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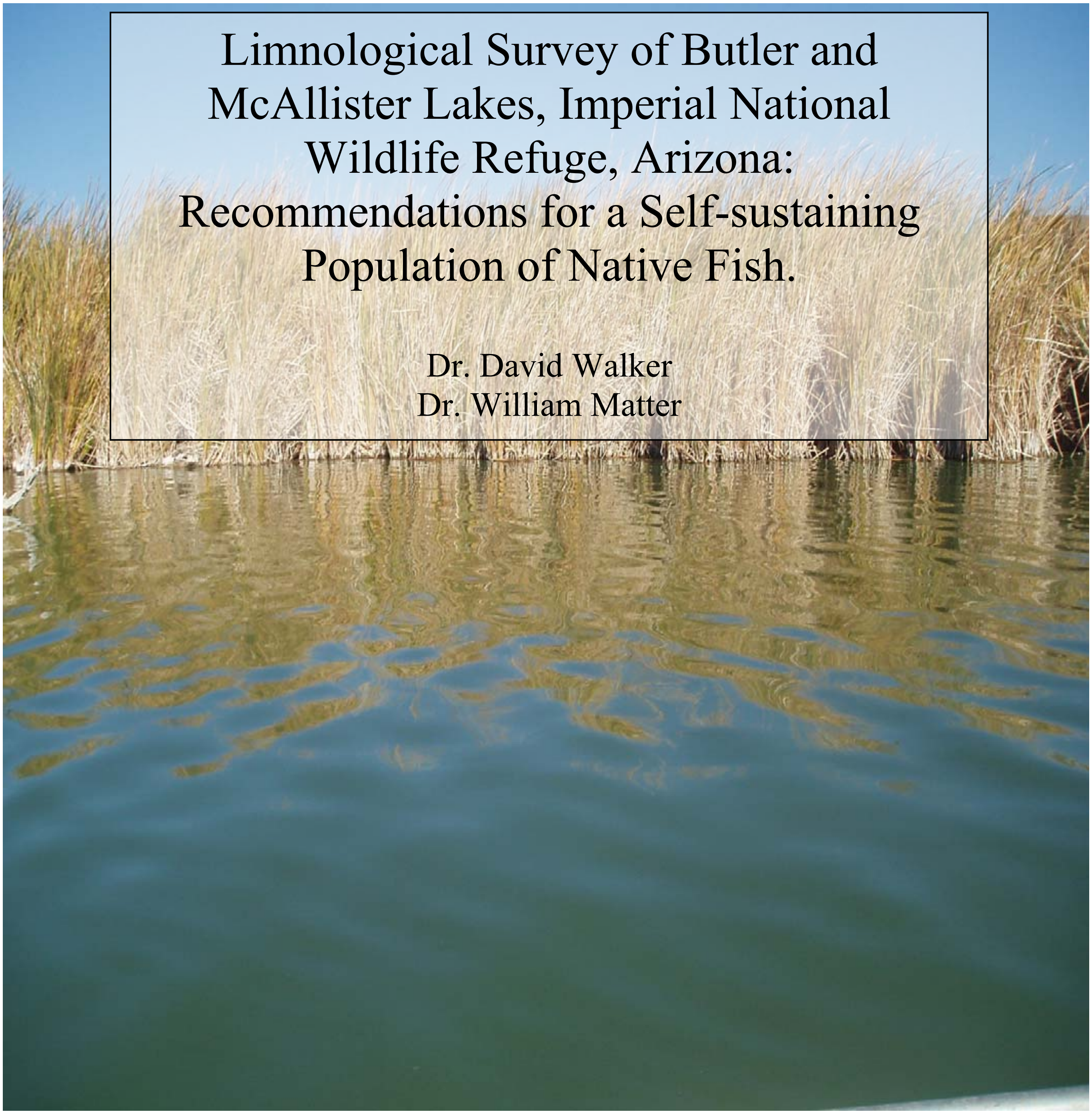

Limnological Survey of Butler and McAllister Lakes, Imperial National Wildlife Refuge, Arizona: Recommendations for a Self-sustaining Population of Native Fish.

Dr. David Walker
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EXECUTIVE SUMMARY

A limnological survey of Butler and McAllister Lakes on Imperial National Wildlife Refuge, Arizona was performed for one year beginning in December of 2005. A suite of physical, chemical, and biological variables were collected quarterly and then analyzed and discussed in this report.

Butler Lake was found to be extremely hyper-eutrophic and, in its current state, unable to support native fish species. Zooplankton was depauperate within the lake while aquatic macroinvertebrates found in the littoral zone closer to shore increased in biomass and diversity. A huge algal biomass was noted during the summer of 2006 with super-saturation of dissolved oxygen near the surface and anoxia within less than half a meter below the surface. Of the physico-chemical variables collected and analyzed, mean dissolved oxygen levels were far too low to support native fish.

Analyses of sediment samples revealed high levels of both mercury and arsenic within Butler and McAllister. While no speciation of these elements was performed, it is likely that both metals are being bio-accumulated and/or bio-magnified within the lake to higher trophic levels. We also found a potent hepato-toxin produced by algae within the lake (cylindrospermopsin). In its current state, both backwaters might be toxic to terrestrial and semi-terrestrial species relying on them for water and/or food.

McAllister Lake, while not as eutrophic as Butler, suffers from salinity levels often outside the range of survival for native fish species. A draw down treatment was performed just prior to our investigation and the positive results from this treatment were observed into the summer of 2006. No algal toxins were found within McAllister.

The draw down treatments performed in McAllister, while significantly decreasing salinity, is a disturbance to the surrounding area and often need to be repeated. We recommend the construction of an automated draw down system which is triggered by specific conductivity levels of 5000 - 6000 µS/cm2. Additionally, sediments within both Butler and McAllister are degrading water quality to the point where native fish survival would be unlikely. We recommend dredging both backwaters to improve water quality conditions. We also recommend performing some sediment coring and hydro-acoustic work prior to any dredging.

Within Butler, we recommend re-establishing an open water connection with the LCR to decrease residence time and increase dilution and flushing. Any open water connection re-established with the LCR needs to exclude non-native species by installing a cylindrical wire wedge screen system as evaluated by Normandeau Associates (2006).

Specifically, our recommendations for McAllister Lake are to install an automated pumping system which will draw down lake level so that recharge, dilution and flushing can occur and maintain relatively constant specific conductivity levels of not greater than 5000 - 6000 µS/cm2. We also recommend dredging both McAllister and Butler and re-establishing an open water connection with the LCR using cylindrical wire wedge screen technology in Butler to exclude non-native fish species.

We also recommend that, if these recommendations are implemented, at least one year post-treatment monitoring utilizing similar methodology used in this original study

INTRODUCTION AND BACKGROUND

A limnological survey of Butler and McAllister Lakes was undertaken beginning in December of 2006. This involved quarterly sampling of a suite of chemical and biological variables for a period of one year to determine major constraints to the habitability of either backwater for native fish species and recommendation(s) of remedial actions to alleviate these constraints.

Historically, backwater formation along the Lower Colorado River (LCR) relied upon a flow regime which no longer exists. Backwaters were likely formed due to scouring flood events which did any of several things to alter structure and function of any individual backwater. Upon formation of a new backwater, biological productivity might have been initially low followed by a continuum of inter-disturbance productivity which increased at some rate dependent upon several factors such as hydraulic residence time which in turn was dependent upon residence time and either a surface or sub-surface hydraulic connection with the river. Those backwaters with a relatively low hydraulic connection would have had a faster relative rate of increasing biological production. This would have been due to nutrient accumulation and recycling within a relatively more "closed" system as compared to those backwaters where the residence time was lowered so that some dilution and flushing occurred.

Within backwaters with a decreased connection to the LCR, and a relatively long residence time, biological productivity would gradually increase to the point of eutrophication or, at some later stage, hyper-eutrophication. Higher trophic levels, such as fish, in backwaters with high levels of primary production (i.e. the rate of algal growth is high), probably found environmental conditions increasingly stressful for survival. In such hyper-eutrophic backwaters, feedback loops exist between anoxic sediment and overlying water. Sediments are repositories of nutrients, metals, and salts which, under conditions of low dissolved oxygen and high levels of reduction, solubilize from the sediment into overlying water. These nutrients often spur algal growth which, when it dies, causes a decrease in dissolved oxygen due to bacterial respiration. In hyper-eutrophic aquatic systems, excessive algal growth at the waters surface almost always results in dissolved oxygen depletion in bottom waters resulting in increased solubilization of nutrients from sediments into overlying water which spurs yet more algal growth and so on.

Salinity in backwaters with decreased connectivity to the LCR increases through evaporative loss (Walker *et al.* 2007). Salinity, like hyper-eutrophication, is another stressor for higher trophic levels such as fish. Excessive salinity may favor only those species which are halophytic (salt tolerant). This may include even species of algae so that overall biological productivity is decreased to the point where little can survive in such backwaters. Like hyper-eutrophic systems, backwaters with salinity outside the range of survival for several organisms suffer from a generalized lack of dilution and flushing.

The LCR now contains several non-native fish species which adversely affect the survival of native species through several mechanisms such as predation, resource competition, destruction of spawning beds, etc. In backwaters with a direct surface connection to the LCR, and with no mechanism to exclude non-native species from entering, survivability of native species is low even though water quality conditions may be favorable for their growth.

Historically, backwaters served as critical habitat for different life stages of native fish species. Juvenile bonytail chub (*Gila elegans*), flannelmouth sucker (*Catostomus latipinnis*) and razorback sucker (*Xyrauchen texanus*) are known to utilize backwaters as rearing habitat going into the higher-flow mainstem only after attaining certain lengths (USFWS 2002, Holden *et al.* 1986). The Colorado River, like all other rivers, once contained a multitude of habitat types which served as critical areas for several aquatic, semi-terrestrial, and terrestrial species. Regulation via large dams on the mainstem and channel straightening has greatly reduced the diversity of habitat types which once existed. Environmental conditions of warm, turbid water coupled with sporadic and flashy flows once facilitated the speciation of organisms adapted to these conditions. Evolutionary processes resulted in resource partitioning of an assemblage of aquatic organisms within the LCR. This assemblage attained some level of diversity, structure, and function bounded within some range of environmental conditions as they historically existed within the Lower Colorado River Basin. It is said that nature abhors a vacuum. If resources are made available, then something almost always evolves to exploit these resources with few, if any, areas not serving as "habitat". Homogenization of habitat types, or outright elimination of certain types such as backwaters, always results in a generalized decrease in ecosystem-wide biological diversity of those organisms dependent upon and which have evolved within, these areas. The conditions under which native fish species evolved into, for the most part, no longer exist within the LCR.

Proper terminology is important in defining what habitat is and isn't. True "restoration" of all habitat types, including backwaters, within the LCR is not feasible or possible. Restoration would require removing all anthropogenic causes of environmental change within the immediate region and all upstream reaches. Native fish species inhabited, at some point, all areas of the LCR. This allowed outflow of genetic material so that population could occur on a system-wide basis. Due to the anthropogenic reasons previously mentioned, any natural outflow of genetic material seems unlikely to ever occur again. What we are left with is habitat *creation* of backwater areas for relatively small, localized populations of native fish species. These areas do not currently support these species; otherwise, this work would not be needed. The reason they do not support these species is because the conditions which created these areas naturally, no longer exist. In light of this, it must be understood that the creation of habitable backwaters for native fish species, if deemed feasible, would be created "against the grain" of what they now are and will require long-term commitments in planning, maintenance, and monitoring.

An area is not considered habitable where limited or no fertility, fecundity, and genetic diversity occur. A zoo is not habitat. Any primary goal of habitat creation must take the ability to produce subsequent generations into account. Survivability of one generation in an area with limited or no fertility or fecundity should not be considered successful. With limited outflow of genetic material (i.e. emigration), long-term sustainability of any enclosed population will require consistent monitoring to avoid conditions of over-crowding, resource depletion, stunting, etc. Trying to maintain an enclosed population of native fish species is a delicate balancing act.

The creation of habitat for native fish species is a noble and overdue, yet anthropocentric, construct. It should be a task which utilizes sound ecological principles as a guide. Any engineering aspect of habitat creation should rely upon these ecological principles as a basis for determining long-term success. The "throw fish in and see how they do" mentality almost always results in wasting time, energy, and resources. The creation of any backwater for native fish species should be well thought out and debated prior to stocking with fish. It should also be a task which is malleable enough to adapt to changing and/or new findings important to the long-term survivability of native fish species.

GOALS AND OBJECTIVES

The primary goal of this research is to determine what environmental constraints, if any, exist within Butler and McAllister Lakes for the introduction and survivability of native fish species, primarily razorback sucker and bonytail chub. In order to determine what these constraints were, a limnological survey of both lakes was initiated in December, 2006 which lasted for a period of one year. Specific objectives are:

- Collect a suite of biological, physical, and chemical variables for a period of one year and determine what major constraints and/or stressors to native fish species existed within each lake.

- After careful analysis of the variables listed above, determine what actions could feasibly be implemented within either lake to alleviative these constraints and/or stressors for the long-term survival of native fish species, primarily razorback sucker and/or bonytail chub.

SITE DESCRIPTION

Both Butler and McAllister Lakes have been described in the documents entitled *Preliminary Assessment, Butler Lake Native Fish Refugium, Imperial National Wildlife Refuge, Arizona* (USBOR 2004) and *Induced Recharge in McAllister Lake, Arizona to Reduce Salinity for the Possible Introduction of Native Fish Species* (Walker *et al.* 2007). Abbreviated site descriptions given in this report are derived from these two documents.

Both Butler and McAllister Lakes are located on Imperial National Wildlife Refuge (INWR) some 40 miles northeast of Yuma, Arizona (Fig. 1). Climate in the area is arid and hot with an average annual air temperature of 22.9° C and 9 cm of annual precipitation (USBOR 2004). Open water evaporation is estimated at nearly 2.2 m per year (Guay 2003).

Butler

Butler Lake is a 43 acre (17.2 hectare) surface acre backwater ("floodplain lake") located at river mile 61.5 approximately 160 meters east of the Colorado River (USBOR 2004) (Fig. 2). A bathymetric survey of Butler lake was performed by BOR in 2004 (Fig. 3). This survey found an average depth of 0.9 m, a maximum depth of 1.8 m, with the majority of the lake between 0.9 - 1.2 m. Total volume at the lake stage surveyed at the time was 142 acre feet (175,337 m^3). Shoreline length was found to be 2,806 m with a shoreline development index of 1.90.

Three sampling locations were established within the lake (Fig. 4). At the lake stages observed during this study, site BL3 was the deepest (average depth was approximately 0.8 m) followed by site BL1 (average depth approximately 0.7 m) with site BL2 being the shallowest site (average depth approximately 0.4 m).

Butler Lake, during the course of this study, had no surface connection with the LCR and relies upon groundwater seepage (via a sub-surface connection with the LCR) to maintain water within the lake.

The lake is ringed by a thick layer of emergent vegetation primarily cattail (*Typha domingensis*) and water reed (*Phragmites australis*). There appears to be an inward movement of cattail into the lake and new hummock formation was observed over the course of this study. These hummocks will hasten in-filling of the lake and in several aspects, Butler appears to be more marsh-like than lacustrine.

Figure 1. Relationship of Butler and McAllister Lakes to each other and the Colorado River
Map by Julie Martinez, GIS Specialist, USBOR

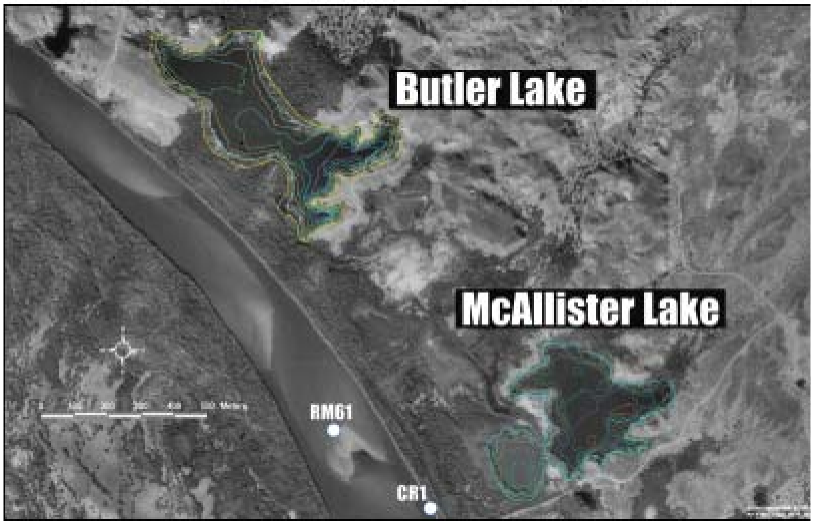


Figure 2. Butler Lake project area and surrounding Lower Colorado River Region
Map by Julie Martinez, GIS Specialist, USBOR

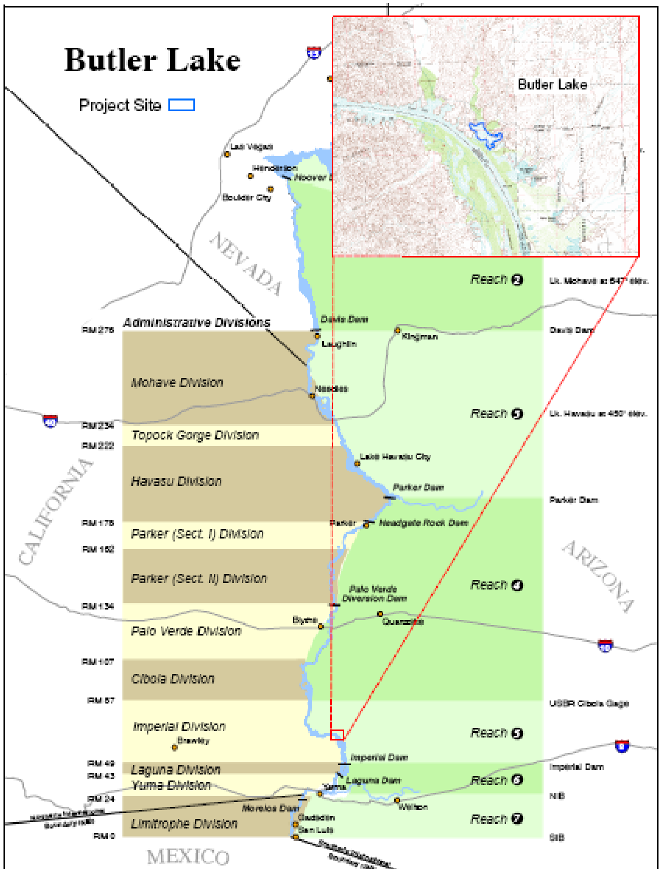


Figure 3. Butler Lake bathymetric survey.
Map by Julie Martinez, GIS Specialist, USBOR.

