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CHAPTER 2 HAZARD IDENTIFICATION AND RISK ASSESSMENT IN SOURCE WATERS (LEVEL 1)

BACKGROUND

Hazards are defined by the World Health Organization as "Physical, biological or chemical agents that can cause harm to public health".

The assessment of the risk associated with an identified hazard must take in to account:

- The likelihood or probability of an identified hazard occurring
- The magnitude or severity of the effect and the consequences of the occurrence.

Risk can be assessed at two levels: maximum risk in the absence of preventative measures and residual risk after consideration of existing preventative measures [1].

The main hazards associated with algal blooms are the cyanotoxins they produce. Table 2-1 lists some of the factors that should be taken into account when assessing the risk associated with the presence of cyanobacteria in a water body. This information has been taken from Nadebaum *et al.* [1].

Table 2-1 Factors associated with the risk posed by cyanobacterial blooms

Typical hazards
Cyanobacterial toxins
Factors to consider in assessing likelihood and severity of hazards
Frequency of blooms occurring within a particular reservoir Extent of toxin problems Extent of monitoring to predict the onset of a bloom Extent and effectiveness of mitigation techniques (e.g. copper dosing, destratification) Severity of stratification over summer Level of available nutrients

A thorough risk assessment of a water source will involve:

- Identification of the factors impacting on the proliferation of cyanobacteria
- An analysis of historical data to determine the factors that may control cyanobacterial growth in this source, and their seasonal variation
- If the data is sufficient, the determination of any apparent relationships or trends between these factors and cyanobacteria species, numbers and toxin production. As it is unlikely that sufficient toxin data will be available, data relating to odour associated with cyanobacteria may be used
- Identification of the current or potential nutrient inputs into the source water. This can be accomplished by on-site inspection of the catchment as far as this is possible, or routine monitoring of nutrients at inflow sites to the water body (see Table 2-2 for examples of potential nutrient inputs into a water body)
- Assessment of the efficacy of current mitigation strategies (e.g. destratification techniques)

This accumulation of knowledge of the source water should allow water managers to anticipate the likelihood of a bloom occurring and the potential challenge to water quality under a particular set of conditions.

FACTORS INFLUENCING CYANOBACTERIAL BLOOM OCCURRENCE

High growth rates of cyanobacteria, resulting in the formation of blooms or scums in source waters, are caused by a combination of chemical, biological and physical factors including nutrient availability, water temperature, degree of stratification, climatic conditions, water body morphology and hydrodynamic stability of the water column (see Chapter 1 for more details). However, the most important factor is generally considered to be nutrient enrichment by nitrogen and phosphorus, or eutrophication, of the water source. Therefore any assessment of the risk of a cyanobacteria bloom in a water body must take these parameters into account. In most cases phosphorus is the key element in the development of cyanobacteria blooms as there is a direct relationship between the concentration of total phosphorus (TP) and the photosynthetic pigment chlorophyll-a (Chl-a).

It is important to identify the individual types of land use contributing to the total nutrient load from external sources (see Table 2-2). This approach will assist with apportioning the risk to individual sources of nutrients, some of which it may be possible to control, or even eliminate. This analysis should be coupled with an estimation of the levels of phosphorus associated with the occurrence of blooms of a particular magnitude expressed as chlorophyll-a. For this purpose a nutrient load screening tool such as NEAP may be applied. This modeling will indicate the percentage of the total load attributable to background, non-point source and point source nutrient inputs. This information may then be used to prioritize mitigation and management efforts.

For more information about assessment of phosphorus and its relationship with chlorophyll-a and several case studies, follow this link

A valuable web-based tool for the assessment of the eutrophication level of a water body is the Nutrient Enrichment Assessment Protocol, NEAP. The outputs from NEAP can include the phosphorus loading generated by the catchment, the trophic state of the water body, and the expected annual mean and peak chlorophyll-a concentrations.

For information on the Nutrient Enrichment Assessment Protocol (NEAP) model for the prediction of cyanobacterial growth follow this link

Table 2-2 Examples of potential nutrient inputs into a water body

Sector	Threat Level	Sub-sector	Activities
Industry	High	Paper, pulp or pulp products industries	Industries that manufacture paper, paper pulp or pulp products
	Medium	Breweries or Distilleries	Produce alcohol or alcoholic products
		Chemical Industries	Agricultural fertilsers, Explosive or pyrotechnics industries that manufacture explosives, Soap or detergent industries (including domestic, institutional or industrial soaps or detergent industries)
		Dredging works	Material obtained from the bed, banks or foreshores on many waters.
Agriculture	High	Intensive Livestock Operations	Feedlots that are intended to accommodate in a confined area and rear or fatten (wholly or substantially) on prepared or manufactured feed (piggeries, poultry, dairies, saleyards)
		Livestock processing industries	Slaughter animals (including poultry). Manufacture products derived from the slaughter of animals including tanneries or fellmongeries or rendering or fat extraction plants, scour, top or carbonise greasy wool or fleeces with an intended production capacity
	Medium	Agriculture	Industries that process agricultural produce including dairy, seeds, fruit, vegetables or other plant material
		Aquaculture or mariculture	Commercial production (breeding, hatching, rearing or cultivation) of marine, estuarine or freshwater organisms, including aquatic plants or animals (such as fin fish, crustaceans, molluscs or other aquatic invertebrates) but not including oysters
	Low	Other Farming	All other farming and agricultural activities
Settlements Urban	High	Wastewater Treatment Plants	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (<250 kilolitres/day)
	Medium	Wastewater Treatment Plants Composting	Including the treatment works, pumping stations, wastewater overflow structures and the reticulation system (<250 kilolitres/day) And related reprocessing or treatment facilities (including facilities that mulch or ferment organic waste, or that are involved in the preparation of mushroom growing substrate, or in a combination of any such activities).
Settlements, rural/dense	High	All	Wastewater, waste and water supply activities in areas outside designated urban settlements

ASSESSING THE RISK OF CYANOBACTERIAL GROWTH

BENTHIC CYANOBACTERIA

The presence of taste and odour compounds such as 2-methyl isoborneol and geosmin in a reservoir in the absence of known planktonic producers is the most direct indicator of a benthic source. Therefore historical data on tastes and odours can be useful in assessing the risk of potentially toxic benthic cyanobacteria. The distribution of benthic cyanobacteria in a reservoir is restricted by the extent of light penetration. Shallow reservoirs, especially those with high water transparency, will have greater area available for benthic cyanobacteria to grow than deep reservoirs. As a general guide, benthic cyanobacteria need about 1% of the surface irradiance to grow, however this may be lower depending upon the species or type. The area of the reservoir potentially available to benthic cyanobacteria can be calculated from the extinction co-efficient of the water and the bathymetry of the reservoir.

PLANKTONIC CYANOBACTERIA

The potential for blooms of planktonic cyanobacteria to occur has been estimated using the ‘Vollenweider’ model, which relates the spring phosphorus loading as total phosphorus to the subsequent algal biomass measured as chlorophyll-a [2,3, 4]. This relationship is applicable where the occurrence of nuisance cyanobacterial blooms is initially driven by catchment processes that contribute excess nutrients, particularly phosphorus, to the water body.

In addition to simple models based upon lake physical parameters [5], there are more complex deterministic 2D and 3D hydrodynamic models linked to water quality models which can be used to model the occurrence of different algal groups including cyanobacteria. These models are generally complex to run and calibrate and require a large amount of data for a wide range of physical and chemical variables for successful validation. Taylor *et al.* [6] reviewed the application of some water quality models for the prediction of taste and odour events. They concluded that although some of these models can simulate algal growth reasonably well, they are not a viable option to simulate geosmin and MIB production and release. This may be a reasonable current assessment, although the ongoing development and improvement of the water quality and algal growth simulation models by various research groups may result in more robust models in the future.

A simple alternative risk assessment approach developed in Australia to assess water bodies for their susceptibility to cyanobacterial contamination is given in the NHMRC ‘Guidelines for Managing Risks in Recreational Water’ [7]. The variables used in the assessment are considered to be the predominant drivers or indicators of the potential for cyanobacterial occurrence. These are:

- Prior history of cyanobacterial occurrence
- Water temperature
- Total phosphorus concentration
- Thermal stratification

These parameters are assigned to categories and assessed in a matrix which defines the risk of the cyanobacterial growth into five categories, ranging from ‘Very Low’ to ‘Very High’ (Table 2-3). This approach is simplistic, as a range of other variables can lead to intermediate risk. However, it is a useful, semi-quantitative assessment for the estimation of potential risk. It should be noted that this approach is probably more suited to the buoyant bloom-forming cyanobacteria, such as *Microcystis* and *Anabaena* sp and may not apply as well to other cyanobacteria such as *Cylindrospermopsis raciborskii* or *Aphanizomenon* spp.

