

Health Aspects of Organic Substances in South African Waters — Opinions and Realities*

J.F.J. VAN RENSBURG

National Institute for Water Research, Council for Scientific and Industrial Research, P.O. Box 395, Pretoria, 0001

Abstract

The available literature on the determination of permissible concentrations of organic micro-pollutants in potable water is reviewed in an attempt to propose guidelines for establishing appropriate South African water quality criteria. The results of a screening programme for these substances in South African water supplies are presented and discussed. Several organic pollution indices are used to divide these waters into the two categories of "safe" and "subject to further study to determine a possible health hazard".

Introduction

The present knowledge of the distribution of organic micro-pollutants in water and their impact on the health aspects of water quality has been the subject of several review papers (Packham, 1978; Chain *et al.*, 1979; Stander, 1979). It has been estimated that the volatile organics which constitute the bulk of approximately 1 600 organic compounds identified so far in water, only represent 10 to 20 % of the organic material in water. Many of these are non-toxic, while others may even be beneficial in low concentrations (Barnes, 1975).

Criteria for the presence of foreign matter in a water intended for potable use should be such that, when a water complies with these criteria no adverse effects, additional to those to which the user is normally exposed from other sources, are produced. Implementation of these criteria could involve purification procedures with certain economical implications as well as the unwanted removal of some beneficial and necessary trace substances in water. These factors should be evaluated in view of the health risk involved.

Before beginning a research programme to propose criteria for efficient control of water quality in South Africa, attempts made elsewhere were reviewed to provide suitable guidelines for local studies to amend many of the difficulties encountered elsewhere.

Progress in the USA and Europe

In their recommendations to the Environmental Protection Agency, the National Academy of Sciences reviewed 74 non-pesticides and 55 pesticides out of approximately 300 volatile organic compounds identified in drinking-water. A compound was selected for consideration of its health risk if any of the following criteria applied (Environmental Protection Agency, 1977):

1. Experimental evidence of toxicity in man, or animals, including carcinogenicity, mutagenicity or teratogenicity.
2. Identified in drinking-water at relatively high concentrations.
3. Molecular structure closely related to that of another compound of known toxicity.
4. Pesticide in widespread use, potential contaminant of drinking-water supplies.
5. Listed in the Safe Drinking Water Act or National Interim Primary Drinking Water Regulations.

For *carcinogenic* compounds, the following four principles were applied (EPA, 1977):

1. Effects on animals, properly qualified, are applicable to man.
2. Methods do not now exist to establish a threshold for long-term effects of toxic (carcinogenic) substances. Even if a threshold value did exist, a practice of finding a no-observed-adverse-effect dose and dividing this by a "safety factor" of say 100, would have no scientific basis. Even if 1 000 animals were used and no tumours appeared, we could only be 95 % sure that the true incidence was less than 0,3 %, which is still a high risk for a large population.
3. The exposure of experimental animals to toxic agents in high doses is a necessary and valid method of discovering possible carcinogenic hazards to man.
4. Material should be assessed in terms of human risk, rather than as "safe" or "unsafe". The model used for this purpose is:

$$P(d) = 1 - e^{-(\lambda_0 + \lambda_1 d + \lambda_2 d^2 + \dots + \lambda_k d^k)} \dots \dots \dots (1)$$

where $P(d)$ is the lifetime probability that dose d (total daily intake) will produce cancer and λ_0, λ_1 etc. are non-negative parameters.

Data thus obtained are included in Table 1.

Chronic toxicity of the compounds which were judged to be non-carcinogenic, was assessed by calculating Acceptable Dai-

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TABLE 1
KNOWN OR SUSPECTED ORGANIC CHEMICAL CARCINOGENS FOUND IN DRINKING-WATER

Compound	LD ₅₀ mg/kg body weight (NIOSH, 1977; Martin, 1972)	Upper 95 % confidence estimate of lifetime cancer risk per one $\mu\text{g}/\text{dm}^3$ (EPA, 1977) ¹⁾	Estimated safe drinking-water concentration $\mu\text{g}/\text{dm}^3$ (Handy & Schindler, 1976)	Proposed EPA standards $\mu\text{g}/\text{dm}^3$ (EPA, 1975; EPA, 1978)
Vinyl chloride	500	5×10^{-7}		
Benzene (suspected carcinogen)	3 400	insufficient data available	1 400	
Dieldrin	46	3×10^{-4}		
Kepone	114	4×10^{-4}		
Heptachlor ²⁾	40	5×10^{-5}	1,3	0,1
Chlordane ²⁾	283	2×10^{-5}	9	3
DDT	113	1×10^{-5}		
γ -BHC (Lindane) ²⁾	76	9×10^{-6}	2,5	4
α -BHC	500	7×10^{-6}		
β -BHC	6 000	4×10^{-6}		
PCB	1 295	3×10^{-6}		
Chloroform	800	4×10^{-7}		100
Carbon tetrachloride	2 800	2×10^{-7}		
Trichlor ethylene	4 920	1×10^{-7}		
Bis(2-chloro ethyl)-ether (suspected carcinogen)	75	1×10^{-4}		

¹⁾As calculated from equation (1)

²⁾Not regarded as carcinogens by Handy and Schindler (1976)

ly Intakes (ADI) from available toxicity data and allowing for uncertainties concerning the relative safety of the chemicals. Suggested no-observed-adverse-effects concentrations in water have consequently been calculated assuming that 20 % of the total intake of a material is from water. Their recommendations, together with available LD₅₀ values, obtained elsewhere (NIOSH, 1977) are incorporated in Table 2.

