The German technical standard for the assessment of lake water quality and its application to Hartbeespoort Dam (South Africa)*

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Abstract

The lack of a convenient, integrative definition of the term 'water quality' can create confusion and misunderstanding between disciplines; the term being variously interpreted as meaning bacterial/viral status, salinity status, turbidity status, or nutrient status, for example. The GDR (German Democratic Republic) Technical Standard for the assessment of lake water quality uses a simple quantitative ranking technique to overcome the confusion surrounding the term water quality by integrating hydrographical, trophic state and hygiene-related criteria into a single use-class measurement that can be used to determine the suitable uses for a waterbody. Application of the assessment technique to hypertrophic Hartbeespoort Dam demonstrates the usefulness of this method under southern African conditions.

Introduction

The term 'water quality' means many things to many people. This polychotomy is reflected in the literature with, for example, water quality being defined in terms of nutrient and chlorophyll *a* concentrations (Gilliom, 1984), plankton species and numbers (Haslauer *et al.*, 1984), oxygen and BOD (Hunter *et al.*, 1984), heavy metals and organics (Muchmore and Dziegielewski, 1983), sociological criteria (Van der Meer, 1984), or a combination of these factors (Bhargave, 1985). Interdisciplinary communication is hindered by the lack of a common understanding of the term. Government regulations cover many of the aspects of water quality touched on above (bacteria, salinity or TDS, clarity or turbidity, and phosphorus concentration), yet each discipline will bring to bear a value judgement concerning their particular indicator. Clearly there is a need for a universal basis for the classification of water quality status in natural waters (D'Yachkov, 1984).

This paper examines one such integrative lake water quality classification system; the 1982 Technical Standard promulgated in the German Democratic Republic for the classification of standing waters (GDR, 1982). The assessment technique as outlined by Ryding *et al.* (1986) is applied to Hartbeespoort Dam, South Africa, to demonstrate both its application and usefulness under local conditions and some possible modifications that might improve its relevance.

Materials and methods

Study area

Hartbeespoort Dam (25°43'S, 27°51'E) is a warm, monomictic, hypertrophic impoundment situated at the confluence of the Crocodile and Magalies Rivers, some 37 km west of Pretoria. Built in 1925 to supply water to the Hartbeespoort Government Water Scheme irrigation area, the lake currently supplies water for domestic consumption in the Magalies Water Board area, irrigation farming and an extensive recreational industry. Data on the lake and its catchment were obtained from the published literature, especially NIWR (1985), and are referenced where appropriate.

GDR Technical Standard

An outline of the application of the GDR Technical Standard (GDR, 1982) is given in Ryding *et al.* (1986). Using a quantitatively based ranking system, the physical, chemical and biological characteristics of a water body are designated on a continuum as being unimpaired (scored as 1) or impaired (scored as 5) in three quality classes; namely, hydrography, trophic state and hygiene. Using simple arithmetic means, a use class is determined which defines and/or limits use of a water body for most common water-related activities (drinking water, industrial water, cooling water, irrigation water, recreational waters, bathing, fisheries, waterfowl breeding habitats, and power-boating), this limitation having the force of law in the GDR.

Data requirements for the application of the assessment technique are potentially extensive, although the use of simple arithmetic means derived from available data does allow flexibility in the case of missing data points. Table 1 gives a breakdown of the data requirements in terms of the three quality classes, with the relevant values for Hartbeespoort Dam given as an example.

