AGRICULTURAL SALINIZATION IN THE OLIFANTS RIVER AT LOSKOP VALLEY, MPUMALANGA

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Salinization of South African rivers is serious and has rendered some dams and reservoirs unsuitable for irrigation. The contribution of agriculture to the environmental problem of salinization was empirically analysed in this study. Linear regression models demonstrated that increases in the Total Dissolved Salts (TDS) and chlorine of the Olifants River in the Loskop Valley are at least partially the result of variations in irrigation farming parameters such as fertilizer usage, rainfall and area cultivated to crops such as tobacco, cotton and wheat. The marginal rates of substitution among the independent variables can be employed in the formulation of the economically most efficient local salinization control policy. Other approaches are possible, but should be adopted only after thorough investigation.

LANDBOU-GEÏNDUSEERDE VERSOUTING IN DIE OLIFANTSRIVIER BY DIE LOSKOPVALLEI, MPUMALANGA

Versouting is ernstig in Suid-Afrikaanse riviere en het sommige damme en wateropgaringswerke ongeskik vir besproeiing gemaak. Die bydrae van die landbou tot die omgewingsprobleem van versouting is in hierdie studie empiries ontleed. Reglynige regressiemodelle het getoon dat toenames in die Totale Opgelosse Soute (TOS) en Chloor in die Olifantsrivier by die Loskopvallei minstens gedeeltelik die resultaat is van variasies in besproeiingsboerderyparameters, byvoorbeeld kunsmisgebruik, reënval en die oppervlakte onder gewasse soos tabak, katoen en koring. Die marginale substitusiekoerse tussen die onafhanklike veranderlikes kan benut word in die formulering van die ekonomies mees doeltreffende plaaslike versoutingsbeheerbeleid. Ander benaderings is ook moontlik maar behoort slegs na behoorlike ondersoek ingestel te word.

1. INTRODUCTION

According to the Department of Water Affairs (DWA) (1986), the quality of some South African water sources is declining rapidly. Salinization, and to a lesser extent, eutrophication and pollution by trace metals and micro-pollutants, are important contributing factors. Some reservoirs are not any longer suitable for irrigation for much of the time (DWA, 1986). Salinization is a particularly intractable problem; the only known remedies are dilution with less saline water

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or reverse osmosis to remove dissolved salts, which is a very expensive process (O'Keeffe *et al*, 1992).

Irrigation farming is known, together with urban, industrial and mining effluents, to be a major contributor to salinization of South African rivers. The DWA has had some success in tracing industrial, urban and mining effluents entering water bodies to their sources, but not so for agricultural effluents. While pollution from other sources are addressed with pragmatism and some success, agricultural pollution generally remains undealt with; while the DWA pursues the 'polluter pays' principle with other polluters, it has not been possible to do so with agricultural polluters. The main reasons are:

- agricultural pollution is non-point in source, rendering liability allocation difficult;

- the quantification of pollution and the assessment of the cost of pollution damage is time consuming and expensive;

- agricultural pollution involves large numbers of producers that are geographically dispersed; and

- the political influence of South African commercial farmers has made past governments reluctant to initiate policies that affect their incomes negatively.

This article attempts to determine and quantify the contributions of agricultural practices in the Loskop Valley in Mpumalanga Province to salinization of the Olifants River. It also seeks to draw inferences that may assist in the formulation of salinization control policy.

2. THE STUDY AREA

The Loskop Valley has long history of intensive irrigation farming and an equally serious salinization problem (DWA, 1991). DWA water quality sampling sites are located at downstream and upstream points from the valley on the Olifants River. This allows an assessment of the difference in water quality resulting from irrigation farming practices in the Loskop Valley. The upstream sampling site allows water quality in the Olifants River to be measured before it enters the irrigation region, and the downstream sampling point allows water quality to be measured after the river has received the irrigation return flow and the natural drainage effluent from the entire irrigation region. This portion of the river is not materially influenced by mining and industry. Sewage pollution is very limited; no large towns or cities are situated in the valley. Groblersdal, the major town in the valley, is rather limited in size and population.

The Olifants River Basin study conducted by the Department of Water Affairs (DWA, 1991) identified salinization (i.e. mineralization) as the main agricultural pollution problem in the Loskop Valley. Salts accumulate in surface soils of arid and semi-arid regions because of insufficient rainfall to flush them from the upper soil layers. The accumulated salts are primarily chlorides and sulphates of calcium, magnesium, sodium and potassium. The sources of these salts are the weathering of rocks and minerals (usually, of sedimentary and metamorphic rocks of marine origin), rainfall (in regions that lie close to the sea), groundwater and irrigation (Brady, 1990; DWAF, 1993:45).