Table 2-3 Major parameters that influence cyanobacterial growth. This approach can be applied to *Microcystis* and *Anabaena* sp

	Environmental factor			
Potential for Cyanobacterial Growth	History of Cyanobacteria	Water Temperature (^{o}C)	Nutrients Total Phosphorus (μg/L)	Thermal Stratification
Very Low	No	<15	<10	Rare or Never
Low	Yes	<15-20	<10	Infrequent
Moderate	Yes	20-25	10-25	Occasional
High	Yes	>25	25-100	Frequent and persistent
Very High	Yes	>25	>100	Frequent and persistent/strong

The values in this table are a guide only, based on Australian experience, the actual values, particularly those for temperature and phosphorous, will be dependent on site-specific conditions. In addition, in most situations there will be other conditions that contribute to the formation of a cyanobacterial bloom, as mentioned above. A similar assessment of the risk associated with a range of phosphorous levels has been developed based on the South African experience and is given in Table 2-4. In both of these examples a key phosphorous concentration to trigger a high risk of cyanobacteria is 25 μg L^{-1}.

Table 2-4 Examples of chlorophyll-a-based risk categories that have been defined for South African reservoirs

Median Annual TP (μg L^{-1})	Risk level	
	Low-level problems	Blooms
0 - 5	Low	Negligible
5 – 14	Moderate	Low
14 – 25	High	Moderate
25 – 50	High	
50 – 150	Very High - Extreme	
> 150	Extreme - Permanent	

ASSESSING THE POTENTIAL FOR TOXIN PRODUCTION

The risk assessment procedures above describe the susceptibility of a reservoir to cyanobacterial contamination, but do not provide a quantitative measure of the potential cyanobacteria population. An empirical model has been developed to estimate the potential maximum concentrations of cyanobacteria and associated microcystins and saxitoxins as a function of known phosphorous levels. The conditions are based on historical and current water quality data and theoretical calculations based on published values such as:

- Fraction of total phosphorous that is bioavailable
- Conversion factor for phosphorous to chlorophyll-a
- Chlorophyll-a per cell
- Toxin quota per cell

for various cyanobacteria [8, 9, 10].

Within this model three different algal growth scenarios have been developed with the availability of phosphorus as the yield-limiting variable. These are:

Best case*:* assumes that a low proportion of phosphorus is available for cyanobacterial growth (36%) and converted into phytoplankton, and a low fraction of this biomass is cyanobacteria, so problem cyanobacteria do not become dominant and toxin and odour production occur at the lowest potential rates.

Most likely case*:* assumes median values for the availability of phosphorus (60%) and for conversion of phosphorus into cyanobacterial biomass; cyanobacteria do not dominate and there are median rates of toxin production

Worst case*:* assumes that 80% of the phosphorus is bioavailable, that all of this phosphorus is translated into biomass of cyanobacteria, which become dominant, and toxins are produced and released at the maximum reported rates.

An example of the output from this model is given in Table 2-5, for a reservoir with a current total phosphorus concentration of 80 µg L^{-1}. The projected outputs for cell numbers of the cyanobacteria *Microcystis* and associated microcystin, and *Anabaena*, and saxitoxin indicate the range that could be encountered under these conditions and with a decrease or an increase in ambient nutrient levels. It should be noted that these values will be dependent on the type of cyanobacteria and the strain, and will vary considerably with location and conditions. The values for saxitoxin are based on those determined in Australian blooms of *Anabaena*, and will not translate to blooms of *Anabaena* elsewhere. The information in Table 2-5 is for illustrative purposes, the intention should be to undertake similar calculations for a particular water body once sufficient data is available. This information can then provide a simple indication of the challenge to water quality and therefore the treatment process from cyanobacterial contamination for a certain level of nutrients in the source water. Similar calculations can prove very useful once validated for a particular water source and cyanobacterial species.

Comprehensive details on how to calculate a risk assessment are presented in [11].

More sophisticated deterministic water quality models are also available to predict cyanobacterial growth [12, 13]

Table 2-5 Scenarios for the growth of cyanobacteria and production of toxins for different nutrient ambient concentrations in a reservoir using a simple empirical model. Model assumptions for the three cases are described in Level 2

			Predicted concentrations of cyanobacteria and their metabolites						
Reservoir nutrient status	Total Phosphorus (µg L^{-1})	Scenario modelled:	Bioavailable Phosphorus (µg L^{-1})	*Microcystis aeruginosa* (cells mL^{-1})	Microcystin (Total) (µg L^{-1})	*Anabaena circinalis* (cells mL^{-1})	Geosmin (Total) (ng L^{-1})	Geosmin (Dissolved) (ng L^{-1})	Saxitoxin (Total) (µg L^{-1})
Lower nutrient level	40	Best Case	14.4	2,000	0.03	1,000	36	1.8	0.07
		Most Likely Case	24	27,000	1.15	13,000	960	96	0.9
		Worst Case	32	44,000	12.8	44,400	4,800	720	2.9
Current nutrient level	80	Best Case	28.8	4,000	0.06	2,000	72	3.6	0.13
		Most Likely Case	48	53,000	2.3	27,000	1,920	192	1.8
		Worst Case	64	89,000	25.6	88,900	9,600	1,440	5.9
Higher nutrient level	160	Best Case	57.6	8,000	0.12	4,000	144	7.2	0.26
		Most Likely Case	96	107,000	4.6	53,000	3,840	384	3.5
		Worst Case	128	356,000	51.2	177,800	19,200	2,880	11.7

For details about the assumptions and parameters used to derive the information in Table 2-5 click here

An example of a source water risk assessment based on phosphorus limitation can be found here

RESIDUAL RISK

The scenarios described above suggest the potential for the proliferation of cyanobacteria and the production of cyanotoxins in a water source, i.e. the maximum risk in the absence of preventative measures. The following chapters describe processes that can be implemented to mitigate the risk, such as monitoring programs (Chapter 3), source water management (Chapter 4), water treatment (Chapter 5), and incident management planning (Chapter 6).

CHAPTER 2 HAZARD IDENTIFICATION AND RISK ASSESSMENT IN SOURCE WATERS (LEVEL 2)

FACTORS INFLUENCING CYANOBACTERIAL BLOOM OCCURRENCE

PHOSPHOROUS LEVEL ASSESSMENT

The preferred approach to managing water sources is to aim for control of the frequency with which blooms occur. Provided that adequate historical data are available, this may be achieved by identifying the level of phosphorous at which there occurs a marked increase in the incidence, or percentage occurrence, of algal growth at a specified level, e.g. chlorophyll-a levels exceeding 20 µg L^{-1}.

ANALYSIS

It is generally accepted that chlorophyll-a levels persistently in excess of 20 µg L^{-1} pose problems for the treatment of water. As concentrations increase further above this value, problems pertaining to recreational and direct abstraction uses become more relevant. Algal blooms are generically defined as conditions with chlorophyll-a levels > 40 ug L^{-1}.

In general, a total phosphorus level of 10–25 µg L^{-1} presents a moderate risk in terms of the growth of cyanobacteria. For levels of less than 10 µg L^{-1} there is a low risk of cyanobacteria growth, and a level greater than 25 µg L^{-1} provides high growth potential.

By analyzing available data to produce a similar interpretation for any specific reservoir, the phosphorus concentration-based threshold at which problems of a specific magnitude start to occur can be identified. Based on the management requirements, the identified threshold can be compared with the seasonal mean concentrations of phosphorus and targets set for nutrient load reductions (see following section).

In the example shown in Figure 2-1(L2) it can be seen that for levels of chlorophyll-a in excess of 20 µg L^{-1} there is a rapid increase in the percentage occurrence of blooms at a median phosphorus concentration of approximately 25-27 µg L^{-1} total phosphorus, TP; similarly, for chlorophyll-a > 40 µg L^{-1} the breakpoint at which blooms of this magnitude increase in frequency is slightly in excess of 40 µg L^{-1} and for > 60µg L^{-1} chlorophyll-a, the rise starts at a median TP of between 50 and 60 µg L^{-1}. It may be noticed that this concentration lies within the boundary between meso- and eutrophic lake conditions, as defined by various trophic state boundary values e.g.[3].