Use of the GDR technical standard

Table 2 presents the quality class descriptors used with the GDR Technical Standard assessment method. Assignment of individual data points to quality classes is based on the actual value and its position within the ranges shown for each class, and also on a knowledge of the particular water body in the case of hypertrophic/polytrophic waterbodies falling into quality class 5. For example, the zooplankton biomass criterion of the trophic state class covers a range of $<0,1$ to $>0,8\ g\ m^{-3}$ in quality classes 1 to 4, and a range of 0 to $>0,8\ g\ m^{-3}$ in quality class 5 due to the fact that hypertrophic lakes often have major discontinuities between trophic levels due to unpalatable food sources and inefficient energy transfer between trophic levels (Wetzel, 1983; Barica and Mur, 1980). Thus the value of zooplantkton biomass of $0,18\ g\ m^{-3}$ for Hartbeespoort Dam given in Table 1 could fit into quality class 2 (greater than 0,1 but less than $0,3\ g\ m^{-3}$) or quality class 5. Because Hartbeespoort Dam is hypertrophic and the zooplankton populations are 'artificially' reduced by a sub-optimal food source (Thornton *et al.*, 1986), this criterion is placed into quality

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class 5. This type of assessment requires a sound limnological knowledge to ensure correct classification of each criterion.

Hydrographical criteria include lake mixing status (type of stratification), lake morphometry (mean and maximum depth, hypolimnetic to epilimnetic volume ratio and mean water retention time), catchment characteristics (ratios of catchment area to lake volume and area and percentage of afforestation) and nutrient loading characteristics. Six quality classes apply to the lake criteria, with quality class 3 being divided into stratified and non-stratified rankings (scored as 3,0 and 3,5 respectively). Obviously, non-stratified lakes will not have a stable hypolimnion to allow determination of the hypolimnetic to epilimnetic volume ratio. In meromictic, or permanently stratified water bodies, such as Swartvlei (Allanson and Howard-Williams, 1984), the non-circulating water mass (monimolimnion) should be subtracted from the depth measurements before classification.

Catchment characteristics and nutrient loading characteristics are ranked into five quality classes. Population equivalent loads are determined using nutrient export coefficients based on catchment land use and per capita nutrient loads. Per capita nutrient loads are determined as 540 g BOD_5, 130 g N or 20 g P without treatment times total population divided by the volume of the waterbody in 10^6 m^3. With primary treatment, these loads are reduced by 20%; with secondary treatment, by 60%; and with tertiary treatment, by 80%. Crops and livestock are similarly assessed. Livestock units consisting of individual large animals (horses, cattle), 6 pigs, 14 sheep or 150 chickens can produce up to 12 times the human per capita load, although under normal pasture farming conditions these animal units can be considered equivalent to humans (see Ryding *et al.*, 1986, for a description of multipliers used under other farming methods). Similarly crops can produce up to 9 times the human per capita load per hectare depending on the type of crop and rate of fertiliser application. However, under common agricultural practices, nutrient export coefficients can be used (see Grobler and Silberbauer, 1984, for a compilation of nutrient export coefficients under South African conditions). BOD_5 values are used in cases where lakes are not nutrient limited; nitrogen and phosphorus values are used where these nutrients are limiting to algal growth in a particular waterbody.

Measured phosphorus and nitrogen loads are used as additional criteria where these elements are limiting to algal growth in the waterbody. The use of the phosphorus loading criterion in reservoirs is particularly recommended (Ryding *et al.*, 1986). Nevertheless, a lake can reach a state of enrichment where elements cease to have a direct effect on the water quality as in the case of class 4 and 5 waterbodies (OECD, 1982).

Hygienic characteristics incorporate dissolved solids (cation and anion concentrations, hardness and salinity), special criteria characteristics of unusual water conditions (such as acidified waters and waters of high organic content: iron and manganese concentrations, pH, nitrate and ammonium concentrations, hydrogen sulphide concentrations, and humic content criteria), and public health criteria (heavy metal and pesticide concentrations, and bacterial concentrations). The special criteria relate the degree of deviation of the waterbody from the reference lakes (which are neutral, clear-water lakes) on which the Standard is based. Overall, these hygienic characteristics are related to water use and under certain circumstances, such as the use of a water body for domestic consumption, can override the other quality classes.