Recent measurements have shown TDS values in the water to be high, but not yet serious. Chloride concentrations have increased to levels high enough to affect the leaf quality of tobacco. On the other hand, the catchment has neither pesticide nor heavy metal problems at levels that merit concern. (Grobler, 1994 and Grobler *et al.*, 1994).

3. DATA COLLECTION AND MANIPULATION

The dependent variables studied were emission into the Olifants River of:

(1) Annual masses of total dissolved salts (or solids) - TDS (in tons),

(2) annual masses of chlorides (in tons).

The masses of pollutants were calculated by determining the differences in mean concentrations between the upstream and the downstream sampling points in TDS and chlorides and multiplying these differences with the volume of water flowing through the region. Chemical analysis data and flow data were obtained from the data centre of the DWA.

The independent variables were:

(1) total annual rainfall (mm) - (obtained from the Weather Bureau);

(2) total fertilizer used (kg) in the irrigation area (obtained from OTK Co-operative);

(3) fertilizer used per hectare (kg) on tobacco, cotton, wheat and peas - (obtained from OTK Co-operative); and

(4) total land area cultivated (ha) to crops like tobacco, cotton, wheat and peas - (obtained from OTK Co-operative).

Data for both dependent and independent variables were available for only 1980 to 1992, thereby limiting the number of degrees of freedom for statistical analyses.

4. METHODOLOGY

Not much work of this nature has been reported in literature, probably because of the obvious practical impediments involved in this type of work. Pollution seldom comes from agricultural sources only. Pollution of surface and underground water bodies usually stem from multiple sources, namely industry, mining, sewage and agriculture. In addition, the diffuse and non-point source nature of agricultural pollution makes it difficult to trace pollutants to agriculture.

Studies somewhat similar to the present one involved computer simulation models trying to mimic real-life agricultural pollution, eg. the metamodels of Bouzaher (1993). Metamodels are regression models that explain the input-output relationship of complex simulation models that try to mimic the underlying real-life process of pesticide movements in the soil. Bouzaher (1993), Jury *et al.* (1987) and Khan & Liang (1989) used exponential mathematical models to simulate pesticide pollution. Rinaldo & Marani (1984) used mathematical models to simulate the non-point source pollution of the Venice Lagoon (Italy), caused by nitrogen and phosphorus of agricultural origin. They employed gamma functions.

Multiple stepwise regression analysis was used in this study to determine functional relationships between the dependent and independent variables and to assess the importance of each.

Although Bouzaher (1993) reports the use of simple linear regression models involving ordinary least squares (OLS) procedures by other workers, the choice of this functional form was for practical reasons. Unlike the studies cited above which try to simulate all the natural chemical and physical reactions involved in the emission of agricultural pollutants, this is a field study of the real-life situation, involving a limited number of variables, which aims at unravelling a relationship for economic application.

Linear and non-linear models were fitted to the data. The linear models yielded the best fits, and results of only the linear models will be presented.

5. RESULTS

The results include estimates of physical quantities of pollutant emissions from the Loskop Valley irrigation area, and the functional relationships between Total Dissolved Salts (TDS) (in tons) and dissolved chlorides (in tons) as dependent variables and the respective independent variables of farming parameters. Interpretation of the regression coefficients shall be based on the TDS and chloride emission models that best relate agricultural practices to these emissions.

5.1 Quantities of pollutants emitted into the Olifants River

Table 1 shows emissions of Total Dissolved Salts and chlorides for the Loskop Valley.

Table 1: Annual non-point source emission of salts (TDS in tons) and chloride (in tons) from the Loskop Valley into the Olifants River

Year	Total Dissolved Salts (tons)	Chlorides (tons)
1980	6 647,992	2 234,628
1981	797,920	398,950
1982	6 990,570	1 244,595
1983	10 516,275	2 537,260
1984	9 401,940	1 771,380
1985	5 324,000	1 575,904
1986	840,840	73,788
1987	17 876,205	3 197,370
1988	11 839,696	2 959,924
1989	6 240,284	645,609
1990	32 686,895	1 984,873
1991	49 887,637	335,775
1992	2 338,627	83,105

