

A STUDY OF THE PROBLEMS ASSOCIATED WITH DALANGDIAN RESERVOIR, CHINA

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Introduction

There are over 2,300 lakes over 1 km² in China (total area 80 000 km², accounting for about 0.8% of the total area of the country and with a total freshwater storage capacity of 225 billion m³). In addition there are approximately 87 000 reservoirs with a storage capacity of 413 billion m³. These form the main supply of drinking water as well as water for industrial and agricultural production and aquaculture. Because of a lack of understanding of the frailty of lake ecosystems and poor environmental awareness, human activities have greatly affected freshwater systems (Xie 1995). The most marked impacts have been due to land reclamation, destruction of marginal vegetation, discharge of industrial, domestic and agricultural waste and irrational development and use of freshwater resources. As a result lakes in dry areas are becoming saline, while others are highly polluted and undergoing a process of rapid eutrophication. The majority of the lakes tested to date have been classified as hypertrophic (Dokulil et al. 2000). Thus, although China has 28 of the world's largest lakes (Chang 1987, Chen 1994), the annual storage capacity ranks sixth in the world and the per capita availability is a quarter of the world's average (Jusi 1989) and predicted to fall by the year 2000 (Shiklomanov 1993). In this article, we focus on the problems of one water supply reservoir, Dalangdian Reservoir, and consider options for improving its management.

Site description and methods

Dalangdian Reservoir is situated at the eastern end of the Hebei Plain (longitude 115° 6' - 117° 8', latitude 37° 4' - 38° 9'), approximately 300 km south east of Beijing. It is only 6 m above sea level on a plain of an area of 8,200 km² that represents 38% of the land area of Hebei Province. This is a

warm semi-arid region which receives monsoon air, with a mean temperature of 12.3°C (minimum -21 °C, maximum 40°C) and a mean annual wind speed of 2.6 m sec⁻¹ (maximum 21 m sec⁻¹) largely from the south-east. The reservoir enjoys a frost-free period of 190-200 days, during which solar illumination is high (mean annual sunlight 2400 h) and the bulk of precipitation occurs (590 mm), concentrated in July and August. The weather contributes to a high plant and animal biodiversity around the reservoir, which was the first to be constructed to supply drinking and industrial water for Cangzhou City and was opened in September 1996. It remains the largest reservoir on the plain with a total area of 16.7 km² and a maximum depth of 12.5 m. It is fed by canalized water from the Yellow River (the channel is 350 km long, Figs 1 & 2), between December and January of each year. This is an extremely short period, given that the volume involved is 85 x 10⁶ m³. Thereafter, the water is drawn down for supply purposes so that the final depth is less than 1 m. Li & Tian (2000) have reported some information about the hydrological regime of the reservoir, but this is not available in western journals.

In this study, we investigated the water quality of the reservoir. Samples for analysis of water chemistry and phytoplankton were taken from July 2000 to October 2001 at monthly intervals, from the shoreline, at a depth of 1 m. The analytical procedures were those of Zhang & Huang (1991) and Xie & Wang (1998).

The samples were filtered on site and refrigerated for the 12 h journey to the laboratory. Chlorophyll *a* was extracted in 90% hot ethanol (80 °C) using an ultrasonic agitation bath. The samples were then refrigerated for 2 h and then analyzed spectrophotometrically at 665 nm and 750 nm, the final concentration being determined by the following formula

$$Chla_{ethanol} = 27.9 \times [(E_{665} - E_{750}) - A_{665} - A_{750}] \times V_{ethanol} / V_{sample}$$

where:

$Chla_{ethanol}$ is the concentration of chlorophyll *a* (µg l⁻¹)

E_{665} and E_{750} are the absorption values of the extracted solution at the relevant wavelengths

A_{665} and A_{750} are the absorption values of the acidified extract

$V_{ethanol}$ is the volume of ethanol (ml)

V_{sample} is the volume of filtered water (l).

Algal genera were identified according to Belcher & Swale (1976) and Zhang & Hong (1991) and noted on a presence/absence basis on raw samples examined microscopically at 400x magnification. Water transparency was determined by Secchi disc; conductivity, bicarbonate and NaCl concentration were analyzed using Horiba field analytical instruments.

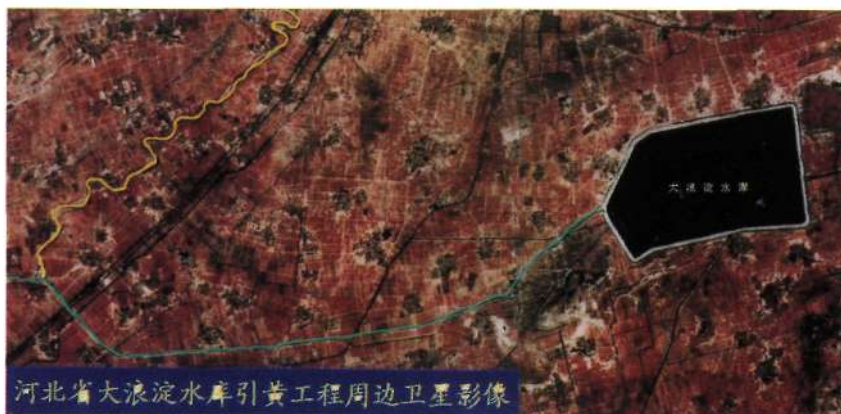


FIG. 1. *Above*: Satellite image of Dalangdian Reservoir showing feeder channel (blue) and the Yellow River (yellow). The length of the feeder channel is 350 km. *Below*: Inflow point for canalized water to the reservoir. Filling time is only three weeks.