Minimum data requirements for the use of the Standard in the assessment of water quality would include mixing status, mean and maximum depth, mean water retention time, catchment area to lake ratios, hypolimnetic oxygen status, phosphorus and nitrogen concentrations, chlorophyll concentration, Secchi disc transparency, trophic state assessment and total alkalinity. In addition, diurnal variation in oxygen saturation, primary production, total dissolved solids, pH, and population equivalent nutrient load data are suggested, as well as data on any relevant hygienic criterion from those lakes having unusual water characteristics or special uses with specific requirements in terms of water quality. Uhlmann (1985) assessed the water quality of Lake McIlwaine, Zimbabwe, using data on about 30 of the 59 criteria set out in Tables 1 and 2. The current assessment of Hartbeespoort Dam uses data on 47 criteria (Table 1). Usually, the hydrographical criteria will be well documented, especially in the cases of man-made lakes, trophic state criteria perhaps less well documented, and hygienic criteria poorly documented unless the lake is being used for a specific purpose or has some unusual characteristics. Nevertheless, it is desirable to use as many data as are available when producing a water quality assessment in terms of the GDR Technical Standard.

Results and discussion

On the basis of the ranges given for the various quality class descriptors used with the GDR Technical Standard assessment method (Table 2), the underlying assumptions of the Standard are identified. For optimal use (e.g. a score or quality class ranking of 1), a lake in hydrographical terms should be relatively large and deep with a low nutrient load. Although the lake would thermally stratify, there would be no hypolimnetic oxygen depletion. Nutrient concentrations should be low as would primary production and algal biomass. In other words, the lake should ideally be oligotrophic. Obviously, there would be low concentrations of dissolved salts and no detectable concentrations of heavy metals, phenols and pesticides. There would be no detectable coliform or enterococci bacteria present. A lake with severely impaired usage would be the opposite of this; a small, shallow lake with high nutrient loads, concentrations, production and biomass that is impacted with heavy metals, organic toxicants and human bacteria (e.g. a lake with a quality class ranking of 5). These criteria reflect the ideal north temperate lake and its antithesis (Wetzel, 1983).

Based on the data for Hartbeespoort Dam given in Table 1, Table 2 also shows the quality class rankings for the impoundment, and the class means for the three classes. For assessment purposes, the three quality class means would be rounded to the nearest whole integer. The grand mean of these three rounded means would yield the use class; the uses being defined in Table 3.

Hartbeespoort Dam scores a grand mean of 3 using the GDR Technical Standard assessment technique which implies a moderately impaired water quality for most common usages.

In terms of the hydrographical criteria which include lake morphology, mixing status, catchment characteristics and nutrient loading rates, Hartbeespoort Dam scores 2,7 which is rounded up to 3 for assessment purposes. The worst score (4) is attained on the basis of the ratio of catchment area to lake volume, suggesting that the lake is rather small in relation to the size of the catchment. Ecologically, this can be related to the fact that diffuse, non-point source runoff can contribute large amounts of sediment and nutritive/polluting materials to a lake. NIWR (1985) suggests that Hartbeespoort Dam is likely to remain enriched as a result of such diffuse inputs. On this basis, the

TABLE 1
DATA REQUIREMENTS FOR THE THREE QUALITY CLASSES USED IN THE GDR TECHNICAL STANDARD ASSESSMENT METHOD AND VALUES FOR HARTBEESPOORT DAM DERIVED FROM THE PUBLISHED LITERATURE