Stokinger (1977), questioned the validity of using such toxicological data and especially any form of extrapolation to low concentrations. Several instances of threshold values of even potent carcinogens were given (Table 3).

Evidence has been forthcoming on specific body antagonists against potentially carcinogenic molecules, similar to those which are known to exist against toxicants (Stokinger, 1977). Examples of such substances are vitamins A and E, selenium and a non-protein sulfhydryl in the liver, glutathion. The use of the latter to detoxify the potent carcinogen vinylchloride has been demonstrated by the use of ¹⁴C vinylchloride. Glutathion is probably also instrumental in the detoxification of the carcinogen benz(a)pyrene by complexing the epoxide metabolite which is believed to be the true carcinogen (Fig. 1).

The levels at which chloroform was tested and found to cause cancer, were 180 and 477 mg/kg body-weight per day. At a level of 100 $\mu\text{g}/\text{dm}^3$ in water this would represent an intake of 140 000 and 380 000 dm^3 water per day for an 80 kg person. In an independent experiment no malignant tumours were found at a feed rate of 30 and 60 mg/kg body-weight per day. This represents a water consumption of 24 000 and 48 000 dm^3/d (Stokinger, 1977).

Barnes (1975) of the Medical Research Council in Surrey pointed out that the establishment of threshold doses is a problem of biology and not probability or reaction kinetics. The modes of action and of disposal by the whole organism will determine the effect of a toxic substance when ingested at regular low doses. The toxic effects of most of the organo-phosphate inhibitors of cholinesterase are, if not immediately fatal, rapidly and totally reversible. Even tri-o-cresyl phosphate which causes an additional delayed structural damage, involving the central and peripheral nervous systems, produced severe ataxia in hens at 12 x 10 mg/kg and 26 x 5 mg/kg daily doses, whilst 76 x 2,5 and 146 x 1,3 mg/kg doses produced no effect.

According to Barnes (1975) a consistent daily intake of

TABLE 2
ORGANIC PESTICIDES AND CONTAMINANTS IN DRINKING-WATER, REGARDED
AS TOXIC BUT NON-CARCINOGENIC

Compound	LD ₅₀ mg/kg body-weight (NIOSH, 1977)	ADI mg/kg body-weight per day (EPA, 1977)	Suggested no adverse effect level from water (20 % intake from water μg/dm ³ (EPA, 1977)	Estimated safe drinking- water concentra- tion μg/dm ³ (Handy & Schindler, 1976)	Proposed EPA standards μg/dm ³ (EPA, 1975; EPA, 1978)
Acrylonitrile	93	NL	NL	40	
Aniline	440			180	
Carbon disulphide	400			160	
Ethylenediamine	1 160			1,5 x 10 ⁶	
Methanol	420			170	
Pyridine	891			360	
Phenol	414			170	
Toluene	3 000			1 200	
Chlorinated pesticides					
Endrin	3			0,1	0,2
Methoxychlor	5 000			170	0,1
Toxaphene	60	0,001	9	2	5
2,4-D	375	0,013	90	12	100
2,4,5-T	650	0,1	700	(20)* ⁴	
Aldicarb	0,93	0,001	7	(0,3)* ⁵	
Paraquat	150	0,009	60	(50)* ⁵	
Azinphosmethyl	16,4	0,013	90	(5)* ⁵	
Diazinon* ¹	150	0,002	14	(50)* ⁵	
Phorate* ²	3,7	0,0001	0,7	(1)* ⁵	
Carbaryl* ²	850	0,08	600	(30)* ⁵	
Folpet* ³	None available	0,2	1 000		
Hexachlorophene	50	0,001	7	(1,6)* ⁴	
Parathion	13	0,004	30	(4)* ⁴	
Malathion	2 800	0,02	140	(900)* ⁵	
Atrazine	1 750	0,02	150	(600)* ⁵	
Di-n-butyl-phthalate	5 000	0,1	800	(160)* ⁴	
Pentachloro-phenol	210	0,003	20	(7)* ⁴	
Styrene	500	0,13	900	(16)* ⁴	

*¹ = Hydrolyses to a more toxic product (Martin, 1972)

*² = Hydrolyses in contact with moisture or in water (Martin, 1972)

*³ = Fungicide listed as practically non-toxic, hydrolyses in water (Martin, 1972)

*⁴ = Values in brackets calculated from $x_c = 3,3 \times 10^{-5}$ (LD₅₀) (Handy & Schindler, 1976) (assuming these substances to have a biological half life of 365 days)

*⁵ = For these compounds a biological half life of approximately 1/10 year is used, Thus $x_c = 3,3 \times 10^{-4}$ (LD₅₀)

DDT produces a steady state between absorption and storage in body fat, metabolism and excretion. With a change in intake level, the steady state changes in the same direction. DDT and dieldrin which behave in a similar fashion cause disorders in the passage of nerve impulses. This effect depends upon the concentrations in the blood which will likewise change with a change in intake level and is totally reversible with a lowering of the concentrations in the blood. In striking contrast, the chlorinated dibenzodioxins and their toxic effects in liver cell membranes are persistent and cumulative (2, 3, 7, 8-tetrachlorodioxin was found to be lethal at a single dose of 200 μg/kg body-weight).