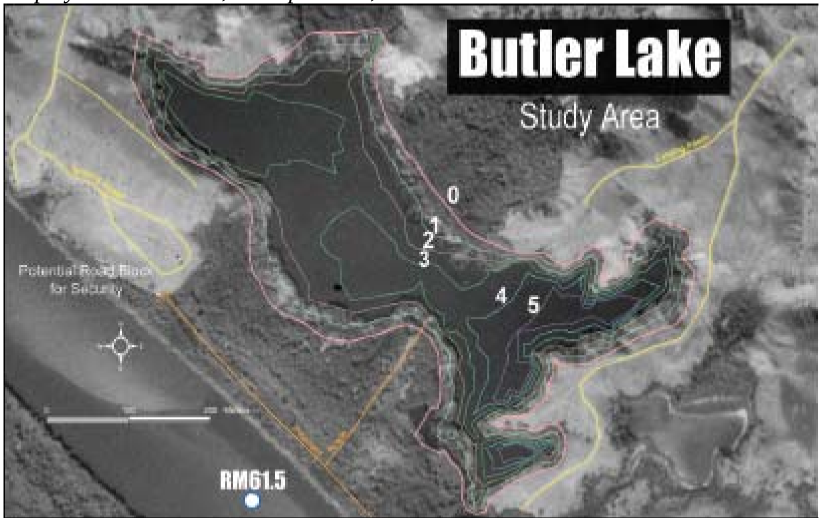
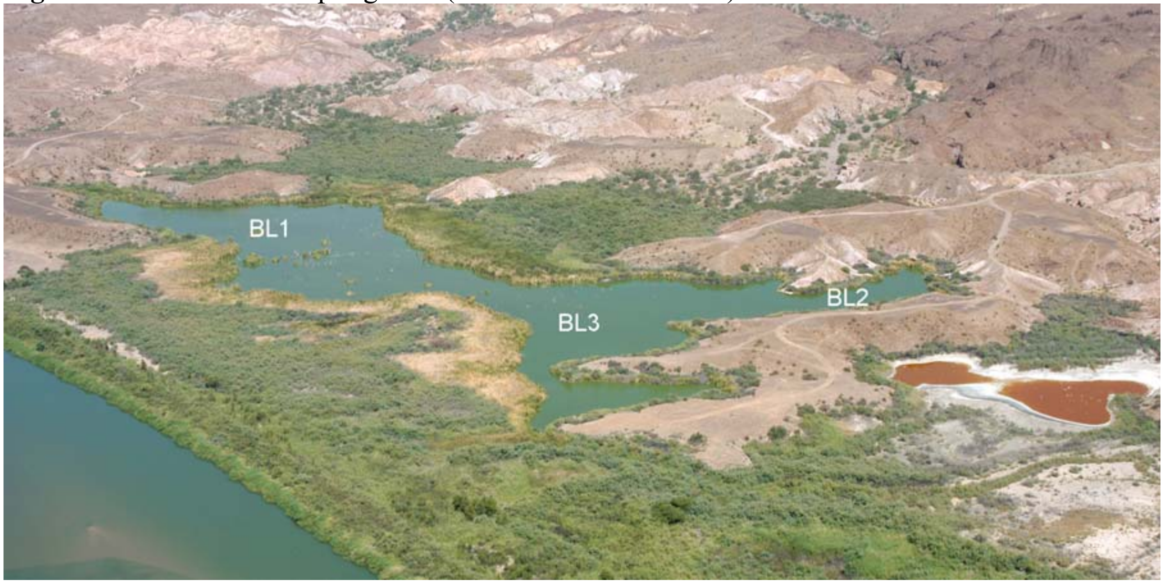


Figure 4. Butler Lake sampling sites (view is to the northeast)



McAllister

McAllister Lake is a 32 surface acre isolated backwater (floodplain lake) with a mean depth of 4.5 feet. This isolated backwater is roughly 1,200 feet east of the river (approximately at river mile 61, Fig. 5) and, like Butler, is seepage-driven with no known surface connections to the river or any other water bodies.

The lake is situated within what is thought of as the “river aquifer” of the LCR. The river aquifer concept infers a significant degree of hydraulic connectivity between the sediments adjacent to the river and the river itself. This connectivity promotes the passage of water between the river and adjacent floodplains.

McAllister Lake, as is typical for many of the LCR's floodplain areas, overlies saturated and partially saturated sediments categorized into younger and older alluvium groupings. The younger alluvium dates back to the Holocene epoch and are the most recently deposited sediments (as old as 10,000 years BP) composed primarily of unconsolidated mixtures of gravel, sand, silt and clay floodplain deposits which can be up to 180 feet thick in some areas. Below the younger alluvium is positioned a more consolidated older alluvium that dates back to the Pleistocene era.
Both of these units are moderately-to-highly transmissive with likely hydraulic conductivities in excess of 500 feet per day. Field observations note that the western flank of McAllister Lake contains some heavier soils, with markedly lower hydraulic conductivities. It has been hypothesized that much of the water that recharges the lake comes from the coarser underlying alluvial sediments.

The Bureau of Reclamation conducted a bathymetric survey during two site visits from February to March 2003 using a high resolution Global Positioning System (GPS) (Corvalis Microtechnology® Model MC-GPS, Version 3.7. Corvalis, OR.) (Fig. 6) The total open water surface area, not including emergent vegetation, was 26.5 acres. The total marsh area, which could not be accounted for during the bathymetry survey, was calculated through shoreline delineation of the bathymetry map and totaled 5.8 acres. Combining surface water and marsh together resulted in total backwater acreage of 32.3 acres. The shoreline perimeter was 8,077 feet, with a shoreline development index of 1.924. The mean depth was 4.5 feet. High water is approximately 183 ft above mean sea level (MSL).

Morphologically, McAllister Lake contains two somewhat distinct basins. To the west, lies a circular pond, which is referred to as the "Western Lobe". This western lobe represents approximately ¼ of the total area of the lake, and maintains no surface connection to the main basin of the lake at elevations below 181 ft above MSL.

To alleviate water quality problems associated with stagnation often found in hyper-eutrophic lakes and ponds and aid in mixing (especially during the critical summer months), three Pond 1® wind-powered aerator/mixers (Lake Aid Systems 1997) were installed at McAllister Lake on July 14, 2004. The Pond 1® units have a reported mixing capability of 400 gallons per minute under average wind-speeds, with a minimum wind-speed requirement of 5 miles per hour, and an effective mixing area of 5 acres in fresh water. Based on windspeed data from Miller (1999), wind at and above this threshold is common at McAllister Lake.

Four sampling sites were established within McAllister; 3 in the main lake and one in the western lobe (Fig. 7). Due to access difficulty, the western lobe was sampled from only twice.

Figure 5. McAllister Lake project area and surrounding Lower Colorado River Region
Map by Julie Martinez, GIS Specialist, USBOR

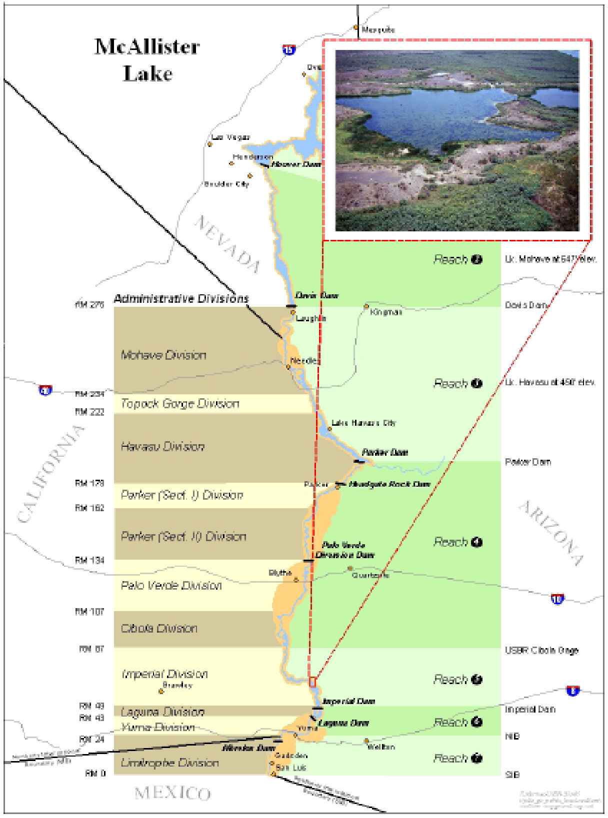
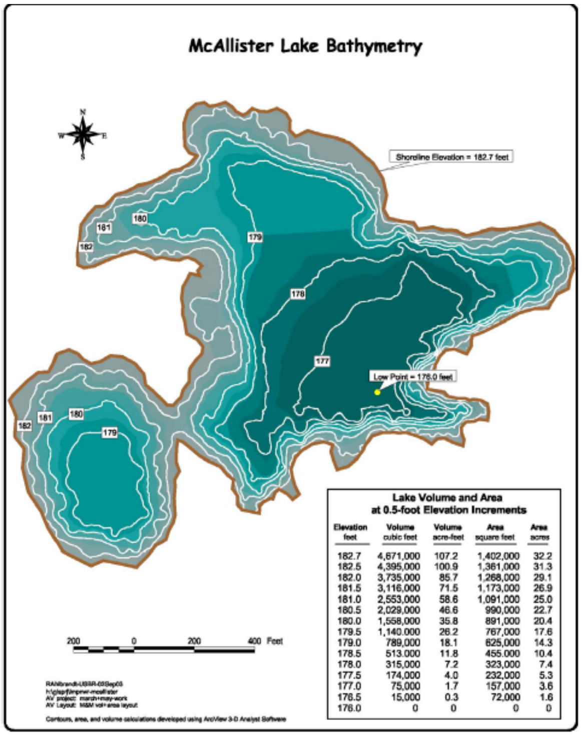


Figure 6. McAllister Lake bathymetry (using NAVD88 vertical datum)



Lake Volume and Area
at 0.5-foot Elevation Increments

Elevation feet	Volume cubic feet	Volume acre-feet	Area square feet	Area acres
182.7	4,671,000	107.2	1,402,000	32.2
182.5	4,395,000	100.9	1,361,000	31.3
182.0	3,735,000	85.7	1,268,000	29.1
181.5	3,116,000	71.5	1,173,000	26.9
181.0	2,553,000	58.6	1,091,000	25.0
180.5	2,029,000	46.6	990,000	22.7
180.0	1,558,000	35.8	891,000	20.4
179.5	1,140.000	26.2	767,000	17.6
179.0	789,000	18.1	625,000	14.3
178.5	513.000	11.8	455.000	10.4
178.0	315,000	7.2	323,000	7.4
177.5	174,000	4.0	232,000	5.3
177.0	75,000	1.7	157,000	3.6
176.5	15,000	0.3	72,000	1.6
176.0	0	0	0	0

Figure 7. McAllister Lake sampling sites (view is to the northwest)

METHODS

Site visits were performed on 12/07/05, 04/04/06, 07/26/06, and 12/05/06 in Butler and on 12/06/05, 04/05/06, 07/25/06, and 12/05/06 in McAllister. Profiles of physico-chemical variables (temperature, dissolved oxygen [% saturation and mg/L], pH, specific conductivity, turbidity, and secchi disk depth) were collected at each site during each visit. The analytes listed in Table 1 were collected during each visit.

Table 1. Analytes collected during each sampling visit.

Analyte	**# of Sites Collected**	**Reporting Unit**
Total P	All	mg/L
Ortho-P	All	mg/L
Nitrate-N	All	mg/L
Nitrite-N	All	mg/L
Ammonia-N	All	mg/L
Total Kjeldahl nitrogen (TKN)	All	mg/L
DOC	All	mg/L
TOC	All	mg/L
BOD	All	mg/L
COD	All	mg/L
Total alkalinity	All	mg/L as CaCO3
Cl	1	mg/L
SO4	1	mg/L
Ca*	1	mg/L
Na*	1	mg/L
Fe*	1	mg/L
Mn*	1	mg/L
Zn*	1	mg/L
Cd*	1	mg/L
Hg	1	mg/L
Se	1	mg/L
As	1	mg/L

* indicates compounds were analyzed for both total and dissolved states.

Sediment samples were collected using an Eckman dredge. Samples were homogenized within the dredge and placed into sterilized glass containers and, like the water analytes listed above, kept on ice following collection for transport back to the University of Arizona/Environmental Research Laboratory. Sediment samples were collected at one site from both lakes in December of 2005 and again in July of 2006.

Table 2. Analytes run from sediment samples.

Analyte	Reporting Unit
TOC	%
Ca	%
Na	%
Total P	μg/g
Be	μg/g
Cd	μg/g
Cr	μg/g
Cu	μg/g
Fe	μg/g
Mn	μg/g
As	μg/g
Mn	μg/g
Se	μg/g

Samples to assess algal composition and biomass were collected at each site during each sampling visit. Samples collected for analysis of chlorophyll *a* and algal identification and enumeration were collected in amber, plastic bottles and preserved with 4-5% glutaraldehyde. Chlorophyll *a* was determined fluorometrically and algae counts and ID were performed using a gridded Sedgewick-Rafter counting chamber.

Some species of algae are known to produce various kinds of toxins. Some species can produce potent hepato- or neuro-toxins. Samples were collected in July of 2006 at both lakes and sent to the USDA-ARS in Stoneville Mississippi for analysis of anatoxin-a, cylindrospermopsin, and microcystin.

Zooplankton was also collected at each lake during each visit. Samples were collected using an 81μm, Wisconsin-style plankton net with a reducing cone. The net was drug through the water at a known velocity and distance so that volume passing through the net could be calculated and organisms enumerated. These samples were also preserved with a 4-5% solution of glutaraldehyde.

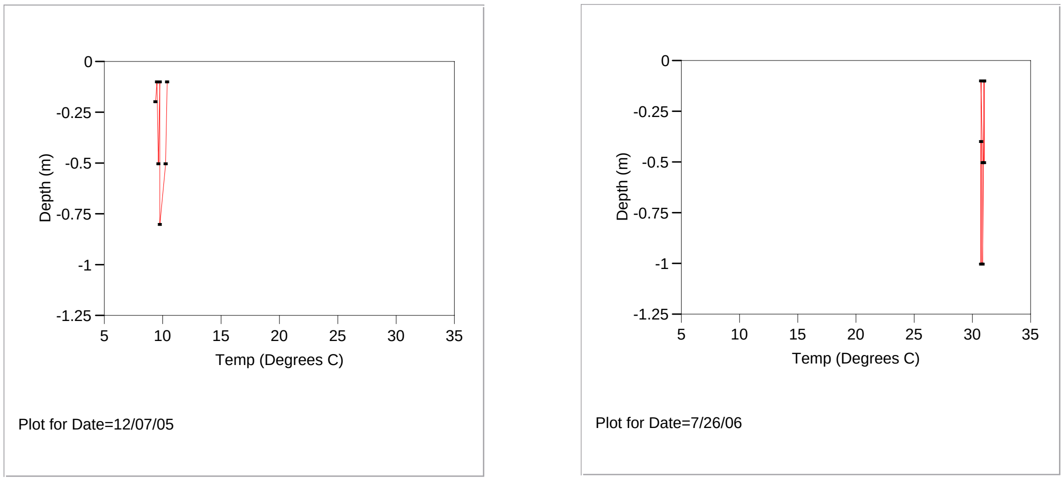
Aquatic macroinvertebrates were collected at each lake during each visit. Samples were obtained from aquatic vegetation within the littoral zone of each lake. A series of 3, 1 minute vegetation sweeps were performed with a standard D-shaped kick net while maneuvering the boat into the emergent vegetation along the shore. Collected material was sub-sampled either at the lake or back at the lab using a standard Caton tray® where precisely one-tenth of the entire sample was used for identification and enumeration of macroinvertebrates.

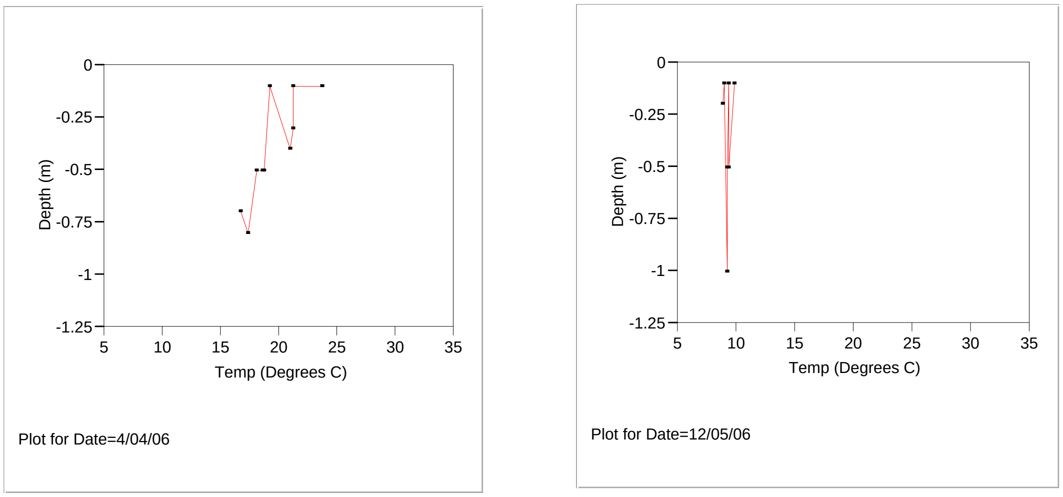
RESULTS

Butler

Thermal stratification was only evident during the spring 2006 sampling (Fig. 8) and even then, there didn't appear to be the development of a true epilimnion; rather, a thin film of dissipated heat appeared at the very surface of the water with temperatures beneath roughly 0.3 m being 7 – 8^{o} C cooler than those at the surface. During this time, a massive and very dense bloom of cyanobacteria was noted. This bloom dissipated not only light, but also heat within the very thin film at the waters surface. Sampling during the summer of 2007 showed no evidence of thermal stratification and temperatures were greater than 30^{0} C throughout the water column. It appears that Butler is too shallow to maintain thermal stratification and heating occurs throughout the water column as spring progresses into summer. Mixing by wind also probably plays a role in keeping water temperature more or less the same from top to bottom.

