A WATER RESOURCES AND SANITATION SYSTEMS SOURCE BOOK WITH SPECIAL REFERENCE TO KWAZULU-NATAL:

PART 4

by

Peter Glen Alcock

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Part 4 contains the following:

Each chapter has its own contents page/s. The pagination in **Part 4** is consecutive. A comprehensive set of contents pages for the entire thesis can be found in Part 1.

This thesis consists of the following:

- Part 1. Chapters 1 - 5
- Part 2. Chapters 6 - 9
- Part 3. Chapters 10 - 12
- **Part 4. Chapters 13 - 15**
- Part 5. Chapters 16 - 17
- Part 6. Chapters 18 - 20

CHAPTER 13: SOILS AND SOIL EROSION

"There is a lovely road that runs from Ixopo into the hills. These hills are grass-covered and rolling, and they are lovely beyond any singing of it. The road climbs seven miles into them, to Carisbrooke; and from there, if there is no mist, you look down on one of the fairest valleys of Africa. About you there is grass and bracken and you may hear the forlorn crying of the titihoya, one of the birds of the veld. Below you is the valley of the Umzimkulu, on its journey from the Drakensberg to the sea; and beyond and behind the river, great hill after great hill; and beyond and behind them, the mountains of Ingeli and East Griqualand.

The grass is rich and matted, you cannot see the soil. It holds the rain and the mist, and they seep into the ground, feeding the streams in every kloof. It is well-tended, and not too many cattle feed upon it; not too many fires burn it, laying bare the soil. Stand unshod upon it, for the ground is holy, being even as it came from the Creator. Keep it, guard it, care for it, for it keeps men, guards men, cares for men. Destroy it and man is destroyed.

Where you stand the grass is rich and matted, you cannot see the soil. But the rich green hills break down. They fall to the valley below, and falling, change their nature. For they grow red and bare; they cannot hold the rain and mist, and the streams are dry in the kloofs. Too many cattle feed upon the grass, and too many fires have burned it. Stand shod upon it, for it is coarse and sharp, and the stones cut under the feet. It is not kept, or guarded, or cared for, it no longer keeps men, guards men, cares for men. The titihoya does not cry here any more.

The great red hills stand desolate, and the earth has torn away like flesh. The lightning flashes over them, the clouds pour down upon them, the dead streams come to life, full of the red blood of the earth. Down in the valleys women scratch the soil that is left, and the maize hardly reaches the height of a man. They are valleys of old men and old women, of mothers and children. The men are away, the young men and the girls are away. The soil cannot keep them any more."

Paton, A., 1987. Cry, the Beloved Country: a Story of Comfort in Desolation, Penguin Books, London, 240 p.

Comment: Allowing for some poetic licence, the quotation captures the main environmental and human impacts of soil erosion. One interpretation of the passage might be the following:

The hilltops and surrounding grasslands overlooking the deeply incised Mzimkulu Valley can be classified as bioclimatic group 3 (Midlands Mistbelt). Lower down in the Valley, a drier climate indicated primarily by dense thickets of thorn trees is evident (bioclimatic group 10 - Riverine and Interior Lowland)*. The importance of a well-maintained grass layer, and especially on steep slopes where soils may be thin, is apparent. Care must be taken to avoid overgrazing and indiscriminate burning, in order to prevent detachment of soil particles and consequent erosion, particularly during high intensity thunderstorms. The relentless nature of soil erosion is indicated, while the transport of sediment in rivers is dramatically emphasized. Valuable soil nutrients necessary for plant growth are also lost as part of the erosion process - resulting in declining crop yields. Poor grass cover on steep slopes will reduce infiltration into the soil profile with the possibility

* Bioclimates are discussed in the chapter on catchments, elsewhere in this publication. It is sad to note that many of the hills made famous by Paton are now covered by commercial forestry plantations.

of springs drying up. The need for careful management of veld in general, and especially in the sensitive thornveld areas, is stressed. Paton uses the example of the titihoya (the Zulu name for the Blackwinged Plover), to illustrate the effects of habitat destruction on wildlife. Paton has employed poetic licence, since the titihoya is mainly found in open short grassland. The point nevertheless, is clear. The grave socio-economic consequences of resource degradation in conjunction with other factors such as employment opportunities, results in an out-migration of the young and able, seldom to return. The book was first published in 1948 - has much changed? A further interpretation of the quotation might examine the problems of communal grazing, the lack of agricultural skills in those left behind - and their subsequent struggle to survive - as well as the allocation of land.

CHAPTER 13: SOILS AND SOIL EROSION

Contents — *Page*

Contents (continued) *Page*

Tables | *Page*

13.1 <u>The nature of soil</u>*

Soils are complex bio-geochemical materials on the land surface, with morphological, physical, chemical and biological properties which differentiate them from the (parent) geological materials from which the soils originate. Soil is a mixture of rock debris and organic substances and has two types of solid components, namely, inorganic minerals derived from weathered rocks, and organic materials derived from plants, microorganisms and animals**. Soil also contains air and water which fill the spaces (pores) between the solid particles. Soil can therefore be regarded as a three phase material, consisting of soil, as well as liquid and gaseous fractions, with the relative proportions of the three phases varying considerably from one soil to another, or within a given soil. Soils can essentially be divided into two categories: a mineral or inorganic soil (consisting mainly of mineral matter, with less than 15% organic matter), and rare organic soils with more than 15% organic matter. The composition of an "average" mineral soil consists of 45% minerals (rock fragments, primary minerals such as quartz and secondary minerals, namely, clays); 25% air; 25% water, and 5% organic matter (Verster, Du Plessis, Schloms and Fuggle, 1992).

Soils are composed of mineral particles of different sizes (the texture of soil). The particles are classified according to size (diameter). Gravel and stones have a diameter >2,0 mm, while coarse sand has a diameter of 0,5 - 2,0 mm. Medium sand has a diameter of 0,2 - 0,5 mm; fine sand a diameter of 0,02 - 0,2 mm; silt a diameter of 0,002 - 0,02 mm, and clay a diameter of <0,002 mm (as defined in terms of the 1977 binomial classification system - discussed later). In most soils (mainly excluding very sandy soils), individual particles are grouped together into aggregates or peds (structural units) of varying size,

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* Discussion based on Verster, E., Du Plessis, W., Schloms, B.H.A. and Fuggle, R.F., 1992. Chapter 10. Soil, In: Fuggle, R.F. and Rabie, M.A. (eds), <u>Environmental Management in South Africa</u>, Juta, Cape Town, p. 181 - 211. (The present chapter was reviewed by D.M. Scotney, Department of Agriculture, Pretoria. The author (P.G. Alcock) is however, responsible for any errors in the text).

** Weathering of rocks is caused by physical, chemical and biological processes. Physical processes include abrasion, temperature changes and alternate wetting and drying, while both wind and water can sift and sort materials into different sizes (usually grouping them into similar sizes). Chemical processes include oxidation, carbonation, reduction, hydrolysis and hydration. Biological processes act either physically or chemically and involve the microbiological degradation of plant and animal waste, as well as the effects of burrowing by macro-fauna (such as earthworms and moles), and the actions of man <u>inter alia</u> ploughing, fertilization, irrigation and construction.

form and strength*. Adhesive agents usually consist of humus and clay. It is accordingly structure which differentiates most soils from weathered rock or other geological materials. Structure essentially controls the size and number of pores associated with aggregates, and determines the rate of water infiltration, the ease of root penetration, and the movement of air and water through the soil. A well structured soil is resistant to erosion.

The properties of soils in general, reflect the environment of a soil and the parent material from which it was derived. Different climates interacting with the various geological formations, and modified by terrain, can result in a complex (although repetitive) soil pattern (for example in Natal/KwaZulu). Properties seen, felt or measured in the field are referred to as morphological or physical properties and include texture; structure; colour; consistence (the degree of cohesion or adhesion within the soil); the presence of nodules and coarse materials, and the distribution of roots. A second category of soil properties can only be determined by laboratory analysis (such as soil reaction, namely, the acidity or alkalinity of a soil or the cation exchange capacity of a soil)**. A third group of soil properties are inferred from the morphological and chemical properties. An example is the dark colour of the top soil which may - although not always - provide a good indication of the amount of organic matter present.

The maximum rate at which a soil can absorb water is referred to as the infiltration capacity, which depends on soil porosity (the total volume of pores) as well as permeability, water content, the presence of organic complexes, and surface conditions. (Further downward movement of water in the soil is known as percolation). If rainfall intensity exceeds the infiltration capacity of the soil, then overland flow becomes evident.

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* Aggregates can be grouped into fine, medium or coarse sizes, with forms comprising prismatic, columnar, blocky, angular, granular or crumb. The strength of aggregates is referred to as structureless (apedal), weak, moderate and strong.

** The cation exchange capacity (CEC) refers to the fact that most soils, due to their clay size components (both inorganic and organic), have a negative electrical charge which is balanced by positively charged ions (cations), so that the system as a whole is electrically neutral. The cations represent a fixed quantity and can be exchanged by other cations. This quantity is employed as a measure of the cation exchange capacity. The CEC can be given for the whole soil or for the clay fraction. Where organic matter is low, the CEC of the clay fraction provides an indication of the type of clay minerals present. The principal cations are sodium, potassium, calcium, magnesium, hydrogen and aluminium (the latter two predominate in acid soils). It should be noted that the higher the soil pH, the higher is the CEC. A high CEC implies that the exchangeable cations are available in the soil as plant nutrients, and that the cations have not been leached (removed) from the soil (Van der Eyk, MacVicar and De Villiers, 1969 - see Section 13.2).

The rate of infiltration in the soil decreases with time, to a rate equal to the water flow through the saturated soil. As water percolates through the soil, molecular adhesion results in some water in the pores clinging to the soil particles. The soil water is most effectively held in small pores, since adhesion in the big pores is not sufficient to retain larger volumes of water against the pull of gravity. Consequently, the latter water drains away to groundwater. The maximum amount of water which can be stored in soil (after gravitational water has drained away) is known as the field capacity of a soil. Water held in pores in the root zone is used by plants. Beyond a certain point, the remaining soil water cannot be abstracted by the roots (being held very tightly by mineral and organic particles), and plants must exert a considerable force to obtain the water (wilting in the process). This stage is referred to as the wilting point. In essence, field capacity and wilting point represent the upper and lower limits of the soil water available for plant growth, with actual values depending on several parameters (Verster et al, 1992).

From a hydrological perspective, it is the capacity of soil to absorb, retain and release or redistribute water which determines hydrological responses within a catchment, inter alia with regard to the runoff potential, the runoff generating mechanisms (overland flow or interflow or base flow), as well as drainage rates and waterlogging. Important vertical and lateral characteristics of soils include (a) surface properties which affect the infiltration rate (such as crusting, sealing and cracking), (b) the distribution and proportion of clay - which influences the permeability and hydraulic conductivity of the soil, and (c) the presence of layers in the soil which result in poor drainage or waterlogging or which may induce interflow (the lateral movement of water). Of primary significance is the water holding capacity of the soil (largely dependent on soil depth and texture), the porosity of the soil at saturation point (when all pores are filled with water), and the field capacity as well as the wilting point (Schulze, Angus and Guy, 1991)*.

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* See Schulze, R.E., Angus, G.R. and Guy, R.M., 1991. Making the most of soils information: a hydrological interpretation of southern African soil classifications and data bases, Proceedings of the Fifth South African National Hydrological Symposium, South African National Committee for the International Association of Hydrological Sciences and the Division of Water Engineering of the South African Institution of Civil Engineers, 7 - 8 November 1991, Stellenbosch, 12 p.

Soil, and therefore water quality problems include acidification (leaching of solutes) of the soil (caused mainly by the excessive use of nitrogen fertilizers)*, and salination (or salinization) involving a build-up of alkali salts in the surface layers of the soil. The latter is due to over-irrigation and poor drainage or irrigation with highly mineralized waters. Likewise problematic is soil contamination by heavy metals as a result of irrigation with water containing industrial pollutants, or through the use of partly purified sewage effluent, or via the land disposal of dry sewage sludge. The compaction of cultivated fine sandy soils as well as crusting (with consequent increased runoff) - both due to incorrect tillage practices - is also cause for concern (Verster et al). A severe problem is accelerated soil erosion with the generation of sediment and the resultant loss of soil fertility (discussed later). Soil erosion is a natural phenomenon which assumes serious proportions where the (accelerated) rate of soil loss exceeds the rate of soil formation at a specific locality. The rate of soil formation in South Africa varies from approximately 0,38 t ha^{-1} y^{-1} for light-textured soils, to 0,31 t ha^{-1} y^{-1} for medium-textured soils, and 0,25 t ha^{-1} y^{-1} for heavy-textured soils. On an overall basis, South African soils form at an average rate of some 1 mm every 40 years (Matthee, 1984, quoted in Verster et al, 1992)**. This is much less than the rates of accelerated erosion common in many parts of the country!

13.2 A brief history of soil classification in South Africa

The first national scientific soil classification system with specific reference to South African conditions was compiled by Van der Merwe (1941)***. It subsequently became apparent (in terms of fieldwork) that a more comprehensive system was required, which was based on the latest scientific evidence and which would be applicable in all parts of the country. Pioneering work in this regard was undertaken inter alia by the South African Sugar Association Experiment Station at Mount Edgecombe (Beater, 1957; 1959;

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* Naturally occurring acid soils are found in high rainfall areas where free drainage results in the leaching of solutes and the biological production of acids. Saline soils (with an alkaline soil reaction) are common where low rainfall, high evaporation and poor drainage inhibits leaching, resulting in an accumulation of salts.

** See Matthee, J.F. la G., 1984. A primer on soil conservation, Bulletin No. 399, Division of Agricultural Engineering, Department of Agriculture, Pretoria, 128 p.

*** See Van der Merwe, C.R., 1941. Soil groups and sub-groups of South Africa, Science Bulletin No. 231, Chemistry Series No. 165, Department of Agriculture and Forestry, Pretoria, 316 p. + app. and maps. (The publication was subsequently revised in 1962 and was issued as Science Bulletin No. 356).

1962)*, as well as by the then Soil[s] [and Irrigation] Research Institute** (now the Institute for Soil, Climate and Water). Such research involved the classification of soils in terms of series and later forms (representing the origins of the binomial soil classification system - namely soil form/series). The next important advance was the soil survey of the Tugela Basin undertaken by Van der Eyk, MacVicar and De Villiers (1969)***. The survey incorporated innovative research work and provided a considerable impetus for the 1977 soil classification system. Phillips (1973)**** included the results of the Tugela Basin study in his seminal work on bioclimatic regions, groups and sub-groups. (See the chapter on catchments, elsewhere in this publication). A major milestone was achieved with the publication of the binomial soil classification system, which was the first detailed system for South Africa as a whole (MacVicar, De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen and Harmse, 1977)*****. The latest classification system is based on soil forms and soil families (Soil Classification Working Group, 1991)******.

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* See Beater, B.E., 1957. Soils of the Sugar Belt Part One: Natal North Coast, Natal Regional Survey Report No. 3, Oxford University Press, Cape Town, 103 p. and map, and Beater, B.E., 1959. Soils of the Sugar Belt Part Two: Natal South Coast, Natal Regional Survey Report No. 4, Oxford University Press, Cape Town, 77 p. and map, as well as Beater, B.E., 1962. Soils of the Sugar Belt Part Three: Zululand, Natal Regional Survey Report No. 5, Oxford University Press, Cape Town, 63 p. and map. (Beater recognized the close relationship between soils and parent materials and accordingly grouped soils into soil series on the basis of the underlying rock types (see Anonymous, 1984b - Section 13.3.1)).

** See MacVicar, C.N., Loxton, R.F. and Van der Eyk, J.J., 1965. South African soil series Part 1. Definitions and key, Report No. 107/64, Soils Research Institute, Department of Agricultural Technical Services, Pretoria, 86 p., as well as MacVicar, C.N., Loxton, R.F. and Van der Eyk, J.J., 1965. South African soil series Part 2. Profile descriptions and analytical data, Report No. 108/64, Soils Research Institute, Department of Agricultural Technical Services, Pretoria, 221 p. (Note that early soil surveys undertaken by the Institute were primarily to determine the suitability of land for irrigation).

*** See Van der Eyk, J.J., MacVicar, C.N. and De Villiers, J.M., 1969. Soils of the Tugela Basin: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 15, Pietermaritzburg, 263 p. and maps. The rationale for the new system was outlined in MacVicar, C.N., 1969. A basis for the classification of soil, Journal of Soil Science, VOL 20(1), p. 141 - 152.

**** See Phillips, J., 1973. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps.

***** See MacVicar, C.N., De Villiers, J.M., Loxton, R.F., Verster, E., Lambrechts, J.J.N., Merryweather, F.R., Le Roux, J., Van Rooyen, T.H. and Harmse Von M., H.J., 1977. Soil classification: a binomial system for South Africa, Science Bulletin No. 390, Department of Agricultural Technical Services, Pretoria, 150 p. (Termed the "Red book").

****** See Soil Classification Working Group, 1991. Soil classification: a taxonomic system for South Africa, Memoirs on the Agricultural Natural Resources of South Africa No. 15, Department of Agricultural Development, Pretoria, 257 p. (Termed the "Blue book").

13.3 The South African soil classification system

13.3.1 The 1977 binomial soil classification system*

The 1977 soil classification system classified the soils of South Africa in terms of 41 soil forms and 504 soil series. Each soil form is defined by a unique vertical sequence of diagnostic horizons. Every form (except Dundee), is subdivided into a number of series (varying from two to 30 or more), all of which have the prescribed horizon sequence of the given form, but which are differentiated within the form according to certain parameters. Soils therefore, are classified firstly with regard to form and then series. The soil classification system is similar to the binomial Linnaean method of classifying plants and animals, where genus corresponds with form, and species corresponds with series. Soil forms and series are referred to by means of a geographic name. Criteria used for series differentiation within forms include soil texture - in terms of clay content and the size grading of the sand fraction (coarse, medium and fine) - as well as the base status (specifically the degree to which the exchangeable calcium, magnesium, potassium and sodium cations (bases) have been leached from the soil). Soils fall into one of three categories, namely: dystrophic (highly leached), mesotrophic (intermediate), and eutrophic (slightly leached) soils**. Also relevant in respect of series is the extent of calcareousness (the accumulation of free calcium carbonate or calcium-magnesium carbonate). Other criteria for series are soil colour*** (where colour is not a criterion per se for the diagnostic horizon), soil reaction, and the nature of the underlying material.

The procedure followed in identifying a particular soil (namely, a soil profile), involves demarcating the master horizons (or levels) found in the profile, specifically, the O, A, E,

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* Discussion based on MacVicar et al (1977 - above). The discussion has been simplified. Readers requiring detailed information should closely examine MacVicar et al.

** Dystrophic soils generally occur in areas with a mean annual rainfall >850 mm, while mesotrophic soils tend to occur in the 700 - 850 mm range, with eutrophic soils found where the mean annual rainfall is <700 mm. According to Scotney, D.M., 1983. Agricultural resources of Natal, Symposium on Thought for Food: the 21st Century, South African Society for Agricultural Extension (Natal Branch), 13 May 1983, Pietermaritzburg, 16 p., over 37% of the soils of Natal/KwaZulu are dystrophic, with the associated problems of high acidity and low nutrient status.

*** Red colours are indicative of a well aerated soil with good internal drainage, while yellow colours reflect moderate drainage and a favourable water regime. Grey colours denote poor internal drainage (periodic waterlogging), while black colours reflect a high organic matter content or a high proportion of smectite clays. Mottling refers to a variable pattern of colours (in spots or streaks), which are evident within the dominant soil colour.

B, C, G and R horizons, followed by identification of the diagnostic horizons, thereby establishing the soil form - and with further examination - the soil series. Horizons formed under given genetic conditions are found in numerous areas where the same environmental parameters occur, resulting in a small number of vertically stratified, usually easily identifiable, master horizons. For example, an O horizon (forming the upper part of the soil), consists of fresh and/or partly decomposed organic matter accumulated under marshy conditions. The A horizon (at or adjacent to the soil surface), mainly consists of mineral particles well mixed with humified organic matter. The E (= eluvial) horizon if present - underlying the O or A horizon - has a lower organic matter and/or sesquioxides* and/or clay content than the immediately underlying horizon, which is usually indicated by a pale colour and a relative accumulation of quartz and/or other resistant minerals of sand or silt sizes. The B horizon (lying between the A and C or R horizons), is characterized by a concentration of silicate clay, sesquioxides or organic matter, alone or in combination. The G (gley) horizon (if present), shows features of strong reduction under anaerobic conditions, usually with grey, blue or green colours (or some such combination). Some subordinate diagnostic properties of the A, B or E horizons are also evident. The C horizon consists of unconsolidated material (including weathered rock), which does not show properties of the other master horizons. Finally, the R horizon comprises consolidated bedrock and is strictly speaking, not a horizon**. Few soils contain all the horizons, although all soils contain certain horizons. The horizons are usually easily identifiable in the field at exposed sites such as deep road cuttings.

Diagnostic soil horizons refer to horizons **as they occur in the field** (to a depth of 1,2 m), where a vertical grouping of pedological features is evident. Five diagnostic surface horizons, namely: organic, humic, vertic, melanic and orthic have been identified in South Africa. Each surface or top soil horizon is defined in terms of certain properties. The O or organic horizon, for example, is defined as having sufficient organic carbon to ensure an average content of at least 10% throughout a vertical distance of 300 mm, which overlies gleyed material, and which is usually black or dark brown in colour. Partly decomposed plant material may be present. Such soil is sometimes referred to as peat.

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* A term used to describe free iron, aluminium (and to some extent), manganese oxides.

** Master horizons may be further subdivided into several transition horizons, namely, O1, O2, A1, A2 (or E), A3, B1, B2 and B3 horizons. Reference is most frequently made to the A1 horizon as characteristic of the A horizon, and the B2 horizon (subdivided into B21 and B22 horizons), as most characteristic of the B horizon.

The other top soil horizons (humic, vertic, melanic and orthic) are similarly defined and are diagnostic of A horizons. Fifteen subsoil horizons have been defined as diagnostic, each again with specific properties. The relevant horizons are the E, G and B (pedocutanic, prismacutanic, gleycutanic, lithocutanic, neocutanic, ferrihumic, hard plinthic, soft plinthic, yellow-brown apedal, red apedal and red structured) horizons; as well as the C horizon, namely, regic sand or stratified alluvium.

A specific soil therefore, is classified or defined in terms of the diagnostic horizons. For example, an Inanda Form soil comprises a humic A horizon and a red apedal B horizon, with three soil series, namely, Fountainhill, Inanda and Sprinz. The three series (usually dystrophic in the B21 horizon), are differentiated according to the clay content of the B21 horizon. The Fountainhill Series has 15 - 35% clay in the B21 horizon, while the Inanda Series and the Sprinz Series have 35 - 55% and over 55% clay in the B21 horizon respectively. The Willowbrook Form by contrast (comprising a melanic A horizon and a G horizon) has four soil series, namely, Chinyika, Emfuleni, Sarasdale and Willowbrook, which are differentiated on the basis of clay content in the A horizon, and the presence or absence of calcareousness in the upper G horizon. The underlying material is not specified for the Inanda and Willowbrook forms, although for Inanda, it is usually saprolite. Two useful publications to aid the reader in soil identification (apart from MacVicar et al - above), are Anonymous (1984a) and Anonymous (1984b)*. A full listing of all the soil forms/series of the 1977 binomial system can be found later in the chapter (see Table M13). Readers should bear in mind that soil phases (incorporating parameters such as depth, slope and extent of erosion), are used for detailed land use planning purposes, although these criteria were not formally specified in the 1977 classification system.

Numerous soil properties are of relevance from a hydrological rather than an agricultural perspective. The degree of leaching provides an indication of internal drainage, with dystrophic soils having a good drainage potential and eutrophic soils, a poor drainage potential. The extent of calcareousness likewise, influences permeability and waterlogging. High water retention levels occur in organic O horizons (with more than

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* See Anonymous, 1984a. Natal Midlands subregion: identification and properties of soils - course notes, Department of Agriculture (Natal Region), Cedara, 61 p. (The publication contains a simplified discussion of soil classification. An especially useful feature is a flow diagram for the identification of diagnostic surface and subsoil horizons). A similar useful publication (with reference to soils of the sugar belt) is, Anonymous, 1984b. Identification of the soils of the sugar industry, Bulletin No. 19 (revised), Experiment Station of the South African Sugar Association, Mount Edgecombe, 112 p.

10% organic carbon), while humic A horizons have free drainage. Vertic A horizons (with a high clay content), are characterized by low hydraulic conductivity and marked shrink-swell properties, implying low infiltration rates when wet and high rates when dry. In terms of subsoil horizons, E horizons are associated with periodic water saturation and high interflow rates, while G horizons are subject to frequent waterlogging. In hard plinthic horizons, the sesquioxides (forming an impermeable layer), result in very poor drainage and a potential for waterlogging. Prismacutanic horizons display abrupt increases in clay content and firmness, with associated decreases in hydraulic conductivity and permeability. Red apedal horizons by contrast, are structureless and well drained (Schulze, Angus and Guy, 1991 - above)*.

13.3.2 The 1991 taxonomic soil classification system

The 1991 taxonomic soil classification system, which is a refinement of the 1977 system, uses a different classification structure (Soil Classification Working Group, 1991 - above). The latest system complements rather than replaces the 1977 system. While the same diagnostic top soil horizons are evident (O and A), 25 diagnostic subsoil horizons and materials have been included in the new system. The B horizons consist of the following: red apedal, yellow-brown apedal, red structured, soft plinthic, hard plinthic, prismacutanic, pedocutanic, lithocutanic, neocutanic, neocarbonate, podzol, and podzol with placic pan horizons. Besides E and G horizons, C horizons consist of dorbank, a soft carbonate horizon, a hardpan carbonate horizon, saprolite, unconsolidated material without wetness, unconsolidated material with wetness and unspecified material with wetness; as well as man-made soil deposits, regic sand and stratified alluvium. There is also an R horizon (hard rock).

Seventy-three soil forms and 404 soil families have currently been identified in South Africa. Soil forms are classified into two or more families, in order to narrow down the ranges in properties still existing in forms, and to add further important properties. Soil series have been omitted. Soil families are defined in terms of 19 sets of properties. Each family has a geographic name and a code, for example, Hutton Form (Hu 1200 Kelvin

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* See also Schulze, R.E., 1985. Hydrological characteristics and properties of soils in southern Africa, 1: runoff response, Water SA, VOL 11(3), p. 121 - 128., as well as Schulze, R.E., Hutson, J.L. and Cass, A., 1985. Hydrological characteristics and properties of soils in southern Africa, 2: soil water retention models, Water SA, VOL 11(3), p. 129 - 136.

Family), which accommodates all dystrophic soils of the Hutton Form, and which have a marked increase in clay from the A to the B horizon. The names of forms (as per the 1977 system) have been used in the 1991 system (with numerous additions), although form names are not used as family names. Certain properties such as soil depth and salinity were not taken into account in the 1977 or the 1991 classification procedure. Texture (as a differentiating parameter), has been excluded in the 1991 system. The usual texture class descriptions still apply however, although specific reference is now made to the top soil texture class (of primary interest to agriculture). The United States Department of Agriculture (USDA) texture classes (with one modification), have been used in the 1991 system. A further change is that diagnostic horizons must now occur (wholly or in part), within 1,5 m of the soil surface. A useful feature of the 1991 classification system is the (C) unconsolidated material with wetness horizon, which has direct relevance to wetland soils. Several other changes were discussed by the Soil Classification Working Group (1991), and the interested reader is referred thereto.

In terms of hydrological properties, Schulze et al (1991) observed that cemented layer placic pan (subsoil) horizons for instance, restrict root development and water movement; while dorbank (a hard to extremely hard layer of subsoil cemented by silica - found in arid regions), is virtually impermeable and is consequently often waterlogged after rain. A hardpan carbonate horizon (a hard, calcium and/or calcium-magnesium carbonate cemented layer), is likewise only slightly permeable and also presents a barrier to root development.

The 1991 taxonomic system is fully applicable in the whole of South Africa, unlike the 1977 system which has a geographic bias towards the moister, eastern half of the country. The 1977 system, for example, does not take the calcareous Karoo soils or the podzols* of the George area into account. Future research work and development of the soil classification system (as envisaged), will include the definition of soil series to be incorporated in the 1991 system. These series will cater for all South African soils. The later derivation of soil series will be based on scientific evidence, rather than subjective criteria. Soil series will accordingly be strictly defined in terms of all relevant properties including wind and water erosion (MacVicar, 1994)** - see the section on soil erosion.

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* Podzols are soils in which the mobilization in (and removal from) an A horizon, of sesquioxides and/or organic matter has occurred, giving rise to a highly leached, whitish E horizon. The upper layer of soil therefore becomes acidic through the leaching of bases which are deposited in the lower horizons.

** MacVicar, C.N., 1994. Personal communication, Cedara Agricultural Development Institute, Cedara.

It should be noted that Land Type maps and data (discussed later) are based on the 1977 soil classification system. There is however, some degree of overlap between criteria defining the 1977 soil series, and soil families (Schulze et al, 1991). Schulze et al observed that many soil series definitions link more closely to hydrological responses than the broader soil family divisions. A certain amount of pedological confusion is likely to persist for a number of years (in practical reality), given the circumstances surrounding the two classification systems (a point clearly evident in the section below). A partial correlation of the two systems is available from the Natural Resource Section, Cedara Agricultural Development Institute, Private Bag X9059, Pietermaritzburg, 3200.

13.4 Regional and sub-regional soil surveys in Natal/KwaZulu (prior to the 1991 taxonomic classification system)

13.4.1 Regional soil surveys

In the discussion which follows, it is important to bear in mind that the soils data refer to the 1977 classification system and earlier versions of the 1977 system. Virtually all the soils literature to-date (up to 1993), with the exception of a few academic rather than planning reports, refers to the 1977 system and/or previous versions. It will be some time before the 1991 system has been incorporated into the planning and scientific literature, with the availability of current data. (A similar problem exists in the geological literature - see the chapter on geology).

The most important soil survey undertaken in earlier years (covering some 30% of Natal/KwaZulu) was the Tugela Basin study. Much valuable experience was gained during the survey in respect of soil mapping and soil classification. The survey report with (13) 1 : 100 000 scale soil maps, remains an important source of data for the Tugela Basin and soils in general. Van der Eyk, MacVicar and De Villiers (1969 - above) mapped the Tugela Basin in terms of soil associations and their dominant soil series, with regard to soils of the Highlands and Midlands Mistbelt (upland and bottomland areas); the soils of the Interior Basins and Coast Hinterland (upland moist/dry sub-regions and bottomlands); the soils of the Interior River Valleys and the Lower Tugela Valley, and miscellaneous soil and land types (the latter of particular relevance to severe soil erosion). Important soil-landscape relationships as well as soil profile data are presented in the report. Readers should note that certain soil series identified in the survey were not included in the 1977 system.

Other important regional soil surveys in Natal/KwaZulu include two surveys undertaken by the then R.F. Loxton Hunting and Associates (now Loxton Venn and Associates) of Johannesburg. The two areas surveyed were Maputaland and the Natal South Coast. The reports were published in 1969/1970 and 1971 respectively (see the chapter on maps). De Villiers (1962)* provided a first approximation analysis of 14 soil zones for Natal/KwaZulu (updated and outlined in Phillips (1973) and Thorrington-Smith, Rosenberg and McCrystal (1978))**. The relevant data are presented in Table M1. A generalized soil map of Natal/KwaZulu was compiled by Fitzpatrick (1978)***, in which soils were classified into 19 soil groups. (Group 3 soils, for example, comprise yellow and red apedal, humic, freely drained, dystrophic soils). Such data have been used for scientific purposes inter alia by Schulze (1982)****. Drennan Maud and Partners, P O Box 30464, Mayville, 4058, undertook a land resources survey of KwaZulu in which soil pedological and land capability data were mapped at a scale of 1 : 100 000 (Table M2). Further data on soils in Natal/KwaZulu (in terms of bioclimatic groups) are discussed below. The major regional sources of pedological data however, are the Land Type memoirs and maps.

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* See De Villiers, J.M., 1962. A study of soil formation in Natal, Ph.D. Thesis, Department of Soil Science, University of Natal, Pietermaritzburg, 256 p. and maps.

** See Phillips, J., 1973. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps, as well as Thorrington-Smith, Rosenberg and McCrystal, 1978. Towards a plan for KwaZulu: a preliminary development plan, VOL 1, The written report, 341 p., and VOL 2, Atlas of maps and illustrations, various pages, KwaZulu Government, Ulundi. (Examine the relevant soil map in each publication. Both maps show the whole of Natal/KwaZulu, excluding East Griqualand).

*** See Fitzpatrick, R.W., 1978. Occurrence and properties of iron and titanium oxides in soils along the eastern seaboard of South Africa, Ph.D. Thesis, Department of Soil Science and Agrometeorology, University of Natal, Pietermaritzburg, 203 p. and map.

**** See Schulze, R.E., 1982. Agrohydrology and climatology of Natal, ACRU Report No. 14, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, 136 p., which contains a generalized soil map based on the Fitzpatrick soil classification.

Table M1: Soil zones of Natal/KwaZulu.

Soil zone	Bioclimatic group	Description	Dominant soil forms (forms most common in the area)	Key soil series (series most common to the given form)
1	3; 4; 5; 6 (2, 8)	Leached soils derived from Karoo rocks in the Highland Sourveld and Midlands Mistbelt	Clovelly Griffin Hutton Mispah	Clovelly Griffin Balmoral*, Doveton and Farningham* Mispah
2	2; 3; 4; 7 (1, 6, 10)	Leached or moderately leached soils of the Highland Sourveld and Coast Hinterland, derived from arenaceous sediments or the Basement Complex	Clovelly Hutton Inanda Magwa Mispah Nomanci	Newport, Oatsdale, Southwold and Springfield Hutton* Inanda Milford Klipfontein Nomanci
3	6; 8 (4)	Soils, many of which contain soft plinthite, derived from argillaceous Karoo sediments in the Moist Tall Grassveld	Avalon Clovelly Hutton Shortlands	Avalon Southwold Doveton* Shortlands*
4	8 (6)	Soils, most of which contain soft or hard plinthite or a natric horizon, derived from arenaceous Karoo sediments in the Dry Tall Grassveld	Avalon Clovelly Estcourt Glencoe Longlands Mispah Shortlands Wasbank	Leksand Springfield Uitvlugt Dunbar and Wesselsnek Longlands Klipfontein Shortlands* Wasbank
5	6; 8 (10)	Soils, most of which contain either plinthite or a natric horizon, derived from argillaceous Karoo sediments in the drier parts of the Tall Grassveld	Avalon Estcourt Mispah Shortlands	Avalon Estcourt Klipfontein Shortlands*
6	8; 10 (2, 3, 4)	Sodic and calcareous soils, derived from argillaceous Karoo sediments in the Dry Tall Grassveld	Arcadia Bonheim Cartref Estcourt Rensburg	Arcadia Bonheim Arrochar Estcourt Rensburg
7	8	Sodic and calcareous soils, derived from arenaceous Karoo sediments in the Dry Tall Grassveld	Arcadia Bonheim Estcourt Rensburg	Arcadia Bonheim Uitvlugt Rensburg

Table M1: Soil zones of Natal/KwaZulu (continued).

Soil zone	Bioclimatic group	Description	Dominant soil forms (forms most common in the area)	Key soil series (series most common to the given form)
8	1; 2; 3; 6; 8; 9; 10 (4)	Soils, many of which are concretionary, derived from glacial and other Karoo sediments in the Transition Veld, Coast, Forest and Southern Tall Grassveld (includes soils derived from pre-Karoo and Basement rocks in the Pongola River Valley)	Clovelly Estcourt Glencoe Glenrosa Longlands Mispah Shortlands Wasbank	Southwold Estcourt Glencoe Williamson Winterton Klipfontein Glendale and Shortlands* Warrick
9	1; 2; 10	Soils derived from rocks of the Basement Complex in the Coast Forest	Glenrosa Milkwood Mispah Shortlands	Williamson Dansland Mispah Glendale
10	1; 9; 10; 11	Soils derived from Stormberg basalt in the Coast Forest and Lowveld	Arcadia Shortlands	Arcadia and Rydalvale Shortlands
11	1; 2; 7; 9; 10 (3)	Soils derived from Table Mountain sandstone in the Coast Forest	Cartref Mispah Shortlands	Cartref Klipfontein Shortlands*
12	8; 9; 10; 11 (1, 4)	Soils derived from Karoo sediments in the Coast Forest and Lowveld	Arcadia Estcourt Glenrosa Milkwood Shortlands	Arcadia Estcourt and Uitvlugt Williamson Milkwood Shortlands*
13	7; 8; 10 (2, 6, 9)	Calcareous soils derived from Karoo sediments or the Basement Complex in the Valley Bushveld	Mispah Shortlands	Muden Ferry and Sunvalley
14	1	Regosolic soils derived from coast dunes	Fernwood Hutton	Fernwood Clansthal

<u>Source</u>: After Phillips, J., 1973. The agricultural and related development of the Tugela Basín and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps.

<u>See also</u>: De Villiers, J.M., 1962. A study of soil formation in Natal, Ph.D. Thesis, Department of Soil Science, University of Natal, Pietermaritzburg, 256 p. and maps.

Note:

(i) The asterisk denotes red soils derived from Karoo dolerite or drift material with a strong doleritic component. Dolerite intrusions are ubiquitous over most of Natal/KwaZulu.

(ii) The vegetation type names as recorded by De Villiers (1962) are those of Pentz (1945); Acocks (1953), and Edwards (1967) - see the chapter on catchments.

(iii) The Gemvale Series (soil zone 9) and the Greenhill Series (soil zones 2 and 8) were not included in the 1977 binomial soil classification system, and have been removed from the above table. The 1977 equivalent of the Gemvale Series is either the Skilderkrans Series (Swartland Form) or the Williamson Series (Glenrosa Form) - MacVicar, C.N., 1994. Personal communication, Cedara Agricultural Development Institute, Cedara.

(iv) Bioclimatic groups in which the soils occur to a minor extent are shown in brackets.

(v) The term "arenaceous" refers to soils with very little clay or silt, consisting mainly of sand sized particles. The term "argillaceous" refers to a substance composed of clay or with a considerable proportion of clay in its composition. The term "natric" (horizon) refers to a special type of argillic horizon which has a prismatic or more commonly a columnar or blocky structure, and which has more than 15% saturation with exchangeable sodium.

Table M2: Soil mapping units and their dominant soil forms in KwaZulu.

Unit	Description	Dominant soil forms
1	Red apedal soils low in bases	Hutton, Inanda and Nomanci
2	Yellow-brown apedal soils low in bases	Clovelly, Griffin, Kranskop and Magwa
3	Acid gley, bottomland soils	Katspruit
4	Red soils (non-calcareous)	Hutton and Shortlands
5	Yellow-brown apedal soils overlying a plinthic horizon	Avalon, Kroonstad, Longlands, Wasbank and Westleigh
6	Duplex soils	Estcourt, Sterkspruit, Swartland and Valsrivier
7	Margalitic soils	Arcadia, Bonheim and Willowbrook
8	Margalitic and non-margalitic gley soils	Rensburg
9	Brown (base saturated) soils	Mayo, Milkwood and Tambankulu

Table M2: Soil mapping units and their dominant soil forms in KwaZulu (continued).

Unit	Description	Dominant soil forms
10	Red calcareous soils	Hutton and Shortlands
11	Clayey, loamy and sandy alluvial soils	Dundee, Inhoek and Oakleaf
12	Shallow soils, highly eroded soils and rock outcrops	Cartref, Glenrosa and Mispah
13	Dry sandy soils	Clovelly and Fernwood
14	Wet sandy soils	Champagne, Fernwood and Kroonstad

Source: After Anonymous, 1987. Report to Secretary of Agriculture and Forestry KwaZulu Government, on a land resources survey of KwaZulu (soils and land capability), VOL 1, 7 p. + app., and VOL 2, Maps, various pages, Report No. 6458, Drennan Maud and Partners, Durban.

See also: Thorrington-Smith, Rosenberg and McCrystal, 1978. Towards a plan for KwaZulu: a preliminary development plan, VOL 1, The written report, 341 p., and VOL 2, Atlas of maps and illustrations, various pages, KwaZulu Government, Ulundi.

Note:

(i) Most of the 26 magisterial districts in KwaZulu are each shown on an individual map sheet, with some map sheets covering more than one magisterial district.

(ii) The land capability survey involved the study of existing climatological data as well as soils information - including erosion hazard - plus flooding frequency and topography, in order to identify zones of arable and non-arable (rainfed) potential.

(iii) Margalitic soils are soils with strongly developed structure in the A horizon and with a high base status. Duplex soils are defined in Footnote (i) of Table M17.

(a) Soils characteristic of bioclimatic groups in Natal/KwaZulu*

The data are presented by means of a series of tables (Tables M3 - M8). The data exclude East Griqualand (discussed separately below), and wetland soils (see later in the chapter). Throughout this discussion "deep" refers to the total soil above bedrock as more than 1,0 m thick; "moderately deep" refers to sola with a thickness of 0,4 - 1,0 m, and "shallow" to sola with a thickness of less than 0,4 m.

(i) Bioclimatic group 1 - Coastal Lowlands

The most common (index) soil series in the uplands are Cartref (16%), Glenrosa (11%), Williamson (8%), Shortlands (6%), and Clansthal (5%) (Table M3). The alluvial soils along the rivers are also an important category comprising 10% of the group.

Table M3: Some properties of soils of bioclimatic group 1.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Red, apedal and structured soils, clayey and loamy soils			
Clansthal (Hutton)	Dominant	Moderately acid medium sandy loam	Deep
Glendale (Shortlands)	Sub-dominant	Moderately acid sandy clay loam	Deep
Msinga (Hutton)	Rare	Moderately acid sandy loam	Deep
Shortlands (Shortlands)	Dominant	Moderately acid clay loam	Deep
Grey, apedal and structured soils			
Cartref (Cartref)	Dominant	Moderately acid medium sandy loam	Deep
Fernwood (Fernwood)	Dominant	Moderately acid medium sand	Deep

* Discussion based on Anonymous, 1973. Natal farming guide, Department of Agricultural Technical Services (Natal Region), Cedara, various pages, and Anonymous, 1974. Development programme for the Natal Region, Department of Agricultural Technical Services (Natal Region), Cedara, 273 p. + app. (The latter is a particularly informative publication). Note: The Logoza Series (Shortlands Form) in bioclimatic group 1 and the Cranwell Series (Willemsdal Form) in bioclimatic group 3, were not included in the 1977 classification system. The Willemsdal Form per se was excluded from the 1977 system.

Table M3: Some properties of soils of bioclimatic group 1 (continued).

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Glenrosa (Glenrosa)	Dominant	Moderately acid medium sandy loam	Moderately deep
Williamson (Glenrosa)	Dominant	Moderately acid sandy loam	Moderately deep

(ii) <u>Bioclimatic group 2 - Coastal Hinterland</u>

In the moist sub-regions 2a - 2c, Inanda and Trevanian are the main (index) soil series together with highly leached members of the Clovelly, Griffin and Hutton forms (Table M4). In the drier sub-regions 2d - 2f, Cartref Series and Williamson Series (index) soils occur extensively.

Table M4: Some properties of soils of bioclimatic group 2.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Clovelly (Clovelly)	Sub-dominant	Strongly acid clay loam or clay	Deep
Griffin (Griffin)	Sub-dominant	Strongly acid clay loam or clay	Deep
Hutton (Hutton)	Sub-dominant	Strongly acid clay loam	Deep
Inanda (Inanda)	Dominant	Strongly acid clay loam	Deep
Trevanian (Glenrosa)	Dominant	Strongly acid sandy clay loam or sandy loam	Moderately deep

(iii) Bioclimatic group 3 - Midlands Mistbelt

Index soils for this group (sub-regions 3a - 3c), include highly leached members of the Clovelly, Griffin and Hutton forms (Table M5). The Clovelly and Griffin forms constitute 75% of the upland arable soils, and the Hutton Form the balance. In the sub-humid (3d and 3e) (drier) sub-regions, soil series such as Vimy, Doveton, Newport, Southwold and Ixopo are important. Wetlands are a vital component of the landscape and must be carefully protected. Shallow soils of the Mispah Form occur throughout the Midlands Mistbelt, but are generally localized.

Table M5: Some properties of soils of bioclimatic group 3.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Red, apedal soils, clayey and loamy and low in bases			
Balmoral (Hutton)	Dominant	Strongly acid clay	Deep
Doveton (Hutton)	Sub-dominant	Strongly acid clay loam	Deep
Farningham (Hutton)	Dominant	Strongly acid clay loam	Deep
Hutton (Hutton)	Dominant	Strongly acid clay loam	Deep
Vimy (Hutton)	Sub-dominant	Moderately acid clay	Deep
Yellow, apedal, clayey soils low in bases			
Balgowan (Clovelly)	Sub-dominant	Strongly acid clay	Moderately deep
Clovelly (Clovelly)	Dominant	Strongly acid clay loam or clay	Moderately deep
Farmhill (Griffin)	Sub-dominant	Strongly acid clay	Deep
Griffin (Griffin)	Dominant	Strongly acid clay loam or clay	Deep
Mispah (Mispah)	Sub-dominant	Strongly acid clay loam or clay	Shallow
Newport (Clovelly)	Sub-dominant	Moderately acid clay loam	Moderately deep

(iv) Bioclimatic group 4 - Highland Sourveld

As with bioclimatic group 3, an important distinction must be made between landscapes characterized by highly leached soils (sub-regions 4a - 4e), and partially leached (sub-regions 4f and 4g) soils (Table M6). Index soils of the highly leached areas comprise the Hutton, Farningham, Cleveland and Griffin series (see bioclimatic group 3), as well as the Oatsdale and Clovelly series. Soils of the Mispah Form are common. Humic phase soils (over 10% organic carbon) also occur in sub-regions 4a - 4e (occupying up to 15% of the arable land). In sub-regions 4f and 4g, partially leached Doveton, Msinga, Newport and Southwold series are the main (index) soils.

Table M6: Some properties of soils of bioclimatic group 4.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Loamy soils			
Cleveland (Griffin)	Dominant	Strongly acid clay	Deep
Oatsdale (Clovelly)	Dominant	Strongly acid sandy clay loam	Moderately deep

(v) Bioclimatic group 5 - Montane

The soils occurring in this bioclimatic group are invariably (highly leached) humic phase soils of bioclimatic group 4.

(vi) Bioclimatic group 6 - Moist Tall Grassveld

The main soil series (partially to highly leached) are the Vimy, Doveton, Ruston, Bergville, Avalon, Leksand, Newport, Southwold, Springfield, Glencoe, Winterton and Albany series (Table M7). Soils of the Mispah Form are also common. The Doveton and Avalon series are regarded as the index soils for bioclimatic group 6.

Table M7: Some properties of soils of bioclimatic group 6.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Albany (Longlands)	Sub-dominant	Moderately acid medium sandy loam	Moderately deep
Avalon (Avalon)	Dominant	Moderately acid sandy loam	Deep
Bergville (Avalon)	Dominant	Moderately acid clay loam	Deep
Doveton (Hutton)	Dominant	Moderately acid clay loam	Deep
Glencoe (Glencoe)	Sub-dominant	Moderately acid sandy loam	Deep
Leksand (Avalon)	Dominant	Moderately acid loamy medium sand	Deep
Newport (Clovelly)	Sub-dominant	Moderately acid silty clay loam	Deep
Ruston (Avalon)	Dominant	Moderately acid silt loam	Deep
Southwold (Clovelly)	Sub-dominant	Moderately acid fine sandy loam	Deep
Springfield (Clovelly)	Sub-dominant	Moderately acid loamy fine sand	Deep
Vimy (Hutton)	Dominant	Moderately acid clay	Deep
Winterton (Longlands)	Sub-dominant	Moderately acid clay loam	Moderately deep

(vii) Bioclimatic group 7 - Valley Thornveld - Tugela

The soils are similar to those of bioclimatic group 10. The more important soil forms represented are Bonheim, Cartref, Estcourt, Glenrosa, Milkwood, Mispah, Rensburg and Shortlands.

(viii) Bioclimatic group 8 - Dry Tall Grassveld

Claypan (duplex) soils such as the Estcourt and Uitvlugt series (regarded as index soils for the group), occur extensively in both upland and bottomland positions, and are often associated with Rensburg Series (bottomland) soils (Table M8). In the vicinity of Estcourt, claypan soils are the most extensive and occupy 30 - 40% of the landscape. Up to 50% of such soils have been seriously eroded (see later in the chapter). Bottomland soils are easily recognized by the severe gully erosion found in these soils. Other important upland soils in this group are the Avalon, Leksand, Newcastle, Glencoe, Wasbank, Bluebank, Kroonstad, Longlands, Arcadia, Glendale and Msinga series.

Table M8: Some properties of soils of bioclimatic group 8.

Series (and form)	Dominance	Reaction and texture of top soil	Depth
Arcadia (Arcadia)	Dominant	Neutral clay	Moderate
Bluebank (Kroonstad)	Dominant	Slightly acid sandy clay loam	Moderate
Estcourt (Estcourt)	Dominant	Slightly acid loam	Moderate
Glendale (Shortlands)	Dominant	Moderately acid clay loam	Deep
Kroonstad (Kroonstad)	Dominant	Slightly acid sandy loam	Moderate
Msinga (Hutton)	Sub-dominant	Moderately acid sandy loam	Deep
Rensburg (Rensburg)	Dominant	Neutral clay	Moderate
Uitvlugt (Estcourt)	Dominant	Slightly acid loamy sand	Moderate
Wasbank (Wasbank)	Dominant	Moderately acid loamy medium sand	Moderate to shallow

(ix) Bioclimatic group 9 - Zululand Bush and Lowveld

The drier parts of this group as in bioclimatic group 8, are dominated by claypan and margalitic soils, many of which are calcareous. The most important soils belong to the Arcadia, Bonheim, Milkwood, Estcourt, Hutton (Shorrocks and Makatini series), Rensburg, Shortlands (Sunvalley Series), and Sterkspruit forms. Members of the Clovelly, Fernwood, Glenrosa, Kroonstad and Mispah forms are also found.

(x) Bioclimatic group 10 - Valley and Interior Thornveld

The soils are eutrophic, and claypan as well as margalitic soils are again prominent. A wide range of soils is evident representing the Arcadia, Bonheim, Milkwood, Estcourt, Shortlands (Ferry, Sunvalley and Tugela series), Hutton (Shorrocks and Makatini series), Sterkspruit, Westleigh, Glenrosa, Mayo, Swartland, Valsrivier and Rensburg forms. The alluvial soils (Dundee Form), are especially important since they are widely irrigated and are highly productive.

(xi) Bioclimatic group 11 - Arid Lowland

The soils are similar to those in groups 9 and 10. The main agricultural soils are the alluvial soils (Dundee Form) and the Ferry, Sunvalley and Tugela series (Shortlands Form), as well as the Zwartfontein, Shorrocks and Makatini series (Hutton Form).

(b) Dominant soils of East Griqualand

These soils are mainly mesotrophic, with a small area (part of sub-region 4e) of highly weathered dystrophic soils (Table M9). Red upland soils are the most extensive single type of soil, although yellow-brown upland soils, sandy soils, yellow-brown ferruginous soils (with water tables), and bottomland soils are also well represented (Bischof, 1980, quoted in Devereux, 1983 - see below).

Table M9: Dominant soil series in the bioclimatic sub-regions of East Griqualand.

Bioclimatic sub-region 4e	Bioclimatic sub-region 4f	Bioclimatic sub-region 8b	Bioclimatic sub-region 8c
Clovelly	Doveton	Avalon	Doveton
Griffin	Katspruit	Doveton	Katspruit
Hutton	Killarney	Katspruit	Killarney
Katspruit	Kroonstad	Kroonstad	Kroonstad
Longlands	Longlands	Longlands	Leksand
Mispah	Mispah	Rensburg	Mispah
	Southwold	Shortlands	Rensburg
	-	Southwold	-

Source: After Devereux, G.P., 1983. A review of the Kokstad extension ward, Cedara Report No. N/A/83/5, Department of Agricultural Technical Services (Natal Region), Cedara, 43 p.

13.4.2 Sub-regional soil surveys

Sub-regional soil surveys in Natal/KwaZulu (see the bibliographic database) have been undertaken by the Department of Agriculture; by forestry companies for their own land holdings (confidential information); by consulting engineering firms (usually for geotechnical requirements* such as town planning or for agricultural purposes - for example - proposed irrigation schemes); by the sugar industry (see below), and by the then Soil and Irrigation Research Institute, later the Institute for Soil, Climate and Water, Private Bag X79, Pretoria, 0001**. Numerous soil survey reports dating back to the early 1900s (mainly for irrigation schemes such as the Makatini scheme) are listed in the NATIN

* A useful geotechnical paper concerning inter alia landslide susceptibility in southern Africa is: Van der Merwe, W.J., 1990. Geotechnical investigations for roads, 1990 Annual Congress of the South African Institution of Civil Engineers, 8 - 11 April 1990, Cape Town, 62 p.

** The Institute is involved with the classification and study of the soil, water and climatic resources of South Africa, mainly from an agricultural perspective. The Institute was in the past (prior to semi-privatisation), and to some extent still is involved in basic research concerning the mineralogical, physical and chemical properties of soils, at a national level. Soil surveys for irrigation projects and investigations into physical (soil) properties are also undertaken, especially where brack and waterlogged conditions prevail. The Institute likewise undertakes soil, water and plant material analyses for the Department of Agriculture and other Government departments. Agricultural meteorological research and data collection forms part of the activities of the Institute (see the chapter on rainfall).

database. The database is maintained by the Institute (see Table B7 in Chapter 2). Many of the latter reports are confidential. Also confidential, are soil surveys undertaken by the Department of Agriculture on private farms. It is at the individual farm level that soil surveying has had the most impact in terms of improved land use, and consequently, agricultural production.

13.4.2.1 Soils data for the sugar growing areas of Natal/KwaZulu

Reference has already been made to the pioneering fieldwork undertaken by Beater (1957; 1959; 1962 - above) in the sugar areas of Natal in terms of soil mapping and classification. The data were revised by Beater (1970)*, who provided more comprehensive information on the soil series of the sugar belt. The work by Beater (1970) was subsequently updated using the 1977 binomial system (Anonymous, 1984)**. The latter publication is an important document with regard to the 33 soil forms, and approximately 130 soil series known to occur in the sugar growing areas of Natal/KwaZulu and the eastern Transvaal. Considerable progress has been made by the South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300, in terms of soil mapping (mainly on a 1 : 6 000 scale) at individual sugar farm level. The mapping includes new areas recently brought into cultivation (see Section 13.21).

13.5 Soil testing in Natal/KwaZulu

Soils in the sugar belt are tested by the South African Sugar Association Experiment Station. The Cedara Agricultural Development Institute undertakes testing for farmers (and others) in the remainder of Natal/KwaZulu. A fee is charged by the Experiment Station and Cedara. Most soil testing for agricultural purposes concerns soil fertility, in order to maximize production. Umgeni Water, P O Box 9, Pietermaritzburg, 3200, also provides a soil testing service. A few private laboratories - often linked to consulting (geotechnical)

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* See Beater, B.E., 1970. Soil Series of the Natal Sugar Belt, South African Sugar Association, Durban, 111 p.

** See Anonymous, 1984. Identification of the soils of the sugar industry, Bulletin No. 19 (revised), Experiment Station of the South African Sugar Association, Mount Edgecombe, 112 p. (It should be noted that the identification of individual soil forms/series in the sugar areas, is via mapped parent material and soil system or by use of the binomial system).

engineering firms - are likewise involved in soil testing. The various laboratories do not necessarily use the same procedures and methods.

13.6 Land Type maps covering Natal/KwaZulu*

The Land Type mapping programme was designed to cover the whole of South Africa. The fieldwork is now virtually complete. Three Land Type 1 : 250 000 scale topo-cadastral maps with accompanying memoirs are currently available for Natal/KwaZulu. (Each map has the same title as the respective memoir). The relevant memoirs/maps are as follows:

- Idema, S.W.J. (ed), 1988. Land Types of the map 2830 Richards Bay, Memoirs on the Agricultural Natural Resources of South Africa No. 11, Department of Agriculture and Water Supply, Pretoria, 823 p. (The memoir and map refer to an area of 2 503 440 ha).

- MacVicar, C.N. (ed), 1986. Land Types of the map 2632 Mkuze, Memoirs on the Agricultural Natural Resources of South Africa No. 6, Department of Agriculture and Water Supply, Pretoria, 225 p. (The memoir and map refer to an area of 891 930 ha).

- MacVicar, C.N. (ed), 1986. Land Types of the map 2730 Vryheid, Memoirs on the Agricultural Natural Resources of South Africa No. 7, Department of Agriculture and Water Supply, Pretoria, 596 p. (The memoir and map refer to an area of 1 897 600 ha).

The Durban, Port Shepstone, Harrismith, Drakensberg and Kokstad reports (presently being finalized), will not be released in a formally published format. The Frankfort report will only be completed at a later stage. The 1 : 250 000 scale Frankfort and Durban maps however, are available. The Frankfort map covers an area of 2 189 800 ha, while the Durban map covers an area of 1 380 870 ha. The maps and memoirs were/are being

* Discussion based on MacVicar, C.N. (ed), 1986. Land Types of the map 2730 Vryheid, Memoirs on the Agricultural Natural Resources of South Africa No. 7, Department of Agriculture and Water Supply, Pretoria, 596 p. (Readers should examine the publication in order to understand this section).

compiled by the Institute for Soil, Climate and Water, Pretoria (then of the Department of Agriculture and Water Supply), now of the Agricultural Research Council.

Each Land Type is an area displaying a marked degree of uniformity of soil pattern, macro-climate and terrain form (slope). The uniformity is such that there would be virtually no advantage in defining (on a country-wide basis), smaller more uniform landscape entities for the purposes of determining agricultural potential. Land Type maps accordingly, constitute the most comprehensive set of mapped soils data available in South Africa (excluding highly detailed regional and localized soil surveys). Tabulated data contained in each memoir include climatic parameters (rainfall, Class A pan evaporation, temperature, heat units and frost) as well as the area, slope and slope length of the crests, scarps, midslopes, footslopes and valley bottoms forming the landscape. Further important data are soil forms/series plus soil depth, clay content, soil texture and mechanical (agricultural) limitations. Various proportional data are likewise provided (see the example below). Specific (characteristic) soil profile data are included (where relevant), as well as a brief outline of the lithology.

Land Types are identified on the maps by different colours and a representative code. The origin of the code, for example Ab78a on map 2830 Richards Bay, is derived from the definition of nine broad soil patterns identified at the beginning of the overall survey. Specifically, map units Aa - Ai (the broad soil pattern of the A category), refer to the presence of yellow and red soils without water tables, belonging to one or more of the Clovelly, Griffin, Hutton, Inanda, Kranskop and Magwa forms, in which one or more of the forms cover at least 40% of the given area. In the Ab designation in particular, red dystrophic and/or mesotrophic soils occupy at least 40% of the Land Type, with yellow soils per se occupying less than 10% of the Land Type. The number 78 refers to the fact that 77 other Land Types with the same broad soil pattern had previously been identified elsewhere in South Africa. The specific Land Type in question is therefore the 78th parcel of land with the designation Ab. The postscript "a", indicates that other parcels of land with the same designation are found in the area covered by the Richards Bay map, but are separated by different Land Types. All parcels of land with the designation Ab78 a or b or c, will have the same broad soil pattern, climate and slope, whereas Ab77 for example, does not have exactly the same climate and/or slope or geology - although the broad soil pattern is the same as that found in the Ab78 Land Type.

Land Type maps were compiled by superimposing climate maps for a particular region over a pedosystem map, and identifying unique Land Type units. A Land Type inventory was then compiled using data collected during the terrain, soil and climate survey phases of the programme. Terrain units used in the inventory are divided into five categories, namely: 1 (a crest); 2 (a scarp); 3 (a midslope); 4 (a footslope), and 5 (a valley bottom). Using a different example, for instance Land Type Fb213 which covers an area of 1 380 ha (on map 2730 Vryheid), the tabulated data reveal that 75% of Land Type Fb213 comprises midslopes (terrain unit 3), with a specific area of 1 035 ha and a slope steepness ranging from 2 - 8%. The slope length varies from 100 - 500 m. The slope shape is convex to concave. The mechanical limitation rating indicates that some 623 ha have no mechanical limitations at all (or with many stones but still ploughable), while 415 ha have large stones and boulders or very shallow soils on rock, or exposed bedrock - making the soil unsuitable for cultivation.

The soil series/land classes and soil depth (per terrain unit - in this case units 3 and 5), are also described in a similar format*. Here for example, Mispah Series soils have a depth of 100 - 200 mm covering 30% or 311 ha of terrain unit 3, and 5% or 17 ha of terrain unit 5 (together occupying 23,8% or 328 ha of Land Type Fb213). The Mispah Series soil has 3 - 15% clay in the A horizon, with a fine to medium sand to sandy loam texture in the A horizon, where rock is the soil depth limiting material. The lowest point of the Land Type is 850 m above sea level. The lithology consists of shale, sandstone and quartzite of the Mozaan Group, with alluvium. More than 80% of the Land Type has slopes less than 8% (suitable for cultivation). Local relief (the difference in height between terrain units 3 and 5 which together comprise all of Land Type Fb213), is 30 - 90 m.

Climate zones are likewise discussed in each memoir. It is important to bear in mind that a specific climate zone may contain one or more Land Types. Every climate zone is allocated a number such as 308S (which covers Land Types Fb207 and Fb213). The letter S refers to the seasonal distribution of rainfall, namely, summer rainfall with a distinct period of relatively low rainfall in winter. The letters W and H are also used in the memoirs, where W represents winter rainfall (with a distinct period of relatively low rainfall in summer); and H indicates all year rainfall with no distinct period of relatively low rainfall.

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* Abbreviations used in terms of soil texture (class) and depth limiting material, refer to abbreviations listed in the 1977 binomial soil classification system (see MacVicar et al, 1977 - above).

The climate data are sometimes approximate (estimated), given inter alia that the total number of weather stations in South Africa is limited. Several climate zones have no station (for example, climate zone 308S). Alternatively, only a limited range of climate data may be available. The weather stations used for each climate zone are indicated in the memoir.

Certain overview climate data are listed in each memoir. The data - in terms of rainfall - include the mean annual total from the station with the highest and the lowest mean annual rainfall respectively; the mean annual total from the mean annual totals of all stations, and the mean of (mean) monthly totals from all stations. The probable monthly rainfall threshold which can be expected to be exceeded for each month, for 60% and 80% of years respectively, is also indicated.

13.6.1 Bioresource units and groups

Numerous bioresource units or BRUs have been demarcated in Natal/KwaZulu using the wealth of data obtained during the Land Type surveys (Camp, 1994)*. A BRU consists of one or more Land Types which have a reasonable degree of uniformity with regard to agricultural production (including grazing) as well as the production techniques applicable to the area - in terms of climate, geology, topography, soils, adapted crops, pastures and timber, plus their yield characteristics**. Nine 1 : 250 000 scale maps are available for Natal/KwaZulu as paper prints and as transparent overlays for the 1 : 250 000 scale topo-cadastral map series. The BRU maps were produced by means of a Geographic Information System (GIS) maintained by the Natural Resource Section at the Cedara Agricultural Development Institute.

An important new procedure which follows on from the BRU maps, concerns bioresource group maps of Natal/KwaZulu. Bioresource group maps were compiled by combining BRUs into 23 bioresource groups, on the basis of vegetation types and climate. The principle employed in bioresource group maps is similar to the bioclimatic group concept pioneered

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* Camp, K., 1994. Personal communication, Cedara Agricultural Development Institute, Cedara.

** A grouping of soil classes according to dryland pasture production potential in Natal/KwaZulu (with map) can be found in Schulze, R.E., 1982. Agrohydrology and climatology of Natal, ACRU Report No. 14, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, 136 p.

by Phillips (1973 - see earlier)*. Bioresource group maps can be used inter alia to indicate the primary production areas in Natal/KwaZulu for 22 crops including commercial forestry plantations (refer to the chapter on catchments). A 1 : 500 000 scale map plus the inventory (contained in a memoir), may be published at a later date by the Natural Resource Section at Cedara (Camp, 1994).

13.6.2 Some implications of Land Types

It is evident that the Land Type maps and memoirs as well as the bioresource maps are a "treasure-trove" of information. Scotney (1995)** observed that the Land Type surveys have placed South Africa in the forefront of the few countries which have developed a standardized natural resources inventory for detailed planning purposes. Land Type data for Natal/KwaZulu (digitised at the 1 : 50 000 fieldwork scale on GIS) - and which form part of the NATIN database - are available at a specified cost from the Institute for Soil, Climate and Water office at the Cedara Agricultural Development Institute. The data can be used for a variety of scientific and planning applications including hydrological modelling; for the geographic determination of wind and water erosion-susceptible land (and extant erosion per terrain unit in each Land Type), as well as for geotechnical purposes, for example, to establish the location of heaving clays and waterlogged soils (at a reconnaissance scale).

Land Type maps can also be used to accurately determine the distribution and extent of wetland soils, thereby improving the management and protection of wetlands (see below). The importance of the wetlands data should not be underestimated in view of the urgent need to formulate a widely acceptable definition of wetlands in Natal/KwaZulu. An inventory of all wetlands (of a particular size), together with a suitable classification system is therefore required. A realistic balance between the need for wetland conservation and present utilization, across Natal/KwaZulu, may then be possible. Land Type maps might also be used to assess the current status of wetlands, by comparison

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* A useful correlation between bioresource groups and four other methods of classifying vegetation/climate - including bioclimatic groups - can be found in the following publication: Camp, K.G.T. and Smith, J.M.B., 1994. Veld management planning in KwaZulu-Natal, Cedara Report No. N/A/94/44, Cedara Agricultural Development Institute, KwaZulu-Natal Department of Agriculture, Cedara, 143 p.

** Scotney, D.M., 1995. Personal communication, Department of Agriculture, Pretoria.

with earlier (historical) soil or topographic maps. The primary purpose of Land Type information however, is to provide data for agricultural planning and production requirements - such as the development of new irrigation schemes and for the improved utilization of pastures and cultivated land*. Scotney (1995) stressed the vital importance of correctly interpreting soil survey information for optimum land use planning, especially in the agricultural and forestry sectors.

The Department of Agricultural Engineering in association with the Computing Centre for Water Research, University of Natal, Private Bag X01, Scottsville, 3209, and the Institute for Soil, Climate and Water is currently engaged in developing several programs (in terms of an interactive soils decision support system incorporated in the ACRU Model), in order to obtain hydrologically relevant information from the Land Type database (Schulze, Angus and Guy, 1991)**. Data will then be available for individual soil series of a terrain unit/s within a Land Type. Averaged values for a given Land Type/s, or for a defined catchment (consisting of several Land Types), will likewise be available. An important advance was the interfacing of the Land Type GIS with hydrological models (namely, the ACRU Model), which was pioneered in the Mgeni catchment***. Further research work being undertaken by the Department of Agricultural Engineering involves the development of a computerized spatial analysis model (a digital Land Type terrain model). Research is also being undertaken on the estimation of the soil erodibility rating (K) parameter (at terrain unit and Land Type level), where (K) is used inter alia in the Universal Soil Loss Equation (USLE) Model and the Water Erosion Prediction Project (WEPP) Model.

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* Natal per se is the most intensively farmed region of South Africa. In 1982 (excluding KwaZulu), there were approximately 7 482 farm units in Natal covering 40 220 km^2, with a mean farm unit size of 538 ha (compared with 437 ha, 20 years earlier) (Schulze, 1982 - above).

** See Schulze, R.E., Angus, G.R. and Guy, R.M., 1991. Making the most of soils information: a hydrological interpretation of southern African soil classifications and data bases, Proceedings of the Fifth South African National Hydrological Symposium, South African National Committee for the International Association of Hydrological Sciences and the Division of Water Engineering of the South African Institution of Civil Engineers, 7 - 8 November 1991, Stellenbosch, 12 p.

*** See Tarboton, K.C. and Schulze, R.E., 1992. Distributed hydrological modelling system for the Mgeni catchment, WRC Report No. 234/1/92, Water Research Commission, Pretoria, 111 p.

13.7 Some soil studies in the coastal and afforested areas of Natal/KwaZulu

Selected data on sands in Natal/KwaZulu are presented in Tinley (1971; 1985)*. Tinley (1971) provided information on sandy soils in the Lake St Lucia area, with particular reference to shallow groundwater as well as vegetation. Tinley (1985) discussed some properties of coastal dune sands, with a brief review of water relations. Tinley (1985) observed that soils of the Fernwood, Hutton, Lamotte and Westleigh forms are common in coastal areas.

Schönau and Fitzpatrick (1981)** examined soils suitable for the cultivation of wattle, pine, Eucalypts and Poplar trees. Soils in most of the commercially afforested areas in Natal/KwaZulu are generally strongly to slightly acid and are highly leached. The dominant soil form in Maputaland (in the environs of Mbazwana) is the Fernwood Form with sandy Hutton Form soils likewise evident. In northern Natal/KwaZulu the Bainsvlei, Clovelly, Griffin and Hutton forms are dominant, with Glenrosa and Mispah Form soils also apparent. In the coastal forestry areas of the Zululand region (Richards Bay and St Lucia), the dominant soil is the Fernwood Form, with Avalon, Bainsvlei, Glencoe, Hutton, Kroonstad and Longlands forms also important. In the inland plateaux areas of the Zululand region (around Eshowe), Clovelly, Griffin and Hutton Form soils predominate, with Glenrosa, Inanda, Magwa, Mispah and Nomanci forms common. Bainsvlei, Clovelly, Griffin and Hutton Form soils are dominant in forestry areas of the Natal Midlands, with Glenrosa, Inanda, Magwa, Mispah and Nomanci Form soils of less importance. Finally, in southern Natal/KwaZulu (bordering the Transkei), Clovelly, Glenrosa, Griffin, Hutton and Mispah Form soils are dominant, with Inanda, Magwa and Nomanci Form soils also found.

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* See Tinley, K.L., 1971. Lake St Lucia and its peripheral sand catchment: the ecology and implications of proposals to reprieve a condemned system, Wildlife Society of South Africa, Durban, 62 p. + app., and Tinley, K.L., 1985. Coastal dunes of South Africa, South African National Scientific Programmes Report No. 109, Foundation for Research Development, CSIR, Pretoria, 300 p. and map.

** See Schönau, A.P.G. and Fitzpatrick, R.W., 1981. A tentative evaluation of soil types for commercial afforestation in the Transvaal and Natal, South African Forestry Journal, No. 116, March 1981, p. 28 - 39. See also, Schönau, A.P.G. and Aldworth, W.J.K., 1991. Site evaluation in Black Wattle with special reference to soil factors, South African Forestry Journal, No. 156, March 1991, p. 35 - 43.

13.8 A brief overview of wetland soils in Natal/KwaZulu*

According to MacVicar (1970), wetland soils usually comprise two main horizons, namely, a top soil which is relatively rich in organic matter and dark in colour, and a subsoil gley merging, at depth, with rock. In wetlands mainly derived from fine-grained sediments or dolerite, a black, heaving montmorillonitic clay top soil with a gleyed clay subsoil is evident (for example, the calcareous Rensburg Series and the non-calcareous Phoenix Series). Gley refers to soils which have been (in the past), or are presently subject to intense chemical reduction due to prolonged saturation with water. Insoluble ferric iron (which gives red and yellow colours to soil) is reduced under saturated, anaerobic (hydromorphic) conditions to soluble ferrous iron - which either remains in the soil solution, or is removed by natural drainage. The result is that sandy materials become light grey in colour (often with red and yellow mottles) and clays become dark grey, with reddish, yellow and in extreme cases, bluish and greenish mottles. (The more severe the process has been, the less frequent are the red and yellow colours). Soil scientists accordingly, refer to gleyed sands (friable) and gleyed clays (firm) (materials which have been gleyed). Wet soils provide a suitable medium for the rapid alteration of primary weatherable minerals to clays. Only highly quartzitic materials remain as porous, gleyed sands. Gleyed clayey soils therefore, are more common than gleyed sands. Gleys are typically found in wetlands, but also occur in upland soils (in specific conditions) (MacVicar, 1970).

Relatively few wetland soil series are evident. True wetlands (in bottomland positions) are characterized by soils with gleyed horizons (as noted above), and include all soils with G horizons of the Champagne, Katspruit, Rensburg and Willowbrook forms (Hill, Scotney and

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* Discussion based on MacVicar, C.N., 1970. Vlei soils of Natal, In: Shone, F.K. (ed), Vleis of Natal: Proceedings of the Symposium held at Pietermaritzburg, South African Institute for Agricultural Extension (Natal Branch), 12 May 1970, Pietermaritzburg, p. 9 - 18., as well as Hill, P.R., Scotney, D.M. and Wilby, A.F., 1981. Wetland development: ridge and furrow system (revised), Report No. N11/1981, Department of Agriculture and Fisheries (Natal Region), Cedara, 45 p., plus Scotney, D.M. and Wilby, A.F., 1983. Wetlands and agriculture, Journal of the Limnological Society of Southern Africa, VOL 9(2), p. 134 - 140. A useful report containing the latest research findings - not reflected in the above discussion - is the following: Kotze, D.C., Hughes, J.C., Breen, C.M. and Klug, J.R., 1994. The development of a wetland soils classification system for KwaZulu/Natal, WRC Report No. 501/4/94, Water Research Commission, Pretoria, 32 p. (A journal paper is also available: Kotze, D.C., Klug, J.R., Hughes, J.C. and Breen, C.M., 1996. Improved criteria for classifying hydric soils in South Africa, South African Journal of Plant and Soil, VOL 13(3), p. 67 - 73). See also the chapter on wetlands and pans, elsewhere in this publication.

Wilby, 1981; Scotney and Wilby, 1983)*. Soils of the Champagne and Katspruit forms in particular, have a high organic content in the O and A horizon respectively. Soils with gleyed horizons found in upland areas include the Avalon, Cartref, Fernwood, Wasbank, Estcourt, Kroonstad and Longlands forms. Many non-gleyed soils (such as the Dundee, Oakleaf, Valsrivier and Bonheim forms) are found on floodplains closely associated with wetlands, and are periodically flooded. Some important characteristics of wetland soils including the erosion hazard are listed in Table M10. Scotney and Wilby stressed that further research on the specific erosion hazard rating of wetland soils is required (notwithstanding the derivation of overall erosion indices for such and other soils, as outlined in Table M13).

Poorly drained soils in general - including wetland soils - present obvious dangers in terms of on site sanitation systems, especially where VIP (Ventilated Improved Pit) latrines are constructed in high concentrations. (See the chapters on water quality, water supply planning, and sanitation). Shallow Mispah Form soils consisting of an A horizon overlying hard rock (often shale), hardpan ferricrete/calcrete/silcrete (a strongly cemented layer consisting of sesquioxides), or dorbank - as well as shallow Milkwood Form soils (also with an A horizon overlying hard rock, hardpan or dorbank), are particularly at risk in this regard. For example, problems have been experienced with effluent seepage from VIP latrines in shallow Mispah soils in the Edendale Township (Pietermaritzburg). Current planning procedures (although this was not always the case), require the compilation of detailed geotechnical reports for new urban areas, in order to determine the suitability of soils for construction and on site sanitation purposes. (Several reports are listed in the bibliographic database). Detailed soil surveys are now also required for the planning of new waste disposal sites (again, such restrictions did not always apply in the past).

* Horizons second or third in vertical sequence (in the subsoil) provide the best indication of the degree of wetness, especially the E, G and gleycutanic horizons. Bottomland soils tend to be clayey (>35% clay), while the clay content of the E horizon in the Kroonstad, Longlands and Cartref forms is often between 6 - 35%. Stonelines and narrow gravelly horizons, which permit the lateral movement of shallow groundwater, are common in many lower slope positions adjacent to wetlands.

Table M10: Some properties of certain wetland (bottomland) soils.

Form and series	Code	Overall drainage	Erosion hazard	Presence of water table	Shrink-swell potential	Agricultural limitations
Champagne						
Champagne	Ch 11	Very poor	Low-moderate	Permanent	Very high	Severe waterlogging; high shrinkage; extreme acidity of Mposa and Stratford series
Ivanhoe	Ch 21	Very poor	Low	Permanent	Very high	
Mposa	Ch 10	Very poor	Low-moderate	Permanent	Very high	
Stratford	Ch 20	Very poor	Low	Permanent	Very high	
Dundee			Stream bank			
Clay	Du 10	Moderately well drained	Moderate	Rare	Variable	Periodic flooding; sediment deposition; sands droughty with nematodes
Loam		Well drained	High	Rare	Low	
Sand		Excessive drainage	Very high	Rare	Very low	
Katspruit						
Katspruit	Ka 10	Very poor	Low	Permanent	Moderate	Waterlogging; occasional flooding; puddling and poor workability; frost damage
Killarney	Ka 20	Very poor	Low-moderate	Semi-permanent	Moderate-high	
Oakleaf						
(Non-red, non-calcareous) Sands	Oa 30-35	Somewhat excessive	Moderate	Rare	Very low	As for Dundee but flooding less severe
Jozini	Oa 36	Well drained	Low	Rare	Low	
Koedoesvlei	Oa 37	Well drained	Very low	Rare	Low-moderate	

Table M10: Some properties of certain wetland (bottomland) soils (continued).

Form and series	Code	Overall drainage	Erosion hazard	Presence of water table	Shrink-swell potential	Agricultural limitations
(Non-red, calcareous) Sands	Oa 40-45	Somewhat excessive	High	Rare	Low	
Limpopo	Oa 46	Well drained	Moderate	Rare	Low-moderate	
Mutale	Oa 47	Moderate	Low	Rare	Moderate	
Rensburg						
Phoenix	Rg 10	Poor	High	Semi-permanent	Very high	High erodibility; impeded drainage; poor workability; brack hazard in Rensburg Series
Rensburg	Rg 20	Poor	High	Semi-permanent	Very high	
Willowbrook						
Chinyika	Wo 21	Poor	Moderate-high	Semi-permanent	High	Impeded drainage; periodic flooding; poor workability
Emfuleni	Wo 10	Poor	Moderate	Semi-permanent	Moderate	
Sarasdale	Wo 20	Poor	Moderate-high	Semi-permanent	Moderate	
Willowbrook	Wo 11	Poor	Moderate	Semi-permanent	High	

<u>Source</u>: After Scotney, D.M. and Wilby, A.F., 1983. Wetlands and agriculture, <u>Journal of the Limnological Society of Southern Africa</u>, VOL 9(2), p. 134 - 140.

See also:

(i) Kotze, D.C., Hughes, J.C., Breen, C.M. and Klug, J.R., 1994. The development of a wetland soils classification system for KwaZulu/Natal, WRC Report No. 501/4/94, Water Research Commission, Pretoria, 32 p. (A journal paper is also available: Kotze, D.C., Klug, J.R., Hughes, J.C. and Breen, C.M., 1996. Improved criteria for classifying hydric soils in South Africa, South African Journal of Plant and Soil, VOL 13(3), p. 67 - 73).

(ii) Schulze, R.E., 1984. Hydrological models for application to small rural catchments in southern Africa: refinements and development, WRC Report No. 63/2/84, Water Research Commission, Pretoria, 248 p. + app. (The relevant chapters were re-published as (iii) and (iv) below).

(iii) Schulze, R.E., 1985. Hydrological characteristics and properties of soils in southern Africa, 1: runoff response, Water SA, VOL 11(3), p. 121 - 128.

(iv) Schulze, R.E., Hutson, J.L. and Cass, A., 1985. Hydrological characteristics and properties of soils in southern Africa, 2: soil water retention models, Water SA, VOL 11(3), p. 129 - 136.

Note:

(i) Refer to Table M13 for the names of soil series coded as Oa 30 - 35 and Oa 40 - 45 (Oakleaf Form).

(ii) The erosion hazard indicated in the above table, is not necessarily in accordance with Table M13.

(iii) Various agricultural management recommendations for the cultivation of wetland soils are outlined in Scotney and Wilby (1983).

(iv) The agricultural potential (with land improvement) of the Dundee and Oakleaf forms is high, and moderate to high for the Katspruit Form soils. The agricultural potential of the Willowbrook Form soils is moderate, low to moderate for Rensburg Form soils, and low for Champagne Form soils.

