# Reclaimed Water: A Health Hazard?

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## Abstract

This paper describes the results of the first three years of a comprehensive survey of the microbiological and chemical quality of drinking waters in the Windhoek and Pretoria areas. Results indicated that all the potable waters analysed, were of a good quality and conformed to the criteria proposed by a number of organizations to ensure a safe, potable water.

One of the potable waters analysed in this study was derived from a source receiving rather large volumes of purified sewage effluents. However, it was shown that this source could still be purified to potable water quality. The fact that most, if not all, of the other cities in South Africa obtain their water from better sources, leads to the belief that the quality of the other potable water in this country would be as good as, if not better than, the values reported in this paper.

The microbiological quality of reclaimed water was shown to be good and chemically, except for its nitrate content, it conformed to all criteria relating to the health of man. Ways and means of reducing the nitrate content are discussed. It is finally concluded that reclaimed water does not present a health hazard.

## Introduction

The increasing pollution of raw water sources by human, industrial and agricultural wastes has made the indirect reuse of wastewater an integral part of modern society. A typical example of indirect reuse in the Republic of South Africa is the use of the polluted Vaal River as a source of drinking water for the Witwatersrand complex.

Reclamation of wastewater is one of the most profitable ways by which our limited water supplies can be augmented (Cillié and Stander, 1974) and treatment plants for this purpose are being used in Windhoek (potable water), Pretoria (research facility), Springs and Durban (paper industry).

The most important task of reclamation plants is to remove microbial pathogens (bacteria, viruses and parasites) and chemicals which pose a health risk. Chemicals may not only have immediate toxicological effects but also long-term effects, i.e. lead inhibits certain enzymes and mitochondrial respiration which may be harmful to the development of the infant brain (Moore, 1975).

This paper deals with the chemical and microbiological quality of various drinking water supplies obtained by conventional treatment of river, dam or borehole resources, as well as reclaimed water produced in Windhoek and Pretoria. The data obtained are necessary to establish quality base lines for the development of reclamation plants which will meet the requirements of safe drinking water.

## Materials and Methods

The National Institute for Water Research started studies on the quality of reclaimed water in 1964 at Windhoek. In 1971 the Stander Water Reclamation Plant in Pretoria came into operation and the studies were expanded to cover both reclaimed water and conventional potable water supplies and sources in the Windhoek and Pretoria areas. The research programme outlined by Hattingh and Nupen (1975) attempts to determine the health aspects of drinking waters by the collection of information on the type and concentrations of constituents in municipal wastewaters, reclaimed waters and other water sources, using chemical, microbiological and bioassaying techniques. The waters under surveillance at present supply about 25 per cent of the total population of the Republic of South Africa.

### Windhoek studies

Laboratory and pilot plant research at Windhoek on the design and function of the various unit processes of the reclamation plant was done before plant construction. All individual processes were tested separately for bacterial, viral and chemical removals, and intensive chemical and microbiological monitoring was carried out at all times during reclamation plant operation (Cillié *et al.*, 1966; Nupen, 1970). Windhoek's drinking water supply comes from a variety of sources such as dams, boreholes and reclaimed water. The quality of the settled sewage, humus tank-, maturation pond effluents and all the other sources of potable water has been measured at regular intervals since 1968.

### Pretoria studies

Pretoria also receives potable water from a variety of sources such as the Rand Water Board, different springs, a dam and a borehole. In addition, the Stander Water Reclamation Plant is situated at the Daspoort Sewage Works and purifies humus tank effluent to potable water quality, although the product is

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**TABLE 1**

**DRINKING WATER QUALITY CRITERIA WHICH MIGHT AFFECT PUBLIC HEALTH AS PROPOSED BY THE WORLD HEALTH ORGANIZATION (WHO), US PUBLIC HEALTH SERVICE (USPHS), SOUTH AFRICAN BUREAU OF STANDARDS (SABS), RUSSIA (USSR), USA NATIONAL ACADEMY OF SCIENCES (NAS), THE BRITISH MINISTRY OF HEALTH (UK), AUSTRALIA, JAPAN AND ENVIRONMENTAL PROTECTION AGENCY (EPA) OF THE USA ALL CONCENTRATIONS IN $\mu g/\ell$ UNLESS OTHERWISE STATED**