Figure 8. Temperature profiles by depth within Butler Lake

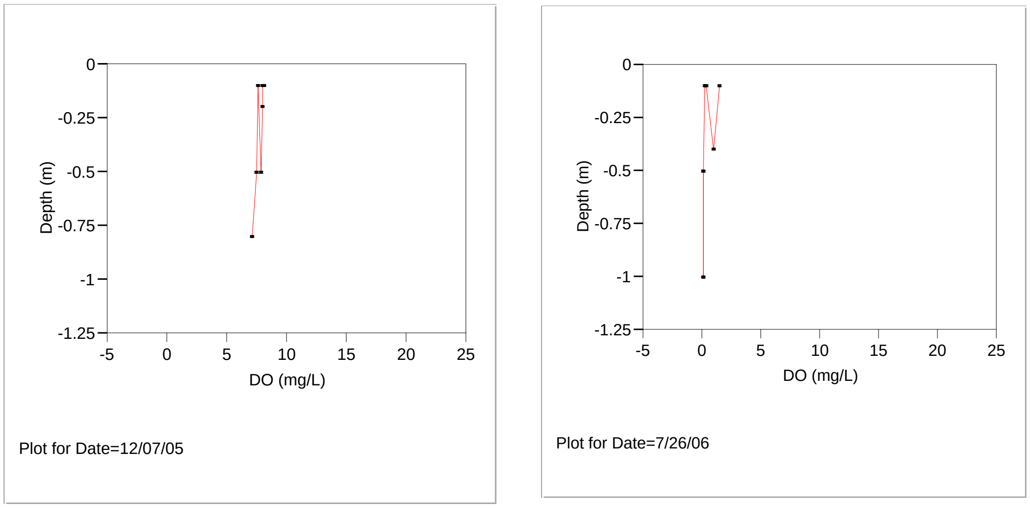




Levels of dissolved oxygen (DO) were extremely variable. During the winter/fall, when water temperatures are cooler and algal biomass relatively low, DO levels are adequate for survival of most species of native fish (Fig. 8). During the spring, the extraordinarily large biomass of algae in a thin film at the surface resulted in super-saturation of DO levels with these plummeting to complete anoxia within 0.3 meters. Levels of DO at the surface could not accurately be obtained because they were actually higher than what the probe and sonde could read (> 20 mg/L and over 200% saturation). This is a direct result of DO as a by-product of an extraordinarily high photosynthetic rate. Anoxia just below actively-photosynthesizing algal cells at the surface is the result of respiration by the algal cells and bacteria. Such extreme variability in DO levels is indicative of a hyper-eutrophic aquatic system.

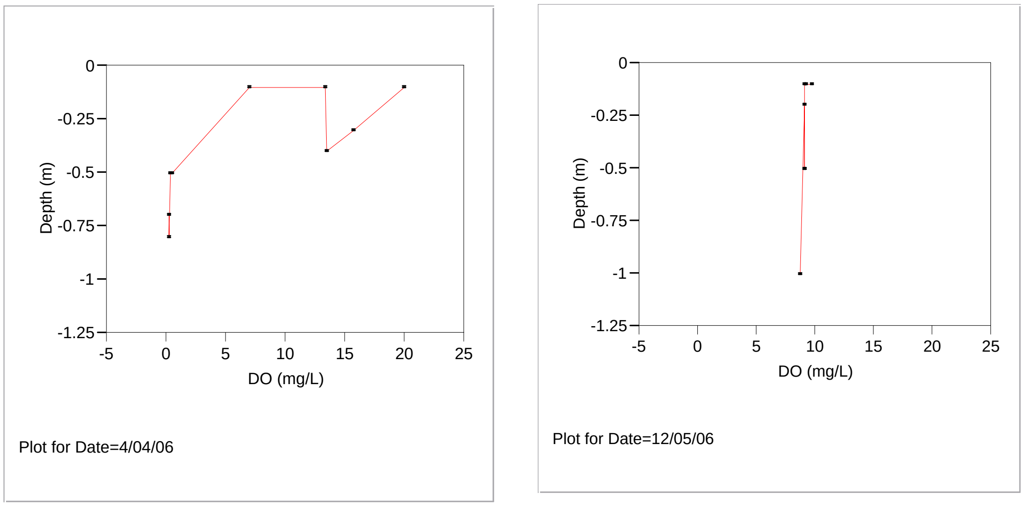
During the summer, levels of DO were very low throughout the water column with no levels greater than 2.0 mg/L. Levels of DO decreased with depth; generally less than 0.5 mg/L. Few, if any, fish species could survive in a system with such low levels of dissolved oxygen. Levels of DO were likely much lower at night when, in the absence of light, algal cells switch from net photosynthesis to net respiration.

Figure 8. Dissolved oxygen levels (mg/L) by depth within Butler Lake.



Plot for Date=12/07/05

Plot for Date=7/26/06



Plot for Date=4/04/06

Plot for Date=12/05/06

Biological and chemical oxygen demand (BOD and COD respectively) within Butler was very high (Fig. 9). BOD was greater in the summer probably due to respiring bacteria fueled by dead and dying algal cells. Both of these parameters were orders of magnitude greater than in urban lakes within Arizona already deemed as hyper-eutrophic. These urban lakes are also plagued with periodic, large, fish kills. There appears to be far more oxygen sinks within Butler than sources. Re-oxygenation of water, in lieu of any remediative action to alleviate the problem, is unlikely if not impossible.

Figure 9. Mean BOD levels (in mg/L) by date within Butler Lake.

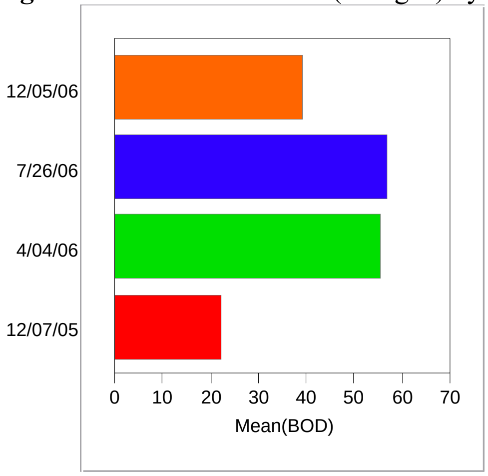
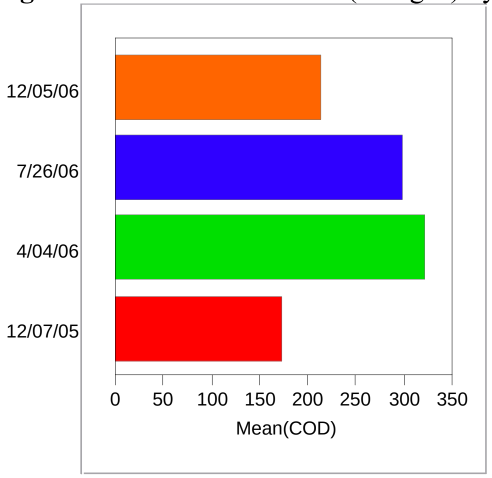
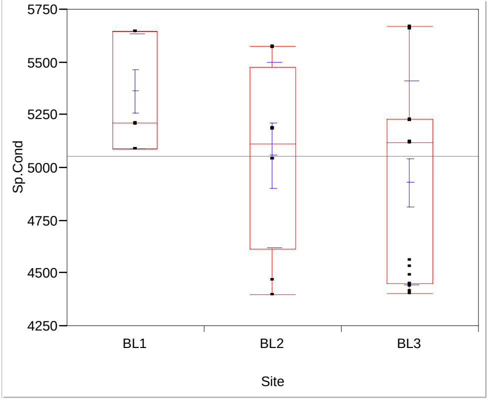


Figure 10. Mean COD levels (in mg/L) by date in Butler Lake.



Levels of specific conductivity, while relatively high when compared to other aquatic systems in the arid southwest, were not outside the range of survivability, or even preference, by native fish species (Fig. 11). Site BL1 had slightly higher levels than sites BL2 and BL3. Total alkalinity within Butler is also quite high (mean = 555 mg/L as CaCO3) indicating a strong buffering capacity to resist sudden swings in levels of pH which were also relatively high (Fig. 12). The largest variability in pH occurred during the spring of 2006 sampling. Again, this is due to the huge algal biomass at the surface utilizing CO_2 from the water for photosynthesis. Underneath this algal biomass, light became limiting and photosynthetic rate, and therefore pH levels, decreased. The summer of 2006 sampling showed the lowest levels of pH likely due to bacterial respiration driving levels down.

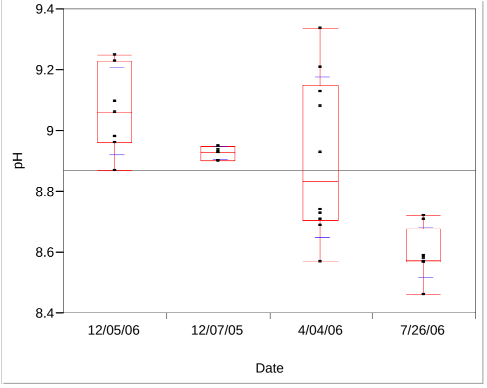
Figure 11. Levels of specific conductivity (µs/cm) by site within Butler Lake.



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
BL1	7	5363.43	270.395	102.20	5113.4	5613.5
BL2	8	5060.50	437.972	154.85	4694.3	5426.7
BL3	17	4929.71	481.676	116.82	4682.1	5177.4

Figure 12. Levels of pH by date within Butler Lake.

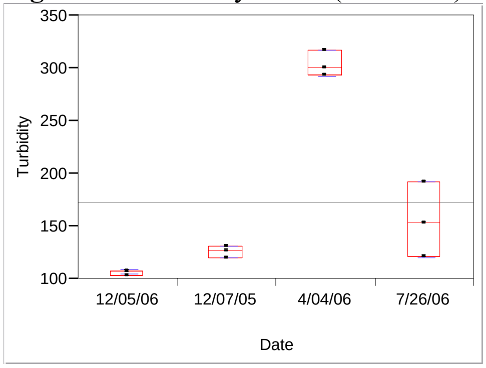


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/05/06	7	9.06429	0.140814	0.05322	8.9341	9.1945
12/07/05	7	8.92857	0.021157	0.00800	8.9090	8.9481
4/04/06	10	8.91300	0.262003	0.08285	8.7256	9.1004
7/26/06	8	8.59625	0.083826	0.02964	8.5262	8.6663

Turbidity within Butler was relatively high even at the lower levels observed during the fall and winter (Fig. 13). The very high levels observed during the spring of 2006 was primarily due to the large amount of algae within the water. Secchi disk depth, an indicator of water transparency, was also very low (Fig. 14), however, the lowest secchi depth levels were not recorded during the large bloom event during the spring sampling. While both turbidity and secchi depth are indicators of light in water, they are measured differently. Turbidity measures the amount of light scattered in water due to particulate material while Secchi depth measures water transparency and takes into account dissolved, colored material which turbidity does not.

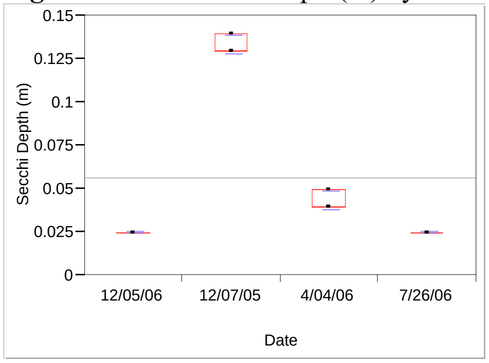
Figure 13. Turbidity levels (in NTU's) by date within Butler Lake.



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/05/06	3	106.333	2.0817	1.202	101.16	111.50
12/07/05	3	126.000	5.5678	3.215	112.17	139.83
4/04/06	3	304.333	12.3423	7.126	273.67	334.99
7/26/06	3	156.000	36.0416	20.809	66.47	245.53

Figure14. Secchi disk depth(m) by date in Butler Lake



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/05/06	3	0.025000	0.000000	0.00000	0.02500	0.02500
12/07/05	3	0.133333	0.005774	0.00333	0.11899	0.14768
4/04/06	3	0.043333	0.005774	0.00333	0.02899	0.05768
7/26/06	3	0.025000	0.000000	0.00000	0.02500	0.02500

Concentrations of total and dissolved iron, manganese, zinc, cadmium, and copper were all un-remarkable. There was a slight increase in dissolved iron and manganese during periods of anoxia (spring and summer). This is probably due to reducing conditions solubilizing particulate forms from the sediment into the overlying water. This often happens in anoxic hypolimnia in lakes and reservoirs.

Levels of arsenic and mercury were found within Butler at levels that, due to bio-accumulation and bio-magnification issues, warrant safety concerns for humans and wildlife. This statement needs to carry the caveat that no speciation of these constituents was performed and detection limits were relatively high compared to US EPA "clean" sampling standards. Nonetheless, cursory reconnaissance indicates that Butler contains relatively high total levels of arsenic and mercury.

Arsenic was found in aqueous samples at levels between 0.016 and 0.020 mg/L. The US EPA criteria level for arsenic in drinking water is 10 ng/L. While drinking water is not an issue in Butler, bioaccumulation (but not biomagnification) of organic arsenic compounds, after biogenesis from inorganic forms, does occur in aquatic organisms. As previously stated, no speciation of arsenic was performed and the degree of toxicity of arsenic is basically dependent on the form (e.g. inorganic or organic) and the oxidation state of the arsenical. It is generally considered that inorganic forms are more toxic than organic forms, and within these two classes, the trivalent forms are more toxic than the pentavalent forms, at least at high doses. Trying to determine potential toxicity of aquatic organisms at the levels found, without speciation, is not possible; however, the fact that relatively high total levels have been found warrants concern about toxicity.

Levels of total mercury in the water were found in Butler ranging from non-detectable (12/07/05) to 27 µg/L (07/26/06). This is a very high level of total mercury; much higher than levels found in a review of mercury in lakes performed by the US EPA (1997). Like arsenic, speciation of mercury is important in determining toxicity, bioaccumulation, and biomagnification. Methylmercury is the most bioavailable form of mercury and is mediated biogenically by sulfur reducing bacteria (SRB's). It is possible to have lakes with low levels of SRB's, high levels of total mercury, and little or no methylation or subsequent biomagnification. While we did not sample for methylmercury, conditions within Butler are relatively ideal for its formation. The large amount of emergent/submergent aquatic vegetation within Butler, and the subsequent decay of the same, makes conditions ideal for a large population of SRB's to thrive. As their name implies, these bacteria obtain energy from the reduction of sulfur ultimately resulting in the formation of H_2S gas. The smell of H_2S gas was very strong within Butler emanating from the sediment and surrounding aquatic vegetation. While the exact rate/percentage of methylation of mercury within Butler is unknown, environmental conditions are ideal for this to occur. If this is the case, then a fast rate of biomagnification within aquatic, and possibly terrestrial and semi-terrestrial, organisms would be expected.

Selenium was found in Butler at relatively low levels (between 0.33 and 0.35 µg/L). This is in-line with the national average for non-seleniferous surface waters of 0.1 to 0.4 µg/L. While the US EPA is revising the acute toxicity criterion for selenium in freshwater, their chronic threshold is 5.0 µg/L. Speciation is very important in determining Se toxicity. To determine exact toxicity would require analysis of selenite and selenate which was not performed in this study. Nonetheless, selenium levels within Butler during this project were not found to be a constraint or hazard to aquatic life or human health.

Sediment samples were analyzed for the presence of metals including arsenic, mercury, and selenium. Samples were collected at site BL1 on 07/26/06. Levels of arsenic were 3.59 µg/g, mercury was 0.034 µg/g, and selenium was 0.41 µg/g. These levels indicate that sediments within Butler are probably significant sources and sinks of arsenic and mercury with their bio-availability dependent upon environmental conditions enhancing either solubilization or mineralization.

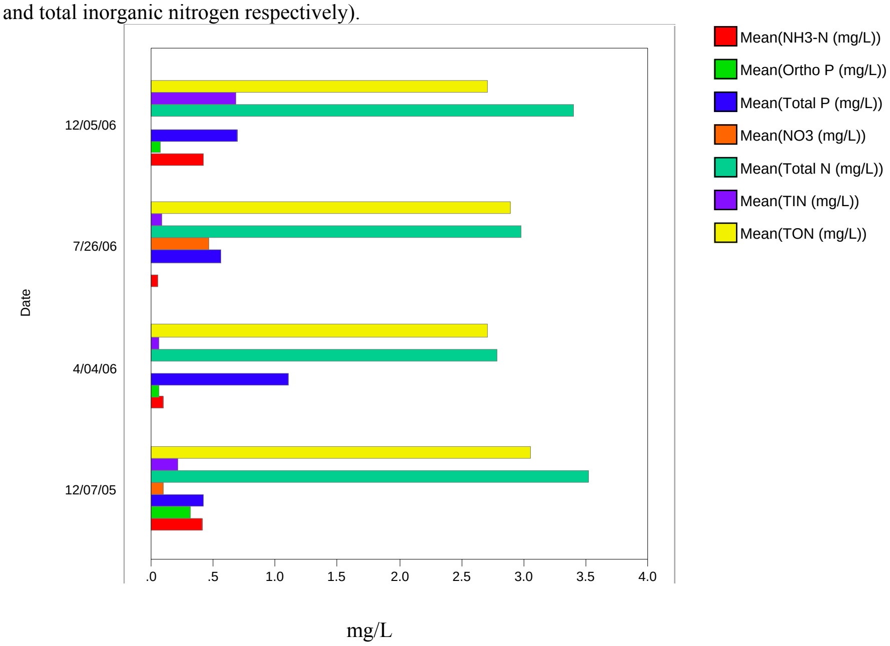
Other metals analyzed from sediment samples taken in Butler are given in Table 3. While some species of these compounds are known toxicants to aquatic life (Cd, Cr, Cu, Zn), they were only found in very low levels within the water indicating that, for the most part, these compounds are bound to sediments. However, this does not mean that these constituents are not toxic to aquatic life as they could be absorbed or ingested from the sediment.