FIG. 2. Feeder channel to Dalangdian reservoir in full flow (*above*) and one month later when dry (*below*), indicating the arid nature of the zone.

Seasonal changes in Dalangdian Reservoir

Although the results are based on a presence/absence basis, Table 1 shows a general trend of algae being detected in early summer followed by a general increase until August. Cyanobacteria, particularly, are in evidence in late summer when the water level is low, the population being dominated by *Microcystis aeruginosa*. *Ceratium* spp. are also a component of the late summer community although diatoms and green algae are also present. The emphasis given to cyanobacteria is based on discussions between two of us (Z.X.S. & J.G.J.) and examination of preserved samples. There is no doubt that the phytoplankton population is dominated by *Microcystis* species in late summer. It is during this period that the maximum biomass (as determined by Chlorophyll *a*) of algae is observed (Fig. 3). Chlorophyll *a* concentrations increase from undetectable in the winter months, before introduction of water from the Yellow River, to 12 - 14 mg m³ in mid- to late summer. Electrical conductivity and pH are relatively stable and Secchi disc readings vary, relating sometimes to the algal biomass and, at other times, to the amount of sediment brought in from the Yellow River. This is reflected, to some extent, in the analyses of suspended solids (0.20 - 0.33 g l⁻¹) with the highest readings being recorded as the reservoir is filled. The general pattern is, therefore, one of an increasing biomass of algae as the summer progresses and the volume of water in the reservoir decreases.

The chemical characteristics of the reservoir reflect these changes. Chemical Oxygen Demand is at its highest (5.2 mg l⁻¹) in late summer compared with 3.0 mg l⁻¹ in early spring. Total nitrogen concentrations vary to a lesser degree, although the pattern is the same, the concentrations range only from 0.8 to 1.04 mg l⁻¹.

What is of greater concern are the high, and relatively stable, concentrations of phosphorus in the reservoir. Total phosphorus concentrations in winter are around 0.6 mg l⁻¹, but late summer concentrations range from 0.5 to 0.8 mg l⁻¹. Similarly, soluble phosphorus concentrations are 0.14 - 0.18 mg l⁻¹ during the winter but rise to 0.29 mg l⁻¹ during August and September.

Nitrate concentrations range between 2 and 4 mg l⁻¹, with a possible minimum during winter months. Other analyses show that mean levels for the following determinands were as follows: Cl⁻ 0.17 - 0.19 g l⁻¹, HCO₃⁻ 0.13 - 0.18 g l⁻¹, Na⁺ and K⁺ 0.15 - 0.21 g l⁻¹, SO₄²⁻ 0.15 - 0.27 g l⁻¹, Ca²⁺ 0.04 - 0.06 g l⁻¹. Total suspended solids were fairly stable ranging from 0.2 to 0.33 g l⁻¹, the highest values being recorded soon after the reservoir was filled.

Table 1. Occurrence of algal genera in Dalangdian Reservoir between July 2000 and October 2001.

Genus	Month from July 2000 to October 2001																
	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	
Fragilaria				+						+	+	+					
Asterionella	+	+	+														
Scenedesmus				+	+					+	+	+					
Closterium	+	+	+								+	+	+	+	+		
Botryococcus	+	+	+											+	+	+	
Spirogyra	+	+	+											+	+	+	
Oedogonium	+	+	+											+	+	+	
Oocystis				+	+											+	+
Microcystis	+	+	+										+	+	+	+	
Aphanizomenon	+	+	+										+	+	+	+	
Ceratium	+	+	+											+	+	+	+

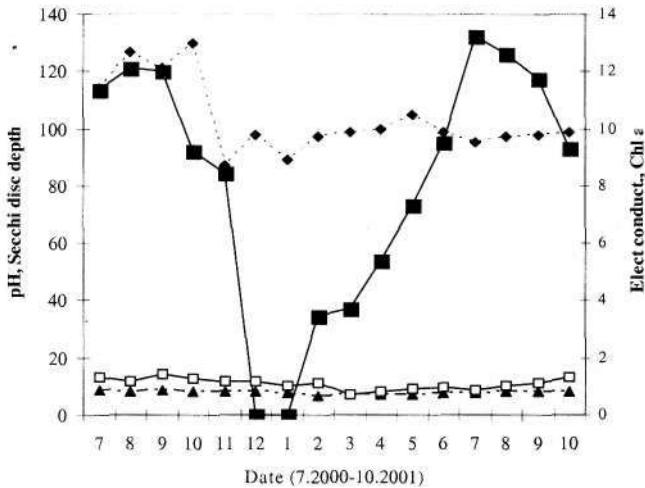


FIG. 3. Physicochemical and biological characteristics of Dalangdian Reservoir: pH (solid triangles); Secchi disc depth, cm (solid diamonds); electrical conductivity, $\mu\text{S cm}^{-1}$ (open squares); chlorophyll *a*, mg m^{-3} (solid squares).

