Water quality guidelines for livestock watering in Southern Africa

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Abstract

The validity of the water quality guidelines for livestock watering is questionable as these are based largely on international guidelines and lack locally established water quality constituent lists, levels of acceptability and reference to Southern African livestock production systems. The water quality constituents fluoride, chloride, total dissolved solids and sulphate were identified in a review of subterranean water samples from non-hydrogauging stations from the Northern Province, North-Western Province and the Northern Cape Province as being the primary constituents of concern for livestock watering. Biological trials investigating toxicological and palatability aspects regarding the constituents fluoride, chloride, total dissolved solids, sulphate, nitrate and nitrite were conducted in sheep, cattle and poultry. The results indicated that the guidelines in use were too conservative for specific categories of livestock within Southern African livestock production systems, and that the guideline format used was inadequate in assessing the effects of water quality over the diverse range of livestock production systems found in Southern Africa. For a more accurate assessment of the effects of water quality for a given livestock production system the format should be based on ingestion levels, as opposed to a mg/*ℓ* basis, and should take into account site-specific synergistic and antagonistic interactions within and external to the water to a greater extent. The results led to the compilation of the interim water quality guidelines currently in use and to the formulation of a water quality guideline index system.

Introduction

Water quality guideline levels and constituents considered to be relevant for livestock watering differ between countries (Adelaar, 1974; Ensminger et al., 1990; Hart et al., 1992; Kempster et al., 1985; Smith, 1988; South African Water Quality Guidelines, 1993 and USEPA, 1976). This reflects both environmental and livestock production system differences and indicates the need for each country to have its own site-specific levels and constituents. Research regarding these factors for Southern Africa is needed, mainly as the present levels and constituent selections are based largely on assumptions as yet untested in the Southern African context owing to a lack of locally established guidelines (Casey et al., 1994). Livestock watering guidelines published by Kempster et al., (1985) and Smith (1988) differ considerably from those recommended by Adelaar (1974), Marincowitz and Conradie (1985) and the Borehole Water Association of Southern Africa (1990). The latter guidelines are still in use by Namibia, the Department of Agricultural Development and the Directorate of Soil Protection and Borehole Services. The South African Water Quality Guidelines (1993) are a combination of the international and the less conservative local guidelines (Adelaar, 1974).

Verification of the validity of the guidelines in use is required in order to accurately estimate the fitness for use of a water source for livestock production. The effects of changes in water quality on livestock production can be divided into three categories, namely, livestock consumption, livestock watering systems and livestock product quality. Livestock consumption refers to water quality problems arising from the ingestion of constituents which adversely affect the health and/or production of the animal. Toxicological and palatability norms are used to measure livestock consumption effects. For livestock watering systems, norms such as scaling, corrosion and encrustation are used. Livestock product quality involves product quality and consumer health hazard norms. Livestock consumption issues form the focus of this paper.

The most recent guidelines as published by the Department of Water Affairs and Forestry (1996), are the first to incorporate to some degree the problematic aspect of a water quality constituent having a wide range of effects at the same concentration depending on relevant site-specific factors. The format still has shortcomings, mainly as synergistic and antagonistic factors affecting tolerance levels, ingestion levels and subsequent production are not accounted for sufficiently. Although constituents are seldom mutually exclusive, interdependency between constituents is not catered for sufficiently. These guidelines are the first to provide information regarding possible mitigatory and treatment options, but due to the complex factors determining the suitability of a water source and the different livestock production systems that occur in Southern Africa, no solution for sources which exceed the recommended levels or ranges is given. While this may not necessarily be a guideline function, the scenario of inherently saline waters with high concentrations of potentially adverse constituents presents itself frequently in the arid zones and developing areas of Southern Africa. As a result most international guidelines, many of which have been incorporated into the 1996 guidelines, only serve to inform the user of the high risk associated with use without providing a management tool for utilising the water more optimally. In many of these cases livestock production continues, but the efficiency thereof is lowered. This has economic and environmental implications, such as increased cost of production and decreased feed utilisation, often adding to overgrazing problems, particularly in small-scale production systems.