Table 3. Sediment metals taken from site BL1 on 07/26/06

Analyte	**Result (µg/g)**
Be	1.17
Cd	0.20
Cr	22.50
Cu	23.03
Fe	27,250
Mn	618.1
Zn	91.3

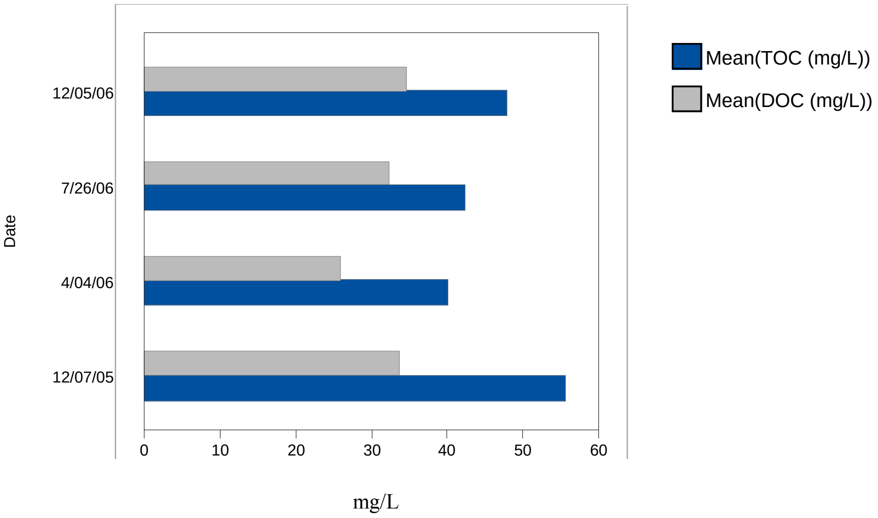
Nutrient levels were very high within Butler (Fig. 14). On a strict stoichiometric basis, Butler might be considered phosphorous "limited". The idea of nutrient limitation is often erroneously applied in hyper-eutrophic systems where ratios between primary nutrients (nitrogen, phosphorous, and carbon) might indicate "limitation" even when overall concentrations are several orders of magnitude higher than what it would take to ever limit algal growth. This is the case within Butler where levels of all nutrients are much higher than what it would take to limit algal growth. Both total nitrogen and phosphorous would need to be an order of magnitude lower than what was found to begin to limit algal growth.

Figure 14. Mean nutrient levels within Butler Lake by date ("TON" and "TIN" stand for total organic nitrogen and total inorganic nitrogen respectively).



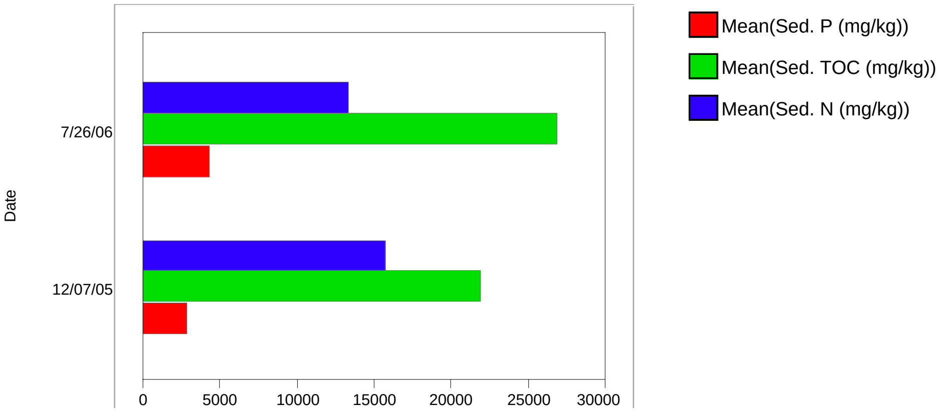
Large concentrations of organic carbon were noticed in aqueous samples from Butler (Fig. 15). Surprisingly, levels were not correlated with the amount of algal biomass in the water and the highest levels were observed during summer. This may mean that seasonal die-backs of emergent aquatic vegetation are the larger source of organic carbon into the water. This same general trend was noted in the levels of nutrients as well.

Figure 15. Total and dissolved organic carbon levels within Butler Lake by date.



Carbon, nitrogen, and phosphorous were analyzed from sediment samples during the summer and winter (Fig. 16). These levels, like nutrients found in aqueous samples, were very high. Like metals, the sediment acts as both a source and sink for nutrients into overlying water depending upon environmental conditions. During periods of anoxia, nutrients such as phosphorous, will be solubilized and released from the sediment to be utilized by primary producers and then by other trophic levels. During these same periods, nitrogen will be reduced to nitrite and possibly ammonia. Upon the death of these organisms, nutrients will be re-deposited back into the sediment where they will either be sequestered during periods of increased DO (i.e. winter) or re-solubilized and incorporated into biomass once again (i.e. summer). Once initiated, this feedback mechanism usually results in eutrophication occurring in an exponential fashion.

Figure 16. Sediment nutrient levels from Butler Lake by date.



There was a huge algal biomass in Butler; especially during the spring and summer (Fig. 17). This huge biomass is evidence that nutrient limitation does not exist within Butler. Algal diversity was very low consisting almost entirely of cyanobacteria (Fig 18).

The rate of primary production within Butler is truly astounding and indicative of extreme hyper-eutrophication. Most of the cyanobacterial species found within Butler are capable of producing potent hepato- or neuro-toxins. Samples were collected during July of 2006 and sent to USDA for analysis of microcystin, anatoxin-a, and cylindrospermopsin. Anatoxin-a was found in relatively high numbers (14.3 ng/L). Anatoxin-a is postsynaptic, depolarising, neuromuscular, blocking agent that binds strongly to the nicotinic acetylcholine receptor and causes death by respiratory paralysis. Its toxic effects are very fast acting and irreversible. The production of anatoxin-a within Butler Lake should be considered a threat to both terrestrial and aquatic wildlife. Since it is doubtful that anyone would purposefully ingest water from Butler in its current state, human exposure is unlikely and ingestion is the only known route of exposure. Anatoxin-a is produced by species of anabaena and anabaenopsis (Fig. 20).

Figure 17. Chlorophyll *a* levels within Butler Lake by date.

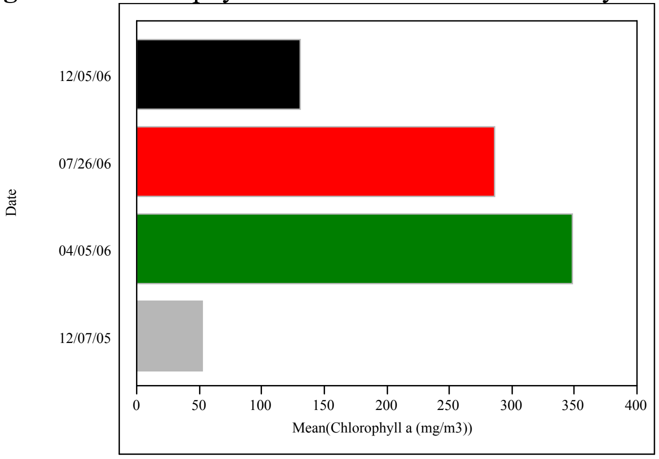


Figure 18. Algal divisions found within Butler Lake.

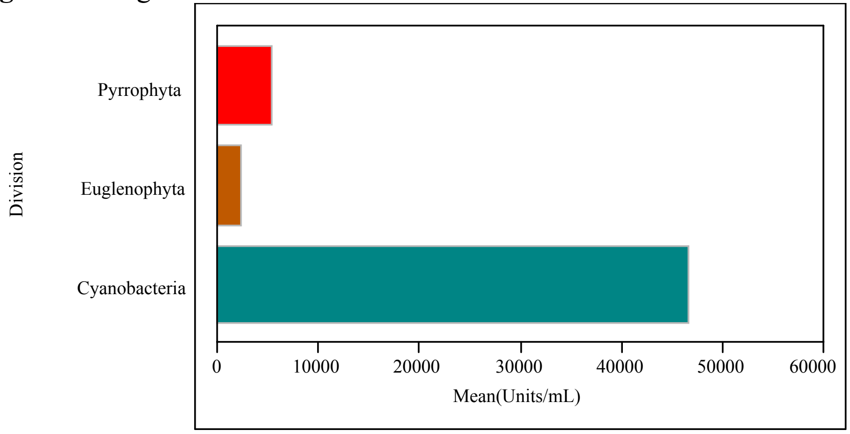


Figure 19. Species of cyanobacteria found within Butler Lake.

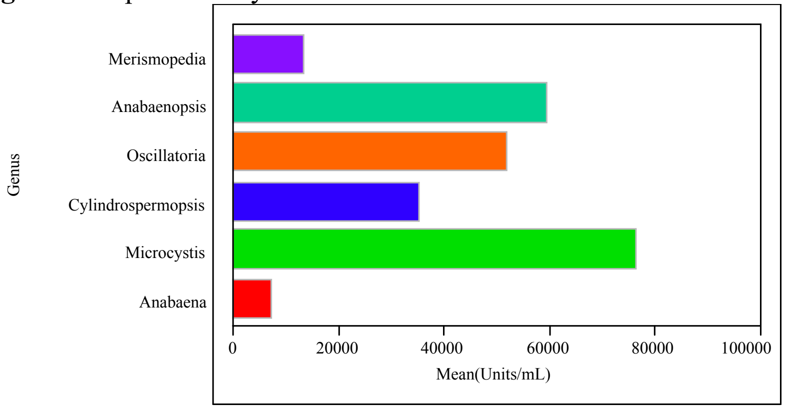
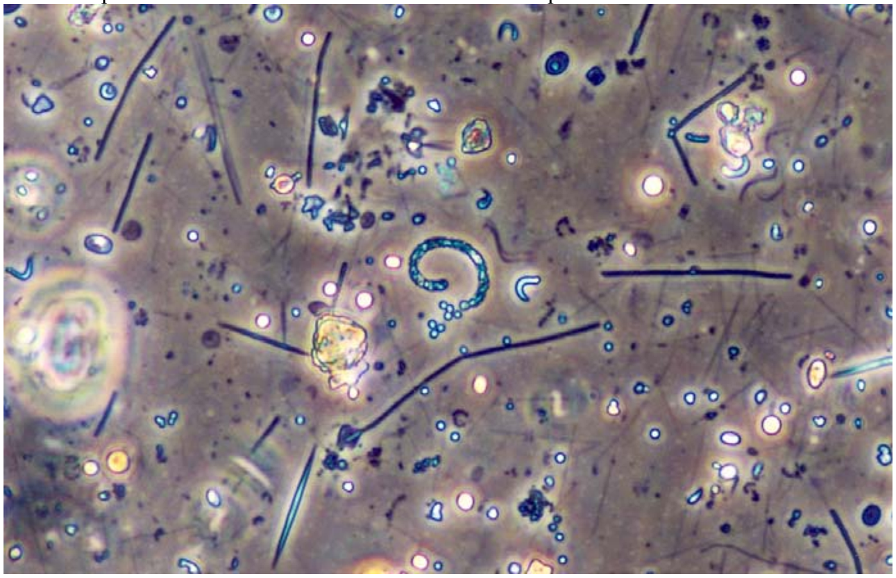


Figure 20. Photo-micrograph of the algal assemblage found within Butler on 07/26/06. Anabaenopsis is in the center. The darker filaments are species of Oscillatoria.



Abundance and diversity of zooplankton was low. Only three Orders were represented and these were of very low numbers (Table 4). The most commonly found zooplankters were calanoid copepods. No zooplankters were found during the summer of 2006 sampling when a relatively large amount of anatoxin-a was found in the water. The production of toxins by algae may be an evolved response as protection from grazing by zooplankters. It appeared to be an effective mechanism by the algal assemblage in Butler as little, or in some cases, no zooplankters were found even though the zooplankton net should have effectively concentrated the sample.

Table 4. Zooplankton collected from Butler Lake by date.

Date	Order	#/m^3
12/07/05	Calanoida	6
04/05/06	Calanoida	2
04/05/06	Anomopodae	2
12/05/06	Calanoida	8
12/05/06	Amphipoda	5

While the open-water fauna in Butler was very depauperate, aquatic macroinvertebrates collected from the littoral zone were much more diverse (Figs. 21 and 23). Dipteran midge flies (Family Chironomidae) were the most commonly found species and usually occurred in the greatest abundance. While these were not identified to the genus level, the species collected were probably chironomus, a very pollution-tolerant species capable of surviving in water with very low dissolved oxygen. Interestingly, glass shrimp were found during the spring and summer of 2006 (Order Decopoda; Family Palaemonidae, Fig. 22). These small crustaceans are normally associated with relatively low salinity estuaries and salt marshes so to find them in Butler was surprising. They are omnivorous eating algae, zooplankton, small worms, midges, etc.

Other macroinvertebrates found within Butler included damsel- and dragon fly larvae and true bugs or "hemipterans". The species found were either predatory or collector-gatherers. All obtain oxygen from the atmosphere rather than dissolved from the water.

Figure 21. Number of aquatic macroinvertebrates in Butler Lake by Order and date.

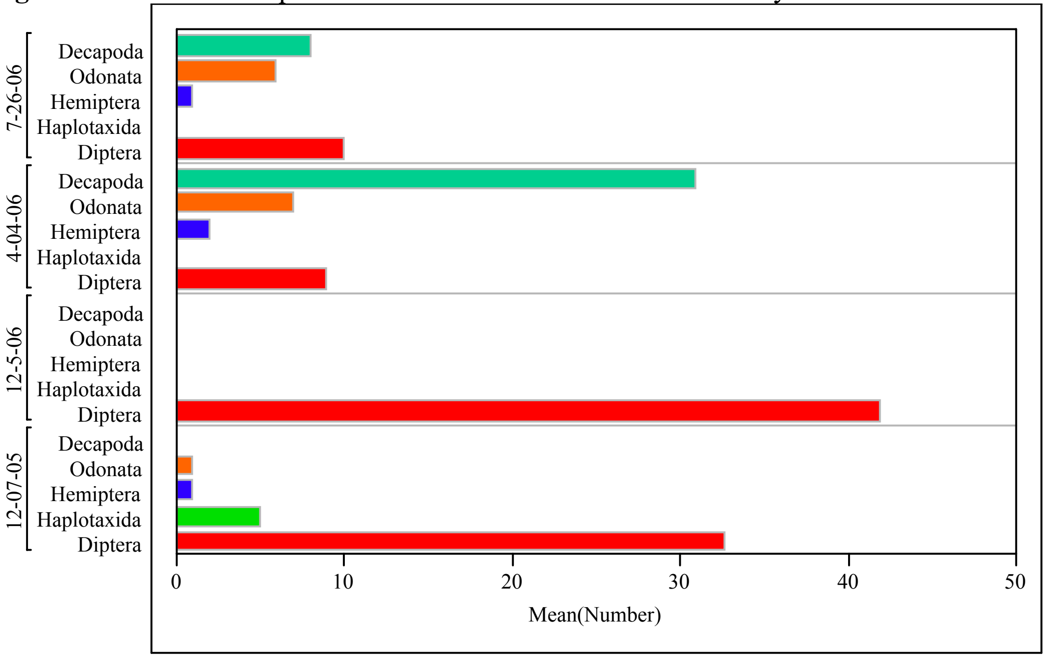
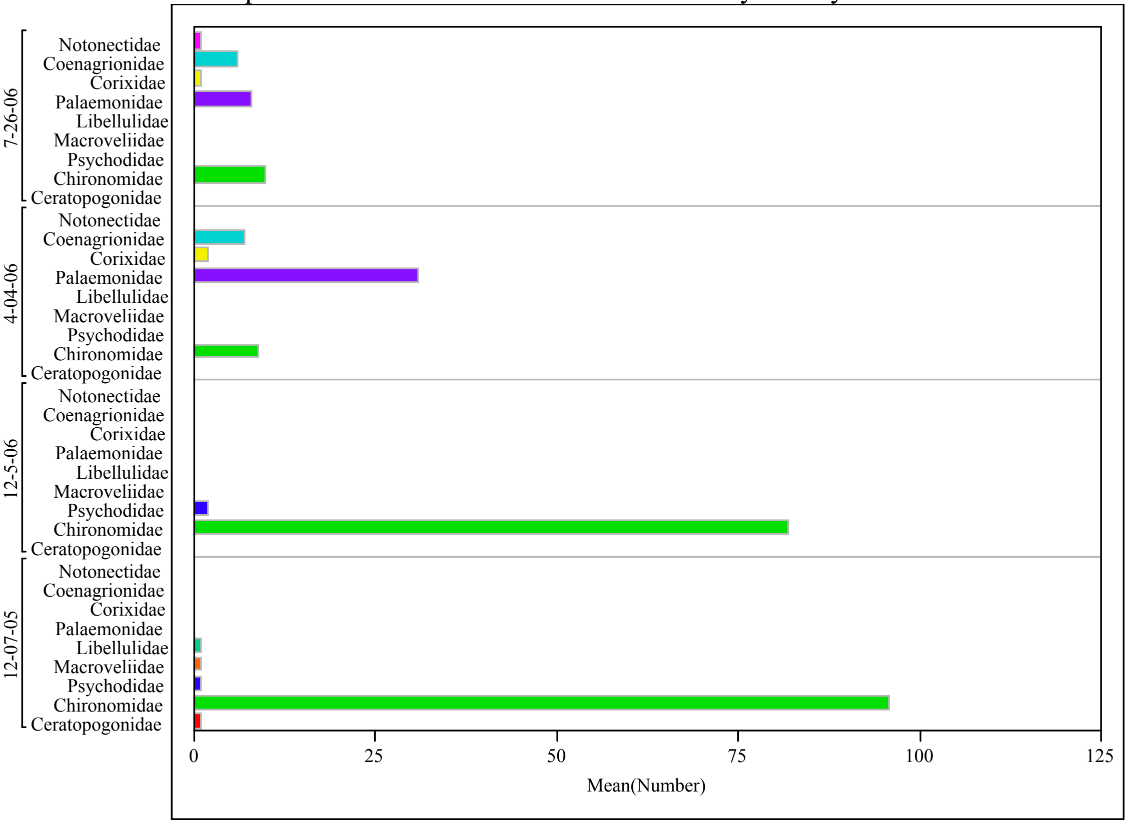


Figure 22. Glass shrimp were commonly found within Butler Lake (picture not taken of organisms collected from the lake)

http://images.google.com/imgres?imgurl=http://omp.gso.uri.edu/doee/biota/inverts/arthro/shrshrm.jpg&imgrefurl

Figure 23. Number of aquatic macroinvertebrates in Butler Lake by Family and date.