(v) MacVicar, C.N., 1970. Vlei soils of Natal, In: Shone, F.K. (ed), Vleis of Natal: Proceedings of the Symposium held at Pietermaritzburg, South African Institute for Agricultural Extension (Natal Branch), 12 May 1970, Pietermaritzburg, p. 9 - 18., observed that wetland soils in bottomland positions in bioclimatic groups 3 and 4 areas (Midlands Mistbelt and Highland Sourveld respectively), typically consist of Champagne, Ivanhoe, Katspruit and Warrington series. Katspruit, Killarney and occasionally Rensburg series soils are typical of bottomland wetlands in the Moist Interior Basins of the Tugela Basin. In the Dry Interior Basins of the Tugela Basin, Rensburg and occasionally Killarney series soils are found in bottomland wetlands. In the Coastal Lowlands (bioclimatic group 1), the Phoenix Series (identical to the Rensburg Series, except that the former is not calcareous), occur in landscapes comprising clayey soils (derived from shales, dolerite, schist and fine-grained sandstones). By contrast, Warrington Series soils are found in areas of Recent sands. In arenaceous landscapes excepting Recent sands, Katspruit and to some extent Warrington series are common wetland soils. Very acid (peat) Mposa Series soils are found in permanently wet swamps (often near sea level), mainly to the north of Mtunzini. In the Arid Lowland (bioclimatic group 11) - in the vicinity of Mkuze, the Makatini Flats and Pongola - the main wetland soils are those of the Rensburg and sometimes the Killarney series. In semi-arid areas in the environs of Weenen, few intact wetlands are found, although Rensburg and Weenen series soils occur where water collects (resulting in waterlogging for a few months each year). With reference to the wetland soils distribution pattern described by MacVicar (1970), Begg (1988 - see (vii) below) found that in the Mfolozi catchment, 24,5% of the landscape (falling within bioclimatic group 1) was occupied by wetlands. The next most important category was bioclimatic group 6 (7,1% of the landscape), with 4,3%; 2,8% and 2,4% of the landscape covered by wetlands in bioclimatic groups 8, 9 and 4 areas respectively. The proportion of the landscape covered by wetlands in bioclimatic groups 2, 3 and 10 areas was 0,5%; 1,2% and 0,9% respectively. Soils information (and other relevant data such as hydrology) for wetlands are also presented in Begg, G., 1989. The wetlands of Natal (Part 3): the location, status and function of the priority wetlands of Natal, Natal Town and Regional Planning Commission Report, VOL 73, Pietermaritzburg, 256 p. and map.

(vi) Begg, G., 1986. The wetlands of Natal (Part 1): an overview of their extent, role and present status, Natal Town and Regional Planning Commission Report, VOL 68, Pietermaritzburg, 114 p., with reference to the Tugela Basin, observed that alluvial soils comprise 901 km^2 or 3,1% of the Basin, with acid gley soils such as the Katspruit Form, comprising 390 km^2 (1,4% of the area of the Basin)*. Margalitic and non-margalitic gley soils (for example, the Rensburg Form), covered 3 450 km^2 (12,0% of the Basin). In total, some 16,5% or 4 741 km^2 of the Basin was covered by hydromorphic bottomland soils (out of a total area of 28 702 km^2). As described later in this chapter however, many of the wetlands in the Tugela Basin have been destroyed by overgrazing and sheet or gully erosion, and the data quoted refer to the situation in 1969. Today, the extent of wetland degradation (notwithstanding remedial measures) is likely to be more severe.

* Data drawn from Van der Eyk, J.J., MacVicar, C.N. and De Villiers, J.M., 1969. Soils of the Tugela Basin: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 15, Pietermaritzburg, 263 p. and maps.

(vii) Begg, G., 1988. The wetlands of Natal (Part 2): the distribution, extent and status of wetlands in the Mfolozi catchment, Natal Town and Regional Planning Commission Report, VOL 71, Pietermaritzburg, 278 p. and map, provided overview data in terms of 43 quaternary sub-catchments; and the distribution of wetlands in the sub-catchments. The data include soils, geology, veld types, bioclimatic and physiographic regions, altitude, mean annual precipitation and mean annual runoff, as well as land use.

13.9 Some primary publications on soils with special reference to Natal/KwaZulu (see also the publications list for soil erosion)*

- Anonymous, 1984. Identification of the soils of the sugar industry, Bulletin No. 19 (revised), Experiment Station of the South African Sugar Association, Mount Edgecombe, 112 p.

- Anonymous, 1984. Natal Midlands subregion: identification and properties of soils-course notes, Department of Agriculture (Natal Region), Cedara, 61 p.

- Anonymous, 1987. Report to Secretary of Agriculture and Forestry KwaZulu Government, on a land resources survey of KwaZulu (soils and land capability), VOL 1, 7 p. + app., and VOL 2, Maps, various pages, Report No. 6458, Drennan Maud and Partners, Durban.

- Du Plessis, J.P., 1995. Modelling of flow phenomena in porous media, WRC Report No. 585/1/95, Water Research Commission, Pretoria, 70 p.

- Fitzpatrick, R.W., 1978. Occurrence and properties of iron and titanium oxides in soils along the eastern seaboard of South Africa, Ph.D. Thesis, Department of Soil Science and Agrometeorology, University of Natal, Pietermaritzburg, 203 p. and map.

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* There was no local journal which catered exclusively for academic papers on soils, prior to the advent of the South African Journal of Plant and Soil in 1984. Much valuable material can be found in conferences of the Soil Science Society of South Africa. The latter, unfortunately, are difficult to obtain. Readers should contact the Society as well as the Institute for Soil, Climate and Water, both in Pretoria (see addresses at the end of the chapter).

- Harmse Von M., H.J., Van der Watt, H. v. H., Van Rooyen, T.H. and Burger, R. du T., 1984. Glossary of soil science terms, Soil Science Society of South Africa, Pretoria, 140 p. (This publication is highly recommended).

- Idema, S.W.J. (ed), 1988. Land Types of the map 2830 Richards Bay, Memoirs on the Agricultural Natural Resources of South Africa No. 11, Department of Agriculture and Water Supply, Pretoria, 823 p.

- Johnston, M.A., 1994. An evaluation of the four-electrode and electromagnetic induction techniques of soil salinity measurement, WRC Report No. 269/1/94, Water Research Commission, Pretoria, 191 p.

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13.10 Soil erosion in Natal/KwaZulu

13.10.1 Some causes of soil erosion*

A number of factors contribute to the process of soil erosion (excluding longer term geological and climatic parameters). The assumption is made that geologically normal rates of erosion operate within natural ecosystems which are in dynamic equilibrium. Accelerated soil erosion is an essentially man-induced process, which occurs at an increased (although highly variable) rate under conditions of ecological disequilibrium. Factors determining shorter term soil erosion include **climate**, which influences the effectiveness of hydrodynamic or aerodynamic processes and rainfall energy; **parent (or host) material** where the primary influence concerns the presence or absence of erodible

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* Discussion based on Dardis, G.F., Beckedahl, H.R., Bowyer-Bower, T.A.S. and Hanvey, P.M., 1988. Soil erosion forms in southern Africa, In: Dardis, G.F. and Moon, B.P. (eds), Geomorphological Studies in Southern Africa, A.A. Balkema, Rotterdam, p. 187 - 213., as well as Beckedahl, H.R., Bowyer-Bower, T.A.S., Dardis, G.F. and Hanvey, P.M., 1988. Chapter 12. Geomorphic effects of soil erosion, In: Moon, B.P. and Dardis, G.F. (eds), The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, p. 249 - 276. See also, Garland, G.G., 1995. Soil erosion in South Africa: a technical review, Directorate of Resource Conservation, National Department of Agriculture, Pretoria, 52 p. (The report cites some 100 references on soil erosion in this country).

material; the **vegetation cover** influencing runoff, infiltration, interception and peak discharge; plus the **surface and/or subsurface soil texture** which affects the infiltration capacity and rate as well as the patterns of interflow. Other factors include the **presence or absence of a surface or near surface impermeable layer** influencing infiltration, seepage, solution, dispersion or dissolution of surface or subsurface materials - and accordingly - the potential for the development of surface cracking, piping, tunnels and cavities; **human interference** such as overgrazing, building practices and land use; the **ecological balance** implying the extent to which for instance, vegetation and the type and intensity of land use contribute to disequilibrium conditions and finally, the **rock strength** which affects the penetration depth and the rate of operation of the erosion process. Also of significance is **water quality** which can play a major role, especially on irrigated land.

The parameters determining the extent and severity of natural soil erosion in southern Africa are highly complex. Water and wind are the main geomorphic agents with inter alia human interference acting as a catalyst - resulting in accelerated rates of erosion. The mechanical process of soil erosion occurs when the disaggregating forces and the forces of removal, overcome the forces of internal resistance within the soil. Intense soil erosion may then occur which persists until a new equilibrium has been achieved (Dardis, Beckedahl, Bowyer-Bower and Hanvey, 1988; Beckedahl, Bowyer-Bower, Dardis and Hanvey, 1988).

The forms of water which are important in soil erosion are rainfall, surface flow and subsurface flow, with sea water playing a role in coastal areas. The erosive effect of rainfall is mainly dependent on its physical characteristics, namely: the rate and extent, the frequency of occurrence, the velocity of the raindrops and their direction of fall - together with soil characteristics (particularly texture and soil chemistry) - as well as vegetation cover and topography. Rainfall accordingly, is responsible for much of the initial breakdown of the soil structure (frequently through rainsplash), whereas total soil losses are primarily determined by the erosive power and transporting ability of surface flow. Surface flow, in addition, carries away material loosened by other erosive agents. Erosion caused by surface flow can be divided into unconfined and confined aspects. Unconfined erosion is due to sheetwash, sheetflow and sheetflooding. By contrast, confined erosion results from accumulated sheetwash or channel flow (represented by various stages of rill and gully development). A further form of confined erosion involves the development of subsurface soil pipes (largely attributed to subsurface flow), where the roof and side walls of the soil pipes or tunnel networks sometimes collapse, creating surface features. The chemical properties of the water can affect the latter process (Beckedahl et al, 1988).

Wind erosion results in the removal of top soil and surface lowering. Wind erosion occurs primarily in areas with a low precipitation and high temperatures, and with fine sandy soils (less than 15% clay). Open landscapes (especially with a lack of protective vegetal cover), offer little wind resistance. The prevailing wind direction and speed are the most important (non-soil) factors influencing wind erosion. Wind-induced soil movement is a complex process involving suspension, saltation - a bouncing movement of individual particles - and creep (associated with particle sizes of <0,1 mm; 0,1 - 0,5 mm and >0,5 mm respectively). Of particular importance is deflation (the large scale removal of fine material). The erosion of coastal dune systems - which from an ecological perspective is highly significant in view of the pressure on the coastal zone - constitutes something of a special case of wind erosion. Accordingly, dune "blow outs" (akin to sand movement in an egg timer), can result in serious damage inter alia to dune vegetation*.

In essence, a variety of factors establish the potential for erosion in any specific area, with the extent of erosion (excluding longer term processes), largely dependent on land management and use. Most regions of southern Africa are susceptible to erosion, some highly so (including parts of Natal/KwaZulu) (Beckedahl et al, 1988). Fears (not necessarily based on reality), have long been expressed regarding desert encroachment in South Africa**.

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* For a further discussion, see Tinley, K.L., 1985. Coastal dunes of South Africa, South African National Scientific Programmes Report No. 109, Foundation for Research Development, CSIR, Pretoria, 300 p. and map. (Note that the map illustrates the erosional status of the South African coastline).

** See for example, Kokot, D.F., [1955]. Desert encroachment in South Africa, African Soils, VOL 3(3), p. 402 - 409. See also, Bond, W.J., Stock, W.D. and Hoffman, M.T., 1994. Has the Karoo spread? A test for desertification using carbon isotopes from soils, South African Journal of Science, VOL 90(7), p. 391 - 397., as well as Bousman, B. and Scott, L., 1994. Climate or overgrazing?: the palynological evidence for vegetation change in the eastern Karoo, South African Journal of Science, VOL 90(11/12), p. 575 - 578. Examine likewise Dean, W.R.J., Hoffman, M.T. and Willis, C.K., 1996. The light and the way in South African desertification research, South African Journal of Science, VOL 92(4), p. 170 - 171. For a further perspective see Botha, G.A., De Villiers, J.M. and Vogel, J.C., 1990. Cyclicity of erosion, colluvial sedimentation and palaeosol formation in Quaternary hillslope deposits from northern Natal, South Africa, Palaeoecology of Africa and the Surrounding Islands, VOL 21, p. 195 - 210., as well as Botha, G.A., Wintle, A.G. and Vogel, J.C., 1994. Episodic late Quaternary palaeogully erosion in northern KwaZulu-Natal, South Africa, Catena, VOL 23(1/2), p. 327 - 340.

13.11 The classification of soil erosion in southern Africa

13.11.1 Soil erosion features

Two tables are presented. The first (Table M11), is a simplified classification of soil erosion features based on soil surface morphology. Subsurface processes are not considered. The classification is not comprehensive and provides a simple, practical method for the rapid field and aerial photographic assessment of the degree of erosion severity in southern African countries (Anonymous, 1981)*. Seven types of erosion caused by water as well as one type of erosion caused by wind constitute the primary categories of the system. The soil erosion classification system identifies the degree and intensity of erosion by means of five classes, namely: Class 1 no apparent erosion; Class 2 slight erosion; Class 3 moderate erosion; Class 4 severe erosion, and Class 5 very severe erosion. An erosion subclass (1) provides for an assessment of the current state or activity of the erosion process. Where erosion has reached bedrock or where eroded areas have been revegetated, the symbol (1) accordingly indicates an inactive or stable state of erosion. Each erosion map unit is identified by an erosion code showing the symbol/s for the type/s of erosion, the class of erosion, and the activity status of the erosion (in cases of inactive erosion). The dominant type of erosion is indicated by placing the symbol first in the code order. The code allows for a maximum of two erosion types per mapping unit.

Example of the erosion code:

Type/s of erosion	Class	Activity
SR	3	(1)

The example denotes a combination of sheet and rill erosion with sheet erosion dominant, of Class 3 intensity (moderate erosion), and which is in an inactive state.

The second classification system (Table M12), is a morphogenetic field-based method of classifying a wide range of accelerated soil erosion forms. The classification does not however, suggest the cyclical development of features (Dardis et al, 1988). The classification is based on the following criteria: flow type; flow regime (the latter is defined

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* See Anonymous, 1981. A system for the classification of soil erosion in the SARCCUS region, Department of Agriculture and Fisheries, Pretoria, 20 p.

Table M11: Summary of the types and classes of soil erosion in southern Africa.

Type of erosion	Class of erosion	Symbol	Description and remarks
1. Erosion caused by water			
Sheet (surface) Uniform removal of surface soil	None apparent	S1	No visible signs of erosion on air photos. Level of management appears to be high
	Slight	S2	Areas of light-tone observed on air photos. Erosion deduced from poor cover, sediment deposits and plant pedestals
	Moderate	S3	Eroded areas obvious on air photos. Plant cover very poor and sediment deposits extensive. Associated with small rills
	Severe	S4	Sheet erosion of such severity always associated with rills and gullies. Much or all of the A horizon has been removed
	Very severe	S5	Same as S4
Rill Removal of soil in small channels or rivulets, mainly on arable land	None apparent	R1	As for sheet erosion
	Slight	R2	Small, shallow rills (mainly <0,1 m) present but not readily observed on air photos
	Moderate	R3	Rills of considerable depth (mainly 0,1 - 0,3 m) and intensity usually observed on air photos
	Severe	R4	An abundance of deep rills (<0,5 m) easily observed on air photos. Subsoil may be exposed
	Very severe	R5	Large, well defined rills, but may be crossed by farm machinery. Associated with gully erosion

Table M11: Summary of the types and classes of soil erosion in southern Africa (continued).

Type of erosion	Class of erosion	Symbol	Description and remarks
<u>Gully (donga)</u> Removal of soil in large channels or gullies by concentrated runoff from large catchment areas	None apparent	G1	As for sheet erosion
	Slight	G2	Clearly observed on air photos and usually up to 1 m deep. Cannot be crossed by farm machinery
	Moderate	G3	Intricate pattern of deep gullies (mainly 1 - 3 m) exposing entire soil profile in places. Many "islands" of top soil remain
	Severe	G4	Landscape dissected and truncated by large (3 - 5 m deep) gullies. Approximately 25 - 50% of the area is unproductive
	Very severe	G5	Large and deep (often >5 m) gullies have totally denuded over 50% of the area

Table M11: Summary of the types and classes of soil erosion in southern Africa (continued).

Type of erosion	Class of erosion	Symbol	Description and remarks
Landslide Soil mass slumps downwards, leaving vertical scarp	Five class ratings also apply to these types of erosion but are seldom used	L	Usually visible on air photos. Over-saturation causes soil mass to slide downslope, leaving a vertical scarp at the top. Catchment area normally absent
Terracette Step-like formation on steep slopes		T	Easily observed on air photos. Usually associated with steep slopes (>15%) in high rainfall areas. Aggravated by trampling
Creep Gradual viscous movement of the soil mass downslope		C	A natural phenomenon which may be seen in mountainous areas. Recognition aided by observation of other features. Not readily observed on air photos
Stream bank Undercutting and slumping in, of stream and river banks		B	Occurs on outer curves of streams and rivers, where fast-flowing water undercuts the banks. May or may not be seen on air photos

Table M11: Summary of the types and classes of soil erosion in southern Africa (continued).

Type of erosion	Class of erosion	Symbol	Description and remarks
2. Erosion caused by wind			
Wind Sandy materials (>85% sand) removed by suspension, saltation and creep during strong winds	None apparent	W1	Seldom observed in well vegetated and humid areas where clayey soils predominate
	Slight	W2	Not readily observed on air photos. Field checks show evidence of removal and deposition. Loamy soils (15 - 35% clay and 65 - 85% sand) may predominate
	Moderate	W3	Easily observed on air photos. Sand is deposited against obstructions and small dunes are formed. Soils are mostly sandy (<15% clay and >85% sand)
	Severe	W4	Large parallel sand dunes observed on air photos. Vegetation is sparse and soils very sandy (<10% clay)
	Very severe	W5	Over 50% of the area is rendered unproductive by blow outs and deposition of sand

Source: After Anonymous, 1981. A system for the classification of soil erosion in the SARCCUS region, Department of Agriculture and Fisheries, Pretoria, 20 p.

See also: Beckedahl, H.R., Bowyer-Bower, T.A.S., Dardis, G.F. and Hanvey, P.M., 1988. Chapter 12. Geomorphic effects of soil erosion, In: Moon, B.P. and Dardis, G.F. (eds), The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, p. 249 - 276.

Note: Moderate (3) to very severe (5) classes often include a combination of two or more types of water erosion.

Table M12: Soil erosion types in southern Africa.

Flow type	Flow path	Flow regime	Geometry	Host material	Dominant processes
Water-activated (surface areas)	Unconfined	Hydrodynamic	Sheet; horizontal or gently inclined planar surface; weak anastomosing or braided channelling	Relatively resistant surface or near-surface soil, colluvium or bedrock layer	Overland flow; sheetwash; sheetflooding
Wind-activated (surface areas)	Unconfined	Aerodynamic	Sheet; horizontal or inclined planar, undulating or sinusoidal surface; no channelling	Relatively resistant surface or near-surface soil, colluvium or bedrock layer/ homogeneous, poorly resistant weathering products, colluvium or sand	Aeolian; saltation; deflation
Sheet erosion (surface areas)	Confined (closed conduit)	Hydrodynamic	Linear channels (rills)	Relatively resistant surface or near-surface soil, colluvium or bedrock layer/ homogeneous, poorly resistant weathering products, colluvium or sand/heterogeneous weathering products, colluvium or sand with variable degrees of resistance between individual beds or layers	Overland flow; sheetwash
Subsurface erosion (chemistry)	Confined (closed conduit)	Hydrodynamic	Subsurface cavity; vein; crack; isolated cavity; non-linear	Heterogeneous weathering products, colluvium or sand with variable degrees of resistance between individual beds or layers	Subsurface flow; solution; deflocculation
Subsurface erosion (soil piping and tunnel erosion)	Confined (closed conduit)	Hydrodynamic	Conduit; linear; meandering; bedrock-cut; V-shaped	Relatively resistant surface or near-surface soil, colluvium or bedrock layer/ heterogeneous weathering products, colluvium or sand with variable degrees of resistance between individual beds or layers	Subsurface flow; piping; roof and sidewall collapse

Table M12: Soil erosion types in southern Africa (continued).

Flow type	Flow path	Flow regime	Geometry	Host material	Dominant processes
Soil pipe collapse and enlargement (surface and subsurface areas)	Confined (closed conduit)/ confined (open conduit)	Hydrodynamic	Linear closed-open conduit; single channel or channel network	Heterogeneous weathering products, colluvium or sand with variable degrees of resistance between individual beds or layers	Overland and sub-surface flow; roof and sidewall collapse; headcut erosion
Lateral feature enlargement (surface and subsurface areas)	Confined (open conduit)	Hydrodynamic	Linear open conduit; single channel or channel network; U-shaped; flat-bottomed	Heterogeneous weathering products, colluvium or sand with variable degrees of resistance between individual beds or layers	Overland flow; piping; sidewall collapse; headcut erosion; sidewall rilling
Vertical feature enlargement (surface areas)	Confined (open conduit)	Hydrodynamic	Open conduit; single channel or weakly developed channel network; V-shaped	Relatively resistant surface or near-surface soil, colluvium or bedrock layer/ homogeneous, poorly resistant weathering products, colluvium or sand	Overland flow; sidewall rilling; headcut erosion; general absence of piping
Advanced erosion (surface areas)	Unconfined/ confined (open conduit)	Hydrodynamic/ aerodynamic	Planar surface; degraded	Relatively resistant surface or near-surface soil, colluvium or bedrock layer	Overland flow; sheetwash; rill erosion; aeolian activity

Source: (i) After Dardis, G.F., Beckedahl, H.R., Bowyer-Bower, T.A.S. and Hanvey, P.M., 1988. Soil erosion forms in southern Africa, In: Dardis, G.F. and Moon, B.P. (eds), Geomorphological Studies in Southern Africa, A.A. Balkema, Rotterdam, p. 187 - 213.

(ii) After Beckedahl, H.R., 1993. Personal communication, Department of Geography, University of Natal, Pietermaritzburg.

See also: (i) Beckedahl, H.R., Bowyer-Bower, T.A.S., Dardis, G.F. and Hanvey, P.M., 1988. Chapter 12. Geomorphic effects of soil erosion, In: Moon, B.P. and Dardis, G.F. (eds), The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, p. 249 - 276.

(ii) Beckedahl, H.R., 1996. Subsurface soil erosion phenomena in Transkei and southern KwaZulu-Natal, South Africa, Ph.D. Thesis, Department of Geography, University of Natal, Pietermaritzburg, 224 p. (The thesis has a useful bibliography).

Note: (i) The soil erosion forms are more fully described in Dardis, Beckedahl, Bowyer-Bower and Hanvey (1988 - above).

(ii) Various terms are used in the international literature to describe "gullies". The word gully (an open channel) is derived from French; ravine (a steep-sided, U - or V-shaped open channel) is also derived from French; arroyo (a steep-sided open channel) is derived from Spanish, whereas gulch (a ravine-type open channel) is a North American term. Lavakas (also a ravine-type open channel) is used in the Malagasy Republic. Donga (open channel) is a southern African word.

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in terms of flow type and flow path); the geometry of the erosion feature; the nature of the host material, and the dominant processes acting on a particular soil erosion form. Nine major types of soil erosion are described. It should be noted that some soil erosion forms may be composite features, providing evidence for instance, of two or more erosion forms superimposed on each other - such as rills occurring on the sidewalls of a V-shaped gully.

13.11.2 Soil erodibility rating

(a) Water

Preliminary information on the erodibility by water of all South African soil series (as per the 1977 binomial soil classification system), is presented in Table M13. Soil erodibility in this regard, was largely defined as a surface phenomenon. In the absence of detailed

South African research, the interpretation was based on surface and profile characteristics. It was therefore assumed that the texture of the top soil was the same as the upper B horizon. The erodibility rating was undertaken primarily as input data for the Soil Loss Estimation Model for Southern Africa - discussed later (Scotney, 1995)*. Liggitt and Fincham (1989)** suggested that the binomial soil classification system was possibly a poor basis for determining soil erodibility (especially for gullies), in view of the importance of geological type (lithology) as an erosion (pre-disposing) factor. It is apparent that certain lithologies are more susceptible to gully erosion than others.

Table M13: Erosion hazard rating of South African soil series.

Code and form	Series	Erosion hazard rating
Arcadia Form		
Ar 40	Arcadia	Moderate
Ar 11	Bloukrans	High
Ar 21	Clerkness	High
Ar 41	Eenzaam	Moderate
Ar 20	Gelykvlakte	Moderate
Ar 10	Mngazi	Low
Ar 32	Nagana	Low
Ar 12	Noukloof	Low
Ar 31	Rooidraai	Low
Ar 30	Rydalvale	Low
Ar 42	Wanstead	Moderate
Ar 22	Zwaarkrygen	Moderate
Avalon Form		
Av 13	Ashton	High
Av 26	Avalon	Moderate
Av 12	Banchory	High
Av 27	Bergville	Low

* Scotney, D.M., 1995. Personal communication, Department of Agriculture, Pretoria.

** See Liggitt, B. and Fincham, R.J., 1989. Gully erosion: the neglected dimension in soil erosion research, South African Journal of Science, VOL 85(1), p. 18 - 20.

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Av 37	Bezuidenhout	Low
Av 33	Bleeksand	High
Av 34	Heidelberg	High
Av 20	Hobeni	High
Av 14	Kanhym	High
Av 24	Leksand	High
Av 10	Mastaba	High
Av 32	Middelpos	High
Av 31	Mooiveld	High
Av 25	Newcastle	High
Av 17	Normandien	Very low
Av 22	Rossdale	High
Av 16	Ruston	Low
Av 36	Soetmelk	Moderate
Av 21	Uithoek	High
Av 30	Viljoenskroon	High
Av 23	Villiers	High
Av 11	Welverdiend	High
Av 35	Windmeul	High
Av 15	Wolweberg	High
Bainsvlei Form		
Bv 23	Ashkelon	High
Bv 36	Bainsvlei	Moderate
Bv 12	Camelot	Moderate
Bv 20	Chelsea	High
Bv 30	Delwery	High
Bv 13	Dunkeld	High
Bv 16	Elysium	Low
Bv 10	Hlatini	High
Bv 34	Kareekuil	High
Bv 31	Kingston	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Bv 26	Lonetree	Low
Bv 25	Maanhaar	Moderate
Bv 11	Makong	Moderate
Bv 27	Metz	Very low
Bv 22	Oosterbeek	Moderate
Bv 37	Ottosdal	Low
Bv 24	Redhill	Moderate
Bv 32	Trekboer	High
Bv 15	Tygerkloof	Moderate
Bv 33	Vermaas	High
Bv 21	Vungama	Moderate
Bv 35	Wedgewood	High
Bv 17	Wilgenhof	Very low
Bv 14	Wykeham	Moderate
Bonheim Form		
Bo 41	Bonheim	Moderate
Bo 20	Bushman	High
Bo 30	Dumasi	Moderate
Bo 31	Glengazi	Low
Bo 10	Kiora	Moderate
Bo 21	Rasheni	Moderate
Bo 11	Stanger	Low
Bo 40	Weenen	High
Cartref Form		
Cf 10	Amabele	High
Cf 12	Arrochar	High
Cf 13	Byrne	Low
Cf 21	Cartref	High
Cf 22	Cranbrook	Moderate
Cf 30	Grovedale	High
Cf 31	Kusasa	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Cf 32	Noodhulp	Moderate
Cf 11	Rutherglen	High
Cf 20	Waterridge	High
Champagne Form		
Ch 11	Champagne	High
Ch 21	Ivanhoe	High
Ch 10	Mposa	High
Ch 20	Stratford	High
Clovelly Form		
Cv 33	Annandale	High
Cv 18	Balgowan	Very low
Cv 40	Bleskop	High
Cv 36	Blinkklip	Moderate
Cv 17	Clovelly	Very low
Cv 28	Clydebank	Very low
Cv 35	Denhere	High
Cv 46	Dudfield	Moderate
Cv 11	Geelhout	Moderate
Cv 25	Gutu	Moderate
Cv 47	Klippan	Low
Cv 38	Klipputs	Low
Cv 10	Lismore	High
Cv 12	Lundini	Moderate
Cv 34	Makuya	High
Cv 14	Mossdale	Moderate
Cv 48	Nelspan	Low
Cv 27	Newport	Very low
Cv 16	Oatsdale	Low
Cv 23	Ofazi	High
Cv 41	Oranje	High
Cv 32	Paleisheuwel	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Cv 31	Sandspruit	High
Cv 22	Sebakwe	Moderate
Cv 45	Skipskop	High
Cv 21	Sonnenblom	Moderate
Cv 26	Southwold	Low
Cv 15	Soweto	Moderate
Cv 24	Springfield	Moderate
Cv 30	Sunbury	High
Cv 37	Summerhill	Low
Cv 42	Thornhill	High
Cv 44	Torquay	High
Cv 20	Tweefontein	High
Cv 43	Vaalbank	High
Cv 13	Vidal	High
Constantia Form		
Ct 25	Cintsa	High
Ct 12	Constantia	High
Ct 23	Dwesa	High
Ct 22	Fencote	High
Ct 13	Harkerville	High
Ct 24	Kromhoek	High
Ct 14	Noetzie	High
Ct 20	Palmyra	High
Ct 10	Strombolis	High
Ct 11	Tokai	High
Ct 21	Vlakfontein	High
Ct 15	Wynberg	High
Estcourt Form		
Es 20	Assegaai	Very high
Es 11	Auckland	Very high
Es 22	Avontuur	Very high

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Es 35	Balfour	Very high
Es 40	Beerlaagte	Very high
Es 37	Buffelsdrif	High
Es 42	Darling	Very high
Es 13	Dohne	Very high
Es 31	Elim	Very high
Es 33	Enkeldoorn	Very high
Es 36	Estcourt	High
Es 14	Grasslands	Very high
Es 41	Heights	Very high
Es 10	Houdenbeck	Very high
Es 21	Langkloof	Very high
Es 30	Mozi	Very high
Es 12	Potela	Very high
Es 16	Rosemead	High
Es 32	Soldaatskraal	Very high
Es 34	Uitvlugt	Very high
Es 15	Vredenhoek	Very high
Es 17	Zintwala	High
Fernwood Form		
Fw 40	Brinley	High
Fw 11	Fernwood	High
Fw 21	Langebaan	High
Fw 42	Mambone	High
Fw 10	Maputa	High
Fw 20	Motopi	High
Fw 22	Saldanha	High
Fw 12	Sandveld	High
Fw 30	Shasha	High
Fw 41	Soetvlei	High
Fw 32	Trafalgar	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Fw 31	Warrington	High
Glencoe Form		
Gc 16	Appam	Low
Gc 33	Beatrix	High
Gc 20	Boskuil	High
Gc 15	Delmas	High
Gc 10	Driepan	High
Gc 24	Dunbar	High
Gc 26	Glencoe	Moderate
Gc 37	Graspan	Low
Gc 11	Hartog	High
Gc 13	Klipstapel	High
Gc 32	Kwezana	High
Gc 34	Leeudoorn	High
Gc 36	Leslie	Moderate
Gc 27	Ontevrede	Low
Gc 21	Penhoek	High
Gc 31	Ribblesdale	High
Gc 17	Shotton	Very low
Gc 23	Strathrae	High
Gc 22	Talana	High
Gc 12	Tranendal	High
Gc 35	Uitskot	High
Gc 30	Vlakpan	High
Gc 14	Weltevrede	High
Gc 25	Wesselsnek	High
Glenrosa Form		
Gr 28	Achterdam	Moderate
Gr 27	Dothole	Moderate
Gr 24	Dunvegan	High
Gr 15	Glenrosa	Moderate

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Gr 13	Kanonkop	High
Gr 22	Knapdaar	High
Gr 26	Lekfontein	Moderate
Gr 25	Lomondo	High
Gr 21	Majeng	High
Gr 20	Malgas	High
Gr 10	Martindale	High
Gr 11	Oribi	Moderate
Gr 12	Paardeberg	Moderate
Gr 14	Platt	Moderate
Gr 29	Ponda	Low
Gr 19	Saintfaiths	Very low
Gr 23	Southfield	High
Gr 17	Trevanian	Low
Gr 16	Williamson	Moderate
Griffin Form		
Gf 10	Burnside	Moderate
Gf 11	Cleveland	Low
Gf 32	Cradock	Low
Gf 20	Erfdeel	Moderate
Gf 13	Farmhill	Very low
Gf 12	Griffin	Very low
Gf 22	Ixopo	Very low
Gf 30	Runnymeade	High
Gf 33	Slagkraal	Low
Gf 21	Umzimkulu	Low
Gf 31	Welgemoed	Moderate
Gf 23	Zwagershoek	Very low
Houwhoek Form		
Hh 20	Albertinia	High
Hh 10	Elgin	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Hh 21	Garcia	High
Hh 31	Gouna	High
Hh 30	Houwhoek	High
Hh 11	Stormsrivier	High
Hutton Form		
Hu 10	Alloway	Moderate
Hu 11	Arnot	Moderate
Hu 18	Balmoral	Very low
Hu 25	Bontberg	Moderate
Hu 22	Chester	Moderate
Hu 24	Clansthal	Moderate
Hu 27	Doveton	Very low
Hu 17	Farningham	Very low
Hu 31	Gaudam	High
Hu 47	Hardap	Moderate
Hu 16	Hutton	Low
Hu 21	Joubertina	Moderate
Hu 15	Kyalami	Moderate
Hu 23	Lichtenburg	High
Hu 40	Lowlands	High
Hu 43	Maitengwe	High
Hu 37	Makatini	Low
Hu 44	Malonga	High
Hu 33	Mangano	High
Hu 38	Marikana	Low
Hu 14	Middelburg	Moderate
Hu 48	Minhoop	Low
Hu 32	Moriah	High
Hu 26	Msinga	Low
Hu 41	Nyala	High
Hu 35	Portsmouth	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Hu 42	Quaggafontein	High
Hu 30	Roodepoort	High
Hu 46	Shigalo	Moderate
Hu 36	Shorrocks	Moderate
Hu 12	Stonelaw	Moderate
Hu 45	Vergenoeg	High
Hu 28	Vimy	Low
Hu 13	Wakefield	High
Hu 20	Whithorn	High
Hu 34	Zwartfontein	High
Inanda Form		
Ia 10	Fountainhill	Very low
Ia 11	Inanda	Very low
Ia 12	Sprinz	Very low
Inhoek Form		
Ik 11	Coniston	Very low
Ik 10	Cromley	Low
Ik 21	Drydale	Low
Ik 20	Inhoek	Moderate
Katspruit Form		
Ka 10	Katspruit	Moderate
Ka 20	Killarney	Moderate
Kranskop Form		
Kp 10	Kipipiri	Very low
Kp 11	Kranskop	Very low
Kp 12	Umbumbulu	Very low
Kroonstad Form		
Kd 17	Avoca	High
Kd 16	Bluebank	High
Kd 22	Katarra	Very high
Kd 20	Koppies	Very high

Table M13: **Erosion hazard rating of South African soil series (continued).**

Code and form	Series	Erosion hazard rating
Kd 13	Kroonstad	Very high
Kd 14	Mkambati	Very high
Kd 10	Rocklands	Very high
Kd 15	Slangkop	Very high
Kd 12	Swellengift	Very high
Kd 18	Uitspan	High
Kd 21	Umtentweni	Very high
Kd 11	Velddrif	Very high
Kd 19	Volksrust	Moderate
Lamotte Form		
Lt 10	Alsace	High
Lt 21	Burgundy	High
Lt 14	Chamond	High
Lt 22	Franschhoek	High
Lt 25	Hooghalen	High
Lt 12	Lamotte	High
Lt 11	Laparis	High
Lt 15	Lillesand	High
Lt 20	Lorraine	High
Lt 24	Ringwood	High
Lt 23	Tillberga	High
Lt 13	Vevey	High
Longlands Form		
Lo 22	Albany	Moderate
Lo 32	Chitsa	Moderate
Lo 21	Longlands	High
Lo 10	Orkney	High
Lo 30	Tayside	High
Lo 31	Vaalsand	High
Lo 20	Vasi	High
Lo 11	Waaisand	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Lo 12	Waldene	High
Lo 13	Winterton	Low
Magwa Form		
Ma 12	Frazer	Very low
Ma 11	Magwa	Very low
Ma 10	Milford	Very low
Mayo Form		
My 10	Mayo	Low
My 11	Msinsini	Very low
My 21	Pafuri	Low
My 20	Tshipise	Moderate
Milkwood Form		
Mw 10	Dansland	Moderate
Mw 21	Graythorne	Low
Mw 11	Milkwood	Low
Mw 20	Sunday	Moderate
Mispah Form		
Ms 21	Hillside	High
Ms 22	Kalkbank	High
Ms 11	Klipfontein	Moderate
Ms 12	Loskop	Moderate
Ms 23	Misgund	High
Ms 10	Mispah	Moderate
Ms 20	Muden	High
Ms 13	Plettenberg	Moderate
Ms 24	Vredendal	High
Ms 14	Winchester	Moderate
Nomanci Form		
No 11	Lusiki	Very low
No 10	Nomanci	Low

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Oakleaf Form		
Oa 43	Allanridge	High
Oa 45	Calueque	High
Oa 21	Doornlaagte	High
Oa 25	Hazelwood	High
Oa 17	Highflats	Very low
Oa 22	Holpan	High
Oa 36	Jozini	Low
Oa 23	Kirkton	High
Oa 13	Klipplaat	High
Oa 37	Koedoesvlei	Very low
Oa 16	Leeufontein	Low
Oa 26	Letaba	Moderate
Oa 34	Levubu	Moderate
Oa 46	Limpopo	Moderate
Oa 41	Lovedale	High
Oa 11	Madwaleni	Moderate
Oa 24	Magersfontein	High
Oa 27	Makulek	Low
Oa 47	Mutale	Low
Oa 42	Naulila	High
Oa 30	Oakleaf	High
Oa 44	Okavango	High
Oa 31	Oshikango	Moderate
Oa 15	Pollock	Moderate
Oa 14	Rockford	Moderate
Oa 32	Sezela	Moderate
Oa 10	Smaldeel	High
Oa 33	Vaalriver	High
Oa 35	Venda	Moderate
Oa 40	Voorspoed	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Oa 20	Warrenton	High
Pinedene Form		
Pn 27	Airlie	Low
Pn 12	Bethlehem	High
Pn 25	Chatsworth	High
Pn 15	Eykendal	High
Pn 10	Fortuin	High
Pn 13	Graymead	High
Pn 22	Hermanus	High
Pn 17	Kilburn	Low
Pn 32	Kleinrivier	High
Pn 36	Klerksdorp	High
Pn 34	Nagtwagt	High
Pn 33	Oewer	High
Pn 16	Ouwerf	Moderate
Pn 30	Papiesvlei	High
Pn 14	Pinedene	High
Pn 11	Radyn	High
Pn 20	Rotterdam	High
Pn 31	Stormsvlei	High
Pn 26	Suurbraak	Moderate
Pn 24	Tulbagh	High
Pn 23	Vyeboom	High
Pn 21	Wemmershoek	High
Pn 37	Witpoort	Moderate
Pn 35	Yzerspruit	High
Rensburg Form		
Rg 10	Phoenix	High
Rg 20	Rensburg	High
Shepstone Form		
Sp 12	Addington	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Sp 11	Bitou	High
Sp 13	Gouritz	High
Sp 15	Inhaminga	High
Sp 22	Kunjane	High
Sp 23	Pencarrow	High
Sp 24	Portobello	High
Sp 25	Pumula	High
Sp 14	Robberg	High
Sp 21	Shepstone	High
Sp 20	Southbroom	High
Sp 10	Tergniet	High
Shortlands Form		
Sd 11	Argent	Very low
Sd 10	Bokuil	Low
Sd 30	Ferry	Moderate
Sd 21	Glendale	Low
Sd 20	Kinross	Moderate
Sd 12	Richmond	Very low
Sd 22	Shortlands	Low
Sd 31	Sunvalley	Low
Sd 32	Tugela	Low
Sterkspruit Form		
Ss 27	Antioch	High
Ss 13	Bakklysdrift	Very high
Ss 15	Dehoek	Very high
Ss 10	Diepkloof	Very high
Ss 17	Driebaden	High
Ss 21	Graafwater	Very high
Ss 25	Grootfontein	Very high
Ss 20	Halseton	Very high
Ss 24	Hartbees	Very high

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Ss 12	Ruacana	Very high
Ss 22	Silwana	Very high
Ss 23	Stanford	Very high
Ss 26	Sterkspruit	High
Ss 16	Swaerskloof	High
Ss 11	Tina	Very high
Ss 14	Toleni	Very high
Swartland Form		
Sw 12	Breidbach	Moderate
Sw 21	Broekspruit	Moderate
Sw 32	Hogsback	Moderate
Sw 40	Malakata	High
Sw 41	Nyoka	Moderate
Sw 42	Omdraai	Moderate
Sw 22	Prospect	Moderate
Sw 10	Reveillie	High
Sw 30	Rosehill	High
Sw 11	Skilderkrans	Low
Sw 31	Swartland	High
Sw 20	Uitsicht	High
Tambankulu Form		
Tk 10	Fenfield	Moderate
Tk 20	Loshoek	Moderate
Tk 21	Masala	Low
Tk 11	Tambankulu	Low
Valsrivier Form		
Va 31	Arniston	Moderate
Va 32	Chalumna	Moderate
Va 21	Craven	Moderate
Va 30	Herschel	High
Va 12	Lilydale	Moderate

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Va 41	Lindley	Moderate
Va 22	Marienthal	Moderate
Va 42	Sheppardvale	Moderate
Va 10	Sunnyside	High
Va 40	Valsrivier	High
Va 11	Waterval	Moderate
Va 20	Zuiderzee	High
Vilafontes Form		
Vf 45	Blombosch	High
Vf 23	Blythdale	High
Vf 31	Brenton	High
Vf 24	Chantilly	High
Vf 44	Dassenhoek	High
Vf 21	Fairbreeze	High
Vf 43	Geelbek	Very high
Vf 11	Hudley	High
Vf 22	Klaarwater	High
Vf 34	Knysna	High
Vf 40	Kransduinen	Very high
Vf 20	Matigulu	High
Vf 41	Mazeppa	High
Vf 35	Meulvlei	High
Vf 10	Moreland	High
Vf 14	Moyeni	High
Vf 25	Nhamacala	High
Vf 33	Rheebok	Very high
Vf 30	Sedgefield	Very high
Vf 32	Swinton	High
Vf 13	Tinley	High
Vf 42	Vallance	High
Vf 15	Vilafontes	High

Table M13: Erosion hazard rating of South African soil series (continued).

Code and form	Series	Erosion hazard rating
Vf 12	Zeekoe	High
Wasbank Form		
Wa 12	Burford	High
Wa 13	Endicott	Low
Wa 30	Hamman	High
Wa 10	Hoopstad	High
Wa 11	Kromvlei	High
Wa 20	Rondevlei	High
Wa 31	Sandvlei	High
Wa 22	Warrick	Moderate
Wa 21	Wasbank	High
Wa 32	Winterveld	Moderate
Westleigh Form		
We 10	Chinde	High
We 32	Davel	Moderate
We 22	Devon	Moderate
We 20	Kosi	High
We 30	Langkuil	High
We 31	Paddock	High
We 12	Rietvlei	Moderate
We 13	Sibasa	Low
We 11	Westleigh	High
We 21	Witsand	High
Willowbrook Form		
Wo 21	Chinyika	High
Wo 10	Emfuleni	High
Wo 20	Sarasdale	High
Wo 11	Willowbrook	Moderate

<u>**Source:**</u> After Anonymous, 1976. Soil loss estimator for southern Africa: development and proposed application of a model - proceedings of a workshop held at Cedara in November 1976, Natal Agricultural Research

Bulletin No. 7, Department of Agricultural Technical Services (Natal Region), Cedara, 64 p. + app.

Note:

(i) The Dundee Form (with only one series, the Dundee Series - Du 10 - was not listed in Anonymous (1976 - above). (See Table M10).

(ii) The Robmore Series - Gr 18 (Glenrosa Form) and the Mbanyana Series - Oa 12 (Oakleaf Form) were also not listed in Anonymous (1976). Both series can be regarded as being moderately erodible (Scotney, D.M., 1995. Personal communication, Department of Agriculture, Pretoria).

(iii) The code for series of the Glenrosa Form is either referred to as Gr, or Gs, in the literature.

(b) Wind

Scotney (1973)* in an overview analysis of soils susceptible to wind erosion in Natal/KwaZulu, identified five soil series with a very severe wind erosion hazard potential. These soils are the Cedarville Series (Avalon Form); the Zwartfontein Series (Hutton Form), and the Langebaan, Maputa and Fernwood series (Fernwood Form). Soils with a severe rating include the Bleeksand, Newcastle and Villiers series (Avalon Form); the Ofazi Series (Clovelly Form); the Estcourt Series (Estcourt Form); the Clansthal and Shorrocks series (Hutton Form), and the Strathrae Series (Glencoe Form). Scotney observed that light-textured soils of the Kroonstad, Longlands and Wasbank forms also have a severe rating, although these soils are less widespread in wind eroded areas, and are moist for much of the year. Certain sandy soils of the Mispah Form likewise, have a severe erosion rating. Soils with a moderate wind erosion hazard rating are the Avalon Series (Avalon Form); the Hutton and Makatini series (Hutton Form); the Oatsdale (humic) Series (Clovelly Form), and the Cleveland Series (Griffin Form). The Glendale Series of the Shortlands Form by contrast, has a slight wind erosion hazard rating.

It is important to bear in mind that virtually all susceptible soils have a high sand fraction. In general, soils with a severe wind erosion hazard are among those classified as having a total sand content of over 85%, with less than 15% clay in the B horizon, and which are

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* See Scotney, D.M., 1973. An assessment of wind erosion hazard in Natal soils, Fifth National Congress of the Soil Science Society of South Africa, 13 - 16 February 1973, Salisbury, Rhodesia, 10 p. (The Cedarville Series of the Avalon Form was a tentative series name, but is equivalent to the (1977) Rossdale Series).

mostly mesotrophic to eutrophic (moderately to slightly leached). (The degree of leaching reflects the overall moisture regime). A high clay and silt as well as moisture content usually reduces the wind erosion hazard. Soils with a sand content of 65 - 85% and with 15 - 35% clay in the B horizon are moderately susceptible to wind erosion. Dystrophic (highly leached) soils with a sand content of less than 65% and with over 35% clay in the B horizon have a slight wind erosion hazard rating. Light-textured humic soils however, are susceptible to deflation. Wind erosion results in a decline in productivity as the finer, most fertile sand and especially the clay fractions are lost. Soil fertility reserves are accordingly depleted and yields inevitably decline. A similar process is evident in soils eroded by water per se, with valuable plant nutrients washed into rivers and eventually into the sea.

13.12 A brief examination of soil erosion in Natal/KwaZulu*

Serious erosion occurs in all the bioclimatic groups of Natal/KwaZulu. The degree of severity is least in bioclimatic groups 1 - 5 inclusive, moderate in group 6 and worst in groups 8 - 11 inclusive**. Scotney (1978) used a five point rating system ranging from very slight (1) to very severe (5), to indicate the erosion status in each bioclimatic group (Table M14). The data include assessments for cultivated land, natural veld and wind erosion on private and State owned land, comprising 65% of Natal/KwaZulu.

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* Discussion based on Scotney, D.M., 1978. Soil erosion in Natal: 1978, Department of Agricultural Technical Services (Natal Region), Cedara, 19 p. For an overview of the erosion properties of various soils see Van der Eyk, J.J., MacVicar, C.N. and De Villiers, J.M., 1969. Soils of the Tugela Basin: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 15, Pietermaritzburg, 263 p. and maps. (The latter publication refers to the pre-1977 binomial soil classification system).

** It should be remembered that sheetwash erosion on cultivated fields in areas of low severity (which may be inconspicuous by comparison with large dongas), is often more serious than first appearances would suggest.

Table M14: A general assessment of erosion in the bioclimatic groups of Natal/KwaZulu, 1978.

Bioclimatic group	Overall assessment	Cultivated land	Natural veld	Wind erosion
1	2	2	1	2
2	2	2	2	-
3	1	2	1	-
4	1	1	1	1
5	1	-	1	-
6	3	3	3	-
7	4	4	4	-
8	5	4	4/5	3
9	4	3	4	-
10	5	4	5	-
11	4	4	4	-

<u>Source</u>: After Scotney, D.M., 1978. Soil erosion in Natal: 1978, Department of Agricultural Technical Services (Natal Region), Cedara, 19 p.

In bioclimatic group 1, erosion is generally slight and occurs mainly on steep, light-textured soils. Approximately 96% of the arable land is planted to sugar cane, which provides reasonable protection the year after establishment. Severe erosion however, often occurs on land planted to pineapples, bananas and vegetables, especially in the Indian owned market gardening areas. Wind erosion in the form of blow outs occurs in the Recent sands along the coast. Stream bank erosion in the sugar areas (where much of the indigenous vegetation has been removed from the banks of streams) is a severe problem*. Erosion in bioclimatic group 2 is usually slight, but moderate in areas with steep slopes and which are underlain by Table Mountain sandstone and Dwyka Tillite. About 80% of the cultivated land and is planted to sugar cane, pastures or trees, which provide considerable protection from erosion. Sand-winning is a common practice which has caused serious

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* Of growing concern is the destruction of peatlands (Mposa Series) as part of the general degradation of Swamp forests and other wetlands in the environs of St Lucia (briefly discussed in the chapter on catchments). A survey of the peatlands of the northern coastal plain is currently underway. For further information contact the Department of Environment Affairs, Private Bag X447, Pretoria, 0001.

erosion, much of which remains active. A characteristic of group 2 is deep gullies in natural drainage channels, associated with Dwyka derived soils.

Few areas of severe erosion are evident in bioclimatic group 3 despite the broken topography prevalent in the group. Soils of low erodibility, as well as good vegetal cover and safe land use practices are largely responsible for the limited erosion. General erosion is very slight in bioclimatic group 4, with the exception of sub-region 4f, where a higher incidence of erosion is found. Obvious erosion in group 4 is confined to unprotected arable land and areas trampled by livestock. Other sites are cattle paths, overgrazed steep north facing slopes, ploughed firebreaks and light-textured humic soils subject to wind erosion.

Most of bioclimatic group 5 is managed for water production and recreation and is well conserved. Apart from natural erosion such as slip scars and terracettes, man-induced erosion is mainly confined to steep north facing slopes immediately below the Cave sandstone. Further sites include cattle tracks and localized trampled areas as well as footpaths (see later in the chapter). Soil erosion in bioclimatic group 6 is moderate on both cultivated land and natural veld. Slopes are generally favourable for cultivation, although conservation practices are often poor. Highly erodible soils are common in group 6. The natural veld is in fair condition, although localized overstocking and mismanagement has resulted in serious erosion. Gully erosion is evident and many wetlands (vleis) have been damaged. Erosion is severe in bioclimatic group 7 (mainly confined to natural veld). Overstocking, poor veld management, inadequate water supplies - and hence severe localized erosion at existing sources - as well as steep slopes have largely influenced the rate of erosion.

In bioclimatic group 8, incorrect land use, together with poor cropping and inadequate veld management practices have resulted in very severe erosion in sandy and heavy-textured soils. Sheet erosion is common in most upland soils, although many of the extensive bottomlands are severely gully eroded. A characteristic of the group is bush encroachment, which is associated with poor grass cover and high soil loss rates*. Wind erosion has caused marked losses in cultivated fields with light-textured soils. In

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* The destruction of veld by harvester termites (Hodotermes mossambicus) is problematic at times in winter, and during periods of drought in the drier areas of bioclimatic groups 8 - 11. These termites are distributed over some 40 000 000 ha of land in South Africa. The situation in Natal/KwaZulu however, is less serious than in the interior provinces (Anonymous, 1996. PPRI and KwaZulu-Natal launch termite project, Agricultural News, 30 September 1996, p. 8).

bioclimatic group 9, poor veld management and overstocking has resulted in bush encroachment and moderate erosion. Considerable soil losses from cultivated fields have occurred due to erodible soils and poor conservation practices.

Bioclimatic group 10 constitutes the largest area of Thornveld and very severe soil erosion has occurred in the past. High population and livestock densities and the labour farm system; as well as the poor distribution of water sources, the lack of fencing and inadequate veld management, plus small farm size and highly erodible soils have all played a role in the severe soil erosion (the worst in Natal/KwaZulu). Much of the erosion is in the form of very deep and extensive dongas and totally denuded land. Severe soil erosion has also occurred in bioclimatic group 11. Bush encroachment is a further problem, with group 11 areas sharing many of the erosion features of group 10.

Soil losses from arable fields in Natal/KwaZulu are well in excess of acceptable limits and in some cases have reached alarming proportions. In 1974 for example, it was found that 329 000 ha or 47% of the cultivated land assessed in the province required mechanical protection, with some 6 700 km of contour banks needed for such protection. Soil losses from well managed natural veld, by contrast, are low (various estimates are presented in the literature). Unfortunately, heavy overstocking and poor management of the veld, as well as incorrect veld burning practices are still common in parts of Natal/KwaZulu - especially in the drier areas with erodible soils and vulnerable grasslands. The uneven distribution of stock watering points in these areas is also a major contributory factor. Donga erosion is prevalent in many bottomlands (Scotney, 1978).

Soil losses from commercially afforested land are largely associated with harvesting (mainly on steep slopes), especially if the brushwood is burnt (various estimates are found in the literature). Water and wind erosion from firebreaks and poorly planned and maintained forest roads is also problematic. A new environmental approach however, has been adopted by commercial forestry firms which addresses these issues*. The previous

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* See Anonymous, 1990. Mondi Paper Company Limited Forests Division incorporating Mondi Forests, N.T.E. Limited, St Lucia Sugar Farms and North East Cape Forests: environmental conservation code of practice, Mondi Paper Company Ltd, Johannesburg, 27 p., as well as Bigalke, R.C. (ed), 1990. Guidelines for the application of conservation practices in production forestry, Forestry Council, [Johannesburg], 14 p. Both reports adopt an Environmental Impact Assessment approach and therefore include information inter alia on burning, planting constraints, harvesting and natural assets as well as water resources. The latter report has subsequently been updated. See: Anonymous, 1995. Guidelines for environmental conservation management in commercial forests in South Africa, Forestry Industry Environmental Committee, [Forest Owners' Association], Johannesburg, 38 p.

practice of ploughing firebreaks has now ceased, although evidence of past damage is apparent in certain areas. Other sites of erosion include road verges, quarries, construction areas, mine dumps and slimes dams, as well as sand-winning operations and urban areas. Particularly important zones of erosion are sugar cane fields, in cases where all or nearly all natural vegetation has been removed from the river banks. Numerous examples of the latter are evident in the coastal belt of Natal/KwaZulu. Revegetation of such (and other) land is actively being promoted by the South African Sugar Association Experiment Station at Mount Edgecombe and the Natal Parks Board. Plants suitable for revegetation - as recommended by both agencies - are listed in Tables M15 and M16. Also included is information on alien vegetation and commercial plantations.

Catchment degradation is evident in Natal/KwaZulu not only in situ, but also in terms of the effects on "estuaries" (Begg, 1978)*. Estuaries have changed their form and shape largely as a result of sediment carried downstream**. (See the chapters on "estuaries" and water quality). Siltation also directly influences the storage capacity and therefore the economic lifespan of impoundments. For example, the Camperdown Dam built on the Mlazi River in 1905 was 75% silted up within a period of 22 years, while the Shongweni Dam built on the same river in 1928 was 37% silted up by 1951 (Adler, 1981)***. Large volumes of sediment deposited during floods have also caused serious economic losses, particularly on the Mfolozi Floodplain****. Other effects of water-induced soil erosion include a loss of soil fertility plus land capability - and hence reduced

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* See Begg, G.W., 1978. Session 2. Management of rivers, flood plains and estuaries in Natal and KwaZulu - the impact of the sugar industry on the estuaries of Natal, In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 64 - 70.

** For a technical discussion on sediment aggradation (deposition) and degradation (erosion) in sand bed river channels see, Le Grange, A. du P. and Rooseboom, A., 1993. The development of a model to simulate channel deformation in alluvial rivers, WRC Report No. 236/1/93, Water Research Commission, Pretoria, various pages.

*** See Adler, E., 1981. Ons kwynende bodem/Our shrinking land, Ekos, VOL 1(3), p. 6 - 21. (Other reports refer to the construction date of the Camperdown Dam as 1901 and the construction date of the Shongweni Dam as 1927. The overall sedimentation trend however, is clear).

**** See Liggitt, B., 1988. An investigation into soil erosion in the Mfolozi catchment, INR Investigational Report No. 28, Institute of Natural Resources, University of Natal, Pietermaritzburg, 110 p. See also, Liggitt, B. and Fincham, R.J., 1989. Gully erosion: the neglected dimension in soil erosion research, South African Journal of Science, VOL 85(1), p. 18 - 20.

Table M15: Indigenous trees suitable for the afforestation of degraded watercourses.

Category	Botanical name	Common name	Area	Frost resistance
Trees with vigorous rooting characteristics	Acacia robusta	Splendid thorn	CM	X
	Bridelia micrantha	Mitseeri	C	
	Combretum erythrophyllum	River bushwillow	M	XXX
	Ficus natalensis	Natal fig	CM	
	Ficus sur	Cape fig	CM	
	Harpephyllum caffrum	Wild plum	C	X
	Leucosidea sericea	Ouhout	MB	XXX
	Macaranga capensis	Wild poplar	C	
	Phoenix reclinata	Wild date palm	CM	X
	Raphia australis	Kosi palm	C	
	Rauvolfia caffra	Quinine tree	C	
	Rhus chirindensis	Bostaaibos	CM	XX
	Syzygium cordatum	Umdoni	CM	X
	Voacanga thouarsii	Wild frangipani	C	
Pioneer or precursor trees	Acacia karoo	Sweet thorn	CMB	XXX
	Albizia adianthifolia	Flat crown	C	X
	Antidesma venosum	Tasselberry	C	
	Buddleja salviifolia	Sagewood	MB	XXX
	Celtis africana	White stinkwood	CMB	XX
	Croton sylvaticus	Forest croton	CM	X
	Trema orientalis	Pigeonwood	CM	
Trees with commercial and medicinal value	Bersama lucens	Glossy bersama	C	
	Curtisia dentata	Assegai	M	X
	Milletia grandis	Umzimbeet	C	X
	Ocotea bullata	Stinkwood	M	
	Podocarpus falcatus	Outeniqua yellowwood	MB	XXX
	Podocarpus latifolius	Real yellowwood	MB	XXX
	Warburgia salutaris	Pepper-bark	C	

Source: After Wyatt, J., 1990. Indigenous afforestation of degraded watercourses, Wildlife Management Technical Guides for Farmers No. 24, Natal Parks Board, Pietermaritzburg, 2 p.

See also: Rowntree, K., 1991. An assessment of the potential impact of alien invasive vegetation on the geomorphology of river channels in South Africa, Southern African Journal of Aquatic Sciences, VOL 17(1/2), p. 28 - 43.

Note:

(i) The codes used under "Area" are C = coastal; M = midlands, and B = berg/or highlands. The degree of frost resistance is indicated by X for slightly tolerant; XX for fairly tolerant, and XXX for total frost resistance. The unmarked trees will not tolerate frost.

(ii) Riverine vegetation is essential for catchment stabilization. Such vegetation plays a major role in the regulation of runoff, the maintenance of water quality, the reduction of flood intensity, and the amelioration of drought conditions. Soil erosion is contained through the protection of steep river banks and the immediate slopes - thereby preventing sheetwash and the downstream transport of sediment. Root "weirs" also maintain the river bed, preventing scouring (in small rivers and streams). Afforested strips in addition, provide wildlife with suitable habitats.

(iii) For a further discussion of management, conservation and rehabilitation issues, see Tinley, K.L., 1985. Coastal dunes of South Africa, South African National Scientific Programmes Report No. 109, Foundation for Research Development, CSIR, Pretoria, 300 p. and map, as well as Wyatt, J., 1993. Wetlands: assessment, management and rehabilitation of South African wetlands - an illustrated field guide for practical use by land agency extension services (draft), Renfreight Wetlands Campaign, [Natal Parks Board], Durban, 27 p. Literature on the rehabilitation of mining areas can be found in the bibliographic database. See also, Mentis, M.T. and Ellery, W.N., 1994. Post-mining rehabilitation of dunes on the north-east coast of South Africa, South African Journal of Science, VOL 90(2), p. 69 - 74. (The paper refers to the St Lucia debate).

(iv) It should be noted (in terms of the Conservation of Agricultural Resources Act No. 43 of 1983), that no cultivation of any land may take place within the flood area of a watercourse (defined as the 1 : 10 year flood line), or within 10 m horizontally outside the flood area of a watercourse (without a permit and subject to certain conditions). According to Wyatt (1990 - above), an indigenous afforestation programme may however, be initiated within 5 m of a watercourse. Wyatt (1990) suggested that commercial timber plantations must have an exclusion zone of approximately 30 m from any watercourse. The exclusion zone could be variable between 60 m in the lower reaches of the catchment where the river gradient is low and the soil moisture is high, to 15 m where the slope is steep and rapidly drained (resulting in a narrower moisture-saturated zone).

(v) The impacts of alien (undesirable) invader plants, mainly in riverine ecosystems, are receiving increased attention especially in terms of reduced runoff. Approximately 10 x 10^6 ha of land in South Africa has already been invaded by alien plants. Infestation is particularly acute in the western Cape and in the eastern Transvaal. While riverine environments may be invaded by a complex of alien plants, the two major invaders in the higher-lying areas of Natal/KwaZulu are Acacia dealbata (Silver Wattle) and Sesbania punicea (Red Sesbania)*. The hydrological implications of riparian vegetation (both alien and indigenous) as well as commercial plantations are currently being investigated by the Division of Forest Science and Technology, CSIR, P O Box 395, Pretoria, 0001. The Plant Protection Research Institute, Private Bag X134, Pretoria, 0001, offers a mapping and management advisory service with reference to alien plants. For an overview of some riparian issues see Bosch, J.M., 1985. A procedure for defining riparian zones in catchments, Report No. JFRC 85/35, Jonkershoek Forestry Research Centre, Department of Environment Affairs, Stellenbosch, 12 p., plus Bosch, J., Le Maitre, D., Prinsloo, E. and Smith, R., 1994. Proposed research programme for riparian zones and corridors in forestry areas, FRD Programme Report Series No. 14, Foundation for Research Development, Pretoria, 50 p. See in addition: Versfeld, D.B., 1990. Harvesting and the management of riparian zones, Wood Southern Africa, VOL 15(3), p. 32 - 41, 86 - 87.

(vi) A project known as the RDP Water Conservation Programme (and which forms part of the Reconstruction and Development Programme), was announced in October 1995 by the Department of Water Affairs and Forestry. The project involves the removal of invasive alien vegetation from important catchments and riparian zones in the western and eastern Cape, the Transvaal and in Natal/KwaZulu (the foothills of the Drakensberg and St Lucia). The project, as envisaged, will have a number of long term benefits including increased water yields, the preservation of biological diversity, and the creation of employment opportunities.

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* See Hoffmann, J.H. and Moran, V.C., 1988. The invasive weed Sesbania punicea in South Africa and prospects for its biological control, South African Journal of Science, VOL 84(9), p. 740 - 742. (See also the section on agrichemicals in the chapter on solid waste management, elsewhere in this publication).

Table M16: Some grasses suitable for the protection and conservation of stream banks and watercourses.

Botanical name	Common name	Frost resistance
Dry to moist environments		
Andropogon appendiculatus	Bluestem grass	Resistant
Cynodon dactylon	Couch grass	Resistant
Eragrostis capensis	Heartseed lovegrass	Moderately resistant
Eragrostis lappula	Phokwane	-
Imperata cylindrica	Cottonwool grass	Resistant
Pennisetum clandestinum	Kikuyu	Moderately resistant
Stenotaphrum dimidiatum	Buffalo grass	No resistance
Stenotaphrum secundatum	Coastal buffalo grass	No resistance
Wet environments		
Acroceras macrum	Nile grass	Moderately resistant
Digitaria swazilandensis	Richmond finger grass	Resistant
Echinochloa crus-galli	Barnyard millet	Moderately resistant
Hemarthria altissima	Red swampgrass	Moderately resistant
Ischaemum arcuatum	Turf grass	Moderately resistant
Leersia hexandra	Wild ricegrass	Resistant

Source: (i) After the South African Sugar Association Experiment Station, Mount Edgecombe, 1991.

(ii) After Tainton, N.M., 1996. Personal communication, Pietermaritzburg.

See also: (i) Haigh, H., 1973. Grassing eroded areas in the Drakensberg, Forestry in South Africa, No. 14, June 1973, p. 31 - 33.

(ii) Scotney, D.M. and McPhee, P.J., 1992. Chapter 1. Soil erosion and conservation, In: Van Oudtshoorn, F.P., Guide to Grasses of South Africa, Briza Publikasies, Pretoria, p. 11 - 34. (The chapter contains a useful list of grasses suitable for erosion control in summer rainfall areas).

(iii) Tainton, N.M., Bransby, D.I. and Booysen, P. de V., 1979. Common Veld and Pasture Grasses of Natal, Shuter and Shooter, Pietermaritzburg, 198 p.

productivity and income - the costly construction and maintenance of soil conservation works, flooding, and the destruction of terrestrial and aquatic wildlife habitats. Also apparent is a visibly degraded landscape.

The effects of wind erosion (less serious in Natal/KwaZulu by comparison with the interior provinces), have received limited attention in the literature. The approximate area of highly wind-susceptible soils in Natal/KwaZulu was estimated at 9 360 km^2 (Scotney, 1973)*. Three main areas in the province are subject to considerable wind erosion. In the north along the coastal belt from Durban to Mtunzini, a narrow strip of land - seldom more than 6 km wide and some 490 km^2 in extent - is prone to wind erosion. This area increases in width from Mtunzini to the Mozambique border, covering some 5 600 km^2 of land. Approximately 180 km^2 of land along the coast (in scattered areas) south of Durban, is also liable to erosion by wind. The extent of drift sands in particular along the coastal belt, in 1936, was estimated to be of the order of 15 km^2 (Keet, 1936, quoted in Scotney, 1978 - above)**. Drift sands occur mainly in areas to the north of Port Durnford (including the environs of St Lucia). Drift sand conditions, unless stabilized, persist for many years. Scotney (1978) provided an example from the St Lucia area where in the period 1937 - 1970, relatively little expansion of the eroded zone occurred, although the area was still in an active state of erosion. Weisser (1987)*** found that drift sands in the Port Durnford environs had decreased in size and number in recent years as a result of conservation measures.

An area of approximately 2 930 km^2 in the Newcastle, Vryheid, Dundee and Ladysmith environs (extending in the latter case, to the vicinity of Winterton), is likewise at risk in terms of wind erosion. In the south, on the Cedarville Flats, some 160 km^2 of land is similarly prone to wind erosion. Scotney (1973) identified special areas near Mooi River and Underberg which are also at risk with regard to the potential loss of soil fertility

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* See Scotney, D.M., 1973. An assessment of wind erosion hazard in Natal soils, Fifth National Congress of the Soil Science Society of South Africa, 13 - 16 February 1973, Salisbury, Rhodesia, 10 p.

** See Keet, J.D.M., 1936. Report on drift sands in South Africa, Bulletin No. 172, Forestry Series No. 9, Department of Agriculture and Forestry, Pretoria, 45 p.

*** See Weisser, P.J., 1987. Dune vegetation between Richards Bay and Mlalazi Lagoon and its conservation priorities in relation to dune mining, Natal Town and Regional Planning Commission Supplementary Report, VOL 19, Pietermaritzburg, 71 p. (The publication includes a chapter on dune vegetation rehabilitation following mining by Richards Bay Minerals Ltd).

caused by wind erosion. Scotney (1973) observed that the distribution of sandy soils is closely related to geological formation. Susceptible soils of the coastal belt are mainly associated with red and grey Recent sands of Quaternary origin. By contrast, extensive areas of Middle Ecca sandstone and Beaufort shales result in the light-textured soils of northern Natal/KwaZulu and the Mooi River as well as Underberg environs. Unconsolidated materials of alluvial and aeolian origin occur on the Cedarville Flats. All these areas are characterized by sandy soils and level to gently undulating terrain (with the partial exception of the coastal belt), and are often used for cropping purposes. Most of the serious erosion occurs between July and October, when conditions are dry and strong Berg winds of low humidity are frequent. Berg winds may often reach speeds in excess of 18 m s^{-1}. According to Chepil (1957) and Stallings (1959, both quoted in Scotney, 1973), the generally accepted threshold value for initial soil movement is 6 - 7 m s^{-1} at a height of 250 mm above the ground. Scotney (1973) noted however, that the threshold value is a constantly changing parameter, and is most strongly influenced by the particle size distribution.

Scotney (1973) warned of the consequences of intensive cropping in marginal cropping areas, on soils susceptible to wind erosion. Scotney recommended that a number of remedial measures should be undertaken - which are aimed at increasing the nutrient, organic and moisture content of the soil. Also important is the provision of maximum plant cover during the dry winter months, and a reduction in wind velocity (brought about by the planting of shelter belts). Other measures include minimum tillage, strip cropping, the use of chemical weed control, and the division of large fields into smaller panels. Scotney stressed that soils with a severe wind erosion hazard should be withdrawn from intensive cropping regimes, unless the lands are well protected during the months July - October. Regulation 5 of the Conservation of Agricultural Resources Act No. 43 of 1983 (see later in the chapter), deals specifically with wind erosion. Farmers in terms of the Act, are required to provide shelter belts on cultivated land in areas where wind erosion is problematic.

A study undertaken by J.L. Schoeman of the Institute for Soil, Climate and Water, Pretoria, revealed that 25% of South Africa has soils which are highly sensitive to wind erosion*.

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* Quoted in <u>Agricultural News</u>, 17 February 1992, p. 6. It would appear that the study refers to the 1 : 2 500 000 scale soil erosion map of South Africa - see the chapter on maps, elsewhere in this publication.

Two areas of particular concern are the north western Cape and the western half of the summer rainfall region (both characterized by sandy soils in areas with high wind velocities).

13.13 Soil erosion surveys and remedial measures in Natal/KwaZulu

Few large scale and detailed soil erosion surveys have been undertaken in Natal/KwaZulu. Current techniques may involve the use of satellite imagery as well as Geographic Information Systems*. The two most important (historical) surveys in Natal were undertaken in the Drakensberg environs and in the Tugela Basin. The Drakensberg (soil) Conservation Area, covering all land situated in the triangle between the Mooi and Tugela rivers from their junction up to the Drakensberg - on the Lesotho border - was proclaimed in 1944 (Government Notice GN 77/44), in order to safeguard water supplies. Official policy involved the acquisition of all privately owned land above 1 830 m in the High Drakensberg and adjacent areas (a process only recently completed by the Natal Parks Board). (See the chapter on catchments). A number of severely eroded farms in the Estcourt and Weenen districts were also expropriated by the State over a period of time (discussed later).

Pioneering investigative and remedial research work in the Drakensberg Conservation Area (and elsewhere in Natal), was undertaken by Pentz (1938; 1940; 1945)** and by Scott (1952)***, not only in terms of soil erosion per se, but also with regard to veld burning, bush encroachment, the reclamation of degraded veld, runoff control, and veld management in general. Unfortunately, subsequent information on the areal extent of soil erosion and remedial measures in the Drakensberg Conservation Area was never

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* The Institute for Soil, Climate and Water is examining the use of satellite imagery for the identification and mapping of degraded land in South Africa.

** See Pentz, J.A., 1938. The value of botanical survey and mapping of vegetation as applied to farming systems in South Africa, Memoir No. 19, Botanical Survey of South Africa, Department of Agriculture and Forestry, Pretoria, 15 p. + app. and map, as well as Pentz, J.A., 1940. Soil erosion survey of the reclamation area in Natal, Science Bulletin No. 212, Veld Management and Pasture Research Series Memoir No. 2, Department of Agriculture and Forestry, Pretoria, 18 p., and Pentz, J.A., 1945. An agro-ecological survey of Natal, Bulletin No. 250, Soil and Veld Conservation Series No. 7, Department of Agriculture and Forestry, Pretoria, 10 p.

*** See Scott, J.D., 1952. A contribution to the study of the problems of the Drakensberg Conservation Area, Science Bulletin No. 324, Natal Agricultural Research Institute Science Series No. 2, Department of Agriculture, Pretoria, 170 p.

(concisely) made available in a published format - and which is accessible to researchers outside the Department of Agriculture.

Garland (1987)* provided a useful review of erosion factors associated with footpaths (a relatively little studied topic generally), and veld burning in the Giant's Castle area of the Natal Drakensberg. Garland observed that the interrelationships between certain soil variables are complex (both those described in the literature as well as those examined in the study). Garland found that soil loss from footpaths was directly related to a number of rainfall parameters (most importantly rainfall erosivity, specifically the mean annual kinetic energy of rainfall - see SLEMSA later in the chapter). Garland concluded that veld burning immediately adjacent to footpaths can result in a severe erosion hazard, with high soil losses from such paths. Garland also examined small terracettes (steps in the surface soil) which are especially characteristic of the High Drakensberg. Terracettes are either parallel or sub-parallel to the contour or crescent-like in shape, and vary from a few to several metres in length. Riser heights are normally less than 1 m. The processes resulting in the formation of terracettes are not proven, and may range from sheet erosion to frost heave.

Garland proposed a footpath erosion risk assessment index for the Giant's Castle area, namely:

$$ER = KE + L + S$$

where ER = the erosion risk score
KE = the mean annual kinetic energy of rainfall score
L = the lithology score
S = the land slope score

The assessment index is designed for use at mapping scales of 1 : 50 000, although it can be modified for application at larger or smaller scales. It must be borne in mind that the assessment concerns the **potential** for erosion from footpaths and footpath/burning activities per se. Four erosion hazard classes were identified, specifically: Class 1 little or no maintenance required; Class 2 maintenance required at a few sites; Class 3 maintenance required at many sites, and Class 4 maintenance required at most sites. The

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* See Garland, G.G., 1987. Erosion risk from footpaths and vegetation burning in the central Drakensberg, Natal Town and Regional Planning Commission Supplementary Report, VOL 20, Pietermaritzburg, 74 p. and map.

index does not provide quantitative estimates of soil loss. Garland stressed that the cost of the remedial measures may well exceed the full value of the land. However, if remedial measures are not undertaken, then further effects such as the sedimentation of downstream dams may in time have significant implications (in conjunction with other causes of soil erosion). Schulze (1979 - see SLEMSA), provided soil loss estimates for the northern Drakensberg by means of a model.

A major regional soil survey in Natal/KwaZulu was that of the Tugela Basin where soil erosion phases were mapped. The maps provided a reliable basis for estimating the extent of erosion in specific bioclimatic groups and land classes (Table M17). Some sub-regional soil erosion surveys in Natal/KwaZulu (and elsewhere) are listed in the bibliographic database.

Table M17: The percentage distribution of soil erosion in the Tugela Basin.

Land and erosion classes	Bioclimatic group				
	4	6	8 (clayey)	8 (sandy)	10
Uplands Sheet	33 1	60 16	39 37	57 25	31 19
Gully	-	1	-	-	4
Bottomlands Sheet	12 -	13 1	19 -	25 -	- -
Gully	-	2	16	18	-
Denuded	-	-	1	-	17
Steep/rocky	54	27	41	18	52
Erosion percentage of bioclimatic group	1	20	53	43	40
Erosion percentage of soil associations mapped in each bioclimatic group	2	27	90	52	83

<u>Source</u>: (i) After Scotney, D.M., 1978. Erosion in Natal: 1978, Department of Agricultural Technical Services (Natal Region), Cedara, 19 p.

(ii) After Van der Eyk, J.J., MacVicar, C.N. and De Villiers, J.M., 1969. Soils of the Tugela Basin: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 15, Pietermaritzburg, 263 p. and maps.

See also:

(i) Garland, G. and Broderick, D., 1992. Changes in the extent of erosion in the Tugela catchment, 1944 - 1981, South African Geographical Journal, VOL 74(2), p. 45 - 48.

(ii) Phillips, J., 1973. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps.

(iii) Thorrington-Smith, E., 1960. Towards a plan for the Tugela Basin: second interim report of the regional survey of the Tugela Basin, prepared in the Office of the Town and Regional Planning Commission, Natal, Natal Town and Regional Planning Commission Report, VOL 5, Pietermaritzburg, 266 p. and maps. (One map is a broad overview of the extent of donga erosion in the Tugela Basin).

(iv) Thorrington-Smith, Rosenberg and McCrystal, 1978. Towards a plan for KwaZulu: a preliminary development plan, VOL 1, The written report, 341 p., and VOL 2, Atlas of maps and illustrations, various pages, KwaZulu Government, Ulundi. (The publication contains a useful veld type map for Natal/KwaZulu showing inter alia Valley Bushveld (Thornveld) areas - based on Acocks (1975; 1988)). (See the chapter on catchments).

Note:

(i) The extent of erosion in bioclimatic groups 8 and 10 areas is evident, where 50 - 90% of the soils have been severely eroded (based on the mapping/sampling techniques used in the survey). Gully erosion is especially widespread in the bottomlands of group 8. For a more detailed analysis, it is important to examine the (13) 1 : 100 000 scale soil maps provided by Van der Eyk, MacVicar and De Villiers (1969), which show inter alia gully erosion. See in particular Miscellaneous soil/land types W. Unstable aeolian sands (wind erosion) and Z. Land denuded of soil by gully erosion (water erosion). Sheet eroded land (x) and gully eroded land (y) phases (as opposed to larger parcels of land totally denuded of soil), are also indicated.

Some of the worst erosion has occurred in the (upland) sandy and loamy (with soft plinthic horizons) Leksand and Avalon series, as well as in the (upland) loamy Estcourt Series and the sandy Uitvlugt and Avoca series (all three being duplex soils). Severe erosion was also found in the (upland) clayey Arcadia, Bonheim and Gelykvlakte series (margalitic soils) and in the (riverine) clayey and loamy Sunvalley, Ferry and Weenen series (red, calcareous soils); as well as in the (bottomlands) clayey and loamy Rensburg, Willowbrook, Killarney, Estcourt and Uitvlugt series (margalitic and non-margalitic gley soils). Duplex soils which are particularly at risk consist of a relatively coarse-textured A horizon which overlies (with an abrupt transition), a relatively clayey B horizon. Due to the shallow depth to the impermeable B horizon, saturation of the A horizon during high intensity storms occurs rapidly. Thereafter, additional rain is carried away by surface flow. In the absence of adequate grass cover, sheet erosion and subsequently rapid gully erosion is the norm (Van der Eyk et al).

(ii) Pentz, J.A., 1940. Soil erosion survey of the reclamation area in Natal, Science Bulletin No. 212, Veld Management and Pasture Research Series Memoir No. 2, Department of Agriculture and Forestry, Pretoria, 18 p., in an analysis of soil erosion in that part of the Drakensberg Conservation Area situated between the Bushmans and Blaauwkrantz (Bloukrans) rivers (bioclimatic group 10 and to some extent group 8), found the following: Of the 45 801 ha surveyed, 8 781 ha was completely eroded down to bedrock in terms of sheet or donga erosion. Badly eroded (cultivated) areas covered 6 172 ha, while sheet eroded and overgrazed hillslopes (not denuded beyond repair), covered 15 162 ha. Only 15 686 ha or 34,2% of the survey area was regarded as being in a fair condition. Land in fair condition consisted mainly of farms which were not used as labour farms. Subsequent remedial work has been undertaken by the Department of Agriculture and the Natal Parks Board in the region (centred on Weenen), although the extent of erosion is still serious.

(iii) In order to better understand man-induced changes to the natural vegetation and the important implications arising therefrom (including soil erosion), the following should be examined: Edwards, D., 1967. A plant ecological survey of the Tugela River Basin, Memoir No. 36, Botanical Survey of South Africa, Botanical Research Institute, Department of Agricultural Technical Services, Pretoria/Natal Town and Regional Planning Commission Report, VOL 10, Pietermaritzburg, 285 p. (See especially, p. 197 - 211).

(iv) Scotney, D.M., 1983. Agricultural resources of Natal, Symposium on Thought for Food: the 21st Century, South African Society for Agricultural Extension (Natal Branch), 13 May 1983, Pietermaritzburg, 16 p., with reference to white owned farms in Natal, noted that overstocking of the veld was a serious problem in bioclimatic groups 7 - 11 inclusive. Scotney observed that despite the more favourable stocking rate in other bioclimatic groups, severe deterioration in veld species composition and cover was evident wherever correct management was lacking. Scotney stressed that the standard of veld management throughout Natal (including the Tugela Basin) was far from satisfactory, and that much of the degraded veld will require protection. Phillips (1973 - above) estimated the global overstocking rate in black settled areas in Natal in 1967 (prior to the political advent of KwaZulu), to be of the order of 26%.