This paper gives a brief summary of research results which led to the development of the guidelines published by the Department of Water Affairs and Forestry (1996), which are viewed as interim guidelines, and in conclusion describes the need for a water quality guideline index system in Southern Africa.

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Methods

Review of subterranean water quality data

The first phase involved a review of data of Southern African subterranean water samples in order to ascertain which constituents pose the greatest "potential" hazards for livestock watering which would then serve as a starting point for further research. The word "potential" is emphasised due the uncertainty surrounding the validity of the available guidelines. If a constituent exceeded the recommended guideline it was taken to be potentially hazardous and designated as a potentially hazardous constituent (PHC). The more conservative guidelines recommended by Kempster et al. (1985) were used in the assessment as this lessened the possibility of overlooking potential problems should the higher ranges of the less conservative guidelines be incorrect. The region incorporated in the study ranged over the northern borders of South Africa with the focus on subterranean water sources due to the importance of this water source in these regions (Parsons and Tredoux, 1993).

Originally data from the Department of Agricultural Development, Transvaal Division, were reviewed. This was abandoned due to a lack of specifications regarding sampling methods, storage and analytical procedures and site dispersion. Due to the different sampling methods and analytical procedures used between available databases, one database was used in preference to a conglomeration of several. The database found to be most suited was the chemical database from the Directorate of Geohydrology of the Department of Water Affairs and Forestry (DWAF). A total of 2 293 data sets comprising chemical analyses from non-hydrogauging stations (normally boreholes) from the Northern, North-Western and Northern Cape Provinces for the period 1987 to 1990 was obtained. The samples had been analysed for TDS (total dissolved solids), Na, Mg, Ca, F, Cl, NO_3, SO_4, PO_4, TAL (total alkalinity), Si, K, NH_4 and pH. Due to the absence or insufficient amount of data for certain drainage regions some pre-1987 data were incorporated. Additions to this database during the period 1991 to 1994 (5 094 samples) and data from the Atomic Energy Corporation (AEC) (18 834 samples) were used for comparative purposes. Due to either long intervals between sampling or high frequency of sampling on specific sites, the database from the Atomic Energy Corporation did not form the focus of the review.

The occurrence of a PHC was expressed as a percentage of the total number of recorded PHCs within designated areas. The Northern and North-Western Province areas were combined due to the method of data retrieval which differed between these provinces and the Northern Cape Province. The former were obtained on a drainage region basis, whereas the latter on a latitudinal and longitudinal basis. If a borehole had one or more recorded PHCs it was classified as unfit for livestock watering and expressed as a percentage of the number of boreholes reviewed for that area. The characteristics of the data reviewed did not allow for the identification of correlations or trends between constituents (Sanders et al., 1987; Hem, 1970 and Bredenkamp et al., 1991). Finally, with the assistance of the agricultural extension officers, livestock producers in areas which recorded a high incidence of PHCs were visited.

Biological trials investigating toxicological and palatability effects

Based on the results from the review and discussions with extension officers, farmers and toxicologists, the water quality constituents F, TDS, Cl, SO_4, NO_3 and NO_2 were identified as having the highest research priority. Biological trials investigating the effects of these constituents on livestock were then conducted using sheep, beef and dairy cattle, broilers and layers. Results were tested at the $P < 0.05$ level of significance.

Toxicological

Effects of F in the drinking water

In South African Mutton Merino (SAMM) wethers, Bonsmara beef steers, Ross broilers and Silver grey Hy-line layers the effects of sodium fluoride (NaF) in the drinking water on growth and health over the production cycle were investigated. This was from weaning to market mass for sheep and cattle, a 49-d growth period for broilers, and a 74-week production period for layers. Water treatments were applied daily and ranged from < 1 mg/ℓ F to 20 mg/ℓ F. Growth, production and performance parameters were monitored with histopathological and macroscopic pathological analyses conducted after slaughter.