| | Quality criteria proposed by | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | WHO | | | | | |
| **Parameter** | **USPHS (1962)** | **Japan (1968)** | **UK (1969)** | **USSR (1970)** | **European (1970)** | **International (1971)** | **SABS (1971)** | **NAS (1972)** | **Australia (1973)** | **EPA (1975)** |
| Arsenic | 10 | 50 | | 50 | 50 | 50 | 50 | 100 | 50 | 50 |
| Barium | 1 000 | | | 4 000 | 1 000 | — | — | 1 000 | 1 000 | 1 000 |
| Cadmium | 10 | | | 10 | 10 | 10 | 50 | 10 | 10 | 10 |
| Chromium | 50 | 50 | | 100 | 50 | — | 50 | 50 | 50 | 50 |
| Copper | 1 000 | 10 000 | | 100 | 50 | 50 | 1 000 | 1 000 | 10 000 | — |
| Cyanide | 10 | 10 | | 100 | 50 | 50 | 10 | 200 | 10 | — |
| Lead | 50 | 100 | | 100 | 100 | 100 | 50 | 50 | 50 | 50 |
| Mercury | — | 1 | | 5 | — | 1 | — | 2 | — | 2 |
| Phenolic compounds | 1 | 5 | | 1 | 1 | 1 | 1 | 1 | — | — |
| Selenium | 10 | — | | 1 | 10 | 10 | — | 10 | 10 | 10 |
| Silver | 50 | — | | — | — | — | — | — | 50 | 50 |
| Zinc | 5 000 | 1 000 | | 1 000 | 5 000 | 5 000 | 5 000 | 5 000 | 5 000 | |
| Organic Matter (CCE) | 200 | — | | — | 200 – 500 | — | — | 300 | 700 | — |
| Pesticides | | | | | | | | | | |
| Total chlorinated hydrocarbon | — | — | | — | — | — | — | 1 066 | — | 1 092 |
| Total organo phosphorus and carbamates | — | — | | — | — | — | — | 100 | — | — |
| Total chlorophenoxys | — | — | | — | — | — | — | 52 | — | 110 |
| Nitrate-Nitrogen (mg/ℓ) | 10 | 10 | | 10 | <11,5 | 10 | 10 | 10 | 10 | 10 |
| Fluoride (mg/ℓ) | 0,6 – 1,7 | 0,8 | | 1,5 | 0,7 – 1,7 | 0,6 – 1,7 | 1,0 – 1,5 | 1,4 – 2,4 | 1,5 | 1,4 – 2,4 |
| Coliforms/100 mℓ | <1[(1)] | 0 | <10 | — | — | 0 | <10 | — | 0 | <1 |
| *E. coli* I/100 mℓ | — | 0 | 0 | — | — | 0 | 0 | — | 0 | — |
| Total plate count/mℓ | — | | — | — | — | — | <100 | — | | — |
| Virus/ℓ | — | | — | — | — | 1[(2)] | — | — | | — |

(1) Less than 10% of samples should be positive in any one month
(2) 1 Plaque forming unit on testing 10ℓ sample

not used as a source of drinking water. The quality of the different potable water sources in the Pretoria area, as well as that of the Daspoort Sewage Works, has been measured since 1972.

The Stander Water Reclamation Plant was designed as a research facility and, therefore, changes to its design and mode of operation were made to optimise the process. For these reasons, the plant was not operated on a continuous basis until February, 1975. The chemical and microbiological quality of the raw water input and the reclaimed water produced, have, however, been determined since 1972. A thorough investigation, based on 75 snap samples taken on alternate days and at different times of the day and night, was conducted during the continuous operation of the plant in 1975. The flow diagram of this plant has been outlined by van Vuuren (1975).

The analytical methods used have been described earlier (Hattingh and Nupen, 1975).

## Quality Criteria

The quantity and quality of industrial and sewage effluents which may be released to the environment are controlled by Act No. 54 of 1956. In terms of this Act, two standards – a special and a general – were promulgated for effluents in 1962. There are no statutory standards for potable water in South Africa (Barnard and Hattingh, 1975). The South African Bureau of Standards' specification for water for domestic supplies (Specification 241) may be applied by industry, local authorities or water authorities and is obligatory where water is being used in the manufacturing or processing of an edible product bearing the SABS mark.

Table 1 summarizes the standards proposed by various authorities for those constituents regarded as being detrimental to human health.

**TABLE 2**

**THE AVERAGE CHEMICAL QUALITY OVER THE PERIOD 1971 TO 1975 OF THE SETTLED SEWAGE (SS), HUMUS TANK EFFLUENT (HTE) AND MATURATION POND EFFLUENT (MPE) OF THE GAMMAMS SEWAGE WORKS, WINDHOEK**