Parameter	Units	Hartbeespoort Dam	Reference
1. **Hydrography**			
Type of stratification	—	monomictic	Robarts *et al.* (1982)
Mean depth	m	9,6	NIWR (1985)
Maximum depth	m	32,5	
Hypolimnion vol./Epilimnion vol.	—	0,35	
Mean water retention time	a	0,87	
Catchment area/Lake vol.	—	21,25	
Catchment area/Lake area	—	207,2	
Percent of catchment forested	%	±66 (?)	
Population Equivalent load	PE/vol.	>110,9	
P-load	$g\ m^{-2}.a^{-1}$	14,2	
N-load	$g\ m^{-2}.a^{-1}$	85,5	
2. **Trophic State** (summer period)			
Oxygen saturation variation (diurnal)	%	80-150	Robarts *et al.* (1982)
Hypolimnion oxygen concentration	$mg\ \ell^{-1}$	0	NIWR (1985)
Orthophosphate concentration	$mg\ \ell^{-1}$	0,30	
Total phosphorus concentration	$mg\ \ell^{-1}$	0,45	
DIN concentration	$mg\ \ell^{-1}$	0,97	
Annual primary production	$g\ m^{-2}.a^{-1}$	1 470	
Primary production ratio (mg C $m^{-3}.d^{-1}$/mg C $m^{-2}.d^{-1}$)	—	1,0	
Phytoplankton volume	—	—	
Chlorophyll *a* concentration	$mg\ m^{-3}$	40	NIWR (1985)
Secchi disc transparency	m	0,8	
Vertical extinction coefficient	m^{-1}	2,54	
Zooplankton biomass	$g\ m^{-3}$	0,18	
Trophic state	—	hypertrophic	
3. **Hygiene**			
Calcium concentration	$mg\ \ell^{-1}$	42	NIWR (1985)
Magnesium concentration	$mg\ \ell^{-1}$	23	
Sodium concentration	$mg\ \ell^{-1}$	50	
Chloride concentration	$mg\ \ell^{-1}$	45	
Sulphate concentration	$mg\ \ell^{-1}$	100	
Total $CaCO_3$ hardness	$mg\ \ell^{-1}$	175	
Temporary $CaCO_3$ hardness	$mg\ \ell^{-1}$	140	
Total salinity	$mg\ \ell^{-1}$	385	
Iron concentration	$mg\ \ell^{-1}$	0,05	
Manganese concentration	$mg\ \ell^{-1}$	0,05	
pH	$mg\ \ell^{-1}$	9,3	
Ammonium in epilimnion	$mg\ \ell^{-1}$	0,09	
Hydrogen sulphide in epilimnion	$mg\ \ell^{-1}$	0	
Hydrogen sulphide in hypolimnion	$mg\ \ell^{-1}$	10	
Humic compounds as COD	$mg\ \ell^{-1}$	—	
Humic standard	—	oligohumous	NIWR (1985)
Nitrate concentration (max)	$mg\ \ell^{-1}$	1,65	
Nitrate concentration (mean)	$mg\ \ell^{-1}$	0,93	
Fluoride	$mg\ \ell^{-1}$	—	
Phenols	$mg\ \ell^{-1}$	0,002	Greichus *et al.* (1977)
Detergents	$mg\ \ell^{-1}$	—	
Dissolved copper	$mg\ \ell^{-1}$	0,003	Greichus *et al.* (1977)
Dissolved chromium III	$mg\ \ell^{-1}$	—	
Dissolved chromium VI	$mg\ \ell^{-1}$	—	
Dissolved lead	$mg\ \ell^{-1}$	0,004	Greichus *et al.* (1977)
Dissolved arsenic	$mg\ \ell^{-1}$	0,001	
Dissolved zinc	$mg\ \ell^{-1}$	0,036	
Dissolved cadmium	$mg\ \ell^{-1}$	—	
Dissolved cobalt	$mg\ \ell^{-1}$	—	
Dissolved nickel	$mg\ \ell^{-1}$	—	
Dissolved mercury	$mg\ \ell^{-1}$	0,001	Greichus *et al.* (1977)
Aromatic hydrocarbons	$mg\ \ell^{-1}$	0,0003	
Organophosphoric hydrocarbons	$mg\ \ell^{-1}$	—	
Coliform bacteria	no $m\ell^{-1}$	—	
Enterococci bacteria	no $m\ell^{-1}$	—	

TABLE 2

QUALITY CLASS DETERMINATION USING THE GDR TECHNICAL STANDARD AND SHOWING CLASS FOR HARTBEESPOORT DAM BASED ON DATA GIVEN IN TABLE 1 (AFTER GDR, 1982)