It is believed that the rate of development of cancer from chemical carcinogens is determined by the number of cells damaged by the chemicals — the fewer the number of damaged cells, the more readily the normal defence mechanisms of the body will be able to control their unlimited multiplication.

Typically, with aflatoxin at 5 mg/kg in the diet of young rats for 6 weeks, all the rats developed cancer within 18 months, but when fed for 3 weeks only, none developed tumours. Evidence indicates that for many carcinogens the latent period before cancer develops, bears some inverse relation to the size of the dose (Barnes, 1975).

If the existence of threshold values and therefore acceptable daily intake levels (ADI) is accepted, experimental evidence on which the ADI's could be based and from them the Maximum Permissible Concentration (MPC) in water, is available for less than 50 % of the compounds already identified in water (WHO, 1975).

In a report to the Environmental Protection Agency (Handy and Schindler, 1976), the estimation of a safe drinking-water concentration for a pollutant (excluding the carcinogens) was based upon the assumption that a maximum body pollutant

TABLE 3
EVIDENCE FOR THRESHOLDS IN CARCINOGENESIS (STOKINGER, 1977)

Test substance	Route	Species	Dose levels eliciting tumours	Dose levels not eliciting tumours	Duration
Bis-chloromethylether	Inhalation	Rat	100 g/l	10 µg/l 1 µg/l	6 months daily
1,4-dioxane	Oral	Rat	1 % in H ₂ O	0,1 % in H ₂ O 0,01 % in H ₂ O	2 years
	Inhalation	Rat	>1000 mg/l	111 mg/l	2 years daily
Coal tar	Topical	Mouse	6400 mg 640 mg 64 mg	>0,64 mg	64 weeks, twice weekly
Beta-naphthylamine	Inhalation, topical	Man	>5 % beta in alpha form	<0,5 % beta in alpha form	22 years
Hexamethyl phosphoramide	Inhalation	Rat	4000 µg/l 400 µg/l	50 µg/l	8 months
Vinyl chloride	Inhalation	Rat	2500 µg/l	<50 mg/l	7 months
			200 mg/l 50 mg/l	>10 mg/l	
Vinylidene chloride	Inhalation	Man	>200 mg/l	1950-1959 160 mg/l average: 30-170 mg/l 1960, <50 mg/l decreasing to 10 mg/l	25 years

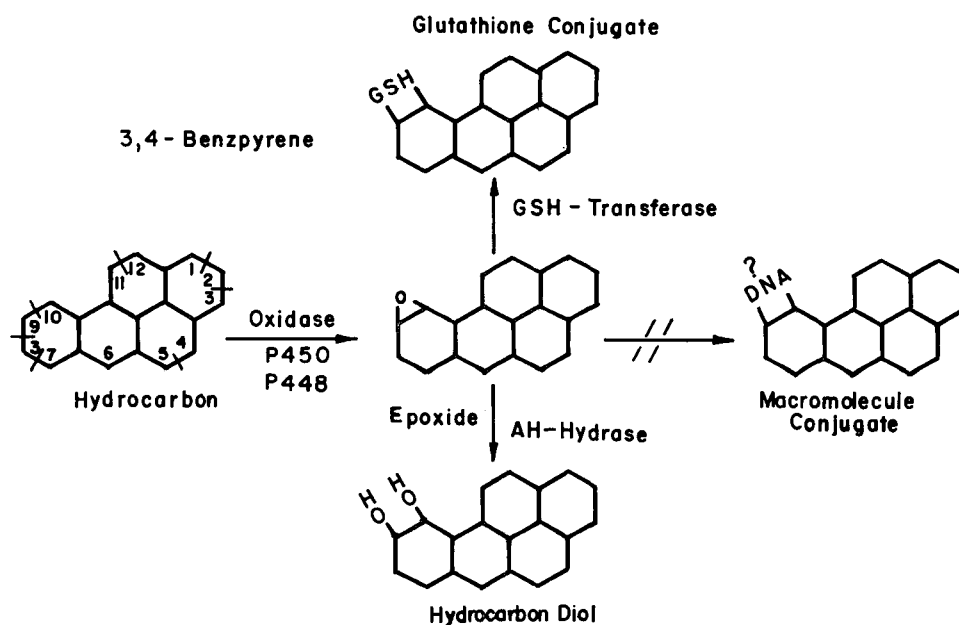


Figure 1
Mechanism of 3,4 Benzpyrene metabolism showing non-carcinogenic glutathione complex (Stokinger, 1977).

concentration of 0,05 % of its LD₅₀, can be considered safe. A thirty-day half-life in the body is assumed for all compounds excepting those known to be retained in the body for prolonged periods of time, and a one-year half-life for the exceptions. Typical results are shown in Tables 1 and 2. Comparison of the combined results (EPA, 1977; Handy and Schindler, 1976) indicates several large discrepancies in the results obtained (Table 2). Phorate and carbaryl hydrolyze fairly rapidly (Martin, 1972) and, together with the relatively harmless fungicide Folpet, must constitute possible health hazards in drinking-water of very low probability. The carcinogenicity of heptachlor, chlordane and lindane (as well as the other BHC's at the $\mu\text{g}/\text{dm}^3$ level in water is also doubtful (Barnes, 1975; Stokinger, 1977).