| | | SS | HTE | MPE |
|---|---|---|---|---|
| | Conductivity (mS/m) | 129 | 91 | 94 |
| mg/ℓ | Alkalinity* | 743 | 119 | 169 |
| | COD** | 163 | 59 | 62 |
| | MBAS*** | 3,4 | 1,5 | 0,8 |
| | Ammonia-N | 57,1 | 11,1 | 8,5 |
| | Organic-N | 7,3 | 3,6 | 3,0 |
| | Nitrate-N | 0,6 | 13,6 | 7,4 |
| | Nitrite-N | <0,1 | 0,8 | 0,4 |
| | Ortho-P | 10,7 | 10,5 | 9,5 |
| | Organic-P | 7,2 | 3,0 | 1,7 |
| | Organic-C | 56 | 27 | 25 |
| | Fluoride ($F^-$) | 0,4 | 0,3 | 0,3 |
| | Chloride ($Cl^-$) | 87 | 72 | 79 |
| | Sulphate ($SO_4^=$) | 102 | 103 | 104 |
| | Sodium (Na) | 110 | 99 | 115 |
| | Potassium (K) | 24 | 22 | 23 |
| | Calcium (Ca) | 45 | 45 | 43 |
| | Magnesium (Mg) | 9 | 8 | 8 |
| µg/ℓ | Aluminium (Al) | 442 | 201 | 223 |
| | Boron (B) | 413 | 346 | 391 |
| | Barium (Ba) | <250 | <250 | <250 |
| | Beryllium (Be) | <25 | <25 | <25 |
| | Cadmium (Cd) | <25 | <25 | <25 |
| | Cobalt (Co) | <25 | <25 | <25 |
| | Chromium (Cr) | <25 | <25 | <25 |
| | Copper (Cu) | <25 | <25 | <25 |
| | Iron (Fe) | 421 | 127 | 134 |
| | Manganese (Mn) | 143 | 39 | 54 |
| | Nickel (Ni) | <25 | <25 | <25 |
| | Lead (Pb) | <25 | <25 | <25 |
| | Strontium (Sr) | 199 | 190 | 186 |
| | Zinc (Zn) | 183 | 95 | 82 |

*Alkalinity at pH 4,3 ($CaCO_3$)
**COD = Chemical oxygen demand
***MBAS = Methylene blue active substances.

## Results

### Quality of the water in Windhoek

*Sewage works*

The average chemical and microbiological qualities over the period 1971 to 1975 are presented in Tables 2 and 3, respectively. The improvement in the chemical quality of the settled sewage by biological action is shown by a 62 per cent reduction in the COD value and a reduction in total nitrogen from 65 mg $\ell^{-1}$ to 29 mg $\ell^{-1}$ in the humus tank effluent. A similar improvement is shown by a reduction in total phosphate amount by 23 per cent and in synthetic detergents (MBAS) to 56 per cent.

Biological sewage purification has little effect on ions such as Na, K, Ca, Mg, $SO_4$ and $PO_4$.

The improvement in the microbiological quality of the settled sewage by biological action is most pronounced in the maturation pond (Table 3). The virus count of the humus tank effluent is reduced on the average from 32 × $10^3$ $TCID_{50}$ $\ell^{-1}$ to 100 $TCID_{50}$ $\ell^{-1}$ – a reduction of two logs. In addition, the coliform count was also greatly reduced. The maturation ponds is, therefore, a very efficient microbiological barrier.

*Potable water*

The average chemical quality of the different sources is given in Table 4 and the microbiological quality in Table 5. The chemical quality of all these waters is good and conforms to the standards outlined in Table 1.

However, evidence of faecal contamination in one of the treated drinking water supplies was shown by the presence of *E. coli* and, more significantly, the recovery of virus during 1970, 1971, 1974 and 1975.

The other sources of drinking water, i.e. treated dam water and borehole waters all showed evidence of bacteriological and viral pollution during the test period.

*Reclaimed water*

Reclamation of potable water was commenced during 1969. This plant was operated during the summer months since the

**TABLE 3**

**THE AVERAGE MICROBIOLOGICAL QUALITY OVER THE PERIOD 1971 TO 1975 OF THE SETTLED SEWAGE (SS), HUMUS TANK EFFLUENT (HTE) AND MATURATION POND EFFLUENT (MPE) OF THE GAMMAMS SEWAGE WORKS, WINDHOEK**

| | | | SS | HTE | MPE |
|---|---|---|---|---|---|
| /mℓ | Total plate count (37 °C/24 h) | x $10^4$ | 5 600 | 2 700 | 700 |
| /100 mℓ | Coliforms* (37 °C) | x $10^4$ | 16 950 | 1 330 | 0,06 |
| | Faecal coliforms* (44,5 °C/18 h) | x $10^4$ | 2 020 | 173 | 0,008 |
| | *Psuedomonas aeruginosa* | x $10^3$ | 10 860 | 115 | 1 |
| | *Clostridium* * *perfringens* | x $10^3$ | 1 170 | 30 | 11 |
| | Staphylococci* | x $10^2$ | 37 | 42 | 0,7 |
| /litre | Total enterovirus | x $10^3$ | 56 | 32 | 0,1 |
| | Total parasite ova | | 9 | 3 | 0 |

