Darwell Transfer Scheme

Final report part III

Water Quality in the Darwell Reservoir

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Predictions of Algal Productivity in the enlarged Darwell Reservoir.

Introduction.

The growth of algae in water is influenced by many things. However research carried out over many years has established that reasonably reliable estimates of the size of algal crops can be made by considering four main factors: the amount/ concentration of available nutrients; the relative balance between different nutrients: the residence time in the lake; the light environment. In this report we will use several equations based on different assumptions to estimate the algal biomass in the Darwell reservoir after enlargement.

Methods.

Physical and chemical data used for the estimation of likely water quality in the present and enlarged reservoir are given in table 1. Bathymetric parameters for the present lake are from Binnie and partners Feasibility Study and for the proposed reservoir have been supplied by RKL. Chemical data are mean values for the period of data supplied by the NRA (Rother) and Southern Science (Darwell reservoir as described by raw water quality at the Brede (Br) and Beauport (Be) works). Flow data are annual means supplied by Southern Science. Estimates of P and N loadings and concentrations and the chlorophyll concentrations which would result from these nutrients under different sets of assumptions are given in table 2.

Retention times.

The first consequence of the reservoir enlargement is an increase in the average retention time of water by a factor of 3, to about 100 days. This increases the time available to algae to use the nutrients at their disposal, so that they are more likely to develop their biomass to its full potential.

Nutrient concentrations.

In the following discussion nitrogen has has been approximated by the nitrate concentration. The areal loading of nitrogen (ie the amount of nitrogen added to the water below one square metre of the lake surface each year) will decrease. However the increase in retention time balances the reduction so that the predicted concentration of N remains unchanged. Predictions for the present lake give concentrations which are similar to the maximum concentrations observed in the lake. Maximum observed concentrations are used for comparison as annual means are heavily weighted by summer concentrations which are reduced due to uptake by algae.

The major part of the P load originates from the river Rother. Although the areal loading of P is about the same in the old and new reservoirs, the concentration in the new is about 43% higher because of the increased retention time in the latter. If we exclude one extremely high P concentration which is an order of magnitude higher than all the other values, then the predicted P concentration in the present reservoir is close to the observed maximum concentration. Hence nitrogen concentrations will remain much the same whereas phosphorus concentrations will increase significantly.

Nutrient limitation of algal growth.

There are a large number of empirical equations which predict chlorophyll concentrations from total P concentrations. They all make different assumptions and predict different descriptions of the algal biomass such as annual mean concentration, summer mean, summer maximum, etc. We will use three measures here which have been applied extensively. Summer mean chlorophyll concentrations predicted by Dillon and Rigler's equation give similar values to maximum summer concentrations predicted by Reynolds formula. Predictions of about 100mg m^{-3} made for the present reservoir are consistent with observations of maximum chlorophyll concentrations observed at Beauport. (There appear to be major differences between chlorophyll concentrations measured at Brede and at Beauport?) The predictions for the enlarged reservoir suggest that chlorophyll concentrations will have the potential to increase by about 50%. The Vollenweider equation provides an estimate of the annual mean chlorophyll concentration based on different principles. Because it predicts annual means, it includes the winter concentrations when growth is poor. Hence the concentrations appear to be much lower than for the previous equations. The Predicted concentrations for the present reservoir are higher than annual mean concentrations observed at Beauport (again data for Brede are very odd). Predictions for the enlarged reservoir are only slightly greater than for the present reservoir. However the Vollenweider equation assumes complete mixing and, if stratification occurs or blue green algae predominate all the phosphorus could be concentrated by algae into the top 5 or 1m respectively. This would have the effect of increasing the chlorophyll concentrations by a factor of between about 3and 10 respectively bringing them to the same order as estimates from the other methods where complete mixing is not assumed. The implication is that permanent or intermittent destratification of the enlarged reservoir may be beneficial in reducing the P concentration and hence algal populations.

Although it has been suggested that the N/P ratio is a critical factor in determining dominance by blue-green algae the evidence is confused. However it is true that if nitrogen becomes low when there is still available phosphorus then nitrogen fixing algae are likely to be selected with the attendant problems of taste and odour and floating algal scums. There is no equivalent of the Vollenweider equation for N but Sakamoto has produced a relationship which is analogous to the Dillon and Rigler equation. In the present reservoir the nitrogen could support about 50% more biomass than the phosphorus will allow so that nitrogen fixing blue greens would not be expected at present. However in the enlarged reservoir, the predicted chlorophyll concentrations are the same so that nitrogen may well become limiting in the new situation resulting in frequent blue green algal blooms.

Light limitation of algal growth.