The information in the preceding paragraphs forces one into the unenviable situation of having to set water quality standards by applying questionable methods on incomplete (and sometimes non-existent) data.

Existing and Proposed Standards

The proposed USA water quality standards are listed in Tables 1 and 2. Apart from these, the Environmental Protection Agency also published a list of chemical indicators of industrial contamination (EPA, 1978), containing a large variety of halogenated compounds, benzenes, polynuclear aromatic hydrocarbons and a few other aromatic hydrocarbons. The so-called "Consent Decree" chemicals (Keith, 1979) were listed as

toxic pollutants for which technology-based effluent limitations would be required. No detection limits have been specified in both cases and the lists are obviously intended for the eventual control of effluent discharges. However, $10 \mu\text{g}/\text{dm}^3$ was suggested as a reasonable level to analyse for industrial effluents (Keith, 1979).

In western Europe, the International Standards (WHO, 1971) specify limits of $1 \mu\text{g}/\text{dm}^3$ for phenolic compounds and $0,2 \mu\text{g}/\text{dm}^3$ for polynuclear aromatic hydrocarbons. These standards are presently being revised.

In the USSR the maximum permissible concentrations (MPC) for more than 400 chemicals are specified in surface waters used as sources of drinking-water. MPC's vary from about $1 \mu\text{g}/\text{dm}^3$ to a few mg/dm^3 (Central Water Planning Unit, 1978).

South Africa

Phenols (at $1 \mu\text{g}/\text{dm}^3$) are the only organic chemicals incorporated in existing potable water criteria (SABS, 1971).

According to the accepted practice elsewhere a preliminary screening programme was introduced by the National Institute for Water Research in 1974 so that the extent of organic micro-pollution and its potential health hazards could be assessed. As discussed in previous papers (Van Rensburg and Hassett, 1980; Van Rensburg, Van Rossum and Hattingh, 1978) the choice of compounds to be determined, lower limits of

TABLE 4
THE ORGANIC MICROPOLLUTANTS SELECTED FOR ANALYSIS

Organic compounds	Lower hazard limit ($\mu\text{g}/\text{dm}^3$)
Volatile halogenated hydrocarbons (VHH) Trihalomethanes (chloroform, bromoform, bromodichloromethane, dibromochloromethane), tetrachloromethane	1 per compound
Chlorinated hydrocarbons (CH) Lindane, chlordane, dieldrin, endrin, (bis)chloroisopropylether, hexachlorobutadiene, hexachlorobenzene, PCB's, DDT-complex, endosulfan Dichlorobenzene, other chloroethers	0,1 per compound 1
Chlorophenols (CPHEN) Di-, tri-, tetra- and pentachlorophenols	1 per compound
Polynuclear aromatic hydrocarbons (PAH) Benz(a)anthracene, benzo(b)- and (k)fluoranthene, benzo(a)pyrene, dibenz(a,h)-anthracene, indeno(1,2,3,-cd)-pyrene Anthracene, phenanthrene, fluoranthene, naphthalene, acenaphthene, fluorene, chrysene	0,1 per compound 1 per compound
Phenolic compounds (PHEN) Phenol, cresols, xlenols, β -naphthol etc	1 per compound
Other compounds (DIV) Dibutylphthalate, diphenylether, nitrotoluene Unidentified compounds to be identified by GC-MS	1 per compound If more than 1 (0,1) per compound