An important soil erosion survey and rehabilitation programme is underway in the 469 ha Kikimbi/Dendetu area to the west of Stanger in the Mvoti River catchment (Anonymous, 1993)*. The area, which is inhabited by Indian market gardeners and small scale farmers, was severely eroded during the September 1987 floods in Natal/KwaZulu. The erosion hazard is extremely marked in the Kikimbi/Dendetu area due to the highly erodible soils and steep slopes ranging from 10 - 15%. It was estimated that some 1 500 000 m^3 of soil in the area was washed away during the three day flood period, when a total of 800 mm of rain was recorded. The loss of top soil was estimated at 2 000 t ha^{-1}, by comparison with a "normal" loss for the area of some 10 - 20 t ha^{-1} y^{-1}. Sugar cane production declined from 16 000 t y^{-1} to approximately 8 000 t y^{-1}. The annual loss of income due to flood damage was estimated to be in excess of R800 000. In total, 25% of the Kikimbi/Dendetu area was severely damaged. The resulting socio-economic impact included abandonment of some plots, with production and income being reduced to zero. In view of the small size of plots (averaging 0,9 ha), it was impossible for individual farmers to rehabilitate their holdings as isolated units. The Department of Agriculture accordingly declared the area to be a Key Soil Conservation Project. Rehabilitation of the area will be undertaken as a complete unit. The Directorate of Soil Conservation and Drilling Services, Chief Directorate: Agricultural Engineering and Water Supply of the Department of Agriculture, Private Bag X515, Silverton, 0127, aims to restore the optimum farming potential of the area over a period of 18 months. It was estimated that some 37 km of access roads, and more than 500 stone packs (gabions) placed in 30 km of waterways, as well as contour banks plus other conservation works will need to be constructed. The project as envisaged will reduce the sediment load in the Mvoti River. It is evident that erosion per se and erosion resulting from severe flooding extracts a high price! (See the section on civil defence/protection in the chapter on the surface water resources of Natal/KwaZulu).

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* See Anonymous, 1993. Rehabilitation to optimise farming potential/Rehabilitation will stop abandonment of area, Agricultural News, 20 September 1993, p. 8 - 9. The use of Vetiver grass (Vetivaria zizanoiodes) is being considered in the Kikimbi/Dendetu area, in order to rehabilitate and stabilize the land. Vetiver grass is hardy and can withstand extreme conditions. The roots of the grass become established six months after planting and the grass will mesh as a hedge in two growing seasons. The grass is also non-invasive, keeps growing for years, and is not damaged by fire (Kotze, J., 1994. Vetiver grass efficient in combating soil erosion, Agricultural News, 7 November 1994, p. 4 - 5). The grass is also being considered for use in the forestry industry. See: Jarmain, R.M., 1994. Firebelt erosion control: whither now?, Wood Southern Africa and Timber Times, VOL 19(7), p. 38 - 39.

Detailed data on extant soil erosion in KwaZulu are not readily available (excluding Land Type maps), although the soil degradation and social problems of Msinga and environs (KwaZulu Area No. 3) (bioclimatic group 10) are well known. A severe erosion problem is developing in the Nqutu area which is part of the Mfolozi River catchment (KwaZulu Area No. 3). Concern has also been expressed in the Drakensberg Catchment Area regarding soil erosion in KwaZulu Area No. 8 (the Upper Tugela Location)* - see the chapter on catchments. Apart from the obvious physical effects of soil erosion, it has been suggested that terrain degradation and hence competition for remaining resources, might have been a pre-disposing factor in the violence which has beset parts of rural KwaZulu in recent times**.

The distribution of productive land in KwaZulu is far more favourable than is commonly believed (see the chapter on catchments). Thorrington-Smith, Rosenberg and McCrystal (1978)*** reported that bioclimatic groups 1 - 4 inclusive (comprising high potential agricultural land), constitute some 40,8% of KwaZulu. Medium potential agricultural land (bioclimatic groups 6 and 8), occupies 17,8% of KwaZulu. Low potential (without irrigation) land - bioclimatic groups 7, 9, 10 and 11 - covers 41,5% of KwaZulu.

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* Davies Lynn and Partners, P O Box 2328, Durban, 4000, have data on soil erosion for KwaZulu Area No. 8. The data-set includes 1 : 10 000 scale orthophoto maps showing the areal extent of soil erosion.

** It could be argued that land degradation in Africa generally (along with other poverty-related social ills) is of grave political and strategic importance - which if left unchecked - could result in civil unrest and the eventual disruption of essential services. A brief, although useful overview of the effects of unrest and war on health, is the following: FitzSimons, D.W. and Whiteside, A.W., 1994. Conflict, war and public health, Conflict Studies Report No. 276, Research Institute for the Study of Conflict and Terrorism, London, 37 p. (The publication can be examined at the Economic Research Unit, University of Natal, Durban).

*** See Thorrington-Smith, Rosenberg and McCrystal, 1978. Towards a plan for KwaZulu: a preliminary development plan, VOL 1, The written report, 341 p., and VOL 2, Atlas of maps and illustrations, various pages, KwaZulu Government, Ulundi. A slope map (for KwaZulu areas only) is provided in the publication - divided into land generally steeper than 1 : 6 and land generally flatter than 1 : 6. Generalized slope maps for the various catchments of the Tugela Basin (land steeper than 1 : 25; land with a slope between 1 : 25 - 1 : 50, and land flatter than 1 : 50) are presented in Thorrington-Smith, E., 1960. Towards a plan for the Tugela Basin: second interim report of the regional survey of the Tugela Basin, prepared in the Office of the Town and Regional Planning Commission, Natal, Natal Town and Regional Planning Commission Report, VOL 5, Pietermaritzburg, 266 p. and maps. The following should also be examined: Van der Eyk, J.J., MacVicar, C.N. and De Villiers, J.M., 1969. Soils of the Tugela Basin: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 15, Pietermaritzburg, 263 p. and maps. Two miscellaneous soil/land types are of particular interest in the latter report, namely: M. Stony land, steep land or land with very shallow soils and N. Mountainous land (mostly steep) but including inaccessible land of the high plateaux. The data are mapped on (13) 1 : 100 000 scale map sheets. Important slope data are also found in the 1 : 250 000 scale Land Type maps and memoirs (see earlier in this chapter).

Approximately 51,7% of the Coastal Lowlands (bioclimatic group 1), which is potentially the most productive bioclimatic group, is situated in KwaZulu. Another highly rated agricultural region is the Coastal Hinterland (bioclimatic group 2), of which 57,6% is in KwaZulu. It should be borne in mind however, that much of Natal/KwaZulu is hilly with steep slopes. The province therefore, has an inherently high soil erosion potential. King (1982)* observed that the Natal/KwaZulu landscape appears to have been "turned inside out", in the sense that in most countries, flat plains are overtopped by high ridges or mountain peaks. In Natal/KwaZulu by contrast, the uplands are flat or undulating and the relief is provided by deeply incised valleys.

According to Scotney (1988)**, few studies have accurately detected long term changes in the rates of accelerated erosion in South Africa, although Roux and Opperman (1986)*** suggested that erosion in the Karoo peaked 40 - 50 years ago. Similarly, Garland (unpublished, quoted in Scotney, 1988) observed that erosion in Natal/KwaZulu increased from colonial times until about the 1950s, but has tended to decline over the last 40 years. It is evident nevertheless, that erosion is increasing in parts of KwaZulu. A most worthwhile research project would involve the synthesis of historical and current information on soil erosion in Natal/KwaZulu. The analysis could be used to assess the effectiveness of past erosion policies, and to plan future strategies. It is frankly surprising that such an analysis - for the whole province - has not yet been undertaken.

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* See King, L., 1982. The Natal Monocline: Explaining the Origin and Scenery of Natal, South Africa, University of Natal Press, Pietermaritzburg, 134 p.

** See Scotney, D.M., 1988. Chapter 12. The agricultural areas of southern Africa, In: Macdonald, I.A.W. and Crawford, R.J.M. (eds), Long-term Data Series Relating to Southern Africa's Renewable Natural Resources, South African National Scientific Programmes Report No. 157, Foundation for Research Development, CSIR, Pretoria, p. 316 - 336.

*** See Roux, P.W. and Opperman, D.P.J., 1986. Chapter 6. Soil erosion, In: Cowling, R.M., Roux, P.W. and Pieterse, A.J.H. (eds), The Karoo Biome: a Preliminary Synthesis, Part 1 - Physical Environment, South African National Scientific Programmes Report No. 124, Foundation for Research Development, CSIR, Pretoria, p. 92 - 111.

13.14 The National Grazing Strategy*

The National Grazing Strategy was announced in 1985 by the then Department of Agriculture and Water Supply. Paramount is the concept of a stocking rate which does not exceed the carrying (grazing/browsing) capacity of the natural veld. Estimates of the correct stocking rate have been central to many studies on grassland management and conservation. Nearly all such studies indicate excessive stocking rates in South Africa generally, which together with poor veld management, is the major cause of widespread veld degradation. Bruwer (1977, quoted in Scotney, 1988) estimated that some 60% of the veld in South Africa is in poor condition. The Karoo is a case-in-point. Roux and Opperman (1986) suggested that the Karoo is overstocked by approximately 30%, with progressive deterioration of the veld evident. Data (including maps) now available from the Department of Agriculture for the various agricultural regions in South Africa, provide appropriate grazing capacity guidelines**. This information is essential for the implementation of the Conservation of Agricultural Resources Act No. 43 of 1983.

The incidence of drought is an important contributory factor in determining grazing capacity. Studies undertaken by the then Department of Agriculture and Water Supply for the period 1956 - 1986, revealed that nearly 27% of the magisterial districts of South Africa are drought stricken (in terms of a formal disaster drought declaration by the Department), for more than 50% of the time. Roux and Opperman suggested that the Karoo experiences drought conditions for approximately 30 - 50% of the time.

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* Discussion based on Scotney (1988). According to Scotney, 87% of the land used for agriculture in South Africa consists of natural grazing. A useful overview of factors influencing grasslands, including fire and grazing, is the following: Walker, R.S., 1988. Chapter 8. Long-term data series from South African grasslands, In: Macdonald, I.A.W. and Crawford, R.J.M. (eds), Long-term Data Series Relating to Southern Africa's Renewable Natural Resources, South African National Scientific Programmes Report No. 157, Foundation for Research Development, CSIR, Pretoria, p. 253 - 267. See also, Meissner, H.H., Hofmeyr, H.S., Van Rensburg, W.J.J. and Pienaar, J.P., 1983. Classification of livestock for realistic prediction of substitution values in terms of a biologically defined Large Stock Unit, Technical Communication No. 175, Department of Agriculture, Pretoria, 40 p., as well as Turner, J.R. and Tainton, N.M., 1990. A comparison of four different standards of reference for the animal unit for determining stocking rate, Journal of the Grassland Society of Southern Africa, VOL 7(3), p. 204 - 207.

** Grazing capacity guidelines for wetlands are presented in Wyatt, J., 1993. Wetlands: assessment, management and rehabilitation of South African wetlands - an illustrated field guide for practical use by land agency extension services (draft), Renfreight Wetlands Campaign, [Natal Parks Board], Durban, 27 p.

An Interim Veld Recovery Scheme was announced in June 1994 by the Department of Agriculture (Anonymous, 1994)*. The purpose of the scheme is to provide assistance to livestock farmers in order to allow the veld (damaged by the 1992/93 drought), to recover. In terms of the scheme, the Department of Agriculture will make a payment in cases where the natural grazing has not fully recovered. The scheme applies to all areas (including former homelands and national states), which were declared as disaster drought areas for at least nine months or more during the years 1991, 1992, 1993 and up to and including the 1st of May 1994. A monthly payment will be made for stock reduction below the long term grazing capacity of the given farm unit (up to and including 50% of the long term grazing capacity). Various conditions apply to the subsidy. A further scheme, the Disaster Drought Assistance Scheme for Stock Farmers, is also currently in operation (see the chapter on rainfall). It should be noted that a version of the PUTU crop growth simulation model originally developed at the Department of Agrometeorology, University of the Orange Free State - and which is known as the PUTU-farm model - has been compiled by the Glen Agricultural Development Institute of the Department of Agriculture, Private Bag X01, Glen, 9360. The latter model can be used to simulate maize production and veld productivity in terms of drought risk**.

13.15 A short history of some resource conservation measures in South Africa***

According to Scotney (1988 - above), concern for the environment was first expressed by the Governor of the Cape, W.A. Van der Stel, some 300 years ago. Specifically, veld burning was discouraged and various Placaaten (No. 38 of the 9th of November 1658; No. 71 of the 16th of December 1661, and No. 215 of the 19th of February 1687) were issued. Laws regarding the burning of veld in Natal were passed in 1865 and 1869. Similar laws were passed in 1895 in the Transvaal, and in 1908 in the Orange Free State (Scott, 1952)****. Some early conservation milestones in South Africa were the

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* See Anonymous, 1994. Interim Veld Recovery Scheme, Agricultural News, 20 June 1994, p. 2, 4.

** For an examination of a similar model, see Du Pisani, A.L., 1987. The CERES-MAIZE model as a potential tool for drought assessment in South Africa, Water SA, VOL 13(3), p. 159 - 164.

*** Discussion based on Adler, E., 1981. Ons kwynende bodem/Our shrinking land, Ekos, VOL 1(3), p. 6 - 21.

**** See Scott, J.D., 1952. A contribution to the study of the problems of the Drakensberg Conservation Area, Science Bulletin No. 324, Natal Agricultural Research Institute Science Series No. 2, Department of Agriculture, Pretoria, 170 p.

1916 Select Committee on Drought Distress Relief report, the 1923 final report of the Drought Investigation Commission, and the 1929 Conference on Soil Erosion held in Pretoria*. Proposals resulting from the 1929 Conference included the need for the establishment of a permanent Soil Erosion Advisory Council. Also necessary was the creation of a separate organization (under the then Department of Agriculture) to combat soil erosion, as well as to facilitate the granting of State assistance to farmers for the prevention of soil erosion. (See Table B8 in Chapter 2 for a listing of various Commissions and Committees of Inquiry). The Soil Erosion Advisory Council was duly formed in 1930. A number of soil erosion schemes were initiated in 1933, which provided for the subsidization of soil erosion works including small dams for stock watering purposes. Special funds were made available for soil and veld conservation research. Increased attention was also given to weed control with an emphasis on the encroachment of useless or noxious vegetation on both arable and grazing land. The State assumed full responsibility for the administration of weed control with the passing of the (since repealed) Weeds Act No. 42 of 1937 (Adler, 1981).

In 1939, the Division of Soil and Veld Conservation was created in the then Department of Agriculture and Forestry specifically to deal with soil erosion. The conservation programme included the expropriation and permanent protection of important mountain catchments (see the chapter on catchments). The promulgation of the (since repealed) Forest [and Veld Conservation] Act No. 13 of 1941 was the next important development. The Act made provision inter alia for the expropriation by the State, of any land required for drift sand reclamation as well as for erosion control, and for the conservation of water resources. The Act also provided for the reclamation of land at public expense, and for the proclamation of any land as a Conservation Area. The declaration of a Conservation Area implied that the State would proceed with the reclamation and conservation of all badly eroded land in the specific area. The Drakensberg Conservation Area (approximately 809 370 ha - the largest in South Africa), was proclaimed in 1944. In the scheme drawn up for the Drakensberg Conservation Area, the proposed plan of action was divided into two main parts, namely, major works undertaken by the State, and minor works undertaken by farmers with assistance if necessary, from the State. Major works referred to reclamation works on a large scale involving a given sub-region, while minor works

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* The literature of the time and even up to the early-mid 1940s, was littered with deeply vexed and panic-stricken papers concerning the Evils of Soil Erosion! (my emphasis - and theirs); as well as: Is South Africa Drying Up? (my emphasis and theirs) - see the bibliographic database.

included all types of conservation measures such as fencing, contouring, the introduction of crop rotation with pasture leys, and smaller reclamation works. Farm planning was initiated in the Drakensberg Conservation Area in order to effect the stated policy measures (Scott, 1952). Farm planning is now standard practice in South Africa. Farm planning encompasses physical/biological and hydrological aspects, as well as economic and financial matters and general management issues. By 1946, five Conservation Areas covering 1 404 612 ha had been proclaimed in South Africa (Adler, 1981).

In 1941, the then Department of Agriculture and Forestry reported on soil erosion in South Africa, and later, the reconstruction of post-war agriculture (in 1944). The National Veld Trust (P O Box 72862, Lynnwood Ridge, 0040) was established in 1944. The Trust was deeply involved in public education and received much public support. In 1946, the Soil Conservation Act No. 45 of 1946 was promulgated. The Trust played a major role in the compilation of the Act, as well as the subsequent establishment of the Buffalo and Umgeni River Catchment Associations (since defunct), plus the Vaal River Catchment Association. According to Scott (1978)* the promulgation of the Act resulted in a decrease in public concern with soil erosion - since the problems of erosion were then regarded as "solved". The Act however, provided the legislative machinery for the more effective rehabilitation of the veld. Improved soil erosion control was also possible (Adler, 1981). The Act created the Division of Soil Conservation and Extension in the then Department of Agriculture, as well as the Soil Conservation Board. The Act therefore followed on from the Forest [and Veld Conservation] Act No. 13 of 1941. Besides the right to expropriate land in any Conservation Area, the State now also had the power to suspend (for a specified period), some or all of a farmer's rights of ownership. In other parts of Natal, Soil Conservation Districts (established at the request of farmers and not by the State), were demarcated. Soil Conservation District Committees - currently termed Conservation Committees - became responsible for drawing up soil erosion control and conservation schemes for their own districts. The committees (with the assistance of the then Department of Agriculture) were likewise responsible for adherence to the agreed plans in their respective districts. By 1949, more than 25% of the farms in South Africa fell within proclaimed Soil Conservation Districts (Adler, 1981). Numerous other programmes were

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* See Scott, J.D., 1978. Session 2. Management of rivers, flood plains and estuaries in Natal and KwaZulu, [Talk by J.D. Scott], In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 70 - 72.

launched and the State made provision for financial support and incentives, mainly in the form of subsidies, grants and loans. Further aid and incentives were provided by means of the Grass Leycrop Scheme (1958 - 1971), the Stock Reduction Scheme (1961 - 1979), and the Veld Reclamation Scheme (1966 - 1971). According to Adler close on R100 million was spent by the State on financial aid to combat soil erosion, in the period 1948 - 1981. In 1948 however, it was estimated that the costs of the envisaged programme would be some R200 million spread over the next 25 years.

In black settled areas, the counterpart of the Conservation Area or District was the Betterment Area. Wide powers were conferred on the then Department of Native Affairs, later the Department of Bantu Administration and Development* mainly in terms of the since repealed (Native) subsequently, Black Administration Act No. 38 of 1927 and the since repealed (Native) subsequently, Development Trust and Land Act No. 18 of 1936. Among the more important of these powers was the enforced withdrawal from agricultural use of degraded land, and the annual culling of livestock (Thorrington-Smith, 1960)**. Other measures included the demarcation of arable and grazing land, the establishment of grass contour strips, and the identification of residential zones to prevent housing construction in valuable grazing areas - thereby facilitating the desired implementation of rotational grazing. The Betterment Scheme was initiated by virtue of Proclamation Proc 31/39 and was considerably expanded in terms of Proc 116/49. The latter was repealed by Regulation Proclamation Proc R R196/67. (See also R192/67 and R197/67). Betterment planning is widely regarded as having failed, with few successes evident. Much resentment was generated in particular, with the separation of housing and

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* The Department was more recently known as the Department of Plural Relations and Development (for a very brief period), then the Department of Co-operation and Development, and was finally known as the Department of Development Aid. Political changes resulted in the closure of the Department in December 1991.

** See Thorrington-Smith, E., 1960. Towards a plan for the Tugela Basin: second interim report of the regional survey of the Tugela Basin, prepared in the Office of the Town and Regional Planning Commission, Natal, Natal Town and Regional Planning Commission Report, VOL 5, Pietermaritzburg, 266 p. and maps. (Brief details of Betterment plans are listed for the various river catchments). See also: Rowland, J.W. (ed), 1974. <u>The Conservation Ideal: Being the SARCCUS Record for the Period 1952 - 1970</u>, Southern African Regional Commission for the Conservation and Utilization of the Soil, Pretoria, 377 p. Some background on Betterment Areas is provided by Cross, C., 1991. Chapter 4. Informal tenures against the State: landholding systems in African rural areas, In: De Klerk, M. (ed), <u>A Harvest of Discontent: the Land Question in South Africa</u>, Institute for a Democratic Alternative for South Africa, Cape Town, p. 63 - 98. See also Chapter 5. Land reforms - State initiatives, p. 99 - 111., and Chapter 11. Agriculture in the bantustans: towards development policies, p. 239 - 258. See in addition: Yawitch, J., 1982. <u>Betterment: the Myth of Homeland Agriculture</u>, South African Institute of Race Relations, Johannesburg, 102 p. Readers should likewise refer to the so-called Tomlinson Commission which reported in 1955 - see the end of this chapter.

arable/grazing land, and general disturbance of the socio-economic fabric. Soil conservation regulations issued in terms of the (repealed) Act No. 18 of 1936 still apply in KwaZulu, by virtue of the Abolition of Racially Based Land Measures Act No. 108 of 1991. It is the statutory function of the KwaZulu Department of Agriculture and Forestry, Private Bag X05, Ulundi, 3838, to undertake and advise on soil erosion control measures in KwaZulu.

The next important milestone, following on from the Soil Conservation Act No. 45 of 1946, was the 1961 report of the then Department of Agricultural Technical Services on the conservation of mountain catchments in South Africa (see Table B8 in Chapter 2). Subsequently, the Soil Conservation Act No. 76 of 1969* was passed which repealed Act No. 45 of 1946. The 1969 Act resulted in the appointment of special inspectors in the newly formed Division of Soil Protection (Adler, 1981). According to Scotney (1978)**, 347 cases of malpractice in South Africa in the period 1969 - 1978 were brought to the attention of the Division, with 21 directions served to enforce conservation measures. There was widespread evidence that many of the requirements of farm plans were not being applied in practice, in direct contravention of Act No. 76. Scotney observed that numerous flagrant transgressors of the Act however, escaped prosecution.

In the period 1946 - 1978, over 6 000 farm units in Natal (comprising some 4 300 000 ha) were physically planned, with the construction of appropriate soil conservation works such as contour banks. A further 300 000 ha of arable land in the province still needed to be protected at that time (Adler, 1981; Scotney, 1978). Around 1981, the Director of the Division of Soil Protection reported that 73% of the total agricultural land in South Africa had been planned in terms of the relevant legislation. It was further reported that the amount of subsidies paid out for soil conservation measures (and therefore activities), had declined from R7,2 million in 1977/78 to R2,5 million in 1978/79. In terms of 1981 prices, it was estimated that the cost to the State of constructing erosion control works (mainly contour banks), on the approximately

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* For a brief discussion of the Act, see Shrand, D. and Davis, G., 1971. Law and Finance for the Farmer, Legal and Financial Publishing Company, Cape Town, 423 p. See also, Verster, E., Du Plessis, W., Schloms, B.H.A. and Fuggle, R.F., 1992. Chapter 10. Soil, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 181 - 211.

** See Scotney, D.M., 1978. Soil erosion in Natal: 1978, Department of Agricultural Technical Services (Natal Region), Cedara, 19 p.

8 000 000 ha of arable land in South Africa still requiring protection, would be of the order of R213 million (Adler, 1981). Problems associated with the programme included the high extension input required to motivate farmers, the non-acceptance of conventional layouts, failure to maintain contour terraces, and poor tillage practices. Emphasis is now placed on runoff control planning for catchment areas, which provides a framework for the proper planning of individual farms on a hydrological basis (Scotney, 1978).

A further conservation milestone was the Subdivision of Agricultural Land Act No. 70 of 1970 which effectively reduced the number of uneconomic farm units in South Africa, thereby helping to promote correct conservation methods*. (Small farms are often overstocked and their owners seldom have the capital to spend on soil conservation works). Problems experienced with Act No. 76 of 1969 resulted in the promulgation of the Conservation of Agricultural Resources Act No. 43 of 1983 (see later in the chapter). In 1985, the National Grazing Strategy was announced. In 1986, the Economic Advisory Council undertook an investigation into the restructuring of agriculture in South Africa. Recent trends suggest that State assistance, for example in times of drought, will only be forthcoming for those farmers who can prove active compliance inter alia with soil erosion control requirements.

From a scientific viewpoint, important achievements included the release of the 1977 binomial soil classification system. The system made a significant contribution to improved land use and conservation through a better understanding of soil resources and erosion hazards. The development of the Soil Loss Estimation Model for Southern Africa (SLEMSA) is regarded as a major milestone in the history of conservation in South Africa. The model was derived in the absence of detailed local research on soil loss estimates (Scotney, 1978). The release of the 1991 taxonomic soil classification system was likewise of importance.

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* It is likely that Act No. 70 of 1970 will be repealed in due course to accommodate the needs of small scale black farmers.

Considerable progress has been made in Natal/KwaZulu with the rehabilitation of the Thornveld (bioclimatic group 10) in the Weenen area (Le Roux, 1978)*. The use of simple methods including stone packs or gabions placed in dongas has proved effective with the eventual in-filling of soil against the stone pack, and the consequent revegetation of the donga. Notwithstanding such (and other) successes, much remains to be done. In a recent survey of the economic impact of farmland degradation in Natal, it was estimated that the reduction in potential income from cattle farming - as a result of veld deterioration - was of the order of R100 million annually (Anonymous, 1994)**. The study involved 3 000 000 ha of commercial agricultural land, of which 50 600 ha had been totally destroyed by erosion. Only 15% of the 353 900 ha of cultivated land examined, was adequately protected by conventional mechanical means. The investigation revealed that mechanical protection alone, is insufficient to reduce erosion on cultivated lands to a rate where it would at least equal the rate of soil formation. The survey also showed that the effect of sediment in rivers is serious, with some R1 million spent annually in dredging the St Lucia Estuary. In practical terms the cost of replacing the Spioenkop Dam for instance (due to sediment infill), would be of the order of R147 million at 1994 prices, assuming that the entire dam had to be replaced. The original cost of the dam which was built in 1973 was R11 million.

The sequence of historical events in terms of soil erosion (as summarized above), provides a back-drop for the situation in parts of KwaZulu. Of particular concern is the "tragedy of the commons" scenario (see the bibliographic database), where communally owned land is exploited for grazing purposes. In these circumstances there is little effective control over stocking rates and veld management in general. There is accordingly, virtually no incentive for individuals to reduce stock numbers. Poverty and the small size of individual land holdings also contribute to the problems of environmental degradation. Other factors include the high proportion of rural households headed by women - who may lack the necessary agricultural skills (with fallow land evident in parts of KwaZulu).

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* See Le Roux, S.D., 1978. Session 3. New approaches to farming projects and their effects on the environment - an extension programme in the Thornveld areas of Natal, In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 87 - 90. (A number of other papers in the proceedings are also of relevance to soil erosion and related issues).

** See Anonymous, 1994. Degradation of Natal soil affects all sectors of economy, Agricultural News, 13 June 1994, p. 3.

While emerging black farmers need not repeat the long and often-troubled history of soil erosion control experienced by their white counterparts, it is evident that the next major horizon involves widespread education programmes and State-funded conservation works in black settled areas. The Agricultural and Rural Development Research Institute (ARDRI) of the University of Fort Hare, Private Bag X1314, Alice, 5700, has undertaken pioneering work in terms of soil erosion education and remedial measures in the Ciskei. The Department of Geographical and Environmental Sciences, University of Natal, Durban, has begun to develop a similar programme in KwaZulu (Garland, Robinson and Pile, 1994)*. Some soil erosion remedial work has also been undertaken in KwaZulu by the Institute of Natural Resources, University of Natal, Pietermaritzburg. The Department of Agriculture - as the result of a change in policy where assistance is now provided to small scale black farmers - is involved with soil erosion advisory services in many developing areas**.

Prototype natural resources management programmes (in a broad sense) have been initiated by the Social Development Research Unit, Human Sciences Research Council, P O Box 17302, Congella, 4013, in the Maputaland and Paulpietersburg environs. The Natal Parks Board, P O Box 662, Pietermaritzburg, 3200, provides environmental advice and assistance to communities bordering protected areas controlled by the Board. The Division of Nature Conservation, Chief Directorate: Administration, Community Services Branch, Natal Provincial Administration, Private Bag X9037, Pietermaritzburg, 3200, manages three resource areas where rural residents are trained in the optimum use of natural resources. (See the chapter on catchments). Several environment and development orientated non-government organizations such as the Farmer Support Group of the University of Natal, Pietermaritzburg, have also begun to address ecosystem degradation as well as training in community resources management (with important implications for soil erosion control). The Group is currently active in the (Nt)Shongweni catchment near Cato Ridge. The examination of indigenous knowledge systems and

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* See Garland, G.G., Robinson, J.R. and Pile, K.G., 1994. Policy, perception and soil conservation: a case study from Cornfields, Natal, Department of Geographical and Environmental Sciences, University of Natal, Durban, 41 p. See also, Brinkcate, T.A. and Hanvey, P.M., 1996. Perceptions and attitudes towards soil erosion in the Madebe community, Northwest Province, South African Geographical Journal, VOL 78(2), p. 75 - 82.

** See Coetzee, E., 1994. Gabions to stabilize land/Training trainers to train farmers, Agricultural News, 12 September 1994, p. 5 - 6.

folklore surrounding the use of natural resources (including water), is an integral component of presently evolving resource policies*.

Past neglect of agriculture in the developing areas may impose severe penalties in the future (amounting to a tax on following generations). Mitigating factors may include the accelerating rate of urbanization of the black population**. A detailed analysis of the implications of migration however, is beyond the scope of the present publication.

13.16 The Soil Loss Estimation Model for Southern Africa (SLEMSA)***

The Soil Loss Estimation Model for Southern Africa (SLEMSA) was developed using soil loss data collected from field plots in the then Rhodesia (see reports by Elwell in the bibliographic database). SLEMSA, like the Universal Soil Loss Equation (USLE)

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* Attempts to understand relevant folklore might, in certain remote areas of South Africa, be beneficial for the success of land reclamation projects. Reference is made here to the badly eroded Inxu Valley of the Tsolo District of the Transkei, which is inhabited by the Mpondomise people. The land was cursed by traditional Bushmen rainmakers, due to the indiscretion of the then chief of the Mpondomise. A period of severe drought followed by high intensity rainfall (in the 1940s), is said to have caused sudden and widespread erosion - which was attributed by some - to the curse of the rainmakers. Great hardship ensued. (Relations between the surviving rainmakers and the Mpondomise people have apparently been restored). See: Hall, S. and Marsh, R., 1996. Beyond Belief: Murders and Mysteries of Southern Africa, Struik Publishers, Cape Town, 128 p. The particular legend in question is also discussed in the following: Škotnes, P. (ed), 1996. Miscast: Negotiating the Presence of the Bushmen, UCT Press, Rondebosch, 383 p.

** For a discussion of these issues, see Phillips, J., 1973. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps, as well as Thorrington-Smith, E., 1978. Session 4. People, problems and planning in KwaZulu and Natal - should conservation and planning in Natal and KwaZulu be development-orientated?, In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 123 - 131. (Other papers in the proceedings are also relevant). An overview population density map for KwaZulu can be found in Thorrington-Smith, Rosenberg and McCrystal, 1978. Towards a plan for KwaZulu: a preliminary development plan, VOL 1, The written report, 341 p., and VOL 2, Atlas of maps and illustrations, various pages, KwaZulu Government, Ulundi. See also, Cross, C., Bekker, S., Clark, C. and Richards, R., 1992. Moving on: migration streams into and out of Inanda, Natal Town and Regional Planning Commission Supplementary Report, VOL 38, Pietermaritzburg, 76 p., as well as Cross, C., Bekker, S. and Clark, C., 1993. Fresh starts: migration streams in the southern informal settlements of the DFR, Natal Town and Regional Planning Commission Supplementary Report, VOL 40, Pietermaritzburg, 100 p.

*** Discussion based on Schulze, R.E., 1979. Hydrology and water resources of the Drakensberg, Natal Town and Regional Planning Commission Report, VOL 42, Pietermaritzburg, 179 p.

Model* (with which it is conceptually closely related), was designed to predict long term mean annual soil losses from sheet and rill erosion, for specific combinations of physical and terrain management conditions. It should be borne in mind that soil loss in terms of the model is differentiated from sediment yield as measured in rivers and dams - see the chapter on water quality - since not all eroded soil enters a particular watercourse. Much of the eroded soil is deposited in depressions or along toe slopes. This deposition is not accounted for in the model and SLEMSA accordingly, is essentially a model concerned with soil removal from cultivated fields. Five erosion control variables were identified and expressed numerically, namely: rainfall energy (E); percentage effective vegetal cover (i); soil erodibility (F); percentage slope steepness (S), and slope length (L). SLEMSA uses a combination of three sub-models, specifically a sub-model for estimating soil losses from bare fallow (K), a canopy cover sub-model (C), and a topographic sub-model (X). SLEMSA has the form:

$$Z = K\,C\,X$$

where Z = predicted mean annual soil loss in t ha^{-1} y^{-1}

K = mean annual soil loss in t ha^{-1} y^{-1} from a standard field plot (30 x 10 m) at a 4,5% slope, for a soil of known erodibility F, under a weedfree bare fallow regime and a specified rainfall energy E in J m^{-2} y^{-1}

C = the ratio of soil lost from a cropped plot or veld, to that lost from the bare fallow

X = the ratio of soil lost from a plot of length L and slope percentage S, to that lost from the standard plot

Like the USLE, numerical values must be assigned to the variables for each specific situation and then substituted in the formula. The bare fallow sub-model (K) uses the soil erodibility factor (F), which is available for each soil series of the 1977 binomial soil classification system. (The average F values for all soil series are presented in Anonymous (1976) cited below Table M13). F values should reflect all factors which influence the soil runoff properties and resistance to detachment such as tillage, management or crop rotation. The energy factor E (also part of the bare fallow sub-model), represents the kinetic energy of raindrops as they strike the soil or vegetation, and which have the

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* The Institute for Soil, Climate and Water, Pretoria, is currently involved with the development and testing of a Revised Universal Soil Loss Equation (RUSLE) Model. A Modified Universal Soil Loss Equation (MUSLE) Model is also available. The latter model has been used inter alia by Schulze.

potential to break down the soil structure and to splash soil particles into the air - thereby initiating, or sustaining soil erosion especially on sloping ground (Schulze, 1979). Following splash erosion (in cases where the vegetation has been depleted), entrainment of the soil particles by sheetwash occurs, and even slight runoff can result in significant soil losses. Much of the accelerated erosion in southern Africa is accordingly due to a combination of high intensity storms, sloping land, and a lack of protective vegetal cover (Beckedahl, Bowyer-Bower, Dardis and Hanvey, 1988)*.

Data on rainfall erosivity are rare, since rainfall intensity and duration are only recorded at the few autographic raingauges in South Africa. A widely used parameter where the data are not available, is the EI_{30} index. The index is empirically derived and is the product of the total kinetic energy of a rainfall event (E) and the maximum 30 minute intensity (I_{30}). A rainfall event is defined as a period during which more than 12,5 mm falls, but which is separated from any other periods of rain by more than six hours. Showers of less than 12,5 mm are included only if 6,3 mm or more falls in 15 minutes. An upper limit for rainfall intensity of 76 mm h^{-1} is applied (Smithen and Schulze, 1982)**. Schulze (1979) working in the Natal Drakensberg (discussed below), established a relationship between mean annual precipitation and E values, in terms of two different equations for areas above and below 1 500 m respectively. Smithen (1981)*** correlated daily rainfall occurrence and amount with the EI_{30} parameter, while Smithen and Schulze (1982) provided an overview analysis of the spatial distribution of rainfall erosivity expressed as EI_{30}, across southern Africa. Further details of the SLEMSA Model including the canopy cover sub-model and the topographic sub-model can be found in Schulze (1979).

Schulze (1979) in an application of the SLEMSA Model in the Drakensberg Key Area (the Cathedral Peak/Winterton/Champagne Castle area), found that mean annual soil loss estimates varied from less than 1 t ha^{-1} y^{-1} to over 20 t ha^{-1} y^{-1}. In one case, soil losses were estimated to be as high as 70 t ha^{-1} y^{-1} (a combination of steep slopes, highly

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* See Beckedahl, H.R., Bowyer-Bower, T.A.S., Dardis, G.F. and Hanvey, P.M., 1988. Chapter 12. Geomorphic effects of soil erosion, In: Moon, B.P. and Dardis, G.F. (eds), The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, p. 249 - 276.

** See Smithen, A.A. and Schulze, R.E., 1982. The spatial distribution in southern Africa of rainfall erosivity for use in the Universal Soil Loss Equation, Water SA, VOL 8(2), p. 74 - 78. (See also, Erratum, Water SA, 1982, VOL 8(3), p. 165 - 167).

*** See Smithen, A.A., 1981. Characteristics of rainfall erosivity in South Africa, M.Sc. (Agric Eng) Thesis, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, 126 p.

erodible soils and poor vegetative cover). High soil losses along the Drakensberg Escarpment may be explained by high E values in combination with steep slopes (in an area where the F and C values would not otherwise have been conducive to considerable soil losses). High soil loss estimates were especially apparent in several parts of KwaZulu Area No. 8 (the Upper Tugela Location), with relatively low E values but also with a marked interaction of already eroded soils and poor vegetative cover. The latter situation is indicative of accelerated erosion under conditions of ecological disequilibrium, with the former implying geologically normal rates of erosion (see the chapter on catchments). Schulze (1979) stressed that caution is necessary in interpreting the results provided by SLEMSA (on a regional scale). The model is particularly sensitive to the rainfall energy and soil erodibility inputs. Schulze concluded that the model has considerable value as an index, for indicating areas of high and low erosion potential. Estimated soil losses however, are long term means subject to considerable inter-annual variation. Accordingly, the soil losses obtained should be viewed as relative and not absolute values. Further testing of the model is required. Scotney (1978 - above) recommended the use of soil loss tolerance values (T values) in soil loss estimates. Tentative T values of 2, 3 and 4 t ha^{-1} y^{-1} have been set for clays, loams and sands respectively, which could provide a benchmark figure for controlling losses. Scotney (1995)* observed that T values have yet to be applied in practice, in South Africa.

13.17 Land Type maps

A further significant development concerning soil erosion research and control was the introduction of the Land Type maps, which permit rapid identification of erosion-susceptible terrain (discussed earlier in the chapter). Land Type information was used by soil scientists working in conjunction with Rooseboom (1992), to obtain revised sediment yield data for South Africa. (See Section 15.11.3 in the chapter on water quality).

13.18 Rainfall simulators

Soil erosion research has also involved the use of rainfall simulators. The purpose of rainfall simulators is inter alia to derive soil loss prediction data under field conditions with respect to soil erodibility indices, as well as to assess the effects of canopy cover and

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* Scotney, D.M., 1995. Personal communication, Department of Agriculture, Pretoria.

mulch, topography and rainfall energy. Simulators have been used to demonstrate erosion principles to farmers.

13.19 Summary

Adler (1981 - above) estimated that the annual transported soil loss across South Africa as a whole at that time, was of the order of 233 - 363 x 10^6 tons. Adler concluded that much remains to be done in terms of soil erosion research and the implementation of remedial measures. Adler stressed that there is a lack of detailed information regarding the intensity of erosion and the actual soil losses incurred under various forms of land use - including industrial and urban areas as well as roads, railways and mining areas - and which is correlated with specified conditions of slope, vegetation cover, climate and management.

It is sobering to note that the total available land for agricultural purposes per head of population in South Africa in 1970, was approximately 5,5 ha capita^{-1}. The total available arable land per head of population in 1970 was some 0,6 ha capita^{-1}. The projection for the year 2020 is 1,5 ha capita^{-1} (total agricultural land) and 0,2 ha capita^{-1} (total arable land), due to population pressure and the effects of land degradation in general. Of the approximately 85 700 000 ha of agricultural land in South Africa, only 11,9% is arable - of which only 4 000 000 ha or 4,7% of the total agricultural area is classified as high potential land. Such land includes the 1 000 000 ha under irrigation in 1990 (Anonymous, 1990)*.

13.20 Soil erosion and the Conservation of Agricultural Resources Act No. 43 of 1983**

The Conservation of Agricultural Resources Act No. 43 of 1983, repealed both the Soil Conservation Act No. 76 of 1969 and the Weeds Act No. 42 of 1937. Various reasons

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* See Anonymous, 1990. Pressure on agricultural land is increasing, Agricultural News, 14 May 1990, p. 3.

** Discussion based on Verster, E., Du Plessis, W., Schloms, B.H.A. and Fuggle, R.F., 1992. Chapter 10. Soil, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 181 - 211. (Note: Certain aspects of the Conservation of Agricultural Resources Act No. 43 of 1983 are examined elsewhere in the current publication - see for example, the chapter on fire in grasslands and forests, and the chapter on wetlands and pans. See also the chapter on the laws of South Africa).

were given for the promulgation of the 1983 Act. These reasons included a degree of rationalization of environmental legislation, as well as dissatisfaction with the 1969 Act which contained only preventive measures - and which were not always successfully applied. Stronger measures were therefore needed. The 1983 Act does not apply to urban areas (except for weeds and invader plants), as well as in (former) South African Development Trust (SADT) areas. Also excluded is land situated in a proclaimed Mountain Catchment Area. The Act likewise, does not apply in KwaZulu and the other homelands and in the national states. The State President however, is empowered to extend the operation of the Act to (former) SADT land in terms of the Abolition of Racially Based Land Measures Act No. 108 of 1991.

The objectives of the 1983 Act are to provide for the conservation of the natural agricultural resources of South Africa. This is to be achieved through the maintenance of the production potential of land; by the combating and prevention of erosion and the degradation or destruction of water resources; by the protection of vegetation, and by the combating of weeds and invader plants. Persuasion rather than coercion is one of the main goals of the current Act, although severe penalties are prescribed. Prosecutions are easier to institute in terms of the 1983 Act, than under the 1969 Act (Verster, Du Plessis, Schloms and Fuggle, 1992).

Extensive powers have been given to the Minister of Agriculture by virtue of Act No. 43 of 1983. The Minister may appoint members of a Conservation Advisory Board, and establish national, regional and local conservation committees. The Conservation Advisory Board advises the Minister, and consists of an executive officer plus another official from the Department of Agriculture, as well as a representative of the Department of Environment Affairs, a representative of the South African Agricultural Union, and representatives of regional conservation committees. The purpose of regional conservation committees is to advise all conservation committees in a given region on the conservation of the natural agricultural resources; and also to advise the Conservation Advisory Board and the Department of Agriculture on all matters relating to the application of the Act or a scheme (outlined below), in the particular region. Regional committees consist of the regional director and an officer of the Department in the region concerned, as well as two representatives of each area in the region, and one representative of each provincial agricultural union in that region. The Natal Regional Conservation Committee is based at the Cedara Agricultural Development Institute. Local conservation committees are required to promote the conservation of the natural agricultural resources in a specified area in terms of the Act, and to advise the Department of matters relating to the Act or any scheme in their area. Local conservation committees work closely with staff of the Department of Agriculture. (Soil) conservation committees established by virtue of the 1969 Act are deemed to have been established under the 1983 Act. In order to assist the reader, the administrative regions and offices of the Department of Agriculture in Natal are listed in Table M18. Table M19 provides data on the various conservation committees in Natal.

The Minister of Agriculture may define control measures applicable to specific areas or land users. These measures (prescribed by regulation) include the cultivation of virgin soil (Regulation 2) and land with a certain slope (Regulation 3)*; the protection of cultivated land against erosion through the action of water (Regulation 4) and wind (Regulation 5); the prevention of the waterlogging and salinization of irrigated land (Regulation 6); and the utilization and protection of vleis, marshes, water sponges and watercourses (Regulation 7). Other measures include regulation of the flow pattern of runoff (Regulation 8); the utilization and protection of veld (Regulation 9); the grazing capacity of veld (Regulation 10); the number of animals which may be kept on veld (Regulation 11); the prevention and control of veld fires (Regulation 12); and the restoration and reclamation of eroded land (Regulation 13), as well as disturbed or denuded land (Regulation 14).

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* Virgin soil is defined as any land which has not been cultivated during the last 10 years. The land cannot be cultivated unless written permission is received from the Department of Agriculture. Land with a slope exceeding 20% may also not be cultivated without written permission. Such land may only be cultivated if the land was already under cultivation on or before the 26th of May 1984, provided that the land is effectively protected against excessive soil erosion.

Table M18: Administrative regions and offices of the Department of Agriculture in Natal.

Sub-region and office location	Extension offices
Sub-regions	
Dundee Sub-region P O Box 125, Dundee, 3000	Bergville; Ladysmith; Newcastle
Vryheid Sub-region P O Box 723, Vryheid, 3100	Vryheid North and South extension offices (Vryheid); Eshowe; Pongola
Drakensberg Sub-region P O Box 745, Pietermaritzburg, 3200	Estcourt; Howick; Kokstad; Underberg
Pietermaritzburg Sub-region P O Box 345, Pietermaritzburg, 3200	Durban; Greytown; Ixopo; Phoenix; Port Shepstone; Stanger; Umzinto
Agricultural research stations	
Cedara Agricultural Development Institute/ Research Station/College of Agriculture Private Bag X9059, Pietermaritzburg, 3200	
Dundee Agricultural Research Station P O Box 626, Dundee, 3000	
Kokstad Agricultural Research Station Private Bag X501, Kokstad, 4700	
Makatini Agricultural Research Station Private Bag X004, Jozini, 3969	
Horticultural centres	
Pinetown Horticultural Centre Private Bag X9014, Pinetown, 3600	
State Agricultural Land Administration offices	
Jozini State Agricultural Land Administration Office Private Bag X006, Jozini, 3969	
Pietermaritzburg State Agricultural Land Administration Office Private Bag X9083, Pietermaritzburg, 3200	

Source: After the Department of Agriculture, Cedara, 1993.

Note:

(i) The headquarters of the Department of Agriculture in Natal is at Cedara.

(ii) The State Agricultural Land Administration offices consist of staff formerly part of the (now defunct) Department of Development Aid.

(iii) The Dundee and Vryheid Sub-regions fall under the control of the Northern Natal Agricultural Development Centre at Vryheid, while the Drakensberg and Pietermaritzburg Sub-regions fall under the Southern Natal Agricultural Development Centre in Pietermaritzburg.

Table M19: Conservation committees in Natal, 1993.

Conservation committee	Address
Alfred	c/o R. Buhr, P O Box 113, Harding, 4680
Bergville	c/o J. Coventry, P O Box 128, Bergville, 3350
Camperdown	c/o M. Stainbank, P O Eston, 3740
Dundee	c/o F. Joubert, P O Box 28, Dundee, 3000
Eshowe	c/o I. Stewart, Private Bag X522, Eshowe, 3815
Estcourt	c/o D. MacKay, P O Box 1122, Estcourt, 3310
Gingindlovu	c/o D. Brett, P O Box 10, Nyoni, 3802
Hlabisa	c/o P. Kennedy, P O Box 214, Mtubatuba, 3935
Impendle	c/o M. Laurens, Private Bag, Nottingham Road, 3280
Ixopo	c/o P. Muirhead, P O Box 150, Ixopo, 3276
Kamberg	c/o J. Armstrong, P O Box 13, Rosetta, 3301
Ladysmith	c/o H. Streatfield, P O Box 26, Ladysmith, 3370
Lions River	c/o K. Todd, P O Box 208, Merrivale, 3291
Lower Tugela	c/o H. Theil, P O Box 95, Darnall, 4480
Lower Umfolozi	c/o R. Barnes, P O Heatonville, 3881
Matatiele	c/o J. Van Zyl, P O Box 24, Cedarville, 4720
Melmoth	c/o R. McMurray, P O Box 223, Melmoth, 3835
Mooi River	c/o D. Davies, P O Box 222, Mooi River, 3300
Mount Currie	c/o R. Murray, P O Box 288, Kokstad, 4700
Newcastle	c/o G. Smith, P O Box 85, Newcastle, 2940
New Hanover	c/o C. Klipp, P O Box 31, Dalton, 3236
Ngotshe	c/o J. Opperman, P O Box 523, Vryheid, 3100
Nkwaleni	c/o R. Lloyd, P O Box 50, Nkwaleni, 3816
Port Shepstone	c/o A. Abbott, P O Box 111, Port Edward, 4295
Richmond	c/o A. Morris, P O Box 209, Richmond, 3780
Tambotie	c/o L. Nel, P O Box 16, Pongola, 3170

Table M19: Conservation committees in Natal, 1993 (continued).

Conservation committee	Address
Umvoti	c/o N. March, P O Box 147, Greytown, 3250
Umzinto	c/o D. Cole, Private Bag X0512, Umzinto, 4200
Underberg	c/o T. Briscoe, P O Box 56, Underberg, 3257
Utrecht	c/o J. Davel, P O Box 165, Utrecht, 2980
Vryheid North	c/o B. Beater, P O Box 927, Vryheid, 3100
Vryheid South	c/o E. Kassier, P O Box 972, Vryheid, 3100
Weenen	c/o P. Coetzee, P O Box 12, Weenen, 3325
Winterton	c/o J. Stockil, P O Box 10, Winterton, 3340

Source: (i) After Peard, R.H., 1981. A tribute to the soil conservation committees of Natal: a review of their achievements to date, Report No. N.17/1981, Department of Agriculture and Fisheries (Natal Region), Cedara, 81 p. + app.

(ii) After the Department of Agriculture, Cedara, 1993.

The Minister (on the advice of the Conservation Advisory Board) and with the agreement of the Minister of Finance, has the power to provide subsidies for schemes in respect of the construction of soil conservation works*, and for the repair of damage due to floods or other disasters in terms of the natural agricultural resources or soil conservation works. Subsidies may also be made available for the restoration or reclamation of eroded, disturbed, denuded or damaged land; and for the planting and cultivation of specified crops which improve soil fertility or counteract the vulnerability of the soil to erosion. Subsidies may also be paid for stock reduction purposes (see earlier in the chapter). Details of all these schemes must be published in the Republic of South Africa Government Gazette. The schemes are aimed at conservation-minded farmers, rather than wasteful, uncaring farmers.

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* A soil conservation work, means any work constructed on land for the prevention of erosion or the conservation of land subject to erosion, and for the conservation or improvement of vegetation or the soil surface. A conservation work also refers to the drainage of superfluous surface or groundwater, the conservation or reclamation of any water resource, and the prevention of the silting of dams and water pollution. Typical small (farm) works involve the construction of weirs, camp fencing and stock watering facilities as well as land protection measures such as contour banks. Small (farm) works are known as Section 8 works, in contrast to Section 11 works which involve the construction of works too expensive or large for individual farmers.

Part of the 1983 Act (mainly the restoration and reclamation of eroded, disturbed or denuded land), does not apply to mining areas. These areas are controlled under the Mines and Works Act No. 27 of 1956/Minerals Act No. 50 of 1991. The latter Act makes provision for soil erosion control in mining areas or in worked-out mining areas; as well as for the re-establishment of vegetation and the restoration of river banks (Wells, Van Meurs and Rabie, 1992)*.

The Minister by means of a direction (issued through a duly authorized executive officer of the Department of Agriculture), may require any remedial measures (prescribed by the Act), to be undertaken on any land, where the costs may be recovered from the owner of the land. The executive officer also has the power to order a land user to render assistance, for which no compensation is paid. The land user is obliged to maintain soil conservation works at his own expense. Soil conservation works can only be altered, removed or destroyed by specific permission or by order of the executive officer. Failure to comply with such duties will result in the recovery of costs from the land user. In the event of continued failure or non-compliance with these duties, the executive officer may order the land owner to repair or reconstruct soil conservation works, or to repeat any related measure. The Minister may (in certain circumstances), order any land owner to compensate a land user for an increase in the value of the land, as the (beneficial) result of soil conservation work undertaken by the land user. Any land owner may also be ordered to pay an amount (determined by the Minister) to another land owner, in respect of a decrease in the value of the latter's land, due to soil conservation works constructed by the first owner on his land. Expropriation of any land (if required in terms of effective remedial measures) is permissible by virtue of the Act. The Act also makes provision for voluntary demonstration farms or parts of farms. With the permission of the land owner - and subject to mutual agreement between the Minister and the land owner - any measure for the purposes of public demonstration or research (in respect of veld, soil or water conservation, or for the combating of invader plants), can be undertaken on the farm. Compensation will then be paid by the Minister to the land owner (Verster et al, 1992).

A number of practical problems are evident with regard to the 1983 Act. A major problem is the lack of manpower to enforce the Act. There are only some 14 inspectors (with

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* See Wells, J.D., Van Meurs, L.H. and Rabie, M.A., 1992. Chapter 15. Terrestrial minerals, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 337 - 379.

powers delegated by the relevant executive officer) for the whole of South Africa. A shortage of agricultural technicians is a further difficulty. The technicians are required to advise farmers on practical soil conservation measures. Problems have also arisen with conservation committees, where not all the committees have been established or are fully functional. Additional difficulties include committees being used as a forum for other farming issues, rather than for conservation purposes. The essentially voluntary nature of committees sometimes results in problems of continuity, with changes in chairmen/secretaries, and the amalgamation and dissolution of committees. Similar continuity problems are experienced with conservancies (see the chapter on catchments), as well as irrigation boards (see the chapter on the surface water resources of Natal/KwaZulu). A very low rate of prosecution for offences under the Act is also apparent.

Subsidies payable in terms of the Act inter alia for soil conservation works, veld utilization works, drainage works and the Stock Reduction Scheme, are never sufficient to cover all costs. Farmers (even very conservation-minded farmers) accordingly, may be trapped between shorter-term gain and the self-funding or part-funding (if a subsidy is obtained) of conservation works. These works may only realize economic benefits approximately 5 - 10 years after the expenditure has been incurred*. It would appear that expenditure on soil conservation works does not necessarily increase the sale price of a farm by an equivalent amount (Verster et al, 1992). Begg (1990)** suggested that soil conservation subsidies should be extended to cover the costs of the rehabilitation of degraded wetlands (on farms). A prerequisite for this programme would involve detailed cost-benefit analyses of the value of wetlands in specific areas. Begg made several recommendations for wetland preservation with specific reference to the Conservation of Agricultural Resources Act No. 43 of 1983.

A further difficulty with soil erosion control is the number of related Acts administered by various Government departments. Uniformity of approach is therefore difficult to achieve. Other Acts of relevance include the Water Act No. 54 of 1956; the Forest Act No. 122 of 1984; the Mountain Catchment Areas Act No. 63 of 1970 (not applied in

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* For a further discussion see Tainton, N.M., 1987. Ethics, legislation and profit as determinants of conservation farming, Journal of the Grassland Society of Southern Africa, VOL 4(1), p. 5 - 6.

** See Begg, G., 1990. The wetlands of Natal (Part 4): policy proposals for the wetlands of Natal and KwaZulu, Natal Town and Regional Planning Commission Report, VOL 75, Pietermaritzburg, 86 p.

Natal/KwaZulu); the Common Pasture Management Act No. 82 of 1977, and the Subdivision of Agricultural Land Act No. 70 of 1970. Additional Acts are the National Roads Act No. 54 of 1971; the National Parks Act No. 57 of 1976 (not enforced in Natal/KwaZulu); the Defence Act No. 44 of 1957, and the Mines and Works Act No. 27 of 1956/Minerals Act No. 50 of 1991. Provincial legislation also has a bearing, namely, the (Natal) Nature Conservation Ordinance No. 15 of 1974, the (Natal) Roads Ordinance No. 10 of 1968, and the (Natal) Town Planning Ordinance No. 27 of 1949 (urban areas).

13.21 The South African Sugar Association Experiment Station

The South African Sugar Association Experiment Station at Mount Edgecombe is actively involved in research and extension work including soil erosion issues for sugar farms in Natal/KwaZulu and the eastern Transvaal. Numerous technical specifications for waterways, terraces, roads and soil conservation works in general, have been prepared for the sugar industry. Considerable research has been undertaken on the application of the CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems) suite of models in the sugar belt. The model was originally developed by the United States Department of Agriculture. The Experiment Station is the equivalent of the Department of Agriculture in sugar areas. Extension officers of the Experiment Station are responsible for encouraging compliance with Act No. 43 of 1983 in the sugar growing areas (Stead and Stranack, 1991)*.

Sugar farmers are offered a choice between an initial development plan (IDP) or a comprehensive, fully integrated land use plan (LUP). By 1978, some 55% of farms involving 70% of the area under sugar cane were covered by IDPs. Detailed planning gained impetus in 1975 and by 1978, approximately 10% of farms (15% of the entire sugar growing area), had been planned at an advanced technical level (Scotney, 1978)**. IDPs indicate the borders of the farm and show all roads and all cultivation breaks wider than 3 m. Field boundaries are defined and each field is given a name or

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* See Stead, B.A. and Stranack, R.A., 1991. Extension strategy to implement the Conservation of Agricultural Resources Act (1983) on the Natal North Coast, Symposium: Communication in Successful Extension Action, South African Society for Agricultural Extension (Natal Branch), 20 June 1991, Hilton, 6 p. + app.

** See Scotney, D.M., 1978. Soil erosion in Natal: 1978, Department of Agricultural Technical Services (Natal Region), Cedara, 19 p.

number. Other data include overlays showing soil types, as well as the location of crests and waterways. Subsequently, crest and drainage line overlays were expanded to include contours, and the new IDPs then became the basis for LUPs. The advanced planning system is based on contiguous areas of similar slope which are treated as a single entity. The preparation and implementation of LUPs involves considerable fieldwork as well as drawing office input. Particular attention is paid to soil and water conservation measures in the compilation of IDPs and LUPs.

13.21.1 Regional environment committees of the South African Sugar Association

In 1989 the South African Sugar Association established a number of regional environment committees for each sugar mill group, covering all the sugar cultivation areas in Natal/KwaZulu and the eastern Transvaal (Table M20). The purpose of the committees is to advise on various aspects of the environment including water pollution from sugar mills, cane spillage on roads, and soil erosion. There is close co-operation between the (soil) conservation committees (discussed earlier), and the regional environment committees of the Sugar Association. Overall natural resources policy for a given area is set by the relevant (soil) conservation committee.

Table M20: Contact addresses of regional environment committees established by the South African Sugar Association, 1993.

c/o P. Palmer, P O Bruyns Hill, 3234	c/o B. Hagemann, P O Box 68, Darnall, 4480
c/o M. Stainbank, P O Eston, 3740	c/o R. Barnes, P O Heatonville, 3881
c/o H. Radley, P O Box 35, Malelane, 1320	c/o R. McMurray, P O Box 223, Melmoth, 3835
c/o B. MacNeillie, P O Box 378, Mtubatuba, 3935	c/o W. Latham, P O Box 7, Nkwaleni, 3816
c/o D. Brett, P O Box 10, Nyoni, 3802	c/o L. Nel, P O Box 16, Pongola, 3170
c/o G. Walsh, P O Box 289, Richmond, 3780	c/o C. Sherwell, C G Smith Sugar Ltd, P O Sezela, 4215
c/o B. Strode, P O Box 40, Umhlali, 4390	c/o P. Goble, Kinfauns, P O Upper Tongaat, 4402

Source: After the South African Sugar Association, Durban, 1993.

13.22 Some primary publications on soil erosion with special reference to Natal/KwaZulu

(a) General publications

- Adler, E., 1981. Ons kwynende bodem/Our shrinking land, Ekos, VOL 1(3), p. 6 - 21.

- Adler, E.D., 1985. Soil conservation in South Africa, Bulletin No. 406, Department of Agriculture and Water Supply, Pretoria, 44 p.

- Anonymous, 1948. First annual report of the Soil Conservation Board for the period 11th October 1946 - 30th June 1947, Government Printer, Pretoria, 4 p. (This was the first report issued - thereafter the following reports were made available: 1948 - 1949; 1950; 1951; 1952; 1953 - 1954; 1955; 1956; 1957; 1958; 1959; 1960; 1961; 1962; 1963; 1964; 1965; 1966; 1967; 1968, and 1969. No reports were issued after that date when the Board was disbanded). Note: An annual report for the Department of Agriculture/Agriculture and Forestry was published as part of the Farming in South Africa series during the years 1926 - 1941 and 1943 - 1955. These reports contain information on soil erosion control expenditure. Thereafter, soil erosion data can be found in the (separately published) annual reports of the Department.

- Anonymous, 1981. A system for the classification of soil erosion in the SARCCUS region, Department of Agriculture and Fisheries, Pretoria, 20 p.

- Anonymous, 1989. Gully stabilisation and repairs, Information Booklet No. 6, South African Sugar Association Experiment Station, Mount Edgecombe, 17 p. (The publication presents technical information in a "user friendly" manner, suitable for the layman).

- Arbuthnot, J.D., 1995. Report of the ESA Working Group on Land Degradation, Directorate of Resource Conservation, Department of Agriculture, Pretoria, 74 p. (The publication provides a useful overview of current projects concerning soil erosion and associated land issues).

- Beckedahl, H.R., Bowyer-Bower, T.A.S., Dardis, G.F. and Hanvey, P.M., 1988. Chapter 12. Geomorphic effects of soil erosion, In: Moon, B.P. and Dardis, G.F. (eds), The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, p. 249 - 276.

- Bennett, H.H., 1945. Soil erosion and land use in the Union of South Africa, Department of Agriculture and Forestry, Pretoria, 28 p. (The publication provides an historical perspective).

- Dardis, G.F., Beckedahl, H.R., Bowyer-Bower, T.A.S. and Hanvey, P.M., 1988. Soil erosion forms in southern Africa, In: Dardis, G.F. and Moon, B.P. (eds), Geomorphological Studies in Southern Africa, A.A. Balkema, Rotterdam, p. 187 - 213.

- Garland, G.G., 1987. Erosion risk from footpaths and vegetation burning in the central Drakensberg, Natal Town and Regional Planning Commission Supplementary Report, VOL 20, Pietermaritzburg, 74 p. and map.

- Garland, G.G., 1995. Soil erosion in South Africa: a technical review, Directorate of Resource Conservation, National Department of Agriculture, Pretoria, 52 p. (The report has a useful bibliography).

- Garland, G.G., Robinson, J.R. and Pile, K.G., 1994. Policy, perception and soil conservation: a case study from Cornfields, Natal, Department of Geographical and Environmental Sciences, University of Natal, Durban, 41 p.

- Le Grange, A. du P. and Rooseboom, A., 1993. The development of a model to simulate channel deformation in alluvial rivers, WRC Report No. 236/1/93, Water Research Commission, Pretoria, various pages.

- Liggitt, B., 1988. An investigation into soil erosion in the Mfolozi catchment, INR Investigational Report No. 28, Institute of Natural Resources, University of Natal, Pietermaritzburg, 110 p.

- Liggitt, B. and Fincham, R.J., 1989. Gully erosion: the neglected dimension in soil erosion research, South African Journal of Science, VOL 85(1), p. 18 - 20.

- Matthee, J.F. la G., 1984. A primer on soil conservation, Bulletin No. 399, Division of Agricultural Engineering, Department of Agriculture, Pretoria, 128 p. (The publication contains technical information on soil erosion and remedial measures).

- Phillips, J., 1973. The agricultural and related development of the Tugela Basin and its influent surrounds: a study in subtropical Africa, Natal Town and Regional Planning Commission Report, VOL 19, Pietermaritzburg, 299 p. and maps.

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(b) Specific source documents

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Technical Services, Pretoria, 90 p. (The publication should be consulted for details of higher degree theses undertaken in the Department of Agrarian Extension at the University of Pretoria. The theses listed may contain - as part of a general agronomic survey of a particular area - data relating to soil erosion and associated issues).

<u>For further information contact:</u>

- Agricultural and Rural Development Research Institute, University of Fort Hare, Private Bag X1314, Alice, 5700.

- Departments of Agricultural Engineering/Agronomy/Animal and Poultry Science/ Geography/Grassland Science, University of Natal, Private Bag X01, Scottsville, 3209.

- Department of Civil Engineering, University of Pretoria, Pretoria, 0002.

- Department of Civil Engineering, University of Stellenbosch, Private Bag X1, Matieland, 7602.

- Department of Earth Sciences, University of the Western Cape, Private Bag X17, Bellville, 7535.

- Department of Environment Affairs, Private Bag X447, Pretoria, 0001.

- Department of Environmental and Geographical Science, University of Cape Town, Private Bag, Rondebosch, 7701.

- Department of Geography, University of Durban-Westville, Private Bag X54001, Durban, 4000. (The Department has expertise in the compilation of bibliographies on soils and soil erosion in South Africa. Several studies on soil erosion, particularly for Natal/KwaZulu, are available).

- Department of Geography, University of the Orange Free State, P O Box 339, Bloemfontein, 9300.

- Department of Geography, University of South Africa, P O Box 392, Pretoria, 0001.

- Department of Geography and Environmental Management, Rand Afrikaans University, P O Box 524, Auckland Park, 2006. (The Department has expertise in aeolian sand deposits especially along the Cape West Coast. The Department is likewise involved in the rehabilitation of land damaged by mining activities).

- Department of Geographical and Environmental Sciences, University of Natal, Private Bag X10, Dalbridge, 4014.

- Department of Landscape Architecture, University of Pretoria, Pretoria, 0002. (The Department undertakes site surveys involving ecological planning and is a source of relevant expertise).

- Department of Water Affairs and Forestry, P O Box 1018, Durban, 4000.

- Directorate of Resource Conservation, Department of Agriculture, Private Bag X120, Pretoria, 0001. (The Directorate is involved in the recently announced LandCare Programme as well as the National Action Programme to Combat Desertification - both of which are aimed at preventing resource degradation).

- Directorate of Soil Conservation and Drilling Services, Chief Directorate: Agricultural Engineering and Water Supply, Department of Agriculture, Private Bag X515, Silverton, 0127. (Further details of Department of Agriculture offices in Natal are provided in Table M18, earlier in this chapter).

- Division of Earth, Marine and Atmospheric Science and Technology, CSIR, P O Box 320, Stellenbosch, 7599.

- Division of Forest Science and Technology, CSIR, P O Box 395, Pretoria, 0001.

- Farmer Support Group, University of Natal, Private Bag X01, Scottsville, 3209.

- Forest Owners' Association, P O Box 1553, Rivonia, 2128.

- Forestry Council, c/o Coopers and Lybrand, P O Box 2536, Johannesburg, 2000. (Further relevant forestry organizations are listed in the chapter on catchments).

- Geological Survey, Department of Mineral and Energy Affairs, P O Box 900, Pietermaritzburg, 3200/Private Bag X112, Pretoria, 0001.

- Institute for Commercial Forestry Research, P O Box 100281, Scottsville, 3209.

- Institute for Soil, Climate and Water, Private Bag X79, Pretoria, 0001. (The Natal office of the Institute is c/o the Department of Agriculture, Private Bag X9059, Pietermaritzburg, 3200).

- KwaZulu Department of Agriculture and Forestry, Private Bag X05, Ulundi, 3838.

- KwaZulu Department of Nature Conservation, Private Bag X98, Ulundi, 3838.

- Land and Agriculture Policy Centre, P O Box 243, Wits, 2050.

- Natal Agricultural Union, P O Box 186, Pietermaritzburg, 3200.

- Natal Parks Board, P O Box 662, Pietermaritzburg, 3200.

- National Veld Trust, P O Box 72862, Lynnwood Ridge, 0040.

- Range and Forage Institute, Private Bag X05, Lynn East, 0039.

- Research Institute for Reclamation Ecology, Potchefstroom University for Christian Higher Education, Private Bag X6001, Potchefstroom, 2520. (The Institute is involved inter alia with the rehabilitation of areas disturbed by construction or mining activities).

- Social Development Research Unit, Human Sciences Research Council, P O Box 17302, Congella, 4013.

- Soil Science Society of South Africa, P O Box 30030, Sunnyside, 0132.

- South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300.

- South African Vetiver Network, c/o the Institute of Natural Resources, University of Natal, Private Bag X01, Scottsville, 3209. (The Network is a source of information on Vetiver grass and promotes the active use thereof in this country. The grass is already being used to rehabilitate mine dumps and slimes dams, and for the stabilization of road verges as well as banks).

- Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS), Private Bag X250, Pretoria, 0001. (For a brief background on SARCCUS see: Bridgens, A.B., 1989. Southern African Regional Commission for the Conservation and Utilization of the Soil, SARCCUS, Pretoria, 14 p.).

- Termite Research Unit, Plant Protection Research Institute, Private Bag X134, Pretoria, 0001. (The Unit has expertise on the role of termites in veld degradation).

NOTES:

NOTES:

CHAPTER 14: FIRE IN GRASSLANDS AND FORESTS

The value of grasslands...

Grass

Grass so humble, that all things tread
Its tender blades. Grass - the bread,
The staff of life; a constant need
Of man and beast - a power indeed.

M. Duggan, quoted in Meredith, D. (ed), 1955. The Grasses and Pastures of South Africa, Central News Agency, [Johannesburg], 771 p.

The poetry of grasslands...

Winternag

O koud is die windjie
  en skraal.
En blink in die dof-lig
  en kaal,
so wyd as die Heer se genade,
lê die velde in sterlig en skade.
  En hoog in die rande,
  versprei in die brande,
is die grassaad aan roere
  soos winkende hande.

E. Marais, quoted in Malherbe, D.F., 1959. Afrikaanse Verse: 'n Bloemlesing vir die Middelbare Skool, Nasionale Boekhandel Bpk, Cape Town, 214 p.

Fire - a dangerous friend...

Die vlakte

Oor die bulte se rug slaat die gloed in die lug
  van brande wat ver-weg kwyn,
en doringbome fluister in rooi skemerduister
  van gevare wat kom of verdwyn...

J.F.E. Celliers, quoted in Opperman, D.J., 1979. Senior Verseboek, Tafelberg-uitgewers Bpk, Cape Town, 278 p.

CHAPTER 14: FIRE IN GRASSLANDS AND FORESTS

Contents *Page*

Tables *Page*

14.1 Prescribed veld burning in Natal*

Prescribed veld burning is undertaken to destroy moribund material from the previous season, to stimulate vegetative reproduction (tillers) and accordingly, to promote vigorous growth inter alia to prevent soil erosion - especially in high intensity rainfall events. Burning is also applied to control the encroachment of grass or bush invader species, and to ensure palatable foliage and cover for livestock and wildlife. Veld burning however, is a complex issue and is subject to further research and recommendations. These complexities are not discussed here. A very brief, non-technical overview can be found in Anonymous (1990)**. Prescribed burning is controlled under the Conservation of Agricultural Resources Act No. 43 of 1983, whereby (except by written permission from the Department of Agriculture), no land user may burn veld or utilize veld which has been burnt. Permission will only be granted if veld burning is an acceptable management practice, or if exceptional circumstances prevail on the farm unit concerned. Burning may only be undertaken during given periods, and is subject to the provisions of the Forest Act No. 122 of 1984. A land user is therefore required (under normal circumstances) to apply to the Department of Agriculture for permission to burn veld. Permission is then granted to burn in accordance with the Natal veld burning control measures, for the specific farm unit. Land users need only apply once for a particular farm unit and consent remains valid until withdrawn, or the veld control measures are amended. Permission cannot be transferred from the old land user to a new land user, who must in turn apply for permission. Natal has been divided into six veld burning zones in terms of the control measures (Table N1).

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* Discussion based on Anonymous, 1985. Veld burning control measures in Natal Region, Department of Agriculture and Water Supply (Natal Region), Cedara, 8 p., and Haigh, H., 1991. Forestry development: the farmer, the Forest Act and fires, Extension Leaflet No. 1/91, Department of Water Affairs and Forestry, Pietermaritzburg, 4 p. See also, Trollope, W.S.W., 1981. Recommended terms, definitions and units to be used in fire ecology in South Africa, Proceedings of the Grassland Society of Southern Africa, VOL 16, p. 107 - 109.

** See Anonymous, 1990. Important guidelines for burning of veld/Burning of veld an acceptable practice, Agricultural News, No. 32, 13 August 1990, p. 4 - 5.

Table N1: Natal veld burning control measures, 1985.

Zone	Details
Cold Grassveld (These areas include the cold drier phases of bioclimatic groups 4 and 8 situated in East Griqualand)	No veld may be burnt before 15 August During the period 15 August - 31 August veld may be burnt: • within five days of 15 mm of rain falling within 24 hours • or if the veld was withdrawn from grazing during the period 1 February - 31 May of the previous season Veld may be burnt without rain from 1 September - 15 October No veld may be burnt after 15 October Grazing should not commence on burnt veld until the leaf growth of the grass has attained a minimum length of 100 mm
Cool Moist Grassveld (These areas comprise the Highland Sourveld, Montane Veld and Uplands Moist Tall Grassveld and include bioclimatic groups 4 and 5, and the cooler phases of bioclimatic group 6)	No veld may be burnt before 1 August During the period 1 August - 15 August veld may be burnt: • within five days of at least 15 mm of rain falling in 24 hours • or if the veld was withdrawn from grazing during the period 1 February - 31 May of the previous season Veld may be burnt without rain from 16 August - 30 September No veld may be burnt after 30 September Grazing should not commence on burnt veld until the leaf growth of the grass has attained a minimum length of 100 mm

Table N1: Natal veld burning control measures, 1985 (continued).

Zone	Details
Intermediate Moist Grassveld (These are areas of high rainfall (>800 mm) on mixed and sourveld with temperatures intermediate between the warm Coastal Lowlands and the Coastal Hinterland. Such areas comprise bioclimatic group 3, the cooler phase of bioclimatic group 2, and the warm phase of bioclimatic group 6)	No veld may be burnt before 15 July During the period 15 July - 15 August veld may be burnt: • within five days of at least 15 mm of rain falling in 24 hours • or if the veld was withdrawn from grazing during the period 1 February - 31 May of the previous season Veld may be burnt without rain from 16 August - 30 September No veld may be burnt after 30 September Grazing should not commence on burnt veld until the leaf growth of the grass has attained a minimum length of 100 mm
Warm Moist Grassveld (These are areas of high rainfall (>800 mm) in warm areas on mixed and sourveld. This includes bioclimatic groups 1 and 2, namely, the Coastal Lowlands and the Coastal Hinterland)	No veld may be burnt before 1 July During the period 1 July - 31 July veld may be burnt: • within five days of at least 15 mm of rain falling in 24 hours • or if the veld was withdrawn from grazing during the period 1 February - 31 May of the previous season Veld may be burnt without rain from 1 August - 15 September No veld may be burnt after 15 September Grazing should not commence on burnt veld until the leaf growth of the grass has attained a minimum length of 100 mm
Dry Tall Grassveld (This area comprises bioclimatic group 8)	No veld may be burnt before 15 August During the period 15 August - 31 October veld may be burnt within five days of 15 mm of rain falling in 24 hours No veld may be burnt after 31 October Grazing should not commence on burnt veld until the leaf growth of the grass has attained a minimum length of 100 mm

Table N1: Natal veld burning control measures, 1985 (continued).

Zone	Details
Dry Thornveld (These areas include bioclimatic groups 7, 9, 10 and 11)	The burning of sweetveld is permitted only in exceptional circumstances. Application must be made to the Department of Agriculture each time the need to burn arises, indicating the reasons for burning. Veld may only be burnt on the authority of written permission from the Department

Source: After Anonymous, 1985. Veld burning control measures in Natal Region, Department of Agriculture and Water Supply (Natal Region), Cedara, 8 p.

Note:

(i) The Natal veld burning control measures as outlined, remain current although the measures are in the process of being revised. A map of the six areas can be found in Anonymous (1985).

(ii) The Department of Agriculture recommends that grazing land should be burnt only once every three years.

(iii) If the land user wishes to burn veld under circumstances other than the above, then special authorization must be obtained from the Department of Agriculture on each such occasion (the burning of firebreaks excepted). The burning of firebreaks however, is prohibited at certain times of the year in terms of the Forest Act No. 122 of 1984. The Mountain Catchment Areas Act No. 63 of 1970 also makes various provisions for fire control in declared Mountain Catchment Areas. There are no declared Mountain Catchment Areas in Natal/KwaZulu, and the Act is therefore not relevant in the province.

(iv) To cater for adverse weather conditions, a relatively late date after which veld may not be burnt is stipulated for each zone. Land users are encouraged to burn as early as possible (within the permitted period), to avoid damage to the veld after growth has commenced.

(v) Schulze (1982) provided a method for determining selected planning data, for instance when the average first burning date is likely to be, and what the probability is of rainfall requirements for burning having been met, on average, by a certain date. The only data required are the bioclimatic group and the mean annual precipitation at the site. Various maps illustrating the methodology are presented. See: Schulze, R.E., 1982. Agrohydrology and climatology of Natal, ACRU Report No. 14, Agricultural Catchments Research Unit, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, 136 p.

Notwithstanding the Natal veld burning control measures, additional regulations under the Forest Act No. 122 of 1984 (as noted above), also apply to both agricultural land and commercial plantations. These regulations vary from year to year depending on conditions, and are published in the Republic of South Africa Government Gazette. The regulations are for open fires, the burning of ground cover (plantation slash/harvest residue), sugar cane and fire belts (Table N2).

The Minister of Water Affairs and Forestry, in consultation with the Minister of Agriculture (in terms of the Forest Act), may declare any area to be a Fire Control Area with a fire control committee. The purpose is inter alia to transfer responsibility for fire matters to land users (according to local circumstances), where the committee is required to formulate a fire protection scheme, and to organize the necessary fire prevention and fire fighting procedures for the area. Land situated within the jurisdiction of a local authority can also be declared a Fire Control Area. The members of the committee must then include one representative of the Natal Agricultural Union, one representative from each local authority included in the area - and in timber growing areas - at least two representatives of timber growers' organizations. The Minister of Water Affairs and Forestry may also declare two or more Fire Control Areas to be a Fire Control Region with a regional fire control committee. The purpose of the committee is to co-ordinate fire fighting activities in the respective Fire Control Areas, including fire hazard forecasting and radio networks.

The aerial fighting of "run-away" grass, sugar cane and especially forest fires is undertaken by the Natal Fire Protection Association (previously known as the Natal Midlands Fire Protection Association), based at Oribi Airport in Pietermaritzburg. The operational area of the Association extends from the Tugela River to Harding, and includes the adjacent coastline as well as land up to Winterton. The Association determines the daily fire risk and hence the probability of demand for aerial water bombers, by using a fire danger index (discussed later in the chapter). Numerous regulations cover the burning and control of fires in South Africa and the interested reader is referred to the Forest Act No. 122 of 1984 and the Conservation of Agricultural Resources Act No. 43 of 1983. Several pamphlets briefly explaining pertinent aspects of the Forestry Act in terms of fires, are available from the Department of Water Affairs and Forestry, Pietermaritzburg (Natal Region), and Eshowe (Zululand Region).

Table N2: Burning regulations in terms of the Forest Act No. 122 of 1984, dated the 25th June 1993.

Magisterial district	Periods of prohibition in terms of the						Burning of maize harvest residue permitted	
	making of fires in the open air		burning of ground cover		clearing of fire belts			
	(from)	(to)	(from)	(to)	(from)	(to)	(from)	(to)
Zululand coast Hlabisa Lower Umfolozi Mtunzini	1 July 1993	30 November 1993	1 August 1993	30 September 1993	1 August 1993	30 September 1993	-	
Zululand interior Babanango Eshowe Mtonjaneni	As above		1 July 1993	31 October 1993	As above		-	
Northern Natal Dannhauser Dundee Glencoe Klip River Newcastle Ngotshe Paulpietersburg Utrecht Vryheid Weenen	As above		1 July 1993	31 October 1993	As above		1 July 1993	30 September 1993
East Griqualand Mount Currie	As above		As above		As above		As above	
Natal Midlands Alfred Bergville Camperdown Estcourt Impendle Ixopo Kranskop Lions River Lower Tugela Mooi River New Hanover Pietermaritzburg Polela Richmond Umvoti Underberg	As above		As above		As above		As above	

Source: After Anonymous, 1993. Republic of South Africa Government Gazette No. 14877 of the 25th June 1993, Government Printer, Pretoria, 48 p. (Government Notice GN 1057/93).

Note:

(i) With reference to the stipulated areas and periods, no person shall from 18h00 on Fridays to 06h00 on Mondays make a fire in the open air or, if such a fire has been made, allow it to continue to burn or add fuel thereto - excluding (a) fires made within a demarcated picnic or camping area, caravan park or holiday resort (only at places within such a demarcated area which have been specifically prepared and maintained for that purpose), (b) fires for the preparation of food on residential stands, and (c) fires to facilitate the harvesting of sugar cane from 18h00 on Fridays to 08h00 on Saturdays and from 17h00 on Sundays to 16h00 on Mondays.