Effects of NO_3 in the drinking water

In SAMM wethers the effects of NO_3 in the drinking water at 100 mg/ℓ NO_3 and 200 mg/ℓ NO_3 on the apparent digestibility of a medium energy commercial feedlot ration and blood parameters over a 60-d period were tested.

Palatability

The effects of NaCl, Na_2SO_4, $CaCl_2$, $MgSO_4$ in the drinking water in SAMM wethers, Bonsmara steers and Friesland dairy cattle were tested. Treatment administration ranged from a continuous basis with incremental increases (with similar growth, production, performance and histopathological parameters monitored as in the toxicological trials) to three-day treatment periods with four-day recovery periods.

Interaction between salinity and F

A combined treatment comprising NaF (15 mg/ℓ) and a saline water treatment (3 000 mg/ℓ to 6 000 mg/ℓ TDS) was investigated in SAMM wethers and Bonsmara steers.

Results and discussion

Review of subterranean water quality data

Fluoride had the highest incidence of PHCs recorded in the combined Northern and North-Western Provinces (Table 1) with TDS second and Cl third. These three constituents comprised 87.7% of the PHCs recorded for this area. Fluoride was responsible for the highest number of PHCs in the Northern Cape Province (Table 1), and with Cl and TDS accounted for 81.2% of the PHCs recorded in this area. Of a total of 1 162 samples for the combined Northern and North-Western Provinces 180, potentially hazardous levels were recorded, yielding a total of 130 boreholes (11.2%) classed as unfit for livestock watering. For the Northern Cape Province 1 131 samples yielded 1 588 potentially hazardous levels and 723 boreholes (63.9%) unfit for livestock watering. In total 37% of the samples reviewed had 1 768 potentially hazardous levels and resulted in 853 boreholes being classified as unfit for livestock watering.

A large number of concentrations were recorded between the more conservative guidelines (Kempster et al., 1985) and less conservative local guidelines (Adelaar, 1974), highlighting the