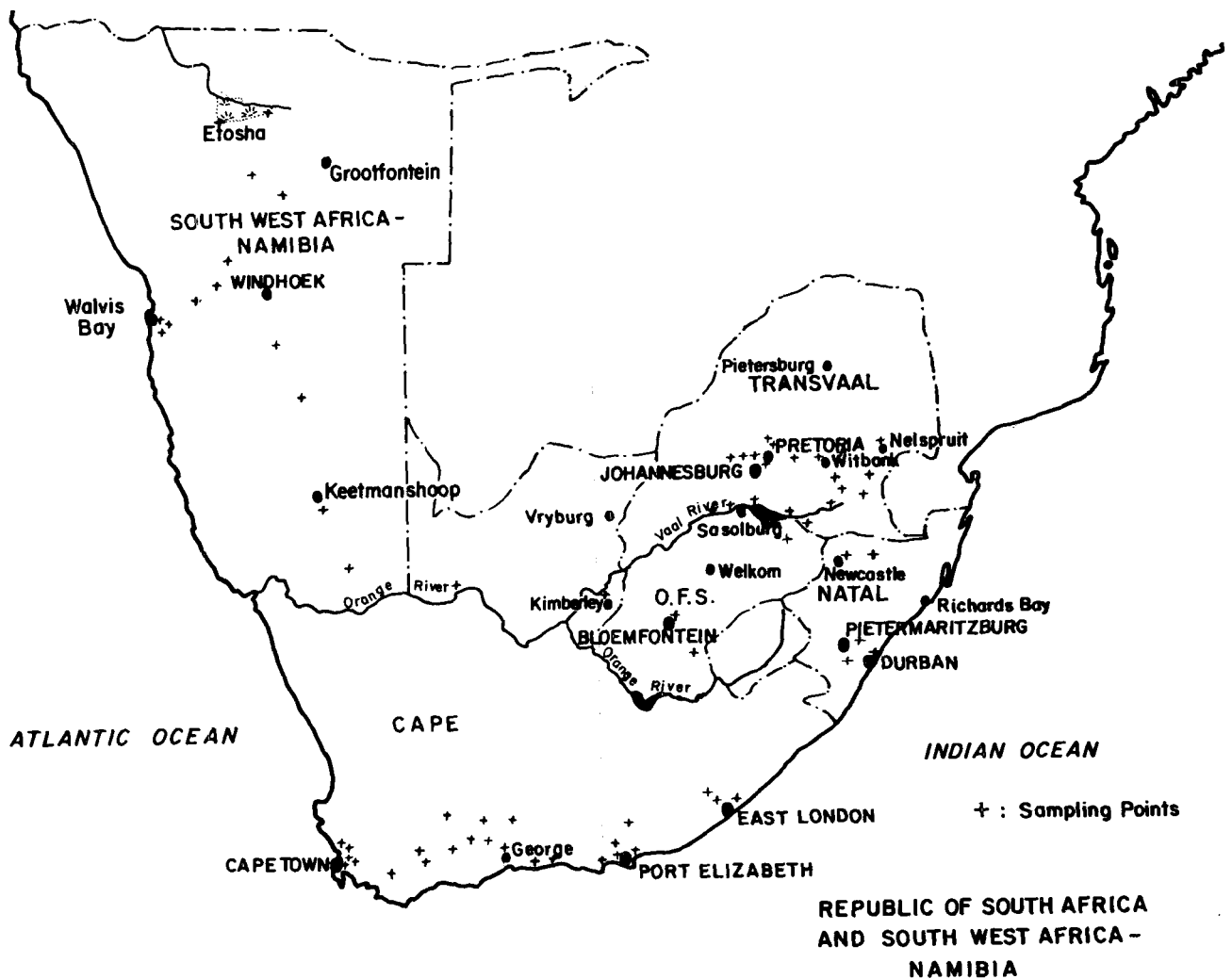


Figure 2
Distribution of sampling points.

detection and analytical methods employed, had to be adapted to South African conditions. Table 4 summarizes the organic compounds to be determined.

Routine Screening

A series of chromatographic analytical techniques for the determination of the compounds in Table 4 was developed and used to screen South African potable water supplies. For the sake of economy, limits of detection and accuracy fulfilled only the needs for the specific task on hand (Van Rensburg, 1977; Van Rensburg, Theron and Kühn, 1981; Van Rensburg, Van Huyssteen and Hassett, 1978).

Results of Screening Programme

Raw and finished water samples from 124 different sampling points (Figure 2) have been analysed so far. Some of the data ob-

tained are summarized in Tables 5 and 6. A few typical gas chromatograms are illustrated in Figure 3.

Organic Pollution Indices (OPI)

The selection of compounds (Table 1) covers a wide range, and the analytical procedures developed for the determination of these compounds provide a wealth of analytical data for assessing the health implications of a water supply. Apart from the quantitative determination of these compounds, the presence of a large number of unknown, analytically related compounds is indicated (Fig. 3). To present these data in a useful form, an organic pollution index (OPI) can be used. As shown in Tables 5 and 6, these are numbers indicating, from left to right, the total recovery of compounds by the particular chromatographic analytical technique (in $\mu\text{g}/\text{dm}^3$), followed by the number of peaks (compounds) in the concentration ranges $>10 \mu\text{g}/\text{dm}^3$, 1 to $10 \mu\text{g}/\text{dm}^3$, 0,1 to $1 \mu\text{g}/\text{dm}^3$ and 0,01 to $0,1 \mu\text{g}/\text{dm}^3$. The use of this indexing method is illustrated by comparison of the

TABLE 5
ORGANIC POLLUTION INDICES (OPI) OF WATER SAMPLES BY CAPILLARY COLUMN GAS CHROMATOGRAPHY

Sample	OPI - GEN				OPI - CH				OPI - Phenols						
	Total conc. ($\mu\text{g}/\text{dm}^3$)	Peak distribution ¹				Total conc. ($\mu\text{g}/\text{dm}^3$)	Peak distribution ¹				Total conc. ($\mu\text{g}/\text{dm}^3$)	Peak distribution ¹			
		A	B	C	D		A	B	C	D		A	B	C	D
Barrage - raw	19,0	—	3	41	77	0,7	—	—	4	9	39,0	—	10	66	24
Parys - raw	8,8	—	1	20	58	0,2	—	—	1	3	35,0	1	4	6	1
Parys - final	5,3	—	1	10	43	0,3	—	—	1	4	20,0	—	4	42	5
Brits - final	6,6	—	—	9	4	0,3	—	—	1	4	3,5	—	—	11	15
Upington - final	1,7	—	—	4	27	0,1	—	—	—	4	3,0	—	—	10	15
Port Elizabeth - final	3,6	—	—	7	36	1,1	—	—	2	8	4,6	—	1	9	12
East London - final	3,6	—	1	9	31	0,1	—	—	—	2	not determined				
Cape Town - final	4,1	—	—	8	41	0,3	—	—	2	24	not determined				
Durban - final	8,0	—	2	18	64	1,3	—	—	2	24	not determined				
Bloemfontein - final (2)	4,1	—	—	13	62	0,4	—	—	1	6	0,4	—	—	2	0
Rand Water Board - final	5,3	—	—	10	50	0,7	—	—	1	12	not determined				
Newcastle - final	12,0	—	4	9	24	0,1	—	—	1	14	0,06	—	—	—	1
Suggested limits (3)	<u>10</u>	0	<u>0</u>			<u>1</u>	0	0	<u>0</u>		<u>10</u>	0	<u>0</u>		