(ii) With reference to the stipulated areas and periods no person, except any person who has permission to burn veld in terms of the Conservation of Agricultural Resources Act No. 43 of 1983, shall destroy by burning any ground cover, including slash in any timber plantation or any harvest residue: provided that maize harvest residue may be destroyed by burning from 16h00 to 06h00 in the areas and during the periods stipulated.

(iii) The clearing and maintenance of a fire belt by burning is prohibited in the stipulated areas and periods.

14.2 The burning regime for mountain catchment grasslands of the Natal Drakensberg*

The grasslands of Natal/KwaZulu (including the Drakensberg) consist of the so-called climax or "pure" grasslands; the so-called fire climax ("false" or secondary) grasslands which are considered to have arisen through the restraining influence of fire - in areas where another vegetation form (for example, forest) would be the natural climax - and thirdly, edaphic grasslands. The most suitable burning regime for grasslands in general, remains controversial given inter alia that the objectives of burning are often in dispute. Specific goals therefore, for the management of catchment grasslands on State land in the Drakensberg forest region are still being examined. There is agreement that the primary goal is to maintain dynamic communities (of the various grassland formations) in optimum condition, by preserving their biotic diversity within certain limits (Table N3).

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* Discussion based on Bainbridge, W.R., 1987. Management of mountain catchment grassland with special reference to the Natal Drakensberg, In: Von Gadow, K., Van der Zel, D.W., Van Laar, A., Schönau, A.P.G., Kassier, H.W., Warkotsch, P.W., Vermaas, H.F., Owen, D.L. and Jordaan, J.V. (eds), South African Forestry Handbook, Southern African Institute of Forestry, Pretoria, p. 494 - 508., and Bainbridge, W.R., 1994. Personal communication, Natal Parks Board, Pietermaritzburg.

Table N3: Veld burning prescriptions in natural areas of the Drakensberg forest region, 1986 - 1991.

Management formation	Burning prescription		
	Burning period		
	April	May June July August September	October
	Autumn	Early winter (1) Winter (2) Early spring (3)	Late spring
(a) Forest and forest margins (including forest remnants) with surrounding grasslands	SP1	Apply low intensity burns to surrounding grasslands in early winter; the forest and forest margins communities to be largely protected from fire	SP2
(b) Montane heath-scrub (seral to forest) with surrounding grasslands	SP1	As for (a)	SP2
(c) Sub-alpine scrub heath (Passerina-Phillipia-Widdringtonia fynbos) with surrounding grasslands	SP1	The most favourable burning period for the heathlands is not known, but it is likely to be at least 15 - 20 years. No burning of fynbos in the present prescription period. Apply low intensity burns to surrounding grasslands in early winter	SP2
(d) Alpine dwarf heath (Erica-Helichrysum dwarf fynbos) with surrounding grasslands	SP1	The heathland communities have not been shown to be fire-dependent. The most favourable burning period, if any, is likely to be in excess of 20 years. No burning of fynbos in the present prescription period. Apply low intensity burns to surrounding grasslands in early winter	SP2
(e) Protea wooded grasslands (Protea spp. in seasonal grasslands, see (h) below)	SP1	Burn at any time after the first frosts in one of the above three burning periods, in rotation, for example 1, 2, 3; 2, 1, 3, etc; under conditions where the fire can be contained within the compartment	SP2

Table N3: Veld burning prescriptions in natural areas of the Drakensberg forest region, 1986 - 1991 (continued).

Management formation	Burning prescription						
	Burning period						
	April	May	June	July	August	September	October
	Autumn	Early winter (1)	Winter (2)		Early spring (3)		Late spring
(f) Protea wooded grasslands (Protea spp. in mixed seasonal/ evergreen grasslands, see (j) below)	SP1	As for (e)					SP2
(g) Aquatic and semi-aquatic vegetation (hygrophilous, aquatic and semi-aquatic communities)	SP1	Not known. To be incorporated in surrounding grasslands area treatments (as for e) until better information is available					SP2
(h) Seasonal grasslands (subtropical seasonal grasslands)	SP1	As for (e)					SP2
(i) Evergreen grasslands (temperate evergreen grasslands)	SP1	As for (e)					SP2
(j) Mixed seasonal/evergreen grasslands	SP1	As for (e)					SP2

Source: (i) After Bainbridge, W.R., 1987. Management of mountain catchment grassland with special reference to the Natal Drakensberg, In: Von Gadow, K., Van der Zel, D.W., Van Laar, A., Schönau, A.P.G., Kassier, H.W., Warkotsch, P.W., Vermaas, H.F., Owen, D.L. and Jordaan, J.V. (eds), South African Forestry Handbook, Southern African Institute of Forestry, Pretoria, p. 494 - 508.

(ii) After Bainbridge, W.R., 1994. Personal communication, Natal Parks Board, Pietermaritzburg.

See also: (i) Everson, C.S., [1988]. Prescribed burning in the Montane grasslands of the Drakensberg, Information Leaflet No. 20, Department of Environment Affairs, Pretoria, 4 p.

(ii) Everson, T.M., Smith, F.R. and Everson, C.S., 1985. Characteristics of fire behaviour in the Montane grasslands of Natal, Journal of the Grassland Society of Southern Africa, VOL 2(3), p. 13 - 21.

(iii) Everson, T.M., Van Wilgen, B.W. and Everson, C.S., 1988. Adaptation of a model for rating fire danger in the Natal Drakensberg, South African Journal of Science, VOL 84(1), p. 44 - 49.

(iv) Wyatt, J., 1993. Wetlands: assessment, management and rehabilitation of South African wetlands - an illustrated field guide for practical use by land agency extension services (draft), Renfreight Wetlands Campaign, [Natal Parks Board], Durban, 27 p. (The publication provides some brief guidelines on the burning of wetlands. The publication has subsequently been updated. See the chapter on wetlands and pans). More detailed information on the burning of wetlands can be found in the following: Kotze, D.C. and Breen, C.M., 1994. Agricultural land-use impacts on wetland functional values, WRC Report No. 501/3/94, Water Research Commission, Pretoria, 70 p., plus Kotze, D.C., Breen, C.M. and Klug, J.R., 1994. WETLAND-USE: a wetland management decision support system for the KwaZulu/Natal Midlands, WRC Report No. 501/2/94, Water Research Commission, Pretoria, 76 p. + app., as well as Oellermann, R.G., Darroch, M.A.G., Klug, J.R. and Kotze, D.C., 1994. Wetland preservation valuation and management practices applied to wetlands: South African case studies, WRC Report No. 501/5/94, Water Research Commission, Pretoria, various pages.

Note: (i) SP1 denotes that special permission is required to burn before the first general frosts in April/May, while SP2 indicates that special permission is required to extend treatments after September. Permission will depend on the degree of "mixing" of the sward.

(ii) For a discussion of man-induced vegetation changes (as opposed to climatic factors), see February, E., 1994. Palaeoenvironmental reconstruction in the Natal Drakensberg using wood charcoal as a conservation management tool, South African Journal of Science, VOL 90(10), p. 549 - 551. (The paper reinforces the difficulties of an acceptable definition of "pristine", namely, unchanged).

(iii) The fire intensity classification used in South Africa is given below. The intensity of a fire is influenced by fuel load, fuel moisture, relative humidity, air temperature and wind speed. Fuel load, relative humidity and air temperature are the most important factors.

Intensity ($kJ\ s^{-1}\ m^{-1}$)	Description
≤500	Very cool
501 - 1 000	Cool
1 001 - 2 000	Moderately hot
2 001 - 3 000	Hot
>3 000	Extremely hot

When burning to remove moribund and unacceptable grass material, a cool fire is required to dispose of the material and to minimize damage to the grass sward. Such a fire will be obtained if applied when the air temperature is less that 20°C, with a relative humidity greater than 50%. By contrast, a hot fire is required to eradicate and/or to prevent bush encroachment. In order to destroy bush growth up to 2 m in height an air temperature of 25 - 30°C, a relative humidity of less than or equal to 30%, and a grass fuel load of more than 4 000 kg ha^{-1} is necessary (Trollope and Ward, undated)*.

It is the limits however, which are currently being defined. Retention of the status quo with regard to proportional grassland species composition is a major objective, except in the case of overgrazed grasslands, or grasslands overprotected from fire, and with an undesirable species composition.

It is accepted that the main management tool for the preservation of mountain grassland communities is fire. Fire treatments must be correctly applied in order to prevent soil erosion as well as a reduction in streamflow plus water quality; and to prevent invasion

* See Trollope, L. and Ward, H.K. (eds), undated. An agricultural guide book for Ciskei, Agricultural and Rural Development Research Institute and the Faculty of Agriculture, University of Fort Hare, in association with the Ciskei Department of Agriculture, Forestry and Rural Development, Alice, 324 p.

by undesirable grass and shrub species*. The prescriptions outlined in Table N3 make provision for the most favourable known treatment for each management formation (vegetation category), where the grasslands are exposed to a variety of treatments which promote ecological resilience.

14.2.1 Timing of burns

There is a phased reduction of fuel loads over the dry season with the application of three rotating burning periods, namely, early winter (May), winter (June and July) and early spring (August and September) in Protea wooded grasslands (both in seasonal and mixed seasonal/evergreen grasslands), aquatic and semi-aquatic vegetation, seasonal grasslands, evergreen grasslands, and mixed seasonal/evergreen grasslands. Burns are applied in a "mosaic" to reduce the risk of run-away fires. Early winter burns only are recommended for the other grasslands.

14.2.2 Frequency of burns

The standard treatment prescribes burning every second year for all vegetation categories - excluding those indicated in Table N3. Managers have some discretion depending on the incidence of wildfires, and their success in having achieved their target of areas to be burned during the previous season. These factors (as well as drought conditions) will modify the burning frequency of the compartments (discussed below) on the current burning list (for a given year), to one, three or in some instances, even four yearly intervals. Thereafter, the burning frequency reverts to the standard two year period.

In order to facilitate management, the Drakensberg forest region has been divided into 460 primary management units (blocks), consisting of an entire drainage basin which is separated by watershed and boundary firebreaks. Each block is subdivided into management units (compartments) with a relatively similar terrain, soil type and microclimate, and with a fairly uniform growth response which necessitates uniform burning treatments. Compartments range in size from 350 - 750 ha with a mean area of

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* See for example, Everson, C.S., George, W.J. and Schulze, R.E., 1989. Fire regime effects on canopy cover and sediment yield in the Montane grasslands of Natal, South African Journal of Science, VOL 85(2), p. 113 - 116. See also, Scott, D.F., 1994. The hydrological effects of fire in South African catchments, Ph.D. Thesis, Department of Agricultural Engineering, University of Natal, Pietermaritzburg, 167 p.

approximately 500 ha. Each compartment is separated by permanent boundaries such as paths and natural features (including streams and terrain changes); as well as by occasional firebreaks.

Burning is applied in "safe" periods when the weather is relatively stable (excluding extreme wind and high temperature conditions). Periods when the fuel moisture content is very low are also avoided. Burning is undertaken in accordance with a fire danger index. The compartment boundaries are adequate to contain prescribed burning in these circumstances. The burning treatment applied to each compartment is that prescribed for the predominant vegetation formation in the compartment (Bainbridge, 1987; 1994). It should be noted that the discussion does not refer to grasslands managed for livestock grazing, where different management objectives are evident.

<u>For further information contact</u>:

- Cathedral Peak Forestry Research Station, Private Bag X1, Winterton, 3340.

- Cedara Agricultural Development Institute, Private Bag X9059, Pietermaritzburg, 3200.

- Department of Grassland Science, University of Natal, Private Bag X01, Scottsville, 3209.

- Department of Water Affairs and Forestry, Private Bag X9029, Pietermaritzburg, 3200/P O Box 1531, Eshowe, 3815.

- Natal Parks Board, P O Box 662, Pietermaritzburg, 3200.

14.3 Causes of run-away veld and forest fires in Natal

Most fires occur in the months May to September (data for the 1992 calendar year in respect of fires reported to the Natal Fire Protection Association). It is during these dry months that firebreaks (fire belts) and trash lines are burnt in plantations and veld burning is permitted. Hot Berg winds are common in this period and there is a high probability of run-away fires*. Suspected arson - as per the data for 1992 - was regarded as the primary cause of run-away fires, with most arson-induced fires occurring between 18h00 - 24h00. Other causes included the activities of bee (hive) robbers, smokers and children, as well as lightning and powerline failures. A discussion of the causes of fires in plantations can be found in Kromhout (1990) and Le Roux (1984; 1988)**. The Division of Forest Science and Technology of the CSIR, P O Box 395, Pretoria, 0001, has developed a technique to map veld and bush fires using high resolution LANDSAT satellite imagery. The procedure can be used to assess the true extent of burnt areas and the

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* Severe veld fires which cause widespread damage and destruction in a given district may result in the declaration of a disaster area (in terms of the Fund-raising Act No. 107 of 1978). An example is Proclamation Proc 110/92 in which disasters were declared following serious fires in the Smithfield, Reddersburg and Dewetsdorp magisterial districts. In terms of the latest procedure (post-1994 election), the declaration of a fire-stricken area as a disaster area - and hence the need for subsequent assistance - involves a request by the Premier of the province concerned, to the State President and the Minister of Welfare and Population Development. The Department of Agriculture (at central and provincial level) may however, in certain circumstances, approve an emergency stock feeding scheme as well as subsidies for the repair of farm infrastructure. The aim of State assistance is not to compensate farmers, but rather to enable farmers to continue farming operations. The public are also invited to make donations to a specific bank account number for fire relief purposes. Emergency monies (following the declaration of a disaster area) are disbursed by the Disaster Relief Fund, Private Bag X901, Pretoria, 0001. The Fund is currently administered by the Department of Welfare and Population Development. Data on insurance claims may be obtained from the South African Insurance Association, P O Box 62155, Marshalltown, 2107. (See Anonymous, 1994. Assistance to fire-stricken stock farmers in Ugie District, Agricultural News, 11 July 1994, p. 1. See also, Pringle, E.L., 1987. Is it safe to play with matches: liability for veld and forest fires, De Rebus, No. 235, July 1987, p. 339 - 342).

** See Kromhout, C., 1990. Analysis of fires in privately-owned plantations in the Republic of South Africa: 1985-04-01 to 1989-03-31, South African Forestry Journal, No. 154, September 1990, p. 74 - 87. See also, Le Roux, P.J., 1984. An analysis of fires in privately owned plantations in the Republic of South Africa (1979 to 1983), Wood Southern Africa, VOL 9(12), p. 118 - 123., as well as Le Roux, P.J., 1988. Analysis of fires in privately-owned plantations in the Republic of South Africa (01.04.1979 to 31.03.1985), South African Forestry Journal, No. 146, September 1988, p. 55 - 66. An interesting report on the hydrological implications of forest fires was provided by Scott, D.F. and Schulze, R.E., 1992. The hydrological effects of a wildfire in a Eucalypt afforested catchment, South African Forestry Journal, No. 160, March 1992, p. 67 - 74.

resulting changes in biomass conditions*. A useful source document on fire was compiled by Schirge and Penderis (1978)**.

14.4 Lightning ground flashes and fire

Data on the incidence of lightning ground flashes in southern Africa, and hence a cause of veld and forest fires are presented in Table N4. The highest frequency of ground flashes occurs in the Piet Retief area adjoining Swaziland (11,7 flashes $km^{-2} y^{-1}$). The coastal areas of Natal/KwaZulu have a relatively low incidence with an increase in frequency towards the Drakensberg and northern Natal. A computer-generated map illustrating lightning trends in southern Africa was compiled around 1981 by the then National Electrical Engineering Research Institute of the CSIR in Pretoria. The research programme at that time, was scheduled to continue for a further six years to allow for possible variations not yet apparent in the lightning density pattern. The map contained in the publication cited below Table N4, may be regarded as a sufficient indication of the mean lightning activity across southern Africa, with an error of approximately 10%. Numerous reports relating to lightning research in South Africa were produced by the Institute.

For further information contact:

- Division of Earth, Marine and Atmospheric Science and Technology, CSIR, P O Box 395, Pretoria, 0001.

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* See Edwards, D., De Vos, W.H., Hartkopf, D., Hattingh, D.J., Scheepers, J.J. and Wilby, A.F., 1983. Monitoring of veld burns using satellite imagery, Proceedings of the Grassland Society of Southern Africa, VOL 18, p. 131 - 134.

** See Schirge, G.U. and Penderis, A.H., 1978. Fire in South African ecosystems: an annotated bibliography, South African National Scientific Programmes Report No. 33, Cooperative Scientific Programmes, CSIR, Pretoria, 114 p.

Table N4: **The number of lightning ground flashes $km^{-2} y^{-1}$ in southern Africa, 1975 - 1980.**

Place	Ground flashes ($km^{-2} y^{-1}$)
Natal/KwaZulu and Transkei	
Newcastle	10,1
Vryheid	10,0
Ladysmith	9,6
Dundee	9,1
Mooi River	8,4
Pietermaritzburg	7,3
Greytown	6,3
Durban	5,7
Eshowe	5,0
Empangeni	4,7
Richards Bay	4,5
Umtata	3,1
Margate	1,6
Port St Johns	0,3
Transvaal	
Piet Retief	11,7
Ermelo	8,9
Middelburg	8,9
Krugersdorp	8,1
Standerton	8,1
Pretoria	8,0
Thabazimbi	7,8
Bethal	7,7
Vereeniging	7,6
Heidelberg	7,3
Johannesburg	7,3
Barberton	7,0
Benoni	7,0

Table N4: The number of lightning ground flashes $km^{-2}\ y^{-1}$ in southern Africa, 1975 - 1980 (continued).

Place	Ground flashes ($km^{-2}\ y^{-1}$)
Boksburg	7,0
Brakpan	7,0
Germiston	7,0
Springs	7,0
Witbank	7,0
Machadodorp	6,9
Carletonville	6,8
Kempton Park	6,8
Belfast	6,7
Edenvale	6,6
Roodepoort	6,5
Rustenburg	6,5
Westonaria	6,5
Brits	6,4
Potchefstroom	6,3
Zeerust	6,1
Lydenburg	6,0
Warmbad	5,9
Nylstroom	5,7
White River	5,7
Klerksdorp	5,6
Naboomspruit	5,5
Ventersdorp	5,5
Wolmaransstad	5,5
Lichtenburg	5,4
Potgietersrus	5,3
Sabie	5,3
Tzaneen	5,3
Pietersburg	5,2
Louis Trichardt	3,1

Table N4: **The number of lightning ground flashes $km^{-2} y^{-1}$ in southern Africa, 1975 - 1980 (continued).**

Place	Ground flashes ($km^{-2} y^{-1}$)
Phalaborwa	2,5
Skukuza	2,2
Messina	1,0
Cape and Bophuthatswana	
Mafikeng	5,7
Kimberley	5,3
Aliwal North	4,4
Middelburg	4,4
Colesberg	4,0
Kuruman	3,8
Sishen	3,8
Upington	3,8
Cradock	3,6
Vryburg	3,6
Prieska	3,2
Queenstown	3,2
Cathcart	3,1
De Aar	2,8
Graaff-Reinet	2,7
Humansdorp	2,7
East London	2,2
King Williams Town	2,2
Victoria West	2,2
Carnarvon	2,1
Somerset East	2,1
Aberdeen	1,8
Port Elizabeth	1,8
Mossel Bay	1,6
George	1,5
Uitenhage	1,5

Table N4: The number of lightning ground flashes $km^{-2} y^{-1}$ in southern Africa, 1975 - 1980 (continued).

Place	Ground flashes ($km^{-2} y^{-1}$)
Grahamstown	1,4
Beaufort West	1,3
Port Alfred	1,2
Willowmore	1,1
Plettenberg Bay	1,0
Calvinia	0,9
Riversdale	0,9
Uniondale	0,9
Heidelberg	0,8
Oudtshoorn	0,8
Ladismith	0,6
Prince Albert	0,6
Worcester	0,6
Paarl	0,5
Springbok	0,5
Touws River	0,5
Villiersdorp	0,5
Caledon	0,4
Stellenbosch	0,4
Cape Town	0,3
Hermanus	0,3
Piketberg	0,3
Alexander Bay	0,2
Port Nolloth	0,2
Saldanha	0,2
Simonstown	0,2
Somerset West	0,2
Vredendal	0,2

Table N4: The number of lightning ground flashes $km^{-2} y^{-1}$ in southern Africa, 1975 - 1980 (continued).

Place	Ground flashes ($km^{-2} y^{-1}$)
Orange Free State	
Harrismith	9,6
Bethlehem	7,3
Sasolburg	7,3
Parys	7,0
Kroonstad	6,5
Winburg	6,5
Welkom	5,6
Bloemfontein	4,9
Reddersburg	4,9
Trompsburg	3,5
Namibia	
Tsumeb	4,3
Windhoek	2,3
Aroab	1,8
Keetmanshoop	1,1
Luderitz	0,7
Swakopmund	0,7
Walvis Bay	0,4

Source: After Anonymous, [1981]. Lightning recording scheme, National Electrical Engineering Research Institute, CSIR, Pretoria, 4 p.

See also: (i) Manry, D.E. and Knight, R.S., 1986. Lightning density and burning frequency in South African vegetation, Vegetatio, VOL 66(2), p. 67 - 76.

(ii) Van Olst, M.D.A., 1991. Lightning incidence and radioactive granite, Zimbabwe Science News, VOL 25(4/6), p. 48.

14.5 The fire danger index system*

The fire danger index (FDI) is a standard method and rating used by forest fire protection associations throughout South Africa. The FDI refers to forest and grass fires and provides an index of the daily potential for these fires. Five categories of fire potential alerts are recognized namely, the blue, green, yellow, orange and red stages. A typical day in winter for example, would usually involve the yellow stage, while orange and red stages are likely to be experienced during the months July to September when strong Berg winds are evident.

The FDI is calculated daily at 10h00 and 14h00. The index at 10h00 is often indicative of conditions for the remainder of the day (daylight hours), although the index normally reaches a maximum at 14h00. The FDI is calculated at a number of sites in the Natal Midlands and southern Natal, and is averaged to give an overall fire alert stage for forest areas in the Midlands and southern Natal.

Input data required to calculate the FDI are the air temperature (°C) and the relative humidity percentage, which together constitute the burning index. The burning index is obtained from a nomograph published in Anonymous (1991). The burning index must then be adjusted for the wind speed factor (km h^{-1}) which reflects the fire spread danger (Table N5). A further adjustment (the rainfall correction factor) is required to allow for a measure of fuel moisture (Table N6). The rainfall correction factor refers to the amount of rain (mm) and the number of days elapsing since such rain fell.

Example

Assume that it is the 11th of June 1992 and that the air temperature is 25°C, the relative humidity is 50%, the wind speed is 10 km h^{-1}, and that 3 mm of rain fell at the site on the 9th of June 1992, namely, two days ago.

FDI = (burning index + wind factor) x rainfall correction factor

= (38 + 5) x 0,8

= 34,4

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* Discussion based on Anonymous, 1991. Aerial firefighting operation fire plan 1991, Natal Midlands Fire Protection Association, Pietermaritzburg, 26 p. (Other rating systems are also in use in South Africa - such as the United States (National) Fire Danger Rating System - see the bibliographic database).

The fire alert stage for the 11th of June 1992 was green indicating moderate danger (Table N7). A computer program for this calculation is available.

For further information contact:

- Fire Management Forum, P O Box 612, Bredasdorp, 7280. (The Forum has technical and other expertise in forestry fire issues).

- Forest Fire Association, P O Box 4555, Nelspruit, 1200. (A. Kotze - research on the computer program).

- Natal Fire Protection Association, P O Box 2271, Pietermaritzburg, 3200. (The computer program and fire statistics are available).

- Weather Bureau, Private Bag X097, Pretoria, 0001. (M. Laing - research on the fire danger index).

Table N5: The fire danger rating wind correction factor.

Wind speed ($km\ h^{-1}$)	Correction
0 - 4	Burning index + 0
5 - 10	Burning index + 5
11 - 15	Burning index + 10
16 - 25	Burning index + 15
26 - 30	Burning index + 20
31 - 45	Burning index + 30
>46	Burning index + 40

Source: After Anonymous, 1991. Aerial firefighting operation fire plan 1991, Natal Midlands Fire Protection Association, Pietermaritzburg, 26 p.

Table N6: The fire danger rating rainfall correction factor.

Rainfall (mm)	Number of days since previous rain										
	1	2	3	4	5	6	7-8	9-10	11-12	13-15	16-20	>21
0,1 - 2,6	0,7	0,9	1,0									
2,7 - 5,2	0,6	0,8	0,9	1,0								
5,3 - 7,6	0,5	0,7	0,9	0,9	1,0							
7,7 - 10,2	0,4	0,6	0,8	0,9	0,9	1,0						
10,3 - 12,8	0,4	0,6	0,7	0,8	0,9	0,9	1,0					
12,9 - 15,3	0,3	0,5	0,7	0,8	0,8	0,9	1,0					
15,4 - 20,5	0,2	0,5	0,6	0,7	0,8	0,8	0,9	1,0				
20,6 - 25,5	0,2	0,4	0,5	0,7	0,7	0,8	0,9	1,0				
25,6 - 38,4	0,1	0,3	0,4	0,6	0,6	0,7	0,8	0,9	1,0			
38,5 - 51,1		0,2	0,4	0,5	0,5	0,6	0,7	0,8	0,9	1,0		
51,2 - 63,8		0,2	0,3	0,4	0,5	0,6	0,7	0,7	0,8	0,9	1,0	
63,9 - 76,5		0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,8	0,9	1,0
>76,6			0,1	0,2	0,4	0,5	0,6	0,6	0,7	0,8	0,9	1,0

Source: After Anonymous, 1991. Aerial firefighting operation fire plan 1991, Natal Midlands Fire Protection Association, Pietermaritzburg, 26 p.

Table N7: The fire danger rating system used in South Africa by forest fire protection associations.

Fire alert stage	Blue	Green	Yellow	Orange	Red
Fire danger index	0 - 20	21 - 45	46 - 60	61 - 75	76 - 100
Fire behaviour	Safe	Moderate	Dangerous	Very dangerous	Extremely dangerous
Flame length (m)	0 - 1	1 - 1,2	1,2 - 1,8	1,8 - 2,4	>2,4
Fire control guide	Fires are not likely to start. If started, they spread very slowly or may go out without aid from fire fighters. There is little flaming combustion and intensity is low under all conditions. Control is easily achieved and little or no mopping up is required	Ignition may take place near prolonged heat sources (campfires, etc). Spread is slow in forests, moderate in open areas. These are light surface fires with low flames. Control is readily achieved by direct manual attack methods (beaters) and with minimum fire fighting forces. Difficulty may be experienced on exposed, dry slopes and some light mopping up will be necessary	Flaming matches etc. may start fires. Mature grassland and forest litter will burn readily. Spread is moderate in forests, fast in open areas. Fires burn on the surface with moderate flames. Control is not difficult, but direct and indirect attack with fire truck and labour, as well as water spraying by aircraft should be used. Light to moderate mopping up will be required	Ignition can readily occur. Spread may be fast in forests, though not for sustained periods. Grass fires with a spread of approximately 7 km h^{-1} could outstrip fire fighting forces. Fires may be very hot with local crowning and short to medium range spotting. Control will be very difficult requiring indirect attack methods with major assistance necessary. Mopping up may require an extended effort	Ignition can occur from sparks. Rate of spread will be extremely fast for extended periods. Fires will be very hot with a dangerous heat effect on people within 10 m of the fire. There may be extensive crowning, fire whirls and long range spotting. Control may not be possible by frontal attack during the day and fire fighters should limit their efforts to confining lateral spread until the weather changes. Damage potential is at a maximum and mopping up operations may be very extensive and difficult. Full assistance is necessary for the duration of the fire

Source: After Anonymous, 1991. Aerial firefighting operation fire plan 1991, Natal Midlands Fire Protection Association, Pietermaritzburg, 26 p.

See also:

(i) Barclay, J.J., Jury, M.R. and Washington, R., 1993. Meteorology of fire danger in the Natal Drakensberg, South African Journal of Science, VOL 89(7), p. 341 - 349.

(ii) King, J.A., 1957. Meteorological aspects of forest fire danger rating, Journal of the South African Forestry Association, No. 29, May 1957, p. 31 - 38.

(iii) Laing, M.V., 1988. Forecasting wildfire weather conditions in South Africa, Weather Bureau Newsletter, No. 477, December 1988, p. 2.

(iv) Pretorius, W.H., 1993. Brandgevaarvoorspellings vir die NMFPA, Weather Bureau Newsletter, No. 537, December 1993, p. 4 - 6.

(v) Vowinckel, E., 1958. Some results of forest fire danger rating in South Africa, Weather Bureau Newsletter, No. 107, February 1958, p. 11 - 13.

Note:

(i) Flame length refers to the vertical height of the flames likely to be experienced under given conditions.

(ii) Fire issues are discussed in Inferno, which is published by Forest Media Network, P O Box 21126, Valhalla, 0137.

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CHAPTER 15: WATER QUALITY

The costs of pollution...

Wilderness letter

Something will have gone out of us as a people
if we ever let the remaining wilderness be destroyed...
if we pollute the last clear air and dirty
the last clean streams and push our paved
roads through the last of the silence,
so that never again will people be free
in their own country from the noise,
the exhausts, the stinks of human and automotive waste...

W. Stegner, 1967, quoted in [?], The Sound of Mountain Water, Doubleday, New York, reprinted in Neon, No. 35, May 1981, p. 8.

CHAPTER 15: WATER QUALITY

<u>*Contents*</u> <u>*Page*</u>

Contents (continued) *Page*

Contents (continued) *Page*

Tables *Page*

Tables (continued) *Page*

15.1 Some water quality concepts

The chapter on water quality concentrates on four main themes. The first part of the chapter examines water quality parameters mainly in terms of (human) potable supplies. Water quality for other uses such as livestock watering is also discussed. Sources of water quality data are then described, before an examination of some water quality management philosophies. Thereafter, certain water quality problems in South Africa are briefly outlined. The following section examines effluent and wastewater disposal, with some discussion of the situation in Natal/KwaZulu. The second (major) part of the chapter deals with catchment water quality in Natal/KwaZulu, which in turn, leads to a discussion of riverine ecosystem management issues. The fourth (and final) part of the chapter concentrates on eutrophication, again with some emphasis on Natal/KwaZulu. Certain primary source documents and contact addresses are listed at the end of the chapter.

15.1.1 Criteria, guidelines and standards for drinking water quality*

Drinking water should be fit for human consumption. Accordingly, regulation of environmental contaminants, or the derivation of suitable guidelines is necessary. The determination of substances to be examined, and to what extent these substances should be reduced or eliminated, is problematic (Pieterse, 1989). In general, drinking water should be high quality water containing no pathogenic organisms, where the water is free of biological forms which may be aesthetically objectionable. The water should also be clear and colourless with no unpleasant taste or odour, and should not contain concentrations of chemicals which may be harmful or aesthetically undesirable. Drinking water in addition, should not be corrosive**, nor should it leave deposits on pipes, tanks, plumbing fixtures or water heaters (American Water Works Association, 1987, quoted in Pieterse, 1989). In general, the criterion of water being safe to drink implies that the concentration of a contaminant should be below a level which is harmful to health (Nicholson, 1983, quoted in Pieterse, 1989). Expressed in another way, the criterion concept refers to a specific concentration of a substance which, when not exceeded, will

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* Discussion based on Pieterse, M.J., 1989. Drinking-water quality criteria with special reference to the South African experience, Water SA, VOL 15(3), p. 169 - 178.

** See Osborn, D.W., 1989. Corrosion in potable water systems: the Johannesburg experience, Water SA, VOL 15(4), p. 201 - 208.

protect an organism or an aquatic community with an adequate degree of safety (United States Environmental Protection Agency, 1976, quoted in Pieterse, 1989).

It should be noted that criteria are not regulatory requirements, and merely serve as guidelines to be used in establishing water quality standards. Criteria to evaluate the safety of drinking water are continually being examined as new contaminants and consequent health implications are identified. The formulation of drinking water quality criteria therefore, must involve a consideration of all factors affecting the quality of the water, the public health significance of contaminants, and the current water treatment technology (American Water Works Association, 1987). In South Africa, these factors include the total intake of each substance from the air, food and water; the degree of toxicity of each substance to man; the dietary customs of the various population groups; the geological properties of the region which influence water quality; the cost-benefit implications of water treatment, and the affordability of the final product. Also important is the technological level of the population, their ability to pay, and the availability of required expertise (Aucamp and Vivier, 1990)*. Criteria should not be confused with standards, where the latter represent legally enforceable limits. Standards for drinking water should ideally be identical to criteria in order to provide maximum protection, although standards are influenced by practical and other considerations. Guidelines and criteria are similar, given that neither are legally imposed limits, and both can be used for the determination of standards. Numerous guidelines, criteria and standards have been adopted (or considered) in various countries - such as those of the American Water Works Association (AWWA), the United States Environmental Protection Agency (USEPA), the World Health Organization (WHO) and regulatory authorities in European Economic Community (EEC), subsequently European Community (EC), now European Union countries.

15.1.2 Determinands

The identification of new substances in water and their related health implications (as outlined above), implies that the continual updating of criteria, guidelines and standards is required (Pieterse, 1989). Consequently, previous limits for determinands (also referred

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* See Aucamp, P.J. and Vivier, F.S., 1990. Water quality criteria in South Africa, Technology SA, June 1990, p. 21 - 27.

to as contaminants or constituents) are being questioned, while limits for new determinands must be established. Determinands include aesthetic/physical and inorganic as well as organic determinands, plus microbiological determinands and radionuclides. Certain aesthetic considerations such as colour and taste are in many respects subjective, and are a matter of personal tolerance. The major inorganic determinands (for instance, total dissolved solids or salts, hardness, chloride and sulphate), were previously regarded as of only marginal importance in terms of health. More recent research however, has shown that these determinands can have a number of health implications, depending on circumstances. Heavy metals have very definite health risks. The determination of appropriate criteria for heavy metals is difficult given inter alia, the inadequacy of toxicological data.

Organic substances are the subject of considerable research in developed industrialized countries. Many new organic compounds are produced by the chemical industry each year - where little is known of any acute or chronic toxicity properties*, or of their fate, or the nature of their metabolites (breakdown products) in wastewater processes. Importantly, sources of supply in industrialized countries frequently involve rivers contaminated by industrial effluents. These effluents contain substances resistant to normal biological treatment methods, where the implications of increasing concentrations in rivers and dams, and ultimately drinking water, are not known. New advances in analytical equipment have resulted in the detection of previously unmarked as well as new substances, resulting in further problems with water quality. Quality criteria for organic content are of two types, namely, those reflecting total organic concentrations, and those relating to single compounds. In the latter instance, organic compounds are often subdivided into synthetic organic chemicals and volatile organic chemicals. Some authorities apply a third category, specifically, disinfection by-products. Radionuclides likewise, are receiving research attention with the establishment of defined limits (Pieterse, 1989).

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* The term "acute" refers to a disease of rapid onset, severe symptoms and brief duration. The term "chronic" refers to a disease of long duration, involving very slow changes and often with a gradual onset.

15.1.3 Water quality criteria and risk

The identification of appropriate water quality criteria essentially concerns risk. A balance is necessary between risk assessment and risk management. Risk assessment involves the use of scientific data to define the probability of harm for an individual or a population, as a result of exposure to a particular substance. Risk management by contrast, is the public process of deciding what action to take when risk has been determined to exist (Cotruvo, 1987, quoted in Pieterse, 1989).

The primary risk factors in drinking water are waterborne diseases caused by microbiological organisms (responsible for much ill health, misery and death). These risks are easily contained by disinfection and filtration, although concern has been expressed that the by-products of chlorination per se, may present certain health hazards. Reference is made here to trihalomethanes, namely, chloroform, dichlorobromomethane, dibromochloromethane and bromoform*.

The risk assessment for chemicals (toxicity) involves two broad categories, specifically, acute or chronic toxicity (non-carcinogens), and carcinogenicity. The differentiating characteristic between the two categories of effects depends on the probably unverifiable assumptions that (a) dose thresholds do exist for chronic toxicity effects, and (b) that dose thresholds either do not exist or have not been demonstrated for carcinogenic effects (Cotruvo, 1987). Numerous substances found in drinking waters are known to induce toxicity, although at doses much higher than present in water. Use is made of the Acceptable Daily Intake (ADI) concept, where data are available from animal studies

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* When chlorine is added to drinking water supplies for disinfection purposes, the chlorine reacts with the organic content of the water to produce trihalomethanes (THMs). THMs are regarded as potentially carcinogenic substances. Humic and fulvic acids are found in abundance in surface waters - particularly in rivers of the southern and western Cape and also in certain rivers of the eastern Transvaal - hence the "brownish" colour of the water. Humic acids have a great potential in THM production, and are derived from the decomposition of plant and animal matter. Waters drawn from wetlands may well have a high humic acid content - especially waters draining Champagne Form soils (see the chapter on soils and soil erosion). Highly enriched (eutrophied) waters in impoundments are a further source of organic matter (primarily algae), and are also implicated in THM formation. Higher THM concentrations occur in summer, with lower levels in the winter months. See Pieterse, M.J., 1988. The potential health risk of trihalomethanes in drinking water: a perspective, South African Journal of Science, VOL 84(3), p. 166 - 170., and Van Steenderen, R.A., Theron, S.J. and Engelbrecht, A.C.W., 1989. An investigation into the occurrence and concentration of trihalomethanes and their precursors in South African drinking waters, WRC Report No. 194/1/89, Water Research Commission, Pretoria, 16 p. + app., as well as Van Steenderen, R.A., Pieterse, M.J. and Bourne, D., 1991. THM formation in potable waters with reference to related variables and health data bases, Water SA, VOL 17(4), p. 269 - 272.

(rejected by some), or from human epidemiological studies. (The ADI concept is a well accepted procedure for determining concentration levels for the setting of criteria and standards). The ADI of a chemical is defined as the dose that is anticipated to be without lifetime risk to humans when ingested daily (Cotruvo, 1987). The ADI is usually derived from a detailed analysis of the toxicology of the particular chemical. The no observed adverse effect level (NOAEL, also known as the no observed effect level - NOEL), is established for the most sensitive adverse effect in the test system, where a safety or uncertainty factor is applied to the NOAEL dose to estimate the safe level for human consumption purposes (Cotruvo, 1987).

Four steps are involved in risk assessment. Hazard identification concerns the qualitative evaluation of the ability of the substance to produce carcinogenic effects, and the relevance to humans. Secondly, exposure assessment depends on the number of individuals likely to be exposed, in view of the type, duration and magnitude of the exposure. The hazard or dose-response assessment involves the collation of hazard and exposure information (as well as the use of mathematical models, also based on unverifiable assumptions), in order to estimate an upper bound for the carcinogenic risk at a specified dose. The final step is the characterization of the risk associated with human exposure.

It should be borne in mind that the organic substance contribution of drinking water is very low by comparison with other sources. Zoeteman (1985, quoted in Pieterse, 1989), observed that practically all known organic micropollutants in drinking water account for less than 1% of the daily human intake of these compounds (excluding chloroform); notwithstanding the thousands of organic compounds which may exist in varying concentrations and at different times of the year in natural waters (Van Steenderen, Theron and Engelbrecht, 1989 - above). Travis, Richter, Crouch and Klema (1987, quoted in Pieterse, 1989) proposed regulatory guidelines for the assessment of cancer risk management. These guidelines incorporate individual risk, population risk and cost-effectiveness into a single framework. Three guidelines were suggested, namely: de manifestis (obvious risk) individual lifetime risk (which is a function of population risk), where action above this level is required; and de minimis (for defining an acceptable level of risk which is below regulatory concern) individual lifetime risk (also a function of population risk), where action is not necessary below this risk; and thirdly, an intermediate category where regulatory action should be taken if the cost is below a given sum of money per life saved. The estimation of human cancer risk due to exposure to chemical carcinogens however, remains controversial (Calabrese, 1987, quoted in Pieterse, 1989).

15.1.4 Water quality requirements in South Africa

There are no legally binding drinking water standards in South Africa. More recent guidelines have included the (South African Bureau of Standards) SABS 241-1971 specifications which were subsequently updated in 1984*. The latter specifications outline the minimum physical, bacteriological and chemical requirements for 26 determinands, for the purity of drinking water delivered to the consumer. The data refer to the recommended maximum limit and the maximum allowable limit (Table O1). Several workers in South Africa have also examined drinking water criteria. Kempster, Hattingh and Van Vliet (1980)** presented summarized water quality criteria for a number of different water uses (see later) including human potable needs - not discussed, while Kempster and Smith (1985) and Aucamp and Vivier (1987)*** proposed further potable criteria. Pieterse (1989) provided an overview analysis of the determinands put forward by Kempster and Smith/Aucamp and Vivier (Table O2)****, which represents an increase of 30 determinands (by comparison with the 1984 SABS specifications). The Department of National Health and Population Development, Private Bag X828, Pretoria, 0001, has accepted the basic philosophy of the latest criteria, which will become the relevant criteria in due course. It should be noted that the Department is

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* See Anonymous, 1971. South African Bureau of Standards specification for water for domestic supplies, SABS Specification No. 241-1971, South African Bureau of Standards, Pretoria, 13 p., and Anonymous, 1984. South African standard specification for water for domestic supplies, SABS Specification No. 241-1984, South African Bureau of Standards, Pretoria, 15 p.

** See Kempster, P.L., Hattingh, W.H.J. and Van Vliet, H.R., 1980. Summarized water quality criteria, Technical Report No. TR 108, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, 45 p.

*** See Aucamp, P.J. and Vivier, F.S., 1987. A novel approach to water quality criteria in South Africa, Symposium Water 2000, International Water Supply Association, September 1987, Nice, France, 8 p., as well as Kempster, P.L. and Smith, R., 1985. Proposed aesthetic/physical and inorganic drinking-water criteria for the Republic of South Africa, CSIR Research Report No. 628, National Institute for Water Research, CSIR, Pretoria, 51 p. (The publication contains much useful data including properties of determinands, recommended methods of analysis and suggested sampling frequencies).

**** It is apparent that Table O2 shows only 52 (non-microbiological) determinands as per Pieterse (1989), although the other four (non-microbiological) determinands as per Kempster and Smith (1985), are presented in Footnote (iv) of the table.

Table O1: South African Bureau of Standards (SABS) specifications for water for domestic supplies.

Determinand	Unit	Recommended maximum limit	Maximum allowable limit
Physical and chemical limits Colour	mg ℓ^{-1} Pt (Platinum)	20	Not specified
Odour and taste	Shall not be objectionable		
Turbidity	NTU (Nephelometric turbidity units)	1	5
pH	pH units	6 - 9	5,5 - 9,5
Conductivity	mS m^{-1}	70	300
Bacteriological limits Standard plate count (now known as the heterotrophic plate count)	Counts 1 $m\ell^{-1}$	100	Not specified
Total coliforms	Counts 100 $m\ell^{-1}$	0*	5
Faecal coliforms (E. coli I)	Counts 100 $m\ell^{-1}$	0	0
Macro-determinands Hardness, total	(mg ℓ^{-1}) $CaCO_3$	20 - 300	650
Magnesium	Mg	70	100
Sodium	Na	100	400
Chloride	Cl	250	600
Sulphate	SO_4	200	600
Nitrate + nitrite	N	6	10
Fluoride	F	1	1,5
Zinc	Zn	1	5
Micro-determinands Arsenic	($\mu g\ \ell^{-1}$) As	100	300
Cadmium	Cd	10	20
Copper	Cu	500	1 000
Cyanide	CN	200	300

Table O1: South African Bureau of Standards (SABS) specifications for water for domestic supplies (continued).

Determinand	Unit	Recommended maximum limit	Maximum allowable limit
Iron	Fe	100	1 000
Lead	Pb	50	100
Manganese	Mn	50	1 000
Mercury	Hg	5	10
Phenolic compounds	Phenol	5	10
Selenium	Se	20	50

Source:

(i) After Anonymous, 1984. South African standard specification for water for domestic supplies, SABS Specification No. 241-1984, South African Bureau of Standards, Pretoria, 15 p.

(ii) After Anonymous, 1971. South African Bureau of Standards specification for water for domestic supplies, SABS Specification No. 241-1971, South African Bureau of Standards, Pretoria, 13 p.

See also:

(i) Pieterse, M.J., 1989. Drinking-water quality criteria with special reference to the South African experience, Water SA, VOL 15(3), p. 169 - 178.

(ii) Genthe, B. and Du Preez, M., 1995. Evaluation of rapid methods for the detection of indicator organisms in drinking water, WRC Report No. 610/1/95, Water Research Commission, Pretoria, 19 p.

(iii) Genthe, B. and Kfir, R., 1995. Studies on microbiological drinking water quality guidelines, WRC Report No. 469/1/95, Water Research Commission, Pretoria, 35 p. + app.

(iv) Gericke, M., Bateman, B., Rapholo, F., Mashakana, J., Maharaj, V., Hilner, C.A. and Kfir, R., 1995. Occurrence of protozoan parasites in South African source and treated water, WRC Report No. 451/1/95, Water Research Commission, Pretoria, 41 p. + app.

(v) Grabow, W.O.K., 1996. Waterborne diseases: update on water quality assessment and control, Water SA, VOL 22(2), p. 193 - 202.

(vi) Steynberg, M.C., Kok, M., Chale, B., Grundlingh, J.A., Joubert, J.H.B. and Geldenhuys, J.C., 1995. The removal of invertebrates by sand filtration and the influence thereof on water quality, WRC Report No. KV 76/95, Water Research Commission, Pretoria, various pages.

Note:

(i) If nitrate + nitrite (expressed as N) is present in concentrations >10 mg ℓ^{-1}, the water may be unsuitable for use by babies under one year old. An alternative water supply should be used in such circumstances. As a general rule (unless nitrates are normally found in the water), the presence of both nitrates and nitrites should be viewed as indicative of faecal pollution, while the presence of nitrates only is likely to be an indication of oxidized faecal matter. The water should be free from nitrites, unless it is evident that the water contains naturally occurring nitrates (some of which have been subjected to a reduction process).

(ii) The water should not contain any other determinands in concentrations unsuitable for potable needs. Radioactivity if present, must be within the limits established by the International Commission for Radiological Protection. The recommended maximum limit should (if possible) be observed for all determinands, and the maximum allowable limit should not be applied unless no alternative sources are evident. If no other supplies are available, attempts should be made to improve the quality of the existing source.

(iii) The asterisk indicates that if any coliform bacteria are found in the sample, a second sample should be taken immediately. The second sample should be free of coliform bacteria. Not more than 5% of the total number of water samples (from any given reticulation system), tested per year, may contain coliform bacteria.

(iv) The minimum suggested frequency of sampling for bacteriological determinands, per sampling site (reticulation systems) is as follows: 10 samples a month per 100 000 persons served in areas with >100 000 persons; 10 samples a month in areas with 25 000 - 100 000 persons; three samples a month in areas with 10 000 - 25 000 persons; two samples a month in areas with 2 500 - 10 000 persons, and one sample a month for areas with <2 500 persons. Sampling should be carried out more frequently in the rainy season. Sampling for physical and chemical determinands should be undertaken at least four times a year (at the beginning of the rainy season, in the middle of the rainy season, at the end of the rainy season and in the middle of the dry season).

(v) The above specifications include water for culinary purposes and general household use; but not necessarily water for hot water systems (for which special treatment might be required to prevent scale formation and/or corrosion). Testing of samples must be undertaken in accordance with recognized laboratory procedures and the relevant SABS standard methods. (See Chapter 20, elsewhere in this publication).

(vi) The Escherichia coli (E. coli I) (faecal coliform) bacterial count is the most important bacteriological determinand listed in the above specifications. E. coli I bacteria are referred to as indicator organisms which are indicative of recent faecal contamination of the water*. E. coli I bacteria are found in the intestine of all warm blooded animals including birds, and in man may be present in numbers approaching 1×10^9 g^{-1} of fresh faeces. Expressed in another way, the E. coli I count on most raw sewages ranges between 10^6 - 10^8 organisms 100 $m\ell^{-1}$. (E. coli I is the most frequent type of coliform organism present in the human and animal intestine). The survival time of E. coli I organisms in freshwater is variable and may be measured in weeks. Generally, bacterial survival times (including those of the indicator bacteria), are directly related to the degree of pollution of the water - the longest survival occurs in waters with the greatest pollution. Since the indicators are usually present in much higher numbers than the pathogens (and given also that the identification of pathogens often requires advanced laboratory techniques), the presence of indicators is taken to infer the presence of pathogens hazardous to health. E. coli I is also a pathogen and is a common cause of urinary tract infections, as well as being a secondary invader of skin and tissue lesions. Some E. coli strains (belonging to various serotypes) can cause summer diarrhoea in children and gastroenteritis in adults. E. coli I remains the indicator organism most commonly used in bacteriological tests, although various other candidates are suggested on occasion in view of the reservations sometimes expressed concerning E. coli I. In essence, it is when the normal host defences are inadequate, particularly in early infancy, old age and in the terminal stages of diseases, that most health problems will be encountered due to the bacteriological contamination of drinking water.

The total coliform count is a summation of all coliform bacteria present in the sample, some of which may have little or no significance in terms of faecal contamination. The determinand therefore, provides for a wide spectrum of pollution which may not necessarily be of faecal origin (for example, contamination by soil or vegetable matter). Outside the body, in polluted soil, vegetation and water, other coliforms outlive E. coli I and by survival alone can (in the absence of further pollution), first equal and then exceed the declining numbers of E. coli I. From being the subordinate coliform types in freshly polluted sites, other coliforms can become the predominant, and finally the only coliform organisms left in the originally polluted site. Accordingly, if the majority of organisms are not E. coli I, this may indicate slight, infrequent or remote excretal pollution. If no E. coli I bacteria are present, this may indicate contamination with soil or vegetable matter (which may or may not have been polluted by excreta) at some previous time.

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* Care should be taken to differentiate between the presumptive E. coli count comprising E. coli I and Irregular types II and VI coliform bacteria (the latter two of no proven faecal significance), and the confirmed E. coli I count.

The total or standard (heterotrophic) plate count represents the total number of bacterial colonies observed after incubation of the plates containing the sample and the required agar media. It should be borne in mind however, that for various reasons, the total plate count does not represent the exact concentration of bacteria in the water sample. The principle function of the determinand is the detection of any form of contamination. Plate counts are therefore used to provide an estimate of the general hygienic quality of the water, and also to indicate the efficiency of water treatment processes, as well as the cleanliness of the reticulation system. In essence, the plate count is a measure of the available organic matter (soil, dust, sewage and other extraneous material) present in the water. A rising plate count may be the earliest sign of pollution, and is indicative of a reduced suitability of the water for human consumption. A useful overview of the significance of various bacteria in water (on which the above discussion is based), is the following: Grabow, W.O.K., 1970. Literature survey: the use of bacteria as indicators of faecal pollution in water, CSIR Special Report No. O/WAT 1, National Institute for Water Research, CSIR, Pretoria, 27 p. See also, Anonymous, 1993. South African water quality guidelines, VOL 1, Domestic use, Department of Water Affairs and Forestry, Pretoria, 216 p.

(vii) The SABS specifications (above) provide details of the physical/chemical and bacteriological sampling methods required. It is essential that such directions be followed (including time constraints, mainly in the case of bacteriological samples).

Table O2: Proposed drinking water criteria for South Africa.

Determinand	Unit	Recommended limit (maximum limit for no risk)	Maximum permissible limit (maximum limit for insignificant risk)	Crisis limit (maximum limit for low risk)
Physical and organoleptical limits				
Colour	mg ℓ^{-1} Pt (Platinum)	20	-	-
Conductivity	mS m^{-1} (25 °C)	70	300	400
DOC (Dissolved organic carbon)	mg ℓ^{-1} C (Carbon)	5	10	20
Dissolved oxygen	Percentage saturation	70	30	10
Odour	TON (Threshold odour number)	1	5	10
pH	pH units	6,0 - 9,0	5,5 - 9,5	$<$4,0 or $>$11,0
Taste	TTN (Threshold taste number)	1	5	10
Temperature	°C	$<$25	$<$30	$<$40
Turbidity	NTU (Nephelometric turbidity units)	1	5	10
Microbiological limits				
Standard plate count (now known as the heterotrophic plate count)	Counts 1 mℓ^{-1}	$<$100	1 000	10 000
Total coliforms	Counts 100 mℓ^{-1}	0	5	100
Faecal coliforms (E. coli I)	Counts 100 mℓ^{-1}	0	1	10
Clostridium perfringens	Counts 100 mℓ^{-1}	0	10	100

Table O2: Proposed drinking water criteria for South Africa (continued).

Determinand	Unit	Recommended limit (maximum limit for no risk)	Maximum permissible limit (maximum limit for insignificant risk)	Crisis limit (maximum limit for low risk)
Coliphages	Counts 100 $m\ell^{-1}$	0	10	100
Enteric viruses	$TCID_{50}$ 10 ℓ^{-1}	0	1	10
Macro-determinands	(mg ℓ^{-1})			
Aluminium	Al	0,15	0,5	1,0
Ammonia	N	1,0	2,0	4,0
Barium	Ba	0,5	1,0	2,0
Boron	B	0,5	2,0	4,0
Bromide	Br	1,0	3,0	6,0
Calcium	Ca	150	200	400
Cerium	Ce	1,0	2,0	4,0
Chloride	Cl	250	600	1 200
Copper	Cu	0,5	1,0	2,0
Fluoride	F	1,0	1,5	3,0
Hardness	$CaCO_3$	20 - 300	650	1 300
Iodide	I	0,5	1,0	2,0
Iron	Fe	0,1	1,0	2,0
Lithium	Li	2,5	5,0	10,0
Magnesium	Mg	70	100	200
Manganese	Mn	0,05	1,0	2,0
Nitrate	N	6,0	10,0	20,0
Potassium	K	200	400	800
Sodium	Na	100	400	800
Sulphate	SO_4	200	600	1 200
Uranium	U	1	4	8
Zinc	Zn	1	5	10
Micro-determinands	($\mu g\ \ell^{-1}$)			
Antimony	Sb	50	100	200

Table O2: Proposed drinking water criteria for South Africa (continued).

Determinand	Unit	Recommended limit (maximum limit for no risk)	Maximum permissible limit (maximum limit for insignificant risk)	Crisis limit (maximum limit for low risk)
Arsenic	As	100	300	600
Beryllium	Be	2	5	10
Bismuth	Bi	250	500	1 000
Cadmium	Cd	10	20	40
Chromium	Cr	100	200	400
Cobalt	Co	250	500	1 000
Cyanide	CN	200	300	600
Gold	Au	2	5	10
Lead	Pb	50	100	200
Mercury	Hg	5	10	20
Molybdenum	Mo	50	100	200
Nickel	Ni	250	500	1 000
Selenium	Se	20	50	100
Silver	Ag	20	50	100
Tellurium	Te	2	5	10
Thallium	Tl	5	10	20
Tin	Sn	100	200	400
Titanium	Ti	100	500	1 000
Tungsten	W	100	500	1 000
Vanadium	V	250	500	1 000

Source: After Pieterse, M.J., 1989. Drinking-water quality criteria with special reference to the South African experience, Water SA, VOL 15(3), p. 169 - 178.

See also: (i) Anonymous, 1993. South African water quality guidelines, VOL 1, Domestic use, Department of Water Affairs and Forestry, Pretoria, 216 p. (The report may be read in conjunction with (iii) and (iv) immediately below. Certain other determinands (not listed in the above table) are discussed in Anonymous (1993). The report includes a range-by-range description of effects on consumers in terms of health and aesthetic implications (norms), for various determinand concentrations. See the chapter on health, elsewhere in this publication. Water treatment options plus other data are also provided for each determinand).

(ii) Aucamp, P.J. and Vivier, F.S., 1987. A novel approach to water quality criteria in South Africa, Symposium Water 2000, International Water Supply Association, September 1987, Nice, France, 8 p.

(iii) Aucamp, P.J. and Vivier, F.S., 1990. Water quality criteria in South Africa, Technology SA, June 1990, p. 21 - 27.

(iv) Kempster, P.L. and Smith, R., 1985. Proposed aesthetic/physical and inorganic drinking-water criteria for the Republic of South Africa, CSIR Research Report No. 628, National Institute for Water Research, CSIR, Pretoria, 51 p.

Note: (i) Van Steenderen, R.A., Theron, S.J. and Engelbrecht, A.C.W., 1989. An investigation into the occurrence and concentration of trihalomethanes and their precursors in South African drinking waters, WRC Report No. 194/1/89, Water Research Commission, Pretoria, 16 p. + app., proposed that the maximum trihalomethanes (THMs) level for treated drinking waters in South Africa should be 100 $\mu g\ \ell^{-1}$ (following the United States Environmental Protection Agency requirements). Van Steenderen, Theron and Engelbrecht observed that dissolved organic carbon measurements could be used as a predictor of THM concentrations where chlorine is the disinfectant.

(ii) Clostridium perfringens (also known as C. welchii), is found in the intestinal tract of warm blooded animals, and is present in faeces and sewage in much smaller numbers than E. coli. The main reason for the use of C. perfringens as an indicator of faecal pollution, is that the organism produces spores which survive for a much longer period than the coliform bacteria. These spores are usually resistant to chlorination (as applied to drinking water), and to further environmental conditions which destroy most vegetative bacteria and other microorganisms. The presence of C. perfringens in water indicates that faecal contamination has occurred, while the presence of C. perfringens in the absence of coliform organisms, indicates either that the contamination occurred too long ago for detection by coliform counts, or that the water has been subjected to conditions which destroyed the coliform bacteria. The presence of C. perfringens per se in water is not regarded as a health hazard, although there is evidence that some strains can produce food poisoning. The role of the organism as a pathogen is mainly restricted to gas gangrene in wounds. In summary, the coliform organisms, C. perfringens and faecal streptococci (the latter discussed in the following table) are used to denote pollution, since they occur in the faeces of man and animals in relatively large numbers. They are fairly specific, are relatively resistant to conditions in most water environments, and their detection in water is relatively easy and reliable. The presence of these (indicator) organisms in water is indicative of the presence of faeces and if faeces is present, then pathogenic organisms may also be present. Indicator organisms cannot serve as a direct means of measuring the presence of pathogens (either quantitatively or qualitatively), nor can these organisms be used as a means of studying the survival of other microorganisms in natural or treated waters. It is often assumed that by the time indicator organisms have died in water that pathogenic organisms are also absent. However, because of the great variety of pathogens involved in waterborne disease transmission, and in view of the considerable differences in the physiological and morphological characteristics of pathogens, a lack of indicator organisms does not necessarily imply the absence of pathogenic organisms. The interpretation of bacteriological data accordingly, requires considerable experience - given also problems such as equipment failures, the use of incorrect techniques, carelessness, and water sampling errors. (The latter include variable depths and localities of routine sampling sites) (Grabow, 1970)*.

(iii) The tests required for enteric (intestinal) viruses and coliphages (viruses infecting E. coli bacteria), as indicators of the virological safety of water, are somewhat complicated and can only be undertaken by specially equipped laboratories. (See: Grabow, W.O.K., Coubrough, P., Nupen, E.M. and Bateman, B.W., 1984. Evaluation of coliphages as indicators of the virological quality of sewage-polluted water, Water SA, VOL 10(1), p. 7 - 14)**. According to Grabow et al (1984), the absence of coliphages from treated drinking water offers virtually conclusive evidence of the absence of enteric viruses. The unit of measurement for enteric viruses in South Africa is commonly $TCID_{50}$, which is the dose of virus required to cause 50% infection in tissue culture. Many enteric viruses however, do not cause damage to cell cultures (termed cytopathogenic effects), and other methods such as immunological techniques are required to detect these viruses.

(iv) Kempster and Smith (1985 - above) provided data on four (non-microbiological) determinands not reflected in Table O2. The data are summarized below:

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* See Grabow, W.O.K., 1970. Literature survey: the use of bacteria as indicators of faecal pollution in water, CSIR Special Report No. O/WAT 1, National Institute for Water Research, CSIR, Pretoria, 27 p.

** See also Nupen, E.M., 1975. The effectiveness of various techniques for the removal of bacteria and viruses, [IAWPR] Regional Conference on Practical Aspects of Water Supply and Pollution Control in Southern Africa, 2 - 5 June 1975, Mbabane, Swaziland, 9 p.

Determinand and unit	Recommended limit (maximum limit for no risk)	Maximum permissible limit (maximum limit for insignificant risk)	Crisis limit (maximum limit for low risk)
Chlorine, free residual (mg ℓ^{-1} Cl) (If chlorine is used as a disinfectant. Note that chlorine is not an effective disinfectant at pH values >8,5)	0,2 - 5,0	<0,2 or >5,0	Not specified
Hydrogen sulphide (μg ℓ^{-1} H_2S)	100	300	600
Methylene blue active substances (MBAS) (foaming agents) (mg ℓ^{-1} linear alkylate sulphonate - LAS)	0,5	1,0	2,0
Phenols (μg ℓ^{-1} phenol)	5	10	40

<u>Note</u>: The chlorine, free residual determinand is not relevant to raw water intended for domestic use.

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responsible <u>inter alia</u> for potable (human) water quality issues in terms of the Health Act No. 63 of 1977.

The latest proposals involve a three tier system (Pieterse, 1989). The first level is the recommended or working limit (which ideally should not be exceeded - also known as the maximum level for no risk by the Department of National Health and Population Development). The first category is accordingly, the fundamental water quality criterion which closely follows the recommended limits established by the SABS, USEPA, WHO and the EEC. Drinking water meeting the various levels is considered to be safe for consumption in an individual's lifetime. Concentrations below these levels are within the safe or no risk range. Given however, that the recommended limit is often exceeded (in reality), a second, less stringent criterion, namely, the maximum permissible level or the maximum allowable limit (also known as the maximum limit for insignificant risk) was designated. The range (difference) between the first level (described above) and the second level is known as the insignificant risk range. Within this range, the water supply authority is responsible for drinking water quality decision-making. The third level is the crisis limit, also known by the Department of National Health and Population Development as the maximum level for low risk (the limit where extreme action is necessary). The range between the second level and the third level is the low risk range. The third (crisis) level is a new concept. The crisis limit value for each determinand (as an interim measure), was originally defined as twice the maximum permissible limit value - except for pH, temperature and dissolved oxygen (Kempster and Smith, 1985). Appropriate crisis levels have, and will subsequently be determined by the toxicological characteristics of the various determinands. Kempster, Hattingh and Van Vliet (1980) stressed that functional interactions between determinands must also be considered when evaluating potential toxic effects. Toxic potential, in addition to being determined by concentration, is also influenced by the origin of the specific substance, namely, whether derived from natural sources or man-made pollution. Toxic effects may likewise be due to trace impurities of other substances which are associated with a particular determinand (for example, certain pesticides). Besides the guidelines outlined above, the Department of Water Affairs and Forestry has published water quality guidelines for four major use categories. This is an important publication series with further volumes in preparation*.

Research on determinands in South Africa (as in other countries) is an on-going process. The microbiological quality of water in this country has a high research priority with well developed scientific expertise available (Grabow, 1986)**. The presence of organic compounds in drinking water is also the subject of further research, given that the 1984

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* See Anonymous, 1993. South African water quality guidelines, VOL 1, Domestic use, 216 p., VOL 2, Recreational use, 134 p., VOL 3, Industrial use, 222 p., and VOL 4, Agricultural use, 286 p., Department of Water Affairs and Forestry, Pretoria.

** See Grabow, W.O.K., 1986. Water quality assessment and control in South Africa, South African Journal of Science, VOL 82(7), p. 342 - 346., as well as Augoustinos, M.T., Kfir, R. and Venter, S.N., 1992. Assessment of water quality problems due to microbial growth in drinking water distribution systems, WRC Report No. 252/1/92, Water Research Commission, Pretoria, 25 p. + app. See also, Bourne, D.E., Sayed, A.R. and Klopper, J.M.L., 1990. A data base for use in the epidemiological surveillance of potential changes in drinking water quality in South Africa, WRC Report No. 186/1/90, Water Research Commission, Pretoria, 81 p.

SABS specifications only provide for phenolic compounds. Radionuclides are similarly being examined*.

15.1.5 The interpretation of water quality criteria

The interpretation of water quality criteria must be based on practical reality and the availability of alternative water sources. A common misconception is the automatic rejection of waters only slightly exceeding the maximum allowable limit of the SABS 1984 specifications, or the maximum permissible limit as outlined by Pieterse (1989). However, the transition from a "safe" concentration to a "poisonous" concentration is a gradual change, and is not a sharp cut-off limit (as suggested by water quality criteria data). In order to avoid difficulties, Kempster and Smith (1985), proposed the crisis limit where extreme action must be taken. The stipulation of a crisis limit should prevent unnecessary panic, where a specific determinand exceeds the maximum permissible limit. Provided that the determinand concentration does not exceed the crisis limit, the relevant authority has the opportunity to take urgent, although carefully planned action to reduce the concentration to below the maximum permissible limit. The three tier system also allows the controlling authority to "approve" (or at least not reject), poorer quality water under specified conditions - for example in the rural areas - whereas fixed maximum concentrations may result in immediate concern. A measure of common sense is accordingly required in applying the criteria. In the case of aesthetic determinands of low toxicity, for instance where there is only a slight risk at higher concentrations, the crisis limit can be used with discretion. In the case of extremely toxic determinands however, such as cyanide and heavy metals (for example, mercury), strict compliance with the relevant crisis limits is necessary (Pieterse, 1989). The presence of nitrates and nitrites

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* See Stander, G.J., 1980. Micro-organic compounds in the water environment and their impact on the quality of potable water supplies, Water SA, VOL 6(1), p. 1 - 14., and Van Rensburg, J.F.J., 1981. Health aspects of organic substances in South African waters - opinions and realities, Water SA, VOL 7(3), p. 139 - 149., as well as Reid, I.K. and Loewenthal, R.E., 1989. Investigation into requirements for research in surface water treatment in South Africa, WRC Report No. 217/1/89, Water Research Commission, Pretoria, 13 p. See also, Hattingh, W.H.J., 1979. Suggestions for water research with regard to health aspects of potable water, Symposium on Health Aspects of Water Supplies, National Institute for Water Research and the Institute of Water Pollution Control (Southern African Branch), 15 November 1979, Pretoria, 18 p., as well as Offringa, G., 1993. Water Research Commission strategic plan for research on potable water treatment in South Africa, WRC Report No. AV 4/92, Water Research Commission, Pretoria, 38 p. (The latter report is an important overview document which has relevance to source water quality, water supplies in black settled areas, and drought conditions).

should also be carefully investigated, while high fluoride levels are similarly problematic. (Water is the main intake route for fluoride).

15.1.6 Summary

Drinking water quality criteria (or guidelines) should not be confused with drinking water quality standards. Criteria serve only as guidelines, whereas standards represent legal entities. Most countries use criteria to ensure that an acceptable water quality is maintained, although not all countries have legally binding standards. The establishment of drinking water quality criteria as well as standards is a very involved process. Difficulties associated with implementing and enforcing the standards in a satisfactory manner in industrialized countries, may inter alia require the use of increasingly advanced treatment methods. The process of defining and applying standards also involves risk assessment and risk management, which is largely based on "best estimates", in terms of current scientific and toxicological knowledge.

Well defined drinking water criteria are available in South Africa, although no legally binding standards have yet been promulgated. Further research must and is being undertaken in respect of organic compounds and radionuclides, which is especially relevant in highly industrialized areas such as the Pretoria-Witwatersrand-Vereeniging region. In the end analysis however, it must be borne in mind that chemicals in water represent a very small proportion of the daily dietary intake of various substances. The first priority of an acceptable drinking water supply therefore, is water which is safe in a microbiological sense (Pieterse, 1989). Some implications of water quality in the rural areas of Natal/KwaZulu are discussed later in the chapter.

15.2 Water quality criteria for other categories of water use

The following table (Table O3), which deals with water quality criteria for livestock watering, the protection of inland aquatic species, recreation (direct water contact) and irrigation, is a summary of selected world literature. The table indicates the minimum value (the lowest criterion reported), the median value (the most commonly reported criterion), and the highest criterion reported (the maximum value). The criteria are grouped as aesthetic/physical, biological, high toxicity, moderate toxicity, low toxicity and non-toxic (where relevant), in terms of the functional significance of determinands. The criteria

Table O3: Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements.

Determinand	Unit	Minimum	Median	Maximum
Livestock watering				
Aesthetic/physical				
Conductivity	mS m^{-1}	300	460	1 980
Iron	mg ℓ^{-1}	-	10	-
Radioactivity ($\alpha + \beta$)	Bq ℓ^{-1}	0,20	0,20	0,20
Biological				
Faecal streptococci	Counts 100 $m\ell^{-1}$	-	40	-
High toxicity				
Cadmium	$\mu g\ \ell^{-1}$	10	-	50
Mercury	$\mu g\ \ell^{-1}$	2	3	10
Molybdenum	$\mu g\ \ell^{-1}$	10	10	10
Pesticide, aldrin	$\mu g\ \ell^{-1}$	-	1	-
Pesticide, chlordane	$\mu g\ \ell^{-1}$	-	3	-
Pesticide, dieldrin	$\mu g\ \ell^{-1}$	-	1	-
Pesticide, endrin	$\mu g\ \ell^{-1}$	-	0,5	-
Pesticide, heptachlor	$\mu g\ \ell^{-1}$	-	0,1	-
Pesticide, lindane (γ-BHC)	$\mu g\ \ell^{-1}$	-	5	-
Pesticide, toxaphene	$\mu g\ \ell^{-1}$	-	5	-
Pesticide, 2,4-D	$\mu g\ \ell^{-1}$	-	20	-
Pesticide, 2,4,5-T	$\mu g\ \ell^{-1}$	-	2	-
Pesticide, 2,4,5-TP	$\mu g\ \ell^{-1}$	-	30	-
Moderate toxicity				
Arsenic	$\mu g\ \ell^{-1}$	200	200	1 000
Copper	$\mu g\ \ell^{-1}$	100	500	2 000
Fluoride	mg ℓ^{-1}	1	2	2
Lead	$\mu g\ \ell^{-1}$	50	100	500
Pesticide, DDT	$\mu g\ \ell^{-1}$	-	50	-
Pesticide, malathion	$\mu g\ \ell^{-1}$	-	100	-
Pesticide, parathion	$\mu g\ \ell^{-1}$	-	100	-

Table O3: **Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).**

Determinand	Unit	Minimum	Median	Maximum
Selenium	µg ℓ$^{-1}$	20	50	50
Vanadium	µg ℓ$^{-1}$	100	100	100
<u>Low toxicity</u> Aluminium	mg ℓ$^{-1}$	5	5	5
Chromium	mg ℓ$^{-1}$	0,05	1	5
Cobalt	mg ℓ$^{-1}$	1	1	1
Manganese	mg ℓ$^{-1}$	-	10	-
Nitrate + nitrite (N)	mg ℓ$^{-1}$	20	45	100
Pesticide, methoxychlor	mg ℓ$^{-1}$	-	1	-
<u>Non-toxic</u> Boron	mg ℓ$^{-1}$	5	5	5
Calcium	mg ℓ$^{-1}$	1 000	1 000	1 000
Chloride	mg ℓ$^{-1}$	-	1 500	-
Magnesium	mg ℓ$^{-1}$	250	-	500
Sulphate	mg ℓ$^{-1}$	500	1 000	1 000
Zinc	mg ℓ$^{-1}$	20	25	25
River/dam water <u>Physical</u> Conductivity	mS m^{-1}	-	-	-
pH	pH units	6,0	6,5 - 9,0	9,0
Suspended solids	mg ℓ$^{-1}$	25	-	80
Temperature	°C	-	-	-
<u>High toxicity</u> Cadmium	µg ℓ$^{-1}$	0,1	3	30
Cerium	µg ℓ$^{-1}$	-	20	-
Chlorine (disinfectant)	mg ℓ$^{-1}$	0,002	0,003	0,01
Copper	µg ℓ$^{-1}$	5	5	200
Cyanide	µg ℓ$^{-1}$	5	5	5 000
Hydrogen sulphide	mg ℓ$^{-1}$	0,002	0,002	0,3
Lead	µg ℓ$^{-1}$	20	30	100

Table 03: Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).

Determinand	Unit	Minimum	Median	Maximum
Lithium	$\mu g\ \ell^{-1}$	-	5	-
Mercury	$\mu g\ \ell^{-1}$	0,05	0,2	10
Pesticide, aldrin	$ng\ \ell^{-1}$	1	10	10
Pesticide, chlordane	$ng\ \ell^{-1}$	10	25	40
Pesticide, DDT	$ng\ \ell^{-1}$	1	1,5	2
Pesticide, dieldrin	$ng\ \ell^{-1}$	1	5	5
Pesticide, endosulfan ($\alpha + \beta$)	$ng\ \ell^{-1}$	3	3	6
Pesticide, endrin	$ng\ \ell^{-1}$	2	2	4
Pesticide, heptachlor	$ng\ \ell^{-1}$	1	5	10
Pesticide, lindane (γ-BHC)	$ng\ \ell^{-1}$	10	15	20
Pesticide, malathion	$ng\ \ell^{-1}$	8	100	100
Pesticide, methoxychlor	$ng\ \ell^{-1}$	5	20	30
Pesticide, mirex	$ng\ \ell^{-1}$	1	1	1
Pesticide, parathion	$ng\ \ell^{-1}$	0,4	8	40
Pesticide, toxaphene	$ng\ \ell^{-1}$	5	-	10
Phenols	$\mu g\ \ell^{-1}$	1	1	200
Polychlorobiphenyls	$ng\ \ell^{-1}$	1	-	2
Selenium	$\mu g\ \ell^{-1}$	5	-	10
Silver	$\mu g\ \ell^{-1}$	-	10	-
<u>Moderate toxicity</u>				
Aluminium	$\mu g\ \ell^{-1}$	100	-	1 500
Ammonium (as N)	$mg\ \ell^{-1}$	0,016	0,016	124
Antimony	$\mu g\ \ell^{-1}$	200	-	2 000
Arsenic	$\mu g\ \ell^{-1}$	10	200	1 000
Beryllium	$\mu g\ \ell^{-1}$	11	-	1 100
Bromine (Br_2)	$\mu g\ \ell^{-1}$	-	100	-
Chromium	$\mu g\ \ell^{-1}$	10	50	100

Table O3: Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).

Determinand	Unit	Minimum	Median	Maximum
Detergents (as MBAS)	mg ℓ^{-1} (linear alkylate sulphonate - LAS)	0,2	-	0,5
Fluoride	mg ℓ^{-1}	1,5	1,5	1,5
Iron	µg ℓ^{-1}	200	200	1 000
Manganese	µg ℓ^{-1}	100	-	1 000
Molybdenum	µg ℓ^{-1}	-	100	-
Nickel	µg ℓ^{-1}	25	50	50
Pesticide, 2,4-D	µg ℓ^{-1}	4	4	4
Phthalate esters	µg ℓ^{-1}	0,3	-	3
Thallium	µg ℓ^{-1}	-	100	-
Thorium	µg ℓ^{-1}	-	100	-
Zinc	µg ℓ^{-1}	30	100	100
<u>Low toxicity</u>				
Barium	mg ℓ^{-1}	0,5	1	5
Cobalt	mg ℓ^{-1}	-	1	-
Iodide	mg ℓ^{-1}	-	1	-
Rubidium	mg ℓ^{-1}	-	2	-
Tin	mg ℓ^{-1}	-	1	-
Uranium	mg ℓ^{-1}	0,1	-	10
Vanadium	mg ℓ^{-1}	-	0,5	-
<u>Non-toxic</u>				
Alkalinity (as $CaCO_3$)	mg ℓ^{-1}	>20	>20	>20
Boron	mg ℓ^{-1}	1,5	-	5
Calcium	mg ℓ^{-1}	-	1 000	-
Chloride	mg ℓ^{-1}	50	-	400
Magnesium	mg ℓ^{-1}	-	1 500	-
Oxygen, dissolved	mg ℓ^{-1}	>4	>5	>5,8
Phosphate, total (P)	mg ℓ^{-1}	-	0,1	-

Table O3: Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).

Determinand	Unit	Minimum	Median	Maximum
Potassium	mg ℓ^{-1}	-	50	-
Silica (as Si)	mg ℓ^{-1}	-	50	-
Sodium	mg ℓ^{-1}	-	500	-
Strontium	mg ℓ^{-1}	-	200	-
Sulphate	mg ℓ^{-1}	-	1 400	-
Titanium	mg ℓ^{-1}	-	12	-
Tungsten	mg ℓ^{-1}	-	1	-
Recreation Aesthetic/physical Ammonium (as N)	mg ℓ^{-1}	-	0,8	-
Colour, true	Platinum-Cobalt (Pt-Co) units	-	100	-
Detergents (as MBAS)	mg ℓ^{-1} (linear alkylate sulphonate - LAS)	-	2	-
Light penetration	mm	>1 000	>1 200	>1 200
Odour	TON (Threshold odour number)	-	16	-
Oil and grease	mg ℓ^{-1}	-	5	-
pH	pH units	5	6 - 9	9
Suspended solids	mg ℓ^{-1}	-	25	-
Temperature	°C	>20	<30	<30
Turbidity	NTU (Nephelometric turbidity units)	-	50	-
Biological Faecal coliforms (*E. coli* I)	Counts 100 mℓ^{-1}	50	100	2 000

Table O3: **Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).**

Determinand	Unit	Minimum	Median	Maximum
Total coliforms	Counts 100 $m\ell^{-1}$	500	-	10 000
Faecal streptococci	Counts 100 $m\ell^{-1}$	-	200	-
<u>Moderate toxicity</u>				
Chromium	$\mu g\ \ell^{-1}$	-	100	-
Radioactivity ($\alpha + \beta$)	Bq ℓ^{-1}	0,37	-	0,4
Irrigation				
<u>Physical/biological</u>				
Conductivity	mS m^{-1}	28	80	550
pH	pH units	4,5	4,5 - 9,0	9,0
Faecal coliforms (<u>E. coli</u> I)	Counts 100 $m\ell^{-1}$	100	-	1 000
Faecal streptococci	Counts 100 $m\ell^{-1}$	-	20	-
Nematodes	Counts 1 ℓ^{-1}	-	0	-
Plant pathogens, virus	Counts 10 ℓ^{-1}	-	0	-
<u>High toxicity</u>				
Molybdenum	$\mu g\ \ell^{-1}$	5	10	10
Selenium	$\mu g\ \ell^{-1}$	20	20	20
<u>Moderate toxicity</u>				
Arsenic	$\mu g\ \ell^{-1}$	100	100	1 000
Beryllium	$\mu g\ \ell^{-1}$	100	100	500
Boron	$\mu g\ \ell^{-1}$	300	500 - 750	2 000
Chloride	mg ℓ^{-1}	70	100	150
Chromium	$\mu g\ \ell^{-1}$	100	100	1 000
Cobalt	$\mu g\ \ell^{-1}$	50	-	200
Copper	$\mu g\ \ell^{-1}$	200	200	200
Manganese	$\mu g\ \ell^{-1}$	200	500	2 000
Pesticide, 2,4-D	$\mu g\ \ell^{-1}$	-	700	-

Table O3: **Water quality criteria for livestock watering, for river/dam water (the protection of aquatic life), for recreational (high contact) purposes and for irrigation requirements (continued).**

Determinand	Unit	Minimum	Median	Maximum
Radioactivity ($\alpha + \beta$)	Bq ℓ^{-1}	0,2	0,2	0,2
Vanadium	μg ℓ^{-1}	100	100	10 000
Low toxicity				
Barium	mg ℓ^{-1}	-	1	-
Cerium	mg ℓ^{-1}	-	1	-
Fluoride	mg ℓ^{-1}	1	1	15
Lead	mg ℓ^{-1}	5	5	5
Lithium	mg ℓ^{-1}	0,075	2,5	2,5
Phenols	mg ℓ^{-1}	-	50	-
Sulphate	mg ℓ^{-1}	200	200	200
Thallium	mg ℓ^{-1}	-	10	-
Thorium	mg ℓ^{-1}	-	10	-
Titanium	mg ℓ^{-1}	-	1,2	-
Zinc	mg ℓ^{-1}	2	2	5
Non-toxic				
Aluminium	mg ℓ^{-1}	1	5	5
Iron	mg ℓ^{-1}	1	5	5
Magnesium	mg ℓ^{-1}	-	300	-

Source: After Kempster, P.L., Hattingh, W.H.J. and Van Vliet, H.R., 1980. Summarized water quality criteria, Technical Report No. TR 108, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, 45 p.