TDS values in the Olifants fluctuate widely, (cf. DWA, 1990), often reaching upper limits of 1,050 mg/l. These upper limits and the fluctuations in TDS concentrations influence the survival of aquatic and terrestrial fauna and flora along the river, which later flows through the Kruger National Park (Olifants River Basin Report, DWA, 1992 : 13-15, 98-104). Other water users, eg. rural domestic consumers of river water without purification facilities are at the loosing end, since the dissolved salts affect the taste of drinking water, and washing takes higher quantities of detergent or soap. The increasing TDS levels and specifically the chloride levels affect agriculture itself, especially tobacco production. Some other cumulative effects include reduction in the lifespan of irrigation equipment, costs to industrial and other water users downstream, etc. Future socio-economic costs may include unemployment and urbanization of unemployed people that may arise when TDS and Chloride concentrations reach levels at which the production of tobacco and other crops becomes impossible in the Loskop Valley (as have happened in some other irrigation schemes around South Africa).

5.2 Emission models

Data limitations allowed the mineralization function to be determined for only three of the major enterprises in the Loskop Valley, i.e. tobacco, cotton and wheat (see Tables 2 & 3). Different combinations of variables, as included in the following to functional specifications, were fitted:

$$TDS = f(TRain, TFTob, TFCot, TFWhe, TCLTob, TCLCot, TFUsed) \quad (1)$$

$$CL = g(TFCot, TCLCot, TFUsed) \quad (2)$$

where:

TDS = total quantity of dissolved salts (tons) emitted into the Olifants River;
CL = quantity of dissolved chlorides emitted into the Olifants River;
TRain = total annual rainfall (mm) in the region;
TFTob = total quantity of fertilizer (tons) applied to tobacco in the Valley;
TCLCot = total land area (ha) cultivated to cotton;
TCLTob = total land area (ha) cultivated to tobacco;
TFWhe = total quantity of fertilizer (tons) applied to wheat;
TFCot = total quantity of fertilizer (tons) applied to cotton; and
TFUsed = total quantity of fertilizer (tons) applied to all crops in the valley.

The coefficients were converted to elasticities by finding the product of the coefficient (C_x) and the ratio of the sample means of the independent variable (X) and the dependent variable (Y), i.e. the elasticity (E_x) of an independent variable (X) with respect to the dependent variable (Y) is

$$E_x = C_x X \frac{\bar{X}}{\bar{Y}} \qquad (3)$$

Table 2: Regression statistics for the TDS models

	Model 1	Model 2	Model 3	Model 4
Constant				
Coefficient	-45285262	31138127	-31029571	33048522
Prob. > F	0,0034	0,02	0,0049	0,3996
T Rain				
Coefficient	64611	55940	50440	61729
Prob. > F	0,0018	0,0009	0,0067	0,0006
Av. Elasticity	2,649	2,293	2,068	2,56
TF Used				
Coefficient				1,12
Prob. > F				0,0337
Av. Elasticity				2,93
TFTob				
Coefficient	2,26			
Prob. > F	0,01			
Av. Elasticity	0,0188			
TFCot				
Coefficient		1,90		
Prob. > F		0,058		
Av. Elasticity		1,1615		
TF Whe				
Coefficient			2,13	
Prob. > F			0,0065	
Av. Elasticity			1,3018	
TCLCot				
Coefficient		-8009		-7555
Prob. > F		0,0008		0,0234
Av. Elasticity		-5,077		-4,79
TCLTob				
Coefficient				-6573
Prob. > F				0,01474
Av. Elasticity				-2,57
Model				

R^2	0,7158	0,8632	0,7407	0,8847
F	8,53	18,94	14,29	15,350
Prob. > F	0,0139	0,0003	0,0012	0,0008
DW	1,28	2,135	1,352	1,967

Table 3: Regression statistics for the Chloride models

	Model 5	Model 6
Constant		
Coefficient	-418777	-11644134
Prob. > F	0,6464	0,0017
TFCot		
Coefficient	0,2643	
Prob. > F	0,0261	
Av. Elasticity	0,1615	
TFUsed		
Coefficient		0,1996
Prob. > F		0,0022
Av. Elasticity		0,5215
TCLCot		
Coefficient		814,0
Prob. > F		0,0008
Av. Elasticity		0,5160
Model		
R^2	0,3749	0,712
F	6,60	12,36
Prob. > F	0,0261	0,0020
DW	3,165	3,397

The elasticities provide the percentage relationship between a variation in the dependent variable due to a corresponding unit variation in the independent variable at the mean value.