	Quality Class						
Criterion	**1**	**2**	**3a**	**3b**	**4**	**5**	**Hartbeespoort**
1. **Hydrography**							
Type of stratification	– –	stratified	– – –	– –	nonstratified	– –	3
Mean depth	15	>10	<20	2-10	1-2	<1	3
Maximum depth	>30	>20	<20	NA*	NA	NA	1
Hypolimnion vol./Epilimnion vol.	1,5	>1,0	<1,0	NA	NA	NA	3
Mean water retention time	>10	>1	>0,2	>0,1	<0,1	<0,1	3
Catchment area/Lake vol.	<3	<5	<10		>10	NA	4
Catchment area/Lake area	<30	<60	<300		>300	NA	3
Percent of catchment forested	>80	>50	<20		>10	<10	2
Population Equivalent load	<50	<500	<2 500		<5 000	>5 000	2
P-load	<5	<10	<15		NA	NA	3
N-load	<5	<10	<15		NA	NA	3
						MEAN	2,7
2. **Trophic State** (summer period)							
Oxygen saturation variation (diurnal)	90-120	80-150	60-200		20-300	0-50	2
Hypolimnion oxygen concentration	>6	>1	aerobic		NA	NA	4
Orthophosphate concentration	0-0,002	0-0,005	0-0,1		>0,1	>0,5	4
Total phosphorus concentration	<0,015	<0,04	0,04-0,3		>0,3	>0,5	4
DIN concentration	<0,01	<0,03	<0,1		>0,1	>0,5	5
Annual primary production	<120	120-250	250-400		400-500	>500	5
Primary production ratio ($mg\ C\ m^{-3}.d^{-1}/mg\ C\ m^{-2}.d^{-1}$)	<15	15-30	30-75		75-90	>90	1
Phytoplankton volume	<1,5	<5	5-10	10-20	0-30	>30	–
Chlorophyll *a* concentration	<3	<1	10-20	20-40	40-60	>60	3,5
Secchi disc transparency	>6	>4	>1		>0,5	>0,5	4
Vertical extinction coefficient	<0,5	<0,6	<1,3		>1,3	>2,5	5
Zooplankton biomass	<0,1	<0,3	<0,8		>0,8	0- >0,8	5
Trophic state	oligo-	meso-	eu- strat.	eu- unstrat.	poly-	poly-	5
						MEAN	4,0
3. **Hygiene**							
Calcium concentration	<60	<100	<150		<250	>250	1
Magnesium concentration	<25	<50	<100		<150	>150	1
Sodium concentration	<30	<70	<150		<300	>300	2
Chloride concentration	<50	<100	<250		<500	>500	1
Sulphate concentration	<100	<150	<350		<500	>500	2
Total $CaCO_3$ hardness	<100	<150	<300		<500	>500	3
Temporary $CaCO_3$ hardness	<70	<120	<250		NA	NA	3
Total salinity	350	750	1 500		2 500	2 500	2
Iron concentration	<0,01	<0,5	<1		<3	>3	1
Manganese concentration	<0,02	<0,1	<0,2		<0,5	>0,5	2
pH	6,5-8	7-8,5	7,9-9,5		6,5-10	6-11	3,5
Ammonium in epilimnion	ND*	ND	<0,1		<1	>1	4
Hydrogen sulphide in epilimnion	ND	ND	ND		ND	>0,01	3
Hydrogen sulphide in hypolimnion	ND	ND	>0,01				3
Humic compound as COD	<3	<5	<10		<20	>20	–
Humic standard	oligo-	oligo-	oligo-		meso-	poly-	2
Nitrate concentration (max)	<15	<30	<40		>40	NA	1
Nitrate concentration (mean)	<10	<20	<30		>30	NA	1
Fluoride	<1	<1	<1,2		<5	>5	–
Phenols	ND	ND	<0,005		<0,5	>0,5	3
Detergents	ND	<0,1	<0,2		<2	>2	–
Dissolved copper	ND	ND	<0,05		<1	>1	3
Dissolved chromium III	ND	<0,1	<0,2		<1	>1	–
Dissolved chromium VI	ND	<0,01	<0,02		<0,1	>0,1	–
Dissolved lead	ND	<0,03	<0,05		<0,5	>0,5	2
Dissolved arsenic	ND	<0,01	<0,05		<0,2	>0,2	2
Dissolved zinc	ND	ND	<0,01		<0,1	>0,1	4
Dissolved cadmium	ND	ND	<0,001		<0,01	>0,01	–
Dissolved cobalt	ND	<0,01	<0,1		<1	>1	–
Dissolved nickel	ND	<0,05	<0,2		<1	>1	–
Dissolved mercury	ND	ND	<0,001		<0,01	>0,01	3,5
Aromatic hydrocarbons	ND	ND	<0,0001		<0,001	>0,001	4
Organophosphoric hydrocarbons	ND	ND	<0,001		<0,01	>0,01	–
Coliform bacteria	ND/10 mℓ	ND/1 mℓ	<100		<1 000	>1 000	–
Enterococci bacteria	ND/100 mℓ	ND/10 mℓ	<10		<100	>100	–
						MEAN	2,4
4. **Use-class**					GRAND	MEAN	3,0