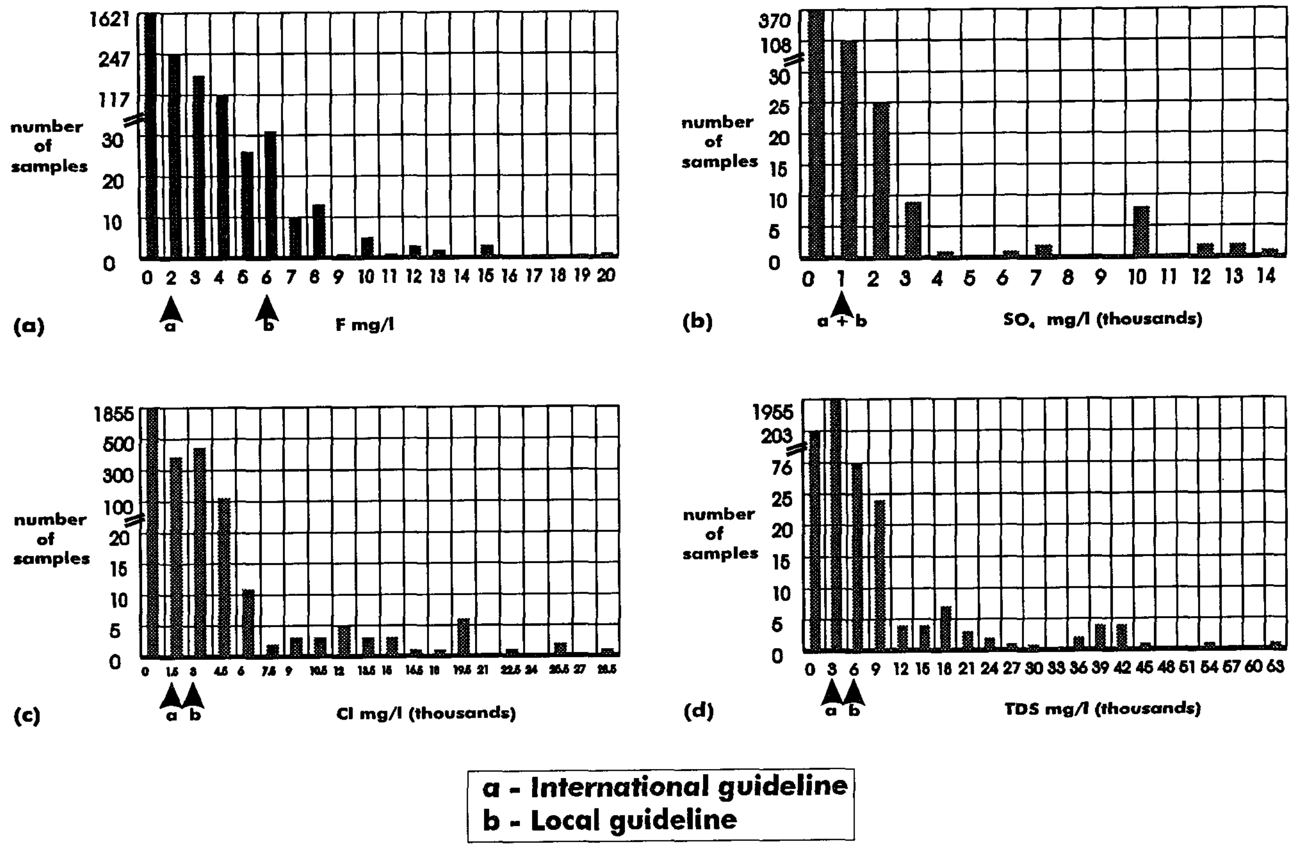

Figure 1

Combined distribution of samples from the Northern Province, North-Western Province and the Northern Cape Province

TABLE 1
INCIDENCE OF POTENTIALLY HAZARDOUS CONSTITUENTS (PHC) IN THE NORTHERN AND NORTH WEST AND IN THE NORTH WESTERN PROVINCES

Water quality constituents	Northern and North West Provinces		Northern Cape Province		Combined provinces
	PHC number	%	PHC number	%	PHC %
F	88	48.9	584	36.8	38
TDS	42	23.2	296	18.6	19.1
Cl	28	15.6	410	25.8	24.8
Na	0	0	69	4.3	3.9
SO_4	7	3.9	152	9.6	9
Mg	7	3.9	28	1.8	2
NO_3	5	2.8	40	2.5	2.5
Ca	3	1.7	9	0.6	0.7
Total	180	100	1588	100	100

need to verify which of the two guidelines are in fact correct and should thus be used to assess water quality for livestock in the Southern African context. Examples for F, Cl, SO_4 and TDS are given in Fig. 1. The incidence of PHCs in excess of the less conservative local guidelines further indicates the need for research to focus on means of utilising at least some water with PHCs. Furthermore, many concentrations recorded were not classified as PHCs, but had concentrations close to the PHC level and may well be in excess of the guidelines in the drinking trough due to the effects of evaporation and poor drinking trough management. An example of this is the recording of 23 samples in the Northern Cape Province having F concentrations of between 5 and 6 mg/ℓ which, aside from seasonal fluctuations, would conceivably exceed the local guideline of 6 mg/ℓ in the drinking trough. Investigations of some reported water quality problems by the authors, particularly in extensive livestock production systems, have found progressive deterioration in water quality from borehole to reservoir to drinking trough. Although samples taken from the drinking trough may not be indicative of the borehole water quality, it would be a more realistic view of what the animals are exposed to.