Results of the regression analyses appear in Tables 2 and 3.

Two other models fitted for chlorine emission did not yield any significant coefficients and were deleted. Model 5, although having an F value significant at p = 0,026, has a low R^2 of only 0,3749. The significance value (p) and R^2 of model

6 are 0,002 and 0,712 respectively. In Model 6, the regression coefficients for the two variables included are highly significant at p = 0,0022 and p = 0,0008.

5.3 Discussion of TDS results

Model 4 yielded significant results in more variables than the other three models, and also plays a larger role in the interpretations, which are as follows:

(1) Rainfall is positively associated with the total dissolved salts (Tons of TDS); a one percent change in rainfall induces a change in the same direction of between 2,07% and 2,65% in emission into the river.

(2) A one percent increase (decrease) in the annual total quantity of fertilizer (in tons) applied to crops leads to an increase (decrease) of 2,93 percent in the quantity of total dissolved salts (TDS measured in tons) emitted into the river. Among the crops included in the model, fertilizer applied to wheat appears to have the largest effect on emissions with an average elasticity of 1,3 percent (Model 3), while fertilizer to tobacco, with an average elasticity of 0,02 percent (Model 1) appears to have a smaller effect than that of fertilizer both to cotton and wheat.

(3) A one percent increase (decrease) in the total land area cultivated to tobacco leads to a decrease (increase) of 2,57 percent in the emission of total dissolved salts.

(4) Similarly, a one percentage increase (decrease) in the total land area cultivated to cotton leads to a decrease (increase) of between 4,79 percent and 5,08 percent in the total dissolved salts emitted into the Olifants River. The inverse relationship between the emission of total dissolved salts and the total land area cultivated to some crops agrees with theory; one environmental benefit derived from use of land is its "sink value" (Goodland, 1993; Samiullah, 1990 : 72; Klopffer *et al.*, 1982), i.e. its ability to accumulate and neutralise the hazardous effects of pollutants deposited on it from natural and anthropogenic (i.e. stemming from human production and consumption activities) sources. The sink value of land results from microbial activities and natural reactions that detoxify hazardous substances. Intensification of farming, especially by applying more fertilizer, manure or pesticides per unit of land, increases the level of pollution. Conversely, if land area is increased for production while all other farming inputs, such as the quantities of fertilizers applied, are held constant, the level of pollution should decrease. The quantities of pollutants emitted from this land into surface water bodies should decrease accordingly.

Unfortunately, sink value does not apply to all pollution situations involving land. Where natural soil reactions cause land itself to be a source of a pollutant, say soils high in acidity, nitrates (eg. Heaton, 1985) or chlorides, the land has no such sink value for the pollutant in question. The functional relationship between land area and pollution is then positive. An increase in area cultivated leads to an increase in the level of pollutants emitted. This is illustrated by the positive coefficient of the variable TCLCot on chlorine emissions.

(5) The difference in the elasticities for TCLTob and TCLCot warrants some discussion. A one percent change in TCLTob leads to -2,57 percent change in total dissolved salts emitted, while a similar change in TCLCot leads to a -4,79 percent change in total dissolved salts emitted. This may be attributable thereto that at Loskop, cotton is grown on heavier soils (OTK, Personal Communication, 1994) which contain higher proportions of absorbed mineral ions (salts) because of the higher proportion of active soil particle surfaces provided by the presence of the clay particles. However, it is important to note that the texture of the soils is predominantly sandy loam for both tobacco and cotton cultivation, and the heaviness (clay content) is relatively small. In real heavy (clayey) soils, we would expect less emission of salts into the river because of limited porosity and the reduced chances for leaching of salts. This explanation for the difference in the elasticities of TCLCot and TCLTob should be tested by soil analysis.

5.4 Discussion of Chloride results

(1) According to Model 6, a one percent increase (decrease) in the quantities of total fertilizer applied to crops in the Loskop Valley leads to a 0,52 percent increase (decrease) in the quantities of chlorides emitted into the Olifants River. This relationship is inelastic; changes in the quantities of fertilizer have a less than proportionate impact on chlorides emitted into the river.

A comparison of the elasticities for TFUsed in Tables 3 and 4 reveals that fertilizer use has a stronger effect on the emission of TDS than of chlorides. This could be expected; chlorides constitute a fraction of the total dissolved salts (TDS).