In order to survive and grow, algae need light. Since light is absorbed by both the water itself and non algal particles in the water , then, even with no algae present, light will not reach the bottom of a deep lake. Different situations can be compared by reference to the "compensation depth". This is the depth at which light input during a 24 hr day is just sufficient to keep the algae alive by balancing the loss of energy required for respiration during the hours of darkness. Above this depth there will be excess energy available for algal growth. Obviously algae absorb light themselves and, all other things being equal, the greater the concentration of algae, the shallower the compensation depth. Using this concept it is possible to calculate the maximum concentration of algae which could be maintained under different light conditions at different times of the year. Results for the enlarged reservoir are given in table 2. These are likely to be extreme values. However with full mixing in mid summer (16h,fully mixed) predicted chlorophyll concentrations are lower than those predicted by the Reynold's nutrient model so that the reservoir will be light limited. If the reservoir stratified with the thermocline at 6m below the surface, then the predicted chlorophyll concentration is similar to values obtained from the Dillon and Rigler and Reynold's models, suggesting that maximum algal concentrations are unlikely to exceed 150-200 mgm^{-3} during stratified periods. Within the precision of the calculations these estimates are not enormously different from the response from the present reservoir. If the present water quality is acceptable then it is likely that no new management strategies will be required. But if better water quality is required then other options must be explored. Destratification should produce chlorophyll concentrations not exceeding 40-70 mgm^{-3}; complete or partial removal of P from the Rother input would reduce concentrations further and active management of the drawoff position would allow water of better quality than would be available with destratification to be located and utilised as algal material will be concentrated in the upper waters. The relative merits of these different options require further study.

Limitations.

All the model equations used in this study are based on mean values for concentrations, retention times, mixing depths, etc. Since many of these parameters commonly vary considerably over the year, the resulting picture is nescessarily rather broad brush. However, international studies by bodies such as the OECD have shown that these methods provide a good indication of the likely direction of change and a reasonable assessment of the amount of change. They give very little information on the likely algal species present and their changes with time. Further work with more sophisticated models is required to throw light on these aspects.

Conclusions.

The concentration of algae in the enlarged reservoir is likely to be only slightly greater (max 150-200 mgm^{-3}) than in the present reservoir. However, nitrogen fixing blue green algal blooms are likely to be more frequent. If stratification is allowed to occur, then algal growth will be limited by nutrients. If the reservoir is completely mixed then algal concentrations are likely to be lower (40- 70 mgm^{-3}) and blue green blooms will not be encouraged. Better water quality still may be obtained by either removing phosphorus from the Rother water or by selecting to draw off water from different levels in the stratified reservoir at different times.

Table 1. Input data for water quality calculations.

	Present		Proposed	
	Average	Drought	Average	Drought
Volume ($m^3 x10^6$)	4.426		20.000	
Area ($m^2 x10^6$)	0.688		1.500	
Mean depth(m)	6.47		13.33	
Max. depth(m)	16.0		29.0	
Inflow ($m^3 x10^6 y^{-1}$)				
Rother	18.980	7.800	45.375	10.543
Catchment	27.690	0.704	27.690	0.704
Total	46.670	8.504	73.065	11.247
Phosphorus (mgl^{-1})				
Rother -Total		0.307		
Catchment -SRP		0.023		
Lake Max.		0.159^{Br}		
Nitrate (mgl^{-1} as N)				
Rother		2.27		
Catchment		2.09		
Lake Max.		2.10^{Br}		

Br = Brede.

Table 2.

Calculated properties of the present and proposed reservoir.

	Present	Proposed	Observed Max
Displacement Time(days)m			
Average	34.6	100	
Dry Weather	190	650	
Areal Nutrient Loading Rate ($g\ m^{-2}y^{-1}$)			
Nitrogen	148.5	107	
Phosphorus	9.5	9.7	
Lake Concentrations ($mg\ m^{-3}$)			
Nitrogen	2170	2200	2100^{Br}
Phosphorus	139	200	159^{Br}
P-load carrying capacity (as chlorophyll concentration $mg\ m^{-3}$)			
Summer mean			
(Dillon and Rigler)	93	158	
Max crop (Reynolds)	113	140	12^{Br}; 114^{Be}
Annual mean (Vollenweider)	25	31	5^{Br}; 15^{Be}
N-load carrying capacity (as chlorophyll concentrations $mg\ m^{-3}$)			
Annual mean (Sakamoto)	153	156	
Light limited carrying capacity (as chlor. concentration mgm^{-3})			
12h day fully mixed		43	
16h day, fully mixed		69	
16h day, 6m mixed depth		172	
16h day, 1m mixed depth		1000	

Br = Brede; Be = Beauport.