See also: (i) Anonymous, 1993. South African water quality guidelines, VOL 2, Recreational use, 134 p., VOL 3, Industrial use, 222 p., and VOL 4, Agricultural use, 286 p., Department of Water Affairs and Forestry, Pretoria. (Additional data including relevant norms are presented in these important reports, which should be read in conjunction with Kempster, Hattingh and Van Vliet (1980)). Examine in addition: Casey, N.H. and Meyer, J.A., 1996. Interim water quality guidelines for livestock watering, WRC Report No. TT 76/96, Water Research Commission, Pretoria, 27 p., as well as Casey, N.H., Meyer, J.A., Coetzee, C. and Van Niekerk, W.A., 1996. An investigation into the quality of water for animal production, WRC Report No. 301/1/96, Water Research Commission, Pretoria, 257 p. + app. (The documents incorporate recent research findings relevant to southern African conditions). See also Section 15.14.3 later in this chapter.

(ii) Anonymous, [1990]. Groundwater: guidelines for boreholes, Borehole Water Association of Southern Africa, the Division of Earth, Marine and Atmospheric Science and Technology of the CSIR, the Department of Agricultural Development, the Department of Water Affairs and the Geological Society of South Africa, Pretoria, 29 p. (The publication contains data on certain determinands, with respect to ruminants).

(iii) Marincowitz, G. and Conradie, W.J., 1985. Boorgatwater vir veesuipings op Soutpanproefplaas, Agrivaal, VOL 7(4), p. 1 - 4. (The paper provides data on certain determinands, with respect to ruminants).

(iv) Lusher, J.A. (ed), 1984. Water quality criteria for the South African coastal zone, South African National Scientific Programmes Report No. 94, Foundation for Research Development, CSIR, Pretoria, 25 p. + app.

(v) Van Vuren, J.H.J., Du Preez, H.H. and Deacon, A.R., 1994. Effect of pollutants on the physiology of fish in the Olifants River (eastern Transvaal), WRC Report No. 350/1/94, Water Research Commission, Pretoria, 214 p.

Note:

(i) The term "MBAS", refers to methylene blue active substances. Note that a number of agrichemicals (pesticides) listed in the above table are no longer commercially available in South Africa, although due to persistence or the use of old stocks, may well be present in the environment. Refer to the chapter on solid waste management, elsewhere in this publication. Some data on pesticide criteria for human (potable) water - as per Kempster, Hattingh and Van Vliet (1980) - are outlined in the latter chapter.

(ii) The criteria for livestock are either similar or less stringent than potable water consumption criteria for humans. The main exception is molybdenum which (for livestock), is 50 times more stringent than for humans (livestock are highly sensitive to poisoning by molybdenum). The median copper criterion for livestock is slightly lower than for humans.

(iii) The (electrical) conductivity and temperature criteria for the protection of freshwater (aquatic) life, depend on local conditions and specific species. Fish, for example, are more sensitive to sudden changes in conductivity and temperature, than to the absolute values. The minimum and median criteria for mercury are based on the danger (to humans) of methyl mercury poisoning following ingestion of mercury-contaminated fish. The same applies to phenol, with regard to the taste of phenol-contaminated fish, rather than phenol toxicity per se - see Lusher (1984). The toxicity of the metallic elements such as lead, zinc and copper to fish, is higher in low calcium-content water or in water with a low conductivity. For these waters, the minimum criteria, rather than the median criteria for metallic elements should be used. It should be borne in mind that dissolved oxygen is especially important for aquatic life. Accordingly, the oxygen levels should exceed the given criteria.

(iv) Water quality criteria for irrigation depend on plant species and soil properties. In general, heavy metal pollutants are less toxic in fine-textured alkaline soils and are more toxic in coarse-textured or acidic soils. Plant species vary considerably in sensitivity to certain determinands such as boron*, chloride and lithium. For example, citrus trees are sensitive to all three of these determinands, and the minimum criteria apply (Kempster, Hattingh and Van Vliet, 1980).

(v) Faecal streptococci occur in the faeces of warm blooded animals in numbers which are usually (but not always), considerably less than those of E. coli I. Faecal streptococci usually do not multiply in water, but die and disappear at approximately the same rate as E. coli I. Faecal streptococci however, die much more rapidly than the other coliform organisms. By comparison with E. coli I, faecal streptococci are a less delicate indicator of recent excretal contamination and they may be absent from natural waters (known to be recently polluted), and which contain E. coli I. Under certain conditions, faecal streptococci outlive E. coli I organisms in water and soil. Where the coliform examination of natural waters is inconclusive in deciding whether recent faecal contamination has or has not occurred (for example, where coliform organisms are found in the absence of E. coli I), then the presence of faecal streptococci provides the required confirmation. Accordingly, the main aim of testing for faecal streptococci is for confirmation purposes where the coliform tests are ambiguous. The value of faecal streptococci as indicators of faecal pollution is however impaired, since the organisms are occasionally found in environments not polluted by human and animal faeces. The presence of faecal streptococci in water is not regarded as a health hazard, although the organisms may result in disease when introduced into tissue, blood and the urinary tract. The organisms are sometimes associated with food poisoning (Grabow, 1970)**. The FC : FS (faecal coliform : faecal streptococci) ratio can be used to determine whether contamination is of human or animal origin. A ratio equal to, or less than 0,7 is indicative of animal faecal pollution, while a ratio of 4,0 or more, is indicative of human faecal pollution. Caution must be exercised in interpreting the results, especially at sewage works where the sewage is chlorinated (Rosser, P.A.E. and Sartory, D.P., 1982. A note on the effect of chlorination of sewage effluents on

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* See Reid, P.C. and Davies, E., 1989. Boron content of South African surface waters: preliminary assessment for irrigation, Water SA, VOL 15(4), p. 261 - 264.

** See Grabow, W.O.K., 1970. Literature survey: the use of bacteria as indicators of faecal pollution in water, CSIR Special Report No. O/WAT 1, National Institute for Water Research, CSIR, Pretoria, 27 p.

faecal coliform to faecal streptococci ratios in the differentiation of faecal pollution sources, Water SA, VOL 8(1), p. 66 - 68).

(vi) Further water quality criteria are presented in Kempster, Hattingh and Van Vliet (1980) with regard to potable water; the food processing industry; steam generation; the brewing industry; paper manufacturing; the soft drink industry; the textile industry; the petroleum industry; the chemical industry; the iron and steel industry, and the leather tanning industry. Some properties of individual determinands are also discussed. More comprehensive data concerning the leather and tanning industry, the power generation industry, the iron and steel industry, the pulp and paper industry, the petrochemical industry, and the textile industry are presented in Anonymous (1993 - above, VOL 3).

(vii) Lusher (1984), provided a useful overview of water quality criteria for coastal zone (marine) waters in South Africa. The publication discusses the quality of sea water in estuarine and marine environments with special reference to pipeline discharges of effluents into the sea. Criteria outlined include aesthetic criteria/physical hazards, conservative materials and properties (such as pH), nutrients, toxic inorganic materials as well as organic compounds and cumulative materials, microbiological determinands, the tainting of fish, and radioactivity. With regard to pipeline discharges, see Anonymous, 1969. The disposal of effluents into the sea off the Natal Coast, Natal Town and Regional Planning Commission Report, VOL 14, Pietermaritzburg, 139 p., and especially, McGlashan, J.E. (ed), 1992. Guide for the marine disposal of effluents through pipelines, WRC Report No. TT 58/92, Water Research Commission, Pretoria, 145 p. (Various other South African publications on pipeline effluent disposal procedures are listed in the latter report). Effluent pipelines discharge domestic sewage as well as industrial wastes. Additional information can be found in the chapter on solid waste management.

presented in the table are guidelines only. Readers should examine the units of the various determinands (for example, pesticides) with care, in order to avoid confusion.

15.3 Water quality analysis in Natal/KwaZulu

Various statutory and commercial agencies, as well as private laboratories, undertake water quality analysis. The more important laboratories include those of the Cedara Agricultural Development Institute, Private Bag X9059, Pietermaritzburg, 3200; the Division of Water Technology, CSIR, P O Box 17001, Congella, 4013; the South African Bureau of Standards, P O Box 30087, Mayville, 4058; the South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300; Mhlatuze Water, P O Box 1264, Richards Bay, 3900, and Umgeni Water, P O Box 9, Pietermaritzburg, 3200. Examination of samples by the Cedara Agricultural Development Institute and the South African Sugar Association Experiment Station mainly concerns irrigation requirements and soil salinity. With the exception of the latter two laboratories, all organizations listed as well as certain municipalities are able to undertake the emergency testing of water in crisis situations such as floods, industrial accidents and sabotage*.

15.4 Sources of routine water quality data

Water quality data can essentially be divided into two categories, namely (output) data required for the testing of the final products of water and wastewater works as well as waste disposal sites and industries; and raw water quality (input) data necessary for scientific, planning and technical purposes. Sources of output data are usually locality specific and refer to the particular plant or site in question. (Effluents are discussed separately, later in the chapter).

The main (overall) source of raw water quality data in South Africa is the Water Quality Database (which forms part of the Hydrological Information System) of the Department of Water Affairs and Forestry. In Natal/KwaZulu both Mhlatuze Water and Umgeni Water

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* For an overview of the CSIR's emergency testing programme, see Slabbert, J.L., 1989. The role of the Division of Water Technology, CSIR, in relief action - emergency analysis of water, Fourth National Conference of the Civil Defence Association of South Africa, 28 - 29 September 1989, Bellville, p. 42 - 49.

are primary sources of data, with mainly historical data available from the Division of Water Technology, CSIR, Durban/Pretoria. A number of local authorities (including Joint Services Boards) are also able to provide water quality data for their respective areas*. Other data sources are listed in James, A.G. and Fuller, H.L.M., 1987. Register of southern African hydrological data sources, South African Water Information Centre, CSIR, Pretoria, 287 p.

15.4.1 Department of Water Affairs and Forestry

(a) Surface water

The Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001, routinely samples rivers, lakes, dams, certain boreholes/wells/springs, "estuaries" and wetlands as well as pipelines, canals, tunnels, treatment works and selected raingauges (for rainwater quality)**. Samples (both microbiological and chemical, although primarily the latter) are analysed by the Hydrological Research Institute (now the Institute for Water Quality Studies). Regional offices of the Department are responsible for carrying out the sampling programme. Routine samples are coded as Q (for a water quality sampling point per se), R (for a water quality sampling point for raw water only, for instance at a water purification works), and S (indicating a water quality sampling point for treated water only, also for example at a water purification works). (See Table J23 in the chapter on the surface water resources of Natal/KwaZulu)***. A listing of sampling points (plus the

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* Some consulting firms are currently managing water and wastewater works for townships in various parts of KwaZulu. Regular management reports are issued which may include not only output data, but also raw water quality and quantity data (river, dam and borehole intakes). An example is the following: Anonymous, 1991. KwaZulu Government Services Coastal Region, Report for December 1991, Aqua-Gold Services Ltd, Pinetown, no pagination. (Certain CSIR data series likewise, are dual-purpose in the sense that both input and output data are available - see later in the chapter).

** Sometimes referred to as the National River Water Quality Assessment Programme and the National Reservoir Water Quality Monitoring Network or collectively as the National Water Quality Monitoring Network.

*** The various routine water quality sampling sites in South Africa are outlined in the following: Anonymous, 1990. List of hydrological gauging stations July 1990, VOL 1: gauging stations in flowing water, Hydrological Information Publication No. 15, Directorate of Hydrology, Department of Water Affairs, Pretoria, 443 p., and Anonymous, 1990. List of hydrological gauging stations July 1990, VOL 2, Part 1: gauging stations in stored/standing water, 177 p., and Part 2: meteorological stations, 153 p., Hydrological Information Publication No. 15, Directorate of Hydrology, Department of Water Affairs, Pretoria.

data) can be obtained from the Department in Pretoria, as well as via the Computing Centre for Water Research, University of Natal, Private Bag X01, Scottsville, 3209.

Data are available from the Department in the form of computer print-outs, photocopies, floppy diskettes and magnetic tapes. (The latter two items must be supplied if such a data format is needed). When data are requested, reference should be made to the specific sampling point/s (station number/s) or the name of the nearest town, the name of the site and the latitude and longitude co-ordinates of the site or area in question. Data can also be retrieved per drainage region (Anonymous, 1988)*.

Routine chemical water quality data include electrical conductivity; pH; total dissolved solids (salts); total alkalinity (as $CaCO_3$); calcium; potassium; magnesium; sodium; chloride; fluoride; silicon; sulphate; nitrate plus nitrite as nitrate; ammonium (as N), and ortho-phosphate (inorganic) as P. Samples can also be analysed inter alia for Kjeldahl nitrogen; sediment (some samples are analysed for particle size grading); total phosphorus; dissolved organic carbon and boron; as well as for a wide range of trace elements, or for specific determinands only**. Routine sampling is usually undertaken at weekly intervals for points in flowing water and monthly for points in stored water. Purification works are sampled on a monthly basis for major ion and trace metal concentrations (certain samples are taken daily). It should be noted that a water quality analysis is uniquely identified by station number, date and time sampled. For non-routine (non-station) sampling points which are sampled only once or at a very low frequency (mainly boreholes), the sample number H is used.

Two important publications dealing with surface water quality in South Africa have been compiled by the Department of Water Affairs and Forestry. The first report consists of six volumes divided into various drainage regions. The volume applicable to Natal/KwaZulu is: Geldenhuys, W.F., Nell, U. and Van Veelen, M., 1991. Surface water quality of South

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* See Anonymous, 1988. Availability of hydrological data, Hydrological Information Publication No. 14, Directorate of Hydrology, Department of Water Affairs, Pretoria, 11 p. + app., as well as Zietsman, D.P. and Schutte, J.M., 1981. The availability of quantitative and qualitative hydrological data, In: Hattingh, W.H.J. (ed), Water Year + 10 and Then?, Technical Report No. TR 114, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, p. 156 - 217.

** Water temperature data can likewise be obtained from the Water Quality Database. See Howard, M.R., 1989. Temperature data available on the Department of Water Affairs' Chemical Data Base, Water SA, VOL 15(3), p. 195 - 198. (The Water Quality Database is also referred to as the National Water Quality Database, as well as the Chemical Data Base).

Africa 1979 - 1988, VOL 6: drainage regions T, U, V, W and X (TDS, SAR, pH and PO_4), Technical Report No. TR 145, Department of Water Affairs and Forestry, Pretoria, 27 p. + app. A water quality inventory is also available in two volumes. The relevant Natal/KwaZulu volume is: Swart, S.J., Van Veelen, M. and Nell, U., 1991. Water quality data inventory, VOL 2: drainage regions G, H, J, K, L, M, N, P, Q, R, S, T, U, V, W, X, Technical Report No. TR 146, Department of Water Affairs and Forestry, Pretoria, 9 p. + app. (Both reports have lengthy appendices). The first report (TR 145), covers a decade of data derived from 1 718 registered river and dam/lake sampling points in South Africa. Four determinands, namely: total dissolved solids, sodium adsorption ratio, pH and ortho-phosphate (inorganic) as P, were selected to represent water quality. All data records were filtered to monthly values by selecting the first sample taken in each month, and by discarding the rest (to avoid statistical problems due to different sampling frequencies). The data for each sampling site are presented as a time series (to illustrate long term variation), as well as plots to show mean seasonal fluctuation. Tables for each year, showing the number of sampling sites for which any given determinand reached either a maximum or minimum value, are included to highlight the worst and best water quality years for each drainage region. Percentile data are also provided, as well as colour coded maps to illustrate the dominant water quality category in each tertiary drainage region. (See the chapter on the surface water resources of Natal/KwaZulu).

The second (inventory) report (TR 146) contains information on all registered water quality sampling sites in South Africa for a period of 10 years up to November 1989. The report does not however, discuss the availability of effluent or groundwater data. The report includes a complete list of all registered water quality sampling sites as at November 1989. Likewise included are maps showing primary, secondary, tertiary and quaternary drainage regions and the locality of all the water quality sampling sites. The data series of each sampling site contains data on 20 or more samples for the period October 1978 - September 1988 (indicated by means of horizontal bar diagrams). For any particular site, the bar diagram shows the availability of water quality data as well as the sampling frequency. Supplementary information on every site is also provided*. It is evident for the periods indicated, that both reports are a most useful source of overview data. Specific data however (inter alia for modelling purposes), should be obtained from the

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* See Miller, J., 1992. New publications available on SA water quality data, SA Waterbulletin, VOL 18(2), p. 22 - 24.

Department of Water Affairs and Forestry, or via the Computing Centre for Water Research.

(b) <u>The proposed national groundwater quality sampling and assessment programme</u>

A considerable research effort is currently underway in terms of groundwater, following the establishment of the National Groundwater Database. (See the chapter on groundwater). A national (on-going) groundwater quality sampling and assessment programme* has been proposed - to be maintained by the Department of Water Affairs and Forestry - given <u>inter alia</u> that <u>very</u> few boreholes (or aquifers) are sampled on a regular basis, with a consequent lack of scientific and planning data. Parsons and Tredoux (1993)** suggested that 14 (field/laboratory) chemical determinands should be used to provide overall data and to define groundwater quality trends (both spatially and over time); as well as the fitness-for-use status with regard to the domestic, agricultural and industrial sectors. Parsons and Tredoux stressed that special attention is required in priority areas as per the proposed programme, with additional areas being regularly monitored according to circumstances (and with regard to the various geohydrological regions and subregions in South Africa)***. Parsons and Tredoux further proposed that some 400 - 1 000 specially constructed groundwater sampling stations should be established, with samples drawn every six months for the first five years of the programme, and with annual or biennial monitoring thereafter. However to begin with, existing boreholes supplying towns with groundwater should be used as sampling stations. Reference has been made in the chapter on groundwater to the major groundwater survey

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* Tentatively termed the National Groundwater Quality Monitoring Network.

** See Parsons, R. and Tredoux, G., 1993. The development of a strategy to monitor groundwater quality on a national scale, WRC Report No. 482/1/93, Water Research Commission, Pretoria, 50 p. + app., as well as Parsons, R. and Tredoux, G., 1995. Monitoring groundwater quality in South Africa: development of a national strategy, <u>Water SA</u>, VOL 21(2), p. 113 - 116., plus Anonymous, 1994. Groundwater quality management strategy for South Africa: overseas visit, Water Quality Management Series, Department of Water Affairs and Forestry, Pretoria, 27 p. + app.

*** The geohydrological regions covering Natal/KwaZulu are: Region 7: the Transvaal Middleveld which extends into northern Natal/KwaZulu (adjoining the Swaziland border); Region 8: the Lebombo Belt with subregion 8B (southern section); Region 12: the Karoo Basin with subregions 12O (southern Natal-northern Transkei Middleveld), and 12P (northern Natal Middleveld); Region 13: the Natal Monocline with subregions 13A (northern Monocline), 13B (Tugela) and 13C (central and southern Monocline); and Region 16: Coastal deposits with subregion 16A covering Maputaland and environs. The geohydrological regions and subregions of Natal/KwaZulu (and the remainder of South Africa), were defined by Vegter (1990, quoted in Parsons and Tredoux, 1993 - above). See Vegter, J.R., 1990. Groundwater regions and subregions of South Africa, Technical Report No. Gh 3697, Directorate of Geohydrology, Department of Water Affairs and Forestry, Pretoria, 52 p.

being undertaken across South Africa (including Natal/KwaZulu). Data from the project will be of immense value in the planning of a national groundwater monitoring programme. To this end, a groundwater-vulnerability-to-pollution map is already available for southern Africa (Lynch, Reynders and Schulze, 1994)*. Current (site specific) groundwater quality monitoring programmes include groundwater recharge areas (for example on the Cape West Coast); certain mines and slimes dams as well as defined industrial undertakings, and also waste disposal sites plus infiltration ponds. The sampling refers to point source contamination rather than extant water quality.

15.4.2 Mhlatuze Water

Mhlatuze Water undertakes the routine sampling of 56 chemical determinands on a weekly basis at four rivers and four lakes within the Mhlatuze supply area. Chemical sampling of the Empangeni and Lake Nseze waterworks (owned by Mhlatuze Water), and the Mkuze and Hluhluwe waterworks (owned by the Development and Services Board), as well as reservoirs and pipelines is undertaken on an hourly, daily and weekly basis**. Mhlatuze Water also samples (on an hourly and daily basis), two ocean outfall pipelines at Richards Bay. The pipelines discharge industrial effluent and treated sewage. The pipeline data are supplied to the Department of Water Affairs and Forestry in Durban, but (as with all other data), are also available from Mhlatuze Water. Bacteriological sampling for total coliforms, E. coli I, the standard (heterotrophic) plate count and faecal streptococci is undertaken on a weekly basis in terms of rivers, lakes, treatment plants, reservoirs and pipelines, as well as the two ocean outfall pipelines. In total, 37 sampling sites are routinely assessed by Mhlatuze Water (over and above the ocean outfall pipelines).

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* See Lynch, S.D., Reynders, A.G. and Schulze, R.E., 1994. Preparing input data for a national-scale groundwater vulnerability map of southern Africa, Water SA, VOL 20(3), p. 239 - 246. For a discussion of groundwater quality monitoring techniques see, Weaver, J.M.C., 1992. Groundwater sampling: a comprehensive guide for sampling methods, WRC Report No. TT 54/92, Water Research Commission, Pretoria, various pages, and Weaver, J.M.C., 1992. Groundwater sampling: an abbreviated field guide for sampling methods, WRC Report No. TT 56/92, Water Research Commission, Pretoria, various pages. (Both publications are a useful source of relevant information on methodology as well as microbiological and chemical determinands).

** Twenty-four chemical determinands are examined on a daily basis at each treatment plant, with 16 chemical determinands examined on a weekly basis at the same sites.

15.4.3 Umgeni Water

Umgeni Water assumed responsibility in March 1987 for the chemical sampling of rivers and dams in the Umgeni catchment*. Sampling was previously undertaken by the then Department of Water Affairs. The assumption of chemical sampling by Umgeni Water was for the purposes of rationalization, and there was some initial overlap of duties and data. Approximately 29 chemical determinands are assessed on a weekly basis for rivers and dams. Six additional determinands are examined on a monthly basis, while four determinands depending on site conditions - such as the suspected presence of heavy metals and pesticides - are sampled quarterly. At certain sites along rivers (for instance, below industrial areas), 33 weekly, 14 monthly and seven quarterly determinands are assessed. All such data are submitted to the Department of Water Affairs and Forestry for inclusion in the Water Quality Database. Samples for legal purposes are taken at various point sources of pollution (for example, in or below industrial areas). The data are likewise supplied to the Department of Water Affairs and Forestry. The latter data are confidential. Chemical samples are also taken on an hourly, daily, weekly, monthly and quarterly basis (where relevant), at sewage works and water treatment plants, reservoirs and pipelines. A number of boreholes and springs are assessed in peri-urban and rural areas. The data are available from Umgeni Water.

Total coliforms, E. coli I, standard (heterotrophic) plate count and faecal streptococci data are derived by Umgeni Water on a weekly basis for rivers, dams, water treatment plants, sewage works, reservoirs, pipelines, boreholes and springs. Weekly samples for algal counts as well as chlorophyll concentrations are obtained from dams. Pathogenic data (such as the presence of cholera and typhoid organisms), are also derived for selected river sites on a weekly basis. In total, some 600 sites are routinely sampled for microbiological/chemical water quality purposes by Umgeni Water. Further sampling sites are being planned for the enlarged supply area.

The invertebrate (biotic) analysis of water is undertaken on a quarterly basis at some 30 river sites in the old supply area. The information provides an indication of the aquatic

* The new boundaries of Umgeni Water as of 21/1/1994 - Proclamation Proc 101/94 - are described in the chapter on the surface water resources of Natal/KwaZulu. The information above, refers to the old supply area. It should be noted that Umgeni Water (as of 1/5/1992), has assumed control over the monitoring of industrial effluents (on behalf of the Pietermaritzburg Corporation), within the municipal boundary. These duties were previously undertaken by Pietermaritzburg Corporation staff.

health of the relevant system, through the use of a biotic index. Umgeni Water has also compiled a water quality index for rivers per se and dams per se in the old supply area. One bacteriological and seven chemical determinands for rivers, and one bacteriological, four biological (algal and chlorophyll data) and six chemical determinands for dams, are used to provide a (weighted) overall water quality index for rivers and dams respectively. Waters are classified as Class A - excellent; Class B - good; Class C - satisfactory; Class D - poor, and Class E - unsatisfactory. An additional class, namely, Class F - bad has been allocated for dams (see later in the chapter). The data (as with the biotic index) are available on a Geographic Information System (GIS), where spatial and temporal changes in water quality are readily apparent. The water quality index is a powerful management tool which is used to assess ambient water quality for rivers, as well as the suitability of water in dams for treatment processes. Umgeni Water operates a 24 hour seven days a week water pollution reporting and analysis service. Phone 0331-3411111 all hours.

15.5 CSIR historical data sources

As outlined earlier, mainly historical data are available from the Division of Water Technology, CSIR, Durban/Pretoria. Some relevant report series are listed below. The original names of the research institutes of the CSIR have been used, as per the document in question. See the bibliographic database.

15.5.1 Water and wastewater treatment plants in KwaZulu

A series of reports is available containing water and effluent quality and management data for selected sites in KwaZulu. The reports refer primarily to water and wastewater treatment plants operated by or on behalf of the KwaZulu Department of Works, but may also include water quality data for some rivers and boreholes.

Example

Charles, K.M. and Coetzee, J., 1991. Report on water supplies and sanitation KwaZulu Northern Region, Summary Report No. 60 (March 1990 to February 1991), for presentation at the 49th Meeting of the KwaZulu Liaison Committee to be held on 28 May 1991, Division of Water Technology, CSIR, Durban, 15 p. + app.

15.5.2 Natal rivers, dams, lakes and urban catchments

(i) Numerous reports (beginning in 1953), and dealing with various water quality aspects of rivers, dams and urban catchments constitute an important CSIR steering committee series. The final report in the series is given in the example.

Example

Natal Rivers Research [Fellowships] Steering Committee: Sixty Eighth Steering Committee Meeting 5th May 1987, Progress Report No. 68, Research Group for the Land-use/Water Quality Programme, National Institute for Water Research, CSIR, Durban, various pages. (Note: The Research Group for the Land-use/Water Quality Programme was previously known as the Research Group for Natal).

(ii) Some water quality data for rivers are found in certain reports of another CSIR steering committee series. The final report in the series is given in the example.

Example

Marine Disposal of Effluents, Forty-ninth Steering Committee Meeting 25 October 1984, Progress Report No. 48, Research Group for Natal, National Institute for Water Research, CSIR, Durban, various pages.

(iii) Some reports are available on water quality with specific reference to Lake Mzingazi at Richards Bay.

Example

Archibald, C.G.M., Fowles, B.K., Muller, M.S. and Warwick, R.J., 1983. Nutrient surveys on Lake Mzingazi, Steering Committee for Limnological Research and Water Treatment at Lake Mzingazi (Richards Bay), Final Report 24 November 1983, Reservoir Research Group (Natal), National Institute for Water Research, CSIR, Durban, 28 p. + app. (The publication includes a Supplement to Final Report June

1984 entitled, An investigation of the water quality of Lake Mzingazi and possible causes of enrichment of the system, 16 p.).

(iv) A few reports are available on the water quality of selected lakes in the vicinity of Richards Bay.

Example

Turner, J.W.D., 1983. Water quality of main lakes in the Richards Bay area, Richards Bay Inland Waters Committee, First Steering Committee Meeting 24 November 1983, Reservoir Research Group (Natal), National Institute for Water Research, CSIR, Durban, 5 p. + app.

15.6 Water quality management in South Africa*

15.6.1 Primary philosophies

The Department of Water Affairs and Forestry is responsible for protecting the quality of South Africa's water resources. Water quality management in South Africa has become a vitally important component of overall water resources management, especially in view of the limited supply of water in a largely semi-arid land. The essential aim of water quality management is to sustain the fitness-for-use of the water, according to the beneficial uses as outlined in the Water Act No. 54 of 1956. Pollution therefore, may be defined as the process whereby water becomes "less fit" for a defined use/s. It should be noted however, that in terms of the Water Act, there is no requirement that water be returned to some original or pristine state (except where this can be justified by the requirements of one of the recognized water uses). Reuse of effluents is accordingly, an integral part of the total water supply management strategy. The Department presently

* Discussion based on Van der Merwe, W. and Grobler, D.C., 1990. Water quality management in the RSA: preparing for the future, Water SA, VOL 16(1), p. 49 - 53. See also, Anonymous, 1991. Water quality management policies and strategies in the Republic of South Africa, Department of Water Affairs and Forestry, Pretoria, 32 p. + app., as well as Lusher, J.A. and Ramsden, H.T., 1992. Chapter 18. Water pollution, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 456 - 492. A most important publication which examines water quality management practices and policies, and is also a reference manual, is the following: CSIR Environmental Services, 1995. Procedures to assess effluent discharge impacts, WRC Report No. TT 64/94, Water Research Commission and the Department of Water Affairs and Forestry, Pretoria, 352 p.

controls water pollution from point sources by requiring effluents to meet uniform (General and Special) effluent standards, which have been set at technologically and economically feasible levels. Relaxation of these standards can be negotiated in individual cases for certain time periods, while technological, economic and socio-political issues are considered (often unfortunately, without the benefit of knowing the impacts of the standards, or their relaxation, on the quality of the receiving water). Despite the standards - and hence the increased focus on water pollution management - the quality of South Africa's water resources has nevertheless continued to deteriorate (Van der Merwe and Grobler, 1990).

The Uniform Effluent Standards (UES) approach to water quality, aims to control the input of pollutants to the water environment by stipulating that the effluent must comply with uniform standards. The basic philosophy of the UES approach is that zero pollution from point sources is the ultimate goal. The uniform standards are usually set to achieve attainable effluent pollutant concentrations, using the "Best Available Technology Not Entailing Excessive Cost" or BATNEEC method. Numerous difficulties have been experienced with the UES approach involving inter alia, the lack of a framework to control non-point (diffuse) pollution - especially where there are high background levels of pollutants from non-point sources. Also difficult to control are multiple point sources of a specific pollutant. Other problems include a focus on effluents rather than the impact of the effluents on the quality of the receiving waters; as well as the requirement that all effluents must comply with the same standards, irrespective of variations in the assimilative capacity of the receiving waters or the costs involved. Furthermore, no incentive is provided for industries to locate at the most optimum environmental site. The main advantage of the UES approach however, is that the standards are simple and straightforward to apply, which is an important feature in South Africa because of the limited availability of skilled manpower. These standards should have the effect of minimizing point source pollution - provided that they are frequently revised to incorporate the latest technology.

In view of the problems experienced with the UES procedure (and given changing socio-economic circumstances)*, the Department of Water Affairs and Forestry recently adopted a Receiving Water Quality Objectives (RWQO) approach and a Pollution Prevention approach to water quality management. The RWQO approach involves the specification of water quality requirements in receiving waters, as well as the control of point and non-point pollutant sources to ensure that water quality objectives are met. The RWQO concept is based on the principle that receiving waters have a natural capacity to assimilate pollutants without detriment to the accepted uses for the waters concerned. It is important to bear in mind that the assimilative capacity of a water body is part of the water resource, and must be correctly managed and shared amongst all water users for the disposal of their wastes. The RWQO approach refers to the control of non-hazardous pollutants. Agreement must be reached on the present or intended uses for which a particular water body is suitable. On the basis of these uses, the concentrations of stated water quality monitoring determinands (including the waste load allocation) in the water must not be exceeded**. Pollution from point sources is controlled by establishing site specific effluent standards, which take into account the contribution of pollutants from non-point sources as well as the RWQO. The availability of "excess" assimilative capacity in a river does not however, absolve dischargers from taking all possible measures to reduce pollution. The RWQO approach therefore focuses on managing the quality of receiving waters in a certain way, in order to minimize interference with the legitimate uses of the waters. The approach is cost-effective, since by considering the assimilative capacity of receiving waters for specific pollutants, the level of control required for the adequate protection of water uses is optimized. The approach also (theoretically) provides

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* These circumstances include a change from an economy dominated by a number of large industries, to an economy in which the informal sector and small businesses (such as in Taiwan), will assume prominence. Likewise, considerable changes have and are taking place in urbanization patterns, with the expansion of low cost high density housing surrounding major towns and cities. Formal areas are served by advanced waste management systems representing point sources of pollution, which are readily accessible and easy to monitor. By contrast, most large informal settlements (at present), are important non-point sources of pollutants, where control of the pollutants is difficult to achieve (or even to monitor).

** The concept of a waste load allocation (WLA) is an integral part of the RWQO approach. The waste load allocation refers to the assignment of allowable discharges to a water body in such a way that the water quality objectives for specified water uses are met. Calculation of the WLA involves cost-benefit analysis, as well as the determination of water quality objectives for desirable water uses. An understanding of the relationships between pollutant loads and water quality is also required, where the relationships are used to predict impacts on water quality. Economic impacts and socio-political constraints are likewise considered. The Department of Water Affairs and Forestry has already undertaken WLA investigations to establish allowable site specific effluent discharges from certain major industries.

an incentive for industries to locate where receiving waters are less sensitive to pollution. From a regulatory (technological) perspective, the RWQO approach is more problematic than the UES approach, since a detailed understanding of the fate of pollutants in water and their impact on water uses is necessary. Secondly, site specific effluent standards are required which are more difficult to apply (especially where skilled manpower is scarce), than Uniform Effluent Standards (Van der Merwe and Grobler, 1990). It is also apparent that the RWQO will vary inter alia with different flow regimes (for instance, summer/winter) and according to regional differences in extant water quality. Random variations in raw water and effluent quality also occur, while variations in sampling frequency and analysis may likewise be problematic. The Department of Water Affairs and Forestry has decided to adopt a policy of interpreting effluent standards in probabilistic terms, with permit conditions stated in absolute terms, but with compliance assessed on a probabilistic basis. Exemptions from compliance with the minimum effluent standards (however defined), will only be considered in special cases and only where the receiving water body has sufficient assimilative capacity, namely, the ability to absorb the effluent without changes in the fitness-for-use of the water (Anonymous, 1991).

Marine pollution control is also based on the RWQO approach. The desired Sea Water Quality Management Objectives (SWQMO) are determined by specifying criteria for the various beneficial uses of the marine environment, namely: fishing, shellfish collecting, swimming, industrial use, and conservation of the marine environment. Special attention is paid to the human health risk and protection of the marine environment. A permit to discharge effluent (derived from non-marine water sources) into the sea, is required from the Minister of Water Affairs and Forestry. Considerable importance is attached to the place of discharge and the quality of the effluent (with regard to the necessary marine impact assessment). Ocean outfall effluent is regularly sampled by the Department of Water Affairs and Forestry or a duly authorized agency (for example, Mhlatuze Water). Difficulties however, are apparent with regard to stormwater drains in urban areas where illegal discharges of effluent or poor quality runoff enters the sea (preventative measures notwithstanding). Also problematic in the marine environment is solid waste including paper, cans, cardboard and plastic. According to the Department of Water Affairs and Forestry, industries producing saline effluents such as tanneries as well as hides and skins curers, should ideally be located on the coast. All saline effluents (subject to specific conditions), can then be discharged into the sea. In this way, further mineralization of inland waters can be avoided (Anonymous, 1991; Lusher and Ramsden, 1992).

The second component of the programme, namely, the Pollution Prevention approach refers to the control of hazardous pollutants (Van der Merwe and Grobler, 1990). The RWQO approach is not appropriate in the case of pollutants which are hazardous to the water environment, in view of their toxicity, persistence and capacity for bioaccumulation. Accordingly, no assimilative capacity is recognized and a precautionary principle is applied. Obvious difficulties are evident in attempting to establish "safe" receiving water quality objectives, since insufficient data are available on the properties of the chemicals as well as their risk to both man and the environment. Reference was therefore made to the list of priority pollutants compiled by the United States Environmental Protection Agency and the British "Red list", to classify hazardous or dangerous pollutants. The Pollution Prevention approach is designed to limit or prevent the input of such chemicals into water environments. Emphasis is placed inter alia on waste control and recycling in order to reduce the quantity of waste. Also important is a reduction in the toxicity of the waste. The Department of Water Affairs and Forestry will encourage manufacturers to co-operate in achieving these goals on a voluntary basis. Legal remedies however, can be applied if necessary.

The Department of Water Affairs and Forestry recognizes that the more inclusive approach to water quality management represents a longer term aim. Many of the new skills, technologies, models, policies and strategies required, will have to be developed over time*. (Some of the new methods are discussed in the report by the CSIR Environmental Services (1995 - above)). In the interim, the UES approach will still be enforced, with the gradual implementation of the RWQO and Pollution Prevention approaches. Experience of the RWQO approach in South Africa to-date has revealed the need for detailed procedures

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* In this regard, see Roux, D.J., Van Vliet, H.R. and Van Veelen, M., 1993. Towards integrated water quality monitoring: assessment of ecosystem health, Water SA, VOL 19(4), p. 275 - 280. The authors stressed the importance of including biological monitoring (biosurveys) in any determination of the health of aquatic ecosystems, where physical and chemical parameters per se are not sufficient. Biological communities are accurate indicators of overall environmental conditions and are especially relevant where variable pollutant inputs occur; for monitoring non-point source impacts, and for monitoring the effectiveness of management practices. Examine likewise Roux, D.J., 1994. The use of toxicity testing in effluent regulation and control: a new dimension to assessment and management of water quality in South Africa, Southern African Journal of Aquatic Sciences, VOL 20(1/2), p. 62 - 78. See also, Palmer, C.G., Rowlston, W.S., Jezewski, W.A. and Skotnicky, P.I., 1994. The design and research potential of an artificial stream system for the investigation of macroinvertebrate water quality tolerances, Water SA, VOL 20(3), p. 247 - 258., as well as Palmer, C.G., Goetsch, P-A. and O'Keeffe, J.H., 1996. Development of a recirculating artificial stream system to investigate the use of macroinvertebrates as water quality indicators, WRC Report No. 475/1/96, Water Research Commission, Pretoria, 185 p. See in addition: Van der Heever, J.A. and Grobbelaar, J.U., 1995. The use of algae in bioassays to detect the presence of toxic compounds in natural waters, WRC Report No. 393/1/95, Water Research Commission, Pretoria, 65 p.

in terms of identifying specific objectives. Likewise important is the careful allocation of assimilative capacity, and the need to estimate future water quality requirements and trends (Anonymous, 1991). In order to effectively undertake the new water quality procedures the existing water quality sampling programmes have been examined, and are being re-designed to function as information systems as opposed to the previous "data-rich but information poor" networks. Accordingly, data will be available on extant water quality, as well as for changes in water quality both spatially and over time, and on how water quality responds to management policies (such as pollution control). Groundwater is presently receiving considerable attention with regard to pollution - the effects of which can have long term implications. Pollution from diffuse sources is especially problematic in groundwater, and may continue unnoticed for years. The determination of the assimilative capacity of groundwater however, is extremely difficult. Four specific water quality monitoring systems have, or are being established by the Department of Water Affairs and Forestry. These are a national monitoring system as well as catchment (regional) monitoring systems, compliance monitoring systems, and project monitoring systems (Van der Merwe and Grobler, 1990).

15.6.2 A national monitoring system

The National River Water Quality Assessment Programme has been designed to provide information on extant water quality (fitness-for-use) across South Africa, as well as to provide data on spatial and temporal changes in water quality (Harris, Van Veelen and Gilfillan, 1992)*. The programme as envisaged, refers initially to freshwater, excluding impoundments. "Estuaries" and impoundments could be incorporated at a later stage. Sampling sites are to be selected near the outflow of each tertiary drainage region, with additional sites located on tributaries (which drain at least 60 - 70% of the tertiary drainage region). In order to describe how water quality changes over distance, each major river or stream (draining at minimum, a secondary drainage region) will be monitored along its entire length. Tertiary drainage regions will be used to determine the maximum distance between sampling points. Every major river will be monitored where it passes through a tertiary drainage region - as close as possible to the point where the river leaves the drainage region. Each river will also be monitored just upstream of the confluence with

* See Harris, J., Van Veelen, M. and Gilfillan, T.C., 1992. Conceptual design report for a National River Water Quality Assessment Programme, WRC Report No. 204/1/92, Water Research Commission, Pretoria, 98 p.

any major tributary, where the tributary will likewise be monitored just upstream of the confluence. (A major tributary is defined as a stream draining at least a tertiary drainage region). It is evident that considerable planning will be needed to properly locate sampling sites according to the data required (rather than, as at present, due to considerations of convenience related to the reading and servicing of flow recorders).

A further vital component of the programme is the selection of determinands. The water quality determinands used, will function as general indicators of the fitness-for-use of water in terms of domestic, recreational, agricultural, industrial and environmental requirements (as defined in the Water Act). An Analytical Hierarchy Process (a computerized ranking procedure) was used to select determinands for inclusion in the programme. The determinands are E. coli, chlorophyll a, pH, turbidity, total dissolved solids and dissolved oxygen. The determinands will be assessed across the whole country, irrespective of drainage region and local circumstances. The construction of an index was investigated to combine information from the six determinands, into a single (summarized) number. Individual water quality rating curves were first developed for each determinand, showing the fitness-for-use rating (on a scale from 1 - 100), as a function of the measured value. Weights were then assigned to each determinand according to its importance in defining fitness-for-use. The overall index value (a combination of rating curves and weighting factors) therefore indicates the general fitness-for-use of the specific combination of the six determinands examined at each site. The current water quality status can be assessed by examining the statistics for each determinand, as well as in combination. Historical water quality data will also be provided, thereby facilitating both short and long term (trend) analysis. Procedures for the immediate reporting of significant deviations from historical values have likewise been developed. In addition, colour coded maps showing drainage regions with a positive, negative or no trend (and insufficient data) for each determinand, and for the index per se are proposed. Other planned measures include annual reports and possibly more frequent reports, with the availability of raw data on request. The entire programme will be regularly evaluated to determine whether stated objectives are being met (Harris et al, 1992).

15.6.3 Catchment (regional) monitoring systems

Catchment-specific (regional) water quality monitoring programmes will provide the detailed data required to manage water quality in a particular catchment (including water releases from impoundments), according to the characteristics of the catchment. Information will also be available concerning the reasons for extant quality, and on the effectiveness of the water quality management strategies employed in the catchment. Regional monitoring systems will therefore be implemented to assess the water quality for various uses within a given catchment; to provide historical water quality data against which future impacts or developments can be measured; to examine the effects of effluent discharges within a catchment, and to monitor industries perceived by the public to be polluting the water environment. Special attention on a regional scale is possible for example, in the case of informal settlements, wetlands and "estuaries", which on a national basis may be of less importance. In essence, regional monitoring programmes must be developed according to local requirements and may be short, medium or long term. Determinands selected for analysis, the frequency of sampling and the location of sampling sites, should all be in accordance with problematic local point and diffuse sources of pollution (Harris et al; Van der Merwe and Grobler, 1990).

Recognition of the complexity of pollution control and the importance of local knowledge, has resulted in regional offices of the Department of Water Affairs and Forestry assuming responsibility for water quality management in their own areas. Overall policy is set by the Pretoria office of the Department. Closer co-operation with other agencies such as the Department of Environment Affairs and the Department of National Health and Population Development is envisaged (Anonymous, 1991).

15.6.4 Compliance/project monitoring systems

Compliance monitoring systems refer to the monitoring of effluents (see the POLMON database later in the chapter). A number of revised procedures have been proposed for compliance monitoring, including an assessment of river reach compliance with the stated water quality management objectives. Finally, project monitoring systems will provide short term data for water quality investigations and research projects, for example, on the effects of certain effluents on receiving water quality (Harris et al).

Profound political and socio-economic changes are underway in South Africa, which have major implications for water quality and water resources management. Such changes must, where possible, be anticipated and incorporated into future scenario planning. It follows that highly industrialized western methods of water quality control may not be appropriate for managing water quality in South Africa in the future. Regular reviews of water quality policies are therefore required. Regional assessments of water quality and water quality management procedures are especially necessary, with an emphasis on drainage regions and specific catchments. Appropriate water quality models will have to be developed to simulate the water quality responses of a complete drainage region or catchment, to various management options. Existing models can be used in this regard (to some extent) for eutrophication and salinity purposes, although the models need to be upgraded to include additional determinands (Van der Merwe and Grobler, 1990).

15.7 Water quality problems in South Africa

According to the then Department of Water Affairs (Anonymous, 1986)*, there are four main water quality problems in South Africa. These are firstly: salination (or salinization) - an increasing concentration of total dissolved solids associated with the increasing use and reuse of water (not a problem in Natal/KwaZulu, except in coal mining areas and in certain northern rivers); and secondly, eutrophication - an excessive nutrient concentration especially nitrogen and phosphorus which is associated with urbanization, urban wastewaters, effluent-rich nutrients, and certain industrial as well as agricultural practices. The third area of concern is trace metals, namely, heavy metals and compounds containing metals which are problematic when introduced into waters as a result of chemical and industrial waste, mining activities, sewage sludge, urban runoff and atmospheric deposition. Finally, micropollutants, mainly organo-chemicals found in minute quantities, are likewise a cause for concern. Many of these synthetic chemicals have toxic, carcinogenic, mutagenic (producing genetic changes), or teratogenic (causing prenatal defects) properties, and are resistant to physical, chemical or biological degradation. Such chemicals can accumulate in aquatic organisms thereby entering the food chain**. Some examples of the types and effects of water pollutants (mainly industrial) are outlined in Table 04.

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* See Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages. See also, Anonymous, 1991. First report on the situation of waste management and pollution control in South Africa, January 1991: report to the Department of Environment Affairs by the CSIR Programme for the Environment, Report No. CPE 1/91, CSIR, Pretoria, 359 p. + app. See in addition the chapter on solid waste management.

** Synthetic organic compounds are often referred to as xenobiotics in view of their potential impacts on aquatic and other organisms.

Table 04: Some examples of the types and effects of water pollutants.

Water pollutant	Industry or activity	Adverse effects
Colour	Pulp and paper, textiles, abattoirs, steel mills, dairies, yeast, tanneries	Aesthetically objectionable; some colour producing pollutants are toxic
Suspended solids	Pulp and paper, textiles, abattoirs, tanneries, canning, breweries, steel mills, boiler-house operations, sewage, mining, agriculture, urban	Blockage of sewer lines and equipment; degradation of rivers by solids deposition and oxygen depletion; interference with disinfection processes
Oil and grease	Abattoirs, wool-washeries, dairies, steel mills, galvanizing, oil refineries, tanneries, sewage, urban	Blockage of sewer lines and equipment; floating scum on water which prevents oxygen transfer; anaerobic conditions; smell and fly nuisance; production of objectionable tastes on chlorination
Organic wastes	Pulp and paper, textiles, yeast, sugar, abattoirs, tanneries, canning, breweries, starch, sewage, agriculture, urban	Overloading of conventional sewage treatment plants; oxygen depletion in rivers; objectionable tastes on chlorination and production of trihalomethanes
Insecticides and pesticides	Chemicals, food, textiles, agriculture	
Trace metals	Pickling, galvanizing, plating, mining, urban, power generation, motor vehicle emissions	Toxic to bacterial and aquatic life placing sewage treatment works out of action; health risk to man, plants and animals
Cyanides	Metal finishing, plating, coking, oil refineries, mining	
Chemical wastes	Coking, synthetic dyes, chemicals, plastics, solvents, textile finishing	Taste and odour; toxic to aquatic life, plants, animals and man
Acids (mineral and organic)	Steel pickling, chemicals, food, mining, power generation, synthetic fuels, motor vehicles	Corrosion; mobilization of pollutants from sediments; oxygen depletion; acid rain
Alkalis	Metal finishing, plating, pulp mills	Toxic to biota; mobilization of pollutants from sediments
Nitrogen and phosphorus	Fertilizer plants, synthetic detergents, sewage, agriculture	Eutrophication; nitrates may have health implications; ammonia may be toxic to fish
Thermal aspects	Cold or warm water discharges	Adverse ecological effects
Detergents	Textiles, metal finishing, sewage	Foaming, possible toxicity
Pathogens and parasites	Hospitals, abattoirs, sewage, agriculture	Spreading of disease

Table 04: Some examples of the types and effects of water pollutants (continued).

Water pollutant	Industry or activity	Adverse effects
Salts	Mining, agriculture, sewage, many industries	Possible irrigation, industrial and potable water problems
Radioactivity	Hospitals, mining, nuclear plants	Genetic damage and health effects

Source: After Hattingh, W.H.J., Kempster, P.L., Sartory, D.P., Toerien, D.F., Van Vliet, H.R. and Viljoen, F.C., 1984. Chapter 3. Pollutants, In: Hart, R.C. and Allanson, B.R. (eds), Limnological Criteria for Management of Water Quality in the Southern Hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, p. 64 - 85.

See also: Anonymous, 1991. First report on the situation of waste management and pollution control in South Africa, January 1991: report to the Department of Environment Affairs by the CSIR Programme for the Environment, Report No. CPE 1/91, CSIR, Pretoria, 359 p. + app. (The publication contains a brief overview of certain types of industrial effluents).

Note:

(i) Many atypical water pollutants in very high concentrations may be released by the petroleum industry, while the atmospheric deposition of contaminants in heavily industrialized areas can have long term effects on aquatic environments. Seepage of water from mines, slimes dams and mine dumps can have serious effects in terms of increased acidity, sulphates and total dissolved solids in both surface and groundwaters. In urban areas, stormwater drains, poorly located and managed waste disposal sites and inefficient/old sewage treatment works - producing effluent high in plant nutrients and with a high biochemical oxygen demand - as well as informal settlements can result in serious water pollution. The reuse of effluents can be responsible for increased salinity in rivers. In agricultural areas, irrigation return flows may be a major cause of increased riverine salinity, while diffuse loads of nutrients and pesticides from heavily utilized pastures and fields, as well as animal feedlots plus soil erosion, all impact on the aquatic environment (Hattingh et al, 1984).

(ii) Some important sources of water contamination by trace metals and micropollutants (which are not easily degraded by conventional biological treatment processes), are outlined below. Several of these pollutants are toxic (for example, mercury, cadmium, DDT, dieldrin and lindane), are persistent and accumulate in sediments and biota. Many organic compounds are readily transported in surface waters, given that the chemicals are extensively bioaccumulated and are adsorbed to sediments. The chemicals can accordingly, be modified to new forms of greater or lesser toxicity.

Group	Major sources
Aliphatic and aromatic hydrocarbons (for example, phenols, benzenes and petroleum hydrocarbons)	Urban runoff; industrial solvent wastes; plastic, resin and paint production; petrochemical industry wastes
Halogenated aliphatic and aromatic hydrocarbons (chloroform and chlorinated benzenes)	Disinfection of water and wastewater; industrial solvent wastes; plastic, resin and paint production; aerosol propellants; domestic effluents; algal growths
Pesticides	Agricultural runoff; domestic usage; pesticide production
Polychlorinated biphenyls (PCBs)	Paper recycling; transformer oils; disposal of hydraulic fluids and lubricants; paint manufacture; fluorescent tube manufacture
Phthalate esters	Plastic, resin, rubber and paint production
Polynuclear aromatic hydrocarbons	Urban runoff; petrochemical industry wastes; bitumen production
Metals	Heavy and fine chemical industry wastes; electroplating industry wastes; mining activities; soil erosion; atmospheric deposition; sewage sludges

Source: After Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages.

(iii) Some, more "conventional" household water quality problems which may be due to natural or man-enhanced causes are outlined below:

Problem	Possible cause
Rust or black-coloured water resulting in stained clothing and fittings; discoloured and unpalatable food and beverages; reduced water flow	Presence of iron or manganese compounds
Rust-coloured slime in toilet cisterns and pipes; "fuzzy" particles in water; stained clothing and fittings; unpleasant odour of water; reduced water flow	Presence of iron bacteria
Greying of clothing (even after a good wash); scum in wash and bath water after use of soap; deposits in appliances and pipes; geyser takes a long time to heat water; reduced water flow	Hard water (presence of dissolved calcium and magnesium salts)
Corroded metal pipes and fittings; green or blue discoloration of clothing and fittings (in copper piping systems), with brown discoloration evident in galvanized piping systems	Acidic water
Water with a "rotten egg" odour; rapid tarnishing of silverware; black discoloration of clothing and fittings	Presence of hydrogen sulphide
Cloudy, turbid water	Particles of suspended or coloured matter
Gaseous well or borehole water	Presence of methane due to decay of organic matter

Source: Fieldwork.

The decline in water quality in a water-starved South Africa prompted the Water Research Commission in association with the Department of Water Affairs, to fund a National Industrial Water and Waste-water Survey (NATSURV), beginning in 1984. The aim of the survey was to establish a database containing information on industrial water intake, raw materials used, products, effluent quality and quantity, and the volume of industrial waste produced. The database can be used to determine targets for water intake and pollution loadings which are reasonably achievable by industry. An important objective of the programme was to identify problem areas requiring further research; and to advise South African industry on the improvement of water and effluent management, at minimum cost.

Several Water Research Commission reports are available*. Relevant information is likewise contained in some earlier CSIR technical guides. (See also Table L7 in the chapter on water supply planning).

15.8 Effluent and wastewater disposal in terms of the Water Act No. 54 of 1956**

As outlined in the chapter on the surface water resources of Natal/KwaZulu elsewhere in this publication, any industrial undertaking (as defined) using more than 150 m^3 of water per day (both public and private water as well as sea water), must make application for a permit in terms of Section 12(1) of the Water Act. Numerous details are required inter alia on the operation of any mine or industrial undertaking; the prevention of wastage of water; the purification, treatment and disposal of effluent and waste as well as the manner and place of disposal; the registration and use of industrial or other disposal sites, and the reuse of water. The industrial undertaking also requires permission from the Water Court

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* For an overview of the NATSURV programme see Steffen, Robertson and Kirsten Inc., 1991. National industrial water and waste-water survey, WRC Report No. 145/1/91, Water Research Commission, Pretoria, 26 p. + app. A listing of the numerous CSIR technical guides and Water Research Commission NATSURV publications can be found in Neytzell-De Wilde, F.G., 1992. Reassessment of the strategy with respect to industrial effluent discharge with special reference to advanced technology treatment methods, Phase 1: Industrial effluent discharge problem areas, WRC Report No. 407/1/92, Water Research Commission, Pretoria, 45 p. + app. Alternatively, contact the Water Research Commission, P O Box 824, Pretoria, 0001, or the Pollution Research Group, Department of Chemical Engineering, University of Natal, Private Bag X10, Dalbridge, 4014. Over 539 industries were surveyed in the period 1984 - 1989 as part of the NATSURV programme. Reports mainly concern the malt brewing; sorghum malt and beer; soft drinks and carbonated water; red meat; white meat; sugar; edible oils; dairy; wine; pulp and paper; tanning; textiles; laundry, and metal finishing industries. It should be noted that the Industrial Environmental Forum of Southern Africa (P O Box 1091, Johannesburg, 2000) was established in 1990. Many major companies (such as Engen Petroleum Ltd), are members. The purpose of the Forum is inter alia for the exchange of pollution control as well as industrial environmental data. The Forum also has a self-monitoring role and a set of environmental auditing guidelines has been compiled. The Chemical and Allied Industries' Association, Private Bag 34, Auckland Park, 2006, which promotes the Responsible Care (environmental) Initiative specifically for the chemical industry, is a member of the Forum. (See the chapter on solid waste management).

** Discussion based on Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages. See also, Lusher, J.A. and Ramsden, H.T., 1992. Chapter 18. Water pollution, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 456 - 492. See in addition: Wiseman, K. and Glazewski, J., 1991. South African law pertaining to the causes and effects of pollution affecting water resources, Report No. CPE 1.5/91, CSIR Programme for the Environment, CSIR, Pretoria, 141 p. For a discussion of some economic (theoretical) aspects of water pollution see Mirrilees, R.I., Forster, S.F. and Williams, C.J., 1994. The application of economics to water management in South Africa, WRC Report No. 415/1/94, Water Research Commission, Pretoria, various pages. (The latter publication also examines other issues such as the price of water and the costs of infrastructure provision).

in terms of Section 11(1) of the Act, for water abstraction (unless exempted)*. Importantly, any industrial undertaking is required (by virtue of Section 21 of the Act) to purify or treat any effluent produced, in accordance with standards prescribed by the Minister of Water Affairs and Forestry, after consultation with the South African Bureau of Standards, Private Bag X191, Pretoria, 0001. The relevant standards consist of a General Standard applied in South Africa as a whole, or a Special Standard for certain catchments, and a Special Standard for Phosphate applicable to a few sensitive catchments (Table 05). The latter standard refers specifically to a reduction in soluble ortho-phosphate (as P), in order to control or reduce eutrophication in impoundments (discussed later in the chapter). Besides the three standards, the Water Act also provides for the introduction of standards relating to the quality of receiving waters, and the quality of effluents which defined industries may produce in terms of available technology and at a reasonable cost (Anonymous, 1986).

It is a requirement in terms of the Act - where water is derived from a public stream or the sea - that the water be disposed of (after appropriate treatment) into the same stream or the sea at the place of abstraction (unless disposed of in a French drain, septic tank, canal, sewer or conduit belonging to a local authority). Following consultation with the South African Bureau of Standards as well as the Minister of National Health and Population Development (in cases where health hazards may be present), the Minister of Water Affairs and Forestry may grant an exemption (subject to an appeal to a Water Court), from compliance with the standards, and from the requirement to return purified effluent to the place of origin (other than the local authority systems as described). Unless the Minister directs otherwise (in terms of specific industries), the discharge of industrial effluent into a French drain, septic tank, canal, sewer or conduit belonging to a local authority is not subject to the effluent requirements of the Water Act. The local authority however, assumes responsibility for the purification of the effluent according to local drainage by-

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* These exemptions include situations where (a) the supply is obtained from a local authority or similar body which has the right to control or supply water, (b) where water is supplied from a Government waterworks, and (c) in cases where sufficient public water is available in a Government water control area. Any undertaking not exceeding the monthly volume of water used one year prior to the promulgation of the Water Amendment Act No. 96 of 1984 is also exempt, as is the use of water for agricultural purposes.

Table O5: The General and Special Standard applicable to direct discharges of effluent or wastewater into freshwater sources in terms of Section 21 of the Water Act No. 54 of 1956.

Determinand	Maximum allowable concentration	
	General Standard	Special Standard
Colour, odour or taste	Shall not contain any substance in any concentration capable of producing any colour, odour or taste	As per the General Standard
pH (units)	5,5 - 9,5	5,5 - 7,5
Dissolved oxygen (percentage saturation)	75	75
Typical (faecal) coli (Counts 100 mℓ^{-1})	0	0
Temperature (°C)	35	25
Chemical oxygen demand (after chloride correction) (mg ℓ^{-1})	75	30
Oxygen absorbed (from N/80 potassium permanganate in 4 hours at 27°C)(mg ℓ^{-1})	10	5
Conductivity:		
Maximum increase above that of intake water	75 mS m^{-1}	15%
In respect of mining effluent (mS m^{-1} at 25°C)	250	250
Suspended solids (mg ℓ^{-1})	25	10
Sodium content (maximum increase above that of intake water) (mg ℓ^{-1})	90	50
Soap, oil or grease (mg ℓ^{-1})	2,5	Nil

Table O5: The General and Special Standard applicable to direct discharges of effluent or wastewater into freshwater sources in terms of Section 21 of the Water Act No. 54 of 1956 (continued).

Determinand	Maximum allowable concentration	
	General Standard	Special Standard
Other constituents (maximum in mg ℓ^{-1}):		
Residual chlorine (as Cl)	0,1	0
Free and saline ammonia (as N)	10,0	1,0
Nitrate (as N)	-	1,5
Arsenic (as As)	0,5	0,1
Boron (as B)	1,0	0,5
Hexavalent chromium (as Cr)	0,05	-
Total chromium (as Cr)	0,5	0,05
Copper (as Cu)	1,0	0,02
Phenolic compounds (as phenol)	0,1	0,01
Lead (as Pb)	0,1	0,1
Soluble ortho-phosphate (as P)	-	1,0
Cyanides (as CN)	0,5	0,5
Iron (as Fe)	-	0,3
Sulphides (as S)	1,0	0,05
Fluorides (as F)	1,0	1,0
Zinc (as Zn)	5,0	0,3
Manganese (as Mn)	0,4	0,1
Cadmium (as Cd)	0,05	0,05
Mercury (as Hg)	0,02	0,02
Selenium (as Se)	0,05	0,05
Sum of concentrations of cadmium (as Cd), chromium (as Cr), copper (as Cu), mercury (as Hg) and lead (as Pb)	1,0	-

Table O5: The General and Special Standard applicable to direct discharges of effluent or wastewater into freshwater sources in terms of Section 21 of the Water Act No. 54 of 1956 (continued).

Determinand	Maximum allowable concentration	
	General Standard	Special Standard
The wastewater or effluent shall contain no other constituents in concentrations that are poisonous or injurious to:		
Humans, animals, fish other than trout, or other forms of aquatic life, or which are deleterious to agricultural use	Applicable	-
Trout or other fish, or other forms of aquatic life	-	Applicable

Source: After Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages.

See also: CSIR Environmental Services, 1995. Procedures to assess effluent discharge impacts, WRC Report No. TT 64/94, Water Research Commission and the Department of Water Affairs and Forestry, Pretoria, 352 p.

Note:

(i) The original legal notification (including methods of water analysis) can be found in the Republic of South Africa Government Gazette No. 9225 of the 18th May 1984, Government Printer, Pretoria, 132 p. (Government Notice GN 991/84).

(ii) Effluent refers to any residual water or any other liquid produced by or resulting from the use of water for industrial purposes (including any substance dissolved or suspended therein), but excluding any liquid produced for commercial purposes.

(iii) The Special Standard is applicable in 27 Natal/KwaZulu catchments:

Catchment	Natal (but not KwaZulu) magisterial district
Mvenyane and Mzimvubu rivers to the Transkei border	Mount Currie (including Matatiele)
Umzimhlara River to the Transkei border	Mount Currie
Ingwangwana River to its confluence with the Mzimkulu River	Mount Currie, Polela and Underberg
Mzimkulu and Polela rivers to their confluence	Underberg and Polela

Catchment	Natal (but not KwaZulu) magisterial district
Elands River to the Pietermaritzburg-Bulwer road	Impendle
Mtamvuna and Weza rivers to their confluence	Alfred
Mkomaas and Isinga rivers to their confluence	Impendle, Polela and Underberg
Lurane River to its confluence with the Mkomaas River	Polela
Sitnundjwana Spruit to its confluence with the Mkomaas River	Impendle
Inudwini River to the Polela District boundary	Polela
Inkonza River to the bridge on the Donnybrook-Creighton road	Polela and Ixopo
Mlazi River to the bridge on District Road 334 on the farm Maybole	Richmond
Mgeni and Lions rivers to their confluence	Impendle and Lions River
Mooi River to the road bridge at Rosetta	Estcourt and Lions River
Little Mooi and Hlatikulu rivers to their confluence	Estcourt
Bushmans River to Wagendrift Dam	Estcourt
Little Tugela River and Sterkspruit to their confluence	Estcourt
M'lambonjwa and Mhlawazeni rivers to their confluence	Bergville
Mnweni and Sandhlwana rivers to their confluence	Bergville
Tugela River to its confluence with the Khombe Spruit	Bergville
Mnyamvubu River to Craigieburn Dam	Umvoti
Mvoti River to the bridge on the Seven Oaks-Rietvlei road	Umvoti
Yarrow River to its confluence with the Karkloof River	Lions River
Incandu and Ncibidwane rivers to their confluence	Newcastle
Ingogo River to its confluence with the Harte River	Newcastle

Catchment	Natal (but not KwaZulu) magisterial district
Pivaan River to its confluence with Soetmelkspruit	Utrecht
Slang River and the Wakkerstroom to their confluence	Utrecht

(iv) In terms of the Special Standard for Phosphate, wastewater or effluent discharged into certain sensitive rivers or their tributaries shall not contain soluble ortho-phosphate (as P) in a higher concentration than 1,0 mg ℓ^{-1}. In Natal/KwaZulu, these rivers (catchment areas) are the Mgeni River upstream of the influence of tidal water, and the Mlazi River upstream of its point of discharge into the sea. (The Special Standard for Phosphate was first applied in South Africa in 1985).

(v) Certain difficulties are evident generally in terms of the relevant standards, including a shortage of inspectors. A related problem is that in the smaller local authorities, the necessary technical and legal expertise is not always available to effectively control the discharge of effluents into sewers. The standards also do not take into account the total (cumulative) discharge of effluents into a particular river, although individual industries may well be meeting the standards. A further problem is that the effluent standards allow pollution up to the specified concentrations, with no incentive to reduce contamination. The standards also do not cater for the numerous new chemical compounds introduced into South Africa each year, some of which are included in effluent discharges. An allied problem is that of effluents which cannot be properly treated at sewage works (in terms of existing technology), or which cause damage to biological processes at the works. Problems are also experienced with successful prosecutions given inter alia, that the negative externalities (damages) are sometimes difficult to prove in relation to a specific offender (Anonymous, 1986). Cunning factory managers (not unknown for example, in Pietermaritzburg), are able to circumvent the Water Act by several means including stormwater discharge; discharge at night or during heavy rain/floods; selective discharge when inspectors are sighted in the vicinity; the use of assorted excuses ranging from "inexperienced" operators to "plant malfunctions", and truly heart-warming denials plus fierce protestations of utter innocence.

laws and the Water Act*. Effluent discharged into a sewer or other conduit controlled by a local authority is deemed to be effluent produced by or resulting from the use of water for industrial purposes by the local authority. The final product from the local authority treatment works is accordingly subject to the General or Special Standard plus the Special Standard for Phosphate (where applicable). Local authorities can be held liable (in theory) for pollution caused by illegal discharges of saline or other effluent into their stormwater drains. The situation is somewhat complex and the reader is referred to Best (1984)** for a more detailed analysis. Importantly, all dischargers of effluent (whether permit holders or not), are obliged to advise the Department of Water Affairs and Forestry of the volumes and quality of effluent being discharged. These industries are also subject to inspection and monitoring to ensure that the data supplied are correct (discussed later in the chapter).

Section 22 of the Water Act has further relevance to pollution control. This section deals with measures to prevent the pollution of surface and groundwater, including surface runoff and the seepage of any substance in use or present on any land. In terms of Section 22, the Department is empowered to take measures to prevent the pollution of stormwater systems draining industrial and mining premises. It should be noted that regulations made in terms of Section 22 are also aimed at minimizing diffuse pollutant loads from all sources. In terms of Section 23 of the Act, the Minister of Water Affairs and Forestry may prohibit or restrict the marketing, manufacture or use of any substance (such as phosphates in detergents), which could cause water pollution. It is an offence (also by virtue of Section 23), for any person to commit any act which could render public, private or sea water less fit for the purpose for which it is (or could usually) be used; or which would negatively impact on aquatic organisms, recreational activities or other legitimate purposes. Section 23 is a more general provision which caters for water pollution which does not result from the direct use of water for industrial purposes. Section 23 applies inter alia to industries which produce solid wastes or liquids without using water (such as the petroleum industry). Section 23A has specific relevance to

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* See Funke, J.W., 1980. South African drainage by-laws for controlling the acceptance of industrial effluents and their impact on industry, Conference of the Institute of Water Pollution Control (Southern African Branch), 2 - 5 June 1980, Pretoria, 15 p. (The paper was formally published as: Funke, J.W., 1980. South African drainage by-laws for controlling the acceptance of industrial effluents and their impact on industry, Imiesa, VOL 5(9), p. 17 - 19, 25).

** See Best, H.J., 1984. The Water Amendment Act, 1984, Water Sewage and Effluent, No. 18, September 1984, p. 5 - 11. (The paper also provides useful background information).

agricultural activities, particularly feedlots (now regarded as an industrial activity subject to permit restrictions)*. In terms of Section 24, the Director-General of the Department may authorize any person to inspect land on which water is used for industrial purposes, or on which any substances (as defined in Section 22) are used or are present. If it is found on inspection that measures taken to comply with the pollution provisions of the Act are insufficient or inadequate, then the Director-General can compel the industrial undertaking or responsible person to take additional steps to reduce or contain pollution (Anonymous, 1986).

Several other Acts have relevance to water quality and pollution in freshwater environments. The Health Act No. 63 of 1977, administered by the Department of National Health and Population Development (with certain powers delegated to provincial and/or local authorities), is of particular importance. The Act provides for regulations relating inter alia to the following: (a) the supply of water for human use and the establishment of water and sewage purification works, (b) the volume and quality of water intended for human use, and (c) the water distribution system. The Act also provides for water sampling and analysis, and controls the addition of any substances to water intended for potable consumption. The Act similarly controls materials used for the construction of water care works or water supply schemes. Other relevant Acts administered by the Department of National Health and Population Development include the Hazardous Substances Act No. 15 of 1973; the International Health Regulations Act No. 28 of 1974, and the Foodstuffs, Cosmetics and Disinfectants Act No. 54 of 1972 (with reference to water as a food) (Anonymous, 1986).

The pollution of groundwater caused by poorly located or managed waste disposal sites is partly controlled by the Environment Conservation Act No. 73 of 1989. In this regard, the Department of Water Affairs and Forestry acts on behalf of the Department of Environment Affairs. The Department of Agriculture likewise administers a pertinent Act, namely, the Conservation of Agricultural Resources Act No. 43 of 1983 which addresses soil erosion and accordingly, sediment. The Animal Slaughter, Meat and Animal Products Hygiene Act No. 87 of 1967/Abattoir Hygiene Act No. 121 of 1992 which refers to the disposal of carcasses, animal products and waste also has a bearing on water quality. The

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* By virtue of Section 3 of the Water Amendment Act No. 68 of 1990. See Funke, J.W., Knoesen, J.G. and Venter, J.C., 1984. Code of practice for the handling of manure from intensive animal feeding units, Water Research Commission, Pretoria, 42 p.

Department of Mineral and Energy Affairs administers the Mines and Works Act No. 27 of 1956/Minerals Act No. 50 of 1991 which deals with certain water quality aspects at mining sites (those not covered by the Water Act No. 54 of 1956). Examples include the establishment of slimes dams along watercourses; and the fencing off of water containing poisonous or injurious matter in suspension or solution, which cannot be allowed to escape without having been rendered innocuous. The Atomic Energy Act No. 90 of 1967/Nuclear Energy Act No. 92 of 1982 has relevance to the safe disposal of radioactive effluent and waste inter alia with regard to the contamination of water. The Lake Areas Development Act No. 39 of 1975 (not applied in Natal/KwaZulu) prohibits the pollution of the sea as well as any lake or river or "estuary" within the protected lake area. The (Natal) Prevention of Environmental Pollution Ordinance No. 21 of 1981 and the (Natal) Nature Conservation Ordinance No. 15 of 1974, both refer to pollution in inland waters (including wetlands). While the Water Act is the primary Act dealing with water pollution, it is evident that the numerous other Acts/Ordinances and controlling authorities, complicate the application of a standard (uniform) regulatory policy (local circumstances notwithstanding). See the chapter on the laws of South Africa as well as the chapter on solid waste management.

15.9 Regional development policy in South Africa, with specific reference to industrial location and environmental pollution*

It is useful to briefly review industrial development policies in South Africa - since industrial location patterns serve to indicate (in general), the areas where pollution problems can be anticipated. Two main policies form the cornerstone of current South African regional industrial development policy. Both policies use incentives to attract industry away from established areas. The two policies are decentralization and deconcentration, both of which are components of the Regional Industrial Development Programme (RIDP), and which subsequently became known as the Industrial Development Programme. Industrial decentralization, begun in 1956, was designed to bring industries to certain Growth Points near to (and later) within homeland/national state borders (the "Border-areas policy"). Deconcentration however, is a more recent policy which emphasizes industrial development on the outer peripheries of existing metropolitan areas. In reality, nearly all

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* Discussion based on Harrison, P., 1989. Growth Points in non-metropolitan Natal: a historical perspective, Monitor, No. 8, Fourth Quarter 1989, p. 6 - 8., and Anonymous, [1991]. Regional development reconsidered, Urban Debate 2010, [Report No.] 3, Policies for a New Urban Future Series, Urban Foundation, Johannesburg, 87 p.

deconcentration points are adjacent to or within homeland/national state borders (Anonymous, 1991).

The Border-areas policy fell short of expectations. In Natal, the greatest success was at Hammarsdale while in 1965, Verulam, Tongaat and Stanger became recognized Growth Points. In 1967, a change in policy occurred in terms of the (now repealed) Physical Planning and Utilization of Natural Resources Act No. 88 of 1967, although no changes were made to incentives for the Durban-Pinetown area. Also in 1967, it was decided to concentrate on fewer Growth Points - which in Natal were identified as Ladysmith, Newcastle and Richards Bay/Empangeni. A decision was also taken to establish a harbour at Richards Bay and to locate an ISCOR plant at Newcastle. In 1968 there was another change in policy when tax incentives were offered to industrialists, thereby encouraging location within homeland areas. This resulted in, for example, the establishment of an industrial estate at Isithebe in KwaZulu in 1972 (Harrison, 1989).

In 1975 the National Physical Development Plan was finalized. The Plan introduced the concept of Development Regions and Development Areas. The Plan also differentiated between planned Metropolitan Axes, Growth Poles (which were to develop as intermediate size cities), and Growth Points. The two Development Axes identified in Natal were the Durban/Pretoria-Witwatersrand-Vereeniging axis and the Richards Bay/Pretoria-Witwatersrand-Vereeniging axis. Richards Bay was identified as one of four new Metropolitan Areas in South Africa, while Newcastle and Ladysmith were together classified as a Growth Pole, with Isithebe remaining a Growth Point. Debate on the effectiveness of the policy culminated in the Good Hope Plan in 1981, which preceded the release of the White Paper on a Regional Industrial Development Programme in 1982. In terms of the new policy, South Africa was divided into nine development regions which cut across political boundaries, and within which industrial growth was to be promoted. The number of Growth Points was increased, although with the intention of concentrating development in a limited number of larger Growth Points. The most generous incentives were to be provided at 44 Industrial Development Points (IDPs), with lesser incentives at 12 Deconcentration Points (DPs), and at 58 Other Industrial Points (OIPs) across South Africa. The declared IDPs in Natal/KwaZulu were Isithebe, Ezakheni, Madadeni, Ulundi, Richards Bay/Empangeni, Ladysmith and Newcastle. The DPs were Pietermaritzburg and Tongaat. The OIPs included Stanger, Verulam, Port Shepstone/Marburg, Vryheid, Dundee, Kokstad, Mooi River, Estcourt and Eshowe.

The rate of decentralization accelerated after 1982, and by 1989 there were 266 factories at Isithebe for example, with numerous factories also established at Ezakheni. Ulundi however, has not attracted many industries. While Ladysmith has continued to attract industries, Newcastle has been affected by the closure of several factories and coal mines (the latter leaving a legacy of acidic mine waters). Similar closures and pollution problems have occurred in Dundee, Glencoe, Vryheid and Utrecht*.

The Richards Bay/Empangeni area has attracted several industries, besides already established companies such as Richards Bay Minerals. The only OIPs which have experienced recent growth of any significance are Verulam, Stanger and the Port Shepstone/Marburg area (the latter attracting a cement factory). Towns such as Greytown, Eshowe, Ixopo, Kokstad and Estcourt (where a Masonite factory was established many years ago), have not developed significantly and are largely agricultural service centres (Harrison, 1989). The shortcomings of the industrial development policy resulted in a further change in 1991 with the introduction of a new policy known as the Industrial Development Programme. The emphasis has now shifted away from artificially stimulating industrial development at localities where industrial potential might be limited (and for political reasons), to an approach where economic forces predominate - in areas where there is a greater natural potential for industrial development (Anonymous, 1991).

<u>For further information consult the following:</u>

- Addleson, M., Pretorius, F. and Tomlinson, R., 1989. Industrial trends and prospects in Natal-KwaZulu: Region E, Natal Town and Regional Planning Commission Report, VOL 72, Pietermaritzburg, 218 p. + app. (The publication contains a useful bibliography).

- Hanekom, F. (ed), 1984. Decentralization towards 2000: a perspective on the Good Hope Plan for the Promotion of Industrial Development as an Element of a Co-

* See Tinney, C.B. and Harding, A.J., 1993. Operating and developing coal mines in the Republic of South Africa, 1993, Directory No. D2/93, Minerals Bureau, Department of Mineral and Energy Affairs, Pretoria, 27 p. + app. (The publication provides details on currently operating coal mines). See also, Simonis, J.J., 1988. Inventaris van alle steenkoolmyne (1987) en uitskothope (1986) in die R.S.A., Technical Report No. Gh 3606, Directorate of Geohydrology, Department of Water Affairs, Pretoria, 59 p., and Anonymous, 1990. Operating mines, quarries and mineral processing plants in the Republic of South Africa, Directory No. D1/90, Minerals Bureau, Department of Mineral and Energy Affairs, Johannesburg, no pagination.

ordinated Regional Development Strategy for Southern Africa, Edited Proceedings of a Symposium at the University of South Africa, Pretoria, 17 August 1982, Juta, Cape Town, 129 p.

- Harrison, P./John, I./Proctor, C., 1991. Revised Regional Industrial Development Programme/Comment on the new RIDP, Monitor, No. 13, Second Quarter 1991, p. 1 - 3.

- Panel of Experts, 1988. Report of the panel of experts on the evaluation of the Regional Industrial Development Programme, as an element of the regional development policy in southern Africa, Development Bank of Southern Africa, Halfway House, 310 p. + app.

- Wilsenach, A. and Ligthelm, A.A., 1993. A preliminary evaluation of the new RIDP and its impact on regional development in South Africa, Development Southern Africa, VOL 10(3), p. 361 - 381.

For further information contact:

- Department of Regional and Land Affairs, Private Bag X833, Pretoria, 0001.

- Department of Trade and Industry, Private Bag X84, Pretoria, 0001.

- KwaZulu-Natal Regional Economic Forum, P O Box 30886, Mayville, 4058.

- Natal Town and Regional Planning Commission/Chief Directorate: Physical Planning and Development, Natal Provincial Administration, Private Bag X9037, Pietermaritzburg, 3200.

15.10 A brief overview of effluent and wastewater problems in Natal/KwaZulu

According to the then Department of Water Affairs, quoted in Neytzell-De Wilde (1992)*, current problems with regard to the treatment of industrial effluents in Natal/KwaZulu primarily involve dyehouse effluents from textile dyehouses - due to poor housekeeping and the use of old technology**. Sewage works receiving such effluents are not able to effectively break down the colour. There is also insufficient data available on the non-biodegradable portion of the organic content in dyehouse effluent. Research into the adequate destruction or removal of dyes, especially colour (without causing additional problems from over-chlorination, for example), is required. Oil refinery effluent is satisfactory, although sulphates which are reduced to sulphides, can result in problems in sewers. Effluents discharged from paper mills are sometimes problematic, with colour and foam causing aesthetic difficulties on occasion. Colour is of concern in abattoir effluent, although other determinands may be problematic at the Cato Ridge abattoir. Alleged mercury contamination by Thor Chemicals (SA) Ltd at Cato Ridge has received much press coverage. A Commission of Inquiry was appointed in March 1995 to investigate the situation at the factory. Some difficulties in relation to nitrogen loading, electrical conductivity and fluoride are being experienced at the ISCOR (Newcastle) works. Cheese making activities undertaken by National Co-op Dairies Ltd (NCD) at Mooi River and Kokstad may result in odour problems due to effluent disposal on land. Poor housekeeping is evident in industries manufacturing edible oils, where effluent discharge into stormwater drains has been detected (mainly in Pietermaritzburg - also the subject of attention by the press). The treatment of sugar mill effluent to the General Standard is not always achieved, although few persistent problems are apparent. A serious problem (as outlined earlier) is evident in northern Natal/KwaZulu in terms of acid mine drainage from coal mines and dumps. Major difficulties include pH, conductivity, sulphate and iron concentrations.

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* See Neytzell-De Wilde, F.G., 1992. Reassessment of the strategy with respect to industrial effluent discharge with special reference to advanced technology treatment methods, Phase 1: Industrial effluent discharge problem areas, WRC Report No. 407/1/92, Water Research Commission, Pretoria, 45 p. + app. (The publication contains a useful overview of issues concerning effluents in South Africa and other countries).

** The (legally binding) General/Special Standard as well as the Special Standard for Phosphate, applicable to effluents and wastewater, should not be confused with water quality guidelines for industries (published by the Department of Water Affairs and Forestry - see Footnote (i) in Table O3). The guidelines however, are an important component of the overall Receiving Water Quality Objectives approach, and should help to achieve a better understanding of the importance of water quality issues by industry.

According to the Department of Water Affairs, quoted in Neytzell-De Wilde (1992), water quality problems (in order of importance) in rivers in Natal/KwaZulu are due to erosion (sediment); faecal runoff (particularly from feedlots as well as densily settled informal areas); acid mine drainage; the activities of local authorities; industrial processes and finally, waste disposal sites (especially privately owned sites). Receiving waters impact studies - for domestic, industrial, agricultural, recreational and environmental uses - have or are being undertaken by the Department on the Tugela, Mvoti, Ngagane, Enyati, Mkuze and Black Mfolozi rivers, as well as along the Sterkspruit (a tributary of the Mlazi River). The Department operates a 24 hour seven days a week water pollution reporting and sampling service. The samples are sent to the Institute for Water Quality Studies or Umgeni Water for analysis. The pollution reporting phone numbers for Natal/KwaZulu are: 031-3061367 (office hours) and 031-783192 (after hours). Alternatively, phone the all-hours emergency number, namely, 10177 (no area code required).