(2) A one percent increase (decrease) in the area of land cultivated to cotton in the Loskop Valley leads to a 0,516 percent increase (decrease) in the

emission of chlorides. This relationship is once again inelastic. Comparison between Tables 3 and 4 reveals that area under cotton influences TDS emission more than chloride emissions. Also, while an increase (decrease) in the area under cotton leads to a decrease (increase) in TDS emitted, it leads to an increase (decrease) in the chloride emission. The positive functional relationship implies that soil is the main source of chlorides. It appears that TDS mainly originate from anthropogenic sources, and increasing areas assist in its neutralization and storage in nature, whilst chloride accumulation originates mainly from natural sources (mainly the rock strata and their weathered minerals, underlying the land itself) and irrigation practices; increases in land area therefore leads to increases in its availability and emission into the river. While a number of the salts constituting TDS ionize in the soil and some are well adsorbed on the surfaces of soil particles, "chlorides are very soluble and are not adsorbed to any significant degree by soil" (DWAF, 1993:45).

(3) Area cultivated to tobacco (TCL Tob) did not significantly affect chloride emissions and does not appear in Table 3. This may possibly be ascribed thereto that while both types of land may contain chlorides, the tobacco plant readily absorbs chloride ions with water; these become deposited in the tobacco leaves, lowering its market quality. This is a well known economic problem with tobacco production in the Loskop Valley (OTK, Personal Communication, 1994). Cotton plants do not absorb as much chlorides as tobacco plants; in addition the cotton fields, being somewhat heavier soil, have somewhat higher capillarity, causing greater proportions of chloride ions to rise to the surface layers of the soil in the high evaporation conditions associated with semi-arid lands (cf. Brady, 1990). However, as shown in Model 5, fertilizer applications to cotton have a positive influence on chlorine emissions.

(4) The non-significane of TRain in the chloride emission models can be explained by another hypothesis, namely that in the Loskop Valley, chlorides are mainly carried by the groundwater stream and the irrigation return flow into the Olifants River, unlike the other salts constituting TDS which are mainly held around the soil particles and require rainfall to wash it into the river, either in solution form or in adsorbed form on soil particles which get deposited as sediments.

(5) The significant relationships between CL and both TFUsed and TFCot indicate that some of the fertilizers applied in the Loskop Valley contain fairly high quantities of chloride ions. This is particulary the case with potassium chloride fertilizers which had previously been used extensively

in citrus, vegetable and maize cultivation, and currently used mainly on citrus. Chloride ions are present also in some other fertilizers. For example, recent chemical analysis of Phalaborwa rock phosphate revealed that it contained 630 mg of chlorine per kg of fertilizer (Bienkowski and Kidson, 1994).

6. Substibution between land and other causal variables

An important environmental policy implication now becomes clear. The elasticities provide environmental managers and policy-makers with an indication of the extent to which any independent variable in a given mineralization model is to be changed in order to achieve a given reduction in the emission of a given pollutant. This reduction could be done efficiently by employing marginal substitution relationships between area cultivated and the quantities of fertilizer applied; rainfall levels cannot be altered, and must be taken as given. Land must be substituted for fertilizer to the point where the marginal rate of substitution (MRS) between area cultivated and fertilizer application equals the inverse ratio of the unit opportunity cost of altering application levels of inputs to achieve a unit reduction in pollutant levels. For example, in the case of the overall agricultural TDS emission model, the economically efficient point of TDS emission reduction will be attained when the

$$MRS_{TFUsed,TCLCot} = \frac{\_TFUsed}{\_TCLCot} = \frac{-K_{TCLCot}}{K_{TFUsed}}$$

where

$MRS_{TFUsed, TCLCot}$	=	marginal rate of substitution of TCLCot for TFUsed in the said model;
_ TFUsed	=	a unit change in TFUsed;
_ TCLCot	=	a unit change in TCLCot;
K_{TCLCot}	=	a cost of increasing the total land area in the "extensification" of cotton cultivation to achieve a unit reduction in TDS emission, and
K_{TFUsed}	=	opportunity cost (in terms of reduced yields) of reducing total fertilizer application to achieve a unit reduction in TDS emission.