*By membrane filtration

## TABLE 4

### THE AVERAGE CHEMICAL QUALITY OF THE DIFFERENT SOURCES OF POTABLE WATER IN WINDHOEK OVER THE PERIOD 1971 TO 1975

| | | Goreangab Dam | | Von Bach Dam Treated | Pahl Quelle Boreholes | Reclaimed water |
|---|---|---|---|---|---|---|
| | | Raw | Treated | | | |
| | Conductivity (mS/m) | 34 | 41 | 25 | 86 | 110 |
| mg/ℓ | Alkalinity* | 98 | 96 | 91 | 273 | 89 |
| mg/ℓ | COD** | 33 | 32 | 40 | 28 | 33 |
| mg/ℓ | MBAS*** | 0,4 | 0,4 | 0,4 | 0,5 | — |
| mg/ℓ | Ammonia-N | 0,9 | 0,4 | 3,6 | 0,7 | 0,1 |
| mg/ℓ | Organic-N | 1,2 | 0,6 | 2,7 | 0,6 | 0,6 |
| mg/ℓ | Nitrate-N | 0,9 | 0,7 | 1,1 | 1,4 | 25,0 |
| mg/ℓ | Nitrite-N | <0,1 | <0,1 | <0,1 | <0,2 | <0,1 |
| mg/ℓ | Ortho-P | 0,4 | <0,2 | 0,9 | 0,6 | <0,2 |
| mg/ℓ | Organic-P | 1,3 | 0,3 | 0,7 | 0,3 | <0,2 |
| mg/ℓ | Organic-C | 14 | 15 | 14 | 13 | 8 |
| mg/ℓ | Fluoride ($F^-$) | 0,2 | 0,2 | 0,2 | 0,8 | 0,1 |
| mg/ℓ | Chloride ($Cl^-$) | 20 | 27 | 5 | 27 | 130 |
| mg/ℓ | Sulphate ($SO_4^=$) | 36 | 40 | 34 | 104 | 210 |
| mg/ℓ | Sodium (Na) | 28 | 29 | 2 | 101 | 154 |
| mg/ℓ | Potassium (K) | 7 | 7 | 4 | 13 | 29 |
| mg/ℓ | Calcium (Ca) | 27 | 36 | 32 | 58 | 57 |
| mg/ℓ | Magnesium (Mg) | 4 | 4 | 2 | 18 | 5 |
| µg/ℓ | Aluminium (Al) | 699 | 309 | 903 | 247 | — |
| µg/ℓ | Arsenic (As) | — | — | — | — | — |
| µg/ℓ | Boron (B) | 147 | 96 | 112 | 176 | — |
| µg/ℓ | Barium (Ba) | <250 | <250 | <250 | <250 | <250 |
| µg/ℓ | Beryllium (Be) | <50 | <50 | <50 | <50 | <50 |
| µg/ℓ | Cadmium (Cd) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Cobalt (Co) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Chromium (Cr) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Copper (Cu) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Iron (Fe) | 813 | 59 | 156 | 250 | <25 |
| µg/ℓ | Manganese (Mn) | 92 | 70 | 25 | 40 | <25 |
| µg/ℓ | Nickel (Ni) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Lead (Pb) | <25 | <25 | <25 | <25 | <25 |
| µg/ℓ | Strontium (Sr) | 122 | 127 | 88 | 381 | 225 |
| µg/ℓ | Zinc (Zn) | 54 | 82 | 54 | 57 | <25 |

*Alkalinity at pH 4,3 ($CaCO_3$)
**COD = Chemical oxygen demand
***MBAS = Methylene blue active substances

## TABLE 5

### THE AVERAGE MICROBIOLOGICAL QUALITY OF THE DIFFERENT SOURCES OF POTABLE WATER IN THE WINDHOEK AREA OVER THE PERIOD 1970 TO 1975

| | | Goreangab Dam | | Purified Von Bach Dam | Pahl Quelle boreholes | Reclaimed water |
|---|---|---|---|---|---|---|
| | | Raw | Purified | | | |
| 1 mℓ | Total plate count | 292 x $10^2$ | 20 | 400 | 600 | <100 |
| /100 mℓ | Coliforms (37°C) | 23 x $10^2$ | 0 | 0 | 14 | 0 |
| /100 mℓ | Faecal coliforms (44,5°C/18h) | 5 x $10^2$ | 0 | 0 | 6 | 0 |
| /100 mℓ | Confirmed *E. coli I* | 3 x $10^2$ | 0 | 0 | <1 | 0 |
| /100 mℓ | *Pseudomonas aeruginosa* | 4 x $10^2$ | 0 | 0 | 2 | – |
| /100 mℓ | *Clostridium perfringens* | 17 x $10^2$ | 0 | 1 | <1 | – |
| /100 mℓ | Staphylococci | 34 | 0 | 0 | <1 | – |
| | Percentage of samples positive for enterovirus | 6 | 3 | <1 | 0 | 0 |

**TABLE 6**

**THE AVERAGE CHEMICAL QUALITY OVER THE PERIOD 1972 TO 1975 OF THE SETTLED SEWAGE (SS) AND HUMUS TANK EFFLUENT (HTE) OF THE DASPOORT SEWAGE WORKS, PRETORIA**

