstrips grazing control by Daphnia	
uncontrolled AFA growth which leads to blooms and crashes		

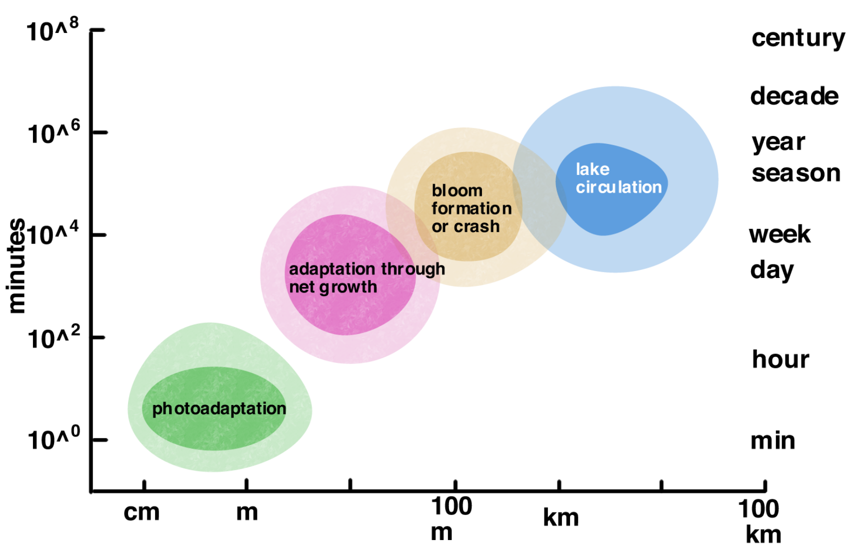
Scale of processes and measurements

The processes that we are most interested in for these lakes were the ones that could lead to rapid accumulation of the algae, AFA, or dissipation of a bloom and factors that might vary from year to year. The biological factors are the intrinsic growth rate of AFA, the rate at which these cells can adapt to a set of conditions, photoadaptation over the day that may limit or promote growth, and lake circulation patterns that could form or break-down a bloom through hydrodynamic (rather than biological) mechanisms. The relevant time and space scales for these processes are shown in Figure 8. Figure 8b shows how our experimental approach was to deliberately "bracket" these time and space scales by using a combination of monitoring approaches including: point samples, dataloggers set at one point, weekly measurements from defined sampling stations spread across the lake, transects (see below) and satellite images or aerial photographs. All of these data except for the transects were available through public data sources, however we collaborated with USGS and the Bureau of Reclamation to share data.

We implemented high-resolution transects to collect data that would connect between established monitoring stations, go across gradients that might be shifting and to provide a more synoptic view that could be linked to the satellite information. We used a combination of Hydro-Lab and Turner instruments and a GPS that were all connected to a datalogger (Table 7). The response time is an important characteristic of the probes that we selected because we had to move the boat through the water at a set speed in order to get an image of the transect (or to connect multiple transects for a 2-D view).

Table 3. Instrumentation, frequency of sampling and spatial resolution for the high-resolution transects. The boat speed was 1.4 meter per second.

Parameter	**Method**	**Distance (frequency)**
Location	Differentially corrected GPS	1.4 m (1 sec)
in vivo chlorophyll a fluorescence	Turner Designs SCUFA	
Turbidity	Turner Designs SCUFA	
in vivo phycocyanin fluorescence	Turner Designs CYCLOPS - PC	
in vivo CDOM fluorescence	Turner Designs CYCLOPS - CDOM	
Conductivity	Hydrolab Sonde 5	8.4 m (6 sec)
Luminescent DO		
pH		
Temperature		



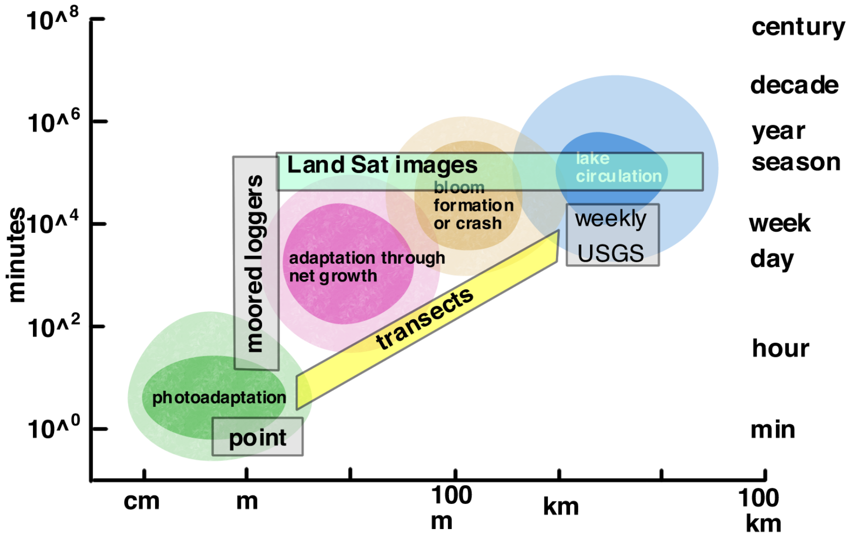


Figure app2-3. a) Relevant time scales of natural processes in Upper Klamath and Agency Lake. b) Bracketing of these scales with a combination of measurement and monitoring approaches.

Limiting the phosphorus loading to the lake has been estimated to take several decades (as discussed later) and the TMDL process that is used to drive and manage P-reductions applies is being applied to the entire upstream basin. In contrast, although wetlands have been removed from the entire lake, restoration of in-lake or adjacent mashes is taking place on the scales of kilometers of shoreline and areas of 10 to 1000 hectares. These marshes can be re-established on time scales of 5 to 10 years and the impact on water quality could be extremely local (only several hundred meters away from the marsh edge) and during limited times of the year (such as when water is being pushed through the marsh). Thus the current restoration tools work on very different scales.

Example of working across scales

The impact of humic material being introduced to the lake is a good example of the utility of examining the problem over multiple time and space scales. Humic rich water is being pumped into Agency Lake during the summer. This water has been stored in the Agency Lake Ranch behind a levee, and the Bureau of Reclamation pumps it out during a certain window of time. One part of the "limno-humic" hypothesis states that the input of humics should inhibit the growth of AFA and decreases the AFA bloom. In order to assess if this water is having any effect on the lake we have to consider the multiple scales of lake mixing and algal growth.

As an example of the coordinated measurements that can help describe the processes, we conducted transects on the same day as LandSat image and in a zone that overlapped continuous data loggers installed by the Bureau of Reclamation and USGS. The LandSat flies over every 16 days so we had to match our sampling schedule to that. The satellite information, even its raw form shows the variations in the distribution of algae across the surface and, in particular, the clearer zones around the pump input. The transects help combine the spatial and temporal information.