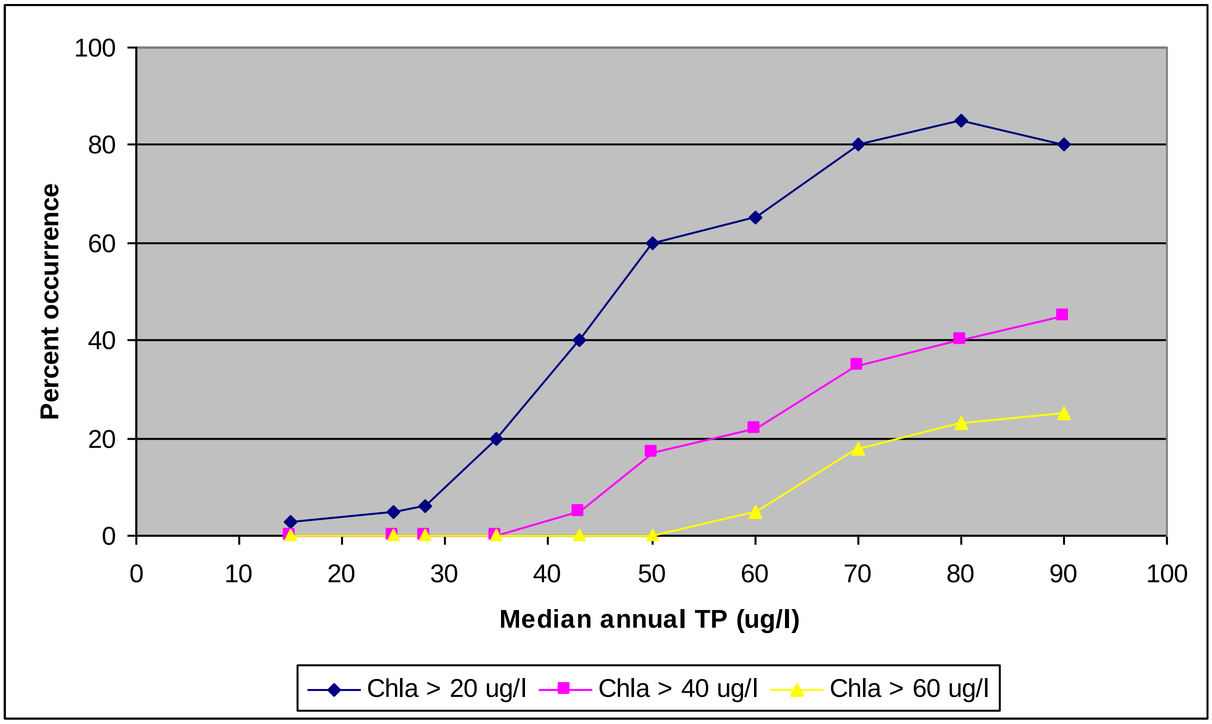

Figure 2-1(L2) Percent occurrence of chlorophyll-a concentrations in excess of specified levels as a function of total phosphorous (example)

By analysing available data to produce a similar interpretation for any specific reservoir, the phosphorus concentration-based threshold at which problems of a specific magnitude start to occur can be identified. Based on the management requirements, the identified threshold can be compared with the seasonal mean concentrations of phosphorus and targets set for nutrient load reductions (see following section).

A large number of South African impoundments are characterized by high ambient levels of phosphorus, with a national median of 55 µg L^{-1} as total phosphorus. This was compared with a combined analysis of the phosphorus:chlorophyll relationships in 40 reservoirs, with the result shown in Figure 2-2(L2).

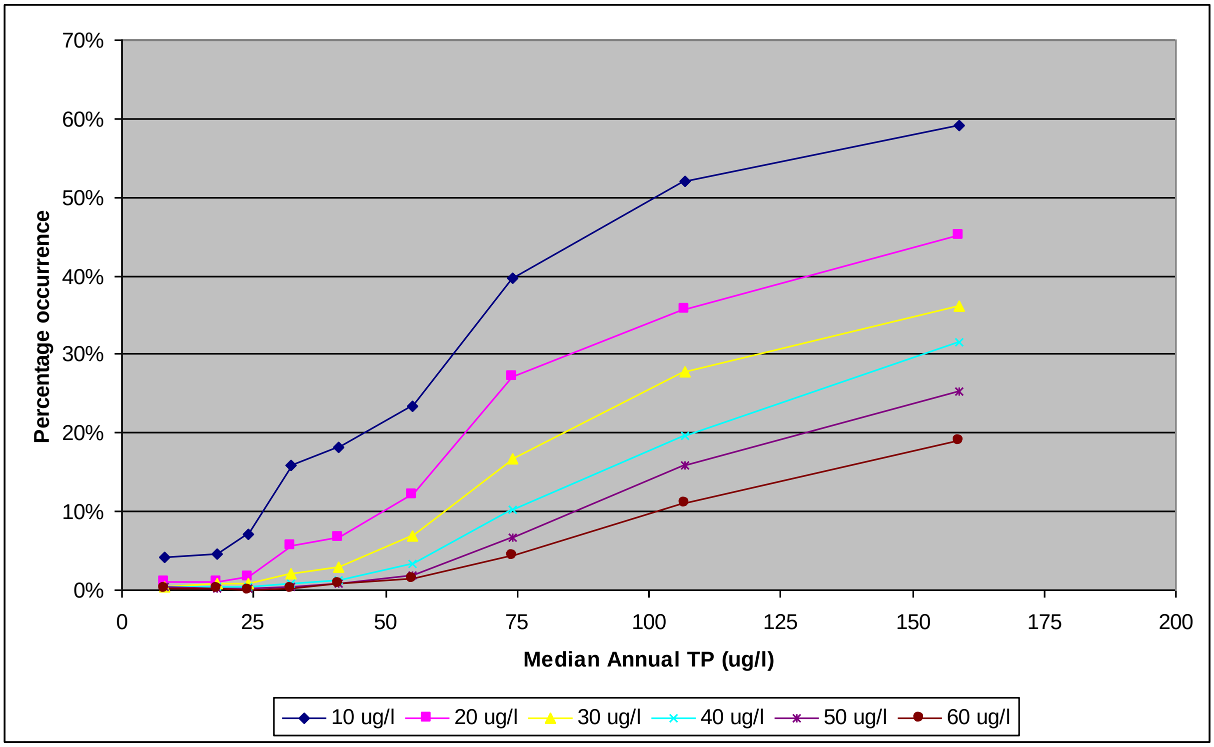

Figure 2-2(L2) Percent occurrence of chlorophyll-a concentrations in excess of specified levels for a set of 40 South African reservoirs.

This analysis reveals that for a median concentration of 55 µg L^{-1} as total phosphorus, problem levels of chlorophyll-a – at the 20 µg L^{-1} threshold - will be experienced 12% of the time (the pink line) and blooms, i.e. chlorophyll-a levels > 40 µg L^{-1}, 5% of the time (the light blue line). This closely reflects the observed situation.

Nutrient-poor reservoirs do not conform to this approach. At the other end of the scale, i.e. high ambient nutrient concentrations, analyses for individual reservoirs reveal a high and persistent level of chlorophyll. For example, Bloemhof Dam (Figure 2-3(L2)) has 50 µg L^{-1} TP as the lower limit of the range of phosphorus concentrations experienced. Under such conditions it can be anticipated that sustained and problematical levels of algal development will be encountered, and the analysis confirms this. In the case of Bloemhof Dam chlorophyll-a levels in excess of 20 µg L^{-1} are encountered 50% of the time, and blooms start to increase in frequency from a concentration of 70 µg L^{-1}. As the median TP for Bloemhof Dam is 86 µg L^{-1} it is clear that the dam will be problematical for much of the year.

A similar situation exists for another dam (Figure 2-4(L2)), with a marked across-the-board increase in chlorophyll-a occurring at a TP level of 60 µg L^{-1}. As there are no “low” TP levels, the precise breakpoints cannot be determined but are likely to lie at the 25 µg L^{-1} TP.

