Physical and chemical factors promoting cyanobacterial abundance in eutrophic a reservoir
by Michael A Briggs

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
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Abstract:
Cyanobacteria (blue-green algae) may periodically become superabundant (bloom) in lakes and reservoirs; with numerous undesirable consequences. Numerous physical and chemical factors have been linked with cyanobacterial dominance. This study focused on identifying those factors promoting cyanobacterial blooms in a highly eutrophic reservoir.

Both the physical environment (water temperature, oxygen content, specific conductance, wind speed, water column stability, and retention time) and the chemical environment (various fractions of carbon, nitrogen and phosphorus) of the reservoir were measured regularly over a two-year period, then correlated with algal abundance derived from direct microscopic counts and chlorophyll analysis. Numerous other factors, including nutrient enrichments, temperature-response and toxicity were also evaluated as part of this study.

A statistical analysis of the data revealed that water column stability, temperature and wind speed are the factors most directly correlated to cyanobacterial abundance. Although temperature and stability have previously been linked to cyanobacterial dominance, there is no known mechanism to explain the correlation with windspeed.

PHYSICAL AND CHEMICAL FACTORS PROMOTING CYANOBACTERIAL ABUNDANCE IN A EUTROPHIC RESERVOIR

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ABSTRACT

Cyanobacteria (blue-green algae) may periodically become superabundant (bloom) in lakes and reservoirs; with numerous undesirable consequences. Numerous physical and chemical factors have been linked with cyanobacterial dominance. This study focused on identifying those factors promoting cyanobacterial blooms in a highly eutrophic reservoir.

Both the physical environment (water temperature, oxygen content, specific conductance, wind speed, water column stability, and retention time) and the chemical environment (various fractions of carbon, nitrogen and phosphorus) of the reservoir were measured regularly over a two-year period, then correlated with algal abundance derived from direct microscopic counts and chlorophyll analysis. Numerous other factors, including nutrient enrichments, temperature-response and toxicity were also evaluated as part of this study.

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CHAPTER 1: GENERAL INTRODUCTION

Cyanobacterial Dominance: Effects and Contributing Factors

Cyanobacteria, also called blue-green algae due to their abundance of the blue-green pigment phycocyanin, are prokaryotic members of the phytoplankton community which, under certain physical, chemical and biotic conditions may dominate this community. Dense cyanobacterial populations ("blooms") can produce numerous undesirable effects.

Elevated cyanbacterial populations have been associated with unpleasant taste and odor of potable waters drawn from affected reservoirs (Persson 1982), and with contact dermatitis and gastrointestinal disorders (Gorham *et al.* 1988). Fisheries may be adversely affected due to inefficient grazing by zooplankton (Gilbert 1990) and oxygen depletion by decaying blooms. Cyanobacteria are also known to produce a wide variety of toxins, and have been implicated in numerous livestock and wildlife deaths (Carmichael and Gorham 1977).

Cyanobacteria are frequently associated with the formation of surface scums – masses of positively buoyant cells. The scums may persist for extended periods of time in apparent good health, or may be invaded by bacteria, fungi or protozoans; rapidly becoming a decaying mass (Reynolds 1987). Wind and currents may further concentrate the scums, and a considerable quantity may accumulate on leeward shores, seriously impacting recreational use of the waters and exacerbating the danger of toxic effects. Toxins released by such rapidly-decaying mats may present a health threat to populations drawing potable waters from affected systems (Berg *et al.* 1987, Lindholm *et al.* 1989). Similar effects may be caused by lysing masses of cells with copper sulfate or other treatments (Falconer 1989). Typical water treatment plants do not effectively eliminate toxins (Carmichael 1991, Gorham and Carmichael 1988), and chronic exposure to low levels of algal toxins may contribute to the formation of liver tumors in humans (Falconer 1989). The reduced aesthetic and recreational opportunities, combined with the potential health risks, provide ample motive to determine which physical and chemical factors contribute to cyanobacterial dominance of the phytoplankton within any particular water body.