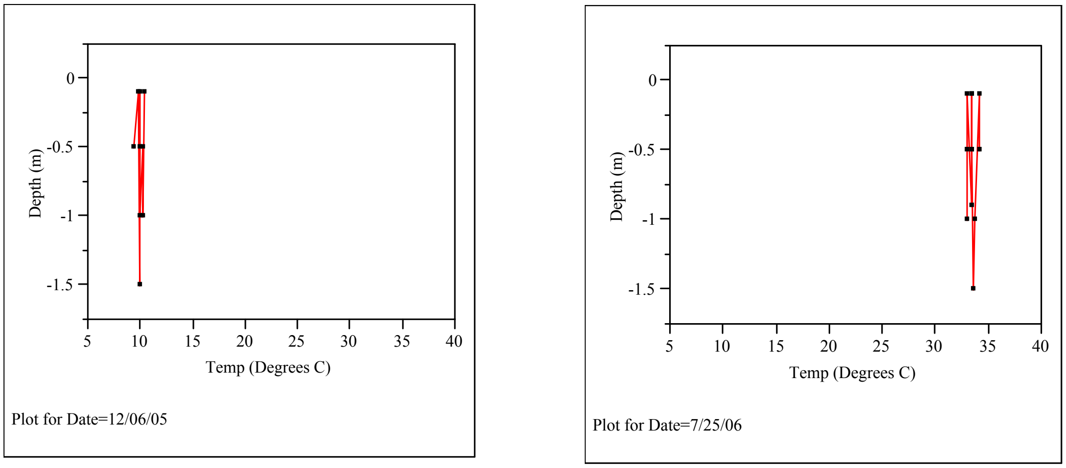


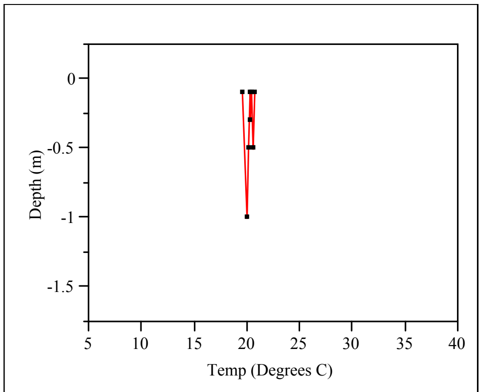
McAllister

Site ML4 (the "western lobe") was distinctly different physically, chemically, and biologically than the main body of the lake so will be discussed separately at the end of this section.

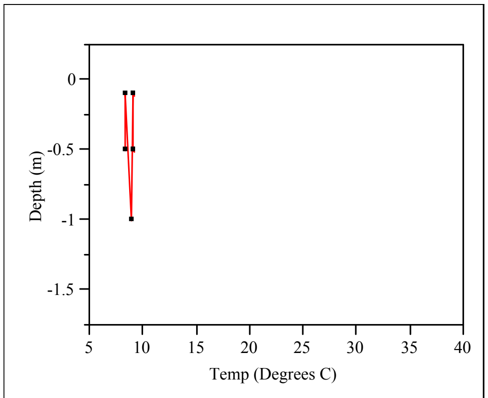
There was no evidence of thermal stratification within McAllister and temperature was, more or less, evenly distributed throughout the water year-round (Fig. 24).

Figure 24. Temperature profiles by depth within McAllister Lake





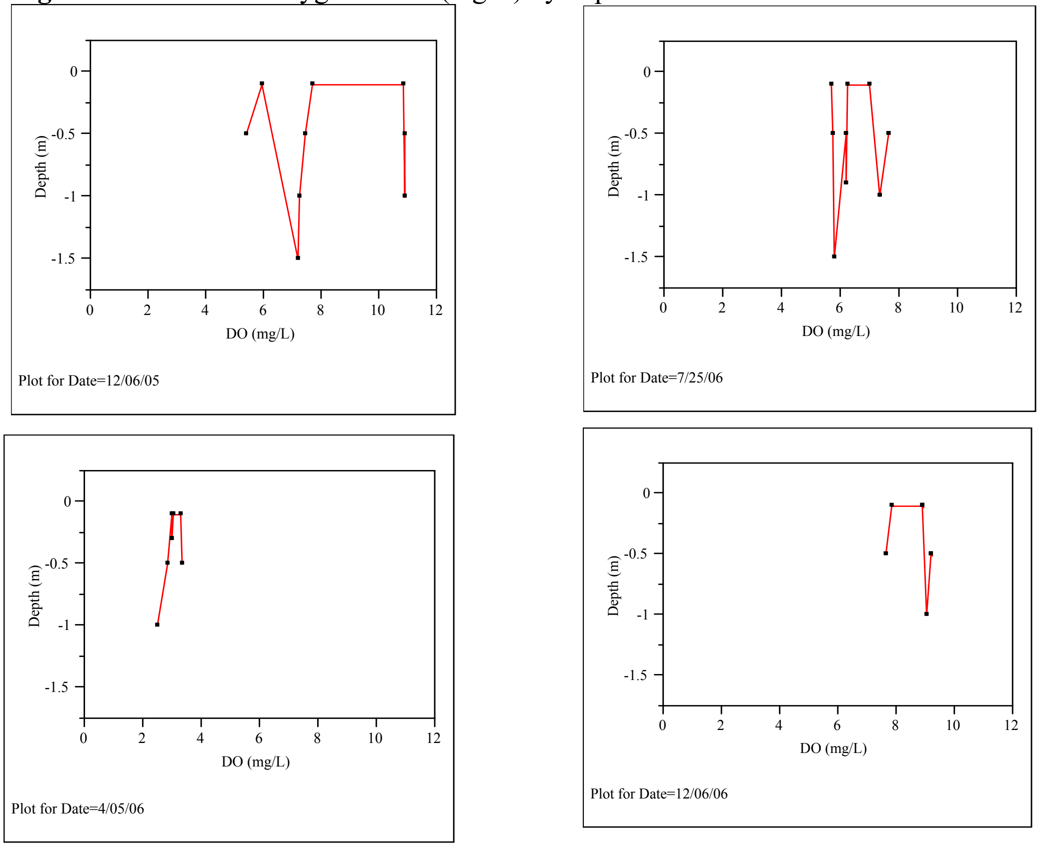
Plot for Date=4/05/06



Plot for Date=12/06/06

Dissolved oxygen levels were generally higher than those found in Butler, however, levels during the spring were relatively low (Fig. 25). While McAllister did not appear to suffer from anoxia during any of our sampling events previous work on McAllister Lake (Walker et al, 2007) shows it to become anoxic, on occasion, during the spring and summer months. Most of these periods of anoxia occurred at night (or early morning) as a result of respiring algae. So, while DO levels within McAllister are considered more favorable than Butler Lake for the survivability of native fish, they probably aren’t high or stable enough to prevent a seasonal fish kill.

Figure 25. Dissolved oxygen levels (mg/L) by depth within McAllister Lake.



Plot for Date=12/06/05

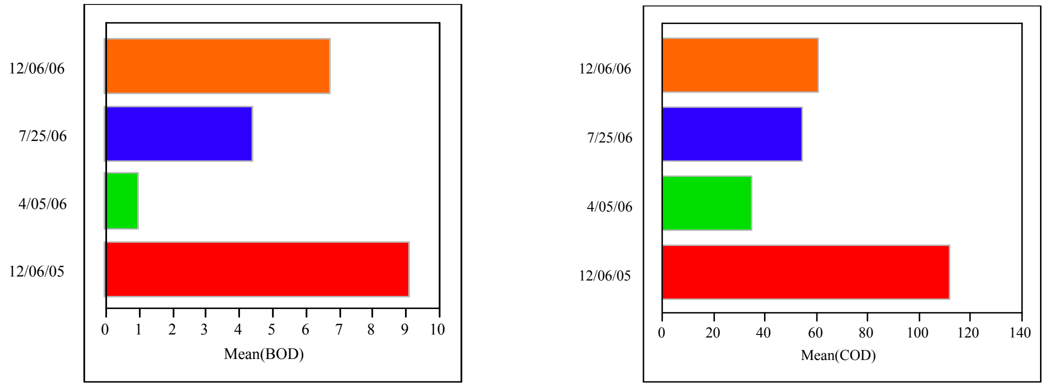
Plot for Date=7/25/06

Plot for Date=4/05/06

Plot for Date=12/06/06

Both BOD and COD were much lower in McAllister than Butler, but still relatively high compared to urban lakes in Arizona (Fig. 26).

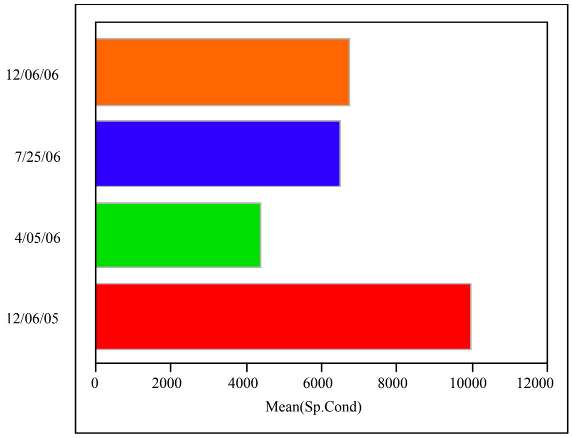
Figure 26. Mean BOD and COD by date within McAllister Lake.



Levels of specific conductivity within McAllister have been thoroughly studied over the past few years. For an in-depth analysis of salinity/specific conductivity within McAllister, and methods to alleviate this problem, the reader is referred to *Induced Recharge in McAllister Lake, Arizona to Reduce Salinity for the Possible Introduction of Native Fish Species* by Walker *et al*, 2007.

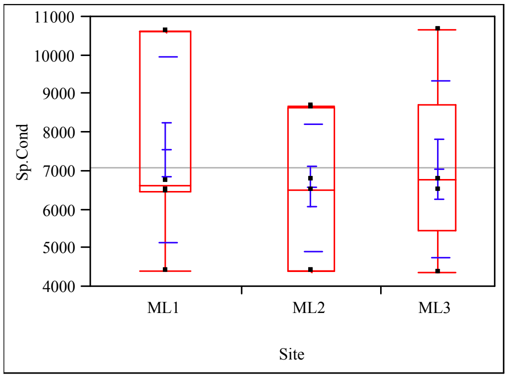
Salinity appears to be a major constraint to the survivability of native fish species within McAllister Lake. A draw-down to induce recharge, dilution, and flushing occurred just prior to our first sampling in December of 2005. The results of this draw-down were noticed during our spring sampling of 2006 when specific conductivity levels were significantly reduced. The target levels for specific conductivity was set, in the report mentioned above, was between 4,000 and 6,500 µS/cm. While levels were within this range some months following the draw-down treatment, they quickly climbed above this range during the summer and winter of 2006 (Fig. 27). While the pumping treatments to induce recharge, dilution, and flushing are very effective at reducing specific conductivity, they are short-lived, expensive, and a disturbance to the surrounding area. Even if specific conductivity levels could be kept within a range to ensure survivability of native fish species, the abrupt and frequent changes caused by the pumping and draw-down treatments are stressful to fish.

Figure 27. Specific conductivity levels (in µS/cm) within McAllister Lake by date.



Site ML2 appeared to have a mean lower levels of specific conductivity than did ML3 or ML1 (Fig. 28). Site ML2 was the most northerly and it seems likely that the subsurface flow from the LCR would affect this site first.

Figure 28. Levels of specific conductivity (μS/cm) by site within McAllister Lake.

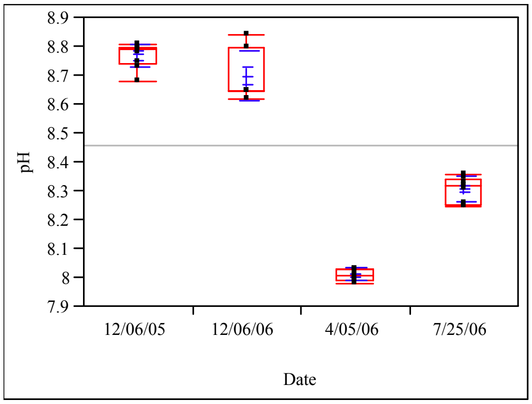


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
ML1	12	7571.67	2410.32	695.80	6040.2	9103.1
ML2	11	6573.82	1655.45	499.14	5461.7	7686.0
ML3	9	7051.00	2281.88	760.63	5297.0	8805.0

Levels of pH were slightly less than Butler and also lower during summer than winter (Fig. 29). This seems odd given that increased daily photosynthesis will raise pH. The total alkalinity was much higher immediately following the draw-down treatment (Fig. 30) as the same salts that increase specific conductivity will also increase alkalinity (i.e., a resistance to changing pH levels or “buffering” capacity). This might have had some influence over maintaining elevated pH levels during this time but total alkalinity levels had generally decreased by the time of the last sampling during December of 2006. It could be that a combination of decreased pH levels at depth when algal biomass is high during the spring and summer, combined with high total alkalinity levels, result in elevated pH.

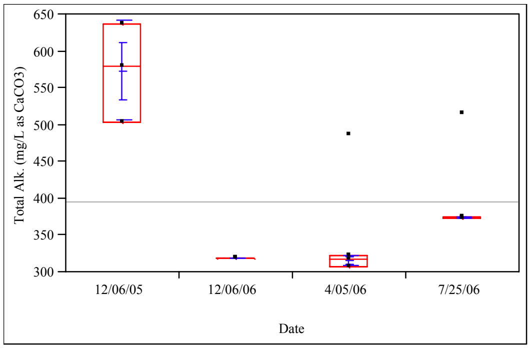
Figure 29. Levels of pH by date within McAllister Lake



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/06/05	9	8.76889	0.041667	0.01389	8.7369	8.8009
12/06/06	7	8.69429	0.087342	0.03301	8.6135	8.7751
4/05/06	7	8.00857	0.019518	0.00738	7.9905	8.0266
7/25/06	9	8.30556	0.042164	0.01405	8.2731	8.3380

Figure 30. Total alkalinity levels (mg/L as CaCO3) by date within McAllister Lake.

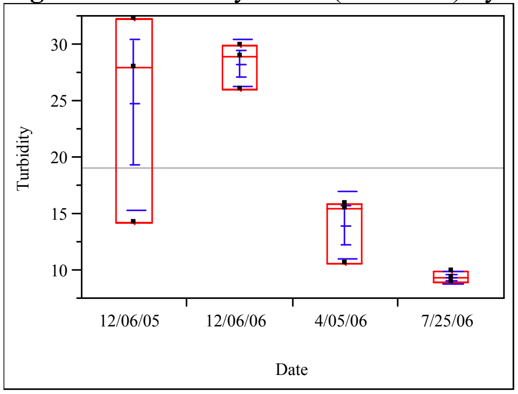


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/06/05	3	573.387	66.9310	38.643	407.12	739.65
12/06/06	3	319.350	0.2252	0.130	318.79	319.91
4/05/06	3	316.017	7.4965	4.328	297.39	334.64
7/25/06	3	374.310	1.2800	0.739	371.13	377.49

Turbidity levels within McAllister were generally much lower than levels found within Butler (Fig. 31). This means there was less particulate material within McAllister to scatter light transmitted through it, than there was in Butler. This may have been due to decreased algal biomass within McAllister as compared to Butler (discussed later in this report). Secchi disk depths were greatest during the spring and winter than the summer (Fig. 32).

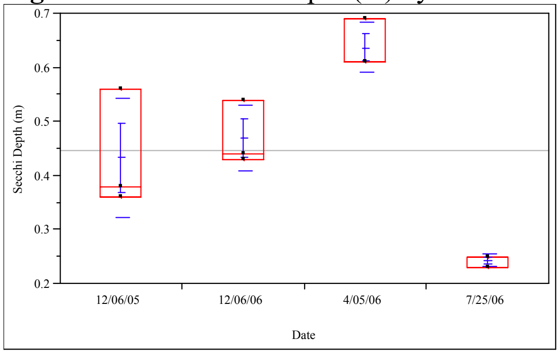
Figure 31. Turbidity levels (in NTU's) by date within McAllister.



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/06/05	3	24.8333	9.45639	5.4596	1.342	48.324
12/06/06	3	28.3333	2.08167	1.2019	23.162	33.504
4/05/06	3	14.0000	2.95127	1.7039	6.669	21.331
7/25/06	3	9.3933	0.52003	0.3002	8.102	10.685

Figure 32. Secchi disk depth (m) by date within McAllister Lake.