Due to a lack of data from the Crocodile River drainage region data from 1980 to 1986 were used. Fluoride concentrations were not as high as expected in view of the occurrence of fluorspar deposits in this region (Crocker et al., 1988). The data reviewed

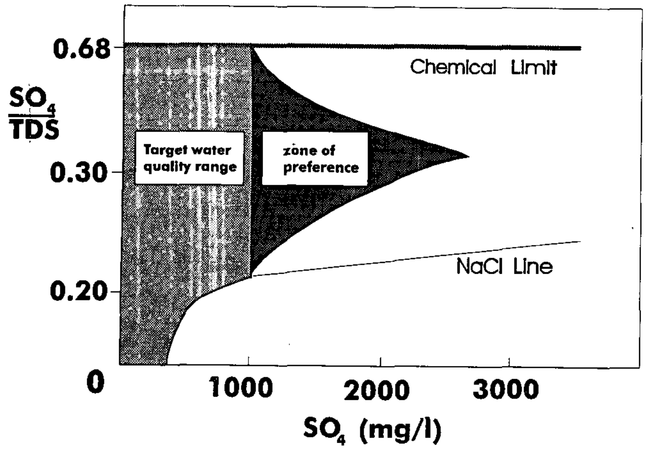

Figure 2
Palatability zone of preference for water intake in Friesland steers

for the period 1991 to 1994 from the DWAF and from the AEC yielded similar results in that the constituents F, TDS and Cl comprised a high percentage of the PHCs recorded (72.58% - DWAF, 71.36% - AEC), while SO_4 and NO_3 had higher recordings of PHCs compared to the 1987 to 1990 period. The results are presented in Table 2. A high number of samples taken from localised high NO_3 areas contributed to the high percentage of PHCs recorded for NO_3 from the AEC data. These levels are due to natural NO_3 accumulation and anthropogenic activities. There are indications that the guidelines used for NO_3 and NO_2 are not conservative enough. This is in light of research indicating possible adverse effects on ruminal cellulolytic bacteria at far lower levels than those which lead to methaemoglobinaemia (Marais et al., 1988), and the role of rumen bacterial species involved (Cheng et al., 1988).

The occurrence of heavy metals in water is of importance in livestock production, not only with regard to industrial pollution but also in subterranean waters (AWRC, 1982), and the exclusion of heavy metals in this review is due to the absence of usable data. For similar reasons the effects of toxic algae are not addressed even though livestock losses have been attributed to them in Southern Africa (Kellerman et al., 1988). Furthermore, the toxic concentrations of heavy metals (in terms of dosage) are often, but not always, subject to less variation than the adverse effects of the constituents of comparatively low toxicity on palatability (Peirce, 1966; 1968a; Saul and Flinn, 1985; Wilson, 1966) and the potentially toxic constituent F (Shupe, 1980; Wheeler and Fell, 1983). Due to advances in the analysis of F (Van Staden and Janse van Rensburg, 1991) and the complexities surrounding minerals in forages (Spears, 1994) it is becoming increasingly difficult to adverse effects to a specific water concentration in mg/ℓ. This was evidenced from interviews with livestock producers who found that some sources which were classed as fit-for-use resulted in a loss of condition when used, while the reverse was also found, with some sources classed as unfit for livestock watering being utilised without any apparent adverse effects. This was true for both local and international guideline classifications. Another factor of relevance was the vast difference found between groundwater quality from different boreholes on the same farm, some merely 30 m apart.

Biological trials investigating toxicological and palatability effects

Toxicological trials

The effects of F in the drinking water

Animal model - sheep

The growth and health of SAMM wethers to market mass (live mass 23 ± 4.1 kg to 41.9 ± 3.5 kg) for 107 d were not significantly affected ($P > 0.05$) by NaF in the drinking water to a concentration of 20 mg/ℓ F or an ingestion rate of 96 mg F/sheep·d (live mass 25 kg) and 122 mg F/sheep·d (live mass 45 kg). In a second trial F at a concentration of 15 mg/ℓ combined with a saline treatment did not significantly affect ($P > 0.05$) the growth or health of SAMM wethers over a 105-d exposure period.