As a group, cyanobacteria have several adaptations which contribute to their periodic dominance. These include, but are not limited to, resistance to grazing (Burns *et al.* 1987), secretion of allelopathic substances (Keating 1978), high thermotolerance (Konopka et al. 1978, Priscu et al. 1984), accessory photosynthetic pigments which facilitate photoadaptation (Paerl 1979, Paerl 1988, Tilzer 1987), and the ability to fix atmospheric nitrogen (Paerl 1985, Smith 1983).

In general, algal cells are denser than water, leading to their potential rapid loss from the euphotic zone. This problem has been overcome by the various genera of eukaryotic algae, which have developed a variety of morphological features to minimize the rate of sinking and foment entrainment, ultimately relying on a turbulent epilimnion to ensure exposure to light within the euphotic zone (Reynolds 1987).

In contrast to the major eukaryotic genera of algae, many cyanobacteria possess specialized internal structures (gas vesicles) which reduce cell density (Walsby 1975).

By regulating the number of gas vesicles produced, their collapse by internal pressure, and the retention of dense photosynthate, cyanobacteria can achieve isopyncy, or even become positively buoyant (Reynolds 1975, Walsby 1975, Viner 1989). Reynolds (1972) found that flotation rates for *Anabaena circinales*, a filamentous, bloom-forming cyanobacteria, were commonly as high as 50m d^{-1}.

The ability of the cyanophytes to actively regulate buoyancy provides a competitive ecological advantage, particularly in strongly stratified waters, where vertical water movements may be insufficient to prevent the settling of more dense eukaryotic competitors. Furthermore, buoyant cyanobacteria are well adapted to endure surface water conditions: they can tolerate the CO_2-depleted eplimnia commonly produced in eutrophic waters (Shapiro 1973, Talling 1976) by using both atmospheric CO_2 and HCO_3^- (the dominant form of inorganic carbon at high pH). They also are highly resistant to photo-oxidation, and capable of temporally separating carbon and atmospheric nitrogen fixation to optimize the use of photosynthetically-derived reductant (Paerl 1979). These adaptations enable them to exploit the availability of atmospheric carbon and nitrogen and high daytime irradiance of surface waters, while simultaneously shading underlying phototrophs (Paerl 1988).

There are several factors which have been shown to influence cyanobacterial buoyancy. Buoyancy is decreased by high light levels (Walsby 1977, Reynolds 1975, Viner 1989). Nitrogen limitation can increase cyanobacterial buoyancy (Klemer et al 1982, Spencer and King 1985), as can reduced CO_2 availability (Shapiro 1973, Walsby 1982). High temperatures, which might prove inhibitory, have been shown to reduce buoyancy (Reynolds 1975).

Collectively, the adaptations of cyanobacteria promote their dominance in warm, eutrophic waters during periods of thermal stratification, intensive grazing by zooplankton or nitrogen limitation.

Objectives of Castle Rock Lake Study

Nuisance blooms of cyanobacteria have occurred in Castle Rock Lake in recent years. The recreational and aesthetic value of the lake has been adversely affected by the presence of surface scums on leeward shores and significant concern exists regarding potential toxicity. In addition, concern exists over potentially low oxygen levels which may result from the rapid collapse of dense blooms. In addition, water drawn from the reservoir for evaporative cooling periodically shows high particulate loading and dissolved organic carbon, resulting in clogging of filters and inefficient cooling. It has been speculated that these effects are caused by cyanobacterial abundance.

This study was undertaken in an effort to assess the consequences and evaluate the factors contributing to cyanobacterial dominance of the reservoir's phytoplankton. Due to the proximity of the inflow and outflow in this lake, and the rapid flushing rate, it is uncertain whether the blooms result from reservoir effects or merely reflect conditions of the Yellowstone River. Specific the objectives of the study were:

1. Determine the influence of water-column stability on the timing and magnitude of blue-green algal blooms.
2. Examine the effect of water temperature on cyanobacterial abundance.
3. Determine the extent to which nutrient loading of nitrogen (N) and phosphorus (P) controls cyanobacterial dominance.
4. Evaluate the potential toxicity of the blue-green algae during blooms.
5. Evaluate the fate of inflowing waters.
6. Determine the sources of dissolved organic carbon (DOC)

References Cited

Berg, K., O. M. Skulberg and R. Skulberg. 1987. Effects of decaying toxin blue-green algae on water quality -- a laboratory study. *Arch. Hydrobiol.* **108:** 549-563.