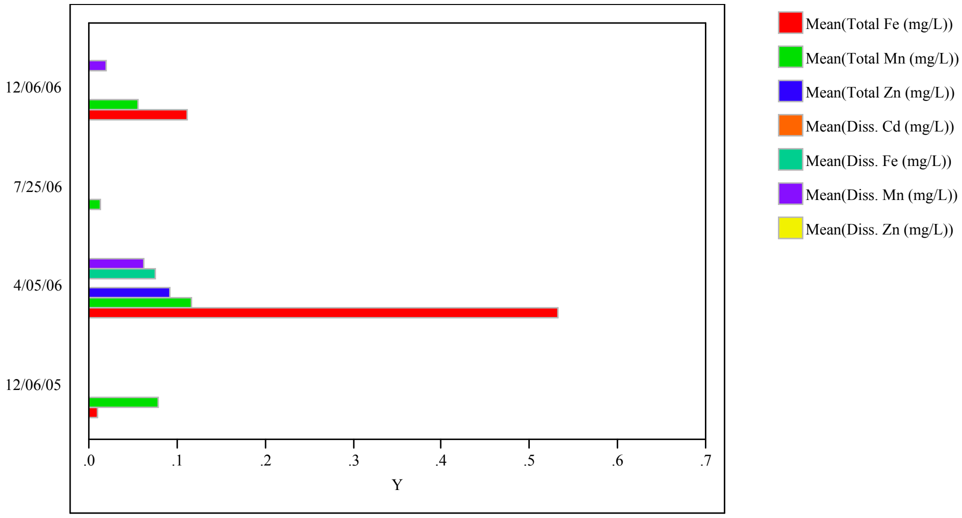


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
12/06/05	3	0.433333	0.110151	0.06360	0.15970	0.70696
12/06/06	3	0.470000	0.060828	0.03512	0.31890	0.62110
4/05/06	3	0.636667	0.046188	0.02667	0.52193	0.75140
7/25/06	3	0.243333	0.011547	0.00667	0.21465	0.27202

Concentrations of total and dissolved iron, manganese, zinc, cadmium, and copper were all either unremarkable or below detectable limits (Fig. 32). Slightly higher levels were noted during the spring 2006 sampling.

Figure 32. Mean concentrations (mg/L) of selected metals from McAllister Lake by date.



Like Butler, levels of arsenic and mercury were found at concentrations within McAllister that warrant safety concerns for humans and wildlife. Also like Butler, no speciation of these compounds (other than the total and dissolved fractionation) was performed nor were samples collected using US EPA's "clean" sampling standards. Aqueous samples were collected twice during this project; on 07/25/06 and again on 12/06/06.

Arsenic was found in aqueous samples ranging from approximately 9 - 10 µg/L; slightly less than Butler but still at levels, due to arsenics bioaccumulative effect, highly toxic to aquatic organisms. Levels of total mercury were found at roughly the same level as in Butler ranging from 8 - 24 µg/L. If methyl-mercury constitutes even a small fraction of this very high level, then both bioaccumulation and bio-magnification is occurring in aquatic organisms currently within McAllister. The level of bio-magnification is currently unknown but it is possible, and possibly likely, that terrestrial organisms ingesting either water or aquatic organisms from McAllister are being affected by mercury toxicity.

Levels of selenium within aqueous samples from McAllister, like Butler, were relatively low ranging from 0.37 to 0.44 µg/L.

Sediment samples were collected for metals analysis from McAllister on 07/25/06. Levels of arsenic from this sampling were 5.08 µg/g, with mercury and selenium being 0.14 and 1.47 µg/g respectively.

Beryllium, cadmium, chromium, copper, iron, manganese, and zinc were also analyzed from these sediment samples and results are shown in Table 5 below. Levels of most metals were generally lower than sediment samples obtained from Butler.

Table 5. Sediment metals taken from site ML1 on 07/25/06

Analyte	Result (µg/g)
Be	0.58
Cd	0.25
Cr	11.6
Cu	14.33
Fe	14,599
Mn	758
Zn	61.4

Generally, levels of specific nutrients in McAllister were lower than those found in Butler (Fig. 33) and overall mean levels of total phosphorous, nitrogen, and carbon were significantly less in McAllister than Butler (Figs. 34-36). Higher levels of salinity/specific conductivity are usually related to diminished dilution/flushing which would infer a weaker hydrologic connection with the LCR. This is somewhat puzzling in that systems with a weaker hydrologic connection would also be expected to become increasingly eutrophic as nutrients accumulated along with salts. This did not appear to be the case when comparing McAllister with Butler as the former was more saline, but less eutrophic, than the latter. It would appear the draw-down treatment caused significant dilution of salts and a lessening of eutrophication-related symptoms within McAllister.

Figure 33. Mean nutrient levels within McAllister Lake by date.

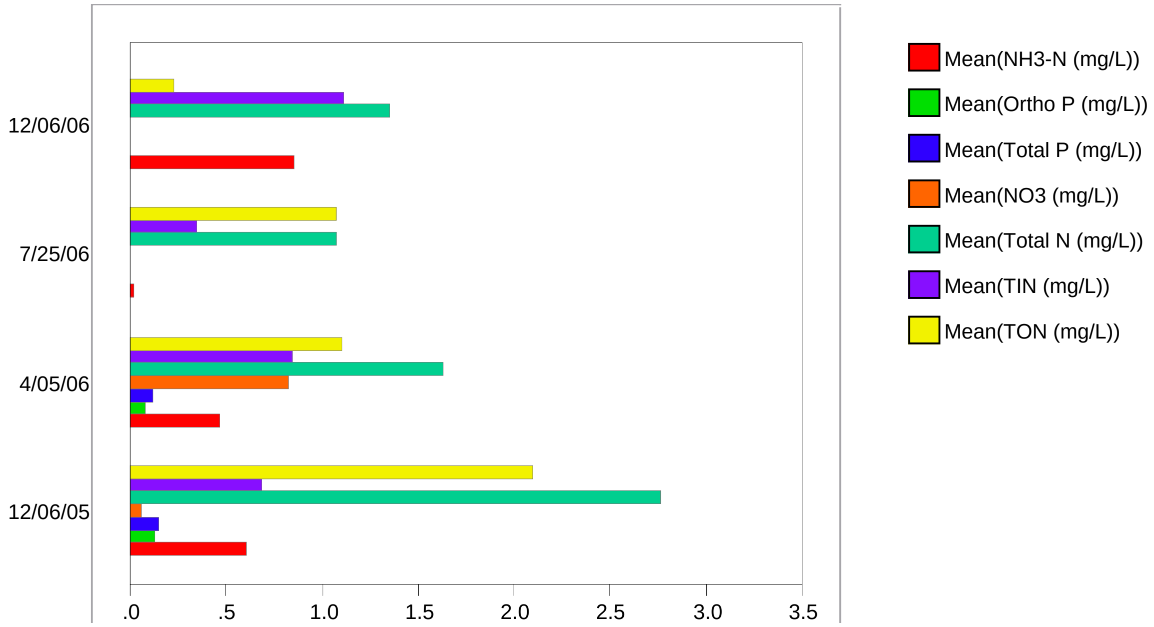
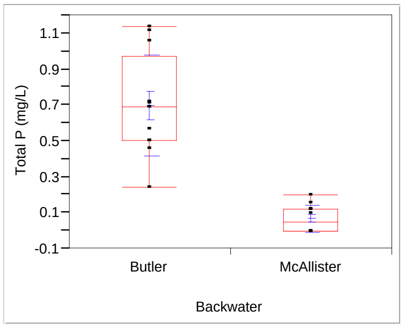


Figure 34. Oneway Analysis of Total P (mg/L) By Backwater



Summary of Fit

Rsquare	0.720397
Adj Rsquare	0.707688
Root Mean Square Error	0.20551
Mean of Response	0.384169
Observations (or Sum Wgts)	24

Analysis of Variance

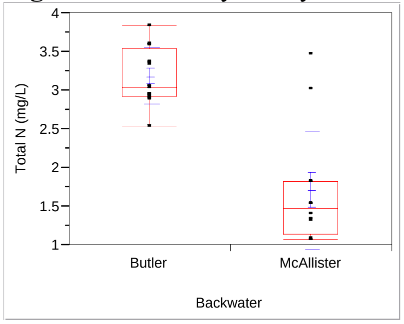
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Backwater	1	2.3939788	2.39398	56.6830	<.0001
Error	22	0.9291585	0.04223		
C. Total	23	3.3231372			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Butler	12	0.700000	0.05933	0.5770	0.82303
McAllister	12	0.068338	0.05933	-0.0547	0.19137

Std Error uses a pooled estimate of error variance

Figure 35. Oneway Analysis of Total N (mg/L) By Backwater



Summary of Fit

Rsquare	0.616448
Adj Rsquare	0.599014
Root Mean Square Error	0.603484
Mean of Response	2.445833
Observations (or Sum Wgts)	24

Analysis of Variance

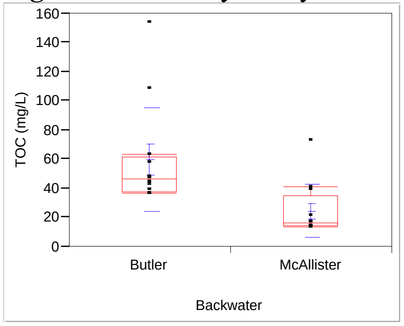
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Backwater	1	12.877350	12.8773	35.3586	<.0001
Error	22	8.012233	0.3642		
C. Total	23	20.889583			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Butler	12	3.17833	0.17421	2.8170	3.5396
McAllister	12	1.71333	0.17421	1.3520	2.0746

Std Error uses a pooled estimate of error variance

Figure 36. Oneway Analysis of TOC (mg/L) By Backwater



Summary of Fit

Rsquare	0.294839
Adj Rsquare	0.262786
Root Mean Square Error	28.43554
Mean of Response	42.3625
Observations (or Sum Wgts)	24

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Backwater	1	7437.760	7437.76	9.1985	0.0061
Error	22	17788.756	808.58		
C. Total	23	25226.516			

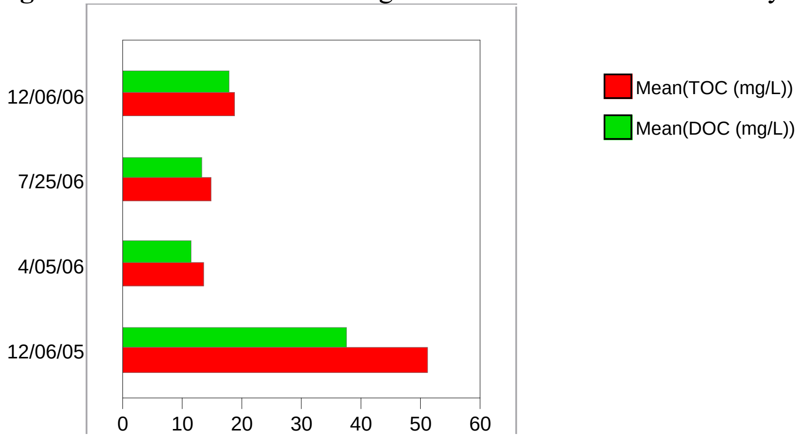
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Butler	12	59.9667	8.2086	42.943	76.990
McAllister	12	24.7583	8.2086	7.735	41.782

Std Error uses a pooled estimate of error variance

Levels of dissolved and organic carbon, while initially on a par with those found in Butler, were significantly reduced following subsequent re-filling after the draw-down treatment (Fig. 37). Levels gradually began to climb but were still significantly lowered even after a year following the draw-down treatment.

Figure 37. Levels of total and organic carbon within McAllister by date.



Sediment nutrient levels within McAllister, while still relatively high compared to urban lakes (Fig. 38), were substantially less than levels found within Butler (Fig. 39). The decrease in sediment nutrient levels within McAllister may explain some of the difference in primary productivity between the two lakes.

Figure 38. Sediment nutrient levels within McAllister Lake by date.

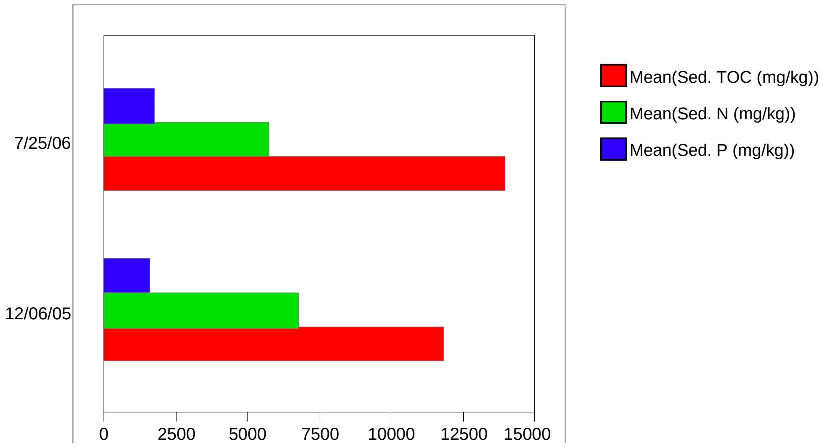
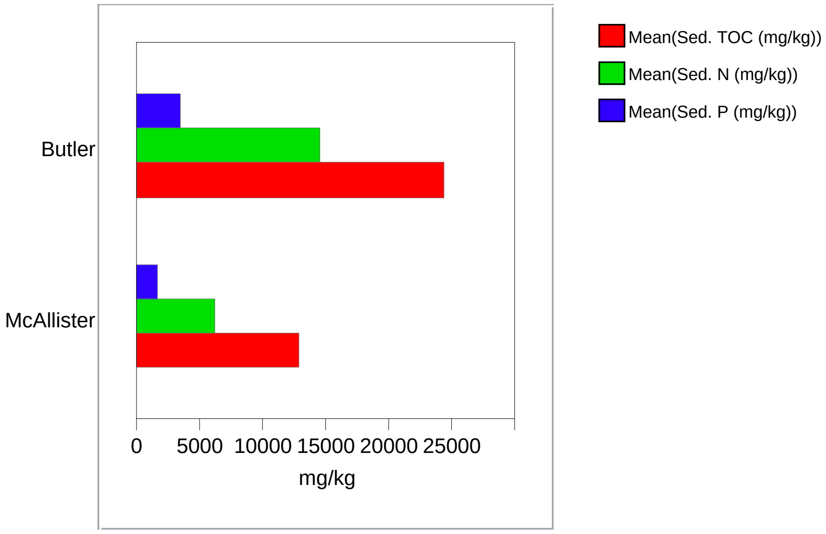


Figure 39. Mean sediment nutrient levels within Butler and McAllister Lakes.



Chlorophyll *a* levels in McAllister were generally much less than those found within Butler. There was, however, a large biomass of algae during the summer 2006 sampling (Fig. 40). Like Butler, the phytoplankton assemblage in McAllister was dominated by cyanobacteria. Phytoplankton diversity, however, was greater in McAllister than Butler (Figs. 41 and 42). The species most commonly found within McAllister was *Cylindrospermopsis raciborskii*; a species capable of producing the potent hepato-toxin cylindrospermopsin under certain environmental conditions (Fig. 43). No algal toxins were found in McAllister when the water was sampled for them on 7/25/06.

Figure 40. Chlorophyll *a* levels in McAllister Lake by date.

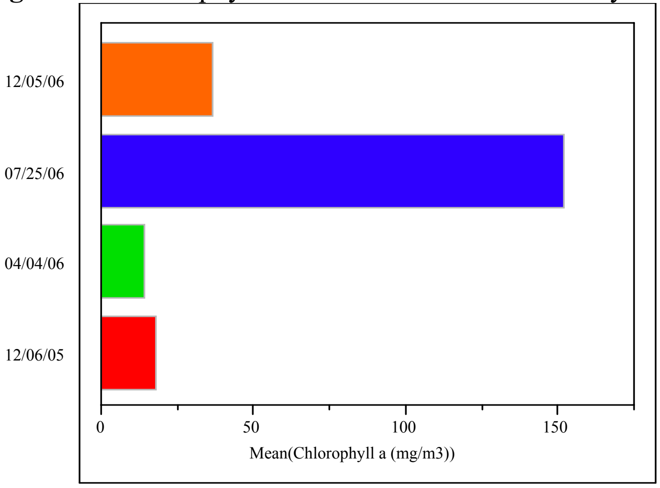


Figure 41. Algae found within McAllister Lake by Division.