*NA = not applicable; ND = not detectable.

high score is justified in this impoundment. Scores of 3 in terms of lake morphology also imply an approach to criticality in terms of the size of the lake. Most southern African man-made lakes can be classed as shallow due to the nature of their construction which directly influences their morphology (Thornton, 1987), and would be expected to score high in terms of these criteria. Alexander (1985) points out that, due to the uncertainties of the rainfall/runoff regime, southern African impoundments are often designed with capacities exceeding mean annual river flow to ensure a sustainable yield; lakes larger than five times the mean annual runoff could not be supported in the relatively dry catchments of the region due to high evaporation rates. The ecological impact of this necessity is often a tendency to turbidity, increased nutrient availability from the hypolimnion of stratified lakes, and enhanced algal growth (see reviews in Davies and Walmsley, 1985).

The ecological impact of the large catchment area to lake volume ratio is enhanced by the presence of a large number of industrial and waste-water treatment point source discharges in the catchment and the shallow lake profile. This is reflected in the mean score of 4 for the trophic state quality class. High phosphorus and nitrogen concentrations and a high algal biomass resulting in an extremely high level of primary production (Robarts, 1984) yield scores of 4 and 5 against these class descriptors. Although zooplankton biomass is relatively low, the score of 5 reflects the hypertrophic status of the lake and the effect of the sub-optimal food source on the secondary producers (Thornton *et al.*, 1986). Thus the subtropical or semi-arid location of Hartbeespoort Dam does not unduly alter the water quality assessment of the waterbody in terms of its hydrographical and trophic state parameters. Any impairment of the lake's water quality due to factors such as a large catchment area to lake area ratio, turbidity levels, or hydrological variability is indeed reflected within the lake as measured by the criteria of the Standard.

The mean score of 2,4 for the hygiene-related quality class, rounded down to 2 for assessment purposes, is comprised of scores for determinands reflecting mineral status, toxic nutrient status, heavy metal and toxicant status, and microbiological status of the waterbody. The score of 2 implies a good quality water. This is interesting in view of the emphasis given to the salination of South African waters (Hall and Görgens, 1978; Hart and Allanson, 1984). Examination of the data given by OECD (1982) suggests that north temperate lake waters are commonly more saline than southern African lake water (Thornton, 1987), and this is reflected in the descriptors used in the GDR Technical Standard. With the exception of hardness, the waters of Hartbeespoort Dam are classified as being of good quality. The high score of 3,5 for pH reflects the high biotic production which tends to raise pH values (Wetzel, 1983), whilst the presence of high concentrations of ammonium in the surface water of the impoundment results in a high score against that determinand. Detectable levels of heavy metals and pesticides in Hartbeespoort Dam yield scores of between 2 and 4 in those categories (Greichus *et al.*, 1977). In the case of waters used for potable purposes, however, a quality class mean greater than the grand mean would override the grand mean as the use class because these hygiene factors affect human health (this proviso does not apply in the case of Hartbeespoort Dam where the grand mean or use class of 3 exceeds the hygiene quality class score of 2).