| | | SS | HTE |
|---|---|---|---|
| | Conductivity (mS/m) | 97 | 69 |
| mg/ℓ | Alkalinity* | 304 | 154 |
| | COD** | 309 | 51 |
| | MBAS*** | 3,7 | 1,0 |
| | Ammonia-N | 43,8 | 7,8 |
| | Organic-N | 9,4 | 1,8 |
| | Nitrate-N | 0,9 | 7,2 |
| | Nitrite-N | <0,1 | 0,3 |
| | Ortho-P | 7,7 | 7,1 |
| | Organic-P | 1,3 | 1,0 |
| | Organic-C | 136 | 26 |
| | Fluoride ($F^-$) | 0,3 | 0,3 |
| | Chloride ($Cl^-$) | 71 | 50 |
| | Sulphate ($SO_4^=$) | 76 | 59 |
| | Sodium (Na) | 80 | 55 |
| | Potassium (K) | 15 | 13 |
| | Calcium (Ca) | 40 | 38 |
| | Magnesium (Mg) | 18 | 19 |
| μg/ℓ | Silver (Ag) | <25 | <25 |
| | Aluminium (Al) | 309 | 136 |
| | Arsenic (As) | <1 | <1 |
| | Boron (B) | 722 | 271 |
| | Barium (Ba) | <250 | <250 |
| | Beryllium (Be) | <5 | <5 |
| | Cadmium (Cd) | <5 | <5 |
| | Cobalt (Co) | <25 | <25 |
| | Chromium (Cr) | <25 | <25 |
| | Copper (Cu) | 209 | <25 |
| | Mercury (Hg) | 1 | <1 |
| | Iron (Fe) | 492 | 60 |
| | Manganese (Mn) | 89 | 30 |
| | Nickel (Ni) | <25 | <25 |
| | Lead (Pb) | 43 | <25 |
| | Strontium (Sr) | 125 | 73 |
| | Zinc (Zn) | 245 | 89 |
| | Phenol | 86 | 64 |
| | Cyanide ($CN^-$) | 89 | 66 |

*Alkalinity at pH 4,3 ($CaCO_3$)
**COD = Chemical oxygen demand
***MBAS = Methylene blue active substances

chlorination facilities were inadequate to ensure complete disinfection during the winter months when the ammonia figure rose to higher levels. During February, 1971, Windhoek had heavy rains and shortly afterwards a further fresh water supply from the Von Bach Dam came into operation which alleviated the serious shortage of fresh water in Windhoek. The reclamation plant has since been modified to resemble the Stander reclamation plant in Pretoria. The average chemical and microbiological quality of the reclaimed water in Windhoek is presented in Tables 4 and 5 respectively.

The chemical quality of the reclaimed water was as good as that from the other potable sources in Windhoek. The microbiological quality, however, was significantly better than the other supplies since at no time could virus be isolated from 10 ℓ or even 100 ℓ of the product water.

## Quality of the water in Pretoria

*Sewage works*

The average chemical quality of the settled sewage and humus tank effluent at the Daspoort Sewage Works over the period 1972 to 1975 is given in Table 6.

The following average reductions were achieved: COD 84%; MBAS 73%; total nitrogen 68%; total phosphorus 2% and organic C 81%. Once again little reduction in Na, K, Ca, Mg, $SO_4$ and Cl took place, but trace metals such as Al, B, Cu, Fe, Mn, Pb and Zn were reduced to low levels.

The average microbiological quality of the settled sewage and humus tank effluent is outlined in Table 7. The microbiological quality of the settled sewage at Daspoort is different from that of the Gammams Works at Windhoek (Table 3) in that the counts were much lower, the reason for this being that the Gammams Works receives little industrial effluent and, therefore, less dilution of the sewage by effluents containing relatively low loads of micro-organisms took place. In addition, the Daspoort Works differed from the Gammams Works in that the latter included maturation ponds which had a pronounced effect on the microbiological quality (Table 3).

**TABLE 7**

**THE AVERAGE MICROBIOLOGICAL QUALITY OVER THE PERIOD 1972 TO 1975 OF THE SETTLED SEWAGE (SS), HUMUS TANK EFFLUENT (HTE) OF THE DASPOORT SEWAGE WORKS, PRETORIA**

| | | | SS | HTE |
|---|---|---|---|---|
| 1 mℓ | Total plate count (37°C/24 h) | x $10^4$ | 680 | 72 |
| 100 mℓ | Coliforms* (37°C) | x $10^4$ | 1 960 | 140 |
| | Faecal coliforms* (44,5°C/18 h) | x $10^4$ | 1 020 | 30 |
| | *Pseudomonas aeruginosa* | x $10^3$ | 11 | 2 |
| | *Clostridium perfringens** | | 42 | 21 |
| 1 litre | Total enterovirus | x $10^3$ | 5 | 1 |
| | Total parasite ova | | 18 | <1 |

*By membrane filtration.