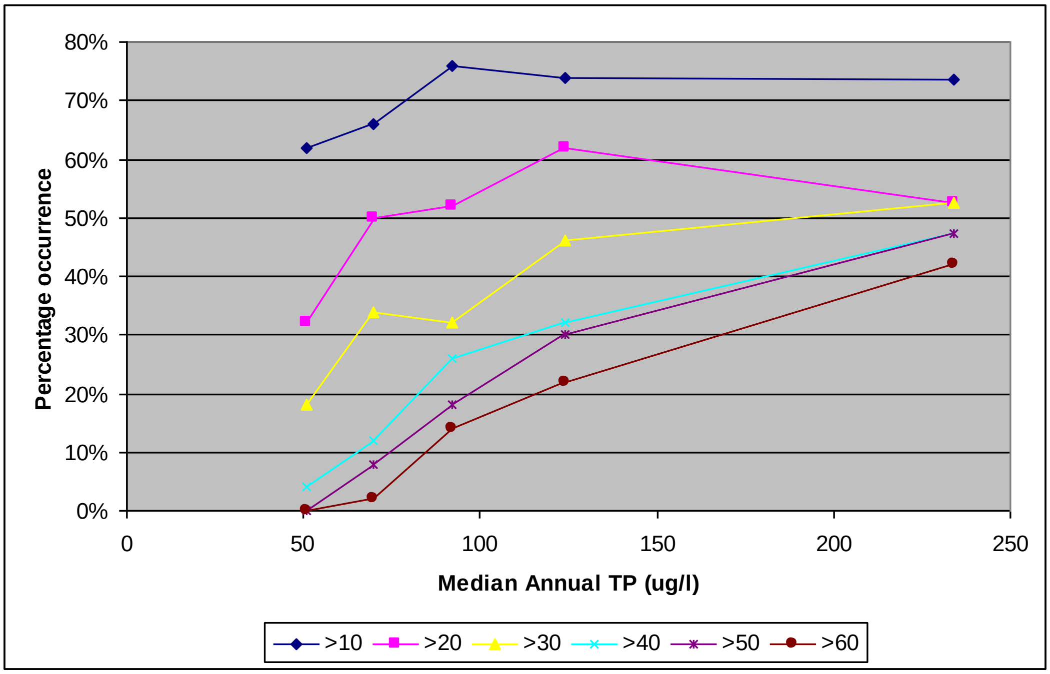

Figure 2-3(L2) Percent occurrence of chlorophyll-a concentrations in excess of specified levels in Bloemhof Dam

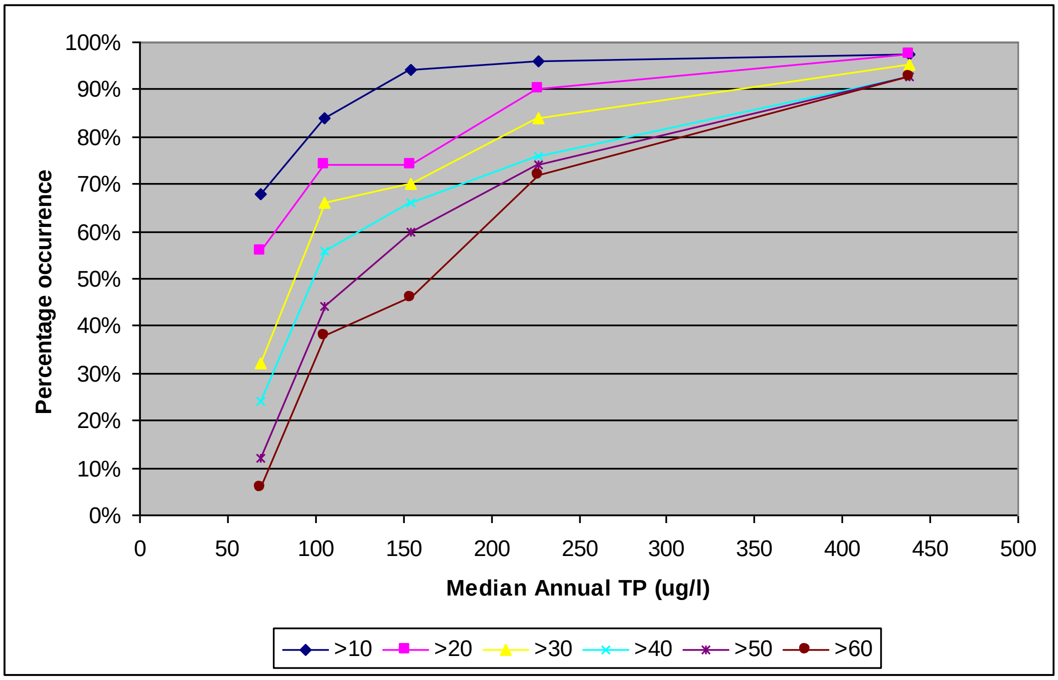

Figure 2-4(L2) Percent occurrence of chlorophyll-a concentrations in excess of specified levels in Bon Accord Dam.

Based on this analysis, the following chlorophyll-a-based risk categories can be provisionally defined for South African reservoirs as follows:

Median Annual TP (µg L^{-1})	**Risk level**	
	Low-level problems	Blooms
0 - 5	Low	Negligible
5 – 14	Moderate	Low
14 – 25	High	Moderate
25 – 50	High	
50 – 150	Very High - Extreme	
> 150	Extreme - Permanent	

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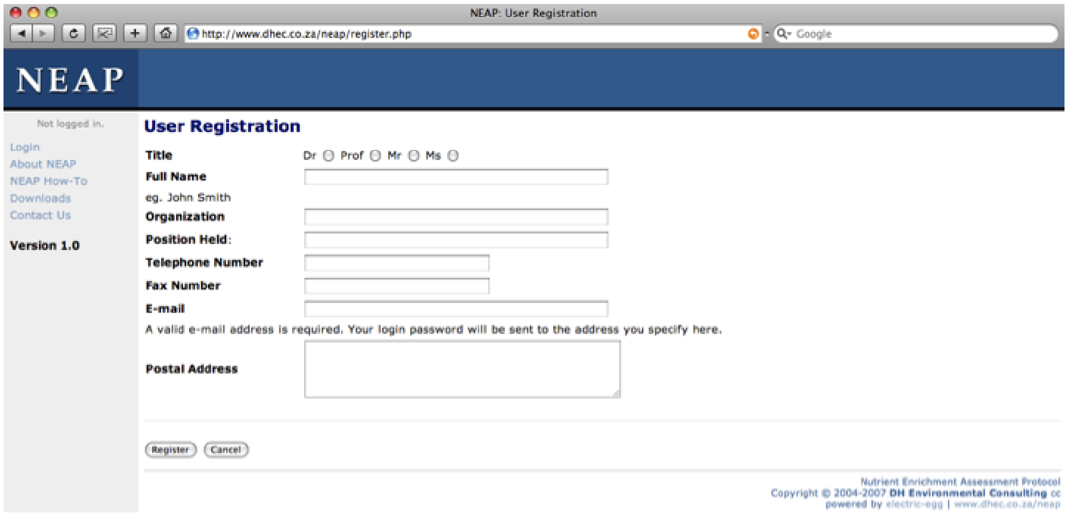
NUTRIENT LOADING ASSESSMENT

Various options are available for undertaking basic assessments of the nutrient loading status and associated trophic state in a lake or reservoir. These range from simple application of Vollenweider-type relationships [2], to software packages that integrate nutrient loading and reservoir hydromorphology. An example of the latter is the NEAP V1.0 internet-based package developed for South Africa

(http://www.dhec.co.za/neap/login.php).

WHAT IS NEAP?

NEAP is an internet-based phosphorus based nutrient loading tool for lakes and/or reservoirs which, depending on the level of information entered, allows the user to select one or more outputs that describe, for example, the P-loading generated by the catchment, the trophic condition of the lake, and the lake's likely response to a change in phosphorus loading. NEAP is based on a range of existing phosphorus load-response relationships. By using available information, NEAP V1.0 has been calibrated for use under South African conditions, and in particular for use in reservoirs. It is a relatively simple process to adjust or re-calibrate the model for use in any particular country or region, or indeed for a particular waterbody. In many cases site-specificity overrides regional or national genericity – requiring that a site-specific calibration be used for an individual reservoir.



User Registration

Title Dr ○ Prof ○ Mr ○ Ms ○
Full Name
eg. John Smith
Organization
Position Held:
Telephone Number
Fax Number
E-mail
A valid e-mail address is required. Your login password will be sent to the address you specify here.
Postal Address

Nutrient Enrichment Assessment Protocol
Copyright © 2004-2007 **DH Environmental Consulting** cc
powered by electric-egg | www.dhec.co.za/neap

THE NEAP DEVELOPMENT PHILOSOPHY

NEAP has been purposefully designed as a simple, phosphorus-based, eutrophication screening tool. As such, it provides a means, which is not data intensive, of determining the degree of nutrient enrichment, or trophic status, of the water body. Once calibrated, it allows the user to determine the manner in which the annual mean concentration of phosphorus is likely to change in response to an increase or decrease in the loading of this element. Such determinations can be made with NEAP at a high (70%) level of confidence.