As shown in Table 2, Hartbeespoort Dam ranks as moderately impaired in terms of the use class score of 3. Reference to Table 3 shows that the water of Hartbeespoort Dam is suitable for most uses, although comprehensive water treatment procedures are required before the water may be used for domestic consumption, and recreational use of the water body would be disallowed. Van Vuuren *et al.* (1983) report on the use of the dissolved air flotation filtration (DAFF) process at the Schoemansville Water Works abstracting water from Hartbeespoort Dam and confirm the need for comprehensive treatment methods to achieve a potable standard, whilst Hofmeyr (1978) and NIWR (1985) report on the extensive use of the lake for all forms of aquatic recreation including swimming, sailing, fishing and power-boating, reflecting the multipurpose use of South African waterbodies in contrast with most European and North American lakes. The lake water is also usable for irrigation, although the use class ranking of 3 indicates that the quality of the water is not perfect.

The conclusions that can be drawn from the use class score of 3 (moderately impaired) do not differ significantly from the conclusions that can be drawn from a detailed comparison of the chemical composition of Hartbeespoort Dam water with internationally accepted standards for irrigation, drinking, stock watering, recreational and conservation waters compiled by Kempster *et al.* (1982). This comparison suggests that Hartbeespoort Dam water would be generally unacceptable for each of these usages with at least one indicator exceeding the recognised criteria (Tables 1 and 4). In particular, the mean pH value recorded in Hartbeespoort Dam exceeds the internationally accepted standards in every case. Both total and soluble phosphorus concentrations exceed the criteria for drinking and stock watering waters. These interpretations are consistent with the conclusions drawn from the GDR Technical Standard, which yielded high scores for pH and phosphorus concentrations (Table 2).

Neither the GDR Technical Standard nor the standards summarised by Kempster *et al.* (1982) class the irrigation use of Hartbeespoort Dam water as impaired on the basis of chloride concentration, a contentious point with tobacco growers in the Hartbeespoort Government Water Scheme (NIWR, 1985). In terms of the Technical Standard, water quality starts deteriorating at chloride concentrations in excess of 100 mg ℓ^{-1}, whilst the mean criterion recorded by Kempster *et al.* (1982) is 100 mg ℓ^{-1}. This latter value agrees with that experimentally determined by Snyman *et al.* (1976) as being detrimental to tobacco. There is similar agreement between the other mineral indices recorded by Kempster *et al.* (1982) and the GDR Technical Standard indices, and their respective limitations on the usage of lake waters.

The foregoing demonstrates the applicability of the GDR Technical Standard to Hartbeespoort Dam and confirms the recommendations of Ryding *et al.* (1986) who suggest that the standard should be universally applicable throughout the various climatic zones based on the validation of the technique using data from tropical Lake McIlwaine, Zimbabwe (Uhlmann, 1985, after Thornton, 1982). The technique now has demonstrable application to a subtropical lake. Given a good data base, the technique is easy to use, producing a result that, in its component quality classes, is intelligible to the engineer, the limnologist and the microbiologist/environmental chemist, and in its total use class is intelligible to water resource managers and planners. The GDR Technical Standard therefore fulfils the need for an integrative approach to the definition of water quality. On the other hand, it has been shown to have a north temperate zone bias in terms of its definition of the ideal lake which is not inappropriate in the tropical and sub-tropical zone context, even considering the peculiarities of southern African man-made lakes, particularly in terms of their hydrographical parameters and mineral status. Thus, this approach to water quality assessment is to be recommended.