- (1) Peak distribution; number of peaks found in the various concentration ranges:
 A: $>10 \mu\text{g}/\text{dm}^3$; B: $1-10 \mu\text{g}/\text{dm}^3$; C: $0,1 - 1 \mu\text{g}/\text{dm}^3$; D: $0,01 - 0,1 \mu\text{g}/\text{dm}^3$.
 (2) Representing one of the city's supplies.
 (3) Underlined values are not to be exceeded.

TABLE 6
VOLATILE HALOGENATED HYDROCARBONS AND CHLOROPHENOLS FOUND IN WATER SAMPLES

	VOLATILE HALOGENATED HYDROCARBONS								CHLOROPHENOLS											
	COMPOUNDS FOUND ($\mu\text{g}/\text{dm}^3$)							OPI	VIII	COMPOUNDS FOUND ⁽²⁾ ($\mu\text{g}/\text{dm}^3$)					OPI	CP ⁽¹⁾				
	CCl ₄	CHCl ₃	C ₂ Cl ₄	CHBrCl ₂	CHBrCl	CHBr ₂	Total ($\mu\text{g}/\text{dm}^3$)			Peak distr. ⁽¹⁾	Cl ₂	Cl ₃	Cl ₄	Cl ₅			Total ($\mu\text{g}/\text{dm}^3$)	Peak distribution ⁽¹⁾		
Barrage raw	0.04	1.2	0.04	0.01	ND	0.03	2.5	0	1	3	3	0.11	0.57	0.07	0.46	1.4	0	0	1	3
Parys raw	0.04	0.4	ND	0.1	0.05	0.2	1.6	0	0	3	1	ND	ND	ND	ND	0.05	0	0	0	2
Parys final	0.13	1.9	0.09	10.3	11.5	2.5	26.8	1	3	4	1	ND	ND	ND	ND	0.03	0	0	0	1
Brits final	0.4	18.3	0.11	22.9	13.7	3.5	67.0	3	4	2	0	0.06	0.32	0.12	0.46	1.6	0	0	4	5
Upington final	0.02	0.43	ND	ND	ND	ND	5.0	0	1	2	1									
Port Elizabeth final (3)	0.12	9.8	0.25	13.1	12.5	3.4	40.0	2	2	4	1	0.17	0.42	0.09	0.27	1.4	0	0	3	4
East London final	0.03	2.0	0.07	1.0	0.55	0.06	3.9	0	2	2	3	0.21	0.8	0.11	0.43	2.1	0	0	4	7
Cape Town final (3)	0.03	7.6	0.03	2.2	1.08	0.11	12.5	1	2	3	2	0.25	0.88	0.27	0.85	2.9	0	9	7	5
Durban final (3)	0.19	12.8	0.32	12.2	7.26	0.9	35.5	2	2	6	2	0.17	0.65	0.14	0.75	2.4	0	0	4	6
Bloemfontein final	0.09	2.7	0.11	1.1	0.66	0.03	5.8	0	2	4	2	0.14	0.65	0.07	0.31	1.6	0	0	2	7
Rand Water Board final	0.35	5.7	0.28	4.9	3.3	0.29	15.6	0	3	5	1	0.16	0.51	0.04	0.29	1.2	0	0	3	9
Newcastle final	0.09	7.7	ND	17.0	3.02	0.6	29.0	1	2	2	1									
Suggested limits (4)						<u>50</u>	<u>0</u>								<u>10</u>	0	<u>0</u>			

- (1) Number of peaks in concentration ranges A: $>10 \mu\text{g}/\text{dm}^3$; B: $1 - 10 \mu\text{g}/\text{dm}^3$; C: $0,1 - 1 \mu\text{g}/\text{dm}^3$; D: $<0,1 \mu\text{g}/\text{dm}^3$.
 (2) Cl₂-Total dichlorophenols; Cl₃-Total trichlorophenols; Cl₄-Total tetrachlorophenols; Cl₅-Pentachlorophenol.
 (3) Representing one of the city's supplies.
 (4) Underlined values are not to be exceeded.