In most cases, the calibration of dynamic models is severely limited by the availability and/or quality of data. Increasing model complexity also often renders the model lake-specific. The purpose of a screening tool, such as NEAP, is to provide management-related answers without having to resort to an extended period of data collection. The underlying philosophy of NEAP has been to provide a fast and simple to use approximation of the level of eutrophication in a particular reservoir, and to inform options for management. Should more detailed examinations be required, more complex models can be employed as the data become available.

It is intended that subsequent releases of NEAP will incorporate a level of functionality that will support the integration of biogeochemical processes (fate and loss relationships), as well as refinements such as the inclusion of aquaculture impacts. Importantly, later versions will be able to include support for assessing 'virtual' nutrient load reductions relating to management approaches targeting 'top-down' foodweb manipulation.

WHAT IS NEAP'S LEVEL OF RESOLUTION?

NEAP is a First Level tool, with its central value in its simplicity. NEAP is an annual time-step (dT = 1 year) model, i.e. it requires the minimum level of data for all parameters. Notwithstanding this, the model is robust and allows for relatively rapid screening and classification of individual systems, as well as providing indications of how each assessed waterbody will respond to a change in phosphorus loading.

Once NEAP has been used to classify and rank systems, more sophisticated predictive tools, requiring monthly, weekly or daily data for a wide range of parameters may be employed. Decisions to rehabilitate a lake or reservoir should not be made on the basis of NEAP alone, nor should higher level predictive modelling necessarily have to follow the use of NEAP. For this reason, a risk assessment component has been integrated into NEAP, providing an indication of the confidence with which the final output is made.

It should be noted that estimates of catchment nutrient loading can contain errors as high as 50% - therefore accuracy requires a comprehensive assessment process.

INTRODUCTION TO THE MODEL BASE OF NEAP

NEAP is a single layer, single variable (total phosphorus) empirical model that incorporates simple allowances for aspects that are essentially features of multi-layer models, for example the very important need to include sediment loading sub-models.

Several single layer, single variable models have been developed to study the behaviour of phosphorus in different reservoirs. Internationally, the Vollenweider General Lake Model relationship provides the best generic starting point for modelling phosphorus in lakes [2]. Previously, work conducted on a limited number of South and southern-African reservoirs showed that the OECD-type models [3] provided the closest relationship between predicted and observed conditions [14]. This study, which examined 12 models, confirmed that the OECD relationship for phosphorus loading provided a generic fit for South African conditions. However, a predominant characteristic of South African impoundments and shallow lake/vlei environments is a high rate of water exchange (low hydraulic retention times). A more detailed comparison of these models on specific reservoirs indicated that the use of the Walker Reservoir Model [15], a relationship derived for systems with high flushing rates, was more appropriate. Both models have been incorporated and NEAP makes the appropriate selection based on the lake flushing rate determined from the hydrological information that is entered.

NEAP is an annual, single time-step model, i.e. it produces outputs based on annual total or mean values for each parameter.

Models used in NEAP, compared with the Vollenweider General Lake Model:

1. *Vollenweider General Lake Model*
   $P = L_p / q_s (1 + T_w^{0.5})$
2. *OECD (Combined Data Set)*
   $P = 1.55([P\}_j / (1+ \sqrt{T_w}))^{0.82}$
3. *Walker Reservoir Model*
   $P = L*T_w (1-R) / z$
   $R = 1 + [1-(1 + 4Nr)^{0.5}] / 2Nr$
   $Nr = (K_2*L*T_w^2)/z$
   $K_2 = 0.17q_s / (q_s + 13.3)$
   Where: P = average in-lake total phosphorus (mg L^{-1})
   $[P]_j$ = annual mean inflow of phosphorus (mg m^{-3})
   L_p = annual total phosphorus areal loading (mg m^{-2} y^{-1})
   q_s = annual areal water loading rate (m y^{-1})

T_w = hydraulic retention time, years
z = mean depth, m

FEATURES OF NEAP

NEAP V1.0 is a modular, web-based tool incorporating the following components:

- A user login and registration module;
- An "About NEAP" section that describes what NEAP can be used for;
- A "How-to" section that provides a step-by-step explanation, supported by worked examples, of how NEAP can be used, and which allows the user to download a checklist of requirements that can be completed, and the correct units established, prior to entering data into NEAP;
- Six calculation modules that allow the user to determine one or more of the following:
- An estimation of the total phosphorus load back-calculated from the observed in-lake condition;
- A phosphorus-loading module that allows for the aggregation of phosphorus loads from multiple sources, and which outputs a predicted in-lake mean annual phosphorus concentration. This module includes allowance for internal loads from sediments to be added;
- A chlorophyll-a prediction module – generating an annual mean and peak concentration for chlorophyll-a based on the calculated in-lake phosphorus concentration;
- A trophic state prediction module, with output in two formats;
- A load-reduction module that outputs the change in condition in response to a selected reduction in phosphorus loading;
- A risk assessment, based on the concentration at which problematical levels of bloom development (expressed as chlorophyll-a) are likely to be encountered.
- A user feedback section that allows the user to post queries to the NEAP developers, or to request assistance or advice for a particular problem.

USER UNDERSTANDING OF EUTROPHICATION

It is extremely important that the NEAP user has a reasonable working understanding of what eutrophication is – i.e. that eutrophication is not simply a function of phosphorus loads and concentrations – and that a wide variety of biophysical and chemical factors can enhance or constrain the observed level of eutrophication in a particular waterbody. It is as important for the water resource manager to be able to determine whether or not a particular resource is eutrophic as it is to determine the likelihood of it becoming so, or where it lies on a trend towards an impaired trophic state.

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ASSESSING THE POTENTIAL FOR TOXIN PRODUCTION

ASSUMPTIONS USED IN THE CYANOTOXIN PRODUCTION RISK ASSESSMENT MODEL

Table 2-1(L2) Assumptions and variables used in the simple cyanobacterial risk assessment model to derive growth and toxin production by cyanobacteria based upon phosphorus supply in reservoirs.

	Variables used in each Scenario Category		
Variable inputs and assumptions used for the risk assessment scenario model for calculation of cyanobacterial biomass, toxin and odour production	**Best Case**	**Most Likely Case**	**Worst Case**
Proportion of Total Phosphorus (TP) pool in the reservoir that is bioavailable	0.36	0.6	0.8
Proportion of the bioavailable P that is converted to Chl-a	0.5	0.8	1.0
Proportion of Chl-a that is either *Anabaena* or *Microcystis*	0.1	0.5	1.0
The Chl-a content of *Anabaena circinalis* (pg/cell) [8]	0.72	0.72	0.72
The Chl-a content of *Microcystis aeruginosa* (pg/cell) [8]	0.36	0.36	0.36
The production of saxitoxins by *Anabaena*	0.33	0.33	0.33
The ratio of microcystin to *Microcystis* Chl-a	0.04	0.12	0.4

The model calculates chlorophyll yield from available phosphorus concentration which can be modified depending upon the scenario selected. Chlorophyll-a is then translated to cell numbers of *Microcystis* or *Anabaena* using published cell chlorophyll quotas. Cellular content or ‘cell quota’ ranges for geosmin, saxitoxin and microcystin are applied to estimate the likely yield of the cyanobacterial metabolites under the chosen scenarios.

The assumptions and calculations used with the simple cyanobacterial risk assessment model and their justification are as follows:

1) Two general starting assumptions apply for this model:

   - that the climatic conditions are favourable for cyanobacterial growth and therefore the eventual population size is determined by the carrying capacity of the reservoir.
   - that all other conditions for optimum growth are met and the phosphorus concentration is the limiting factor that will determine the eventual algal and cyanobacterial biomass.

2) Phosphorus concentrations: The level of total phosphorus (TP) in the example here (i.e. 80 µg L^{-1} TP) was derived from the average spring/summer concentrations in an actual drinking water reservoir. For the scenario purposes the projected lower and upper levels were selected arbitrarily as half and double this concentration. If historical data is available for your reservoir then it is possible to select equivalent values for the model calculations.

3) Phosphorus availability: The proportion of total phosphorus (TP) that is bioavailable for uptake and utilisation by organisms will vary between water bodies and an empirical range is used here. The values selected here are: 0.36 for best case; 0.6 for most likely case; 0.8 for the worst case.