TABLE 3
RECOMMENDED WATER USES PERMITTED IN TERMS OF THE QUALITY CLASSES DETERMINED WITH THE GDR TECHNICAL STANDARD ASSESSMENT TECHNIQUE

Type of Use	Quality class 1	2	3a	3b	4	5
Drinking water	simple* treatment	normal* treatment	comprehensive treatment*	complicated treatment*	unusable	unusable
Industrial water	simple treatment	normal treatment	comprehensive treatment*	complicated treatment*	impaired use	unusable
Cooling water	perfect	perfect	perfect	can be used	impaired	impaired
Irrigation	perfect	perfect	usable	usable	impaired	unusable
Recreation	perfect	perfect	perfect	usable	impaired	unusable
Bathing	------- inadmissible in water supply reservoir -------				questionable	unusable
Fisheries	--- natural feeding ---		natural feeding in water supply reservoir		artificial feeding	at risk
Waterfowl	------------ inadmissible ------------				permitted	admissible
Power boating	---- inadmissible ----		usable except in water supply reservoirs		permitted	admissible

*Simple treatment = filtration plus chlorination
Normal treatment = alum dosing, filtration, liming, chlorination
Comprehensive treatment = DAFF, alum dosing, filtration, activated carbon filtration, liming, chlorination
Complicated treatment = denitrification, alum dosing with polyelectrolytes, activated carbon filtration, ozonation

TABLE 4
INTERNATIONALLY ACCEPTED STANDARDS (IAS) FOR THE ASSESSMENT OF WATER QUALITY COMPARED WITH THE STANDARDS SET OUT BY THE GDR TECHNICAL STANDARD (AFTER KEMPSTER *ET AL.*, 1982)

Parameter	Units	Use: Irrigation		Potable/Stock		Recreation		Conservation	
		GDR	IAS	GDR	IAS	GDR	IAS	GDR	IAS
pH		6,5-10,0	4,5-9,0	7,0-8,5	6,5-9,0	6,5-10,0	6,0-9,0	6,0-11,0	6,5-9,0
Conductivity	mS m^{-1}		80		100-460				
Sodium	mg ℓ^{-1}	< 300		< 70	270	< 300		> 300	500
Potassium	mg ℓ^{-1}				12-2 000				50
Calcium	mg ℓ^{-1}	< 250		< 100	200-1 000	< 250		> 250	1 000
Magnesium	mg ℓ^{-1}	< 150	300	< 50	150-500	< 150		< 150	1 500
Ammonium	mg ℓ^{-1}	< 1		ND	0,50	< 1	0,80	< 1	0,02
Nitrate	mg ℓ^{-1}	> 30		< 20	10-45	> 30		NA	
Silica	mg ℓ^{-1}				18				50
Sulphate	mg ℓ^{-1}	< 500	200	< 150	200-1 000	< 500		> 500	1 400
Total phosphorus	mg ℓ^{-1}	> 0,3		< 0,04	0,25	> 0,3		> 0,5	
Dissolved phosphorus	mg ℓ^{-1}	< 0,1		< 0,03	0,10	> 0,1		> 0,5	
Chloride	mg ℓ^{-1}	< 500	100	< 100	250-1 500	< 500		> 500	50-400
Alkalinity	mg $CaCO_3$ ℓ^{-1}	< 500		< 120	500	< 500		NA	> 20
Iron	mg ℓ^{-1}	< 3		< 0,5	0,01-0,30	< 3		> 0,5	0,20
DOC	mg ℓ^{-1}				2-8				

Conclusions

The German Democratic Republic Technical Standard for the assessment of lake water quality provides a convenient, integrative approach to water quality assessment. It is equally applicable to north temperate as well as south (sub-) tropical lakes, although minor adjustments may be needed to fulfill local requirements more closely in the case of specific lakes.

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