By any measure, these results indicate that Dalangdian reservoir is at the eutrophic end of the scale. The values for chlorophyll *a* in this large water body equate to those found in the smaller lakes at the upper end of the Pearsallian series, e.g. Esthwaite Water and Blelham Tarn (Pearsall 1921; Jones 1972). The concentrations of total and soluble phosphorus, on the other hand, are almost an order of magnitude higher than those experienced in Lake District waters. Even more marked are the concentrations of major ions, chloride, bicarbonate, sodium, potassium, sulphate and calcium, which are orders of magnitude higher than those experienced in U.K. waters (Carrick & Sutcliffe 1982). These values reflect the increasing salinity of soils and desertification in northern China (Tian et al. 2000) - a problem that has been developing for over 50 years.

To take a more Chinese perspective we compared our results with those published by Dokulil et al. (2000). The ratio of chlorophyll *a* to total phosphorus concentrations indicate that Dalangdian reservoir can be classified as eutrophic/hypertrophic at the end of the summer but, even at the time of filling, the phosphorus concentrations indicate that it falls within this area of classification (Forsberg & Ryding 1980).

Analysis of the Yellow River water provides some indication of the source of enrichment. Total suspended solids are 3 g l^{-1} and total phosphorus and soluble phosphorus account for an astonishing 36 and 1.7 g l^{-1} , respectively, when the feeder channel is in full flow. The bulk of this sedimentary material is deposited at the western end of the lake, beyond the normal sampling point. Fortunately, because of prevailing winds and the shallowness of the reservoir, no de-oxygenation occurs, thus reducing the potential for phosphorus recycling. There is no doubt that climatic factors, particularly winds and associated turbulence (Reynolds 1997), play their part in the development and maintenance of the algal population in Dalangdian reservoir, but its future as a water supply cannot be assured until the filling regime is modified.

The future for Dalangdian Reservoir

The general consensus is that, although China is well endowed with lakes, the vast majority of these may be classified as being eutrophic or hypertrophic (Xie 1995; Dokulil et al. 2000). There is some attempt, however, to balance economic growth with the constraints of waste-load control (Ni et al. 2001), although significant barriers to the sustainable supply of high quality water in the face of increased population and economic development have been identified (Huang & Xia 2001). This problem is exacerbated by the historical trend of establishment of human

populations close to lakes and the consequent urbanisation and development of industry and agriculture.

There is no such population development around Dalangdian Reservoir but the water body is situated in an arid zone. Because of changes in the climate, particularly in this region, it has been predicted that the availability of water per person will have reduced by approximately 50% by the year 2000 (Shiklomanov 1993). The chlorophyll and total phosphorus data from Dalangdian reservoir indicate that it is eutrophic/hypertrophic. There are also concerns about the late summer blooms of cyanobacteria, particularly *Microcystis aeruginosa*. There is no separation of water for industrial and drinking purposes and treatment (which is expensive) involves filtration and chlorination. Although there is awareness of the need for regional water management (Guoh et al. 2001), it is difficult to see a solution to the current problem at Dalangdian reservoir. The filling regime, which introduces $85 \times 10^6 \text{ m}^3$ of water over a very short time period in December and January, does not permit the opportunity to treat the inflow, but proposals have been made for treatment (Li & Tian 2000). If this period of filling could be extended for six months then it would be possible to treat the water via a low-cost option such as a phytoremediation channel.

However, events have overtaken any suggested remedial measures for the incoming water to the reservoir. Plans are well underway to transfer water from the Yangzi River to the Yellow River and to increase water supply to the reservoir. This also includes proposals for a threefold increase in the area covered by the reservoir. If this is done as one major engineering construction it will not solve the current problems, in fact it is likely to make them worse. It does, on the other hand, provide an opportunity for water quality improvement in one of two ways.

The first option might be to build three reservoirs. The first (probably the present water body) would receive incoming water and then transfer it to the lower reservoirs via a series of phytoremediation channels. China is rich in plant species that have been used in phytoremediation, e.g. poplar (*Populus* spp.), and there are numerous shrub species that could be used lower in the channels. Proposals to use floating macrophytes, particularly introduced species, should be avoided, given their invasive tendencies. The water body, and any extension of it, is clearly too large (with high local wind speeds) to implement any proposals for floating rafts of macrophyte supported by expanded polystyrene. Such a remedial measure might be considered for smaller water bodies such as fish ponds.

The second option is the one that we would prefer to see implemented. Given the engineering capability in China, it should be possible to divert all incoming water into a large wetland that would act as a "stripping zone". Water could then be introduced to an enlarged reservoir over a longer time

period and, more importantly, having had nutrients (and pollutants) removed. Given the time scale for water transfer plans, we consider that this option should be given serious consideration.

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