A multilateral agreement on the control of water pollution was signed in 1985 by South Africa, Transkei, Bophuthatswana, Venda and Ciskei (Anonymous, 1986)*. In terms of the agreement, member states (via permanent water commissions - see the chapter on surface water resources), are responsible for promoting the effective control of sources of water pollution. The agreement covers the enforcement of Uniform Effluent Standards, regulations for solid waste disposal, and the control of pollution from mine dumps and mines. In the case of Natal, the relevant agreement is with the Transkei. A similar agreement was entered into with KwaZulu, while international agreements were reached with Lesotho, Swaziland and Mozambique (inter alia) with regard to Natal.

15.10.1 Sources of primary information on industrial water pollution (trade effluents) in Natal/KwaZulu

(a) Direct sources

(a) The Directorate of Water Quality Management, Department of Water Affairs and Forestry, P O Box 1018, Durban, 4000. The Directorate maintains extensive files on industries in Natal/KwaZulu in terms of physical location, items manufactured, the manufacturing process, water abstraction

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* See Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages.

requirements, and the type and volume of solid waste as well as effluents produced. The names of manufacturing firms and service industries such as abattoirs most likely to produce noxious effluents, and details of solid wastes requiring careful handling in specified disposal sites are listed in a Departmental database. Numerous companies are regularly monitored at or near the particular site.

The Directorate of Water Quality Management, Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001, has a Water Pollution Control Management Information System (POLMON) database*. The database lists inter alia the permits issued by the Department - in terms of the Water Act No. 54 of 1956 - to local authorities, mines and industries who discharge treated effluent directly into a river or dam or canal leading to a river. The database contains details of each permit issued, for example, the volume of effluent allowed, and the water quality standards that the effluent must conform to. Also included in the database are the results of regular monitoring tests of the effluent in question, which are undertaken to check on compliance with the conditions of the permit. Some 10 000 permits have been issued in South Africa to-date.

(b) Umgeni Water, P O Box 9, Pietermaritzburg, 3200. Umgeni Water also has an industrial database. The database is for the old supply area which extends from Howick to Ballitoville and south to Kingsburgh, but excludes the Durban and Pinetown municipal areas. The database contains information on the physical location, items manufactured, the manufacturing process, and the type and volume of solid waste and effluents produced, for certain manufacturers and service industries. Umgeni Water regularly monitors effluents in or below selected industrial areas**. Monitoring will be extended to include industrial sites in the recently enlarged supply region.

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* Sometimes referred to as the (National) Pollution Monitoring Network.

** See Anonymous, 1990. A pollution survey of industries in the Pietermaritzburg area, Internal Report No. PP 6/90, Umgeni Water Pollution Prevention Section, Umgeni Water, Pietermaritzburg, no pagination.

(c) Individual municipalities and other local authorities. Entrepreneurs establishing new industries (above a certain size), as well as entrepreneurs buying existing factory premises for manufacturing or related purposes, are required by most local authorities to complete an industrial questionnaire. Details are requested on the items manufactured and the manufacturing process, as well as pollutants (gases, liquids and solid waste) likely to be produced by the company. Manufacturing firms and service industries termed "wet", namely, those producing effluents/wastewaters (either untreated or treated) which are legally discharged into municipal sewers, are regularly monitored on or near the factory premises by the larger municipalities in Natal/KwaZulu*.

(b) Indirect sources (to determine basic locational and product data)

(a) The Durban Regional Chamber of Business** (formerly the Durban Metropolitan Chamber of Commerce and the Natal Chamber of Industries respectively), P O Box 1506, Durban, 4000. The latter Chamber representing firms in the Durban Functional Region and in the coastal areas, still maintains a database of all members, and published an annual directory (the last being the 1991/1992 issue). Both sources could serve as an indirect reference on industries in Natal/KwaZulu. The directory provides data inter alia on the name of each company, the product manufactured or activity undertaken, the postal address and the phone number. A classified index is included. The (former) Durban Metropolitan Chamber of Commerce likewise, produced a directory of members in 1990. There are 15 other Chambers of Commerce and/or Industry in Natal/KwaZulu located at Mooi River, Estcourt, Greytown, Howick, Kokstad, Ixopo, Ladysmith, Matatiele, Pietermaritzburg, Newcastle, Dundee, Margate, Vryheid, Empangeni and Ballitoville. It is possible that not all industrial firms (from a water pollution

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* Certain changes have taken place in Pietermaritzburg following the sale of the Darvill Wastewater Works (formerly owned and operated by the Pietermaritzburg Corporation). Umgeni Water is now responsible for monitoring trade effluents discharged into the city's sewers (as indicated earlier in the chapter). Umgeni Water has subsequently been granted the power to prosecute offenders, in terms of the Pietermaritzburg drainage by-laws.

** Now known as the Durban Chamber of Commerce and Industry.

viewpoint), may necessarily belong to a Chamber. Enquiries may have to be made locally.

See: (i) Anonymous, 1990. Durban Metropolitan Chamber of Commerce Directory, Intratex Printing and Publishing Company, Pinetown, 251 p. (Information available in the publication includes the name of each company, the postal address, and the product made or activity undertaken. The directory also contains a classified index and a map of the Durban Metropolitan Area).

(ii) Anonymous, 1991. Natal Chamber of Industries 1990/1991 Year Book and Directory, Natal Chamber of Industries, Durban, 113 p. (Both this publication and the publication above refer to the period when separate Chambers of Industry and Commerce existed in Durban. No new source publications have yet been produced by the Durban Regional Chamber of Business).

(b) Natal/KwaZulu Business Register. A publishing firm (operating under different names), produces an annual register of certain businesses (manufacturing and other categories) in Natal/KwaZulu. The publication includes the name of the company, the postal address, the product made or activity undertaken, and a classified index as well as maps of the industrial suburbs of towns and cities in Natal/KwaZulu.

See: (i) Anonymous, 1993. 93/94 Natal/KwaZulu Business Register, Swan Publishing Company, Pinetown, various pages.

(ii) Reference can also be made to the individual Braby's directories for various municipalities in Natal/KwaZulu (which contain business information). Firms manufacturing specified items can likewise be traced via the telephonic Yellow Pages Directory operated by Telkom SA Ltd. Only those companies which subscribe to the service are listed. Phone 10-11-8 at any time.

(c) The South African Regional Statistical Database. The Division of Information Services, CSIR, P O Box 395, Pretoria, 0001, established the South African Regional Statistical Database which for the manufacturing sector, contains data on the number of factories in each postal code area or in South Africa as a whole. Similarly available is the postal/street address and the type of product made or activity undertaken by each of the listed firms. This information can also be obtained by using the Standard Industrial Classification (SIC) code, whereby every industrial undertaking is classified in terms of a specific economic category (Table O6)*. There are 10 major divisions, namely: 1 (agriculture, hunting, forestry and fishing); 2 (mining and quarrying); 3 (manufacturing); 4 (electricity, gas and water); 5 (construction); 6 (wholesale and retail trade, repair of motor vehicles/motor cycles and household goods and catering and accommodation services); 7 (transport, storage and communication); 8 (financing, insurance, real estate and business services); 9 (community, social and personal services), and 0 (activities not adequately defined and unemployed persons not economically active).

Table O6: An example of the SIC industrial classification code.

Major division 2		
Mining and quarrying		
Division 21		Coal mining
210	21000	Coal mining
Division 22		Crude petroleum and natural gas production
220	22000	Crude petroleum and natural gas production
Division 23		Metal ore mining, except gold mining
Sub-group 2302		Non-ferrous ore mining, except gold mining
230	23010	Iron ore mining
230	23020	Chrome mining
230	23021	Copper mining
230	23022	Manganese mining
230	23023	Platinum mining

* Basic data on numerous South African companies, classified according to the SIC code, are likewise available from the Bureau of Market Research, University of South Africa, P O Box 392, Pretoria, 0001.

Source: After Anonymous, 1988. SIC standard industrial classification of all economic activities (fourth edition), Central Statistical Service, Pretoria, 92 p.

See also: Anonymous, 1993. SIC standard industrial classification of all economic activities (fifth edition), Report No. 09-90-02, Central Statistical Service, Pretoria, 247 p.

Note:

(i) The above classification is based on the fourth edition of the SIC code. Several changes were introduced in the fifth edition.

(ii) The CSIR database - see the text - also contains information on the number and types of operating mines, quarries and mineral processing plants as well as statistics on the economically active population, all according to magisterial districts. Data are likewise available on the number of unemployed as a percentage of the economically active population (according to development regions); the areas of statistical regions (according to magisterial districts), and the areas planted and the total production for agricultural crops - according to magisterial districts.

(iii) An indirect source of information on major industries in South Africa is the following: Anonymous, 1994. The JSE handbook, August 1994, Flesch Financial Publications, Johannesburg, 258 p. (The handbook is published twice a year and briefly reviews all companies listed on the Johannesburg Stock Exchange. The publication provides some details on the nature of business conducted by each firm, as well as the head office address. Similar details can be found in McGregor, R., 1993. McGregor's Who Owns Whom, Juta, Cape Town, 1085 p. + app. The book is updated annually. See in addition, Anonymous, 1993. 1993/94 National Trade Index of South Africa, Intratex, Pinetown, 464 p. The latter publication is regularly updated).

15.11 Catchment water quality in Natal/KwaZulu

15.11.1 An historical overview

A comprehensive survey of rivers, dams and subsequently urban catchments in Natal/KwaZulu was initiated in 1953 by the CSIR, Durban, in association with the Natal Town and Regional Planning Commission, Private Bag X9037, Pietermaritzburg, 3200. The research was carried out under the auspices of the Natal Rivers Research Fellowships Steering Committee. The programme, which was terminated in 1987 (see earlier in the chapter), provided a wealth of data (only some of which was formally published - see the bibliographic database). A series of comprehensive reports, partly based on the work, was published in the period 1967 - 1979 by the Natal Town and Regional Planning Commission (NTRPC)*. The reports constitute a valuable baseline analysis of water quality in Natal/KwaZulu, against which later data can be compared. The reports are accordingly, required reading for any overview assessment of water quality in the province. A series of pollution studies was, in addition, undertaken in the Mgeni catchment by the CSIR, Durban, which likewise provide important effluent baseline data**.

The CSIR/Natal Town and Regional Planning Commission reports contain comprehensive information on numerous rivers (Table O7), with regard to chemical and microbiological determinands, plus hydrobiological (faunal) data. Data on algae are also presented (in part). Chemical determinands examined, included dissolved oxygen; biochemical oxygen demand; electrical conductivity; total dissolved solids; pH; the saturation pH value (pH_S); the stability index ($2pH_S$ - pH); temperature; turbidity; colour; ammonia (as N); Kjeldahl nitrogen; nitrate (as N); nitrite (as N); phosphate (as PO_4); total alkalinity (as $CaCO_3$); total

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* See (a) Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 1: objectives of river surveys, description of methods used and discussion of water quality criteria, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 101 p., (b) Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 2: survey of the Three Rivers Region, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 224 p. and maps, (c) Brand, P.A.J., Kemp, P.H., Oliff, W.D. and Pretorius, S.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 3: the Tugela River and its tributaries, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 68 p. + app., (d) Archibald, C.G.M., Coetzee, O.J., Kemp, P.H., Pretorius, S.J. and Sibbald, R.R., 1969. Water quality and abatement of pollution in Natal rivers, Part 4: the rivers of northern Natal and Zululand, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 52 p., (e) Kemp, P.H., Chutter, F.M. and Coetzee, D.J., 1976. Water quality and abatement of pollution in Natal rivers, Part 5: the rivers of southern Natal, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 100 p., (f) Archibald, C.G.M., Coetzee, O.J., Cox, S.M.H., Kemp, P.H., Pretorius, S.J. and Sibbald, R.R., 1971. Water quality and abatement of pollution in Natal rivers, Part 6: factors affecting water quality in the sugar growing areas of Natal, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 119 p., and (g) Fowles, B.K., Butler, A.C., Brown, H.M., Kemp, P.H., Coetzee, O.J. and Metz, H., 1979. Water quality and abatement of pollution in Natal rivers, Part 7: special studies in the rapidly developing areas of Newcastle and Ladysmith, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 93 p. See also, Schoonbee, H.J. and Kemp, P.H., 1965. An account of the Umgeni River survey, CSIR Research Report No. 325, National Institute for Water Research, CSIR, Pretoria, 63 p. + app. It is interesting to note that possibly the very first attempt at regulating water quality in Natal was in 1881. See Hime, A.H., Campbell, H.C. and Kretzschmar, E., 1881. Natal Commission Appointed to Enquire Into and Report Upon the Pollution of Streams in the Coast Districts, Government Printer, Pietermaritzburg, 5 p. (The document which forms part of the Natal Colonial Publications collection - Reference No. NCP 8/3/18 - is available at the Natal Archives Depot, Private Bag X9012, Pietermaritzburg, 3200).

** See for example, Schoonbee, H.J. and Kemp, P.H., 1963. Pollution studies in the Umgeni Basin (Natal), Part 4: a biological and chemical survey of the Umsunduzi River at Pietermaritzburg, CSIR Special Report No. W26, National Institute for Water Research, CSIR, Pretoria, 48 p. (Many of the problems listed in the report are current today - over 30 years later).

Table O7: Natal/KwaZulu rivers examined in the CSIR/Natal Town and Regional Planning Commission survey.

VOL 13 (Part 2)	VOL 13 (Part 5)
Sinkwazi	Umkomaas
Nonoti	Amahlongwa
Umhlutuni	Umpambinyoni
Umvoti	Umzinto
Umhlali	Inkomba
Tongaat	Sezela
Umhloti	Ifafa
Umhlanga	Mtwalume
Umgeni	Umhlungwa
Umbilo	Mhlabatshane
Umhlatuzana	Umzumbe
Umlaas	Injambili
Isipingo	Idombe
Umbogintwini	Umtentweni
Amanzimtoti	Umzimkulu
Little Amanzimtoti	Boboyi
Illovo	Zotsha
Umzimbasi	Umhlangeni
Umgababa	Uvongo
Ingane	Mbizane
	Mpenjati
	Mtamvuna
VOL 13 (Part 3)	**VOL 13 (Part 6)**
Buffalo	Nonoti
Sundays	
Bushmans	
Mooi	
Tugela	
VOL 13 (Part 4)	**VOL 13 (Part 7)**
Amatikulu	Buffalo
Umlalazi	Ngagane

Table O7: Natal/KwaZulu rivers examined in the CSIR/Natal Town and Regional Planning Commission survey (continued).

VOL 13 (Part 4)	VOL 13 (Part 7)
Umhlatuzi	Ncandu
Umfolozi	Klip
Nyalazi	Ngogo
Hluhluwe	Modderspruit
Umsinene	Sand
Mkuze	
Pongola	

<u>Source</u>: See the long footnote at the beginning of Section 15.11.1.

<u>Note</u>:
(i) Part 1 of the survey provides an overview of objectives and methodology.

(ii) River names may be spelt differently in the chapter on "estuaries", as well as in the chapter on the surface water resources of Natal/KwaZulu. A map should be consulted in cases of confusion.

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hardness (as $CaCO_3$); calcium; magnesium; sodium; potassium; sulphate; chloride; silica, iron and fluoride, and free carbonic acid (as CO_2). Microbiological determinands included presumptive and confirmed <u>E</u>. <u>coli</u> I; confirmed Irregular II and VI coliform organisms; <u>Staphylococcus aureus</u>; <u>Shigellae</u>; <u>Salmonellae</u>; the standard plate count, and filamentous sulphur bacteria (termed "sewage fungus"). Factors affecting water quality are discussed in the reports including the influence of geology on the concentration of specific determinands. Biotic index data are also provided. Importantly (for baseline purposes), the water quality in various river reaches (of the rivers examined in the survey) was classified in terms of five classes, namely: Class I - water of the highest quality; Class II - water of medium quality; Class III - water of poor quality; Class IV - mineralized water; Class V - water which is either faecally contaminated (and a danger to health) or is organically enriched, and Class VI - foul water which is (or is likely to be) a public nuisance or a public danger (Table O8). The classification system was intended to apply to the worst conditions in a river at any time.

Table O8: A water quality classification of Natal/KwaZulu river waters, as developed by the CSIR, 1967.

Determinand	Class I	Class II	Class III	Class IV	Class V	Class VI
Total dissolved solids (mg ℓ^{-1})	<100	<500	<1 000	>1 000	-	-
Biochemical oxygen demand - five days at 20°C (BOD) (mg ℓ^{-1})	<1,5	<3	<5	<5	-	-
Dissolved oxygen (percentage saturation)	85 - 115	>60	>60	>20	>20	<20
pH (pH units)	6,9 - 8,5	6,0 - 9,5	6,0 - 9,5	-	-	-
Confirmed *E. coli* I (Counts 100 mℓ^{-1})	<50	<1 500	<50 000	-	-	-
Presumptive *E. coli* I (Counts 100 mℓ^{-1})	<50	<5 000	<50 000	-	-	-
Standard plate count (now known as the heterotrophic plate count) (Counts 1 mℓ^{-1})	<5 000	-	-	-	-	-
Other microbiological determinands	No *Salmonellae*; *Shigellae*; *Staphylococcus aureus*; *Pseudomonas aeruginosa*; *Proteus*; nor sewage fungus	No sewage fungus	-	-	-	-
Appearance of the water	Free from slicks, odours and suspended materials other than normal river silt	Free from slicks, odours and suspended materials other than normal river silt	Free from slicks, odours and suspended materials other than normal river silt	-	-	-

Source: After Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 1: objectives of river surveys, description of methods used and discussion of water quality criteria, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 101 p. (The publication provides useful background data on determinands used in the survey).

Note:

(i) Class IV - VI waters may show virtually any values of the determinands not specifically tabulated.

(ii) The confirmed as well as presumptive E. coli I and standard plate count values are not applicable to samples taken after recent rainfall.

(iii) So-called sewage fungus are not true fungi, but are members of the higher bacteria (filamentous sulphur bacteria); and are regarded as indicative of recent and/or remote organic disturbance of the water.

(iv) Class IV - VI waters are defined as unsuitable for potable or domestic purposes. Class III waters are marginal for such purposes, unless subjected to special treatment (with no other sources of supply available).

(v) Class III waters may not be suitable for agriculture (except irrigation), but can be used for many industrial purposes. Class IV - VI waters are not usually acceptable for industrial or agricultural requirements (except for irrigation).

The water quality classification data are summarized in certain of the reports by means of colour-coded maps which illustrate the class of water for given river reaches. In terms of the surveys, no Class I waters were found, while Class II waters were generally evident in the upper and middle reaches of rivers rising in the central parts of Natal/KwaZulu. Class III waters were relatively rare, while Class IV and V waters were apparent in the lower reaches of rivers near the coast. Class IV waters were also found in the vicinity of Vryheid (due to acid mine drainage). Class VI waters were evident in the lowest reaches of rivers such as the Mhlatuze, the Nonoti, the Tongati, and the Mhlatuzana rivers. A number of difficulties however, were subsequently experienced with the classification system, inter alia with regard to total dissolved solids, bacteriological counts and biochemical oxygen demand. Determinand variability was also not specifically considered. A revised classification system developed by the CSIR during the course of the research is presented in Table O9. **Readers should not confuse the two systems**, which each apply to certain NTRPC reports.

Table O9: A revised water quality classification of Natal/KwaZulu surface and groundwaters, as developed by the CSIR, 1971.

Conductivity	Biochemical oxygen demand (five days at 20°C)	
	Low (At least 95% of the time <4 mg ℓ^{-1})	**High** (More than 5% of the time >4 mg ℓ^{-1})
Low (At least 95% of the time <75 mS m^{-1})	Class 1	Class 4
Intermediate	Class 2	Class 5 (All toxic water to be included in this class)
High (More than 5% of the time >225 mS m^{-1})	Class 3	

Source: After Archibald, C.G.M., Coetzee, O.J., Cox, S.M.H., Kemp, P.H., Pretorius, S.J. and Sibbald, R.R., 1971. Water quality and abatement of pollution in Natal rivers, Part 6: factors affecting water quality in the sugar growing areas of Natal, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 119 p.

See also:

(i) Kemp, P.H., 1971. Chemistry of natural waters - VI: classification of waters, Water Research, VOL 5(10), p. 943 - 956.

(ii) Kemp, P.H., 1977. A guide to ionic relationships in natural waters, CSIR Research Report No. 329, National Institute for Water Research, CSIR, Pretoria, 127 p. A slightly different version of the above table is presented in the report. A medium biochemical oxygen demand category is included (with no data), which is linked to the intermediate (medium) conductivity category. The high biochemical oxygen demand category is referred to as "more than 5% of the time above 10 mg ℓ^{-1}". The higher value enables a clear distinction to be made between borderline waters and waters in a really foul condition. A further water classification system based on the given table is included in the Kemp report, which has relevance to limited sampling procedures, where only a few samples can be taken (for reasons of economy). The Kemp report also contains a valuable discussion of the chemistry of natural waters. The important statistical analyses of (mainly chemical) water quality data and required sampling frequencies are discussed in Kemp, P.H., 1978. Statistics in water sampling, CSIR Research Report No. 338, National Institute for Water Research, CSIR, Pretoria, 83 p.

(iii) Readers requiring information on a biotic index for South African flowing waters are referred to Chutter, F.M., 1972. An empirical biotic index of the quality of water in South African streams and rivers, Water Research, VOL 6(1), p. 19 - 30. (The index is intended only as a measure of organic pollution and is not for toxic pollution.

The index also cannot be used if a major flood or drought has occurred in the recent past. A value of 0 indicates clean unpolluted water, while a value of 10 is indicative of highly polluted water: in terms of collections of animals (faunal communities) from the stones -in-current biotype). The Chutter biotic index was applied in later parts of the CSIR/Natal Town and Regional Planning Commission survey (see Part 5), while the biotic index proposed in Part 1 was slightly modified, and was used for faunal samples from sediments and marginal vegetation (see Part 5). The Chutter index has subsequently been modified and updated for the rapid bioassessment of South African rivers*.

Note: (i) The classification system in Table O9 is based on the **probable utility of the waters**, and refers to chemical determinands (given that the results of biological vis-a-vis chemical tests are sometimes conflicting). In addition, waters with very high bacteriological counts can often be identified by high biochemical oxygen demand (BOD) values. The BOD reflects the concentration of organic matter in the water, while conductivity is used to assess the degree of mineralization of the water. For the purposes of classification, it is sufficient to know that the BOD of a poor quality water is unduly high, where errors in the BOD determination arising from the dilution of the sample, are not important. The 4 mg ℓ^{-1} value refers to the upper limit for raw water which can (usually) be successfully treated by municipal purification works (Archibald et al, 1971 - above). An important limitation of BOD is that the determinand will not provide a reliable result if the water contains toxic substances which inhibit bacterial life. A low BOD value is accordingly, not necessarily a sign of clean water. Whenever BOD assessments are made, it is essential to check that toxic substances are clearly absent. Spiking samples with known amounts of organic substances; using special bacteriological tests; comparing BOD values with the results of related chemical tests, and observing the fauna and flora of the water can all be applied for verification purposes. The presence of toxins (besides indicating that the BOD result is spurious), also implies that the water has been polluted and is not suitable as a supply source. Such waters should be considered as Class 5 waters.

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* The revision was completed after this chapter was written. The new procedure, which is still evolving, is known as the South African Scoring System (SASS) and was developed by Chutter (1994). The SASS is based on the presence or absence of benthic macroinvertebrate groups. Each taxon is allocated a sensitivity/tolerance score in terms of the water quality conditions it is known to tolerate. The higher the score, the greater is the organism's sensitivity and the lower is its tolerance. The number of taxa, the average score per taxon, and the total sample score must be calculated for each sample. Average score per taxon scores consistently above five and total scores consistently above 80 are indicative of clean, unpolluted water at a particular site. The SASS can be used, for example, to track sources of pollution, for monitoring the effectiveness of river rehabilitation, and to assess the impact of accidental chemical spillage. See Chutter, F.M., 1994. Chapter 15. The rapid biological assessment of stream and river water quality by means of the macroinvertebrate community in South Africa, In: Uys, M.C. (ed), Classification of Rivers, and Environmental Health Indicators: Proceedings of a Joint South African/Australian Workshop, 7 - 11 February 1994, Cape Town, WRC Report No. TT 63/94, Water Research Commission, Pretoria, p. 217 - 234. Examine also: Chutter, F.M., 1995. The role of aquatic organisms in the management of river basins for sustainable utilization, Water Science and Technology, VOL 32(5/6), p. 283 - 291.

An examination of BOD and conductivity together, usually reveals the uses for which a water is not suited, and therefore, those uses for which the water is acceptable (Kemp, 1977).

(ii) Class 1 waters are usually suitable for municipal water systems and for most other uses. Class 2 waters are suitable for municipal water systems, provided that the water is abstracted by means of a properly designed impoundment (for dilution purposes). The water is probably suitable for drinking by private consumers and for most other uses, but is not acceptable for irrigation except in special circumstances - due to a moderately high conductivity and therefore total dissolved solids concentration. Class 3 waters with a low BOD and a high conductivity are not suitable as a source of municipal water, although the water is usually suitable for drinking by private consumers (provided that conductivity is not excessive). The water however, is not acceptable for industrial use and is also not suitable for irrigation purposes (most of the time). The water can be used for livestock watering, provided that conductivity is not too high. Impoundment per se is not sufficient to upgrade Class 3 waters to a Class 1 category, and some form of desalination is required, before the waters can be used for a wide range of purposes. Dilution with low salinity water is an alternative treatment procedure. Class 4 waters with a low conductivity are probably acceptable for irrigation, but are not suitable for human and livestock drinking requirements, or for industrial purposes (due to organic enrichment and the need for specialized treatment). Class 5 waters are unsuitable for every use except irrigation (under special circumstances) (Kemp, 1977). Archibald et al (1971) stressed that a water described as probably suitable for some particular use, should not be accepted for that use until data on other chemical determinands (such as heavy metals), as well as bacteriological data have been derived.

(iii) In terms of the revised classification system, most of the surface waters in Natal/KwaZulu are of the Class 1 category. Certain rivers north of the Tugela (such as the Pongola, Mkuze and Hluhluwe rivers) should be classified as Class 2 - given that these rivers are to some extent fed by groundwater with a high conductivity, and due also to increased salinity caused by irrigation return flows. Most of the small rivers of the coastal belt fall into Class 4 and 5, since the rivers are organically enriched. Many of the rivers in the coal mining areas of northern Natal/KwaZulu can be categorized as Class 2 and 3 waters due to acid mine drainage, while sugar mills in the coastal belt are usually responsible for organic pollution which degrades the water to Class 4. (The situation has improved to some extent in certain areas, since 1971). Pollution of surface waters due to urban runoff (in the larger centres) and at other sites (specific industries), results in Class 3, 4 and 5 waters. Groundwater in Natal/KwaZulu is usually of a Class 2 category, although Class 1 and Class 3 waters are also common. Groundwater is mainly free from organic matter. Accordingly, Class 4 and 5 groundwaters are rare.

(iv) Archibald et al (1971) suggested that (in principle), it should be reasonably simple and cost effective to reduce organic pollution, so that many of the Class 4 waters can be restored to a Class 1 level, with Class 5 waters mostly upgraded to Class 2. Acid mine drainage (mineral pollution) is much more difficult to control and there is little hope of improving the Class 2 and 3 waters of smaller rivers in the coal mining areas. The larger rivers of the coalfields however, are unlikely to be degraded to the same extent (due inter alia to the dilution effect caused by higher flow volumes, and more stringent pollution control requirements). It should be borne in mind that the classification system does not directly refer to pollution, since polluted waters can fall into any one of the five classes (mainly Classes 3 - 5).

(v) Many of the surface waters of Natal/KwaZulu are scale-dissolving with a relatively high saturation pH value (pH_S), and have a low buffering power which makes pH_S correction difficult. (A high pH_S value - with reference to calcium carbonate - denotes the chemical ability of water to attack concrete, asbestos-cement and certain metal fittings) (Kemp, 1971; 1977). Rivers in the province carry considerable suspended sediment loads during the rainy season and algal blooms are common. The self-purifying powers of Natal/KwaZulu rivers are high due to a shallow depth, swift turbulent flow and prolific biological activity. In view of the shallowness of the rivers, self-purification proceeds mainly on the river bed (after deposition of the organic material), which results in relatively deep, although not extensive, oxygen sags. The surface waters of Natal/KwaZulu can essentially be divided into two categories, namely, a series of chlorided waters and a series of sulphated waters. Most unpolluted rivers and dams have chlorided waters, with very few unpolluted rivers and dams belonging to the sulphated waters category. Polluted Natal/KwaZulu river waters however, especially those receiving sulphate-rich drainage water from coal mines, fall into the sulphated waters category*. Chlorided waters have a higher sodium content for a given total dissolved solids (TDS) value. These waters may present a sodium hazard when used for irrigation, with the sodium adsorption ratio (a better index of sodium hazard), some two or three times greater than for sulphated waters. Chlorided waters have slightly higher pH_S values than sulphated waters of comparable TDS, although pH values are very similar. Most waters of either series have scale-dissolving properties when the TDS is approximately 100 mg ℓ^{-1} or less, and scale-forming properties when the TDS is some 300 mg ℓ^{-1} or more. Sulphated waters are rather more corrosive to metals. Differences in TDS influence the properties of both types of waters far more than differences in chemical composition. In essence, low TDS is invariably associated with low pH, poor buffering powers, high pH_S, scale-dissolving properties and low total and permanent hardness.

* See Thompson, J.G., 1980. Acid mine waters in South Africa and their amelioration, Water SA, VOL 6(3), p. 130 - 134.

High TDS is virtually always accompanied by a high pH, strong buffering powers, low pH_S, scale-forming properties and high total and permanent hardness (Kemp, 1971; 1977).

(vi) According to Cass (1982)*, the Mzinyashana River (headwaters), the Wasbank River and the lower reaches of the Mkuze River are totally unsuitable for irrigation. Many of the larger rivers in the interior of Natal/KwaZulu - especially in the central and southern parts of the province - have good irrigation quality water. Difficulties are apparent in some rivers of northern Natal/KwaZulu (the Pongola and Mkuze rivers), while many of the smaller rivers throughout Natal/KwaZulu also have poor irrigation quality water. A steady deterioration in water quality is evident in most rivers with passage towards the sea, which also has implications for irrigation.

(vii) The conversion for μmho cm^{-1} (the original units used in Table O9) to mS m^{-1} is as follows: 10 μmho cm^{-1} = 0,01 mmho cm^{-1} = 1 mS m^{-1} = 0,001 S m^{-1}. In general, conductivity (mS m^{-1}) at 20°C x 6,7 = total dissolved solids (mg ℓ^{-1}) (Kemp, 1977).

A different (mapped) version of the river water quality concept (for the whole of South Africa), was completed by O'Keeffe in 1985**. The map was a preliminary attempt to highlight current knowledge on the conservation status of South African rivers, and to identify sites which should be protected. Five categories of river reaches were defined, namely, blue, green, brown, red and black. The colour blue was used to denote insufficient data and accordingly no assessment. Green denoted pristine reaches in which the channel and catchments had not been significantly modified. Brown indicated slight (although significant) changes such as mild pollution, increased siltation, water regulation (for example, dams), the presence of alien animals or plants, and disturbed catchment vegetation. The colour red implied that substantial changes were evident, for instance, locally severe pollution, major water regulation and dominant alien species. The colour black identified river reaches where all natural aspects of the channel and the catchment were badly degraded.

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* See Cass, A., 1982. Irrigation water quality of some Natal rivers, Water SA, VOL 8(3), p. 155 - 164. (Cass divided surface waters used for irrigation purposes into four classes, with reference to specific water, climatic and soil parameters as well as the salt tolerance of certain crops).

** See O'Keeffe, J.H., 1985. The conservation status of South African rivers, scale 1 : 2 500 000, obtainable from the Department of Regional and Land Affairs, Private Bag, Mowbray, 7705. The map was produced as a companion to the following publication: O'Keeffe, J.H. (ed), 1986. The conservation of South African rivers, South African National Scientific Programmes Report No. 131, Foundation for Research Development, CSIR, Pretoria, 117 p.

Sites, river reaches or rivers of outstanding conservation importance were likewise marked on the map. In Natal/KwaZulu, these areas are the Pongolo and Mkuze floodplains; the Enseleni, Upper Black Mfolozi and Mfolozi rivers; the Slang, Buffalo, Tugela and Mooi rivers; and the Mvoti, Upper Mgeni, Mgeni at Howick Falls, Mkomazi, Fafa and Mtamvuna rivers. Readers should note that while the O'Keeffe map includes factors other than water quality per se, a comparison of the CSIR/Natal Town and Regional Planning Commission maps and the O'Keeffe map would provide overview (visual) data on water quality issues in Natal rivers. Umgeni Water (see earlier in the chapter), has developed a water quality index (Table O10), a visual summary of which is available on GIS. The latter data are a valuable source of current information on water quality in the old Umgeni Water supply area.

Relatively little detailed long term information has been published on surface water quality in Natal/KwaZulu (excluding river faunal studies). The only major regional studies undertaken to-date, are the CSIR/Natal Town and Regional Planning Commission reports, a few other pollution surveys, and the (less accessible) CSIR Natal Rivers Research Fellowships Steering Committee reports. Certain published data are available from the Department of Water Affairs and Forestry (discussed earlier in the chapter). Sub-regional surveys usually undertaken over a limited time period - and with a restricted number of determinands examined - have primarily involved the Pongolo and Mfolozi floodplains, St Lucia, the Pietermaritzburg Metropolitan Area and the Durban Functional Region. (Refer to the bibliographic database). Not much published information is available on acid mine drainage in northern Natal/KwaZulu (see NTRPC reports VOL 13, Parts 3, 4 and 7); and water quality in general in wetlands. Urban catchment studies, centred on Durban and Pinetown, have only fairly recently received detailed attention in the literature. Data on "estuaries" have been summarized in several Natal Town and Regional Planning Commission reports written by G. Begg (see the relevant chapter). A series of studies was undertaken by the CSIR per se, and in association with the University of Natal, on water quality in selected impoundments in Natal/KwaZulu. A number of water quality studies have been undertaken by the CSIR, and the University of Zululand, on lakes in the Richards Bay-St Lucia environs. Various other reports are listed in the bibliographic database.

Table O10: The water quality index for rivers and dams developed by Umgeni Water.

Determinand	Concentration range	Score	Weighting factor
Rivers			
Electrical conductivity ($mS\ m^{-1}$)	<10	95	
	10 - 20	82	
	20 - 40	67	
	40 - 60	52	
	>60	37	2
Suspended solids ($mg\ \ell^{-1}$)	<4	95	
	4 - 8	82	
	8 - 15	67	
	15 - 25	52	
	>25	37	5
Turbidity (Nephelometric turbidity units - NTU)	<5	95	
	5 - 12	82	
	12 - 20	67	
	20 - 30	52	
	>30	37	1
Total organic carbon ($mg\ \ell^{-1}$)	<1,0	95	
	1,0 - 1,5	82	
	1,5 - 2,5	67	
	2,5 - 5,0	52	
	>5,0	37	6
Nitrate ($mg\ \ell^{-1}$)	<0,2	95	
	0,2 - 0,5	82	
	0,5 - 1,2	67	
	1,2 - 2,0	52	
	>2,0	37	4
Soluble reactive phosphorus (also referred to as soluble ortho-phosphate (as P) in the literature) ($\mu g\ \ell^{-1}$)	<5	95	
	5 - 10	82	
	10 - 20	67	
	20 - 50	52	
	>50	37	7

Table O10: The water quality index for rivers and dams developed by Umgeni Water (continued).

Determinand	Concentration range	Score	Weighting factor
Total phosphorus ($\mu g\ \ell^{-1}$)	<21	95	
	21 - 40	82	
	40 - 100	67	
	100 - 200	52	
	>200	37	3
E. coli (Counts 100 $m\ell^{-1}$)	0 - 100	95	
	101 - 499	82	
	500 - 1 200	67	
	1 201 - 5 000	52	
	>5 000	37	8
Dams			
Electrical conductivity ($mS\ m^{-1}$)	<10	95	
	10 - 20	82	
	20 - 40	67	
	40 - 60	52	
	>60	37	2
Suspended solids ($mg\ \ell^{-1}$)	<4	95	
	4 - 8	82	
	8 - 15	67	
	15 - 25	52	
	>25	37	6
Turbidity (Nephelometric turbidity units - NTU)	<5	95	
	5 - 12	82	
	12 - 20	67	
	20 - 30	52	
	>30	37	3

Table O10: The water quality index for rivers and dams developed by Umgeni Water (continued).

Determinand	Concentration range	Score	Weighting factor
Total organic carbon (mg ℓ^{-1})	<1,0	95	
	1,0 - 1,5	82	
	1,5 - 2,5	67	
	2,5 - 5,0	52	
	>5,0	37	7
Soluble reactive phosphorus (also referred to as soluble ortho-phosphate (as P) in the literature) (μg ℓ^{-1})	<2,0	95	
	2,0 - 3,5	82	
	3,5 - 5,0	67	
	5,0 - 7,0	52	
	>7,0	37	5
Total phosphorus (μg ℓ^{-1})	<21	95	
	21 - 40	82	
	40 - 100	67	
	100 - 200	52	
	>200	37	4
E. coli (Counts 100 mℓ^{-1})	<50	95	
	50 - 100	82	
	100 - 500	67	
	500 - 1 200	52	
	>1 200	37	1
Chlorophyll a (μg ℓ^{-1})	<1,5	95	
	1,5 - 3,0	82	
	3,0 - 5,0	67	
	5,0 - 9,0	52	
	>9,0	37	3

Table O10: The water quality index for rivers and dams developed by Umgeni Water (continued).

Determinand	Concentration range	Score	Weighting factor
Taste and odour algae (Counts 1 $m\ell^{-1}$)	<250	95	
	250 - 1 000	82	
	1 000 - 3 000	67	
	3 000 - 8 000	52	
	8 000 - 15 000	37	
	>15 000	15	10
Algae numbers (Counts 1 $m\ell^{-1}$)	<2 000	95	
	2 000 - 5 000	82	
	5 000 - 10 000	67	
	10 000 - 50 000	52	
	>50 000	37	9
Filter clogging algae (Counts 1 $m\ell^{-1}$)	<750	95	
	750 - 1 200	82	
	1 200 - 1 700	67	
	1 700 - 3 000	52	
	>3 000	37	8

Source: After Umgeni Water, Pietermaritzburg, 1994.

Note:

(i) The above determinands are assessed on a weekly basis for selected river/dam sampling sites. The water quality index for rivers/dams is calculated for each month, using the median values of weekly results (for each sampling site). The index accordingly, provides for comparisons of water quality at various river and dam sampling sites respectively. Temporal variations are also apparent.

(ii) The determinands were selected to reflect specific water properties as listed below:

Rivers	Problem indicated	Impoundments
Electrical conductivity	Total dissolved solids, inorganic pollution	Electrical conductivity
Suspended solids	Particulate matter, erosion, siltation	Suspended solids
Turbidity	Particulate matter, erosion, coagulant demand, algal growth	Turbidity
Total organic carbon	Indication of organic pollution, algal growth, oxygen demand potential	Total organic carbon
Nitrate	Nutrients indicating potential for algal growth	
Ammonia	Sewage discharge, anaerobic conditions, nutrients indicating potential for algal growth	
	Trophic status, treatment problems, indication of algal biomass production	Chlorophyll a
	Trophic status, specific treatment problems	Taste and odour causing algal numbers
	Trophic status, treatment problems, oxygen demand, possible recreational impairment, possible health hazards	Total algal numbers
	Specific treatment problems	Filter clogging algal numbers
Soluble reactive phosphorus	Nutrients indicating potential for algal growth	Soluble reactive phosphorus
Total phosphorus	Trophic status, nutrients indicating potential for algal growth	Total phosphorus
E. coli	Faecal pollution	E. coli

Note: Trophic (energy) status refers to the degree of excessive enrichment by plant nutrients, of a water body (especially dams and lakes) namely, the extent of eutrophication. (See Section 15.15 later in the chapter).

(iii) The water quality index applies to the old supply area of Umgeni Water (see the chapter on the surface water resources of Natal/KwaZulu). The index will be re-assessed when sampling is undertaken in the enlarged supply area.

(iv) A score is assigned for each range of every determinand. The scores are then multiplied by the respective weighting factor for each determinand. The total score for each sampling site is then divided by the sum of the weighting factors for rivers and dams respectively (namely, 36 and 58), to provide a weighted score or class value. The class values are as follows. Note that an additional class applies only to dams (Class F - bad).

Class value	Class	Description
>85	A	Excellent
75 - 85	B	Good
60 - 75	C	Satisfactory
45 - 60	D	Poor
30 - 45	E	Unsatisfactory
<30	F	Bad

(v) The following example illustrates the procedure. Assume that river sampling site Mgeni 1 has a median monthly value of 50 mS m^{-1} (conductivity); 17 mg ℓ^{-1} (suspended solids); 25 NTU (turbidity); 3,5 mg ℓ^{-1} (total organic carbon); 1,8 mg ℓ^{-1} (nitrate); 37 μg ℓ^{-1} (soluble reactive phosphorus); 132 μg ℓ^{-1} (total phosphorus) and >5 000 counts 100 mℓ^{-1} (E. coli). The required calculation is as follows: (52 x 2) + (52 x 5) + (52 x 1) + (52 x 6) + (52 x 4) + (52 x 7) + (52 x 3) + (37 x 8) = $\frac{1\,752}{36}$ = 48,7 = Class D water.

(vi) Any river site where the median E. coli result exceeds 10 000 counts 100 mℓ^{-1}, or where the median electrical conductivity exceeds 60 mS m^{-1}, or where the median ammonia concentration exceeds 0,2 mg ℓ^{-1} (the latter not reflected in the above table), will automatically be rated as Class E water.

(vii) Where median monthly E. coli counts of 10 000 organisms; 2 000 organisms and 100 organisms 100 mℓ^{-1} are found in rivers and dams, the recreational (high contact) health risk is assessed by Umgeni Water as serious, moderate and negligible respectively.

(viii) Previously proposed river water quality criteria for the Mgeni River can be found in Schoonbee, H.J. and Kemp, P.H., 1965. An account of the Umgeni River survey, CSIR Research Report No. 325, National Institute for Water Research, CSIR, Pretoria, 63 p. + app.

It is evident that there is a pressing need for review documents on surface water quality in Natal/KwaZulu which collate all the existing information. One of the main problems with water quality studies is the cost of data collection, and the availability of laboratory facilities and staff. It is for these reasons that major long term studies can only be undertaken by Government or quasi-government agencies. The longest running research programme on surface water quality in Natal/KwaZulu, namely, the CSIR Natal Rivers Research Fellowships Steering Committee report series will never be repeated - on the same scale - due inter alia to a shortage of research funds and privatisation of the CSIR. A comprehensive assessment of the data is required to determine changes in water quality over the 34 year research period. Such an analysis could be used in support of water quality management strategies (for example, the RWQO approach) currently being developed by the Department of Water Affairs and Forestry. The data could also provide a valuable reference benchmark for detailed river basin surveys undertaken by consulting engineering firms working in association with Government departments and/or water and irrigation boards. It is interesting to record the involvement of Umgeni Water and the Department of Water Affairs and Forestry in the Mgeni Catchment Water Quality Management Plan study. The study is presently being finalized by the consulting engineering firm Ninham Shand Inc., Pretoria. Also involved is BKS Inc., Pretoria. A number of reports, following from the study, will be issued in due course.

It should be noted that the Directorate of Strategic Planning of the Department of Water Affairs and Forestry in Pretoria has a comprehensive GIS database. The system incorporates (or will incorporate) numerous data on topography, catchment areas, streams and rivers; flow gauging stations, rain/evaporation/temperature/wind speed and solar radiation measurement sites as well as water quality sampling points. Other data are flood, geohydrological and hydrological zones; mean annual rainfall zones; evaporation and sediment production zones; climate, vegetation and soil type regions; lightning zones; irrigation-potential areas, and afforestation-potential regions. Also included in the database (with varying degrees of completeness) is the location of powerlines, pipelines, canals, railways and roads, bridges and tunnels, plus sewer and water networks within local authority areas. Further locality data include windmills and other pumps, dams, boreholes, mine outfalls, industrial outfalls, purification works and waste disposal sites; irrigated and non-irrigated farming areas; "estuaries", wetlands, pans and nature reserves; and water and irrigation board areas together with Joint Services Board and municipal areas, as well as magisterial and census enumeration districts. Such data - with the later addition of missing and current information - provide comprehensive instruments for catchment management in general, and water quality management in particular.

A recent technological development was the use of Integrated Environmental Management (IEM) procedures in terms of GIS, for the Letaba and Sabie River catchments in the eastern Transvaal. The study pioneered the use of both IEM and GIS with regard to environmentally sensitive planning in the two highly stressed catchments*. The techniques evolved are suitable for other catchments in South Africa.

15.11.2 Some catchment water quality issues in Natal/KwaZulu

Rivers and dams reflect the state of the catchment which they drain. Very often the waste generated in a particular area ends up in rivers draining the entire region. Such waste (the self-purification processes of rivers notwithstanding), ultimately reaches the coastal zone with serious effects on "estuaries". It is a fact of life that rivers in Natal/KwaZulu (as in most other parts of the world), show an inevitable decline in water quality with progression towards the sea. Issues of concern include the destruction of wetlands and riverine vegetation with a reduction in flood regulation and water purification properties; the loss or degradation of high potential agricultural land due to mismanagement and urbanization, and the impacts of industrial contamination and rapid urbanization on river systems in general - in some cases resulting in rivers becoming little more than stormwater drains. Other problems are the often "mixed blessings" of impoundments as well as irrigation schemes, and the decline within **less than one lifetime**

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* A series of five reports outlining the study should be consulted for further information. All reports are available from the Water Research Commission, Pretoria. (The executive summary provides a useful overview). See Van Riet, W.F., J[anse] van Rensburg, J.D., Dreyer, R. and Slabbert, S., 1994. Geographic Information Systems (GIS) and the Integrated Environmental Management (IEM) procedure in the planning and management of water resources: executive summary, WRC Report No. 300/1/94, Water Research Commission, Pretoria, 8 p. + app.

of the once pristine estuaries of Natal/KwaZulu*. Although standards of living (for some) have risen, it is often the poor while part of the causal chain, who suffer the most from environmental degradation. Health impacts, both on man and the environment continue to escalate, which science (even with sufficient financial backing) can only partly repair - but seldom restore.

Reference has already (briefly) been made to the problems of acid mine drainage and salinity in northern Natal/KwaZulu, as well as to industrial pollution "hot-spots" mainly in the Durban-Pietermaritzburg Metropolitan Axis. The need for an up-to-date review of water quality in the province has also been discussed. In this section, some emphasis is placed on sediment in Natal/KwaZulu, as well as on water quality modelling for catchment management purposes. In this regard, the development of a distributed water quantity/quality modelling system for the Mgeni catchment is regarded as imperative. The catchment, as the primary catchment in Natal/KwaZulu, provides for the water needs of some 45% of the population of the province, where approximately 20% of South Africa's Gross National Product is produced (Breen, Akhurst and Walmsley, 1985)**. The modelling system (when completed) will link rural, urban and industrial land uses and accordingly, point and non-point pollution sources. Considerable work has already been

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* Symptomatic of the catchment ills evident in Natal/KwaZulu, is the large scale death of fish (due to oxygen starvation caused by sediment-laden waters), which occurs on an all-too-frequent basis in the lowest reaches of the Mfolozi catchment. The gratuitous fall-out often includes the deposition of tonnes of debris on the beaches in the environs of St Lucia. According to Densham, W.D., 1994. Personal communication, Natal Parks Board, Pietermaritzburg, most fish kills occur during the first major spring rains (the "first flush" effect discussed later), when waters of the Mfolozi River are "too thick to drink, too thin to plough". Soil erosion and hence the production of sediment has also assumed alarming proportions in the Tugela catchment, with inter alia a reduced land carrying capacity and serious flooding evident. A 100-fold increase in sediment yield has reduced the Tugela Estuary from a system deep enough to allow the entry of Royal Navy gunboats at the turn of the 19th Century, to a system which today is less than one metre deep, and which is accordingly referred to as a river mouth (Begg, G., 1986. The wetlands of Natal (Part 1): an overview of their extent, role and present status, Natal Town and Regional Planning Commission Report, VOL 68, Pietermaritzburg, 114 p.). Strong emphasis was placed by the Water Research Commission on catchment management as an important research need for South African hydrology. (See Cousens, D.W.H., Braune, E. and Kruger, F.J., 1988. Surface water resources of South Africa: research needs, WRC Report No. AV 1/88, Water Research Commission, Pretoria, 79 p.).

** See Breen, C.M., Akhurst, E.G.J. and Walmsley, R.D. (eds), 1985. Water quality management in the Mgeni catchment, Natal Town and Regional Planning Commission Supplementary Report, VOL 12, Pietermaritzburg, 27 p. See also, Walmsley, R.D. and Furness, H.D., 1987. A programme description for water resource research in the Mgeni catchment, Natal Town and Regional Planning Commission Supplementary Report, VOL 21, Pietermaritzburg, 27 p.

undertaken on both water quantity and quality aspects of the Mgeni modelling system*. The research reported on here however, mainly concerns water quality. A different (runoff) flow-weighted sampling procedure, as opposed to the usual routine grab sampling method (discussed later) was adopted in the research. One of the objectives was to establish the relationship between land use and nutrient/pollutant (determinand) concentrations, and the export potential of specific catchments. The information provided in the following pages can be read to varying degrees at two levels, namely, from a modelling viewpoint as well as in terms of water quality per se - both with reference to given land uses.

After a discussion of sediment, the next part of the chapter deals with the pollution potential of urban stormwater runoff. Rural and peri-urban catchments are then examined. The following section concentrates on the impact of urbanization on "estuaries". The latter study reflects the shift in emphasis from resource utilization and exploitation to resource management - where environmental water requirements for estuaries for example - must be considered along with potable, agricultural and industrial needs (Gardner and Archibald, 1992)**. Finally, potable water quality in peri-urban and rural areas of KwaZulu is discussed.

15.11.3 Sediment

(a) Sediment processes

While the sediment load of a river provides a general guide to the status of erosion in the catchment, sediment per se does not reflect actual soil loss since not all the eroded soil enters the channel. Concern has long been expressed regarding suspended sediment in South African rivers (Midgley, 1952; Roberts, 1952; Middleton and Oliff, 1961; Schwartz

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* The modelling system is being developed by the Department of Agricultural Engineering, University of Natal, Pietermaritzburg. Relevant research is also being undertaken by the Department of Hydrology, University of Zululand, Private Bag X1001, KwaDlangezwa, 3886, as well as by the Division of Water Technology, CSIR, P O Box 17001, Congella, 4013. A first report on the Mgeni modelling system (excluding water quality) is available. See: Tarboton, K.C. and Schulze, R.E., 1992. Distributed hydrological modelling system for the Mgeni catchment, WRC Report No. 234/1/92, Water Research Commission, Pretoria, 111 p.

** See Gardner, B.D. and Archibald, C.G.M., 1992. Catchment development impacts on river and estuarine systems, Natal Town and Regional Planning Commission Report, VOL 78, Pietermaritzburg, 21 p.

and Pullen, 1966)*. Sediment in Natal rivers was specifically addressed by the CSIR, Durban, in terms of certain Natal Rivers Research Fellowships Steering Committee reports (see the bibliographic database), which included the work undertaken by Middleton and Oliff (1961). The practical implications of suspended sediment for water treatment resulted in a report by Wylie (1968)**, with special reference to the Mvoti, Mdloti and Mkomaas rivers.

Wylie (1965)*** in a study of 11 rivers in Natal found that the Tugela River carried the highest suspended sediment load, while the Mgeni at Dargle and the Lions River had the lowest load. Wylie observed that the maximum suspended sediment concentrations in Natal rivers generally, occurred during the summer months, although peak monthly loads were often evident during periods of less than maximum runoff (especially in the case of the larger rivers where runoff was high). Middleton and Oliff (1961) found that sediment loads did not increase in proportion to runoff; nor was any direct relationship apparent between sediment concentration and the discharge stage of the Tugela River. Both Wylie (1965) and Middleton and Oliff stressed that the sampling and analysis of sediment is problematic and may be subject to considerable errors. It is possible, for instance, that much of the total sediment transport of a river for a period of several years can occur during a major flood - perhaps in one day - when both scour and transport properties are high****.

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* See Midgley, D.C., 1952. A preliminary survey of the water resources of the Union of South Africa, Ph.D. Thesis, VOL 1, 315 p., and VOL 2, p. 316 - 529., Faculty of Engineering, University of Natal, [Pietermaritzburg], as well as Roberts, D.F., 1952. Analysis of the amount of silt carried by South African rivers, Transactions of the South African Institution of Civil Engineers, VOL 2(5), p. 147 - 159. (See also Discussion, 1952, VOL 2(11), p. 279 - 291). See in addition: Middleton, E.A. and Oliff, W.D., 1961. Suspended silt loads in the Tugela River, Civil Engineer in South Africa, VOL 3(12), p. 237 - 244. (See also Discussion, 1962, VOL 4(6), p. 114 - 117). Examine also Schwartz, H.I. and Pullen, R.A., 1966. A guide to the estimation of sediment yield in South Africa, Civil Engineer in South Africa, VOL 8(12), p. 343 - 346. (See also Discussion, 1967, VOL 9(9), p. 232).

** See Wylie, S.C., 1968. Variables in the flocculation of some Natal river waters, CSIR Research Report No. 264, National Institute for Water Research, CSIR, Pretoria, 19 p. + app.

*** See Wylie, S.C., 1965. Interim report: the influence of river sediment loads on water treatment in Natal - the measurement of suspended sediment loads in Natal rivers, Natal Rivers Research Fellowships Steering Committee Meeting on 6th December 1965, Main Project No. 715, Code No. 6201/9715, Research Group for Natal, National Institute for Water Research, CSIR, Durban, 6 p. + app.

**** See Rooseboom, A. and Le Grange, A., 1992. Equilibrium scour in rivers with sandbeds, Water SA, VOL 18(4), p. 287 - 292.

Rooseboom (1992 - see below), observed that suspended sediment loads in South African rivers mainly consist of particles <0,2 mm in diameter. (It should be noted that the bed load - the proportion of rolling sediment - seldom exceeds 10% of the total sediment load). According to Rooseboom, it is not the carrying capacity of the river which defines the actual sediment load, but rather the availability of sediment in the catchment (dependent in turn, on several factors such as climate, vegetation cover, soils, geology, topography and catchment size). Rooseboom suggested that it is probably only in the very flat, dry areas of southern Africa, that the sediment carrying capacity of runoff is the limiting factor in determining the sediment loads of rivers. By contrast, it would appear that numerous rivers in the wetter regions have the potential for transporting more sediment than is usually produced in their catchments. Also of relevance is that low sediment loads in waters released from many dams result in an increase in the transport capacity of the water. Rooseboom found that sediment loads tend to be high (in a high runoff period), following long periods of low flows, with the converse also true. The same trend was noted by the CSIR in Natal/KwaZulu rivers (Anonymous, 1990)*. In this regard, Roberts (1973)** in an examination of several South African rivers (including the Tugela River), found a typical double peak in monthly sediment loads. The first peak is in early summer, usually in November (coinciding with the onset of seasonal runoff), where the first floods of the season remove much of the material accumulated in catchments during the dry winter. A second peak is evident during the months of maximum runoff (usually January and February), where the sediment load is related inter alia to the rate of sediment production (probably higher in summer).

The (since defunct) Umgeni River Catchment Association as well as the city engineers of both Durban and Pietermaritzburg were deeply concerned about the sedimentation of major storage dams in the Mgeni catchment (as long ago, as the early 1950s). Various remedial measures were undertaken including the construction of sediment (flood) bypass works at the Nagle and Shongweni dams. (See the chapter on soils and soil erosion). Other measures included the sponsorship of an essay competition on pollution for black schools,

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* See Anonymous, 1990. Hydro factors affecting siltation in the lower reaches of Natal/KwaZulu rivers, CSIR Report No. EMA-D 9006, Division of Earth, Marine and Atmospheric Science and Technology, CSIR, Stellenbosch, 22 p. + app.

** See Roberts, P.J.T., 1973. An explanation of a "double peak" phenomenon in mean monthly suspended sediment concentrations for some South African rivers, Technical Note No. 42, Department of Water Affairs, Pretoria, 9 p. + app.

with prizes in the form of bursaries and school books; as well as sponsorship of short training courses on basic soil conservation and anti-pollution practices for chiefs and indunas. Much attention was devoted to the Zwartkops Location (the present-day Vulindlela District of KwaZulu) in the Henley Dam catchment area (Harris, 1993)*. Umgeni Water (as successor to the Umgeni River Catchment Association), together with other agencies such as the Natal Parks Board and the Wildlife Society of Southern Africa, has developed an educational programme for school children involving videos, pamphlets and water quality testing kits. The emphasis of the latter programme is on overall water quality issues, and catchment management principles in particular.

(b) Sediment overview studies

Doornkamp and Tyson (1973) as well as Rooseboom (1975; 1978)**, examined sediment across South Africa generally. Le Roux (1990)*** reviewed sediment production research in South Africa, and found evidence of considerable variations in research findings. With the exception of some work undertaken specifically for Natal/KwaZulu, most sediment studies in South Africa have concentrated on the western half of the country (see the bibliographic database). McCormick, Cooper and Mason (1992)****, in an analysis of sediment yield in Natal/KwaZulu rivers suggested that sediment data provided by Rooseboom were overestimates, and that sediment yield for the Natal/KwaZulu coastline should be re-examined. An important study of the hydrological factors influencing sedimentation in the lower reaches of rivers and "estuaries" in Natal/KwaZulu, based on Rooseboom (1975), was undertaken by the CSIR, Stellenbosch (Anonymous, 1990). (Refer to the chapter on estuaries, where sediment data for the 71

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* Harris, D.V., 1993. Personal communication (retired City Engineer, Pietermaritzburg Corporation), Pietermaritzburg.

** See Doornkamp, J.C. and Tyson, P.D., 1973. A note on the areal distribution of suspended sediment yield in South Africa, Journal of Hydrology, VOL 20, p. 335 - 340., as well as Rooseboom, A., 1975. Sedimentproduksiekaart vir Suid-Afrika (gebaseer op streeksindeling deur Harmse), Technical Report No. TR 61, Department of Water Affairs, Pretoria, 5 p. + app., and Rooseboom, A., 1978. Sedimentafvoer in suider-Afrikaanse riviere, Water SA, VOL 4(1), p. 14 - 17.

*** See Le Roux, J.S., 1990. Spatial variations in the rate of fluvial erosion (sediment production) over South Africa, Water SA, VOL 16(3), p. 185 - 194. (A useful reference work in this regard is Moon, B.P. and Dardis, G.F. (eds), 1988. The Geomorphology of Southern Africa, Southern Book Publishers, Johannesburg, 320 p. See chapters 3 (fluvial systems) and 12 (soil erosion) in particular).

**** See McCormick, S., Cooper, J.A.G. and Mason, T.R., 1992. Fluvial sediment yield to the Natal Coast: a review, Southern African Journal of Aquatic Sciences, VOL 18(1/2), p. 74 - 88.

main "estuaries" in Natal/KwaZulu are presented). Relatively few comprehensive studies on sediment can be found in the South African literature. It is apparent that further research is required inter alia in Natal/KwaZulu, in order to effectively estimate the sediment yields of rivers - a point emphasized by Rooseboom (1992)*.

Rooseboom (1992) revised his earlier work by incorporating more recent data, and by using advanced techniques. A new sediment yield map for South Africa was produced using GIS procedures. Rooseboom based his study inter alia on rainfall erosivity; mean slope (reflecting energy gradients for the definition of sediment transport capacities); agricultural land use, and a basic soil erodibility index for South Africa. The report contains a comprehensive review of theoretical concepts. The importance of long term data for the accurate determination of mean annual sediment loads was stressed (given the high degree of daily and annual variability of sediment carried by South African rivers). Rooseboom divided South Africa into nine distinct sediment yield regions. These regions were subdivided into sub-regions with high, medium and low sediment yield potential depending on soil erodibility. Natal/KwaZulu is in Region 4 (which includes other parts of South Africa as well as Swaziland). Rooseboom found that the measured sediment yield values for Region 4 varied between 5 - 723 t km^{-2} y^{-1}. The values were based on sediment yield data for 20 reservoirs - of which 13 are in Natal/KwaZulu - as well as three sediment gauging stations in the province. Most of the reservoirs examined are in the

* See Rooseboom, A., 1992. Sediment transport in rivers and reservoirs: a southern African perspective, WRC Report No. 297/1/92, Water Research Commission, Pretoria, various pages, and Rooseboom, A., Verster, E., Zietsman, H.L. and Lotriet, H.H., 1992. The development of the new sediment yield map of southern Africa, WRC Report No. 297/2/92, Water Research Commission, Pretoria, various pages and maps. (Two maps (no scale given) are presented in the latter report, namely, Revised sediment yield map of southern Africa (1992) - sediment yield regions; and the Revised sediment yield map of southern Africa (1992) - broad scale soils and slopes. Larger scale versions of the maps are available. The main report includes a detailed bibliography). Various maps of sediment yield per primary drainage region based on Rooseboom (1978) can be found in Middleton, B.J., Lorentz, S.A., Pitman, W.V. and Midgley, D.C., 1981. Surface water resources of South Africa, VOL V: drainage regions MNPQRST. The eastern Cape Part 1 (Text), various pages, and Part 2 (Appendices), various pages, HRU Report No. 12/81, Hydrological Research Unit, University of the Witwatersrand, Johannesburg, as well as in Pitman, W.V., Middleton, B.J. and Midgley, D.C., 1981. Surface water resources of South Africa, VOL VI: drainage regions UVWX. The eastern escarpment Part 1 (Text), various pages, and Part 2 (Appendices), various pages, HRU Report No. 9/81, Hydrological Research Unit, University of the Witwatersrand, Johannesburg.

Mgeni and Tugela catchments*. Rooseboom observed that sugar cane areas (with a high sediment yield potential) are not well represented, where sediment yields in excess of 1 000 t km^{-2} y^{-1} are possible. Very little data similarly, are available for far northern Natal/KwaZulu. Rooseboom calculated a standardized regional mean sediment yield for Region 4, of 155 t km^{-2} y^{-1}. This figure should be used to calculate weighted mean sediment yield values for various catchment sizes within Region 4, depending on soil erodibility (high, medium and low potential). Rooseboom stressed that the data should be used with local conditions in mind, especially where available information (such as for the sugar growing areas), is scarce. The Rooseboom report is an important document which should be carefully examined by readers interested in sediment problems.

15.11.4 Water quality of urban catchments in Natal/KwaZulu**

The Division of Water Technology, CSIR, Durban, in association with the Natal Town and Regional Planning Commission reported on water quality with special reference to urban catchments in the Durban Functional Region. The overall aim of the programme was to investigate the pollution potential of non-point urban stormwater runoff - with a consequent assessment of the effects of existing urban development on the receiving water quality of rivers. The data are accordingly available for the planning of future land use zones, with a knowledge of the water quality and pollution abatement implications. Urbanization in catchments results in increases in both runoff volumes and peak flows, given the large area of impervious surfaces (including roofs), the reduction of natural storage, and the availability of efficient drainage channels. Urbanization also greatly increases pollutant loads to receiving waters due to the larger volumes of water. The initial removal (erosion), entrainment and further transport of particulate matter is

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* Measured sediment yield data per unit area provided by Rooseboom (over different time periods), for the 13 dams in Natal/KwaZulu, revealed that the yields varied from 10 - 723 t km^{-2} y^{-1} in the following order: Midmar (Mgeni); Craigieburn (Mnyamvubu); Albert Falls (Mgeni); Henley (Msunduze); Camperdown (Mlazi); Wagendrift (Bushmans); Windsor (Klip); Hluhluwe (Hluhluwe); Chelmsford (Ngagane); Shongweni (Mlazi); Spioenkop (Tugela); Pongolapoort (Pongola) and finally, Hazelmere (Mdloti) with the highest yield. Data are also presented on the percentage of sediment in the dams. Such data are, to some extent, an update of the information contained in the chapter on the surface water resources of Natal/KwaZulu.

** Discussion based on Simpson, D.E., 1992. Urban runoff pollution research in Natal, Natal Town and Regional Planning Commission Supplementary Report, VOL 37, Pietermaritzburg, 36 p. (Some overall stormwater runoff quality data for South Africa are provided in Anonymous, 1991. First report on the situation of waste management and pollution control in South Africa, January 1991: report to the Department of Environment Affairs by the CSIR Programme for the Environment, Report No. CPE 1/91, CSIR, Pretoria, 359 p. + app.).

enhanced by higher runoff velocities. Concentrated runoff from large urban areas can lead to increased water treatment costs, the degradation of rivers and "estuaries", and the transmission of bacteriological and viral diseases through direct water contact in dams and rivers (Simpson, 1992).

Pollutants are generated in urban areas through a number of physical processes such as normal commercial and industrial activities; the accidental spillage of materials; the escape of waste disposal site leachate; littering and dumping; the erosion of buildings and paved surfaces; vehicle wear and emissions, and general decay. Runoff therefore contains a wide variety of pollutants in both soluble and particulate forms. Pollutants can range from simple inorganic compounds, for example nitrates and phosphates, to complex organic compounds. Field, Tafuri and Masters (1977, quoted in Simpson, 1992) observed that between 40 - 80% of the total organic load of a city entering a receiving watercourse, is due to non-point sources (sources other than plants treating domestic and industrial effluents). The quality of the "first flush" runoff after a long dry period is especially problematic. According to Field (1985, quoted in Simpson, 1992) some 50% of the 129 priority pollutants listed by the United States Environmental Protection Agency have been detected in urban runoff studies in the USA. These chemicals include mutagenic substances with a potential for bioaccumulation, and hence with specific health implications. The atmosphere is a further source of pollutants in the form of gases and aerosols, with both dry and wet deposition occurring (the latter is of particular significance in acid rain). Street surfaces are the major collection area for wear and emission products from vehicles with zinc, lead, cadmium, copper and asbestos evident (Wigington, Randall and Grizzard, 1983, quoted in Simpson, 1992). Between 40 - 90% of the contaminants on streets occur as particles smaller than 0,25 mm in diameter (Barkdoll, Overton and Betson, 1977, quoted in Simpson, 1992). Normal street cleaning methods however, are not really effective in removing these fine particles (which contain much of the metal contaminants and adsorbed phosphorus). Sediment loads in urban areas are derived from construction sites and soil erosion in general.

Simpson (1992) examined three different types of catchments, namely, a 6,8 ha residential area on the Berea Ridge in Durban proper (catchment No. 1); a 12 ha commercial catchment in Pinetown consisting of low-rise office blocks, shopping complexes and parking lots (catchment No. 2), and a 91,5 ha mixed residential, commercial and industrial catchment (catchment No. 3), also in Pinetown. The roads of all catchments are tarred and regular manual sweeping and cleaning of the curbs and pavements was undertaken during the survey.

Simpson derived first approximation rainfall-runoff relationships for the three catchments which could be used for other urban catchments with similar physical characteristics. Problems however, will be experienced in urban catchments with different physical properties. Simpson therefore tested the urban hydrological model WITWAT (suitable for ungauged catchments), in catchment No. 3. The simulated runoff volumes ranged from 10% lower to 7% higher than observed, while the peak flow data generally showed only a slightly greater variance*. Time to peak results also matched reasonably well. Simpson concluded that the model apart from being able to predict runoff from different size storms, could also be used (once calibrated), to simulate the effects of progressive urbanization on runoff. Accurate measurements of the parameters of the particular catchment however, are necessary. The runoff data so obtained can be used in conjunction with determinand load equations developed by Simpson, to predict determinand loads in catchments with similar land uses as per the research catchments.

Chemical determinands in runoff were assessed in the period 1976 - 1977 (catchment No. 1); 1978 - 1980 (catchment No. 2), and 1982 - 1986 (catchment No. 3). Runoff was sampled throughout hydrographs. Six determinands in catchment No. 1 were not sampled with a sufficient frequency for the calculation of mean concentrations. Some trends in mean determinand concentrations for the three catchments are presented in Table O11. The mixed land use catchment (catchment No. 3), consisting of 50% residential, 30% commercial and 20% industrial land use categories, generally had the poorest quality of runoff, reflecting industrial activities. The mean zinc concentration was highest in the

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* The graph of the rate of runoff (discharge) plotted against time for a point on a channel (a gauging station) is called a hydrograph. Discharge is measured as volume per unit time ($m^3\ s^{-1}$). Where runoff reaches a channel during or within a short period after rainfall begins, a higher rate of discharge is evident in the channel, which is termed storm runoff or direct runoff. Water which percolates to groundwater moves at much reduced velocities, reaching the channel slowly over a long period of time. Such water, known as base flow or dry-weather flow, sustains runoff during periods of no rain. A hydrograph accordingly, can be separated into component parts in order to analyse the volume, peak flow rate and the timing of storm runoff. One method of estimating the volume of storm runoff is through direct correlation with rainfall. A typical storm hydrograph consists of three main sections, namely, a steep rising limb, a peak and a shallower recession limb. The time of rise (or time to peak) refers to the time difference between the onset of greater runoff during or following a storm, up to peak runoff. The lag to peak is the difference in time between the centre of mass of rainfall and the peak runoff rate. Readers requiring a more detailed discussion should examine any standard hydrological textbook.

Table O11: Some trends in mean determinand concentrations for the three urban catchments examined by Simpson (1992) in the Durban Functional Region.

Determinand	Trend
Chemical oxygen demand	Commercial > mixed > residential
Suspended solids	Mixed > commercial > residential
Inorganic nitrogen (nitrate + ammonia)	Mixed > residential > commercial
Total nitrogen	Mixed > commercial > residential
Soluble phosphorus	Residential > mixed > commercial
Total phosphorus	Mixed > commercial > residential
Chromium	Mixed > commercial
Copper	Mixed > commercial
Iron	Mixed > commercial
Lead	Mixed > commercial
Manganese	Mixed > commercial
Zinc	Commercial > mixed

Source: After Simpson, D.E., 1992. Urban runoff pollution research in Natal, Natal Town and Regional Planning Commission Supplementary Report, VOL 37, Pietermaritzburg, 36 p.

Note: Chemical oxygen demand was examined as a measure of organic concentration. Although also assessed, soluble organic nitrogen (Kjeldahl nitrogen-ammonia) and total dissolved solids data are not reflected in the table.

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commercial catchment (catchment No. 2) due to higher traffic counts as a source of zinc. The residential catchment (catchment No. 1) had the lowest mean concentrations for four out of six determinands. Both the commercial and mixed catchments had higher chemical oxygen demand values than the residential catchment - as would be expected. Simpson observed that the variability in mean annual concentrations for different years (as high as 50% for some determinands), was strongly influenced by the amount of rain, and washoff from pervious areas during large storms. Mean determinand concentrations likewise, varied widely between runoff events. There was a tendency for small runoff events to have higher mean concentrations than larger events (due to the washoff of determinands stored on catchment surfaces being diluted only to a limited extent). Simpson also found that the quality of runoff during a specific storm was highly variable due to two factors.

Firstly, high concentrations were often detected in the initial storm runoff, as a result of the washoff of determinands which had accumulated on impervious surfaces in the preceding dry period (the first flush effect). Secondly, changes in rainfall intensity (observed as peaks in hydrographs) strongly increased concentrations through mechanisms such as scour and erosion, resulting in high suspended solids and related determinand concentrations, but with lower concentrations for certain soluble determinands.

The mixed catchment generally had the highest export coefficients (expressed as the product of mean annual determinand concentrations and total annual runoff volumes in terms of mass/area/time, namely, $kg^{-1}\ ha^{-1}\ y^{-1}$). The only exception was for zinc, where the export coefficient for the metal was higher in the commercial catchment. The residential catchment had the lowest export coefficients for determinands assessed in all three catchments. The effects of industrialization appeared to be dominant in the mixed catchment, notwithstanding the fact that the commercial catchment had the greatest impervious area percentage and accordingly, the highest runoff coefficient. Linear regression analysis revealed that determinand loads could be predicted for the catchments on a runoff event basis, albeit with variable accuracy. Predicted behaviour was found to be different for various determinands, with washoff loads of suspended solids rising at a greater rate (with increasing runoff), than for chemical oxygen demand. A similar trend was evident for total phosphorus vis-a-vis total nitrogen. Simpson observed that improved prediction accuracy is possible by using equations derived from multiple regression analysis, although further data, namely maximum flow rate and the preceding number of dry days before the given storm, are required.

The study also examined the potential environmental impact of urban runoff, where mean runoff event concentrations were compared with median and maximum water quality criteria for the protection of aquatic life, as provided by Kempster, Hattingh and Van Vliet (1980 - see earlier in the chapter). It was found that median water quality criteria were exceeded in all runoff events for suspended solids, lead and iron concentrations; and by 66% of events for chromium, 87% for ammonia and 99% for copper and zinc concentrations. The water quality data were also assessed in terms of the General/Special Standard for effluents. The General Standard was exceeded by all runoff events for suspended solids, by 79% of events for chemical oxygen demand, and by 90% of events for lead concentrations. Exceedance of the Special Standard was high for chromium, copper, iron, lead, manganese and zinc.

In a further comparison, Simpson (1992) assessed the mixed catchment (catchment No. 3), in terms of three large sub-catchments higher up in the Mgeni catchment, namely: the Msunduze River above Henley Dam (the Vulindlela District of KwaZulu), the Mgeni River above Midmar Dam, and the Karkloof River above Albert Falls Dam. The first catchment consists of an expanding peri-urban/rural settlement, with the other two areas comprising agricultural and forestry land. As expected, determinand concentrations as well as export coefficients were very low in the three sub-catchments vis-a-vis the mixed catchment - bearing in mind differences in catchment size, and the effects of rapid determinand transport to rivers in the urban catchment.

Simpson briefly reviewed methods to reduce urban runoff volumes, peaks and determinand loads. These include the direct discharge of roof-runoff onto lawns in residential areas (instead of the stormwater system), and the use of porous asphalt surfaces at car parking lots. Other methods are end-of-pipe treatment facilities such as detention/retention systems and artificial wetlands. The conservation of green belts is a further possibility, while partial treatment of the foul first flush stormwater runoff is an important consideration. Simpson stressed the significance of proper pollution abatement planning in urban development, and emphasized the need for a revision of existing stormwater runoff policies to safeguard water quality. Further information is provided in the chapter on sanitation.

15.11.5 Water quality in agricultural and evolving peri-urban catchments in Natal/KwaZulu

Simpson (1991)* examined water quality in three small catchments in Natal/KwaZulu. The catchments were the Cedara (Agricultural Development Institute) research catchments near Pietermaritzburg, the Ntabamhlope research catchments near Estcourt, and the Ntuze research catchments near Empangeni. The first two catchment networks are maintained by the Department of Agricultural Engineering, University of Natal, Pietermaritzburg, while the Ntuze catchments are managed by the Department of Hydrology, University of Zululand, KwaDlangezwa.

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* See Simpson, D.E., 1991. Quantification of the effects of land-use on runoff water quality in selected catchments in Natal, WRC Report No. 237/1/91, Water Research Commission, Pretoria, 126 p.

(a) Research catchments characteristics

The land uses of the Cedara catchments are representative of certain land uses within the Mgeni River catchment, where 20% of the Mgeni catchment consists of forests of various types, with 37% of the Mgeni catchment under grassland and general farming (Bromley, 1989, quoted in Simpson, 1991). Two specific catchments at Cedara were selected. The first, a 5,25 km^2 catchment (U2H016) is characterized by forests, farming and smallholdings (forests 56,8%, scrub and grassland 31,8% and smallholdings 11,4%). The second is a 1,31 km^2 catchment (U2H018) which consists of forested land (77,2%) with some scrub and grassland (22,8%). The mean slope of the first catchment is 16,4% and 29,2% for the second catchment. The mean soil erosion potential (calculated using the Universal Soil Loss Equation) of the two catchments is 3,3 and 4,6 t ha^{-1} y^{-1} respectively. The geology and soils are similar.

Two research catchments, namely, catchments V7H010 and V1H028 were studied in the Ntabamhlope area. Catchment V7H010 with an area of 0,08 km^2, has a mean slope of 10% and was used for several years as a wintering feedlot for cattle from the since defunct Department of Agriculture Ntabamhlope Research Station. Runoff from feedlots presents specific water pollution problems. Accordingly, catchment V1H028 was selected as a control to examine these effects. The latter catchment consists of grassland and natural forest, and has a mean slope of 13% and an area of 0,41 km^2. The two catchments are remote from the Mgeni system and eventually drain to the Tugela River.

Two small catchments were likewise selected for study in the Ntuze research catchments. The two catchments have similar sizes, slopes, soils and geological formations, with the major difference comprising alternative land uses. The relevant data for catchment W1H016 (with equivalent data for catchment W1H031 in brackets) is as follows: area 3,23 km^2 (3,19 km^2); mean slope 22% (20%); land use - natural forest 4,5% (28%); plantations 6,5% (0%); sugar cane 2% (0%); grassland 71% (66%); rock outcrops 13% (6%), and subsistence farming 3% (0%). Catchment W1H016 has a limited, although steadily increasing peri-urban settlement density with associated subsistence activities, with sugar cane cultivation and exotic timber plantations also predicted to increase. The changing land use pattern (especially subsistence agriculture), reflects conditions in the Mgeni catchment, which is also subject to increasing settlement with some degree of subsistence agriculture. Catchment W1H031 (adjacent to catchment W1H016), forms part of the Ngoya Forest Reserve managed by the KwaZulu Department of Nature Conservation. A small section of the Reserve is used for cattle grazing. The catchment therefore provides a good control in order to evaluate the effects of land use in catchment W1H016. Published hydrological data for the research catchments are discussed in the chapter on the surface water resources of Natal/KwaZulu, while brief data on the Ngoya Forest Reserve can be found in the chapter on catchments.

(b) <u>Results of investigations in the three catchments</u>

A flow-weighted (continuous or automatic sampling) approach to mean runoff quality assessment - calculated according to the flow volumes that the samples represent - was used in the survey of the three catchments (Simpson, 1991). Such data are required for hydrological modelling purposes, since grab samples usually reflect base flow only, and not the rising or falling limbs of a hydrograph*. Furthermore, routine sampling at existing gauging stations is indicative of mixed rather than specific land uses, and provides only generalized water quality data not suitable for land use/water quality modelling purposes.

A comparison of mean runoff quality data for the 1988/89 versus 1989/90 periods for Cedara catchment U2H016, revealed a major difference for suspended solids (up to 100%) and a lesser rise for turbidity (up to 40%). The differences for catchment U2H018 were lower at 30 - 40% for suspended solids, particulate phosphorus and nitrogen, while the variation for other determinands was less. These variations were regarded as normal and were caused by different rainfall patterns. A comparison of mean runoff quality between the two catchments showed that determinands were higher in the forested catchment U2H018 with reference to suspended solids (20%), as well as particulate phosphorus, particulate nitrogen and nitrate; although lower for dissolved solids (50%) and soluble phosphorus. The higher mean topographical slope and accordingly, the erosion potential for catchment U2H018, was considered to be the reason for the greater solids-associated determinand concentrations. The higher soluble phosphorus concentration for catchment U2H016 was believed to be due to the land use factor (smallholdings and farming

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* Mean runoff quality of the Cedara catchments was calculated from samples taken during base flow and during hydrographs to provide overall means and export coefficients. In the Ntuze catchments, only samples taken immediately before, during and after hydrographs were assessed. The means of the Ntuze catchments represent hydrograph flow quality (excluding base flow). The means for Ntabamhlope were calculated in a similar manner, since the main aim was to determine differences in quality between the land uses during stormflow.

activities). The variation in export coefficients between the two years for the Cedara catchments was found to be less than the variation in quality, given that the total runoff in 1989/90 was lower, although determinand concentrations were higher. Catchment U2H018 had much higher export coefficients than catchment U2H016 (for instance, 2,5 times higher for nitrate and three times higher for suspended solids), largely due to the greater total runoff from catchment U2H018 over the study period (Simpson, 1991).

An examination of mean runoff quality during hydrographs (excluding base flow) for the Ntuze catchments*, showed that the disturbed (mixed) catchment W1H016 had much higher turbidity, suspended solids, soluble phosphorus and nitrate concentrations, than control catchment W1H031 (a protected grassland). Concentrations varied from nearly 50% higher for suspended solids, to more than 250% higher for nitrate. The data confirm a distinctive land use effect, in view of the physical similarity of the two catchments. By contrast, dissolved organic carbon and the volatiles content of suspended solids - assessed in order to characterize dissolved and particulate organic loads derived from the catchments - were higher in catchment W1H031, probably due to natural processes.