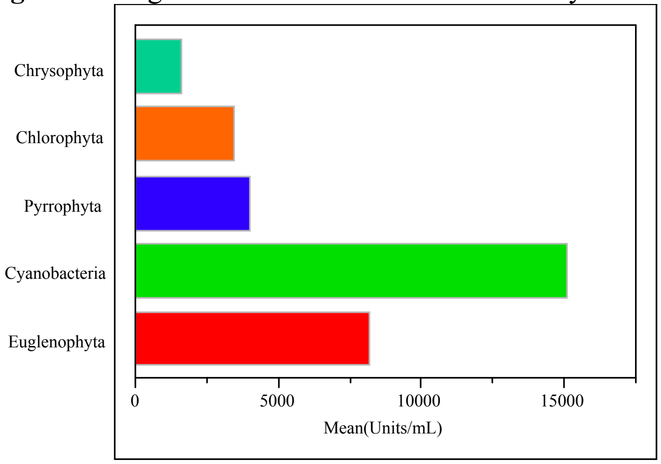


Figure 42. Algae found within McAllister Lake by Genera

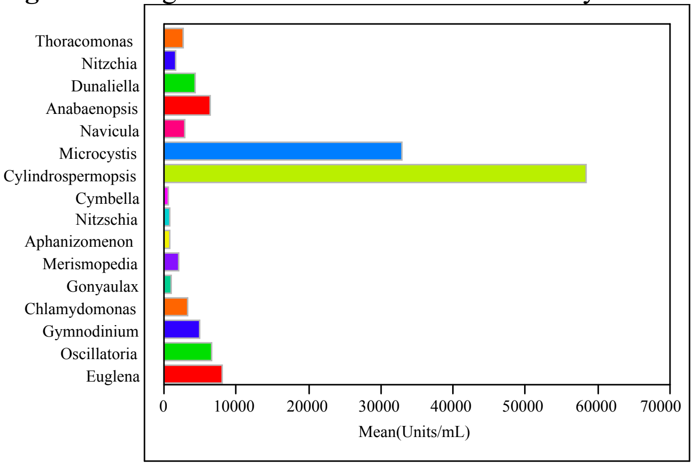
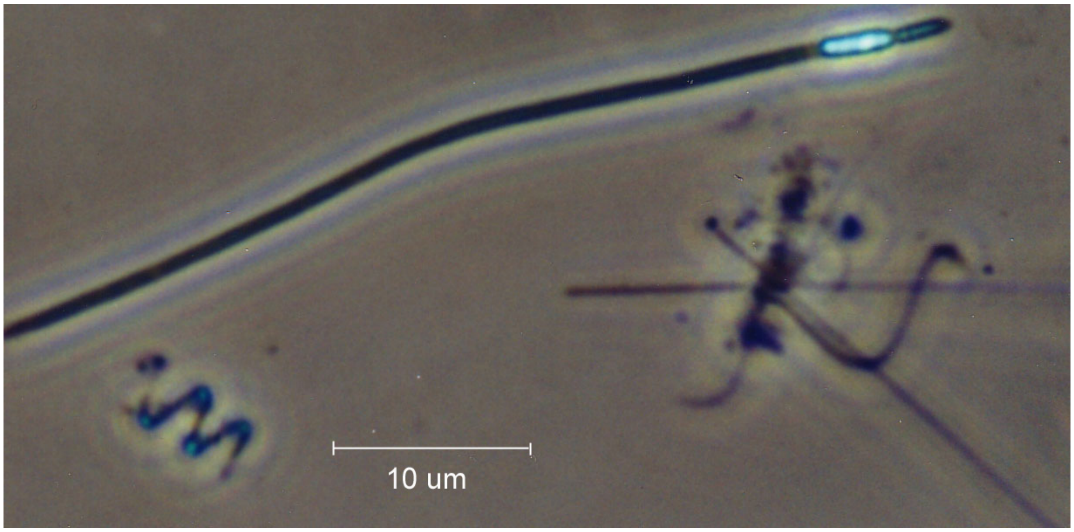


Figure 43. *Cylindrospermopsis raciborskii* found within McAllister Lake in both the curled (lower left) and straight (large filament) morphology.



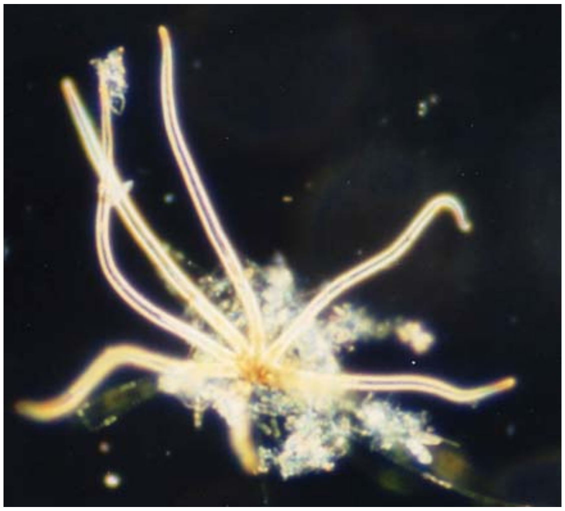
Zooplankton within McAllister was much more diverse, and had a higher biomass, than Butler (Table 6). There was a very large biomass of cladocerans (Fig. 44) found during the spring 2006 sampling and "clouds" of these organisms could be observed in the water; especially in those areas closer to shore.

Table 6.

Date	**Order**	**Family**	**#/m^3**
12/06/05	Copepoda	Calanoida	12
12/06/05	Rotifera	Brachionus	5
04/05/06	Copepoda	Calanoida	22
04/05/06	Amphipoda	Talitridae	17
04/05/06	Anomopodae	Daphnidae	4,875
04/05/06	Anomopodae	Sididae	45
07/25/06	Copepoda	Cyclopoida	13
07/25/06	Hydroida	Hydra	1
07/25/06	Copepoda	Calanoida	11
07/25/06	Rotifera	Brachionus	38
12/05/06	Amphipoda	Talitridae	5
12/05/06	Anomopodae	ephippia	13

Figure 44. *Diaphanasoma sp.* found in McAllister on 04/05/06

Figure 45. Freshwater hydra found in McAllister Lake on 7/25/06



While zooplankton was more diverse in McAllister than Butler, macroinvertebrates collected in the kick net sampling of the littoral zone was less diverse (Table 7). The grass shrimp found in Butler were also found in McAllister. The daphnia found in the zooplankton sampling of the open water were found in even higher levels within the aquatic macrophytes close to shore.

Date	Order	Family	Genera	Number
12/06/05	Decapoda	Palaemonidae	Palaemonetes	4
12/06/05	Diptera	Ceratopogonidae	Culicoides	1
12/06/05	Diptera	Ceratopogonidae	Dasyhelea	2
12/06/05	Diptera	Chironomidae	Chironomus	175
12/06/05	Odonata	Coenagrionidae	Enallagma	1
04/05/06	Anomopodae	Daphnidae	Daphnia	8,671
04/05/06	Decapoda	Palaemonidae	Palaemonetes	3
04/05/06	Diptera	Chironomidae	------------------	1
07/25/06	Diptera	Chironomidae	------------------	3
12/05/06	Decapoda	Palaemonidae	Palaemonetes	9
12/05/06	Odonata	Coenagrionidae	Enallagma	1

Site ML4; the "Western Lobe" of McAllister Lake

This site was sampled twice; once during the spring and once during the summer of 2006. This area had distinctly different attributes than the main body of McAllister and, except for times of high water levels, the two areas (the main body and the western lobe) appeared to have little hydrologic connectivity with each other.

Specific conductivity was higher in the western lobe than in the main body of McAllister (mean = 9174 µS/cm) but dissolved oxygen levels lower (mean = 1.34 mg/L). This area was ringed by a very dense stand of aquatic macrophytes and contained numerous snags of dead trees. While the water appeared to be clearer than the main body, there were often dense mats of algae noticed growing on the bottom occasionally becoming dislodged due to increased buoyancy caused by dissolved oxygen from photosynthesis. The water was often highly stained with colored dissolved organic material from decomposing vegetation.

This western lobe is more eutrophic, saline, and more reminiscent of a true marsh than is the main body of McAllister. These areas, while not amenable to the survival of most fish species, still serve an ecological function and are often inhabited by several terrestrial and semi-terrestrial species.

DISCUSSION & RECOMMENDATIONS

It should be apparent that environmental conditions within either backwater, as they currently exist, are not ideal for the immediate let alone the long-term survival of native fish species. In lieu of the forces which created and maintained these backwaters, human intervention and treatment is needed to create conditions, and therefore habitat, for these species within these backwaters.

The current condition of either Butler or McAllister did not occur overnight; years if not decades of senescence and stagnation lead to their decline as habitable areas for native fish. Converting these ecosystems to a state where long-term survival of native fish can occur will not happen overnight. There is no one single treatment or “magic bullet” which will achieve this goal. Rather, a combination of remedial actions is almost always required to achieve stated goals and objectives.

A hurdle in creating habitat for native fish species is that the historic structure and function of these backwaters is relatively unknown. Without historical data, inference about this structure function based upon sound ecological thought is important. While backwaters may now superficially resemble lakes or ponds, they likely function in much different ways due to their hydrological, and biological, connection with the adjacent river. Any management or remedial action should be couched in terms of the long-term viability of any backwater as a habitat for native aquatic species.

Studies such as this are more than mere academic exercises standing in the way of “progress” toward habitat creation or “restoration”. The *application* of ecological principles, free of anthropocentrism, is what should drive the process of habitat creation. Invariably, this process almost always results in a considerable saving of time, energy, and capital.

Butler

Besides the potentially toxic effects of mercury, arsenic, and cylindrospermopsin, Butler suffers from extreme hyper-eutrophication, not that the issues are mutually exclusive. Indeed, hyper-eutrophication has the potential to exacerbate the toxic effect of the metals while the cylindrospermopsin is a direct result of excessive algal biomass of toxic species.

Butler has far more sinks than sources of dissolved oxygen. An overwhelming “sink” within Butler are the sediments. In its current state, even if clean water were introduced into Butler, and in lieu of any significant dilution or flushing, the sediment would quickly exert their effect on this overlying water once again resulting in a hyper-eutrophic state. *Therefore, any plan to create habitat in Butler for native fish species must include a significant amount of dredging of sediments and a generalized deepening of the lake.* The sides should be steepened so that the growth of aquatic macrophytes, and their eventual growth from the shore toward the middle of the lake, substantially reduced. Removing a significant amount of the sediments from Butler will efficiently reduce or retard any nutrient release into overlying water and should significantly reduce algal biomass within the lake.

With all the stressors/toxicity currently found within Butler, one major asset toward making it viable habitat for native fish species is its proximity to the river. Even if a major dredging operation were to occur in Butler, without substantially increasing dilution and flushing, it would quickly revert back to its current state. Therefore, in addition to a significant dredging operation in Butler, we recommend re-establishing an open-water connection between Butler and the LCR. Any open-water connection with the LCR has the potential of introducing non-native fish which, for a multitude of reasons, are detrimental to the survival of native fish species. Recently, however, cylindrical wedge wire screens have been evaluated for Beal Lake and proven to be efficient barriers to fish passage while still maintaining a hydrologic connection with the LCR (Normandeau Associates, 2006). These screens provided 4 times the amount of water that Beal Lake needed to make up for the maximum rate of evaporative loss. While this rate seems adequate, the report by Normandeau Associates (2006) recommends "over-engineering" to allow for even greater hydraulic performance and we are in complete agreement with this advice. More management options, such as adjusting flow rates for dilution/flushing based upon water quality conditions within Butler Lake, are always preferred. While exact residence times required within Butler to maintain water quality conditions for native fish is presently unknown, having the option of increased dilution and/or flushing based upon water quality variables within Butler, makes finding this threshold likely not necessary. The preferred option would be to have residence times within Butler low enough so that an outlet from the lake back into the LCR could be established. Due to the potential of non-native species introduction via this outlet, it should also be fitted with the same cylindrical wedge wire screens fitted to any inlet.

The combination of dredging and re-establishing an open-water connection with the LCR to increase dilution and flushing within Butler, should closely mimic those conditions that once existed within the lake when it was likely used as an important habitat component by native fish species. However, other methods exist by which non-native fish species could eventually make their way back into the lake. Careful post-treatment monitoring needs to be performed *ad infinitum* within the lake for the presence of non-native species.

In lieu of any genetic outflow from Butler, and if there is successful fertility and fecundity of any resident population of native fish, population level and age classification monitoring of this population should be an on-going effort to avoid any stunting or potential resource depletion for any age class. Butler Lake, in order to succeed as habitat for native fish species, would need to become a highly managed ecosystem. If the dredging and re-establishment of an open-water connection with the LCR were to occur, and the commitment for the long-term monitoring of Butler established, this historic backwater has the potential to be one of the largest native fish refuges along the LCR and one of the relatively most "natural" backwaters of any within the LCR.

McAllister

Much work in the way of monitoring, forced draw down, and dilution of salts and nutrients upon re-filling, has already been performed in McAllister (Walker *et al.* 2007). The benefits of these draw down treatments should no longer be in question as they significantly reduce salinity within the lake. McAllister, while not nearly as hyper-eutrophic as Butler Lake, on occasion still suffers from symptoms of eutrophication such as low dissolved oxygen levels and relatively high pH. Arsenic and mercury were found in McAllister at levels similar to Butler so toxicity issues also still exist within this backwater also.

We observed the positive effects of the winter 2005 draw down treatment even into the summer of 2006 when specific conductivity levels were relatively low for McAllister; however, the effects of these drawdown treatments eventually fade as evaporation causes salinity levels to rise outside the range of survival for native fish species. The best treatment option would be to automate the draw down treatments so that heavy equipment, and the associated disturbance it brings, no longer had to occur. An automated, solar-powered, unit could be installed within McAllister which would trigger pumps to draw water from the lake after specific conductivity levels reached approximately 5000 - 6000 µS/cm2. Such a system would not only decrease salinity, but would also provide dilution and flushing of nutrients so that problems associated with eutrophication would be diminished. Water removed from McAllister could be run down the fire break area to the south of the lake. This area has been used in the past for water removed from the lake during previous draw down treatments.

Sediments within McAllister, like Butler, still exert an influence on water quality within the lake and the automated draw down system previously mentioned may not be enough to counter these effects. Additionally, toxicity issues of arsenic and mercury within the sediment would not be addressed with such an automated draw down system. Therefore, we also recommend dredging and removing sediments from within McAllister; however, this operation would probably not have to occur at the same magnitude as the one proposed for Butler. Like Butler, the sides of McAllister should be steepened so that emergent aquatic macrophytes do not progress toward the middle of the lake and in-filling can be prevented.

This combination of treatments, automated draw down to decrease salinity coupled with dredging, should result in the long term survival of native fish species within McAllister. An increase in water quality, however, might result in the introduction of non-native fish species and the same long term monitoring proposed for Butler should be implemented within McAllister.

The wind-powered aerator/mixers already installed within McAllister, should either remain in place, or be replaced back to their original locations, following any dredging operation. These units, while not directly increasing dissolved oxygen levels within the water, do aid in circulating water within the lake. This effect, even if not directly quantifiable, is deemed positive for the lake in terms of water quality and increased mixing.

Post-Treatment Monitoring

If these recommendations are to be implemented, then at least one year of post-treatment monitoring should occur *prior to the stocking of any native fish.* Results from this monitoring will determine whether conditions are favorable for the stocking of native fish species.

Recommended Studies Prior to any Dredging

In waters without historical data, it is often impossible to predict water quality trends or increases in trophic state. Even when some data has been collected, it is usually transient or relatively short-term compared to the age of the system in question. The subtle accumulation of organic and inorganic pollutants makes determination of trends in water quality difficult to detect. Often, subtle declines in water quality go undetected until a problem becomes bad enough to warrant remedial action; actions that are often very expensive and logistically difficult to implement.

Paleolimnological techniques are often used to assess water quality trends in lakes and reservoirs over time. Incorporated in reservoir sediments is a record of the organisms that lived in and around the lake, as well as proxy data related to processes occurring in the lake, the composition of the lake water, the conditions in its watershed, and past climatological data.

The accumulated sediments within Butler and McAllister are the chronological history of the structure and function of these backwaters. These sediments contain information as valuable as any book in any library and should not be disturbed until they have been cored and examined. These sediment cores are a window into the past natural history of not only these backwaters, but of the entire Lower Colorado River Basin and should be offered the same protection as an archeological site.

A proposal was submitted by the University of Arizona in 2006 (Appendix A) to perform this coring and paleolimnological work within both Butler and McAllister Lakes. This work needs to occur prior to any sediment dredging operation. The sonar work proposed would also give an estimate of the volume of sediment which would need to be removed from either backwater.

SUMMARY

Both Butler and McAllister Lakes have the potential to be habitable areas for native fish species in the long term. While both would be habitat created by human intervention, they would still be among the most "natural" in terms of what we believe the structure and function of backwaters to have historically been. In lieu of the forces which created, maintained, and occasionally destroyed backwaters along the LCR, intervention of this type is the only viable option if native fish species are to be maintained within the area.

The remedial actions (dredging/automated draw down/re-establishing hydraulic connections) recommended in this report should improve conditions within both Butler and McAllister Lakes for the long-term survival of native fish species. This is only feasible with a commitment to long-term monitoring of both areas.

While the focus of creating habitat within Butler and McAllister is for razorback sucker and bonytail chub, we would recommend implementing some level of diversity standard for other aquatic species as well. Neither razorback sucker nor bonytail evolved in an aquatic ecosystem devoid of other native species. We would recommend a plan which includes habitat creation for a diversity of aquatic species.

In creating habitat, we should not merely create places where native fish species can be housed; akin to large aquaria. Rather, we should strive to create areas with a structure, function, and diversity of not only what was believed to have existed in the area, but also a re-creation of those forces which caused speciation of these organisms in the first place. There is no doubt this is a difficult task, requiring difficult decisions, and will not occur quickly or easily. It is, however, an essential frame work for the true re-creation of "habitat" and for the eventual recovery of native species which once inhabited the area.

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APPENDIX A. Coring Proposal for Butler and McAllister Lakes

Hydro-Acoustic Survey and Analysis of Cored Sediments from Butler and McAllister Backwaters.

Dr. David Walker (University of Arizona)
Dr. Paul Gremillion (Northern Arizona University)

Introduction

Both Butler and McAllister backwaters are currently considered hyper-eutrophic and in these systems, in lieu of any point or non-point sources of pollution, autochthonous feedback mechanisms exist which usually result in exponential increases in trophic status. Both the repository and subsequent source of bio-available nutrients and metals lie in the sediment. With limited or minimal scouring from the Colorado River, backwater habitats such as Butler and McAllister will likely accumulate organic material which will, eventually, result in increasing sediment: water ratio.

The accumulation of sedimented organic material have detrimental impacts to aquatic species diversity, especially fish, as dissolved oxygen levels are usually inadequate to sustain these organisms for much of the year. If the goal is to re-introduce native fish species to these backwater habitats, then the issue of accumulated sediments and organic material needs to be addressed. Any other treatment recommended or designed to improve condition for native fish species without first addressing this issue would be short-sided.