Burns, C. W., D.J. Forsyth, J. F. Haney, M. R. James, W. Lampert and R. D. Pridmore. 1987. Mechanisms of co-existence and exclusion of phytoplankton by cyanobacteria in Lake Rotongiao. *New Z. J. Mar. Freshw. Res.* 21: 537-538.

Carmichael, W. W. 1991. Blue-green algae: an overlooked health threat. *Health and Environment Digest* **5:** 1-8.

Carmichael, W. W. and P. R. Gorham. 1977. Factors influencing the toxicity and animal susceptibility of *Anabaena flos-aquae* (cyanophyta) blooms. *Journal of Phycology* **13:** 97-101.

Carmichael, W. W. 1992. Cyanobacteria secondary metabolites -- the cyanotoxins. *Journal of Applied Bacteriology* **72:** 445-449.

Falconer, I. R. 1989. Effects on human health of some toxic cyanobacteria (blue-green algae) in reservoirs, lakes and rivers. *Toxicity Assessment* **4:** 175-184.

Fulton, R. S. 1988. Grazing on filamentous algae by herbivorous zooplankton. *Freshwater Biology* **20:** 263-271.

Gilbert, J.J. 1990. Differential effects of *Anabaena affinis* on cladocerans and rotifers: Mechanisms and implications for zooplankton community structure. *Ecology* **71:** 1727-1740.

Gorham, P. R. and W. W. Carmichael. 1988. Hazards of freshwater blue-green algae (cyanobacteria). *Algae and Human Affairs* Cambridge University Press. pp 403–425.

Keating, K. I. 1978. Blue-green algal inhibition of diatom growth: Transition from mesotrophic to eutrophic community structure. *Science.* 199: 971-973.

Klemer, A. R. 1978. Nitrogen limitation of growth and gas vacuolation in *Oscillatoria rubescens. Proceedings of the International Association for Theoretical and Applied Limnology, Denmark. 20: 2293-2297.*

Klemer, A. R., J. Feuillade and M. Feuillade. 1982. Cyanobacterial blooms: carbon and nitrogen have opposite effects on the buoyancy of *Oscillatoria. Science* **215:** 1629-1631.

Konopka A. and T. D. Brock. 1978. The effect of temperature on blue-green algae (Cyanobacteria) in Lake Mendota. *Appl. Envron. Micro.* 36: 572-576.

Lindholm, T., J. E. Eriksson, and A. O. Meriluoto. 1989. Toxic cyanobacteria and water quality problems -- examples from a eutrophic lake on Åland, south of west Finland. *Wat. Res.* **23:** 481-486.

Paerl, H. W. and P. E. Kellar. 1979. Nitrogen-fixing *Anabaena*: physiological adaptations instrumental in maintaining surface blooms. *Science* **204:** 620-622.

Paerl, H. W. 1985. Microzone formation: Its role in the enhancement of aquatic N_2 fixation. *Limnol. Oceanogr.* **30:** 1246-1252.

Paerl, H. W. 1988. Nuisance phytoplankton blooms in coastal, estuarian and inland waters. *Limnol. Oceanogr.* **33:** 823-847.

Pearson, P. E. 1982. Muddy odor: a problem associated with extreme eutrophication. *Hydrobiolgia* **86:** 161-164.

Priscu J. C. and C. R. Goldman. 1984. The effect of temperture on photosynthetic and respiratory electron transport system activity in the shallow and deep-living phytoplankton of a subalpine lake. *Freshwater Biology* 14: 143-155.

Reynolds, C. S. 1987. Cyanobacterial water-blooms. *Advances in Botanical Research* **13:** 67-143.