Animal model - cattle

The growth and health of Bonsmara steers to market mass (live mass 198.39 ± 17.47 kg to 359 ± 17.2 kg for 124 d) were not significantly affected ($P > 0.05$) by NaF in the drinking water at a concentration of 20 mg/ℓ or an ingestion rate of 350 mg F/steer·d (live mass 250 - 350 kg).

Animal model - poultry

Fluoride to a concentration of 20 mg/ℓ was found to have a positive effect on mass gain, feed intake and production efficiency in Ross broilers, and no significantly adverse effects ($P > 0.05$) on health to slaughter mass (49 d). In Silver grey Hy-line layers, no significant differences ($P > 0.05$) between F treatments to 20 mg/ℓ regarding feed and water intake, mass gain, feed conversion and liver mass were found. In the fifth week of production there was a significant increase ($P < 0.05$) in the breaking strength of eggs in the 20 mg/ℓ F group (4.4450N) compared to the control group (3.9922N), and although subsequent weeks did not differ significantly ($P > 0.05$), this trend continued. Table 3 presents some of the results obtained from the F trials.

The effects of NO_3 in the drinking water

No significant differences ($P > 0.05$) were found in apparent digestibility and blood parameters between control groups, 100 mg/ℓ NO_3 and 200 mg/ℓ NO_3 treatments. Ingestion rates of 391 mg NO_3/sheep·d for the 100 mg/ℓ treatment and 880 mg NO_3/sheep·d for the 200 mg/ℓ treatment were obtained. The results indicated that at the recorded ingestion levels there was sufficient adaptation by nitrite-reducing rumen micro-organisms to prevent methaemoglobinaemia and adverse digestibility effects.

Palatability trials

Two main results were obtained. Firstly, in SAMM wethers no significantly adverse effects ($P > 0.05$) were found for growth or health over a 105-d continuous exposure period to incrementally increasing salinity levels in excess of current guidelines, indicating the ability of the animals to adapt to high TDS concentrations. Secondly, the response of both sheep and cattle to differing chemical treatments indicated that significant factors affecting water intake, and also feed intake, were not only the types of salts and concentration of the salts present, but also the ratios between the specific salts. Responses were significantly influenced ($P < 0.05$) by different ratios of Cl, SO_4 and TDS at different salinity concentrations. The results led to the development of palatability curves used to predict water intake response based on compliance

TABLE 2 INCIDENCE OF PERCENTAGE POTENTIALLY HAZARDOUS CONSTITUENTS (PHC) IN DATABASES FROM THE AEC AND THE DWAF (1991 TO 1994)		
Water quality constituent	**AEC[a]**	**DWAF[b]**
F	56.5	44.6
TDS	5.6	10.76
Cl	10.48	16.0
Na	0.39	10.7
SO_4	5.6	15.2
Mg	0.7	0.27
NO_3	18.06	1.68
Ca	2.5	0.55
Percentage boreholes classed as unfit for livestock consumption	52.88	14

[a]Atomic Energy Corporation database = whole Southern African region (18 834 samples).
[b]Department of Water Affairs and Forestry database = (1991 to 1994) - same regions as 1987 to 1990 review (5 094 samples).

TABLE 3 FINAL LIVE MASS RECORDINGS FOR SOUTH AFRICAN MUTTON MERINO (SAMM) WETHERS AND ROSS BROILERS AND EGG PRODUCTION RECORDINGS FOR SILVER GREY HY-LINE LAYERS EXPOSED TO SODIUM FLUORIDE IN THE DRINKING WATER OVER THE PRODUCTION CYCLE			
Treatment (mg/ℓ F)	**SAMM wethers mean live mass (kg)**	**Ross broilers mean live mass (kg)**	**Silver grey Hy-line layers mean egg production/ hen/week**
< 1	40.1[a]	1.866[a]	6.134[a]
6	44.1[a]	1.901[a]	6.035[a]
10	41.1[a]	1.893[a]	6.133[a]
14	42.9[a]	1.934[a]	6.077[a]
20	41.2[a]	1.951[a]	6.059[a]
Maximum ingestion (mg/animal·d)	122	3.206	4.453