## TABLE 8

### THE AVERAGE CHEMICAL QUALITY OF THE DIFFERENT POTABLE WATERS IN THE PRETORIA AREA OVER THE PERIOD 1972 TO 1975

| | | Rietvlei Dam | | Rietvlei Fountains | Erasmia Borehole | Pretoria Fountains | NIWR Laboratory Tap water | Vaal River at Vereeniging | |
|---|---|---|---|---|---|---|---|---|---|
| | | Raw | Treated | | | | | Raw | Treated |
| | Conductivity (mS/m) | 54 | 58 | 27 | 55 | 49 | 44 | 52 | 37 |
| mg/ℓ | Alkalinity* | 160 | 140 | 98 | 196 | 162 | 71 | 84 | 86 |
| | COD** | 30 | 34 | 18 | 18 | 20 | 47 | 22 | 22 |
| | MBAS*** | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,3 | 0,2 |
| | Ammonia-N | 0,4 | 0,3 | 0,3 | 0,3 | 0,3 | 0,4 | 0,4 | 0,5 |
| | Organic-N | 0,7 | 0,6 | 0,5 | 0,5 | 0,4 | 2,0 | 0,7 | 0,8 |
| | Nitrate-N | 0,1 | <0,1 | 0,6 | 2,1 | 2,1 | 0,7 | 1,3 | 1,0 |
| | Nitrite-N | 0,5 | 0,3 | 0,2 | 0,1 | <0,1 | 0,2 | 0,1 | 0,2 |
| | Ortho-P | 0,5 | 0,6 | 0,2 | <0,2 | <0,2 | 0,2 | 0,4 | <0,2 |
| | Organic-P | 0,4 | 0,2 | 0,1 | 0,1 | 0,1 | 0,2 | 0,2 | 0,4 |
| | Organic-C | 17 | 12 | 7 | 6 | 7 | 7 | 10 | 8 |
| | Fluoride ($F^-$) | 0,3 | 0,3 | 0,1 | 0,1 | <0,1 | 0,2 | 0,4 | 0,2 |
| | Chloride ($Cl^-$) | 31 | 51 | 15 | 46 | 25 | 53 | 36 | 21 |
| | Sulphate ($SO_4^{=}$) | 60 | 76 | 10 | 12 | 10 | 44 | 111 | 58 |
| | Sodium (Na) | 58 | 63 | 10 | 15 | 15 | 46 | 39 | 22 |
| | Potassium (K) | 8 | 8 | 1 | 1 | 2 | 3 | 7 | 4 |
| | Calcium (Ca) | 27 | 28 | 24 | 53 | 44 | 33 | 56 | 42 |
| | Magnesium (Mg) | 15 | 15 | 13 | 31 | 24 | 11 | 30 | 7 |
| μg/ℓ | Silver (Ag) | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| | Aluminium (Al) | 154 | 192 | 145 | 154 | 137 | 149 | 263 | 171 |
| | Arsenic (As) | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 2 |
| | Boron (B) | 188 | 174 | 109 | 107 | 107 | 103 | 259 | 139 |
| | Barium (Ba) | <250 | <250 | <250 | <250 | <250 | <250 | <250 | <250 |
| | Beryllium (Be) | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| | Cadmium (Cd) | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| | Cobalt (Co) | <25 | <25 | <25 | <25 | 27 | <25 | <25 | <25 |
| | Chromium (Cr) | <25 | 26 | <25 | <25 | 25 | <25 | 28 | <25 |
| | Copper (Cu) | 27 | <25 | <25 | <25 | <25 | 40 | 28 | 29 |
| | Mercury | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Iron (Fe) | 1939 | 26 | 26 | 25 | 26 | 71 | 1534 | <25 |
| | Manganese (Mn) | 25 | <25 | <25 | <25 | <25 | <25 | 29 | <25 |
| | Nickel (Ni) | 28 | 27 | <25 | 26 | 27 | <25 | 30 | <75 |
| | Lead (Pb) | <25 | <25 | <25 | 27 | <25 | <25 | 27 | <25 |
| | Strontium (Sr) | 69 | 65 | 24 | 33 | 28 | 67 | 148 | 85 |
| | Zinc (Zn) | 39 | 29 | 28 | 61 | 32 | 41 | 35 | 26 |
| | Phenol | 68 | 56 | 73 | 72 | 61 | 54 | <50 | 71 |
| | Cyanide ($CN^-$) | <50 | <50 | <50 | <50 | <50 | <50 | <50 | <50 |

*Alkalinity at pH 4,3 ($CaCO_3$)
**COD = Chemical oxygen demand
***MBAS = Methylene blue active substances.

*Potable water*

The quality of the different sources of potable water have been measured since 1972 and the average chemical quality is given in Table 8 and the average microbiological quality in Table 9.

*Reclaimed water*

The average chemical and microbiological qualities of the water during 1975 are given in Tables 10 and 11, respectively.

TABLE 9

**THE AVERAGE MICROBIOLOGICAL QUALITY OF THE DIFFERENT SOURCES OF POTABLE WATER IN THE PRETORIA AREA DURING THE PERIOD 1972 TO 1975**