In the Ntabamhlope catchments soluble and particulate phosphorus, nitrate, soluble Kjeldahl nitrogen and chemical oxygen demand concentrations in runoff from the disused feedlot catchment V7H010, were very much higher by comparison with the control catchment V1H028, and approached that of domestic sewage. (Reference has previously been made to the legal aspects of runoff from feedlots. See also the chapters on health and solid waste management).

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* See also Kelbe, B., Mulder, G.J., Bodenstein, B., Hattingh, D. and Verwey, A., 1992. An investigation of the hydrological response to Third World settlements in periurban areas of Natal/KwaZulu, VOL 1, Observational analysis, WRC Report No. 233/1/92, Water Research Commission, Pretoria, 111 p. + app., plus Mulder, G.J. and Kelbe, B., 1992. An investigation of the hydrological response to Third World settlements in periurban areas of Natal/KwaZulu, VOL 2, Numerical analysis, WRC Report No. 233/2/92, Water Research Commission, Pretoria, 87 p. The two reports provide further information on the characteristics of the Ntuze catchments, as well as certain additional water quality data not discussed by Simpson (1991). The application of the CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems) suite of models (developed by the United States Department of Agriculture), to catchments W1H016 and W1H031 in order to simulate the effects of various land uses on hydrological processes, is also discussed in the two reports (in terms of the runoff component of the models). No significant differences in runoff volumes and peak flows which could be specifically related to land use effects were found, although there was clear evidence of differences in water quality (with special reference to sediment). A useful general publication on the effects of land use on water resources is the following: Maaren, H. (ed), 1981. Workshop on the effect of rural land use and catchment management on water resources, Technical Report No. TR 113, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, 213 p.

It is important to note that the Cedara catchments comprising smallholdings, farming and forestry, as well as Ntuze catchment W1H016 with peri-urban settlements and subsistence agriculture, produced the highest nitrate concentrations vis-a-vis the less disturbed and more natural catchments (Ntuze) W1H031 and (Ntabamhlope) V1H028. Should such a trend be confirmed in the longer term (using standard sampling and analysis methods) and bearing in mind the results of Ntabamhlope catchment V7H010, then the current and future implications of less formal urbanization as well as feedlots is once more apparent. This would accord with studies in various countries as well as in other parts of South Africa*. High nitrate concentrations as already discussed, can have considerable health implications for young children.

In all the research catchments examined, suspended solids, turbidity, conductivity, particulate phosphorus and nitrate concentrations (but excluding soluble phosphorus concentrations except in catchment V7H010), were very responsive to changes in flow during hydrographs. Conductivity had an inverse relationship with flow for all catchments (excluding V7H010 - where increasing conductivity with flow was evident). The magnitude of the responses relative to peaks of the hydrographs was not consistent, with a varying relationship apparent through the wet season. Higher concentrations were observed at the beginning of the wet season, which was indicative of a first flush of determinands which had accumulated on surfaces during the dry season.

Quality changes in relation to flow changes during hydrographs revealed different "looped patterns" for determinands in all catchments. In some cases, concentrations were higher on the rising limbs vis-a-vis the falling limbs of the hydrographs (namely, different concentrations at similar flow rates), while other determinands showed a reverse trend.

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* For a brief Transvaal perspective see Silberbauer, M.J. and Moolman, J., 1993. Changes in urban residential land in the Rietspruit catchment, southern Transvaal, Southern African Journal of Aquatic Sciences, VOL 19(1/2), p. 89 - 94. See also, Wimberley, F.R. and Coleman, T.J., 1993. The effect of different urban development types on stormwater runoff quality: a comparison between two Johannesburg catchments, Water SA, VOL 19(4), p. 325 - 330. A Hillbrow case study is presented in Coleman, T., 1993. Effects of urbanization on catchment water balance, 10. Urban runoff quality and modelling methods, WRC Report No. 183/10/93, Water Research Commission, Pretoria, various pages. See in addition: Wright, A., Kloppers, W. and Fricke, A., 1993. A hydrological investigation of the stormwater runoff from the Khayelitsha urban catchment in the False Bay area, south western Cape, WRC Report No. 323/1/93, Water Research Commission, Pretoria, 106 p. + app., as well as Coleman, T.J. and Simpson, D.E., 1996. Adaptation and calibration of an urban runoff quality model, WRC Report No. 299/1/96, Water Research Commission, Pretoria, various pages. (The latter report discusses water quality in the Amanzimnyama and Shembe catchments, Durban). A further model was described by Hughes, D.A. and Van Ginkel, C., 1994. Nutrient loads from developing urban areas, a simulation approach and identification of information requirements, Water SA, VOL 20(2), p. 139 - 150. See also the chapter on sanitation.

Reasons for this pattern concern the first flush effect (higher concentrations on the rising limbs), or dilution of incoming higher concentrations to the weir basin (lower concentrations on the rising limbs). In order to avoid problems, Simpson (1991) suggested that sampling of the incoming rather than the outgoing flow at weir basins is required.

Regression analysis of determinands on flow using linear, multiplicative, exponential and reciprocal methods revealed that no one method gave the best fit for the prediction of any given determinand. For catchment U2H016 (Cedara), the best relationships with flow were evident for conductivity, turbidity and suspended solids, with explained variances of 81%, 66% and 74% respectively. For catchment U2H018, the best relationship with flow was for conductivity (45%). The best relationship for the Ntuze catchments was conductivity at 50% for catchment W1H031, and 61% for W1H016. Simpson observed that the regression equations derived for the various catchments can be used to predict quality from flow, although accuracy is dependent on the strength of the relationships.

Strong correlations were found amongst some determinands, where one determinand can be used to predict another determinand. For example, particulate phosphorus can be deduced from suspended solids in catchments U2H016 and U2H018; while suspended solids can be used to predict total phosphorus in catchments W1H016, W1H031 and V1H028 with coefficients varying from 0,95 - 0,99. However, correlations between suspended solids and turbidity were not as high, with coefficients ranging from 0,67 - 0,88 (the lowest was for the Ntuze catchments). In general, poor correlations were found using conductivity as a predictor for other determinands such as suspended solids, where the highest coefficient was 0,71 for catchment U2H016, with considerably lesser values for the remaining catchments. Variable relationships were evident for other soluble determinands.

Simpson (1991) concluded that any water quality component of a model of the Mgeni catchment should be one which generates determinands continuously, and then removes the determinands by rainfall/runoff processes from a store. To this end, the data derived from the three research catchments can be used for the testing and calibration of the model. The data can also be used as decision support for planning and management considerations. Simpson suggested that the changing land use in catchment W1H016 (Ntuze) should be used to further assess the water quality and hydrological effects of incipient urbanization in the coastal zone. Control catchment W1H031 is ideally sited for such a purpose. Longer term research on the implications of this type of urbanization is accordingly required.

15.11.6 Some impacts of rapid urbanization in the coastal zone, with special reference to "estuaries"*

Gardner and Archibald (1992) examined the Mdloti River catchment (mainly downstream of the Hazelmere Dam), in the Durban Functional Region. The study area was selected as representative of coastal catchments including "estuaries", which are likely to be impacted by very rapid high density informal and formal urbanization (as opposed to slower peri-urban settlement). While the establishment or expansion of formal housing allows for the proper planning of services (to varying degrees), the very opposite applies in the case of informal urban (squatter) settlements - unless subjected to the early upgrading of services. The pace of informal urbanization including land invasions**, especially - but not only - in the Durban-Pietermaritzburg Metropolitan Axis, represents a major catchment management dilemma. (Refer to the chapter on water supply planning).

The catchment implications of very rapid urbanization in the relatively flat coastal zone can include increased volumes of runoff and a reduced time to flood peaks, with the accompanying dangers of flooding on densely settled land below the 1 : 50 year flood line (see the chapter on rainfall). Flooding is due inter alia to the removal of natural vegetation (soil binding, flow alteration as well as evapotranspiration effects) and soil compaction through trampling (greater imperviousness of the soil and reduced infiltration). Badly eroded land can play a significant role in flooding. Other effects of very rapid unplanned urbanization include the bacteriological and virological contamination of rivers (particularly the first flush runoff). Contamination may be especially severe where the runoff is

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* Discussion based on Gardner, B.D. and Archibald, C.G.M., 1992. Catchment development impacts on river and estuarine systems, Natal Town and Regional Planning Commission Report, VOL 78, Pietermaritzburg, 21 p. See also, Gardner, B.D. and Archibald, C.G.M., 1991. Catchment development impacts on river and estuarine systems in the Verulam-Tongaat region, Report No. EFES 05 9108 01, Division of Water Technology, CSIR, Durban, 25 p.

** See Anonymous, 1994. Urban land invasion: the international experience: an executive summary, Urban Foundation Research Summaries on Critical Issues No. 7, Urban Foundation, Johannesburg, 16 p. (A more detailed report, on which the summary is based, is available). See also, Roberts, D., 1994. Bright lights, big cities - sustainable cities: urban environmental challenges for a post-apartheid South Africa, African Wildlife, VOL 48(3), p. 8 - 11. (The paper provides a useful general overview of urban issues with respect to the environment. Some other papers in this journal issue are also informative).

insufficient to carry the organisms out to sea. The nett result is high microbiological counts in the lowest reaches of rivers and in estuaries. Similar problems may well be evident in terms of nitrate, phosphate and some heavy metals. Human health hazards in estuaries can be expected during low flow periods (April - September), when there is minimal flushing of estuarine systems, notwithstanding the self-purification properties of rivers (Gardner and Archibald, 1992). Sedimentation of estuarine systems in Natal/KwaZulu (as discussed in the relevant chapter), is a major problem with marked changes evident in aquatic life as well as the physical characteristics of the estuaries themselves. Man-made changes to urban rivers including the removal of natural riparian vegetation, the flow-reducing effects of rubble, litter and waste in the channel, as well as the impoundment and canalization of rivers, all have a negative impact on estuarine processes (to varying degrees). It is clear that urbanization per se (whether unplanned or planned), will degrade the water resources of the coastal zone*. While informal settlements are major sources of non-point pollutants, formal (established) housing areas also contribute pollutants to river systems, albeit mainly via a treatment works. Commercial and industrial suburbs, particularly where illegal stormwater discharge is unchecked, can have significant effects on water quality. Table O12 summarizes some impacts of urbanization (including industrialization), on river and estuarine systems.

Gardner and Archibald (1992) adopted a modelling approach in their analysis of the lower Mdloti catchment. In order to simulate runoff and water quality aspects (specifically sediment), use was made of the Hydrological Simulation Program-FORTRAN (HSPF) Model which was developed by the United States Environmental Protection Agency. Output from the Agricultural Catchments Research Unit (ACRU) Model (developed by the Department of Agricultural Engineering, University of Natal, Pietermaritzburg) was used to calibrate the HSPF Model. The catchment was subdivided according to current land uses (informal and formal settlements plus industrial, open space, agricultural and natural forestry areas), as well as soil types. To estimate the possible effects of future informal settlements on the hydrological and sediment regime of the Mdloti River, two extreme scenarios were examined, namely: the conversion of all forest land to informal settlement, as well as the

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* A useful case study from an eastern Cape perspective is the following: MacKay, H.M., 1993. The impact of urban runoff on the water quality of the Swartkops Estuary: implications for water quality management, WRC Report No. KV 45/93, Water Research Commission, Pretoria, 217 p. + app. and map. (See the chapter on sanitation).

Table O12: A brief overview of some urban catchment processes and consequent impacts on rivers and "estuaries".

Catchment processes	Effect of processes	Impacts on the lowest reaches of rivers and "estuaries"
Urbanization	Changes in the permeable : non-permeable surface ratio, resulting in adverse changes in runoff peaks and response times	Flash flood damage to property and loss of life; destruction of the habitat
Population growth	(With specific reference to high density informal or low cost housing), may result inter alia in bacteriological and virological contamination	Various water-related diseases
Erosion	Soil export with transport of pollutants in sediment, as well as sediment deposition	Siltation and suffocation of the habitat
Solid waste disposal	Toxic chemical contamination resulting in degradation of aquatic environments	Loss of aquatic species
Effluent disposal	Organic contamination with for instance, oxygen depletion and the release of hydrogen sulphide	Fish deaths
	Eutrophication with the growth of undesirable aquatic macrophytes	Mechanical blockage and loss of recreational areas

Source: After Gardner, B.D. and Archibald, C.G.M., 1992. Catchment development impacts on river and estuarine systems, Natal Town and Regional Planning Commission Report, VOL 78, Pietermaritzburg, 21 p.

Note: The above table provides an outline only and should be applied to specific catchments with local circumstances in mind.

conversion of all open land to informal settlement. The rationale for the first scenario was based on the premise that forest land is probably more "available" for informal settlement than other more controlled land uses - where settlement on forest land would have a severe impact on the lower reaches of the river and the Mdloti Lagoon. It was considered unlikely however, that a total change in land use would occur in the future. The extreme scenarios nevertheless, may provide planners with a benchmark analysis.

On the basis of the model, Gardner and Archibald (1992) found that conversion of natural forest or open land to informal settlement would probably cause a slight increase in total annual runoff*, with dramatic increases in sediment yield. Specifically, the conversion of natural forest (which presently constitutes 17% of the catchment area) to informal settlement would result in a 4% increase in total runoff; while conversion of open land (currently comprising 7% of the study area) would increase total runoff by less than 1%. For the conversion of natural forest however, the projected total increase in the silt and clay components of sediment washed into rivers would be in excess of 120%, with an almost 150% increase for sand. Conversion of open land would increase the total silt and clay load by some 25% (over 50% for sand). The scenario assumed that all silt and clay scoured from the catchment would be washed into the Mdloti Lagoon, where in the presence of sea water, the silt and clay coagulates, with settlement on the bottom resulting in a rapid reduction in the size of the lagoon. In reality, the actual transport of sand depends on the hydraulic characteristics of the Mdloti River below the Hazelmere Dam, although over time the sand would reach the lower parts of the river (the floodplain), and ultimately the Mdloti Lagoon**. Gardner and Archibald suggested that a similar

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* Tarboton and Schulze (1992 - see Section 15.11.2) examined a scenario which doubled the (current) area under forestry, upstream of Midmar Dam in the Mgeni catchment. Using the ACRU Model, it was found that median annual runoff into the dam (in such a scenario), would be reduced by 10%. (The numerous small farm dams built for irrigation and stock purposes, already present upstream of the dam, were shown to have reduced median annual runoff into the dam by some 6%). Importantly, simulation of runoff from certain sub-catchments in the Msunduze catchment, under assumed future "status quo" (lower) and "emergent trends" (upper) bound urbanization conditions, revealed that significant increases in runoff (up to 92% in certain rainfall circumstances) are possible from areas converted into informal settlements. An increase in runoff (up to 11%) from sub-catchments with anticipated additional formal high density housing might likewise be expected. Intra-annual effects on runoff were also apparent (in terms of the simulation).

** For a useful discussion of estuarine sedimentation processes see Alexander, W., 1978. Session 2. Management of rivers, flood plains and estuaries in Natal and KwaZulu - the Department of Water Affairs' view, In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 50 - 55. According to Alexander, it is changes in the morphology of river channels and adjacent floodplains - where functionally present - which is the major cause of estuarine sedimentation (due to the removal of natural vegetation).

modelling approach could be applied to other areas where rapid urbanization is already occurring, or is likely to take place. Modelling accordingly, should be considered in any management plans to limit water quality impacts.

Nicolson (1989)* in an analysis of Released Area 33 (part of Inanda-Newtown near Durban), found that the impact of urbanization (both informal and formal) on the conservation and recreational aspects of the watercourses of Released Area 33, could be readily correlated with settlement patterns. Settlement density was highest along major transport routes where the degradation of watercourses was most apparent. Watercourses in some less densely settled parts however, were in good condition. Nicolson classified the watercourses of Released Area 33 in terms of four grades. Grade 1 watercourses represent the optimal situation with intact natural riparian vegetation, unoccupied adjacent slopes, and few (if any) signs of erosion or destabilization of the river channel. Grade 2 watercourses have good riparian vegetation with sparsely populated (watercourse) slopes and subsistence agriculture. In Grade 3 watercourses there is evidence of disturbed riverine vegetation, with the watercourses confined between densely populated dwellings. In Grade 4 watercourses no riparian vegetation is apparent either due to canalization, or as a result of uncontrolled dense shack settlements. Nicolson found that residents regarded water (for domestic, recreational and aesthetic purposes) as a most valuable natural resource, where a desire for the conservation of open spaces around watercourses was evident. To this end, conservation planning units were designated in terms of the grading system, for the protection of watercourses, valleys and steep slopes.

The need for forward planning of urban settlements is evident, although major land invasions may preclude the protection of open spaces and safeguarding of the aquatic environment. It should be borne in mind however, that the attractions of large urban areas, especially in terms of perceived employment opportunities, are uppermost in the minds of many black residents. Poverty ("financial gridlock") leaves little room for concern with the natural environment, where sheer survival is paramount. Recent trends both in the Durban Functional Region as well as in some of the Johannesburg townships (such as Alexandra) provide evidence of a small, although rapidly growing township-based "Green"

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* See Nicolson, G., 1989. Conservation and recreation planning guidelines for Released Area 33, Report No. 8702, Environmental Advisory Services, Durban, 48 p.

movement. A number of river clean-up and solid waste recycling programmes have been instituted in various areas.

In essence in large cities, both long-established suburbs as well as informal settlements have an impact on water quality. The "mix" of pollutants will vary according to circumstances, although point sources can largely be monitored, and are subject to legal processes. Non-point sources in less well-established areas are difficult to control. Nevertheless, improved services (which must be paid for), are an essential requirement not only for the sake of the health of residents, but also to protect the natural environment (including water resources). The rapidly increasing populations of large towns and cities in South Africa, and the need to create (mainly) industrial employment opportunities, constitute major economic, scientific and planning challenges which must be met. It is inevitable that the environment will suffer.

15.12 Potable water quality in peri-urban and rural KwaZulu

It is only fairly recently that water quality in the peri-urban and rural settlements of KwaZulu has become an important research objective (in terms of the upgrading of potable water supplies). Earlier, as well as some recent studies did not specifically refer to water quality for household supplies. The research however, concentrated on overall water quality for catchment management and urban planning needs. Data are available for specific sampling points where the sampling points are/were located in black settled areas. The reader should examine the CSIR/Natal Town and Regional Planning Commission reports VOL 13 Parts 1 - 7; as well as CSIR Natal Rivers Research Fellowships Steering Committee reports, and Department of Water Affairs and Forestry publications described earlier in this chapter. The retrieval of groundwater data (mainly initial samples taken for new borehole commissioning purposes), is discussed in the chapter on groundwater. Umgeni Water as well as certain local authorities (including Joint Services Boards), have groundwater/surface water quality data for selected areas. Routine surface water quality data are also available from Mhlatuze Water. The Department of National Health and Population Development, Private Bag X54318, Durban, 4000, has data with reference to the health implications of drinking water supplies on farms and in various black freehold areas. Data are likewise available for areas controlled by the (former) Department of Development Aid. Such land is now under the jurisdiction of the Community Services Branch, Natal Provincial Administration. Much of the available data consist of individual grab samples taken for specific purposes, rather than for on-going (routine) monitoring needs.

Chemical contamination in Natal/KwaZulu surface and groundwaters in peri-urban and rural areas is not considered to be a general threat in terms of (untreated) potable requirements. Obvious dangers nevertheless, are evident in rapidly growing peri-urban areas, especially in the Durban-Pietermaritzburg Metropolitan Axis, and in the vicinity of point sources (below industries and treatment works). Other problem areas include high population concentrations, for example, at closer settlements in the rural landscape.

The bacteriological and virological contamination of raw waters in unprotected sources (open springs and open wells and particularly dams and rivers), could well be serious depending on site conditions. While river water quality in the higher reaches of the Natal Drakensberg (and in other mountainous areas) is probably acceptable for very low density settlements, the same cannot be said for areas further downstream. As a golden rule however, residents will not drink or use water for cooking purposes where the water is drawn from rivers and dams, unless no alternatives are available. Residents accordingly, prefer to drink or derive water for cooking needs from open springs or wells - and where possible protected springs*, boreholes and properly constructed wells (Alcock, 1989)**. Raw water pipelines (such as in the dry Ximba Ward of KwaZulu near Nagle Dam), are also preferred as a source of (perceived) high quality water. Water for potable purposes is seldom boiled or purified by means of a disinfectant such as Jik, although certain households purify water on a regular basis. Suitable precautions however, are widely adopted if cholera is evident. Some residents, depending on their perceptions of rainwater as well as the condition of their corrugated iron roof-runoff and storage systems, will drink or use roof-runoff for cooking needs, when available. The use of roof-runoff for potable purposes is sometimes constrained by a fear of deliberate poisoning, especially

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* The objective of spring protection is to prevent the surface contamination of the water. Spring protection is described in the chapter on groundwater.

** For a further discussion of such (and other) water issues in peri-urban and rural areas of KwaZulu, see Alcock, P.G., 1989. Water supply systems for the Ximba Ward of KwaZulu: a proposed strategy, Occasional Publication No. 9, Department of Crop Science, University of Natal, Pietermaritzburg, 128 p. See also, Alcock, P.G., Rivett-Carnac, J.L. and Fourie, K.J., 1988. Current status of water supply and sanitation in rural and peri-urban areas of KwaZulu, Paper No. 2.2, Seminar on Water Supply and Sanitation - KwaZulu, South African National Committee of the International Water Supply Association, the Division of Water Technology of the CSIR, the KwaZulu Government and the Department of Development Aid, 28 - 30 June 1988, Durban, 32 p.

where social tensions are high*. Water for non-potable requirements is often drawn from open sources. Most householders prefer to do their laundry at river and dam sites, although a few residents carry wash water back to the home. Roof-runoff is also used for clothes washing purposes and for general household needs. There is a high degree of water reuse (as would be expected where water must be carried to the homestead). Accordingly, water might first be used to wash the baby, then clothing and to wash the floor of the kitchen, before being thrown on the vegetable patch, fruit trees, or the lawn. Potable and cooking water is stored in the household in 20 or 25 ℓ containers. At certain households, there is a possibility of contamination of the stored water, caused by the incorrect toilet practices of young children (see the chapter on sanitation). Numerous residents are unaware of the possibility of latrine seepage into groundwater, where a primary criterion for "clean" water (water which is safe to drink), concerns turbidity (Alcock, 1989).

Alcock and Verster (1987)** examined the bacteriological quality of waters in the high rainfall Vulindlela District (situated in the Henley Dam catchment area). Alcock and Verster found that the Msindusaan and Henley dams had a moderate E. coli I mean count - as a result of dilution effects - while the Msunduze River and three tributaries had much higher mean counts (generally more than 10 times higher). One tributary (the Tenjaan River) had especially high counts, reflecting a high population density with many unimproved pit latrines situated along the banks of the river. Cattle and goats (common in peri-urban and rural areas), also contributed to the bacterial load in surface waters. Both unprotected and protected springs (the major sources of potable water in the study area), had very low mean E. coli I counts. Rainwater derived from household storage systems had the lowest mean E. coli I counts of all sources, excluding the only borehole. The protection of springs was shown to be an effective procedure for the maintenance of bacteriological water quality - a trend also found in the Valley Trust area near Durban. However, site specific conditions such as poorly located upslope pit latrines and livestock concentration points near the eyes of springs, as well as poor construction techniques, could well negate the effects of spring protection. The water quality of roof-runoff likewise, depends on several

* For a discussion of rainwater systems see Alcock, P.G., 1987. An assessment of household rainwater collection systems in a periurban/rural ward of KwaZulu, Development Southern Africa, VOL 4(1), p. 103 - 110.

** See Alcock, P.G. and Verster, E., 1987. An assessment of water quality in the Inadi Ward, Vulindlela District, KwaZulu, Water SA, VOL 13(4), p. 215 - 224.

factors including the concentration of birds, as well as the condition of the roof and water storage facilities. A generally similar pattern with rainwater and one borehole as the best sources of water (in terms of E. coli I) was found in the Ximba Ward. Unprotected springs (no protected springs in the study area), showed clear evidence of bacteriological contamination - due to the most favoured withdrawal and therefore sampling points being exposed to surface pollution. Few springs are evident in the Ward. A raw water pipeline linking Nagle Dam and Durban contained good quality water with regard to E. coli I. The Msunduze River* had the worst bacteriological water quality (Alcock, 1989 - above).

Data for both the Vulindlela and Ximba areas revealed that strict application of the South African Bureau of Standards specifications with a maximum allowable limit of zero E. coli I counts 100 $m\ell^{-1}$ (see the beginning of the chapter), would result in an automatic rejection of all better quality sources - excluding two rainwater systems in the Ximba Ward. Such a strict rejection would leave residents with virtually no alternative, other than to purchase treated water from some municipal source. It is evident that untreated natural waters, with few exceptions, will seldom meet the SABS specifications all or part of the time. This does not necessarily imply that the water is unfit to drink by healthy people. Much debate has centred on an acceptable E. coli I count for untreated water in peri-urban and rural areas. The World Health Organization has established a maximum acceptable incidence of 50 E. coli counts 100 $m\ell^{-1}$ of water in any one of three successive tests (Mann, 1985)**. The real issue is one of acceptable risk, where selected unprotected springs,

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* According to Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 1: objectives of river surveys, description of methods used and discussion of water quality criteria, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 101 p., bacteriological counts in rivers are greatly influenced by rain. Rain especially after a period of drought, washes organisms and nutrient materials from soil, debris and faecal matter into the river. This results in a very marked increase in E. coli I and heterotrophic plate counts (the first flush effect). By the time the catchment has experienced prolonged rain, most of the E. coli I and heterotrophic plate count bacteria have been removed. The river bacterial counts return to "normal" or even decrease if streams become diluted by excess runoff - provided that no constant source of contamination is apparent. A badly contaminated river (with predominantly high bacterial counts), may become diluted during the rainy season with low E. coli I and heterotrophic plate counts evident, depending on environmental conditions. Brand et al found that in the dry season, heterotrophic plate counts increased steadily in river water as the season progressed. One explanation may be that nutrients and bacteria in river water become more concentrated due to low flow rates, resulting in an increase in the heterotrophic plate count, since such bacteria are then better able to utilize the available nutrient material. Consequently, only a small increase in nutrient concentrations is sufficient to cause a tremendous bacterial "bloom".

** See Mann, C., 1985. The Valley Trust water and sanitation projects, Valley Trust, Botha's Hill, 48 p. (A brief discussion of the health implications of increasing faecal coliform counts in water can be found in the following: Anonymous, 1993. South African water quality guidelines, VOL 1, Domestic use, Department of Water Affairs and Forestry, Pretoria, 216 p.).

as well as protected springs preferably with storage, boreholes, raw water pipelines, and roof-runoff* can (and are being) used for potable purposes without major health implications. The situation in the dry Ximba Ward however, is difficult since many residents are forced to drink directly from the Msunduze River and below the confluence, from the Mgeni River. The risk of drinking river (or dam) water is unacceptably high, unless precautions are taken. Continued exposure to surface waters may also result in schistosomiasis (bilharziasis). In essence therefore, untreated non-river/dam sources of water in low to moderate density settlements are probably acceptable - provided that care is taken to restrict poorly sited pit latrines, graves and livestock concentration points. In the longer term however, reticulated supplies are necessary, especially in high density settlements near major cities and at closer settlements in rural areas. In this regard, parts of Vulindlela and Ximba are currently being supplied by reticulated water, with further expansion of the reticulation system planned. The upgrading of water supplies, combined with efforts to improve sanitation as well as attention to other socio-economic needs, is an integral part of the overall development and catchment management strategies so urgently required in many parts of South Africa.

A first attempt at localized integrated catchment management on an holistic basis in Natal/KwaZulu is currently underway in the Mlazi and Sterkspruit River catchments (above the Shongweni Dam). The (Nt)Shongweni Catchment Management Programme has several objectives. These include sound livestock and arable land use practices; the development of a resource conservation strategy for the control of wetland utilization; the removal or exploitation of problematic exotic (invasive) riverine vegetation, and the planting or maintenance of indigenous riverine species. Further aspects of the programme include water conservation and runoff control as well as appropriate technical and administrative training. The programme is managed by the Farmer Support Group, University of Natal, Pietermaritzburg, and operates in association with Umgeni Water. An important aim of the programme is to develop a model for community participation in catchment management which can be used in other parts of South Africa. The siting of the programme is opportune, given the history of sedimentation of the Shongweni Dam. (See the chapter on soils and soil erosion, as well as Section 15.15 later in this chapter).

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* Farmers in the drier parts of South Africa were dependent (in earlier times) on untreated roof-runoff for some of their potable requirements. The rainwater tanks often contained an interesting and nutritious blend of dust, leaves, algae, mosquitoes, dead lizards and the occasional dead bird or rat, sometimes leavened by rat and bird faeces.

15.13 The classification and zonation of South African rivers: water quality implications*

15.13.1 Classification

A broad knowledge of the classification and zonation of South African rivers - with special reference to Natal/KwaZulu - is important in terms of the effects of pollutants on river biotic communities; and for an understanding of the biotic index concept (an index of water quality based on the animals present in the water). Reference has been made earlier in the chapter to the need to incorporate biological parameters in any assessment of water quality, especially for the environment as a user of water. Rivers and ultimately "estuaries" are very vulnerable ecosystems which reflect the full sum of man's activities in their catchments. Besides pollution, impoundments and water transfers (river regulation) may have profound implications (inter alia through runoff disturbance) for aquatic life forms**. With increasing attention being paid to the environment as a legitimate user of water, so the need to conserve rivers as viable ecosystems (or at least certain reaches of a given river), becomes ever more important. The conservation of aquatic ecosystems is dependent on the sound management of catchments, notwithstanding the difficult to

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* Discussion based on O'Keeffe, J.H., Davies, B.R., King, J.M. and Skelton, P.H., 1989. Chapter 17. The conservation status of southern African rivers, In: Huntley, B.J. (ed), Biotic Diversity in Southern Africa: Concepts and Conservation, Oxford University Press, Cape Town, p. 266 - 289. See also, Noble, R.G. and Hemens, J., 1978. Inland water ecosystems in South Africa - a review of research needs, South African National Scientific Programmes Report No. 34, Cooperative Scientific Programmes, CSIR, Pretoria, 150 p.

** For a useful case study of the minimum flow requirements (instream flow needs) of rivers inter alia with regard to the maintenance of species richness, see Chutter, F.M. and Heath, R.G.M., 1993. Relationships between low flows and the river fauna in the Letaba River, WRC Report No. 293/1/93, Water Research Commission, Pretoria, 79 p. Current thinking on the determination of the minimum flow requirements of South African rivers (specific to each river), concerns the so-called Skukuza Approach developed for the stressed systems of the Kruger National Park and secondly, the Flow Record Simulation Approach. The Skukuza Approach involves a cumulative assessment of both the consumptive and non-consumptive water requirements of each component of the ecosystem, such as fish and riparian vegetation. Where time and resources do not permit the Skukuza Approach, the Flow Record Simulation Approach is suggested. The latter method uses a statistical treatment of hydrological records as well as modelling to estimate total ecosystem needs (O'Keeffe et al, 1989 - above). A new (in South Africa) procedure is the Instream Flow Incremental Methodology (IFIM) with its model PHABSIM I (now upgraded to PHABSIM II). For a comprehensive discussion of this technique see King, J.M. and Tharme, R.E., 1994. Assessment of the instream flow incremental methodology, and initial development of alternative instream flow methodologies for South Africa, WRC Report No. 295/1/94, Water Research Commission, Pretoria, 590 p. See also, Smakhtin, V.Y., Watkins, D.A. and Hughes, D.A., 1995. Preliminary analysis of low-flow characteristics of South African rivers, Water SA, VOL 21(3), p. 201 - 210. (Care should be taken to confirm the meaning of the term "low flow" as found in the literature. Low flow could be used in the context of droughts, or in terms of rare events in semi-arid/arid areas, or with reference to the annual dry season. The term may also be used with regard to a permanently-reduced flow in a river, due to large scale upstream storage and abstraction).

quantify, self-purification properties of rivers (with regard to pollution) and natural recovery processes (in terms of impoundment effects).

There are many different types of rivers in southern Africa, all of which change in character between their source and the sea. As early as the 1950s, it was recognized that there was a need to classify types and reaches of rivers, in order to compare information between rivers, to identify river reaches and rivers of conservation importance, and to allocate priority uses to certain rivers or river reaches. Harrison (1959, quoted in O'Keeffe, Davies, King and Skelton, 1989), defined 12 main hydrobiological regions in southern Africa, based on differences in aquatic biota and water chemistry. Most of Natal/KwaZulu is found within Region E: the south eastern coastal region with mostly short, precipitous, usually deeply incised rivers in a high rainfall zone. Region F: the Drakensberg Mountain region is characterized by torrential mountain streams, probably with many endemic species. A very small part of Natal/KwaZulu in the north west falls within Region H: the eastern escarpment region. Region H consists of the upper reaches of Lowveld subtropical rivers and rejuvenated reaches of Highveld rivers, with fauna possibly similar to the foothill parts of Region E, albeit with more tropical species. The far north east of Natal/KwaZulu lies within Region K: the Lowveld region - which is characterized by subtropical rivers (the Pongola/Usuthu River) with a distinctive fauna.

Noble and Hemens (1978) provided a simple classification of South African rivers based on topography; the zonation exhibited (see below); geological effects on water chemistry, and biota present in the rivers. Seven different types of rivers in South Africa were defined of which two apply to Natal/KwaZulu. The category: Transkei and Natal degrading rivers comprises clear mountain streams with generally very turbid rivers downstream, where dissolved solids are variable. Mountain, intermediate altitude and coastal belt faunas can be clearly identified. The second category: Escarpment/floodplain rivers, refers to northern Natal/KwaZulu where waters were described as clear to turbid, with generally low dissolved solids. Relatively little biotic data are available (excluding the Pongola/Usuthu River). Other rivers in the second category include the Mfolozi and the Mkuze. (See also Footnote (ii) of Table O18, later in the chapter).

O'Keeffe et al (1989) criticized the classification by Harrison as being too broad (a criticism which would also apply to the Noble and Hemens classification). Attention has now shifted towards regional-level classifications using inter alia climate and geology (at a primary level). Other parameters will be used to establish a grouping of similar reaches of rivers at a scale useful for direct conservation and management purposes.

15.13.2 Zonation

Noble and Hemens (1978) outlined a system where all South African rivers can be described in the first instance, in terms of five zones ranging from mountain source to the "estuary" (Table O13). This system was subsequently modified by O'Keeffe and fellow workers. In the revised version seven zones were identified, some or all of which may occur in a particular river, and some of which may be repeated one or more times along a river. The relevant zones are: mountain source, mountain stream, rocky foothill, sandy foothill, midland river, lowland river, and swamp - not excluding the "estuary" (O'Keeffe et al, 1989). Every zone has a definite physical and hydrological character, where each upper zone (at least) has a distinct biota. These zones can be visually identified, given however, that downstream changes from one zone to the next tend to be gradual and not abrupt. Furthermore, the zones generally increase in length downstream, with the first two or three zones often being very short. In terms of biota, the first three zones (mountain source to rocky foothill) tend to support rare (often endemic) species, with the more common species found in the lower zones in disturbed river reaches. The higher zones accordingly, with cool, clean high altitude streams support species which are less tolerant of disturbance, where disturbance could lead to species loss. Upper zones have frequently been invaded by exotic species (such as trout) which are derived from the northern hemisphere. The mountain source and mountain stream zones are often relatively undisturbed, since many (although not all) of these zones are situated in protected areas.

Table O13: Generalized zonation in South African rivers (as per Noble and Hemens, 1978).

Zone	Description	Temperature	Water flow	Turbidity	Biota	Environmental disturbance
1. Mountain source and cliff waterfall	Source often with sponge (high altitude mire) vegetation on humic turf, sometimes with rocky waterfalls over which the stream descends a steep escarpment	Summer mean, well below 20°C	Fast to torrential, turbulent and always oxygenated	Negligible even during storms	Many species only able to survive in cool, flowing, oxygenated water; some species specially adapted to torrential flow	Rare
2. Mountain stream	Starting with mountain torrents, small waterfalls and rapids and little true emergent vegetation. Descending to foothills where the stream bed has a steep gradient, with occasional pools. The bottom consists of rock, pebbles and coarse sand and there are patches of marginal Cyperaceae and grasses. Deposition negligible and stone and vegetation surfaces clean	Summer mean around 20°C	Fast to torrential, turbulent and always oxygenated	Negligible even during storms	As above, also species living between stones and others intolerant of sediment	Where mining and other disturbance causes sediment deposition, the characteristic fauna is quickly eliminated
3. Foothill sandbed	Here the flow velocity is further reduced as the gradient decreases. Stony runs alternate with sand or sediment and marginal riverine vegetation	Summer mean, well above 20°C	Generally slow, but fast in rapids and during floods	Extremely variable, turbid at least during floods	Most species with fairly wide temperature tolerances. Many dependent on but tolerant of sediment and low dissolved oxygen	Organic and toxic pollution, sedimentation, water extraction, canalization, with the presence of aquatic weeds

Table O13: Generalized zonation in South African rivers (as per Noble and Hemens, 1978) (continued).

Zone	Description	Temperature	Water flow	Turbidity	Biota	Environmental disturbance
4. Low and midland stream and river	Characterized by reduced gradient of the river bed with zones of deposition alternating with stony runs in the low foothills and where the river passes over rock outcrops. Erosion often occurs during flooding. In exceptional cases like the Pongolo, with a well developed floodplain	Summer mean, well above 20°C	Generally slow	As above, the water often turbid, especially during floods	As above but fewer flow-dependent species. Many standing water species	As above
5. "Estuary"	See the chapter on "estuaries"	Summer mean, well above 20°C	Generally very slow	Variable	Species tolerant of salinity fluctuations	Sedimentation, pollution and interference with tidal exchange

<u>**Source**</u>: After Noble, R.G. and Hemens, J., 1978. Inland water ecosystems in South Africa - a review of research needs, South African National Scientific Programmes Report No. 34, Cooperative Scientific Programmes, CSIR, Pretoria, 150 p.

<u>**Note**</u>:

(i) The environmental factors which primarily determine the structure and productivity of riverine ecosystems include the amount of fine sand and sediment in the river bed; the water flow velocity (= gradient); the physical nature of the substratum; turbidity; temperature fluctuations (= altitude); dissolved solids, and nutrient availability. In rivers such as the Tugela, several major changes in these factors occur along the length of the river from source to mouth, with distinct zonation clearly evident. In certain rivers in southern Natal/KwaZulu however, the zonation is less apparent. Rivers (depending mainly on topography), will exhibit zonation to a greater or lesser extent, as outlined in the table. Each zone (however defined), is essential for the healthy functioning of the whole river system.

(ii) Most minor tributaries of the larger rivers rise in the fourth zone at middle and low altitudes (Noble and Hemens, 1978).

The rocky foothill zone is the most immediately vulnerable of the river zones, and supports pollution-sensitive and often endemic fauna. This zone is frequently the most suitable part of a river for impoundment purposes, and is also the highest reach subject to larger-scale agricultural and urban activities. Many such zones in South Africa have seen the disappearance or at minimum, the modification of distinctive aquatic communities. The lower zones of a river which do not usually support a particularly rare or sensitive biota, and which are subject to varying degrees of disturbance, are nevertheless important migratory routes for fish and provide feeding and breeding grounds for water birds as well as other species (O'Keeffe et al, 1989).

Davies and Day (1986, quoted in Dallas and Day, 1993 - see below) suggested a further generalized river zonation (Table O14), which has found favour in recent South African literature. Davies and Day divided rivers into three zones, namely, a fast flowing erosive headwater zone, a slower flowing partly-erosive middle zone and a slow flowing, low-lying lower reach or mature river, where materials eroded in the upper reaches are deposited. The final category is the "estuary". The physical basis for the zonation is flow rate, which is high in the upper reaches, declining steadily as stream order - dependent on the number of tributaries - increases.

It is important to bear in mind that the river zonation categories outlined above, constitute an overview analysis of South African rivers in general. More detailed and river-specific zonation must be applied to given catchments, in view of the wide variety of environmental factors prevailing in different parts of the country. Oliff (1960)* with reference to the Tugela River system, provided a model for the zonation of rivers in Natal/KwaZulu. The zonation was based on earlier work undertaken elsewhere in South Africa by Harrison and fellow workers. The Oliff approach was partly used in the CSIR/Natal Town and Regional Planning Commission investigation of the water quality of

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* See Oliff, W.D., 1960. Hydrobiological studies on the Tugela River system, Part 1: the main Tugela River, Hydrobiologia, VOL 14(3/4), p. 281 - 285. (Other rivers of the Tugela system were also examined and the data can be read in terms of water quality per se. See Oliff (1960) - the Bushmans River; Oliff (1963) - the Buffalo River; as well as Oliff and King (1964) - the Mooi River; plus Oliff, Kemp and King (1965) - the Sundays River; and Kemp (1967) - with reference to acidic drainage from mines in the Natal coalfields: all in the bibliographic database).

Table O14: Generalized zonation in South African rivers (as per Davies and Day, 1986).

Characteristic	Headwater zone	Middle zone	Lower zone
Physical Slope	Steep	Gradual	Gradual
Velocity	Fast, erosive	Slower	Slow, depositing
Substratum	Mainly boulders	Mixed boulders and sand	Sand and mud
Temperature	Normally low	Slightly warmer	Warm
Turbidity	Clear, low	Intermediate	High
Solar radiation	Low	Intermediate	High
Riparian vegetation	Canopy-like	Concentrated on banks	Only on banks; often exotic species
Chemical Dissolved oxygen	High	Intermediate	Low
Nutrients	Low	Intermediate	High
Conductivity	Generally increases down the river		
pH	Generally increases down the river		
Biological Energy input (food source)	Allochthonous CPOM	Autochthonous CPOM and FPOM	Autochthonous FPOM
Plankton	Mostly absent	May be present	Often present
Dominant invertebrates	Shredders and collectors	Collectors and grazers	Collectors with deposit feeders also abundant

<u>**Source:**</u> After Dallas, H.F. and Day, J.A., 1993. The effect of water quality variables on riverine ecosystems: a review, WRC Report No. TT 61/93, Water Research Commission, Pretoria, 240 p.

<u>**Note:**</u> (i) Food for riverine animals consists largely of material such as fruit and leaves from the riparian zone, which is gradually broken down from Coarse Particulate Organic Matter (CPOM), to Fine Particulate Organic Matter (FPOM) by animals, bacteria and fungi. Shredders feed by breaking up or shredding leaves and other CPOM. Collectors gather fine particles of food by erecting nets, sieves or strings of saliva which sieve or filter the water. Grazers feed on the algal layer found on rocks and other structures. Deposit feeders consume organic material deposited on the river bed. Predators then prey on other organisms. The importance of terrestrial inputs of CPOM decreases and the transport of FPOM increases with passage down the river. (The term "allochthonous" refers to generation outside the

given system, while the term "autochthonous" means generation within the particular system).

(ii) Plankton consists of small plants (phytoplankton) and animals (zooplankton) which live (suspended) in the water.

(iii) The extent to which specific characteristics change down the course of a river, depends on land use practices and sources of pollution along the river course - where changes are relative in respect of each zone.

(iv) According to O'Keeffe, Davies, King and Skelton (1989 - above), there are two main theories of the ecological functioning of rivers, namely, the River Continuum Concept (implied above), and the Unstructured Community Concept. It is not proven where South African rivers fit in. The first approach suggests that biota have been able to adapt to gradual and relatively predictable environmental changes down the river. The second approach views rivers as stochastic systems subject to violent events (droughts and floods - as in South Africa), where the biota is unstructured, consisting mainly of hardy opportunists and generalists that colonize the river between periodic catastrophes. According to O'Keeffe, J.H., 1986. Ecological research on South African rivers: a preliminary synthesis, South African National Scientific Programmes Report No. 121, Foundation for Research Development, CSIR, Pretoria, 121 p., it would appear that the lower reaches of many South African rivers may tend towards an unstructured community state, although additional research is needed. A different theory, the Serial Discontinuity Concept regards impoundments as interruptions of the river continuum, which result in changes in biotic and abiotic variables, with subsequent recovery at some unknown distance downstream of the impoundment. Data from South African studies have suggested that there are discontinuities as well as recovery processes, although the recovery processes appear to be weak and are easily overcome by further negative impacts such as organic pollution (O'Keeffe et al, 1989).

(v) Another theory - the Intermediate Disturbance Hypothesis - suggests that the level of natural variability in an ecosystem determines the diversity of animal and plant species in a given environment. An important hypothesis is that of Nutrient Spiralling. Nutrients in a closed system (such as a lake) are cycled through being taken up by living organisms, and are then returned to the system (in the process of excretion and decomposition). In rivers (more open systems), the cycling nutrients are continually displaced downstream and are said to traverse an imaginary spiral or helix (O'Keeffe, J.H. (ed), 1986. The conservation of South African rivers, South African National Scientific Programmes Report No. 131, Foundation for Research Development, CSIR, Pretoria, 117 p.).

Natal rivers (Brand, Kemp, Pretorius and Schoonbee, 1967)*. Brand et al with regard to the Mgeni River, divided the river into six zones on a physical basis. These are the source zone, the upper foothill torrent zone, the lower foothill torrent zone, the foothill soft bottom zone, the rejuvenated river zone, and the valley sand bed zone (Table O15). Oliff's zonation of the Tugela River is summarized for comparative purposes in Table O15. Eight zones were identified based on the gradient of the river and the associated fauna**.

15.14 The conservation status of South African rivers***

15.14.1 Background analysis

Man's impact on riverine ecosystems is varied. The overall effects of river regulation (impoundments and inter-basin water transfers) for example, are considerable given the approximately 520 major dams, which together impound half of the mean annual runoff of South Africa (Anonymous, 1986)****. River regulation has important implications for downstream river reaches with regard to runoff, water temperature, channel morphology, water chemistry and sediment, as well as the structure and functioning of biotic communities. Highly relevant is the spread of pest species such as blackflies and disease vectors (see the chapter on health). Impacts will vary greatly between impoundments depending on the water release regime. Surface water releases resulting in an increase in below-dam water temperatures will alter the growth and emergence of stream insects, thereby affecting food chains (Ward, 1985, quoted in O'Keeffe et al, 1989). Bottom releases of water from deep impoundments will tend to decrease stream temperatures, also with biotic effects. Inter-basin transfers of water

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* See Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 2: survey of the Three Rivers Region, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 224 p. and maps.

** A useful background report inter alia with respect to physiographic zones of the sub-catchments of the Tugela River is the following: Thorrington-Smith, E., 1960. Towards a plan for the Tugela Basin: second interim report of the regional survey of the Tugela Basin, prepared in the Office of the Town and Regional Planning Commission, Natal, Natal Town and Regional Planning Commission Report, VOL 5, Pietermaritzburg, 266 p. and maps.

*** Discussion based on O'Keeffe, J.H., Davies, B.R., King, J.M. and Skelton, P.H., 1989. Chapter 17. The conservation status of southern African rivers, In: Huntley, B.J. (ed), Biotic Diversity in Southern Africa: Concepts and Conservation, Oxford University Press, Cape Town, p. 266 - 289.

**** See Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages. (See also the section on the Environmental impacts of dams and other works in the chapter on the surface water resources of Natal/KwaZulu).

Table O15: A physical zonation of the Mgeni River in Natal/KwaZulu.

Zone	Characteristics
1. Source zone (1 981 - 1 829 m)	The Mgeni River unlike the Tugela River, has no true mountain source. The Mgeni River rises in the foothills of the Drakensberg in a wetland plateau area (the Mgeni sponge). Numerous small streams drain the sponge, combining to form the several headstreams of the Mgeni River. A rich variety of wetland vegetation was evident, most commonly Carex spp. and Cyperus spp. as well as Scirpus corymbosus and Juncus oxycarpus. Water of the sponge area remained fairly clear throughout the year, although dense reddish deposits (probably caused by iron bacteria) were evident on several occasions. The lowest recorded mid-winter (day time) temperature of the water was 9,2°C, probably reaching 0°C or lower at night in winter. Most of the pH values were between 6 and 7 with the water usually becoming alkaline during the rainy season
2. Upper foothill torrent zone (1 829 - 1 250 m)	Sponge to Dargle Falls area. This section of the river is characterized by an initial steep gradient immediately below the sponge with the gradient fluctuating between 28 - 14 m km^{-1}, decreasing to some 4 m km^{-1} above Dargle Falls. At the Dargle Falls, the river profile is flattened due to a dolerite sill lying across the watercourse, thereby retarding the downcutting and retreat of the river bed. Despite the steepness of the river a few kilometres below the sponge, and the many rapids cascading over large rocks and boulders, occasional deep pools are evident, shaded in places by indigenous trees. Streams a few kilometres downstream of the sponge carry very little sediment during the summer rains with no sediment apparent in winter. Water temperatures during winter were below 10°C, increasing to more than 20°C in summer. Dissolved solids were low, with pH values in winter just less than 7 and alkaline in summer. Virtually no marginal vegetation was evident a few kilometres downstream of the sponge, with two of the very few species represented being Mariscus congestus and Juncus effusus
3. Lower foothill torrent zone (1 250 - 914 m)	Dargle Falls to Morton's Drift area. As in the upper foothill torrent zone, the lower foothill torrent zone also has a steeper part which gradually flattens towards Howick. The mean gradient (vis-a-vis the upper zone) is much less at 18 - 15 m km^{-1} below Dargle Falls towards Dargle Forestry office; approximately 2 - 3 m km^{-1} at Watersmeet, and less than 1,8 m km^{-1} above and below Fern Hill Flats. At Midmar (Dam) the gradient again increases to some 14 m km^{-1}. Given the general lack of fast current at Watersmeet and Fern Hill Flats, a considerable amount of sediment was deposited in the area, which resulted in a much less turbid river in summer downstream from Midmar (Dam). True aquatic vegetation in the zone consisted largely of Hydrostachys natalensis which is found in fast current habitats, as well as Nitella spp. which prefer slow current habitats and shallow pools. A steady increase in dissolved solids and water temperatures was evident from Dargle Forestry office to Midmar (Dam). The pH likewise, varied between 7,1 - 7,8

Table O15: A physical zonation of the Mgeni River in Natal/KwaZulu (continued).

Zone	Characteristics
4. Foothill soft bottom zone (701 - 671 m)	Morton's Drift to Albert Falls area. The first true soft bottom zone in the Mgeni River is found from below the confluence with the Karkloof River (Morton's Drift to Albert Falls - a distance of 12,1 km), where the gradient averages less than approximately 1,8 m km^{-1}. The marginal vegetation mainly comprised Cyperaceae, Polygonaceae and Gramineae of which the more abundant species were Mariscus congestus; Scirpus paludicola; Cyperus fastigiatus; Polygonum setulosum; Echinochloa crus-pavonis; Miscanthidium capense; Paspalum distichum, and P. urvillei. Water temperatures ranged from approximately 10°C in winter to over 20°C in summer. The very low gradient of the river in this zone results in the turbidity of the water being considerably less at Albert Falls than further upstream. Flood waters from the Karkloof tributary were found (on occasion) to carry high volumes of yellow sediment into the Mgeni River above Morton's Drift - discolouring the whole river - although the flood water was almost clear on reaching Albert Falls. Even during the greatest floods, differences in turbidity were apparent between Morton's Drift and Albert Falls
5. Rejuvenated river zone (671 - 305 m)	Albert Falls to Upuma area. The zone is characterized by a short stretch of some 0,8 km with a steep gradient of more than 15 m km^{-1} immediately below Albert Falls, which is followed by a meandering reach of approximately 27 km with a mean gradient of 3,8 m km^{-1}. A further gradient increase occurs in the next 62 km stretch of the river (above Nagle Dam towards Upuma), where the gradient exceeds some 6 m km^{-1}. The zone then gradually intergrades with the valley sand bed zone. The marginal vegetation of the rejuvenated river zone consisted of a rich variety of species including: Polygonum spp.; Cyperus leptocladus; C. difformis; C. fastigiatus; C. marginatus; Scirpus prolifer; Pycreus polystachyos; Kyllinga eliator; Matricaria nigellifolia; Coix lacryma-jobi; Panicum laevifolium; Paspalum distichum; P. urvillei, and Miscanthidium spp. The gradual downstream increase in dissolved solids was confirmed at Albert Falls and Table Mountain with a considerable increase noted at Upuma - caused by the contribution of more mineralized water from the Msunduze River which joins the Mgeni in this zone. Both the Msunduze as well as the Sterk River (which also joins the Mgeni River below Albert Falls), contribute significant quantities of sediment to the Mgeni River. Further sediment is derived below Inanda

Table O15: A physical zonation of the Mgeni River in Natal/KwaZulu (continued).

Zone	Characteristics
6. Valley sand bed zone (305 - 3,5 m)	Upuma to Mgeni Estuary area. Below Upuma, towards the Umgegu River confluence in the lower part of the Valley of a Thousand Hills, the wide meandering river bed is characterized by large boulders and thick deposits of coarse sand (one source of Mgeni building sand), with sand gradually becoming dominant towards the sea. The gradient throughout most of the zone averages 7 m km^{-1}. Some of the most commonly occurring species represented in the marginal vegetation of this zone were Cyperus distans; C. immensus; Fimbristylis diphylla; F. hispidula; Mariscus congestus; Scirpus prolifer; Pycreus polystachyos; P. flavescens, and Polygonum lapathifolium. Water temperatures averaged more than 20°C but did not exceed 30°C. The turbidity of the water was low (except in summer)

Source:

(i) After Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 2: survey of the Three Rivers Region, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 224 p. and maps.

(ii) After Schoonbee, H.J. and Kemp, P.H., 1965. An account of the Umgeni River survey, CSIR Research Report No. 325, National Institute for Water Research, CSIR, Pretoria, 63 p. + app.

Note:

(i) The data refer to the early 1960s. Numerous land use changes have taken place since then (including the construction of the Midmar and Inanda dams in zones 3 and 6 respectively). Water quality and riverine biotic data therefore, may not necessarily reflect the present situation.

(ii) Data on fauna according to the various zones are presented in both sources referred to above. A comparison of faunal data between the Mgeni and Tugela rivers is also found in both reports.

(iii) Zonation of the Mgeni River is easily established given that the river has a step-like profile determined by the monoclinal deformation of Natal/KwaZulu, and the subsequent denudation of almost horizontally disposed rock formations of varying erodibility. Erosion-resistant dolerite sills play an important role in the topography of the river at Dargle, Howick and Albert Falls. Above such sills, the river profile tends to flatten, regaining a steep gradient below the waterfall caused by the sill. These dolerite intrusions accordingly, result in a series of miniature profiles (each with a torrential and slower flowing section), within the larger river profile (Brand, Kemp, Pretorius and Schoonbee, 1967). Readers should refer to river profile data (in the chapter on the surface water resources of Natal/KwaZulu), as well as to physiographic regions data (in the chapter on catchments).

(iv) The zonation of the Tugela River is briefly outlined below. The zonation was published in Brand, P.A.J., Kemp, P.H., Oliff, W.D. and Pretorius, S.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 3: the Tugela River and its tributaries, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 68 p. + app. Besides the much lower origin of the Mgeni River (by comparison with the Tugela River), the Mgeni River also lacks the waterfall and mountain torrent zones of the Tugela River. The equivalent zones of the two rivers accordingly, only begin with the foothill torrent zone, which for the Mgeni River, has been subdivided into an upper and a lower foothill torrent zone. A further difference is that the comparable physical zones in the Tugela River occur at slightly higher elevations than the corresponding zones in the Mgeni River. The Mgeni River is also less than half the length of the Tugela River.

Zonation of the Tugela River.

River zone	Length (km)	Altitude (m)	Position
1. Source zone	1,3	3 170 - 3 048	Drakensberg plateau
2. Waterfall zone	2,4	3 048 - 2 286	Drakensberg escarpment
3. Mountain torrent zone	6,9	2 286 - 1 524	To above Royal Natal National Park Hostel
4. Foothill torrent zone	16,9	1 524 - 1 219	To the Caverns' Causeway
5. Foothill sand bed zone	170,6	1 219 - 914	Caverns' Causeway to Harts' Hill
6. Rejuvenated river zone	114,3	914 - 421	Harts' Hill to Ngubevu
7. Valley sand bed	201,2	421 - 3	Ngubevu to Tugela River mouth
8. Tugela River mouth	0,8	3 - 0	-

(v) Brand, Kemp, Pretorius and Schoonbee (1967) observed that the longitudinal distribution of the faunal communities did not necessarily coincide with any one physical zone in the Mgeni River. In some cases, certain faunal associations were found to be restricted to only a part of one zone, while in other instances, some associations occurred over several physical zones. Brand et al (1967) noted that the Mgeni data accordingly, did not entirely agree with the results of Oliff (1960 - above), who found a close correlation between the physical zonation and faunal distribution. Brand et al suggested that a biological zonation based on the ecological distribution of the macroinvertebrate fauna of the Mgeni River was required.

(vi) According to O'Keeffe, Davies, King and Skelton (1989 - above), it is difficult to scientifically determine any significant reduction in species diversity in South African rivers, given inter alia that studies cannot sometimes be easily compared (due to different collecting methods, different sampling periods and different levels of species identification). Importantly, relatively few major studies have been undertaken of South African rivers. Fowles (1984, quoted in O'Keeffe et al, 1989) in a re-survey of the Buffalo River (a tributary of the Tugela River), was unable to show any reduction in invertebrate diversity in the Buffalo (following the original survey by Oliff, 1963)*. Fowles concluded that his data suggested only minor changes in water quality as indicated by the benthic (bottom) fauna. A decrease in the biotic index value at some sampling points, provided possible evidence for an improvement of water quality in the period between the two surveys. More data in South Africa generally, are available for fish species, and examples of the local extinction or reduction of fish species are evident - for example, in the Mkomanzana and Mooi rivers in Natal/KwaZulu (O'Keeffe et al, 1989). It is apparent that a great deal of further research is required in order to accurately assess man's impact on riverine fauna in South Africa.

(vii) A useful paper on ecologically descriptive terms used in the biological literature, with regard to plant and animal life in flowing waters, is the following: Wadeson, R.A., 1994. A geomorphological approach to the identification and classification of instream flow environments, Southern African Journal of Aquatic Sciences, VOL 20(1/2), p. 38 - 61. (The paper discusses terms such as "pool", "riffle" and "cascade").

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destroy the natural barriers between catchments, resulting in the translocation of physical and biotic components, and the mixing or destruction of gene pools. Such impacts are difficult to quantify (O'Keeffe et al, 1989).

In terms of riverine pollution in general, reference has been made to pioneering work by Oliff (1960 and later papers) with regard to the Tugela River system, and detailed studies undertaken by the CSIR/Natal Town and Regional Planning Commission on the major rivers of Natal/KwaZulu. O'Keeffe et al (1989) observed that while gross organic pollution problems associated with large urban areas tend to be fairly localized, dramatic effects on species diversity and the functioning of ecosystems may nevertheless be apparent. In future, increasing attention will have to be paid to the impacts of organic contamination

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* See Oliff, W.D., 1963. Hydrobiological studies on the Tugela River system, Part 3: the Buffalo River, Hydrobiologia, VOL 21(3/4), p. 355 - 379.

derived from non-point sources, with special emphasis on informal settlements*. The effects of acid rain**, specific industrial contaminants, runoff from slimes dams and mines, as well as herbicides and insecticides also require detailed examination - particularly from an holistic, synergistic viewpoint. The choking effects of sediment likewise, can result in fish deaths, where sediment in general has serious consequences for all forms of biota (Chutter, 1973, quoted in O'Keeffe et al, 1989).

Alien biota, namely, animals (both invertebrate and vertebrate - mainly fish) as well as large aquatic plants and large terrestrial plants which invade riparian zones (all of which are difficult to eradicate), can also have significant impacts on riverine ecosystems. (Some riparian issues are briefly discussed in the chapter on catchments and in the chapter on soils and soil erosion). Invasive aquatic plants such as Azolla filiculoides, Eichhornia crassipes, Myriophyllum aquaticum and Salvinia molesta are adaptable to a wide range of environmental conditions, where their very fast vegetative growth enables the plants to easily colonize and to spread rapidly over water bodies (Mitchell, 1978, quoted in O'Keeffe et al, 1989). The effects of the plants include habitat alteration; water quality changes (including deoxygenation below the floating mats); the exclusion of light from sub-surface water; competition for nutrients, and waterway obstruction. Other effects are the provision of new habitats for pest organisms such as bilharzia snails, water treatment problems, and reduced aesthetic properties of the water body***.

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* The main sources of organic pollution are effluents from domestic sewage, food processing plants, animal feedlots, abattoirs, and informal settlements without proper services. Organic discharges (also referred to as oxygen-demanding wastes), generally deplete or reduce the concentration of dissolved oxygen in the receiving water body - as a result of aerobic decomposition of the waste by microorganisms. Increases in turbidity (and hence reduced light penetration); suspended solids (and hence substrate modification), and nutrients (nitrogen/phosphorus and accordingly, the increased potential for plant growth), often accompany oxygen depletion. Combined, these factors significantly affect riverine biotas in receiving waters. Enrichment of a water body with organic material nearly always results in a change in the composition of biotic communities (Dallas and Day, 1993 - see Table O14).

** In this régard, see Fey, M.V. and Guy, S.A., 1993. The capacity of soils in the Vaal Dam catchment to retain sulphate from atmospheric pollution, WRC Report No. 414/1/93, Water Research Commission, Pretoria, 90 p. (While the study concerns soil chemistry and therefore potential runoff, it is clear that direct deposition impacts on aquatic environments are also occurring, the full implications of which, have yet to be established in the industrial areas of South Africa).

*** See Pearce, J., 1987. A preliminary investigation of the effects of water hyacinth on algal growth and water quality, WRC Report No. 142/1/87, Water Research Commission, Pretoria, 186 p., as well as Jacot Guillarmod, A., 1977. Myriophyllum, an increasing water weed menace for South Africa, South African Journal of Science, VOL 73(3), p. 89 - 90. A brief non-technical discussion of aquatic plants is the following: Glen, R., 1996. Aquatic plants - are they friends or foes?, South African Wetlands, No. 7, November 1996, p. 4 - 5.

15.14.2 Assessment procedures

Several methods have been suggested for the determination of the conservation status of rivers. The then Directorate of Nature and Environmental Conservation, Transvaal Provincial Administration, Private Bag X209, Pretoria, 0001, used a Conservation Status Assessment (CSA) system based on river zones, for a provincial survey of river conservation status. Abiotic and biotic criteria were used to allocate zones to one of six classes - ranging from pristine to totally modified (Kleynhans and Engelbrecht, 1988, quoted in O'Keeffe et al, 1989). A preliminary river conservation status mapping project for South Africa was completed by O'Keeffe in 1985 (see earlier in the chapter). The map was derived from a first approximation national conservation classification system for rivers, based on the extent to which a river has been modified from its natural state (Le Roux, Bok, Coetzer, Coke and Engelbrecht, 1986)*. The "naturalness" of a river was considered in two categories, namely, biotic and physical. Four groups were identified varying from pristine to badly degraded, while a fifth group referred specifically to rivers with insufficient available data**. Bromley (1989)*** however, in an application of the concept to the Mvoti River catchment found that the procedure was highly subjective, where a more meaningful classification system for South Africa generally, was required (a point acknowledged by the compilers of the classification system).

O'Keeffe, Danilewitz and Bradshaw (1987, quoted in O'Keeffe et al, 1989)**** developed a method using expert system techniques, which allows for a variable input and

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* See Le Roux, P.J., Bok, A.H., Coetzer, A.H., Coke, M.M. and Engelbrecht, J.S., 1986. Appendix 2. A national classification system and map of the conservation status of rivers, In: O'Keeffe, J.H. (ed), The Conservation of South African Rivers, South African National Scientific Programmes Report No. 131, Foundation for Research Development, CSIR, Pretoria, p. 111 - 112.

** Current terminology involves six categories, namely: wilderness (pristine); wild and scenic; largely unmodified; moderately modified; largely modified, and critically modified. The latter category refers to a river or river reach with an almost total loss of most riverine characteristics and functions (Tharme, R., 1994. Personal communication, Freshwater Research Unit, Department of Zoology, University of Cape Town, Rondebosch).

*** See Bromley, K.A., 1989. Environmental aspects of the Mvoti River catchment in relation to water development, INR Working Paper No. 44, Institute of Natural Resources, University of Natal, Pietermaritzburg, 72 p. + app.

**** See O'Keeffe, J.H., Danilewitz, D.B. and Bradshaw, J.A., 1987. An "expert system" approach to the assessment of the conservation status of rivers, Biological Conservation, VOL 40(1), p. 69 - 84. See also, Danilewitz, D.B., O'Keeffe, J.H. and Bradshaw, J.A., 1988. An expert interface to an ecological model, South African Journal of Science, VOL 84(3), p. 189 - 194.

response for rivers or river reaches. The resulting computer program (the River Conservation System - RCS) has been tested on several rivers in South Africa*. The purpose of the RCS is to assess the conservation status of whole river systems, individual rivers, river reaches, or points in a river. Conservation in this context, is defined as a measure of the relative importance of the river for conservation, and the extent to which the river has been disturbed from the natural condition. The program can also be used to investigate the likely consequences of proposed river development schemes such as impoundments**. The procedure provides for a maximum of 58 questions on numerous attributes which are relevant to the conservation of rivers. The attributes are weighted - known as default weighting - in terms of relative river conservation importance (either positive or negative). Given that few South African rivers have been studied in detail, the RCS requires only a maximum and minimum answer to each question. The 42 core attributes are outlined in Table O16. Several rules in the program can change weightings in accordance with local conditions, for instance, the percentage of sewage effluent in runoff or the number of mainstream dams.

The RCS allows for a global minimum conservation status score of 0 (total degradation) and a maximum score of 100 (the highest conservation status) for a river or part thereof; as well as scores for the components of a river, namely, the catchment, the river per se and the biota. The difference between the maximum and minimum scores reflect the level of data available for the river. The program also provides scores for each attribute, from which the most important negative or positive conservation aspects of the river can be identified. The final weighting (and the difference between the maximum and minimum

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* A useful case study of the CSA and RCS methods, involving the Sabie River, is described in the following: MacKay, H. (ed), 1995. A prototype decision support system for the Kruger National Park Rivers Research Programme, WRC Report No. KV 74/95, Water Research Commission, Pretoria, 82 p. Further RCS case studies are discussed in Davies, B.R., O'Keeffe, J.H. and Snaddon, C.D., 1993. A synthesis of the ecological functioning, conservation and management of South African river ecosystems, WRC Report No. TT 62/93, Water Research Commission, Pretoria, 232 p.

** For a general perspective see Weeks, D.C., O'Keeffe, J.H., Fourie, A. and Davies, B.R., 1996. A pre-impoundment study of the Sabie-Sand River system, Mpumalanga with special reference to predicted impacts on the Kruger National Park, VOL 1: the ecological status of the Sabie-Sand River system, WRC Report No. 294/1/96, Water Research Commission, Pretoria, 261 p. + app., as well as Pollard, S.R., Weeks, D.C. and Fourie, A., 1996. A pre-impoundment study of the Sabie-Sand River system, Mpumalanga with special reference to predicted impacts on the Kruger National Park, VOL 2: effects of the 1992 drought on the fish and macro-invertebrate fauna, WRC Report No. 294/2/96, Water Research Commission, Pretoria, 101 p. + app., plus O'Keeffe, J.H., Weeks, D.C., Fourie, A. and Davies, B.R., 1996. A pre-impoundment study of the Sabie-Sand River system, Mpumalanga with special reference to predicted impacts on the Kruger National Park, VOL 3: the effects of proposed impoundments and management recommendations, WRC Report No. 294/3/96, Water Research Commission, Pretoria, 111 p. + app.

Table O16: The attributes and default weighting of the River Conservation System.

Attribute name	Default weighting
River section	
Mean annual runoff ($10^6 m^3$)	3
River length (km)	4
Stream order	1
Water extraction for all uses (percentage)	-9
Sewage effluent (percentage)	-12
Toxic effluent (percentage)	-16
Rubbish	-6
Agricultural runoff (percentage)	-7
Number of mainstream dams	-8
Number of off-mainstream dams	-4
Number of mainstream weirs	-4
Canalization (percentage)	-12
Percentage of flow from inter-basin transfers	-9
Percentage unregulated river	14
Importance of the river to adjacent ecosystems	7
Siltation	-5
Importance of the river as a migratory route	5
Catchment section	
Catchment size ($10^3 km^2$)	2
Percentage natural vegetation in the catchment	18
Percentage disturbed riparian/bank vegetation in the catchment	-12
Percentage forestry under commercial wood	-6
Percentage arable farming	-7
Percentage improved grazing	-4
Percentage irrigated land	-8
Number of towns in the catchment (population >10 000)	-7
Mean population density (km^{-2})	-7
Amount of erosion	-9
Bank stability	-7

Table O16: The attributes and default weighting of the River Conservation System (continued).

Attribute name	Default weighting
Habitat diversity	11
Amount of rainfall (mm)	N/A
Biota section Number of indigenous fish species	9
Number of endemic fish species	17
Number of endemic invertebrate species	10
Number of introduced fish species	-8
Importance of angling	-4
Importance of other recreations	Weighting is dependent on which of the other recreations are considered to be important
Invertebrate diversity	11
Chutter's biotic index	-15
Number of indigenous macrophyte species	12
Number of introduced macrophyte species	-9
Number of Red Data Book species	12
How different is this river biologically from other rivers?	11

Source: After O'Keeffe, J.H., Danilewitz, D.B. and Bradshaw, J.A., 1986. The River Conservation System: a user's manual - an automated "knowledge assistant" to help in the assessment of the conservation status of South African rivers, Ecosystem Programmes Occasional Report Series No. 9, Foundation for Research Development, CSIR, Pretoria, 76 p. + app.

Note:

(i) Chutter's biotic index refers to the paper by Chutter, F.M., 1972. An empirical biotic index of the quality of water in South African streams and rivers, Water Research, VOL 6(1), p. 19 - 30.

(ii) Some of the main functions of rivers are landscape drainage and water supply - as well as sediment, nutrient and water transport; water purification; nutrient recycling; biotic dispersal; vegetation maintenance; the provision of biotic habitats, and groundwater recharge. River uses include domestic, industrial, agricultural, forestry and fisheries components, as well as recreational, aesthetic, conservation and scientific aspects (O'Keeffe, J.H., 1986. Ecological research on South African rivers: a preliminary synthesis, South African National Scientific Programmes Report No. 121, Foundation for Research Development, CSIR, Pretoria, 121 p.).

answers for each question), are used to calculate a research-priority index, thereby providing an indication of where further data are most needed.

O'Keeffe et al (1989) stressed that a number of problems are apparent in the RCS, although the technique is probably the most advanced method for river conservation status assessment in South Africa. The program provides a consistent (although flexible) method for assessing rivers by simplifying the various intuitions and value judgements of ecologists, in a manner easily understood by managers and engineers. Difficulties include a lack of objective verification of the program results - except by comparison with expert scientific opinion. A second problem is that the determination of both conservation importance and levels of degradation by means of a single method has not been successful, given that the two concepts are not necessarily correlated. O'Keeffe et al also observed that very small streams are not realistically assessed, which may likewise be true for very large rivers, or rivers where extreme conditions are evident. The program in addition, requires a considerable understanding of the principles of riverine ecosystems in order to achieve sensible results. Potential users should fully acquaint themselves with the procedure, before attempting to use the program (refer to O'Keeffe, Danilewitz and Bradshaw, 1986).

15.14.3 Overview

O'Keeffe, Davies, King and Skelton (1989 - above) suggested that the most important aim of river conservation research - bearing in mind the continued exploitation of South African rivers - should be to provide guidelines for the wise multiple use of a limited resource. Of primary significance is the maintenance of habitat integrity; the safeguarding of natural riparian vegetation, and the efficient functioning of essential ecological processes such as runoff, nutrient cycling, and material transport. The limited data currently available provide little evidence of a decrease in biotic diversity (even in highly disturbed rivers). However, there is strong evidence that the replacement of indigenous and endemic species by alien and translocated species is occurring, where introduced species may well influence the efficiency of ecosystem processes (for example, nutrient cycling). Accordingly, the proper classification of rivers, as well as continuous long term monitoring (and hence detailed research), is vital for the compilation of suitable guidelines and strategies for river and catchment management*. Some important management issues include the threshold limit of reduced runoff - beyond which the form and functions of a river are seriously impaired - as well as the volume of effluent which will finally overcome the self-purifying properties of a river. Further issues are the effects of land use changes on the hydrology and water quality of rivers; the impacts of impoundments and water transfers on the ecological processes and biota of rivers, and the implications of alien flora and fauna for the indigenous biota of rivers (O'Keeffe et al, 1989)**.

The Foundation for Research Development, then of the CSIR, Pretoria, funded several research projects on rivers and lakes/dams in South Africa. Some primary publications in this regard include O'Keeffe (1986; 1986); Ferrar (1989); Ferrar, O'Keeffe and Davies

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* A National Biomonitoring Programme for Riverine Ecosystems - also known as the National Aquatic Ecosystem Biomonitoring Programme or the River Health Programme - is being planned for South Africa. The Programme which is currently in the design and development stage, is expected to be fully operational by the year 2000. One of the primary tools of the Programme is the South African Scoring System (SASS) developed by Chutter (1994) - see Table O9. The agency responsible for implementation is the Department of Water Affairs and Forestry. The Programme will be incorporated into the overall water quality monitoring strategy of the Department, as discussed in Section 15.6.2; 15.6.3 and 15.6.4. A variant of biological monitoring involves the examination of fish parasites for selected fish species. Both ecto - (external) parasites and endo - (internal) parasites are relevant. In very polluted water, a low ectoparasite and a high endoparasite count is apparent. The procedure has already been tested in the Olifants River (Kruger National Park), by staff of the Department of Zoology, Rand Afrikaans University, P O Box 524, Auckland Park, 2006. The parasite count may be used as a supplement for another test, namely, the American Health Assessment Index (HAI), which is being adapted for South African conditions. The HAI is used to evaluate the status of fish organs and tissues. Numerical values are assigned according to the extent of organ/tissue deterioration caused by polluted water. The use of frogs which are very sensitive to environmental conditions and therefore any changes, is being examined by the Department of Zoology, University of the Witwatersrand, Private Bag 3, Wits, 2050. It is possible that frogs could be used as an environmental indicator in water and on land.

** The effects of low flows on river biota (motivated by the situation in the Kruger National Park), are currently receiving increased research attention. See Chutter and Heath (1993) plus King and Tharme (1994 - Section 15.13.1); as well as Maaren, H., 1993. Low-flow hydrology workshop: proceedings, Water Research Commission, Pretoria, 16 p., and Ferrar (1989 - below). In similar vein refer to Davies, B.R., Thoms, M.C., Walker, K.F., O'Keeffe, J.H. and Gore, J.A., 1994. Chapter 25. Dryland rivers: their ecology, conservation and management, In: Calow, P. and Petts, G.E. (eds), The Rivers Handbook: Hydrological and Ecological Principles, VOL 2, Blackwell Scientific, Oxford, p. 484 - 511. See also, De Moor, I.J. and Bruton, M.N., 1988. Atlas of alien and translocated indigenous aquatic animals in southern Africa, South African National Scientific Programmes Report No. 144, Foundation for Research Development, CSIR, Pretoria, 310 p.

(1988) as well as Hart and Allanson (1984)*, plus Noble and Hemens (1978 - above). The reports are highly relevant review documents which contain a useful synthesis of case studies combined with extensive bibliographies. The reports should be carefully examined by readers requiring detailed information. Up-to-date and major review documents have been compiled by Dallas and Day (1993) as well as by Davies, O'Keeffe and Snaddon (1993)**. The report by Dallas and Day (1993) - together with a companion volume (Dallas, Day and Reynolds, 1994) - is a valuable addition to the literature on water quality criteria in South Africa, with respect to the protection of aquatic life in rivers and dams. (See Table O3 earlier in this chapter). The Dallas and Day report has data on documented sublethal and lethal effects on various fish, invertebrate and algal species for 27 determinands. Readers are reminded that the Department of Water Affairs and Forestry is currently compiling water quality guidelines for the natural environment, as well as for the coastal and marine environment.

The report by Davies, O'Keeffe and Snaddon (1993) is a comprehensive review of the nature and functioning of southern African rivers, and contains an historical perspective of river research in the region. Also included are conservation and management requirements. The report is a concise follow-up of the earlier river publications provided by the Foundation for Research Development. A detailed discussion of South African and Australian experience on river classification and conservation, as well as riverine

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* See O'Keeffe, J.H., 1986. Ecological research on South African rivers: a preliminary synthesis, South African National Scientific Programmes Report No. 121, Foundation for Research Development, CSIR, Pretoria, 121 p., and O'Keeffe, J.H. (ed), 1986. The conservation of South African rivers, South African National Scientific Programmes Report No. 131, Foundation for Research Development, CSIR, Pretoria, 117 p., plus Ferrar, A.A. (ed), 1989. Ecological flow requirements for South African rivers, South African National Scientific Programmes Report No. 162, Foundation for Research Development, CSIR, Pretoria, 118 p. See in addition: Ferrar, A.A., O'Keeffe, J.H. and Davies, B.R., 1988. The river research programme, South African National Scientific Programmes Report No. 146, Foundation for Research Development, CSIR, Pretoria, 28 p., as well as Hart, R.C. and Allanson, B.R. (eds), 1984. Limnological criteria for management of water quality in the southern hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, 181 p.

** See Dallas, H.F. and Day, J.A., 1993. The effect of water quality variables on riverine ecosystems: a review, WRC Report No. TT 61/93, Water Research Commission, Pretoria, 240 p., plus Dallas, H.F., Day, J.A. and Reynolds, E.G., 1994. The effects of water quality variables on riverine biotas, WRC Report No. 351/1/94, Water Research Commission, Pretoria, 230 p., as well as Davies, B.R., O'Keeffe, J.H. and Snaddon, C.D., 1993. A synthesis of the ecological functioning, conservation and management of South African river ecosystems, WRC Report No. TT 62/93, Water Research Commission, Pretoria, 232 p. See in addition: Day, J.A., 1993. The major ion chemistry of some southern African saline systems, Hydrobiologia, VOL 267(1), p. 37 - 59., as well as Day, J.A. and King, J.M., 1995. Geographical patterns, and their origins, in the dominance of major ions in South African rivers, South African Journal of Science, VOL 91(6), p. 299 - 306.

ecosystem health and water quality can be found in Uys (1994)*. Two useful references in terms of the legal aspects of aquatic systems are O'Keeffe, Uys and Bruton (1992) and Stone, Lane, Russell and Best (1986)**. The latter slightly dated report is particularly "user friendly".

15.15 Eutrophication***

Eutrophication refers to the excessive fertilization of water bodies by plant nutrients (especially nitrogen and phosphorus). This can lead to a marked growth of algae and aquatic macrophytes (Ashton, Claassens, Esteves, Grobler, Heynike, Jarvis, Seaman, Silberbauer, Thornton and Wiechers, 1984). The increase in algae can result in colour and odour problems in the water, with the development of unpleasant surface scums****. Macrophytes produce extensive growths which can completely cover the water body, thereby blocking water flow, and resulting in interference with the beneficial uses of the water. Eutrophication can occur in rivers and dams as well as in lakes and "estuaries". In limnological terms, water bodies can be defined with regard to trophic status - varying from oligotrophic (low plant nutrient content and minimal plant production), to eutrophic (high plant nutrient content and excessive plant production), with an intermediate mesotrophic status. At opposite ends of the scale, ultra-oligotrophic and hypertrophic conditions may also be evident. Eutrophication is a natural and/or artificial

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* See Uys, M.C. (ed), 1994. Classification of rivers, and environmental health indicators: proceedings of a joint South African/Australian workshop, 7 - 11 February 1994, Cape Town, WRC Report No. TT 63/94, Water Research Commission, Pretoria, 419 p. (Many important papers are contained in the proceedings).

** See O'Keeffe, J.H., Uys, M. and Bruton, M.N., 1992. Chapter 13. Freshwater systems, In: Fuggle, R.F. and Rabie, M.A. (eds), Environmental Management in South Africa, Juta, Cape Town, p. 277 - 315. (See also Chapter 25. Rivers, p. 647 - 668). Examine likewise Stone, A.W., Lane, S., Russell, W.B. and Best, H.J., 1986. Chapter 7. River conservation - implications for legislation, In: O'Keeffe, J.H. (ed), The Conservation of South African Rivers, South African National Scientific Programmes Report No. 131, Foundation for Research Development, CSIR, Pretoria, p. 74 - 87. See in addition the chapter on the surface water resources of Natal/KwaZulu.