4) Incorporation of bioavailable P into algal biomass: The proportion of bioavailable P that is converted to chlorophyll-a is assumed to be in the range of 0.5 - 1 (i.e. 50-100%). The assumption is that some bioavailable P will be taken up by other organisms, but most bioavailable P is taken up by phytoplankton and directly translated into chlorophyll-a.

5) The proportion of chlorophyll-a that is attributable to either *Anabaena* or *Microcystis* depends upon the degree of dominance achieved by the cyanobacteria and a range of 0.1 – 1 (10%-100%) is used here. Major blooms of cyanobacteria can form practically monospecific populations and the 'worst case' scenario assumes that 100% of the chlorophyll-a is *Anabaena* or *Microcystis* accordingly. The 'most likely case' assumes a value of 50%. Reflecting the fact that minor blooms of cyanobacteria may account for less than half of the chlorophyll-a in the reservoir, the 'best case' assumes that 10% of chlorophyll-a is *Anabaena* or *Microcystis.*

6) The assumed chlorophyll-a content of *Anabaena circinalis* is 0.72 pg cell^{-1} and 0.36 pg cell^{-1} for *Microcystis aeruginosa.* These values are based on values published by Reynolds (1984). This is used to determine the number of cells mL^{-1} from the Chl-a concentration.

7) The ratio of microcystin to *Microcystis* chlorophyll-a is derived from the published data and depends upon the strain and environmental conditions. The 'worst case' scenario assumes a ratio of microcystin to *Microcystis* chlorophyll-a of 0.4, which is the maximum of the range published by Chorus and Bartram [10]. This is reduced to 0.12 for the 'most likely case' and 0.04 for the 'best case' scenario (the mean of the range published by Chorus and Bartram, 1999).

8) The production of saxitoxins by *Anabaena* can then be determined from the number of cells mL^{-1} using the estimated saxitoxin yield of 0.33 µg L^{-1} for *Anabaena* cell density of 5,000 cells mL^{-1} (Humpage & Falconer, unpublished). Cell quotas for toxin production will be variable within and between natural populations and over time and other cell quotas can be used where they are available.

The output from this simple model should be considered in the light of a number of factors that will modify and reduce the risk from toxins. For example:

- The cyanobacteria present may not necessarily produce toxins, even if they are known toxigenic species.
- Management strategies are available in the reservoirs to reduce the growth or impact of the cyanobacterial population (e.g. variable off take height, algicide use, destratification)
- A range of variables associated with local conditions including water chemistry and weather patterns may make the conditions unsuitable for cyanobacterial growth.

Back to level 1

POTENTIAL ALGAL GROWTH SCENARIOS FOR HUMBUG SCRUB RESERVOIR

INTRODUCTION

Although significant numbers of toxic cyanobacteria have not occurred historically, there are some records of two potentially toxic species (*Microcystis aeruginosa* and *Anabaena circinalis*) in Humbug Scrub Reservoir. Recently there has been an increase in the occurrence of small picoplanktonic cyanobacteria, such as *Aphanothece* in the reservoir. This may reflect improvements in taxonomic processes, or may be due to real increases in the diversity and numbers of these types of cyanobacteria. Both the potentially toxic and picoplanktonic cyanobacteria may present a challenge to the Humbug Scrub water treatment plant. The treatment plant is not able to completely remove algal metabolites such as odours and toxins if a bloom were to occur and may suffer from reduced filter performance if significant picoplanktonic cyanobacteria are present.

PROCESS

To address the future risk to water quality and potential challenges to the treatment plant, historical and current water quality data, including physical, chemical and cyanobacterial data were assessed against the current Australian Drinking Water Guidelines (2004)16 and the New South Wales (NSW) Department of Land and Water Conservation Algal Contingency Plan (2000) [17].

A frequency analysis of excursions above guidelines and industry-recognised alert levels (see Chapter 6 for examples of alert levels) was carried out to determine their potential impact on water quality, in particular, the growth of potentially toxic cyanobacteria. This data was used to develop three predicted scenarios. These scenarios can be defined as "likely", "reasonable worst case" and "worst case". They indicate potential outcomes for the growth of the problematic cyanobacterial species *Microcystis aeruginosa* (potentially hepatotoxic) and *Anabaena circinalis* (potentially toxic and odorous) given different defined combinations of conditions. The picoplanktonic cyanobacterium *Aphanothece* has also been included as a representative of this class of cyanobacteria which are small in size but are occurring more frequently in the reservoir.

The scenarios were developed for two sites in the reservoir. The two sites were chosen to represent an ‘open water’ offtake site and an upstream, shallow ‘arm’ site. The sites were considered separately to determine whether the shallow arm sites would have the potential to support higher concentrations of cyanobacteria, toxins or odours which may be transported to the open water offtake sites.

The initial conditions for the scenarios employ historical and current water quality data (ie nutrient concentrations, temperature profiles and cyanobacteria numbers) from Humbug Scrub Reservoir and are built upon projections for meteorological conditions that favour algal growth, combined with scenarios for increased nutrient concentrations.

The projections are arbitrary calculations based upon:
Favourable meteorological conditions for growth

and

Either static or two circumstances leading to increased concentrations of either available and/or total phosphorus

Favourable meteorological conditions are defined as air temperatures greater than 30°C with low wind speeds persisting for a period of weeks. These conditions are generally the result of a stable high-pressure system. These meteorological conditions result in a stable water column with elevated temperature, low turbulence and the development of thermal stratification. Stable air temperatures have been used in the scenarios in this case as these conditions are most likely to give rise to thermal stratification. Many studies have shown that thermal stratification is one of the main factors in supporting cyanobacterial blooms. Small fluctuations in air temperature would not generally allow for complete 'overturn' of the reservoir, especially if stratification was persistent and therefore temperature fluctuations have not been considered in the following scenarios.

DERIVATION OF SCENARIOS

In order for a substantial blue-green algal (cyanobacterial) population to develop, the appropriate physical and climatic conditions must occur. This is a combination of an extended period of low wind, above average air temperatures and adequate solar radiation input. If these conditions persist for long enough, usually for more than 10 to 14 days, the risk of a problematic cyanobacterial bloom is high. The magnitude of the risk will then be determined by the period of time that the conditions persist, the carrying capacity of the reservoir and the types and effectiveness of management operations implemented. The carrying capacity of the reservoir is the total algal biomass that the physico-chemical conditions in the reservoir will support. The factors that are considered to be limiting to the growth of phytoplankton, and therefore cyanobacteria, are the availability of light, phosphorus (P) and nitrogen (N). As turbidity levels are relatively low in Humbug Scrub, it is unlikely that light will be limiting. Nutrient monitoring in Humbug Scrub reservoir shows that the soluble N: soluble P ratio is greater than the Redfield ratio (7:1 by mass). Given this, it is likely that phosphorus will be the limiting nutrient in the reservoir and this assumption underlies the calculations to determine the cyanobacteria carrying capacity of the reservoir.

Theoretical calculations to determine the final algal population biomass in the reservoir based on nutrient levels employ variables that are based upon selected published empirical variables. The variables and assumptions required are:

- That certain proportions of bio-available P will be converted into chlorophyll-a*,* and,
- Assuming that conditions are then appropriate for cyanobacterial growth, a proportion of the chlorophyll-a can be attributed to certain problem species of cyanobacteria.

Published values for chlorophyll-a per cell of *Anabaena circinalis* and *Microcystis aeruginosa* used in this assessment were 0.72 and 0.36 pg cell^{-1} respectively [8]. Therefore for a given chlorophyll-a concentration, the maximum cell concentration for either species can be determined. Concentrations of taste and odour compounds and toxins per cell or per unit chlorophyll-are also published. Bowmer *et al.* [18] report a geosmin:chlorophyll-a ratio of between 59 and 360 ng μg^{-1} at 70 and 17 $\mu mol\ m^{2}\ s^{-1}$ photosynthetically active radiation (PAR). Phytoplankton may experience light intensities, fluctuating at the scale of minutes to hours, from 0 to 1800 $\mu mol\ m^{2}\ s^{-1}$ PAR. Therefore these light intensities represent a small part of the range experienced within an illuminated water column, and are not strictly applicable to Humbug Scrub Reservoir. However, the relationship between geosmin and chlorophyll is stronger than geosmin and cell dry weight and is therefore more suitable. Chorus and Bartram [10] report a mean microcystin:chlorophyll-a ratio of 0.12 $\mu g\ \mu g^{-1}$. These relationships can be used to estimate the maximum geosmin concentration or microcystin concentration given a certain chlorophyll yield in the reservoir.