[a]Means with different superscripts within a column are significantly different ($P < 0.05$) according to Tukey's multiple range test

with a zone of preference. The zone of preference enables recommendations to be made to improve palatability for water sources with one or more palatability constituents exceeding the recommended guidelines. An example of a palatability curve for SO_4 is given in Fig. 2. Water with an SO_4 concentration of greater than the recommended guideline of 1 000 mg/ℓ that falls outside the zone of preference (dependant on the ratios of Na, Cl and TDS) will lead to a decline in production and health of the animal, primarily due to the water intake not fulfilling the production and physiological water requirement of the animal. If the position of a plot of a water source lies above the zone of preference the addition of a non-sulphate containing salt which reduces the SO_4:TDS ratio, despite a higher resultant total salinity, improves the palatability and thus response of the animal to the water. The boundaries of the zone of preference can also be altered by factors external to the water, such as energy content of the ration fed.

Fluoride and salinity interaction

A significant negative correlation (Pearson correlation coefficient of 0.60022 and $P < 0.05$) was found between a saline-fluoride combination treatment and metacarpal bone F concentration in SAMM wethers. In Bonsmara steers a saline-fluoride treatment yielded significantly higher ($P < 0.05$) live mass gains compared to a control group and a higher, though not significant ($P > 0.05$), live mass gain than the F treatment group.

Conclusion

The constituents F, TDS, Cl, and SO_4 were identified as having the main research priority. Although the importance of NO_3 is not made clear in some of the data reviewed, it is foreseeable that it will play an increasingly important role in groundwater quality (Tredoux, 1993). Inadequacies in the available water quality data and guidelines used for assessing the suitability of water for livestock were found. A need exists for a water quality monitoring system that provides information regarding seasonal fluctuations, trends (across time and space), and an effective guideline system that incorporates relevant site-specific factors pertaining to the intended water use. Although a national groundwater quality monitoring strategy has been formulated (Parsons and Tredoux, 1993) it will be some time before the water sources for livestock which fall under the priority areas or constituents monitored include those pertaining to livestock watering.

For toxicological aspects the results indicate that for livestock water quality guidelines to make accurate predictions regarding the types of effects associated with water quality constituents, the guidelines need to be based on ingestion rates rather than on a concentration in mg/ℓ. This is relevant to Southern Africa which is characterised by contrasting environments and subsequently varied livestock production systems. As a large portion of the livestock industry is aimed at producing animals which are slaughtered at a target live mass, the guidelines should distinguish between different categories of livestock in a production system in terms of toxicological implications. The inclusion of site-specific factors and the associated synergistic and antagonistic factors, ranging from climatic to nutritional, is required to make an accurate estimation regarding the suitability of a given water source for a specific livestock production system.

Due to the interdependance between the ratios of salts present and total salinity level, predictions regarding possible palatability effects are best made using palatability curves as opposed to separate tables for each constituent. Primarily nutritional site-specific factors should be taken into account using different curves for different livestock rations.

A water quality guideline index system is currently being developed to accommodate these research findings. The aim is to allow for variable input of the most practical and significant factors that determine the suitability of water for livestock consumption. The envisaged format is an interactive Windows based software package which utilises various weighted and rated formulae to predict the effect of water quality for a given livestock production system, focusing largely on ingestion rates and palatability effects. Based on the production requirements suitability will then be assessed. By manipulating inputs, such as nutritional factors in terms of mineral supplements, energy and protein, the user will be guided to possible solutions for water sources that do not comply with the production system requirements.

The results at present indicate that for some constituents and certain categories of livestock production, even less conservative guidelines than used at present may be acceptable (Casey et al., 1994). Verification of all the constituents listed in local and international guidelines was not practically possible and thus the constituents identified from the review of water quality data and discussions with relevant stakeholders formed the focus of the research conducted. New constituents will be identified as the need arises. The constituent selenium is the latest to be added to the list.

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