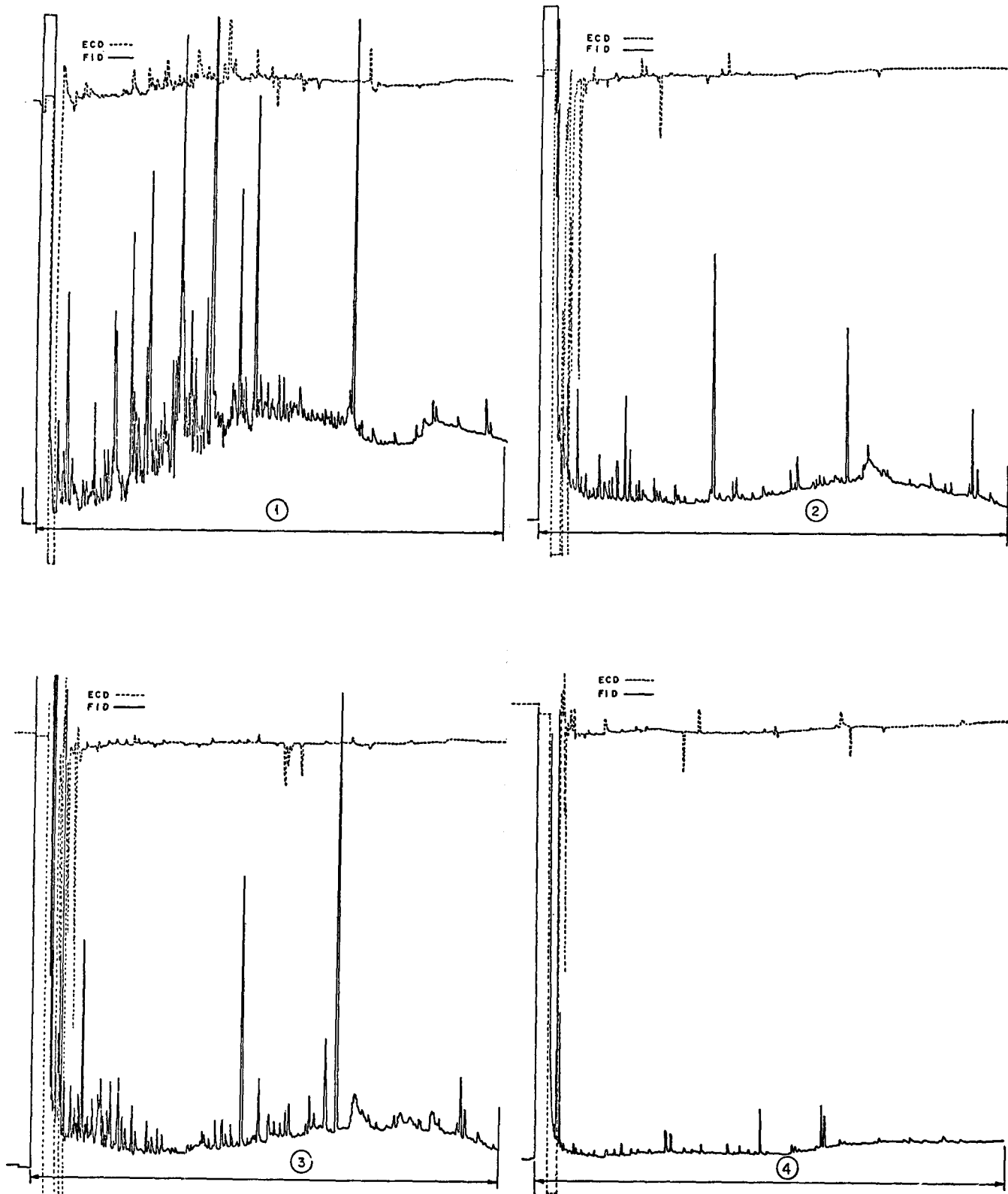


Figure 3
 Open tabular gas chromatograms of extracts from water samples (---: by electron capture detection, the chromatogram being upside down; — — —: by flame ionisation detection). (1) Vaal River 5 km below Barrage; (2) Parys — final water; (3) Brits — final water; (4) Uppington — final water.

TABLE 7
SAMPLING POINTS REQUIRING FURTHER INVESTIGATION (40 OUT OF 124 SAMPLES)

	OPI-GEN	OPI-CH	OPI-FEN	OPI-VHH	Signs of PAH's
<i>PRETORIA</i>					
Rietvlei Dam — raw	x				
Rietvlei Dam — final		x	x		
Pretoria — tap				x	
Klapperkop — final				x	
<i>TRANSVAAL</i>					
Brit — raw		x	x		
Brits — final		x		x	
Schoemansville — raw		x			x
Schoemansville — final		x		x	x
Apies River	x	x	x		
Temba — final		x		x	
Roodeplaat channel	x		x		
Bronkhorstspruit — final			x		
Witbank — final	x	x	x		
Bethal — final	x				
Volksrust — final	x				
Merensky Dam — raw		x	x		
Loskop Dam — raw		x			x
<i>VAAL RIVER</i>					
Rand Water Board —					
Vereeniging — raw	x				
Barrage 5km — final	x	x	x		x
Barrage — Sasol effl.	x	x	x		x
Parys — raw	x	x	x		
Parys — final	x	x	x	x	
Barrage — sluice	x		x		
Barrage — Vanderbijlpark	x		x		x
<i>CAPE</i>					
Steenbras Dam — final				x	
Kloofnek Dam — final				x	
Bonnievale — raw	x		x		x
Bonnievale — final	x	x			x
Humansdorp — final	x				
Oudtshoorn — final	x				
Knysna — final	x				
Montagu — final	x				
Calitzdorp — final			x		
Plettenberg — final	x				
George — final	x				
Ladismith — final	x		x		
Laingsburg — final	x	x			x
Bredasdorp — final		x			x
Kirkwood — final	x	x	x	x	x
Caledon — final	x	x			x
Ashton — final	x	x			x
Touws River — final	x	x	x		x
<i>Settlers Dam</i>					
Grahamstown — raw	x				
<i>Groendal Dam</i>					
Uitenhage — raw					x
<i>Port Elizabeth</i>					
Loerie — raw		x			x
Loerie — final			x	x	
Churchill — raw			x		x
Churchill — final			x	x	
<i>SOUTH WEST AFRICA/NAMIBIA</i>					
Goreangab Dam — final				x	
Rheoboth — raw					x
Rheoboth — final	x				
Rooibank pump P2					x
Otjiwarongo — borehole 9422	x				
borehole 2446			x		
Otjiwarongo — final	x	x	x		
Swakopmund — final	x	x			
<i>BLOEMFONTEIN</i>					
Maselspoort Dam — raw	x				
Maselspoort Dam — final	x	x			
Welbedacht — raw		x			x
<i>NATAL</i>					
Durban — final				x	
Newcastle — final	x				
Newcastle — raw	x	x	x		
Vryheid — final	x				