RESULTS

HUMBUG SCRUB RESERVOIR –SITE A

CALCULATIONS

The calculations for these scenarios can be found in Table 2-2(L2) - Table 2-4(L2).

MOST LIKELY CASE

The likely scenario is derived based upon variations to drivers to the current reservoir conditions. This would be the case if the reservoir has reached a state of equilibrium so that there are no significant changes to source water quality over an extended period.

The calculations indicate that, based upon the current phosphorus concentrations at site A, theoretical populations of either *Anabaena circinalis* or *Microcystis aeruginosa* may occur at cell densities of approximately 1,820 and 3,640 cells mL^{-1}, respectively. These cell concentrations would result in a medium alert level situation and geosmin (odour) and microcystin (toxin) concentrations of approximately 13 ng L^{-1} and 0.16 $\mu g\ L^{-1}$, respectively. While the microcystin concentration is below the Australian Drinking Water Guideline for microcystin, the geosmin concentration is sufficient to potentially cause customer complaints.

The picoplanktonic cyanobacterium *Aphanothece* could theoretically reach a cell concentration of approximately 100,000 cells mL^{-1} under this scenario. Using a biovolume conversion this would result in an Alert Level 1 status using the draft national protocol for monitoring cyanobacteria in Australian surface freshwaters, Alert Levels Framework. If cell concentrations are used a high algal alert level situation would occur using the NSW DLWC Algal Contingency Plan in the reservoir.

REASONABLE WORST CASE

The reasonable worst case scenario considers the situation where there is an increase in the proportion of the current total phosphorus concentration that is bio-available. This may occur due to the distribution of different "species" or types of phosphorus. This may be caused by changes in microbial activity associated with altered physico-chemical environment, which in turn affects the mobilisation of phosphorus in the reservoir.

The calculations for this scenario predict that under these conditions, populations of approximately 6,000 and 12,000 cells mL^{-1} of *Anabaena circinalis* or *Microcystis aeruginosa* may occur, respectively. These cell concentrations would result in a medium alert level situation and geosmin and microcystin concentrations of approximately 43 ng L^{-1} and 0.52 μg L^{-1}, respectively. This geosmin concentration would cause widespread complaints if not removed by the treatment process, however the microcystin concentration remains below the drinking water guideline for microcystin (1.3 μg L^{-1}).

WORST CASE

This scenario considers the situation where the internal and external loads to the reservoir become almost entirely available, the problem species became completely dominant and the odour compound or toxin were produced at their maximum reported rates. For this scenario to develop the absolute total phosphorus concentration would be likely to increase to, or above, 100 μg L^{-1}. In this 'worst-case scenario' high geosmin and microcystin concentrations would occur if there was a bloom of the appropriate species. This extreme worst case is very unlikely to occur in the short term, and would require significant decline in the source water quality over a period of time.

HUMBUG SCRUB RESERVOIR –SITE B

CALCULATIONS

The calculations for these scenarios can be found in Table 2-5(L2) - Table 2-7(L2).

MOST LIKELY CASE

The calculations indicate that, based upon the current phosphorus concentrations at site B, theoretical populations of either *Anabaena circinalis* or *Microcystis aeruginosa* may occur at cell densities of approximately 2,100 and 4,100 cells mL^{-1}, respectively. These cell concentrations would result in a medium alert level situation and geosmin (odour) and microcystin (toxin) concentrations of approximately 15 ng L^{-1} and 0.18 μg L^{-1}, respectively. While the microcystin concentration is below the Australian Drinking Water Guideline for microcystin, the geosmin concentration is sufficient to potentially cause customer complaints.

REASONABLE WORST CASE

The calculations for this scenario predict that under these conditions, populations of approximately 13,000 and 25,000 cells mL^{-1} of *Anabaena circinalis* or *Microcystis aeruginosa* may occur, respectively. These cell concentrations would result in a medium alert level situation for *Anabaena circinalis* and a high alert level status for *Microcystis aeruginosa* and geosmin and microcystin concentrations of approximately 91 ng L^{-1} and 1.1 μg L^{-1}, respectively. This geosmin concentration would cause widespread complaints if not removed by the treatment process and the microcystin concentration is approximating the drinking water guideline for microcystin (1.34 μg L^{-1}), and would require health risk assessment and appropriate water treatment for toxin removal.

WORST CASE

The worst case scenario for Site B is similar to site A

CONCLUSIONS

These scenarios indicate that Humbug Scrub Reservoir could develop taste and odour problems associated with cyanobacterial growth without any deterioration in source water quality, provided the seed source for problem cyanobacteria were available and could reach their potential under favourable meteorological conditions, or there was an increase in internal nutrient load - i.e. for the "likely" case. It is not possible to estimate or speculate upon the introduction or occurrence of the problematic cyanobacterial species in the reservoir, however these species have been recorded in the past. It must also be added that the exact nature of the physico-chemical environment that favours one type of algae or cyanobacteria over another is not entirely understood. These issues relate to subtle factors such as, for example, trace element chemistry, and microbial or grazing interactions.

The "likely" scenario which can be considered quite possible given the current reservoir conditions, could result in a medium alert level/Alert Level 1 situation. The reasonable worst case scenario can be considered to be an infrequent event (1 in 5-10 years), however as it could result in an high alert level status (Alert Level 2) there would be considerable risk associated with this scenario.

It is apparent that under certain circumstances, in the analysis of the scenarios for each site in the reservoirs, that the upstream, arm sites are more likely to support a significant cyanobacterial bloom, which could lead to significant taste, odour or toxin production. An example of this is evident in the reasonable worst case scenario for Humbug Scrub Reservoir. In this situation the predicted levels of both *Microcystis aeruginosa* and *Anabaena circinalis* are approximately twice as high at site B compared to the levels at site A. The corresponding geosmin and microcystin levels are also two-fold higher at the upstream sites.

The algal growth scenarios also show that the reservoir can support high concentrations of picoplanktonic cyanobacteria such as *Aphanothece*. The likely scenario shows that blooms could develop which contain numbers of around 100,000 cells mL^{-1} to 200,000 cells mL^{-1} of *Aphanothece*. This corresponds to around the Alert Level 1 category of the Alert Levels Framework for freshwater algae in drinking water (see Chapter 6).

RISK REDUCTION

To assess risk reduction it is necessary to first identify the factors that affect the consequence and frequency ratings of the hazard.

CONSEQUENCE

The factors that may influence the consequence of an event include,

- Whether the cyanobacterium that occurs is toxic and/or odorous
- Is the monitoring frequency sufficient to detect the cyanobacteria to allow a management response?
- What management strategies and options are available when an alert level event occurs?

In consideration of the factors which influence the consequence of an event, a number of points should be documented.

- There is no possibility for control over the toxicity of taste and odour compounds produced.
- We would expect to exceed the detection or low alert level/Alert Level 1 threshold if the monitoring program in place is adequate. This means that during normal circumstances, even when monitoring is adequate, a low alert level status may persist in the reservoir.
- The 'in reservoir' management strategies that may be applied are destratification, variable offtake height and algicide use. These management options will vary in their feasibility and effectiveness for Humbug Scrub Reservoir. For the use of algicides there are the operational, legislative (permits or registration) and environmental issues associated with their use. These have not been addressed in the past, although they are not insurmountable as an option.

FREQUENCY

The factors that may affect the frequency rating include,

- Weather patterns associated with the El Niño Southern Oscillation
- In reservoir management strategies such as destratification and algicide application.

In consideration of the factors which influence the frequency of an event, a number of points should be documented.

While the weather patterns associated with the El Nino cannot be controlled, it may be predictable and accounted for in the management of monitoring programs.