Dredging is logistically difficult but, combined with some method of increasing dilution and flushing within these backwaters, is a relatively long-term treatment whose benefits will likely be observed for years, if not decades, into the future. It is currently unknown how much sediment exists in either backwater. Knowing what to do with dredged material requires previous knowledge of exact volumes for disposal purposes. Additionally, analyses of cored sediments for levels of total carbon, nitrogen, and phosphorous would provide invaluable information about how much material would need to be dredged in order to prevent recycling of nutrients within a backwater so that project goals can be achieved.

Methods

Side-scan sonar and seismic profiling are powerful tools for mapping the shape and stratigraphy of ocean and lake sediments. These instruments, linked with spatial analysis software, are capable of providing highly accurate maps of bathymetry, sediment thickness, and sediment deposition characteristics. Figure 1 shows an example of seismic profile data used to produce sediment thickness maps of Lake Mead (Twichell et al., 1999). We propose to produce similar bathymetric and sediment thickness maps for Butler and McAllister backwaters. This would provide high-resolution quantification of volume of sediment within each backwater.

In addition to volume- and bathymetric analyses, we would collect sediment cores from each backwater using a Wright-Livingston square rod piston corer. These cores will then be age dated using Lead-210 (^{210}Pb) and/or Cesium-137 (^{137}Cs) radionuclides. We will analyze from selected areas within each core for total carbon, nitrogen, phosphorous, selected metals including arsenic (found in the water within Butler) and selenium. This would provide invaluable information regarding long-term, chronologic information regarding physical, chemical, and biological variables throughout the geologic life-span of both backwaters. The extent of time that will be captured from the cores is currently unknown; however, paleolimnological studies in lakes often capture time frames in the thousands and sometimes tens of thousands of years before the present.
The extent of time that will be captured from the cores is currently unknown; however, paleolimnological studies in lakes often capture time frames in the thousands and sometimes tens of thousands of years before the present.

Analytes derived from age-dated cores, and the reason for their analysis, will be:

- *Nutrients and heavy metals*: We will obtain samples at selected locations of the core for nutrients related to eutrophication and metals related to toxicity of aquatic species (arsenic, selenium, etc.). With this information, we can then make a determination of how much material should be dredged to increase water quality and achieve project goals of re-introducing native fish species. Figure 2 is provided as an example of metal trends in Amistad International reservoir on the Texas/Mexico border (courtesy of Peter C. Van Metre).

- *Fossilized pollen analysis (palynology*): To determine watershed vegetative changes. The amount and/or composition of watershed vegetation will vary as a result of changing climate, wildfire, or human removal. This analysis will also allow us to obtain high resolution data regarding timing and environmental conditions condusive to the expansion of non-native and invasive species such as salt cedar, phragmites, arundo, etc.

- *Fossilized diatom frustules ("valves")*: Diatoms are the most frequently used organisms in paleolimnological studies. Diatoms often occur in relatively high abundances and diversities, are ubiquitous, and readily identified to low taxonomic levels. Diatoms contain many species with relatively limited ecological tolerances. Siliceous diatom valves are well-preserved in lake sediments and are a direct reflection of environmental conditions at the time of deposition.

- *Fossilized chironomid (midge fly) head capsules*: Larval chironomids have long been recognized as excellent indicators of water quality conditions and especially as indicators of hypolimnetic anoxia in lakes and reservoirs. They also make excellent indicators of paleoecological environmental condition (Merlainen et. al. 2000). Chironomid taxa exhibit marked differences in individual responses to water quality degradation leading to anoxia, such as nutrient accumulation or other forms of natural or anthropogenic eutrophication, as a result of physiological adaptations.

Sediment cores are useful only if the quality of the depositional record can be assessed. Cores collected from highly disturbed environments, for example, do not yield a systematic, chronological sequence of sediments. Sedimentation can be subject to highly dynamic conditions, particularly in arid lands where hydrologic events may be large in magnitude. We have discovered that the large-magnitude hydrologic events deliver such massive pulses of sediment that these inputs tend to form distinct sediment strata that protect underlying sediment from disturbance. An example of the distinct stratigraphy we observe in Arizona reservoirs is shown in Figure 3, which is the lithologic description of part of the core we collected from Lyman Lake.

Of the analyses we will perform on the sediment cores, several are dedicated to determining the quality of the depositional record captured and the chronology of the sediment sequences. Other analyses will yield information on past water quality and watershed processes. This information will prove vital in determining which treatments will yield a biotic "result" similar to what historically existed within these and other backwaters along the Lower Colorado River. These analytes are summarized in Table 1.

Project Scope	
Activity	**Application**
Seismic Profiling	• Sediment thickness and distribution patterns • Location of pre-backwater strata • Patterns in loss of backwater storage
Sediment Coring	
• Lead 210	• Chronology
• Cesium 137	• Chronology
• Magnetic susceptibility	• Erosion events
• Photography	• Digital image analysis: Erosion events, summer productivity periods
• Pollen	• Changes in watershed plant assemblages
• Biogenic Silica	• Primary productivity
• Paleo-entomology	• Chironomid head capsule analysis for paleo-redox analysis
• Metals	• Atmospheric pollution deposition / records of past anoxia

Visual assessment of lithology, photographic grayscale analysis, and magnetic susceptibility will be used to assess how well the sediments were deposited in an orderly sequence. Lead-210 and Cesium-137 analyses will provide both chronological data and information on depositional quality. In particular, the shape of the plutonium peak, an artifact of above-ground nuclear testing from the mid-1950s to early-1960s, will provide an assessment of the quality of the sediment record. Figure 4, for example, shows a well-defined curve for plutonium, an analog for ^{137}Cs, in Upper Lake Mary, Arizona sediments.

Another, relatively unproven, analysis that might prove fruitful from analysis of backwater sediments are fossilized otoliths (ear stones) of fish species that historically inhabited these areas. If this technique can be refined, it would provide the first, un-ambiguous chronology of fish species, and environmental conditions conducive to their growth and survival, along the Lower Colorado River.

Budget

Seismic Profiling and Bathymetry

$15,000/backwater

Sediment Coring, Dating, and Magnetic Susceptibility

$7500/backwater

Sediment Analyses

Nutrients: (up to 7 per core for TOC, Total P, and Total N): $1500/backwater

Metals: (up to 7 per core for Fe, Mn, Se, and As): $1500/backwater

Diatom Frustule Analysis: (up to 10 locations/core): $2000/backwater

*Chironomid Head Capsules***:** (up to 10 locations/core): $2000/backwater

Fossilized Pollen: (up to 10 locations/core): $2000/backwater

Figure 1. Typical seismic-profiler images of reservoir sediment, from Lake Mead, Nevada/Arizona (reproduced from Twichell et al., 1999).

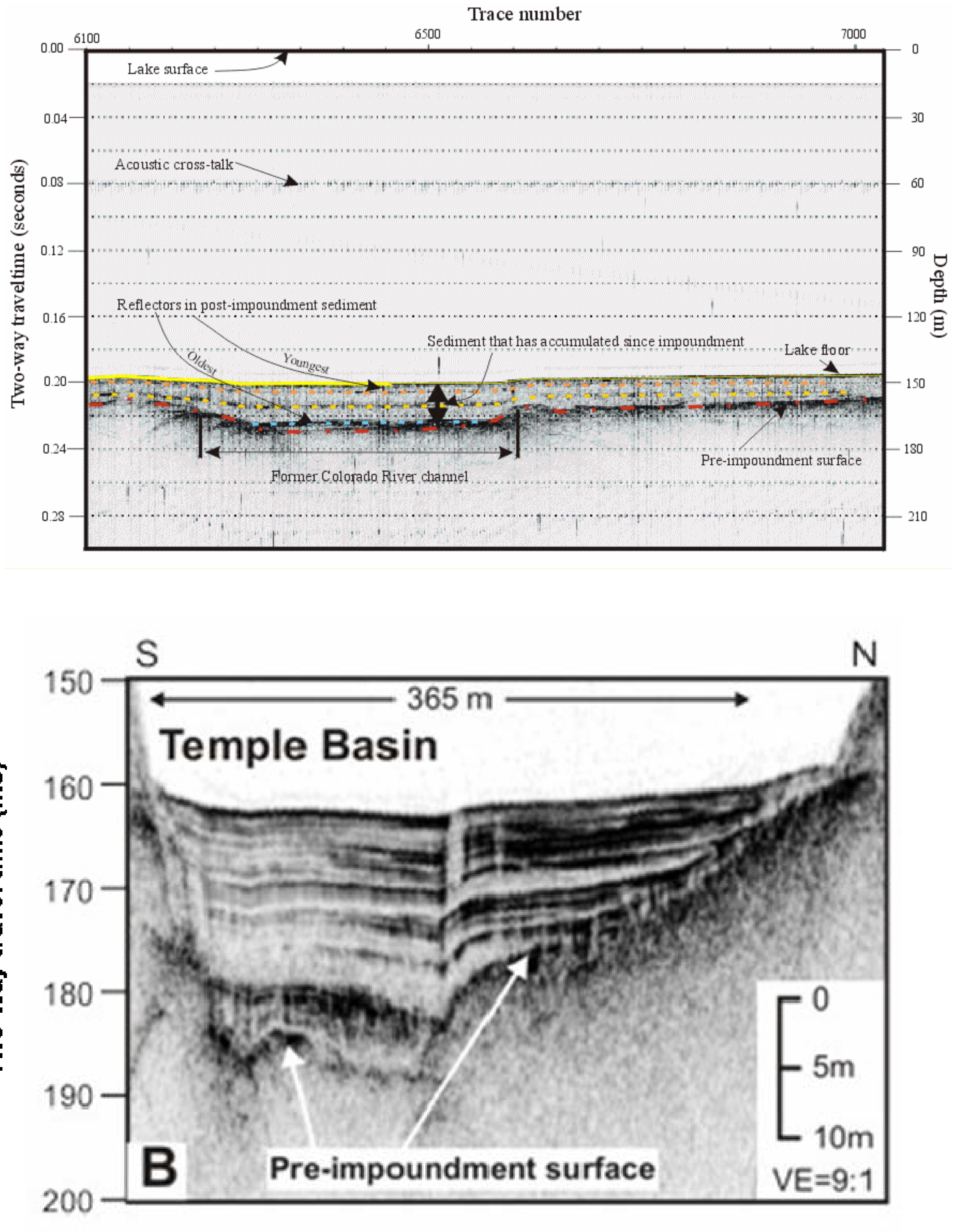

Figure 2. Trends in Eight Metals in Amistad International Reservoir Cores ***From*** Van Metre et. al. 1997.

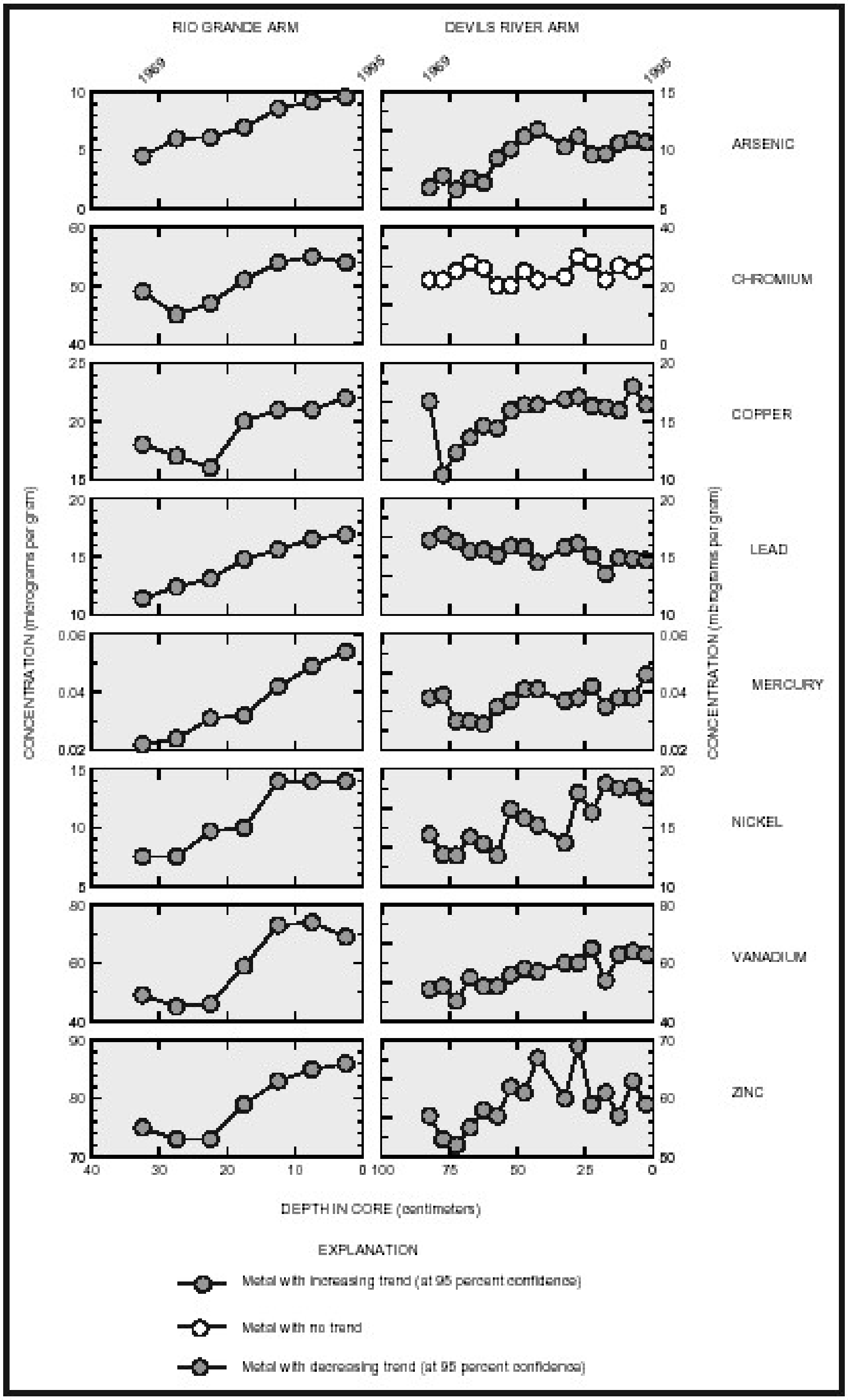

Figure 3. Laboratory notes describing the lithology of the third drive of the Lyman Lake core.

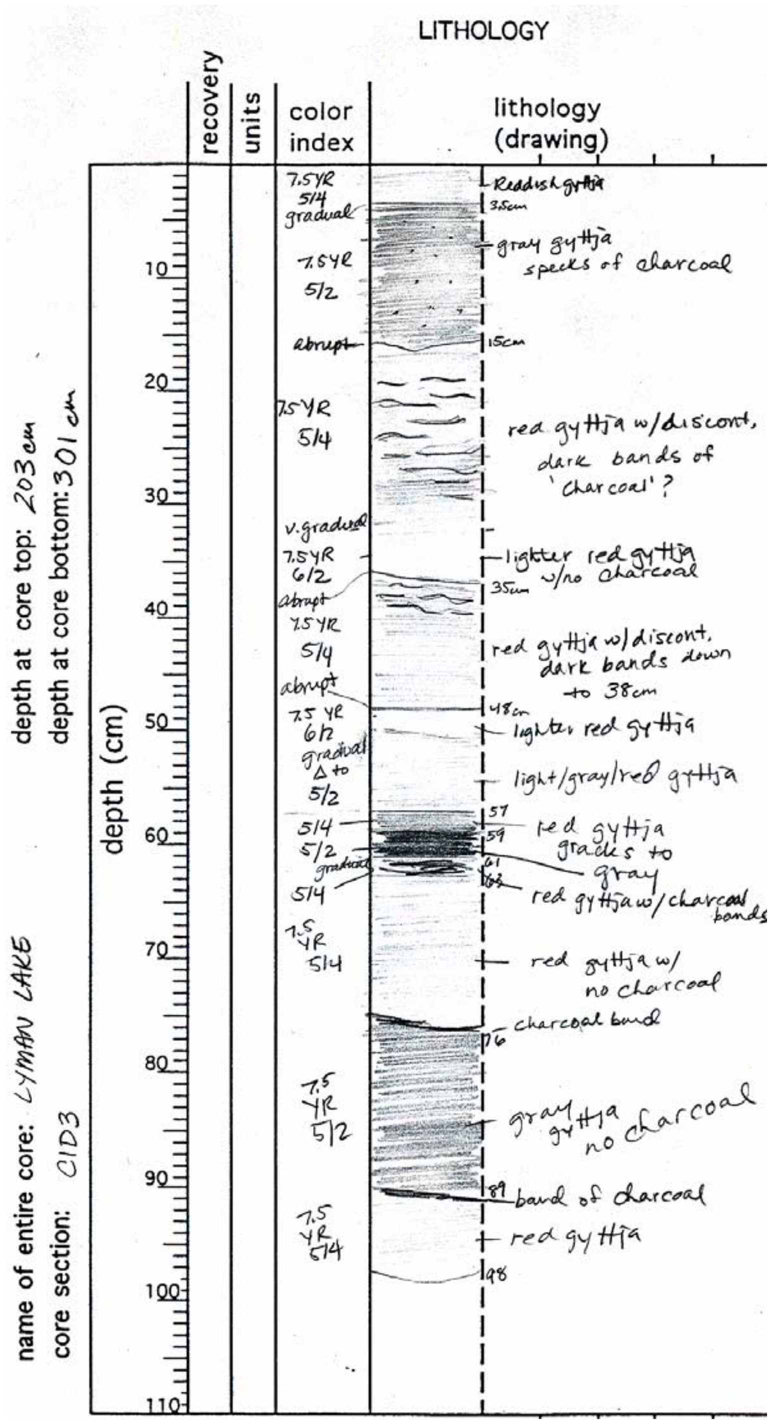

Figure 4. Plutonium isotopes are analogous to ^{137}Cs for dating aquatic sediments. Shown below is a well-defined Pu curve for Upper Lake Mary, Arizona. This curve not only shows markers for 1954 (start of above-ground atomic testing) and 1963 (peak of atomic testing) events, but indicates that minimal sediment disturbance has occurred in the depositional history of the reservoir.