Reynolds, C. S. 1975. Interrelations of photosynthetic behavior and buoyancy regulation in a natural population of blue-green alga. *Freshwater Biology* **5:**323-338.

Shapiro, J. 1973. Blue-green algae: Why they become dominant. *Science 179: 382-384.*

Smith V. H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. *Science* **221:** 669-671.

Talling, J. F. 1976. The depletion of carbon dioxide from lake water by phytoplankton. *J. Ecol.* 64: 79-121.

Tilzer, M. M. 1987. Light dependence of photosynthesis and growth in cyanobacteria: Implications for their dominance in eutrophic lakes. *New Z. J. Mar. Freshw. Res.* 21:401-412.

Viner, A. B. and L. Kemp. 1983. The effect of vertical mixing on the phytoplankton of lake Rotongaio (July 1979 - January 1981). *New Z. J. Mar. Freshw. Res.* **17:** 407-422.

Viner, A. B. 1989. Buoyancy and vertical distribution of *Anabaena spiroides* in Lake Okaro (New Zealand) *Arch. Hydrobiol. 32: 221-238.*

Walsby, A. E. 1977. The gas vacuoles of blue-green algae. *Scientific American* **237:** 90-97.

Walsby, A. E. 1975. Gas vesicles. *Plant Physiology* **36:** 427-439.

CHAPTER 2: STUDY SITE

Physical Characteristics

Castle Rock Lake (Fig. 2.1) is an artificial reservoir located in the northwest region of Colstrip, Montana. Constructed and maintained by the Montana Power Company, it provides water for evaporative cooling of the power plant, as well as providing the domestic water supply and recreational opportunities.

The lake has a single inflow, a pipe entering the northeast lobe carrying water pumped from the Yellowstone River; the pumping rate is varied according to local demands and maintenance of reservoir water level. The lake level is varied annually from about 999.1 m to 1001.1 m which is higher than the majority of the surrounding terrain, virtually eliminating watershed. The lake loses water only to evaporation, seepage or through its single outflow – a pumping tower located near the central eastern shore of the lake. The outflow is provided with moveable blocks which allow water to be withdrawn from selected depths.

The lake basin is formed by two earth dams which form the eastern and southeastern shores. Basin morphology is fairly simple, being essentially rectangular in shape, with all points sloping toward the deepest basin in the northeast quadrant near the outflow (Figure 2.2).

At the mean elevation of 1000 m, the volume of the lake is about 3.3×10^6 m^3, with a mean depth of 7.5 m and a maximum depth of 14.5 m. Under these conditions, the maximum length and breadth of the lake are 1000 m and 729 m respectively.