*** Discussion based on Ashton, P.J., Claassens, G.C.D., Esteves, F. de A., Grobler, D.C., Heynike, J., Jarvis, A.C., Seaman, M.T., Silberbauer, M.J., Thornton, J.A. and Wiechers, H.N.S., 1984. Chapter 6. Eutrophication, In: Hart, R.C. and Allanson, B.R. (eds), Limnological Criteria for Management of Water Quality in the Southern Hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, p. 134 - 152., as well as Walmsley, R.D. and Butty, M., 1980. Guidelines for the control of eutrophication in South Africa, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 27 p.

**** See Wnorowski, A.U., 1993. Research on taste and odour forming microorganisms in South African surface waters, WRC Report No. 320/1/93, Water Research Commission, Pretoria, 100 p.

process, depending on the enrichment source. Natural processes involve the weathering and leaching of substrates in the catchment. Accordingly, vegetation patterns, geological formations and precipitation are important factors. The artificial (accelerated) enrichment of water systems (cultural eutrophication) is due to man's activities. In the latter case, land use practices are a significant factor causing eutrophication through alteration of the pathways and rates of nutrient transport from the catchment. In most catchments both natural and artificial sources of nutrients contribute to eutrophication (Walmsley and Butty, 1980).

Enrichment stimulates the production of organic material by primary producers (plants and certain bacteria), which can then be used either by secondary producers (animals such as zooplankton and fish), or by decomposers (such as bacteria and fungi). Several symptoms can be used to diagnose the onset of eutrophication, depending on local conditions. Relatively minor changes are apparent at first, with profound changes occurring as eutrophication proceeds. These changes can include a vast increase in planktonic vegetation; a massive incursion of blue-green algae*; the total elimination of oxygen from the hypolimnic (the colder deep) water layers during summer; the accumulation of considerable quantities of nutrients, and the appearance of hydrogen sulphide, ions of ammonia, manganese and iron. Further major changes are the concentration and sedimentation of non-mineralized organic substances and the formation of methane and other organic volatiles, as well as the disappearance of the fauna of the deeper regions of the water. Macrophytes and floating algae may be found in dense clusters along

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* See Schoeman, F.R. and Archibald, R.E.M., 1976. The diatom flora of southern Africa, CSIR Special Report No. WAT 50, National Institute for Water Research, CSIR, Pretoria, no pagination. (The publication is very comprehensive and was expanded (on-going) in the period 1976 - 1980). See also: Joska, M.A. and Bolton, J., 1994. Final report: preliminary investigation into algal weeds in inland waters, WRC Report No. 426/1/94, Water Research Commission, Pretoria, 66 p., as well as Joska, M.A. and Bolton, J.J., 1994. Guide to common filamentous freshwater macroalgae in South Africa, WRC Report No. TT 66/94, Water Research Commission, Pretoria, 39 p. Refer also to Truter, E., 1987. An aid to the identification of the dominant and commonly occurring genera of algae observed in some South African impoundments, Technical Report No. TR 135, Department of Water Affairs, Pretoria, 101 p. Information can likewise be found in a series of pamphlets (W.1 - W.20) on water plants in South Africa, compiled by the then Botanical Research Institute and distributed by the Directorate of Agricultural Information, Department of Agriculture, Private Bag X144, Pretoria, 0001. Example: Anonymous, 1980. Floating pondweed/Drywende fonteinkruid: (Potamogeton thunbergii Cham. and Schlechtd.), Family: Potamogetonaceae, Water Plants: Southern African Plants W.1/1980, Farming in South Africa, 2 p. See in addition, Musil, C.F., 1973. Water plants of Natal - a guide to the important species, Wildlife Protection and Conservation Society of South Africa, [Durban], 62 p. (It should be noted that macrophytes may be emergent or submerged, and free-floating or rooted to the bottom. Algae may be planktonic (the phytoplankton), attached to the bottom (the benthic algae), or attached to other plants (the epiphyton). Blue-green algae are also known as cyanobacteria due to their close relationship with bacteria).

shorelines, resulting in a considerable variation in the oxygen content of the water during the day. The same process occurs in watercourses with advanced eutrophication, where the dense mass of plants can impede the flow of water (Walmsley and Butty, 1980).

15.15.1 Factors controlling eutrophication

The nutrient loads of water bodies are determined by climatic factors such as rainfall, the variability of runoff and weathering plus erosion; as well as by catchment characteristics (surface geology and land form), and by human activities (various nutrient sources and changing land use patterns) (Ashton et al, 1984). External nutrient loads are derived from point and non-point sources. Non-point source inputs are rather variable due to a dependence on runoff. Point source inputs for example, from sewage works, industries and abattoirs are more constant. Less important sources of nutrients are atmospheric deposition (including N-fixation), as well as internal recycling through physical, chemical and biological processes. Since most of the nutrient load received by a lake, dam or "estuary" is derived from the catchment, it follows that the variability of the total input will depend on the point : non-point source ratio. Nutrient losses from the system consist largely of mass transfers via the water body outlet, plus irreversible sedimentation. At a high pH, denitrification and the volatilization of ammonia (with respect to N), may also be of relevance.

An important concept is that of nutrient limitation, where the growth rate of phytoplankton in stored/standing water, is restricted by the chemical element with the least favourable demand/supply ratio. The addition of that element per se will stimulate phytoplankton growth, while the addition of other elements will have no effect. The most important plant mineral elements are carbon, nitrogen, phosphorus and silica. Phosphorus and nitrogen are the most essential of the growth-limiting nutrients. Some (earlier) debate concerned the role of light availability as a limiting factor for algal growth in turbid water bodies (Ashton et al), although later research confirmed that high turbidity due to inorganic suspended sediment (solids) does reduce algal growth rates (Rossouw, 1990)*. It should be noted that certain algae such as Microcystis aeruginosa can grow to such large

* See Rossouw, J.N., 1990. The development of management orientated models for eutrophication control, WRC Report No. 174/1/90, Water Research Commission, Pretoria, 80 p. + app.

proportions that the population self-shades itself. The alga accordingly becomes the dominant factor regulating light penetration in the water.

The effect of incoming nutrient loads on in situ water body nutrient concentrations is modified by water body morphometry (deep or shallow, bowl shaped or dendritic); as well as by hydrology (variability of flow and retention time). Also important is the form of the nutrient load (particulate or dissolved), and the bioavailability of the load. The trophic response of water bodies is dependent on the utilization of nutrients by the primary producers with regard to environmental constraints (light, temperature and hydrodynamics) (Ashton et al, 1984). Although both nitrogen and phosphorus are important factors in eutrophication, research and management strategies have concentrated on phosphorus which is more easily controlled than nitrogen. Rossouw (1990) however, found that for certain dams in South Africa, eutrophication-related water quality is primarily regulated by nitrogen availability. Nevertheless even nitrogen-limited impoundments can be forced to phosphorus limitation by a sufficient reduction of phosphorus, and accordingly become responsive to phosphorus load reductions. Unfortunately, many blue-green algae are able to use atmospheric nitrogen - especially during periods of temporary nitrogen deficiency in impoundments - which can to some extent negate control measures (Taylor, Best and Wiechers, 1984)*. Algae can also accumulate phosphate in their cells. The stored phosphate can be used for growth, even if the surrounding water becomes low in phosphorus. Ortho-phosphate is the form of phosphorus which is directly available for algal and aquatic plant growth (Walmsley and Butty, 1980). In practical terms, phosphorus (at relatively high concentrations), can interfere with the coagulation processes used in the treatment of industrial and municipal water supplies (Keup, 1968, quoted in Weddepohl and Meyer, 1992)**.

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* See Taylor, R., Best, H.J. and Wiechers, H.N.S., 1984. The effluent phosphate standard in perspective: Part 1: impact, control and management of eutrophication, Imiesa, VOL 9(10), p. 43 - 56. See also, Wiechers, H.N.S., Taylor, R. and Best, H.J., 1984. The effluent phosphate standard in perspective: Part 2: state of the art of technology for limiting phosphate discharge to the water environment, Imiesa, VOL 9(11), p. 27 - 35. (The papers contain a useful overview of the early literature in terms of eutrophication in South Africa).

** See Weddepohl, J.P. and Meyer, D.H., 1992. Utilization of models to simulate phosphorus loads in southern African catchments, WRC Report No. 197/1/92, Water Research Commission, Pretoria, 160 p. + app.

15.15.2 Specific sources of phosphorus*

Major point sources of phosphorus (P) are domestic wastewaters and industrial effluents (Taylor, Best and Wiechers, 1984). According to Taylor et al, point sources are the main sites for 80 - 90% of the total phosphorus load entering the aquatic environment, although not all the phosphorus actually reaches downstream impoundments. The most important sources of phosphorus in domestic wastewaters are human faeces (50 - 65%), and synthetic laundry detergents (35 - 50%). The mean daily phosphorus load derived from human faeces in South Africa has been estimated at 1,3 g P $capita^{-1}$, and 1,0 g P $capita^{-1}$ for synthetic detergents. Industrial effluents which are high in phosphorus include those derived from commercial laundries, fertilizer production, dairies and feedlots, as well as meat processing and packaging plants (Wiechers and Heynike, 1986).

Raw sewage contains several different forms of phosphorus, inter alia organically bound and inorganic P. The latter includes simple ortho-phosphates and condensed phosphates (polyphosphates). Ortho-phosphate usually constitutes 50% or more of the total phosphorus in raw sewage. The conventional activated sludge and biological filter wastewater treatment processes do not remove phosphorus to any marked degree. However, transformation of organic and polyphosphates to ortho-phosphate during treatment, increases the soluble ortho-phosphate content from 50% to some 90% (fortunately, the easiest to remove by chemical and biological means) (Wiechers and Heynike, 1986).

* Discussion based on Weddepohl and Meyer (1992). Refer also to Wiechers, H.N.S. and Heynike, J.J.C., 1986. Sources of phosphorus which give rise to eutrophication in South African waters, Water SA, VOL 12(2), p. 99 - 102.

Non-point sources of phosphorus* are derived from untreated faecal and detergent-contaminated runoff (such as in informal settlements); urban runoff in general; runoff from agricultural landscapes; wet and dry atmospheric deposition, and groundwater. Also important are lake bottom sediments, especially in shallow impoundments where wind induces considerable mixing, resulting in the resuspension of bottom sediments to the water column (Grobler, 1985)**. Surface drainage is the major non-point source contributor of phosphorus to watercourses (Bath, 1989, quoted in Weddepohl and Meyer, 1992). Phosphorus loading due to surface runoff is dependent on a number of factors such as the phosphorus content of the soil and soil properties including the extent of erosion***. Other factors are topography, geology, vegetative cover, land use, and the application of fertilizers. Similarly relevant are animal populations and pollution. Primary factors are rainfall as well as the volume and duration of runoff (Keup, 1968, quoted in Weddepohl and Meyer).

Phosphorus occurs naturally in soil as a result of the weathering of primary phosphorus-bearing minerals in the parent material. Wilde, Wilson and White (1949, quoted in Weddepohl and Meyer) found that the phosphorus content of sandstone was 0,02%; diabase 0,03%; gneiss 0,04%; unweathered loess 0,07%; andesite 0,16%, and limestone 1,32%. In South Africa, Grobler and Silberbauer (1985)**** confirmed the importance of catchment geology as a source of nutrients - a concept described in the

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* Phosphorus can be grouped into two physical fractions, namely, dissolved and particulate phosphorus. Dissolved inorganic phosphorus is the directly bioavailable form. Other forms (short-lived in natural waters), are dissolved condensed phosphorus (both natural compounds and phosphorus compounds found in detergents - often rapidly hydrolyzed to dissolved inorganic phosphorus), plus dissolved organic phosphorus, all of which are bioavailable only through conversion to inorganic phosphorus. The dissolved organic phosphorus released from soils is more stable and is usually found in lower concentrations than dissolved inorganic phosphorus, in rural and urban runoff. Particulate phosphorus often comprises a high percentage of the total phosphorus input to water bodies. The particulate fraction can consist of organic, inorganic and condensed forms. Condensed particulate phosphorus compounds generally constitute a small percentage of the total particulate phosphorus. Organic phosphorus in eroded soil particles (the main source of particulate phosphorus in rivers), is relatively stable and the fraction converted to dissolved inorganic phosphorus in natural waters is probably small (Browman, Harris, Ryden and Syers, 1979; Rodel, Armstrong and Harris, 1977; Sonzogni, Chapra, Armstrong and Logan, 1982 - all quoted in Weddepohl and Meyer, 1992).

** See Grobler, D.C., 1985. Phosphorus budget models for simulating the fate of phosphorus in South African reservoirs, Water SA, VOL 11(4), p. 219 - 230.

*** For a local perspective see Furness, H.D. and Breen, C.M., 1978. The influence of P-retention by soils and sediments on the water quality of the Lions River, Journal of the Limnological Society of Southern Africa, VOL 4(2), p. 113 - 118.

**** See Grobler, D.C. and Silberbauer, M.J., 1985. The combined effect of geology, phosphate sources and runoff on phosphate export from drainage basins, Water Research, VOL 19(8), p. 975 - 981.

CSIR/Natal Town and Regional Planning Commission survey reports (see earlier in the chapter). The addition of plant residues and fertilizers by man increases the phosphorus content of the top soil, with organic phosphorus predominating in the surface layer. Inorganic phosphorus tends to be high in the subsoil. Depending on the extent of transport via erosion (especially sheet erosion) or less importantly the degree of leaching - the phosphorus on reaching a stream - can become significant for the nutrition of aquatic microorganisms (Weddepohl and Meyer). According to Huettl, Wendt and Corey (1979, quoted in Weddepohl and Meyer), the major portion of phosphorus carried in runoff is often attached to sediment. The phosphorus content of groundwater which enters surface waters via seepage or springs and the pumping of wells is relatively low (Bath, 1989). In general, non-point source derived phosphorus loads are characterized by considerable spatial as well as temporal variability, and are therefore difficult to estimate and to predict.

Novotny, Tran, Simsiman and Chesters (1978, quoted in Weddepohl and Meyer, 1992) outlined an idealized hydrological routing for phosphorus in the environment, in terms of four categories. Firstly, **atmospheric transport** by air movements, wind erosion, dust fallout and precipitation. Secondly, **overland flow transport** due to surface runoff, erosion and sediment pick-up, plus the infiltration and contamination of groundwater, the dissolution of deposited soluble phosphorus, and the adsorption and transformation of phosphorus in the soil. Next, the **channel flow of phosphorus** including convection, dispersion, sedimentation*, scour, adsorption, release, degradation and transformation; followed by the **deposition of phosphorus** in areas where flow velocity decreases. The suspended particulate phosphorus and adsorbed fractions are subject to sedimentation during overland and channel transport, and can settle out in sections of low water velocity, or be resuspended during high flows. The suspended and adsorbed fractions therefore lag behind the water movement, where a portion of the phosphorus may be incorporated into alluvial deposits in the river. The sorption of phosphorus by particulate material plays a vital role in the reduction of soluble concentrations - via the subsequent settling and deposition of the particulate material - which reduces the available phosphorus for algal growth.

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* For a South African perspective, see Grobler, D.C. and Davies, E., 1981. Sediments as a source of phosphate: a study of 38 impoundments, Water SA, VOL 7(1), p. 54 - 60. See also, Grobler, D.C. and Davies, E., 1979. The availability of sediment phosphate to algae, Water SA, VOL 5(3), p. 114 - 122.

15.15.3 The effects of eutrophication

The implications of eutrophication will depend on the beneficial uses of the water. Numerous effects are possible, some of which are listed in Table O17. Importantly, Jones and Lee (1982, quoted in Weddepohl and Meyer, 1992) observed that there is an apparent relationship between the degree of eutrophication (in some water bodies), and the amount of potentially carcinogenic trihalomethanes formed during the chlorination of water for domestic requirements. (See earlier in the chapter).

15.15.4 Eutrophication indicators

Increasing enrichment results in an increase in the biomass which the water body can support. The degree of enrichment can be related to a given characteristic or set of characteristics (indicators), which describe the biomass and/or the conditions resulting from the increase in nutrients (Ashton et al, 1984 - above). Indicators may be biological, chemical or physical (Table O18). The following table (Table O19) provides ranges of values for oligotrophic, mesotrophic and eutrophic water bodies. The selection of appropriate indicators is dependent on the particular site and the beneficial uses of the water. Only a few indicators (such as the total phosphorus concentration) can be widely used. By contrast, hypolimnetic oxygen deficit values for temperate systems are not appropriate for tropical systems, where deoxygenation occurs even in oligotrophic waters. The chlorophyll a concentration* is regarded as the most reliable trophic status indicator - since this indicator is relatively easy to measure, and provides a quantitative indication of the problem conditions (most importantly phytoplankton biomass). The latter indicator can in addition, be quantitatively related to other eutrophication and water quality parameters such as nitrogen and phosphorus concentrations and loads, as well as primary production (Ashton et al).

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* Chlorophyll is the green photosynthetic pigment found in plants. The most common form is chlorophyll a.

Table O17: Some impacts of eutrophication on water use.

Water use	Problems/manifestations/effects
Biota	Extensive anaerobic (oxygen-starved) hypolimnia in water bodies with consequent effects on biota and water chemistry. Increased water treatment costs
Domestic/drinking	Coloured water with bad taste and malodour due to phytoplankton, which results in increased water treatment costs
	Methaemoglobinaemia in babies resulting from high nitrate levels (10 mg ℓ^{-1} N) in drinking water
	Blue-green algal toxicity with chronic and sublethal effects on man; toxicity and death of livestock, pets and bees. Increased water treatment costs
Industrial	Biological fouling problems in industrial plants (such as cooling towers), due to biological growth caused by nutrient enrichment
Irrigation	Nutrient enriched waters generally benefit irrigated crops, although excessive growth of filamentous algae and hydrophytes in irrigation canals, obstructs and reduces water flow
Hydroelectric power generation	Aquatic macrophytes may enter and block turbines, disrupting power generation
General recreation	Aesthetic and health implications impair recreational uses. Algal scums are unsightly, create odour problems, and may induce allergenic responses in swimmers. Macrophytes can block access to the water and interfere with swimming, boating and fishing. Macrophytes can create a habitat for disease vectors, besides reducing adjacent property values
Recreational fishing	Fish production may increase initially in response to eutrophication - although this beneficial effect is eroded by progressive eutrophication, which is accompanied by a shift to coarse fish species (less desirable for recreational anglers)

<u>Source</u>: After Ashton, P.J., Claassens, G.C.D., Esteves, F. de A., Grobler, D.C., Heynike, J., Jarvis, A.C., Seaman, M.T., Silberbauer, M.J., Thornton, J.A. and Wiechers, H.N.S., 1984. Chapter 6. Eutrophication, In: Hart, R.C. and Allanson, B.R. (eds), Limnological Criteria for Management of Water Quality in the Southern Hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, p. 134 - 152.

<u>See also</u>:

(i) Bruwer, C.A., 1979. The economic impact of eutrophication in South Africa, Technical Report No. TR 94, Department of Water Affairs, Pretoria, 48 p.

(ii) Haarhoff, J., Langenegger, O. and Van der Merwe, P.J., 1992. Practical aspects of water treatment plant design for a hypertrophic impoundment, <u>Water SA</u>, VOL 18(1), p. 27 - 36.

(iii) Thornton, J.A., 1987. Aspects of eutrophication management in tropical/sub-tropical regions, Journal of the Limnological Society of Southern Africa, VOL 13(1), p. 25 - 43.

Note: The genera of algae listed below, cause the most severe problems in water bodies. While much emphasis has been placed in the literature on the role of blue-green algae in eutrophication, diatoms can also be a major cause of algal problems in water treatment works (Walmsley, R.D. and Butty, M., 1980. Guidelines for the control of eutrophication in South Africa, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 27 p.).

Algae	Problem
Melosira	Filter blockage
Microcystis	Filter blockage; taste and odour, toxicity and scum formation
Oscillatoria	Filter blockage, taste and odour as well as scum formation
Anabaena	Filter blockage, toxicity and scum formation
Euglena	Filter blockage
Chlamydamonas	Filter blockage and filter penetration
Dinobryon	Taste and odour
Prymnesium	Toxicity to fish
Green unicellular algae	Filter penetration
Small diatoms	Filter penetration

Table O18: Some examples of common eutrophication indicators.

Indicator	Rationale for use
Causal indicator	
Total phosphorus concentration	The most important nutrient associated with eutrophication
Response indicators	
Chlorophyll a concentration	Provides a measure of the phytoplankton standing crop, and is the most commonly used response indicator
Hypolimnetic oxygen deficit	Decomposition of plant material results in oxygen consumption in the bottom waters of a lake/dam
Secchi disc transparency	A change in the phytoplankton biomass results in a concomitant change in water transparency. Also measures turbidity
Phytoplankton cell counts	Cell numbers increase with eutrophication
Phytoplankton cell volume	A direct measure of biomass
Number of species	Enrichment often reduces the number of species present and diversity decreases
Observer assessment	Obvious colour, scum and odour problems

Source: After Ashton, P.J., Claassens, G.C.D., Esteves, F. de A., Grobler, D.C., Heynike, J., Jarvis, A.C., Seaman, M.T., Silberbauer, M.J., Thornton, J.A. and Wiechers, H.N.S., 1984. Chapter 6. Eutrophication, In: Hart, R.C. and Allanson, B.R. (eds), Limnological Criteria for Management of Water Quality in the Southern Hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, p. 134 - 152.

Note:

(i) The Secchi disc is an aluminium disc 200 mm in diameter, which is painted in black and white quadrants. The Secchi depth is the depth at which the disc just disappears from view below the water surface. Secchi depth is a function of both light scattering and light absorption.

(ii) Allanson, Hart, O'Keeffe and Robarts (1990, quoted in Davies, O'Keeffe and Snaddon, 1993)* suggested that the climatological, geochemical and geomorphological features of southern Africa could be grouped into five limnological regions, each with its own characteristics, and therefore management implications. The first region comprises a subtropical coastal peneplain with a strong marine influence, resulting in elevated salinities in subsoil water, as well as "estuaries" with varying degrees of salinity. The low-lying

* See Davies, B.R., O'Keeffe, J.H. and Snaddon, C.D., 1993. A synthesis of the ecological functioning, conservation and management of South African river ecosystems, WRC Report No. TT 62/93, Water Research Commission, Pretoria, 232 p.

northern part of Natal/KwaZulu stretching almost to the Tugela River, falls within this region. The second region is the summer rainfall area of the elevated plateau and the south eastern coast. The total dissolved solids (TDS) content of the surface water is less than 500 mg ℓ^{-1}, with a pH varying between 7,5 - 9,0. Most of Natal/KwaZulu is in this region. The third region is the elevated mountain massif of Lesotho (also known as the Australo-montane or Alpine region). The TDS of surface water is between 47 - 273 mg ℓ^{-1}, with a pH of 6,6 - 8,4 (although generally greater than 7,5 in lowland streams). The Drakensberg Escarpment forms the eastern boundary of the region with regard to Natal/KwaZulu. The fourth region comprises the temperate acid waters of the south and western Cape, with rivers rising in the mountains from leached Table Mountain sandstone. Surface waters are influenced to a varying extent by salts of marine origin at lower altitudes, with a resulting increase in buffering capacity to neutral pH. The fifth region is the arid west stretching northwards, inland from Port Elizabeth to southern Botswana and Namibia. Surface waters are seasonal with a high TDS and alkaline pH.

Table O19: Trophic status criteria for dams/lakes, with a South African example.

Category	Mean productivity (mg Carbon m^{-2} day^{-1})	Chlorophyll <u>a</u> (mg m^{-3})	Total phosphorus (mg m^{-3})	Total nitrogen (mg m^{-3})
Oligotrophic	50 - 300	0,3 - 3,0	5	250
Mesotrophic	250 - 1 000	2 - 15	5 - 30	250 - 1 000
Eutrophic	1 000	10 - 500	30 - 1 000	1 000
Hartbeespoort Dam (Hypertrophic - the most polluted dam in South Africa - after Robarts, 1984, quoted in Ashton <u>et al</u>, 1984)	400 - 30 900	11 - 740	509	2 500

<u>Source</u>: After Ashton, P.J., Claassens, G.C.D., Esteves, F. de A., Grobler, D.C., Heynike, J., Jarvis, A.C., Seaman, M.T., Silberbauer, M.J., Thornton, J.A. and Wiechers, H.N.S., 1984. Chapter 6. Eutrophication, In: Hart, R.C. and Allanson, B.R. (eds), Limnological Criteria for Management of Water Quality in the Southern Hemisphere, South African National Scientific Programmes Report No. 93, Foundation for Research Development, CSIR, Pretoria, p. 134 - 152.

See also:

(i) Anonymous, 1993. South African water quality guidelines, VOL 2, Recreational use, Department of Water Affairs and Forestry, Pretoria, 134 p.

(ii) Walmsley, R.D., 1984. A chlorophyll a trophic status classification system for South African impoundments, Journal of Environmental Quality, VOL 13(1), p. 97 - 104.

(iii) Walmsley, R.D. and Butty, M., 1980. Guidelines for the control of eutrophication in South Africa, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 27 p.

Note:

(i) Walmsley and Butty (1980) defined nuisance values with reference to specific chlorophyll a ranges. In the range 0 - 10 $\mu g\ \ell^{-1}$ no problems are encountered; while in the range 10 - 20 $\mu g\ \ell^{-1}$ algal scums are present, indicative of approaching nuisance conditions. In the range 20 - 30 $\mu g\ \ell^{-1}$ nuisance conditions are apparent. Chlorophyll a concentrations exceeding 30 $\mu g\ \ell^{-1}$ reflect severe nuisance conditions. The selection of the ranges was based on the appearance of surface blooms (scums), plus other symptoms of eutrophication such as anaerobic hypolimnia (Walmsley, 1984).

(ii) Walmsley and Butty (1980) provided three sets of criteria to assess the trophic status of an impoundment. The first method (a) refers to the mean annual chlorophyll a concentration (CHL) of 5 m deep hosepipe samples collected at least fortnightly near the dam wall. The second (preliminary) procedure (b) is applied in terms of increased zooplankton biomass, where a net (100 μm mesh size) is lowered to the bottom of the water body. The wet biomass trapped in the mesh is then weighed to provide a measure of the zooplankton population (assessment based on work by Seaman, Walmsley and Alexander). The third method (c) refers to the mean annual ortho-phosphate/mean annual total phosphorus concentration in the water body; and the annual ortho-phosphate/annual total phosphorus surface loading rate. Method (c) applies to water bodies where phosphorus is the limiting nutrient.

Walmsley and Butty (1980) observed that impoundments can be regarded as phosphorus-limiting, where the inorganic nitrogen : ortho-phosphate loading rate ratio is greater than 5 : 1. Another ratio which is based on the nitrogen : phosphorus content of algal cells is 7 : 1. The latter ratio is also used in the literature. A ratio higher than 7 : 1 indicates potential phosphorus limitation, while a ratio of less than 7 : 1 indicates potential nitrogen limitation. Walmsley and Butty demonstrated that the trophic status of South African impoundments is dependent not only on phosphorus loading, but also on water turbidity. In impoundments where the mean annual Secchi disc transparency is more than 0,4 m, trophic status (as CHL) is linearly related to the ortho-phosphate loading rate in terms of an empirical equation. In turbid water bodies where the mean annual Secchi disc transparency is less than 0,4 m, trophic status (as CHL) is a function of the ortho-phosphate loading rate and water transparency - indicative of the influence of reduced light penetration on algal growth - again in terms of an empirical equation. Several other important equations have been derived for South African impoundments. These include CHL and the mean annual ortho-phosphate/mean annual total phosphorus concentration in water bodies. Such equations form the basis of eutrophication models.

Parameter	Trophic status		
	oligotrophic	mesotrophic	eutrophic
(a) Mean annual chlorophyll a concentration ($\mu g\ \ell^{-1}$)	<3	3 - 9	>9
(b) Mean wet biomass of a vertical haul ($g\ m^{-3}$)	<0,5	0,5 - 1,0	>1,0
(c) Mean annual ortho-phosphate concentration ($\mu g\ \ell^{-1}$) in the surface layer of the water body (0,5 m)	Not predictable	0 - 24	>24
Mean annual total phosphorus concentration ($\mu g\ \ell^{-1}$) in the surface layer of the water body (0,5 m)	≤15	15 - 47	>47
Ortho-phosphate surface loading rate ($g\ m^{-2}\ y^{-1}$)	Not predictable	0 - 3,21	>3,21
Total phosphorus surface loading rate ($g\ m^{-2}\ y^{-1}$)	Not predictable	0,04 - 7,18	>7,18

(iii) Walmsley and Butty (1980) outlined another method for determining trophic status. The authors noted that it is often not possible to conduct a detailed investigation of an impoundment. Some parameters however, can be examined by a spot-check of the water body at the deepest point, especially during summer when most water bodies are thermally stratified. An assessment can then be made on the basis of the parameters, but only in terms of the overall condition of the water body.

Parameter	Details
Surface water pH	If >8,4 then possibly eutrophic
Dissolved oxygen at surface/dissolved oxygen at bottom	If surface supersaturated and bottom anaerobic, then eutrophic
Ortho-phosphate at surface/ortho-phosphate at bottom	If >25 $\mu g\ \ell^{-1}$ and accumulation observed in the bottom waters, then eutrophic
Ammonia at surface/ammonia at bottom	If accumulation in the bottom waters, then mesotrophic or eutrophic
Algal growth potential	If >25 mg ℓ^{-1} then mesotrophic or eutrophic
Chlorophyll a content at surface	If >10 $\mu g\ \ell^{-1}$ then mesotrophic or eutrophic; if >20 $\mu g\ \ell^{-1}$ then eutrophic
Iron and manganese at bottom	If accumulation in the bottom waters, then mesotrophic or eutrophic
Hydrogen sulphide in bottom waters	If present, then mesotrophic or eutrophic

(iv) Walmsley (1984) further developed the chlorophyll a trophic classification system, by means of an examination of 24 South African impoundments. Walmsley found that there appeared to be no common seasonal pattern to the occurrence of chlorophyll a maxima and minima. Trophic status therefore, was best described by a statistical parameter based on annual data (notably the mean value). Statistically significant empirical equations which relate the maximum value and the frequency of occurrence of specific chlorophyll a nuisance ranges, to the mean annual value were determined. Part of the difficulties encountered in the assessment of trophic status is evident where even hypertrophic systems can (at times of the year), display oligotrophic characteristics (Lee, 1973, quoted in Walmsley, 1984). Walmsley (1984) used the chlorophyll a nuisance ranges (described in Footnote (i) above) and the empirical equations to redefine trophic status. Accordingly, oligotrophic impoundments are impoundments where instantaneous chlorophyll a concentrations in the epilimnion (the upper, warmer water layers) - based on an integrated sample from the 5 m layer - never exceed 10 $\mu g\ \ell^{-1}$. In mesotrophic impoundments, chlorophyll a concentrations at times exceed 10 $\mu g\ \ell^{-1}$, but never exceed 30 $\mu g\ \ell^{-1}$. In eutrophic impoundments, the chlorophyll a concentration exceeds 30 $\mu g\ \ell^{-1}$ for at least 8% of the annual cycle. Based on experience in South Africa as well as elsewhere in the world, the Department of Water Affairs and Forestry has (provisionally) adopted a general eutrophication management objective of ensuring that severe nuisance conditions in impoundments should occur for less than 20% of the time. Using empirical equations, this implies the maintenance of a mean chlorophyll a concentration of less than 21 $\mu g\ \ell^{-1}$, which in turn reflects the maintenance of a mean total phosphorus concentration of less than 130 $\mu g\ \ell^{-1}$ in clear water impoundments (Rossouw, 1990)*. Ashton et al (1984) stressed that water quality criteria should be applied with a detailed understanding of the water body in question - and in terms of changes occurring in the water body - all with reference to the beneficial uses of the water.

(v) Rossouw and Grobler (1988, contained in Rossouw, 1990) devised a classification system which can be used to differentiate impoundments with regard to various turbidity classes. A turbid impoundment is defined as an impoundment where the extinction of light in the water column is largely influenced by the presence of inorganic suspended sediments. By contrast, a clear water impoundment is an impoundment where the extinction of light in the water column is due primarily to algae, and not inorganic suspended sediments. Turbidity is measured in Nephelometric turbidity units (NTU). Walmsley and Bruwer (1980)** in a survey of 92 South African impoundments found that 42% of the impoundments had a mean Secchi disc depth of 0,5 m or less, and could be classified as turbid. The geographical distribution of water transparency showed good agreement with the geographical distribution of sediment production, indicating that inorganic suspended sediment is the most important factor influencing water transparency in most impoundments. Low transparencies (high suspended sediment concentrations), will increase the ability of turbid impoundments to tolerate high nutrient loadings before severe eutrophication problems are experienced - due to the effect of reduced light on algal growth. Rossouw (1990) observed that relatively few inorganic suspended sediment data are evident for South African impoundments, although turbidity and Secchi disc depth data (as measures of water transparency), are generally available. Good relationships have been found between turbidity and Secchi depth; and between turbidity and suspended sediment, for certain dams.

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* See Rossouw, J.N. and Grobler, D.C., 1988. Evaluation of the impact of eutrophication control measures on water quality in: Hartbeespoort Dam, In: Rossouw, J.N., 1990. The Development of Management Orientated Models for Eutrophication Control, WRC Report No. 174/1/90, Water Research Commission, Pretoria, p. 1 - 33.

** See Walmsley, R.D. and Bruwer, C.A., 1980. Water transparency characteristics of South African impoundments, Journal of the Limnological Society of Southern Africa, VOL 6(2), p. 69 - 76.

Turbidity class	Secchi depth (m)	Turbidity (NTU)	Inorganic suspended sediment (mg ℓ^{-1})
Highly turbid water	0,0 - 0,1	260	419
	0,1 - 0,2	87	142
Turbid water	0,2 - 0,4	44	72
Less turbid water	0,4 - 1,0	19	32
Clear water	>1,0	<10	<10

Despite the wide acceptance of chlorophyll a as an indicator, it is evident that phytoplankton populations often exhibit considerable variations in their horizontal and vertical distribution in a water body. These variations are usually due to mixing by wind, which is modified by the bathymetry and morphometry of the water body. Spatial variations are especially apparent for buoyant blue-green algae, with up to 40% of the Microcystis aeruginosa population in the Hartbeespoort Dam found on only 0,01% of the dam surface area (Robarts and Zohary, 1984, quoted in Ashton et al). Sampling is accordingly difficult, although the collection of samples from specific depths (to determine vertical population distribution); as well as use of a 5 m long 20 mm internal diameter hosepipe to provide an assessment of the overall population, is recommended (Walmsley and Butty, 1980). Horizontal variability necessitates careful sampling at selected points in the water body, depending on morphometry and raw water intake sites. The use of remote sensing has also been tested*. Other problems include a different chlorophyll a content for various types of algae, as well as changes in the chlorophyll content of individual cells in response to fluctuating nutrient and light factors. The chlorophyll extractability also varies for different algal groups (Ashton et al, 1984). Walmsley and Butty (1980) observed that in addition to determining the chlorophyll a concentration of the water body, it may be necessary to identify the algae present.

* See Howman, A.M. and Kempster, P.L., 1988. Quantifying specific water quality conditions in impoundments, South African Journal of Photogrammetry, Remote Sensing and Cartography, VOL 15(1), p. 15 - 21.

15.15.5 Perceptions of the water quality of impoundments

An increasing environmental awareness amongst members of the public is an encouraging sign of greater environmental "activism" (re: the St Lucia debate). The presence of extra eyes and ears albeit with varying degrees of scientific knowledge, can in certain cases, lead to the discovery of environmental degradation, or pressure for concrete remedial action. Thornton and McMillan (1989)* in a survey of over 3 000 recreational users inter alia of the Hartbeespoort Dam and Zandvlei (near Cape Town), found that visually aesthetic characteristics were the most common means of determining the "clean water" (versus polluted) status of a lake/dam. Thornton and McMillan survey respondents referred to the absence of scums and excessive amounts of algae, clear water with low turbidity, and the abundance of wildlife as evidence of a satisfactory water quality - where the Hartbeespoort Dam was perceived to be polluted and Zandvlei not. Thornton and McMillan provided limnological equivalents of the water quality characteristics cited by their respondents, together with a scale of values acceptable to the public (formulated with reference to survey results and scientific literature). These values were found to correspond to criteria used by limnologists and water managers to define trophic status (Table O20). The values represent the best estimate of levels (which if exceeded), would result in a perception by the public of "pollution".

Thornton and McMillan observed that "greeness" equivalent to chlorophyll a, is the most important characteristic reflecting the public requirement for clear water impoundments with balanced algal/plant growth, which would accord with limnological data. Thornton and McMillan suggested that the survey results could be used as a link between the public - who as tax and rate-payers are required to financially support water body protection or rehabilitation programmes - and water managers/limnologists who must undertake the necessary corrective action. A "meeting of minds" is therefore possible. Missing however from the scenario, are the views of black residents living in the vicinity of rural lakes and dams. The residents may well propose other water quality criteria as well as different reasons for their choices. A separate study is therefore needed.

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* See Thornton, J.A. and McMillan, P.H., 1989. Reconciling public opinion and water quality criteria in South Africa, Water SA, VOL 15(4), p. 221 - 226.

Table O20: Water quality characteristics identified by the South African public and limnological equivalents.

Characteristic	Limnological parameter	Range
No excess algae	Chlorophyll a	<15 mg m^{-3}
Clear water	Secchi disc transparency	1 - 2 m
Hygienic water	Coliform bacteria	<100 counts 100 $m\ell^{-1}$
Well-flushed water	Water residence time	±0,2 - 1,0 year
"Living" water	Dissolved oxygen	>4 mg ℓ^{-1}
No smell	Hydrogen sulphide	$<0,4$ mg ℓ^{-1}
Abundant wildlife	Species diversity	-
No excess weeds	Biomass	?
Low nutrients	Phosphorus and nitrogen	$<0,05$ mg ℓ^{-1} P $<0,2$ mg ℓ^{-1} N
No obstacles	Depth; mean depth	>1 m
No litter/debris	Suspended solids	?
No chemical pollution	For example, pesticides, metals and radioactivity	Various, but generally nil

Source: After Thornton, J.A. and McMillan, P.H., 1989. Reconciling public opinion and water quality criteria in South Africa, Water SA, VOL 15(4), p. 221 - 226.

See also:

(i) Quick, A.J.R. and Johansson, A.R., 1992. User assessment survey of a shallow freshwater lake, Zeekoevlei, Cape Town, with particular emphasis on water quality, Water SA, VOL 18(4), p. 247 - 254.

(ii) Thornton, J.A., McMillan, P.H. and Romanovsky, P., 1989. Perceptions of water pollution in South Africa: case studies from two water bodies (Hartbeespoort Dam and Zandvlei), South African Journal of Psychology, VOL 19(4), p. 199 - 204.

15.15.6 Eutrophication management strategies

Three management options are possible, namely, control of the catchment to avoid or reduce eutrophication; manipulation of the water body to reduce the effects of eutrophication, and the use of advanced water treatment techniques. One of the first indications of incipient eutrophication is the effect of algae in blocking filters at the treatment works, with consequent shorter filter run-times. Procedures which can be adopted in such cases include screening, flotation, chlorination and activated carbon treatment, all of which increase purification costs*. Additional (pre-treatment) chlorination for eutrophic waters (required so that other treatment processes can operate effectively), may result in the formation of trihalomethanes (Ashton et al, 1984).

Manipulation of the water body involves several possible strategies. Walmsley and Butty (1980) discussed a number of methods, few of which have been attempted in South Africa. One option involves nutrient inactivation where phosphates in the water column are precipitated out, or are inactivated by using chemicals such as alum, ferric salts and calcium salts. The resulting floc is virtually sealed into the lake sediments, thereby also preventing the release of phosphorus from the sediments per se**. In impoundments which stratify in summer, the selective discharge of anaerobic bottom waters (rich in nutrients), will have positive effects. In such impoundments it can likewise be beneficial to pump air into the system in order to oxygenate the bottom waters, and/or to destratify the water column. This procedure impedes the development of anaerobic water; reduces phosphate release from sediments; oxidizes iron and manganese ions, and prevents the formation of hydrogen sulphide. Further benefits can include expansion of the volume of the habitat for zooplankton and fish. A change in phytoplankton species succession from blue-green algae and diatoms is also possible. Aeration/destratification however, is costly and may enhance algal growth through the vertical distribution of nutrients into the euphotic zone (the upper water layers where sufficient light is available for photosynthesis) (Ashton et al).

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* See Dickens, C.W.S., Graham, P.M. and Freese, S., 1996. Algal rupture during abstraction from reservoirs and the consequences for water treatment, WRC Report No. 558/1/96, Water Research Commission, Pretoria, 61 p.

** A useful reference is the following: Hattingh, W.H.J. (ed), 1981. Water year + 10 and then?, Technical Report No. TR 114, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, 217 p. (The publication examines inter alia the role of sediments in nutrient release).

A further management option is the mechanical harvesting and disposal of rooted and aquatic macrophytes. The harvesting of fish provides a food source and prevents overstocking in eutrophic water bodies (where fish populations are excessive and secondary production suffers). Certain amounts of nutrients are accordingly removed from the water through fish and macrophyte reduction (Walmsley and Butty). Reduction of selected fish populations can reduce grazing pressure on zooplankton, thereby increasing zooplankton grazing on phytoplankton (Ashton et al). The dilution or flushing of water bodies is another management technique which involves the replacement of nutrient rich waters in the water body, by relatively nutrient poor waters from the catchment. In South Africa, summer floods provide a natural flushing mechanism. A further management option involves a draw-down of the water level. Through draw-down, bottom sediments are exposed to and desiccated by sunlight, resulting in the formation of an oxidized layer which inhibits the exchange of phosphorus into the overlying water column (once the water level is restored). Draw-down also has the beneficial effect of exposing rooted macrophytes to sunlight, with consequent desiccation (Walmsley and Butty).

An option specific to small impoundments requiring rehabilitation, involves the use of plastic sheeting or rubber lining placed on the bottom, in order to prevent the release of nutrients from the sediments. Other bottom sealing methods include the use of fly ash, clays and metal oxides. The dredging and removal of nutrient rich sediments (during drought conditions) is a further possibility. The chemical control of noxious blooms and macrophytes may be undertaken in eutrophic water bodies where the nutrient supply cannot be controlled, and where other management options are not feasible. The latter method has been used in the Hartbeespoort Dam*. In South Africa, several herbicides have been legally registered for the control of water hyacinth, bulrushes, reeds and water fern, although no (registered) herbicides are available for the control of submerged

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* For an overall discussion of eutrophication and other limnological issues in respect of the Hartbeespoort Dam, see National Institute for Water Research, CSIR, 1985. The limnology of Hartbeespoort Dam, South African National Scientific Programmes Report No. 110, Foundation for Research Development, CSIR, Pretoria, 269 p. See also, Ashton, P.J., Scott, W.E., Steÿn, D.J. and Wells, R.J., 1979. The chemical control programme against the water hyacinth Eichhornia crassipes (Mart.) Solms on Hartbeespoort Dam: historical and practical aspects, South African Journal of Science, VOL 75(7), p. 303 - 306.

macrophytes*. No algicides likewise, have been registered in South Africa to control algal growth in water bodies. Copper sulphate has however, been used to control algae in certain circumstances (although not registered for such purposes) (Walmsley and Butty, 1980). Most water bodies in South Africa have multiple uses, where eutrophication impacts differ. Accordingly, site specific management strategies are essential and no single method can be universally applied.

It is apparent that the sensitivity of catchments containing at-risk impoundments varies depending on the quality of the receiving waters. An increase in nutrient inputs to an oligotrophic system can have more serious implications than the same input to a highly eutrophic water body (Walmsley and Butty). Catchment management strategies are numerous. Legal measures include the General/Special Standard as well as the Special Standard for Phosphate** applicable to specific catchments - discussed earlier. Other measures may include the diversion of nutrient rich waters to prevent entry into impoundments - with however - the transfer of these waters downstream, possibly into another impoundment. Alternatively, nutrient reduction can be undertaken by pre-impoundment at the point of entry to the main water body***. Further measures can include direct land use control. These are: attention to soil erosion and the restoration of degraded areas; the use of scientific farming techniques; restrictions on fertilizers and intensive animal feedlots, and the provision of green belts within cities as well as protected areas in the countryside. Also important is the supply of services for informal settlements, and the disposal of industrial and domestic waste in properly planned landfill sites. Eutrophication potential can likewise be reduced, but only to a degree, by limiting

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* See Steÿn, D.J., Scott, W.E., Ashton, P.J. and Vivier, F.S., 1979. Guide to the use of herbicides on aquatic plants, Technical Report No. TR 95, Department of Water Affairs, Pretoria, 29 p. (See also the chapter on solid waste management). Note that the Plant Protection Research Institute, Private Bag X134, Pretoria, 0001, has an on-going research programme aimed at finding insect and fungal enemies to combat the water hyacinth problem in South Africa.

** With regard to the Special Standard for Phosphate, it should be borne in mind that historically, certain sensitive catchments were exempted for a time, from complying with the 1,0 mg ℓ^{-1} soluble ortho-phosphate (as P) requirement. For further details see Anonymous, 1988. Special phosphate standard for sensitive catchments, Water Sewage and Effluent, VOL 8(4), p. 10 - 11. See also, Taylor, R., Best, H.J. and Wiechers, H.N.S., 1984. The effluent phosphate standard in perspective: Part 1: impact, control and management of eutrophication, Imiesa, VOL 9(10), p. 43 - 56. The current (1994) situation is that the Special Standard for Phosphate applies in full in the Mlazi catchment. In the Mgeni catchment, temporary exemptions apply for all major dams excepting the Inanda Dam. The Special Standard is accordingly strictly applied in the Nagle Dam to Inanda Dam river reach (Gravelet-Blondin, L., 1994. Personal communication, Department of Water Affairs and Forestry, Durban).

*** See Twinch, A.J. and Grobler, D.C., 1986. Pre-impoundment as a eutrophication management option: a simulation study at Hartbeespoort Dam, Water SA, VOL 12(1), p. 19 - 26.

phosphates in synthetic detergents (Walmsley and Butty, 1980). In essence, the only long term solutions to the problems of eutrophication involve a reduction of nutrient inputs, especially from point sources, but increasingly also from non-point sources (if possible)*.

15.15.7 A brief overview of eutrophication studies with special reference to Natal/ KwaZulu

The first attempt at a trophic status classification of South African impoundments was undertaken by Toerien, Hyman and Bruwer (1975)**, who ranked 98 impoundments according to their trophic status. Toerien et al (1975) found that approximately 50% of the impoundments were low in plant nutrients, 11% were heavily eutrophied, while the remainder were intermediate. Toerien et al observed that phosphorus was the primary limiting nutrient in 61% of the impoundments. Toerien (1977)*** then provided initial guidelines for eutrophication control in South African impoundments. Walmsley and Butty (**1980**)**** reported on a varying one year study of 21 impoundments including six in Natal/KwaZulu. The latter publication contains a useful synopsis of hydrological characteristics as well as physical and chemical water quality data for each dam (Table 021).

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* According to Uttormark, Chapin and Green (1974, quoted in Walmsley and Butty, 1980), the annual total phosphorus export from croplands by surface runoff in the USA varies from some 18,0 - 30,0 kg ha^{-1} for mixed vegetables, to 0,17 kg ha^{-1} for cotton (depending on the extent of fertilization and soil chemistry). The annual total phosphorus contribution by domestic animals (with reference to feedlots) varies from 0,2 kg per animal for poultry, to 25 kg per animal for dairy cattle. Uttormark, Chapin and Green estimated the annual export values of total phosphorus from urban areas, at 1,1 - 3,1 kg ha^{-1}.

** See Toerien, D.F., Hyman, K.L. and Bruwer, M.J., 1975. A preliminary trophic status classification of some South African impoundments, Water SA, VOL 1(1), p. 15 - 23.

*** See Toerien, D.F., 1977. A review of eutrophication and guidelines for its control in South Africa, CSIR Special Report No. WAT 48, National Institute for Water Research, CSIR, Pretoria, 110 p.

**** See Walmsley, R.D. and Butty, M. (eds), 1980. The limnology of some selected South African impoundments, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 229 p. (The date of this reference is in bold in the text, in order to indicate the specific document in question). See also, Walmsley, R.D. and Bruwer, C.A., 1980. Water transparency characteristics of South African impoundments, Journal of the Limnological Society of Southern Africa, VOL 6(2), p. 69 - 76., as well as Du Plessis, H.M. and Van Veelen, M., 1991. Water quality: salinization and eutrophication time series and trends in South Africa, South African Journal of Science, VOL 87(1/2), p. 11 - 16.

Table O21: **Catchment nutrient loading rates for six dams in Natal/KwaZulu.**

Dam	Ortho-phosphate surface loading rate (g m^{-2} y^{-1})	Total phosphorus surface loading rate (g m^{-2} y^{-1})	Inorganic nitrogen surface loading rate (g m^{-2} y^{-1})	Total nitrogen surface loading rate (g m^{-2} y^{-1})
Albert Falls Dam	0,02	0,25	2,80	4,83
Hazelmere Dam	0,13	4,58	20,57	40,34
Henley Dam	0,23	7,64	73,19	107,34
Midmar Dam	0,05	0,46	3,11	9,18
Nagle Dam	0,17	2,11	23,02	46,75
Shongweni (Vernon Hooper) Dam	9,66	26,30	215,14	304,85

<u>Source</u>: After Walmsley, R.D. and Butty, M. (eds), **1980**. The limnology of some selected South African impoundments, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 229 p.

<u>See also</u>: Murray, K.A., 1987. <u>Wastewater Treatment and Pollution Control</u>, Water Research Commission, Pretoria, 367 p.

<u>Note</u>:

(i) The mean and range of chlorophyll <u>a</u> concentrations ($\mu g\ \ell^{-1}$) for the dams as per the above order was as follows: 5,4 (2,2 - 9,2); 5,7 (0,3 - 12,6); 4,0 (0,7 - 11,4); 2,5 (0,9 - 3,9); 2,6 (1,2 - 6,0) and 15,9 (1,21 - 56,7).

(ii) The mean and range of Secchi depth (m) for the dams as per the above order was as follows: 2,51 (1,50 - 4,37); 0,79 (0,24 - 2,04); 1,0 (0,19 - 3,33); 1,31 (0,59 - 2,0); 2,5 (0,9 - 4,37) and 1,18 (0,12 - 3,30).

(iii) The unprocessed data are available in hard copy from the Division of Water Technology, CSIR, P O Box 395, Pretoria, 0001.

(iv) Toerien and Steyn (1975, quoted in Murray, 1987) ranked 98 South African impoundments in terms of their algal growth potential. The algal growth potential was measured by algal bioassay involving the determination of the maximum cell concentration (in mg ℓ^{-1}) which a suitable test alga can produce in a sample of water. (The water was autoclaved at 121 °C for at least 15 minutes before use). The algal growth potential of 11 impoundments in Natal/KwaZulu was as follows, with overall ranking as indicated: 13th Midmar Dam (8,7 mg ℓ^{-1}); 17th Craigieburn Dam (10,4 mg ℓ^{-1}); 19th J.G. Strydom (Pongolapoort) Dam (11,1 mg ℓ^{-1}); 22nd Pongola weir (12,3 mg ℓ^{-1}); 34th Nagle Dam (16,5 mg ℓ^{-1}); 37th Wagendrift Dam (17,3 mg ℓ^{-1}); 41st Henley Dam (18,9 mg ℓ^{-1}); 50th Mkuzi weir (26,9 mg ℓ^{-1}); 60th Hluhluwe Dam (35,5 mg ℓ^{-1}); 66th Chelmsford

Dam (44,9 mg ℓ^{-1}), and 93rd Shongweni Dam (265,0 mg ℓ^{-1}). The Hartbeespoort Dam by comparison, which was ranked 97th overall, had a value of 549,1 mg ℓ^{-1}. The Rietvlei Dam (near Pretoria) - the worst of the 98 sites examined - had a value of 660,4 mg ℓ^{-1}.

The Albert Falls Dam was found to be a clear water, oligotrophic, phosphate-limited system. The Hazelmere Dam could not be classified since it was only completed in 1977. Walmsley and Butty (1980) noted however, that the dam was already - at the time of the survey - one of the most turbid systems in Natal/KwaZulu. The dam had a high siltation rate and a diffuse nutrient input pattern. Henley Dam was viewed as a small, turbid, oligo-mesotrophic dam with high nitrogen concentrations, where adverse water quality conditions were likely to develop during dry years. Midmar Dam was found to be a clear water, oligo-mesotrophic, phosphate-limited system.

Nagle Dam was classified as a clear water, oligotrophic, phosphate-limited system. The Shongweni (Vernon Hooper) Dam was found to be a small, eutrophic system which was frequently phosphate-limited. Very high nutrient loading rates were observed throughout the year, although the high summer inflows and accordingly the rapid flushing rate, result in the fast export of nutrients from the system. Diatom blooms dominated during the study period, although Walmsley and Butty (1980) observed that nuisance species of blue-green algae could well be evident in warm, dry periods. The Shongweni Dam which is currently some 63% silted up, is no longer in use for water supply purposes. Reasons are varied and include poor water quality with high treatment costs. The construction of the Inanda Dam is also an important factor. The Shongweni Dam (within a 1 500 ha conservation area), is now managed as a private nature reserve and was recently declared as South African Natural Heritage Site No. 156. (See the chapter on catchments). It should be borne in mind that certain water quality data for the Natal/KwaZulu dams (summarized in Walmsley and Butty, 1980) were derived from CSIR Natal Rivers Research Fellowships Steering Committee reports (described earlier in the chapter). Water quality data (including dams/lakes) are available from the Division of Water Technology, CSIR, Durban/Pretoria; Mhlatuze Water, and Umgeni Water. Data are likewise available from some municipalities as well as from the Department of Water Affairs and Forestry.

An important publication on Midmar Dam was compiled by Breen (1983)*, which collated a considerable body of research on the dam. Readers seeking detailed data on Midmar Dam should consult the document as a primary source. In terms of "estuaries", Begg (1978)** noted that although few data were available, it appeared that eutrophication was not a severe problem in Natal/KwaZulu. Water hyacinth blooms however, were observed in the Nonoti, Sipingo and Sezela lagoons. The survey by Begg should be updated to determine the latest trends. The possible eutrophication of coastal lakes has also received attention in Natal/KwaZulu with particular reference to Lake Mzingazi (Walmsley and Grobler, 1986)***. Some of the data presented in the latter publication were drawn from the CSIR Steering Committee for Limnological Research and Water Treatment at Lake Mzingazi (Richards Bay) series of reports (see earlier in the chapter).

In terms of eutrophication control, Walmsley and Butty (1980)**** provided important guidelines and water quality criteria (as discussed). On the basis of the report by Walmsley and Butty as well as the earlier report by Toerien (1977 - above) and the work by Walmsley (1984 - above), the then Department of Water Affairs decided to implement the Special Standard for Phosphate in sensitive catchments (Rossouw, 1990 - above). According to Rossouw, the Special Standard for Phosphate concept was severely criticized. This resulted in a further study, which was undertaken by Grobler and

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* See Breen, C.M. (ed), 1983. Limnology of Lake Midmar, South African National Scientific Programmes Report No. 78, Cooperative Scientific Programmes, CSIR, Pretoria, 140 p. Two useful background reports are the following: Breen, C.M., Akhurst, E.G.J. and Walmsley, R.D. (eds), 1985. Water quality management in the Mgeni catchment, Natal Town and Regional Planning Commission Supplementary Report, VOL 12, Pietermaritzburg, 27 p., as well as Walmsley, R.D. and Furness, H.D., 1987. A programme description for water resource research in the Mgeni catchment, Natal Town and Regional Planning Commission Supplementary Report, VOL 21, Pietermaritzburg, 27 p.

** See Begg, G., 1978. The estuaries of Natal, Natal Town and Regional Planning Commission Report, VOL 41, Pietermaritzburg, 657 p. (Readers are reminded that algal data for several rivers in Natal/KwaZulu can be found in reports published by the Natal Town and Regional Planning Commission. See VOL 13, Parts 1 - 7 listed in Section 15.11.1).

*** See Walmsley, R.D. and Grobler, J.H. (eds), 1986. An evaluation of the impact of urban and recreational development on the ecology and usage of Lake Mzingazi, Proceedings of a Workshop Convened by the Inland Water Ecosystems Section of the Foundation for Research Development, Ecosystem Programmes Occasional Report Series No. 6, Foundation for Research Development, CSIR, Pretoria, 60 p.

**** See Walmsley, R.D. and Butty, M., 1980. Guidelines for the control of eutrophication in South Africa, Water Research Commission and the National Institute for Water Research, CSIR, Pretoria, 27 p.

Silberbauer (1984)*. The Grobler and Silberbauer report examined 19 South African impoundments including the Albert Falls, Midmar and Shongweni dams; and the then yet-to-be completed Inanda Dam. Available data together with a modelling approach was used to assess the impact of eutrophication control strategies on the extant and future trophic responses of reservoirs in sensitive catchments. The two active strategies examined were the Special Standard for Phosphate (and variations thereof), as well as a partial/total ban on phosphorus in detergents. The second option per se was shown to have little effect on trophic status. Research was subsequently undertaken on the specific role of phosphorus in eutrophication with reference to South African conditions. (See for example, Wiechers and Heynike, 1986 - Section 15.15.2).

Factors which need to be considered in applying the Special Standard for Phosphate include the assimilative capacity of impoundments (some dams are more sensitive than others); as well as the point : non-point source phosphorus load ratio in the catchment (Grobler and Silberbauer, 1984). Impoundments where most of the phosphorus load comes from non-point sources, will derive little benefit from a reduction in point source loads. Accordingly, costs associated with the Special Standard for Phosphate cannot really be justified in such circumstances. Some dams may also (at present), not require any eutrophication control measures given a good water quality with very low input loads (for example, the Albert Falls Dam). Certain dams by contrast, such as the Hartbeespoort Dam, require careful management where both legal and other eutrophication control methods are necessary. The role of phosphorus in South African catchments and impoundments - combined with additional factors - prompted the realization that dynamic eutrophication models developed for local, highly variable hydrological conditions were needed for management purposes (Grobler and Silberbauer, 1984). Early attempts were made to apply the Organization for Economic Co-operation and Development (OECD) modelling approach to South African waters (Grobler and Silberbauer, 1984; Jones and Lee, 1984; Walmsley and Thornton, 1984)**. Models specific to South African

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* See Grobler, D.C. and Silberbauer, M.J., 1984. Impact of eutrophication control measures on the trophic status of South African impoundments, WRC Report No. 130/1/84, Water Research Commission, Pretoria, 72 p. + app.

** See Jones, R.A. and Lee, G.F., 1984. Application of OECD eutrophication modelling approach to South African dams (reservoirs), Water SA, VOL 10(3), p. 109 - 114., as well as Walmsley, R.D. and Thornton, J.A., 1984. Evaluation of OECD-type phosphorus eutrophication models for predicting the trophic status of southern African man-made lakes, South African Journal of Science, VOL 80(6), p. 257 - 259.

conditions are discussed inter alia by the National Institute for Water Research, CSIR (1985); Cloot, Schoombie, Pieterse and Roos (1992); Grobler (1985; 1985)*; Rossouw (1990), and Weddepohl and Meyer (1992 - above). Increasing attention is being paid to the modelling of non-point sources in South African catchments, especially in view of the rapid urbanization of the population, and the need to safeguard both health and the environment.

15.16 Some primary publications on water quality in South Africa

15.16.1 Water quality criteria, guidelines and standards

- Anonymous, 1984. South African standard specification for water for domestic supplies, SABS Specification No. 241-1984, South African Bureau of Standards, Pretoria, 15 p.

- Anonymous, 1993. South African water quality guidelines, VOL 1, Domestic use, Department of Water Affairs and Forestry, Pretoria, 216 p.

- Anonymous, 1993. South African water quality guidelines, VOL 2, Recreational use, Department of Water Affairs and Forestry, Pretoria, 134 p.

- Anonymous, 1993. South African water quality guidelines, VOL 3, Industrial use, Department of Water Affairs and Forestry, Pretoria, 222 p.

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* See National Institute for Water Research, CSIR, 1985. The limnology of Hartbeespoort Dam, South African National Scientific Programmes Report No. 110, Foundation for Research Development, CSIR, Pretoria, 269 p., plus Cloot, A., Schoombie, S.W., Pieterse, A.J.H. and Roos, J.C., 1992. A note on a light-temperature dependent model for algal blooms in the Vaal River, Water SA, VOL 18(4), p. 299 - 302., read together with Cloot, A., Schoombie, S.W., Roos, J.C. and Pieterse, A.J.H., 1995. A note on the modelling of the algal blooms in the Vaal River: the silicon effect, Water SA, VOL 21(3), p. 251 - 257. See in addition: Grobler, D.C.S.D., 1985. Management-orientated eutrophication models for South African reservoirs, Ph.D. Thesis, Department of Limnology, University of the Orange Free State, Bloemfontein, 171 p., as well as Grobler, D.C., 1985. Phosphorus budget models for simulating the fate of phosphorus in South African reservoirs, Water SA, VOL 11(4), p. 219 - 230. See also: Görgens, A.H.M., Bath, A.J., Venter, A., De Smidt, K. and Marais, G.v.R., 1993. The applicability of hydrodynamic reservoir models for water quality management of stratified water bodies in South Africa, WRC Report No. 304/1/93, Water Research Commission, Pretoria, various pages.

- Anonymous, 1993. South African water quality guidelines, VOL 4, Agricultural use, Department of Water Affairs and Forestry, Pretoria, 286 p. (The guidelines have subsequently been updated and expanded)*.

- Aucamp, P.J. and Vivier, F.S., 1990. Water quality criteria in South Africa, Technology SA, June 1990, p. 21 - 27.

- Bourne, D.E., Sayed, A.R. and Klopper, J.M.L., 1990. A data base for use in the epidemiological surveillance of potential changes in drinking water quality in South Africa, WRC Report No. 186/1/90, Water Research Commission, Pretoria, 81 p.

- Casey, N.H. and Meyer, J.A., 1996. Interim water quality guidelines for livestock watering, WRC Report No. TT 76/96, Water Research Commission, Pretoria, 27 p.

- Casey, N.H., Meyer, J.A., Coetzee, C. and Van Niekerk, W.A., 1996. An investigation into the quality of water for animal production, WRC Report No. 301/1/96, Water Research Commission, Pretoria, 257 p. + app.

- CSIR Environmental Services, 1995. Procedures to assess effluent discharge impacts, WRC Report No. TT 64/94, Water Research Commission and the Department of Water Affairs and Forestry, Pretoria, 352 p.

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* See (a) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 1, Domestic use, second edition, Department of Water Affairs and Forestry, Pretoria, 197 p., (b) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 2, Recreational use, second edition, Department of Water Affairs and Forestry, Pretoria, 85 p., (c) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 3, Industrial use, second edition, Department of Water Affairs and Forestry, Pretoria, 115 p., (d) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 4, Agricultural use: irrigation, second edition, Department of Water Affairs and Forestry, Pretoria, 199 p., (e) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 5, Agricultural use: livestock watering, second edition, Department of Water Affairs and Forestry, Pretoria, 163 p., (f) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 6, Agricultural use: aquaculture, second edition, Department of Water Affairs and Forestry, Pretoria, 194 p., and (g) CSIR Environmental Services, 1996. South African water quality guidelines, VOL 7, Aquatic ecosystems, first edition, Department of Water Affairs and Forestry, Pretoria, 159 p. Note that each volume irrespective of edition, contains a glossary. A simplified handbook which summarizes some pertinent facts on water quality, especially for domestic use, is available. See: Anonymous, 1996. A guide for the health related assessment of the quality of water supplies, Department of Water Affairs and Forestry and the Department of Health, Pretoria, 46 p.

- Funke, J.W., 1980. South African drainage by-laws for controlling the acceptance of industrial effluents and their impact on industry, Conference of the Institute of Water Pollution Control (Southern African Branch), 2 - 5 June 1980, Pretoria, 15 p. (The paper was formally published as: Funke, J.W., 1980. South African drainage by-laws for controlling the acceptance of industrial effluents and their impact on industry, Imiesa, VOL 5(9), p. 17 - 19, 25).

- Funke, J.W., Knoesen, J.G. and Venter, J.C., 1984. Code of practice for the handling of manure from intensive animal feeding units, Water Research Commission, Pretoria, 42 p.

- Genthe, B. and Kfir, R., 1995. Studies on microbiological drinking water quality guidelines, WRC Report No. 469/1/95, Water Research Commission, Pretoria, 35 p. + app.

- Gericke, M., Bateman, B., Rapholo, F., Mashakana, J., Maharaj, V., Hilner, C.A. and Kfir, R., 1995. Occurrence of protozoan parasites in South African source and treated water, WRC Report No. 451/1/95, Water Research Commission, Pretoria, 41 p. + app.

- Grabow, W.O.K., 1970. Literature survey: the use of bacteria as indicators of faecal pollution in water, CSIR Special Report No. O/WAT 1, National Institute for Water Research, CSIR, Pretoria, 27 p.

- Grabow, W.O.K., 1996. Waterborne diseases: update on water quality assessment and control, Water SA, VOL 22(2), p. 193 - 202.

- Kemp, P.H., 1978. Statistics in water sampling, CSIR Research Report No. 338, National Institute for Water Research, CSIR, Pretoria, 83 p.

- Kempster, P.L., Hattingh, W.H.J. and Van Vliet, H.R., 1980. Summarized water quality criteria, Technical Report No. TR 108, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, 45 p.

- Kempster, P.L. and Smith, R., 1985. Proposed aesthetic/physical and inorganic drinking-water criteria for the Republic of South Africa, CSIR Research Report No. 628, National Institute for Water Research, CSIR, Pretoria, 51 p.

- Lesch, W., 1995. The development of guidelines for the design of streamwater quality monitoring strategies in the forestry industry, WRC Report No. 524/1/95, Water Research Commission, Pretoria, 102 p.

- Lusher, J.A. (ed), 1984. Water quality criteria for the South African coastal zone, South African National Scientific Programmes Report No. 94, Foundation for Research Development, CSIR, Pretoria, 25 p. + app.

- Offringa, G., 1993. Water Research Commission strategic plan for research on potable water treatment in South Africa, WRC Report No. AV 4/92, Water Research Commission, Pretoria, 38 p.

- Pieterse, M.J., 1988. The potential health risk of trihalomethanes in drinking water: a perspective, South African Journal of Science, VOL 84(3), p. 166 - 170.

- Pieterse, M.J., 1989. Drinking-water quality criteria with special reference to the South African experience, Water SA, VOL 15(3), p. 169 - 178.

- Roux, D.J., Jooste, S.H.J. and MacKay, H.M., 1996. Substance-specific water quality criteria for the protection of South African freshwater ecosystems: methods for derivation and initial results for some inorganic toxic substances, South African Journal of Science, VOL 92(4), p. 198 - 206.

- Stander, G.J., 1980. Micro-organic compounds in the water environment and their impact on the quality of potable water supplies, Water SA, VOL 6(1), p. 1 - 14.

- Steynberg, M.C., Kok, M., Chale, B., Grundlingh, J.A., Joubert, J.H.B. and Geldenhuys, J.C., 1995. The removal of invertebrates by sand filtration and the influence thereof on water quality, WRC Report No. KV 76/95, Water Research Commission, Pretoria, various pages.

- Van Rensburg, J.F.J., 1981. Health aspects of organic substances in South African waters - opinions and realities, Water SA, VOL 7(3), p. 139 - 149.

- Van Steenderen, R.A., Theron, S.J. and Engelbrecht, A.C.W., 1989. An investigation into the occurrence and concentration of trihalomethanes and their precursors in South African drinking waters, WRC Report No. 194/1/89, Water Research Commission, Pretoria, 16 p. + app.

15.16.2 National water quality data sources and management issues

- Anonymous, 1986. Management of the Water Resources of the Republic of South Africa, Department of Water Affairs, Pretoria, various pages.

- Anonymous, 1988. Availability of hydrological data, Hydrological Information Publication No. 14, Directorate of Hydrology, Department of Water Affairs, Pretoria, 11 p. + app.

- Anonymous, 1991. Water quality management policies and strategies in the Republic of South Africa, Department of Water Affairs and Forestry, Pretoria, 32 p. + app.

- Fuggle, R.F. and Rabie, M.A. (eds), 1992. Environmental Management in South Africa, Juta, Cape Town, 823 p. (Several chapters are relevant).

- Geldenhuys, W.F., Nell, U. and Van Veelen, M., 1991. Surface water quality of South Africa 1979 - 1988, VOL 6: drainage regions T, U, V, W and X (TDS, SAR, pH and PO_4), Technical Report No. TR 145, Department of Water Affairs and Forestry, Pretoria, 27 p. + app. (This report has an extensive appendix).

- Harris, J., Van Veelen, M. and Gilfillan, T.C., 1992. Conceptual design report for a National River Water Quality Assessment Programme, WRC Report No. 204/1/92, Water Research Commission, Pretoria, 98 p.

- James, A.G. and Fuller, H.L.M., 1987. Register of southern African hydrological data sources, South African Water Information Centre, CSIR, Pretoria, 287 p.

- Mirrilees, R.I., Forster, S.F. and Williams, C.J., 1994. The application of economics to water management in South Africa, WRC Report No. 415/1/94, Water Research Commission, Pretoria, various pages. (The publication examines inter alia the economic theory relating to water pollution).

- Neytzell-De Wilde, F.G., 1992. Reassessment of the strategy with respect to industrial effluent discharge with special reference to advanced technology treatment methods, Phase 1: Industrial effluent discharge problem areas, WRC Report No. 407/1/92, Water Research Commission, Pretoria, 45 p. + app. (The publication contains a useful overview of issues concerning effluents in South Africa and other countries).

- Palmer, C.G., Goetsch, P-A. and O'Keeffe, J.H., 1996. Development of a recirculating artificial stream system to investigate the use of macroinvertebrates as water quality indicators, WRC Report No. 475/1/96, Water Research Commission, Pretoria, 185 p.

- Parsons, R. and Tredoux, G., 1993. The development of a strategy to monitor groundwater quality on a national scale, WRC Report No. 482/1/93, Water Research Commission, Pretoria, 50 p. + app.

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- Roux, D.J., 1994. The use of toxicity testing in effluent regulation and control: a new dimension to assessment and management of water quality in South Africa, Southern African Journal of Aquatic Sciences, VOL 20(1/2), p. 62 - 78.

- Roux, D.J., Van Vliet, H.R. and Van Veelen, M., 1993. Towards integrated water quality monitoring: assessment of ecosystem health, Water SA, VOL 19(4), p. 275 - 280.

- Steffen, Robertson and Kirsten Inc., 1991. National industrial water and waste-water survey, WRC Report No. 145/1/91, Water Research Commission, Pretoria, 26 p. + app.

- Swart, S.J., Van Veelen, M. and Nell, U., 1991. Water quality data inventory, VOL 2: drainage regions G, H, J, K, L, M, N, P, Q, R, S, T, U, V, W, X, Technical Report No. TR 146, Department of Water Affairs and Forestry, Pretoria, 9 p. + app. (This report has an extensive appendix).

- Van der Heever, J.A. and Grobbelaar, J.U., 1995. The use of algae in bioassays to detect the presence of toxic compounds in natural waters, WRC Report No. 393/1/95, Water Research Commission, Pretoria, 65 p.

- Van der Merwe, W. and Grobler, D.C., 1990. Water quality management in the RSA: preparing for the future, Water SA, VOL 16(1), p. 49 - 53.

- Venter, S.N., Steynberg, M.C., Du Plessis, G., De Wet, C.M.E., Hohls, D., Rodda, N. and Kfir, R., 1996. Tools for microbial water quality assessment of South African rivers, WRC Report No. 380/1/96, Water Research Commission, Pretoria, various pages. (The use of microbiological water quality models for highly contaminated catchments is discussed in the report. The study area selected was the Rietspruit catchment south of Johannesburg).

- Weaver, J.M.C., 1992. Groundwater sampling: a comprehensive guide for sampling methods, WRC Report No. TT 54/92, Water Research Commission, Pretoria, various pages.

- Weaver, J.M.C., 1992. Groundwater sampling: an abbreviated field guide for sampling methods, WRC Report No. TT 56/92, Water Research Commission, Pretoria, various pages. (Both Weaver reports are a useful source of relevant information on methodology, as well as microbiological and chemical determinands).

- Wiseman, K. and Glazewski, J., 1991. South African law pertaining to the causes and effects of pollution affecting water resources, Report No. CPE 1.5/91, CSIR Programme for the Environment, CSIR, Pretoria, 141 p.

- Zietsman, D.P. and Schutte, J.M., 1981. The availability of quantitative and qualitative hydrological data, In: Hattingh, W.H.J. (ed), Water Year + 10 and

Then?, Technical Report No. TR 114, Department of Water Affairs, Forestry and Environmental Conservation, Pretoria, p. 156 - 217.

15.16.3 Overview of water quality in Natal/KwaZulu

- Archibald, C.G.M., Coetzee, O.J., Cox, S.M.H., Kemp, P.H., Pretorius, S.J. and Sibbald, R.R., 1971. Water quality and abatement of pollution in Natal rivers, Part 6: factors affecting water quality in the sugar growing areas of Natal, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 119 p.

- Archibald, C.G.M., Coetzee, O.J., Kemp, P.H., Pretorius, S.J. and Sibbald, R.R., 1969. Water quality and abatement of pollution in Natal rivers, Part 4: the rivers of northern Natal and Zululand, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 52 p.

- Brand, P.A.J., Kemp, P.H., Oliff, W.D. and Pretorius, S.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 3: the Tugela River and its tributaries, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 68 p. + app.

- Brand, P.A.J., Kemp, P.H., Pretorius, S.J. and Schoonbee, H.J., 1967. Water quality and abatement of pollution in Natal rivers, Part 1: objectives of river surveys, description of methods used and discussion of water quality criteria, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 101 p.

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- Breen, C.M., Akhurst, E.G.J. and Walmsley, R.D. (eds), 1985. Water quality management in the Mgeni catchment, Natal Town and Regional Planning Commission Supplementary Report, VOL 12, Pietermaritzburg, 27 p.

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- Chutter, F.M., 1972. An empirical biotic index of the quality of water in South African streams and rivers, Water Research, VOL 6(1), p. 19 - 30.

- Coleman, T.J. and Simpson, D.E., 1996. Adaptation and calibration of an urban runoff quality model, WRC Report No. 299/1/96, Water Research Commission, Pretoria, various pages.

- Fowles, B.K., Butler, A.C., Brown, H.M., Kemp, P.H., Coetzee, O.J. and Metz, H., 1979. Water quality and abatement of pollution in Natal rivers, Part 7: special studies in the rapidly developing areas of Newcastle and Ladysmith, Natal Town and Regional Planning Commission Report, VOL 13, Pietermaritzburg, 93 p.

- Kemp, P.H., 1971. Chemistry of natural waters - VI: classification of waters, Water Research, VOL 5(10), p. 943 - 956.

- Kemp, P.H., 1977. A guide to ionic relationships in natural waters, CSIR Research Report No. 329, National Institute for Water Research, CSIR, Pretoria, 127 p.

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- Schoonbee, H.J. and Kemp, P.H., 1963. Pollution studies in the Umgeni Basin (Natal), Part 4: a biological and chemical survey of the Umsunduzi River at Pietermaritzburg, CSIR Special Report No. W26, National Institute for Water Research, CSIR, Pretoria, 48 p. (Refer to the bibliographic database for other reports in this series).

- Schoonbee, H.J. and Kemp, P.H., 1965. An account of the Umgeni River survey, CSIR Research Report No. 325, National Institute for Water Research, CSIR, Pretoria, 63 p. + app.

15.16.4 Specific catchment water quality issues in Natal/KwaZulu

- Alcock, P.G., 1989. Water supply systems for the Ximba Ward of KwaZulu: a proposed strategy, Occasional Publication No. 9, Department of Crop Science, University of Natal, Pietermaritzburg, 128 p.

- Alcock, P.G. and Verster, E., 1987. An assessment of water quality in the Inadi Ward, Vulindlela District, KwaZulu, Water SA, VOL 13(4), p. 215 - 224.

- Alexander, W., 1978. Session 2. Management of rivers, flood plains and estuaries in Natal and KwaZulu - the Department of Water Affairs' view, In: The Relationship Between Agriculture and Environmental Conservation in Natal and KwaZulu: a Symposium, Wildlife Society of Southern Africa (Natal Branch) and the Royal Society of South Africa (Natal Branch), 19 - 20 October 1978, Durban, p. 50 - 55.

- Anonymous, 1990. Hydro factors affecting siltation in the lower reaches of Natal/KwaZulu rivers, CSIR Report No. EMA-D 9006, Division of Earth, Marine and Atmospheric Science and Technology, CSIR, Stellenbosch, 22 p. + app.

- Gardner, B.D. and Archibald, C.G.M., 1992. Catchment development impacts on river and estuarine systems, Natal Town and Regional Planning Commission Report, VOL 78, Pietermaritzburg, 21 p.

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For further information on water quality and water pollution contact:

- Albany Museum, Somerset Street, Grahamstown, 6139. (The Albany Museum maintains the National Collection of Freshwater Invertebrates, which can be used for a number of purposes including water quality studies, and for the assessment of changes in the flow regime of rivers).

- Centre for Water in the Environment, Department of Botany, University of the Witwatersrand, Private Bag 3, Wits, 2050.

- Centre for Water Pollution Research, Department of Civil Engineering/Department of Geography, University of Durban-Westville, Private Bag X54001, Durban, 4000.

- Centre for Water and Wastewater Research, Department of Biotechnology, Technikon Natal, P O Box 953, Durban, 4000.

- Computing Centre for Water Research/Department of Agricultural Engineering, University of Natal, Private Bag X01, Scottsville, 3209.

- Department of Environment Affairs, Private Bag X447, Pretoria, 0001.

- Department of Hydrology, University of Zululand, Private Bag X1001, KwaDlangezwa, 3886.

- Department of National Health and Population Development, Private Bag X54318, Durban, 4000.

- Department of Water Affairs and Forestry, P O Box 1018, Durban, 4000.

- Division of Earth, Marine and Atmospheric Science and Technology, CSIR, P O Box 320, Stellenbosch, 7599.

- Division of Water Technology, CSIR, P O Box 17001, Congella, 4013.

- Institute for Soil, Climate and Water, Private Bag X79, Pretoria, 0001.

- Institute for Water Quality Studies (previously the Hydrological Research Institute), Department of Water Affairs and Forestry, Private Bag X313, Pretoria, 0001.

- Institute for Water Research, Rhodes University, P O Box 94, Grahamstown, 6140.

- Institute of Natural Resources, University of Natal, Private Bag X01, Scottsville, 3209.

- J L B Smith Institute of Ichthyology, Rhodes University, Private Bag 1015, Grahamstown, 6140.

- KwaZulu Department of Health, Private Bag X10, Ulundi, 3838.

- Mhlatuze Water, P O Box 1264, Richards Bay, 3900.

- National Botanical Institute, Private Bag X101, Pretoria, 0001. (The Institute has expertise in respect of problem plants including aquatic and riverine species).

- Plant Protection Research Institute, Private Bag X134, Pretoria, 0001. (The Institute undertakes research on the control of noxious weeds and alien plants).

- Pollution Research Group, Department of Chemical Engineering, University of Natal, Private Bag X10, Dalbridge, 4014. (The Group undertakes research inter alia on wastewater treatment problems experienced by the textile industry. This industry is one of the most problematic in terms of wastewater management).

- South African Bureau of Standards, Private Bag X191, Pretoria, 0001.

- South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe, 4300.

- Sugar Milling Research Institute, University of Natal, Private Bag X10, Dalbridge, 4014.

- Umgeni Water, P O Box 9, Pietermaritzburg, 3200.

- Water Institute of Southern Africa, P O Box 6011, Halfway House, 1685.

- Water Research Commission, P O Box 824, Pretoria, 0001.

- Water Research Group, Department of Civil Engineering, Rand Afrikaans University, P O Box 524, Auckland Park, 2006.

- Water Research Group, Department of Civil Engineering, University of Cape Town, Private Bag, Rondebosch, 7701.

- Water Systems Research Group, Department of Civil Engineering, University of the Witwatersrand, Private Bag 3, Wits, 2050.

- Water Utilization Division, Department of Chemical Engineering, University of Pretoria, Pretoria, 0002.

Note: All universities in South Africa have Departments of Botany/Zoology, many of which have been or are involved in the study of aquatic life forms and sometimes, water quality. The Freshwater Research Unit, Department of Zoology, University of Cape Town, Private Bag, Rondebosch, 7701, is especially active in water research. (The addresses of universities in southern Africa are provided in Chapter 2).

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