| | | Vaal River at Vereeniging | | Rietvlei Dam | | Rietvlei Fountains | | Erasmia Borehole | Pretoria Fountains | | NIWR Laboratory tap water |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Raw | Treated | Raw | Treated | Before $Cl_2$ | After $Cl_2$ | | Before $Cl_2$ | After $Cl_2$ | |
| /mℓ | Total plate count (37 °C/24 h) x $10^2$ | 33 | 0,12 | 44 | 9 | 8 | 12 | 5 | 8 | 12 | 10 |
| /100 mℓ | Coliforms* (37 °C) | 35 | 0 | 30 | 35 | 10 | 3 | 5 | 1 | 10 | 5 |
| | Faecal coliforms* (44,5 °C/18 h) | 17 | 0 | 12 | 5 | 4 | <1 | 4 | <1 | 1 | 50 |
| | Confirmed *E. coli I** | 12 | 0 | 0 | 0 | 0 | 0 | — | — | 0 | 6 |
| | *Pseudomonas aeruginosa* | 9 | 0 | <1 | <1 | <1 | <1 | 0 | 0 | 0 | 1 |
| | *Clostridium perfringens** | 17 | 0 | 113 | 87 | 6 | <1 | <1 | <1 | <1 | 7 |
| | Staphylococci* | 9 | 0 | <1 | <1 | 0 | 0 | 0 | 0 | 0 | 0 |
| /litre | Total enterovirus | 0 | 0 | <1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total parasite ova | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*By membrane filtration.

## Discussion

Water is not the only medium carrying polluting substances. The total environment contains most of these substances in far greater concentrations than in water. The danger of man becoming poisoned or infected through water is often overemphasized.

To date the quality of reclaimed water has complied with most of the chemical requirements and has often been better than drinking water from other sources. No virus was isolated from any of the drinking water supplies in the Pretoria area, but faecal coli were isolated on occasions from some purified dam waters and spring waters. No *E. coli* or virus were ever isolated from the final water from the reclamation plants. The microbiological quality of reclaimed water was equal to, if not better than, the drinking water supplies in both the Pretoria and Windhoek areas.

Although *Ascaris* spp., *Taenia* spp. and Hookworm ova were found in humus tank effluents, their numbers were reduced to zero in the reclamation process.

Although not a gazetted standard, zero virus isolated from a 10 ℓ sample is used by the NIWR as a criterion for drinking waters in South Africa.

Recoveries of virus on occasions confirmed that the absence of faecal coliforms was not a reliable indicator of viral pollution.

If the values in Table 10 are compared with the World Health Organization's criteria for a potable water (Table 1), then the reclaimed water produced at Pretoria fails to comply with respect to the nitrate-nitrogen, phenol and mercury content. It was later established that the stoppers of the bottles used to convey the samples to the laboratory contained mercury in the adhesive of the stopper. Over the period 1972 to 1974, the mercury content has consistently been less than 1 $\mu g$ $\ell^{-1}$ and this observation was confirmed during 1976 after the contamination via the sampling bottles was discovered. The nitrate content of the reclaimed water can conveniently be reduced to more desired levels, i.e. less than 10 mg $NO_3$-N $\ell^{-1}$ by blending it with other potable water as is done at Windhoek or, alternatively, the raw water may be denitrified before reclamation. Denitrification of sewage is possible and should present no problems. If denitrification cannot be used, maturation ponds still present a method to reduce the nitrate-nitrogen content. Phenol does not present a health hazard but gives rise to taste and odour problems.

Some of the wastewaters under test by the NIWR have shown cytotoxicity to tissue culture cells but this toxicity was never observed in the final product from the reclamation plant.

The results presented in this paper indicate that reclamation plants do purify sewage effluents to a high degree of purity. Epidemiological and bio-evaluation studies of reclaimed water have, to date, failed to demonstrate any adverse health effects of the water on humans (Grové, 1974), or rats (Nupen and Hattingh, 1975).

### TABLE 10

### CHEMICAL QUALITY OF RAW WATER TO THE STANDER WATER RECLAMATION PLANT AND THE FINAL WATER PRODUCED DURING CONTINUOUS OPERATION IN 1975

| | | Raw | Final |
|---|---|---|---|
| | Conductivity (mS/m) | 66 | 60 |
| mg/ℓ | Alkalinity* | 158 | 35 |
| mg/ℓ | COD** | 36 | 19 |
| mg/ℓ | MBAS*** | 0,8 | 0,6 |
| mg/ℓ | Ammonia-N | 7,6 | 0,4 |
| mg/ℓ | Organic-N | 4,6 | 1,1 |
| mg/ℓ | Nitrate-N | 11,3 | 15,3 |
| mg/ℓ | Nitrite-N | 0,5 | 0,1 |
| mg/ℓ | Ortho-P | 6,0 | 0,4 |
| mg/ℓ | Organic-P | 1,4 | 0,4 |
| mg/ℓ | Organic-C | 18 | 8 |
| mg/ℓ | Fluoride ($F^-$) | 0,1 | 0,1 |
| mg/ℓ | Chloride ($Cl^-$) | 46 | 90 |
| mg/ℓ | Sulphate ($SO_4^=$) | 45 | 46 |
| mg/ℓ | Sodium (Na) | 46 | 63 |
| mg/ℓ | Potassium (K) | 13 | 12 |
| mg/ℓ | Calcium (Ca) | 41 | 35 |
| mg/ℓ | Magnesium (Mg) | 20 | 4 |
| µg/ℓ | Silver (Ag) | <25 | <25 |
| µg/ℓ | Aluminium (Al) | 109 | 102 |
| µg/ℓ | Arsenic (As) | 2 | 2 |
| µg/ℓ | Boron (B) | 260 | 164 |
| µg/ℓ | Barium (Ba) | <250 | <250 |
| µg/ℓ | Beryllium (Be) | <5 | <5 |
| µg/ℓ | Cadmium (Cd) | <5 | <5 |
| µg/ℓ | Cobalt (Co) | <25 | <25 |
| µg/ℓ | Chromium (Cr) | <25 | <25 |
| µg/ℓ | Copper (Cu) | <25 | <25 |
| µg/ℓ | Mercury (Hg) | 4 (1) | 22 (1) |
| µg/ℓ | Iron (Fe) | 161 | 59 |
| µg/ℓ | Manganese (Mn) | <25 | <25 |
| µg/ℓ | Nickel (Ni) | <25 | <25 |
| µg/ℓ | Lead (Pb) | <25 | <25 |
| µg/ℓ | Strontium (Sr) | 75 | 52 |
| µg/ℓ | Zinc (Zn) | 32 | <25 |
| µg/ℓ | Phenol | 93 | 92 |
| µg/ℓ | Cyanide ($CN^-$) | <50 | <50 |