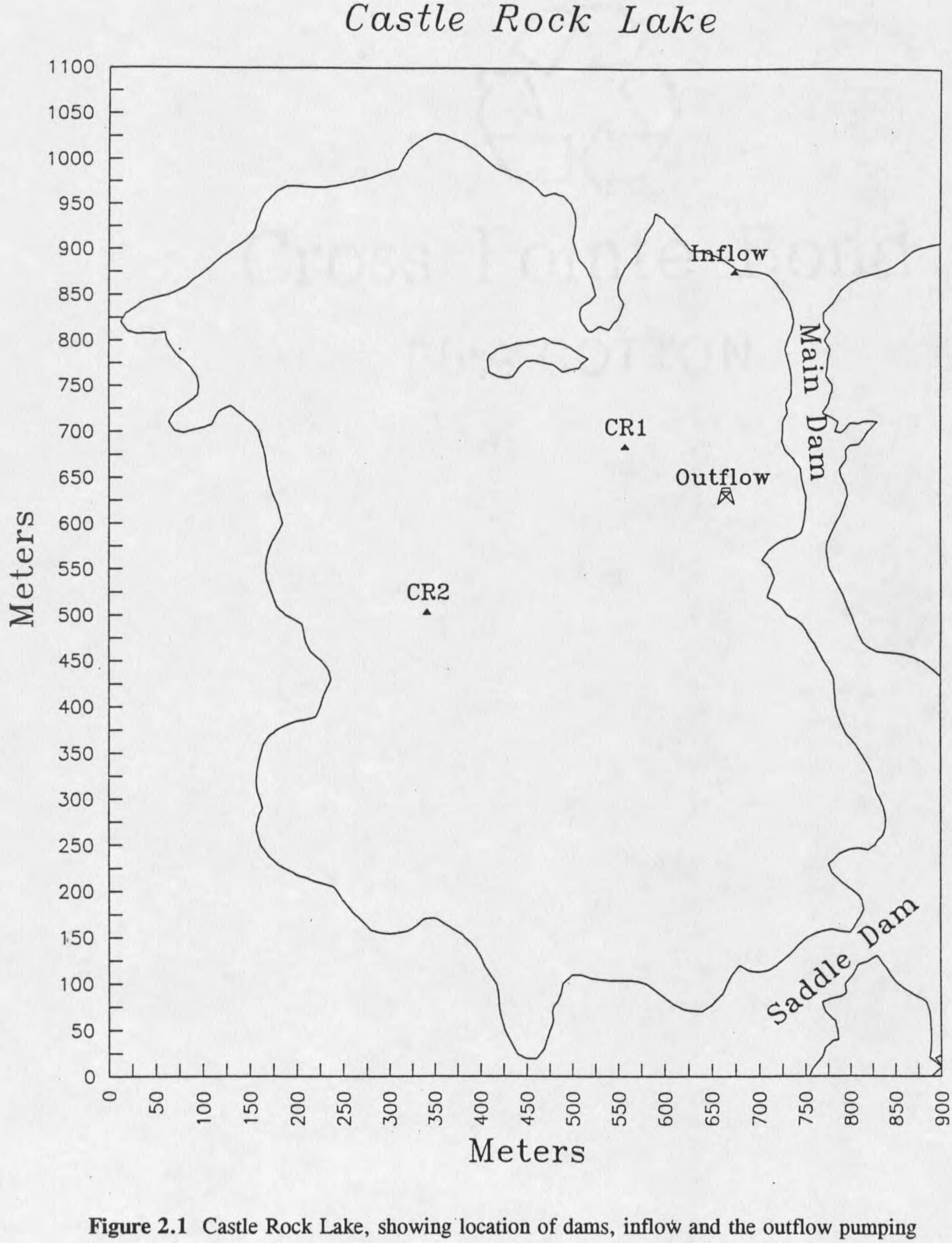

Figure 2.1 Castle Rock Lake, showing location of dams, inflow and the outflow pumping tower. Locations of the permanant sampling stations (designated CR1 and CR2) also shown.