organic pollution index-general OPI-GEN of Table 5 with the chromatograms in Fig. 3. The improvement in quality can be indicated more clearly by a change from 19-0-3-41-17 (for Barrage) to 5-0-1-10-43 (for Parys — final) than by the cumbersome chromatograms of Fig. 3.

While the total concentration will indicate the gross pollution, the grouping of the individual peaks (compounds) into concentration range groups indicates the nature of the pollution in terms of number and concentration of individual polluting substances. When the various limits in Tables 1–4 are taken into account, the probability of an unknown substance presenting a health risk, must increase with its concentration in water. Consequently a water sample with an OPI-GEN of 15-0-2-13-45 (two substances $>1 \mu\text{g}/\ell$) could involve a greater health risk than another sample with OPI-GEN of 20-0-0-42-158 (all substances $<1 \mu\text{g}/\ell$), even if the total concentrations is higher in the latter case. Since a particular OPI will depend upon the complete analytical technique employed, the universal use of OPI's as indicators of pollution will demand the use of corresponding standard analytical procedures.

Five OPI's are used: OPI-GEN(eral), covering the groups (CH), (PAH), (DIV) in Table 4 and related compounds (the solid line chromatograms in Fig. 3), OPI-CH, covering the (CH)-group and related compounds on a highly selective basis; OPI-PHEN for phenolic compounds; OPI-CPHEN, for chlorophenols and OPI-VHH for the volatile halogenated hydrocarbon group.

Lower Hazard and/or Detection Limits

If the estimated safe concentrations in drinking-water and suggested no-adverse-effect-level-from-water, from Tables 2 and 3, as well as the proposed and existing standards and maximum permissible concentrations (MPC's) of the USSR, are studied, it is obvious that MPC's for highly toxic (non-carcinogenic) compounds range from $1 \mu\text{g}/\text{dm}^3$ upwards. Using the proposed standard for chloroform and the risk factors in Table 1, MPC's for the carcinogens would range from $0,1 \mu\text{g}/\text{dm}^3$ (for dieldrin and kepone) upwards. A series of hazard (and detection) limits, as indicated in Table 4 were consequently set to facilitate the development of suitable and economical analytical techniques. These limits must not be regarded as MPC's but merely as a level below which the corresponding chemicals could not possibly present a hazard and need not be detected.

If these limits are combined with the OPI's, a series of OPI hazard limits, as indicated in Tables 5 and 6, are obtained, the underlined numbers constituting the limiting values. When results at sampling points exceed these limits, the sampling points have to be reinvestigated to assess their true health hazard potential.

Of the 124 points sampled those shown in Table 7 exceeded these limits in some way or other. After a closer study of available results, $\pm 30\%$ warranted further investigation.

In addition to covering the rest of South Africa with the present screening programme the sampling points in Table 7 will be reinvestigated, if necessary with more sophisticated equipment, such as computerized gas chromatography-mass spectrometry to identify and quantify the organic chemicals involved.

Conclusions and Planned Future Work

1. The use of OPI's with their corresponding analytical me-

thods, presents a relatively inexpensive and simple way of expressing and evaluating the possible health hazard of organic pollution and should be seriously considered as part of future water quality criteria. By setting realistic levels to these OPI's, relatively inexpensive analytical techniques for their determination could be used. Water supplies exceeding these limits could then be referred to more sophisticated laboratories for detailed investigation and recommendations on the health risk involved.

2. Further studies are in progress to simplify the use of OPI's.
3. With a few exceptions, such as the Vaal River below the Barrage, the water supplies investigated so far constitute no measurable health hazard from volatile organic micro-pollutants.
4. An obvious gap exists at present in our knowledge of non-volatile organic matter present in water. This gap should be closed by the development and application of suitable analytical techniques such as the various forms of liquid chromatography.
5. Whenever biological screening methods for mutagens, such as Ames and tissue culture tests, indicate the presence of mutagens in potable water supplies (Denkhaus *et al.*, 1979), these supplies should be closely investigated with more sophisticated chemical techniques available to identify and quantify the particular mutagen(s), so as to evaluate the health risk involved.

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