*Alkalinity at pH 4,3 ($CaCO_3$)
**COD = Chemical oxygen demand
***MBAS = Methylene blue active substances.

(1) See text for explanation of these high figures.

However, micropollutants responsible for long-term health effects or the occurrence of infection without obvious disease patterns are not detected by the constituents outlined in Table 1. This fact is still under study. The reclaimed water contained only pyrene and fluoranthene as examples of polynuclear aromatic hydrocarbons (PAH) in ng $ℓ^{-1}$ quantities. No other PAH compounds could be detected. Chlorinated hydrocarbons such as chloroform also occurred in the final water in concentrations of 2 to 15 $\mu g\ ℓ^{-1}$. The organic material that could be extracted from the reclaimed water by passing it over XAD-9 resin and recovering the organic material with ether, amounted to 6 $\mu g\ ℓ^{-1}$.

Effectively controlled chlorination to breakpoint with special attention to pH and turbidity, is absolutely necessary for the disinfection of not only reclaimed waters, but all treated drinking waters in order to prevent disease transmission and the spread of $R^+$ bacteria.

Available information confirms that there is no reason to believe that hepatitis viruses differ from other viruses in consisting of nucleic acid wrapped up in a protective coat. Consequently there are certain limitations in their resistance to disinfectants such as chlorine and ozone and to their survival in water and water treatment processes which they cannot exceed (Grabow, 1975).

The results of the research programme obtained so far, indicate that the methods employed in the reclamation plants studied by the NIWR are capable of producing water which complies with regional, national and international standards of purity. Vigilance is continuous, and the proposed operation of reclamation plants as research plants will not only ensure the production of a safe potable water supply to areas of need, but will provide the means to improve on the existing technological development and for the acquisition of background information.

### TABLE 11

### AVERAGE MICROBIOLOGICAL QUALITY OF RAW WATER TO AND FINAL WATER FROM THE STANDER WATER RECLAMATION PLANT, PRETORIA, DURING CONTINUOUS OPERATION IN 1975

| | | | Raw | Final |
|---|---|---|---|---|
| /mℓ | Total plate count (37 °C/24 h) | x $10^2$ | 19 000 | 9 |
| /100mℓ | Coliforms* (37 °C) | x $10^5$ | 13 | 0 |
| /100mℓ | Faecal coliforms* (44,5 °C/18 h) | x $10^5$ | 6 | 0 |
| /100mℓ | *Pseudomonas aeruginosa* | | 1 | 1 |
| /100mℓ | *Clostricium perfringens** | | 8 | 1 |
| /100mℓ | Staphylococci* | | 64 | 0 |
| /100mℓ | Enterococci* | | 91 | 0 |
| /litre | Total enterovirus | x $10^3$ | 24 | 0 |
| /litre | Total parasite ova | | 1 | 0 |
| /litre | *Ascaris* ova | | 1 | 0 |
| /litre | Hookworm ova | | 0 | 0 |
| /litre | *Taenia* ova | | 0 | 0 |
| /litre | Other ova | | 0 | 0 |

*By membrane filtration

## Conclusion

The results reported in this paper have been obtained over a period of at least eight years. The qualities of all the different potable waters analysed by the NIWR were good. One of the potable waters surveyed in this study is derived from a source receiving rather large volumes of purified sewage effluents but it was shown that this source could still be purified to a potable water quality. The fact that most, if not all, of the other cities in South Africa derive their water from better sources, leads to the belief that the other potable water in this country would be of as good, if not better, quality than the values reported in this paper. The quality of reclaimed water, with the exception of its nitrate content, has been shown to be as good as that of other potable waters. If the results for the organic matter and polynuclear aromatic hydrocarbon content and the fact that no toxicity to rats could be shown (Nupen and Hattingh, 1975) into account, then there is no reason to believe that reclaimed water presents a health hazard.

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