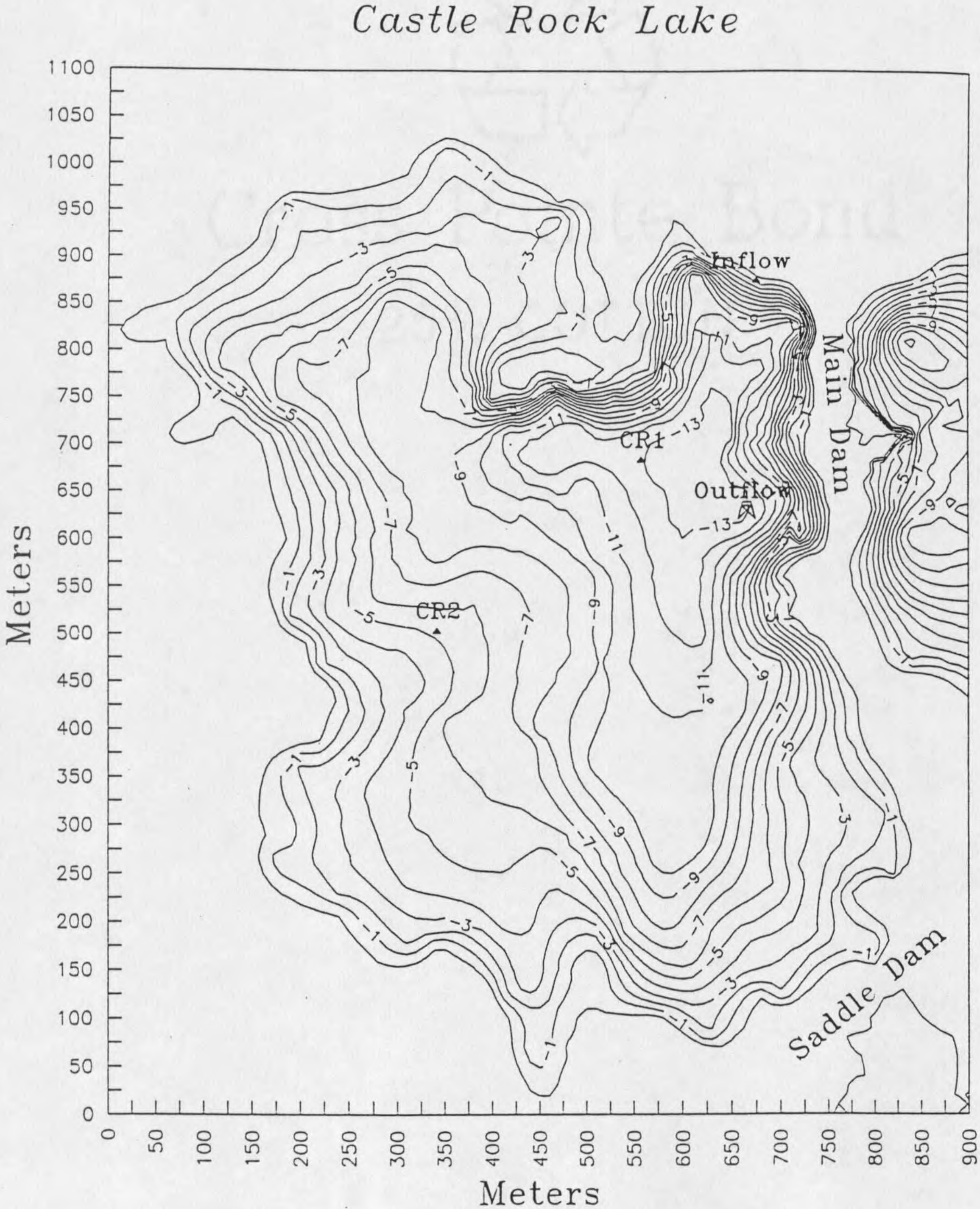

Figure 2.2 Castle Rock Lake, topographic map. Contours shown represent depth in meters.

Shoreline length = 3.9 km, and shoreline development (the ratio of the shoreline length to the circumference of a circle of equal area) =1.65. The theoretical hydraulic retention time (lake volume/inflow rate) ranges from 21 to 54 d, averaging 30.6 d. Owing to the rapid exchange of water and the fairly constant lake level, the variation in retention time is almost entirely from fluctuations of inflow pumping rate.

Selection of Sampling Stations

On July 2, 1992 a YSI model 57 meter was used to acquire vertical profiles of temperature and oxygen from 10 sites distributed throughout the lake (Fig 2.3). A YSI model 33 salinity and conductivity meter was used to obtain conductivity data at the same sites. Analysis of the data (Table 2.1) indicated that variation in the horizontal plane was relatively small for temperature and conductivity, but significantly greater for oxygen. Coefficients of variation (CV=Standard Deviation/Mean x 100) averaged 1.1, 2.7 and 11.3 respectively. It is assumed that the variance in oxygen levels is due to photosynthetically-derived oxygen produced during the sampling period (8:15 A.M. to 3:35 P.M.).

Similar analyses performed on June 30, 1993 and July 29, 1993, in which the sampling period was significantly shortened, indicated reduced variability in all areas, with coefficients of variation averaging 1.35%, 0.9% and 2.6% for temperature, conductivity and oxygen (Figures 2.4-2.5, Tables 2.2-2.3).

In view of the rather homogenous nature of the lake in the horizontal plane, we decided to mark two permanent sampling stations in the lake. The first (CR1), was