Table 2-2(L2) Calculation Table for "Likely" Scenario in Humbug Scrub Reservoir, site A

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of *Aphanothece* is: (pg/cell)
Value:	Yes	**0.364**	**0.8**	**0.5**	**0.5**	0.72	0.36	100	0.1	0.12	**0.41**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Mean of published range (Bowmer *et al.* 1992)	Mean of published range (Bowmer *et al.* 1992)	Mean of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Value found in Laboratory Cultures (Hobson Pers Com)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	This value is calculated from Humbug Scrub historical data.	Most bio-available P is taken up by phytoplankton	Minor blooms of cyanobacteria may account for less than half the Chl-a	Minor blooms of cyanobacteria may account for less than half the Chl-a			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Mean of calculated proportion of chlorophyll-attributable to small cyano's in Humbug Scrub	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
	50	18.20	14.56	7.28	7.28	10,111	20,222	728.00	72.80	0.87	5.97	596,960
	20	7.28	5.82	2.91	2.91	4,044	8,089	291.20	29.12	0.35	2.39	238,784
Current Level	9	3.28	2.62	1.31	1.31	1,820	3,640	131.04	13.10	0.16	1.07	107,453
	5	1.82	1.46	0.73	0.73	1,011	2,022	72.80	7.28	0.09	0.60	59,696
	2	0.73	0.58	0.29	0.29	404	809	29.12	2.91	0.03	0.24	23,878

Table 2-3(L2) Calculation Table for "Reasonable Worst Case" Scenario in Humbug Scrub Reservoir, site A

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of *Aphanothece* is: (pg/cell)
Value:	Yes	**0.6**	**1**	**0.8**	**0.8**	0.72	0.36	100	0.1	0.12	**1**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	Higher proportions of TP are bioavailable in more eutrophic conditions	Most bio-available P is taken up by phytoplankton	Major blooms of cyanobacteria can form practically monospecific dominance	Major blooms of cyanobacteria can form practically monospecific dominance			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Maximum of calculated proportion of chlorophyll-attributable to small cyano's in Humbug Scrub	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
Increase	50	30.00	30.00	24.00	24.00	33,333	66,667	2400.00	240.00	2.88	30.00	3,000,000
	20	12.00	12.00	9.60	9.60	13,333	26,667	960.00	96.00	1.15	12.00	1,200,000
Current Level	9	5.40	5.40	4.32	4.32	6,000	12,000	432.00	43.20	0.52	5.40	540,000
	5	3.00	3.00	2.40	2.40	3,333	6,667	240.00	24.00	0.29	3.00	300,000
Decrease	2	1.20	1.20	0.96	0.96	1,333	2,667	96.00	9.60	0.12	1.20	120,000

Table 2-4(L2) Calculation Table for "Worst Case" Scenario in Humbug Scrub Reservoir, site A

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of *Aphanothece* is: (pg/cell)
Value:	Yes	**0.8**	**1**	**1**	**1**	0.72	0.36	360	0.4	1	**0.8**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	Higher proportions of TP are bioavailable in more eutrophic conditions	Most bio-available P is taken up by phytoplankton	Major blooms of cyanobacteria can form practically monospecific dominance	Major blooms of cyanobacteria can form practically monospecific dominance			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Minor blooms of cyanobacteria may account for less than half the Chl-a	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
Increase	50	40.00	40.00	40.00	40.00	55,556	111,111	14400.00	5760.00	40.00	32.00	3,200,000
	20	16.00	16.00	16.00	16.00	22,222	44,444	5760.00	2304.00	16.00	12.80	1,280,000
Current Level	9	7.20	7.20	7.20	7.20	10,000	20,000	2592.00	1036.80	7.20	5.76	576,000
	5	4.00	4.00	4.00	4.00	5,556	11,111	1440.00	576.00	4.00	3.20	320,000
Decrease	2	1.60	1.60	1.60	1.60	2,222	4,444	576.00	230.40	1.60	1.28	128,000

Table 2-5(L2) Calculation Table for "Likely" Scenario in Humbug Scrub Reservoir, site B

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of Aphanothece is: (pg/cell)
Value:	Yes	**0.13**	**0.8**	**0.5**	**0.5**	0.72	0.36	100	0.1	0.12	**0.41**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Mean of published range (Bowmer *et al.* 1992)	Mean of published range (Bowmer *et al.* 1992)	Mean of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Value found in Laboratory Cultures (Hobson Pers Com)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	This value is calculated from Humbug Scrub historical data.	Most bio-available P is taken up by phytoplankton	Minor blooms of cyanobacteria may account for less than half the Chl-a	Minor blooms of cyanobacteria may account for less than half the Chl-a			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Mean of calculated proportion of chlorophyll-attributable to small cyano's in Humbug Scrub	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
	100	13.00	10.40	5.20	5.20	7,222	14,444	520.00	52.00	0.62	4.26	426,400
	50	6.50	5.20	2.60	2.60	3,611	7,222	260.00	26.00	0.31	2.13	213,200
Current Level	28.6	3.72	2.97	1.49	1.49	2,066	4,131	148.72	14.87	0.18	1.22	121,950
	15	1.95	1.56	0.78	0.78	1,083	2,167	78.00	7.80	0.09	0.64	63,960
	10	1.30	1.04	0.52	0.52	722	1,444	52.00	5.20	0.06	0.43	42,640

Table 2-6(L2) Calculation Table for "Reasonable Worst Case" Scenario in Humbug Scrub Reservoir, site B

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of *Aphanothece* is: (pg/cell)
Value:	Yes	**0.4**	**1**	**0.8**	**0.8**	0.72	0.36	100	0.1	0.12	**1**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	Higher proportions of TP are bioavailable in more eutrophic conditions	Most bio-available P is taken up by phytoplankton	Major blooms of cyanobacteria can form practically monospecific dominance	Major blooms of cyanobacteria can form practically monospecific dominance			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Maximum of calculated proportion of chlorophyll-attributable to small cyano's in Humbug Scrub	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
Increase	100	40.00	40.00	32.00	32.00	44,444	88,889	3200.00	320.00	3.84	40.00	4,000,000
	50	20.00	20.00	16.00	16.00	22,222	44,444	1600.00	160.00	1.92	20.00	2,000,000
Current Level	28.6	11.44	11.44	9.15	9.15	12,711	25,422	915.20	91.52	1.10	11.44	1,144,000
	15	6.00	6.00	4.80	4.80	6,667	13,333	480.00	48.00	0.58	6.00	600,000
Decrease	10	4.00	4.00	3.20	3.20	4,444	8,889	320.00	32.00	0.38	4.00	400,000

Table 2-7(L2) Calculation Table for "Worst Case" Scenario in Humbug Scrub Reservoir, site B

Calculations												
Scenario Assumptions:	The climatic conditions are favourable for cyanobacterial growth	The proportion of bio-available TP is:	The proportion of bio-available P converted to Chl-a is:	The proportion of Chl-a that is *Anabaena*:	The proportion of Chl-a that is *Microcystis*:	The Chl-a content of *Anabaena circinalis* is: (pg/cell)	The Chl-a content per cell of *Microcystis aeruginosa* is: (pg/cell)	The ratio of geosmin to *Anabaena* Chl-a is:	The proportion of extra-cellular geosmin is:	The ratio of microcystin to *Microcystis* Chl-a	The proportion of Chl-a that is *Aphanothece:*	The Chl-a content of *Aphanothece* is: (pg/cell)
Value:	Yes	**0.7**	**1**	**1**	**1**	0.72	0.36	360	0.4	1	**0.8**	0.01
Comments:	Population size is then determined by carrying capacity of the reservoir	Some total P unavailable due to binding to particles etc	Some bioavailable P will be taken up by other organisms	Will depend upon the degree of dominance achieved	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)	Published value (Reynolds 1984)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Bowmer *et al.* 1992)	Maximum of published range (Chorus and Bartram (1999)	Will depend upon the degree of dominance achieved	Published value (Reynolds 1984)
Justification:	Given Stable conditions phosphorus concentration is likely to determine biomass in freshwaters	Higher proportions of TP are bioavailable in more eutrophic conditions	Most bio-available P is taken up by phytoplankton	Major blooms of cyanobacteria can form practically monospecific dominance	Major blooms of cyanobacteria can form practically monospecific dominance			Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Depends upon the strain and environmental conditions	Minor blooms of cyanobacteria may account for less than half the Chl-a	
	Concentration in Reservoir											
	TP	FRP	Chl-a	Chl-a	Chl-a	*Anabaena*	*Microcystis*	geosmin	geosmin	microcystin	Chl-a	*Aphanothece*
	ug/L	ug/L	ug/L	ug/L	ug/L	cells/mL	cells/mL	ng/L	ng/L	ug/L	ug/L	cells/mL
Increase	100	70.00	70.00	70.00	70.00	97,222	194,444	25200.00	10080.00	70.00	56.00	5,600,000
	50	35.00	35.00	35.00	35.00	48,611	97,222	12600.00	5040.00	35.00	28.00	2,800,000
Current Level	28.6	20.02	20.02	20.02	20.02	27,806	55,611	7207.20	2882.88	20.02	16.02	1,601,600
	15	10.50	10.50	10.50	10.50	14,583	29,167	3780.00	1512.00	10.50	8.40	840,000
Decrease	10	7.00	7.00	7.00	7.00	9,722	19,444	2520.00	1008.00	7.00	5.60	560,000

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