The substitution effect between the independent variables provides the cheapest route to the reduction of pollution; the unit cost to society (and the farmer) of reducing pollutant emission levels through an increase in land area in conjunction with other farm inputs (i.e. "extensification" of production) may not be the same as the unit opportunity cost (in crop yields) of reducing pollutant emissions through reductions in total fertilizer quantities. It should be noted that in practice, reductions in total fertilizer usage does not necessarily imply reduced per unit fertilizer application rates for all crops. Fertilizer application rates could be maintained on the most profitable enterprises while reducing the applications for other enterprises or withdrawing land from of other crops.

7. CONCLUSIONS

Relationships between agricultural practices in the Loskop Valley and the emission of dissolved salts and chlorides into the Olifants River were quantified. Such relationships exist with individual enterprises (tobacco, cotton and wheat) as well as aggregate farming practices. In the case of chloride emissions, relationships were found for cotton and also for aggregate farming practices.

The results indicate either positive or negative functional relationships between changes in areas to crops and pollutant emission levels into surface water, depending on the main source of the pollutant. If the main source is external to land (stemming from human and/or other external activities), the relationship is negative, but if the main source is internal to land (stemming from natural physical and chemical reactions within the soil), the relationship is positive. The results indicated that in the Loskop Valley, the total dissolved salts originated mainly from sources external to the land (eg. fertilizer application, tillage activities, irrigation practices, etc.), but chlorides were shown to originate mainly from sources internal to the land, (eg. weathering of rock and its minerals).

Substitution relationships among the independent variables can be used in environmental policy-making. Economic efficiency could be attained in the reduction of pollutant levels of surface water bodies when such reductions are effected to the point where the marginal rate of substitution (MRS) of one independent variable for the other equals the inverse ratio of the opportunity cost of altering the application levels of those inputs to attain a unit reduction in emission levels. This relationship allows the most economical route to the reduction of pollutant emissions. For Loskop Valley, the alternative routes are:

(i) extensification of cotton cultivation (increasing the land area);

(ii) reductions in total or per hectare application of fertilizer;

(iii) a combination of the above two approaches to the extent warranted by the MRS between fertilizer and land and the opportunity cost of changing the various inputs.

These conclusions are certainly not exclusive, and do not preclude other possible routes to reduce pollutant emissions. Such possible routes may include conservation tillage and the reduction of crops that require high fertilizer applications such as citrus and tobacco. However, prescription of these other methods of pollutant reduction can be done only after field studies involving analysis of pollutant emissions and the economic effects of all alternative methods.

REFERENCES

BIENKOWSKI, J.F. & KIDSON, M.V. (1994). *An investigation of the impact of fertilizers on soils of rainfed and irrigated fields*. Agricultural Research Council, Institute for Soil, Climate and Water, Pretoria. Unpublished Report.

BOUZAHER, A., LAKSHMINARAYAN, P.G., CABE, R., CARRIQUIRY, A., GASSMAN, P.W. & SHOGREN, J.F. (1993). Metamodels and nonpoint pollution policy in agriculture. *Water Resources Research*, 29(6):1579-1587.

BRADY, N.C. (1990). *The nature and properties of soils (10th edition)*. Macmillan Publishing Co., New York.

DEPARTMENT OF WATER AFFAIRS (DWA). (1986). *Management of the water resources of the Republic of South Africa*. DWA, Pretoria.

DEPARTMENT OF WATER AFFAIRS (DWA). (1990). *Surface Water Quality of South Africa: 1979-1988, Vol 2 - Drainage Region A & B*. Hydrological Research Institute, DWA Technical Report No TR 145, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF)(1993). *South African water quality guidelines, Vol 1 - Domestic Use*. DWAF, Pretoria.

DWA (1991). *Water resources planning of the Olifants River basin - study of development potential and management of the water resources basin. Study Report, Vol. 1 - Executive Summary*. DWA, Pretoria.

GOODLAND, R.J.A., (1993). *Environmental sustainability and the empowerment of women*. A draft document contributed to the South African Rural Restructuring Program. Environment Department, World Bank, Washington, D.C.

GROBLER, D.F.(1994). A note on PCBs and chlorinated hydrocarbon pesticide residues in water, fish and sediment from the Olifants River, Eastern Transvaal, South Africa. *Water SA*, 20(3):187-94.

GROBLER, D.F.; KEMPSTER, P.L. & VAN DER MERWE, L.(1994). A note on the occurence of metals in the Olifants River, Eastern Transvaal, South Africa. *Water SA*, 20(3):195-204.

HEATON, T.H.E. (1985). Isotopic and chemical aspects of nitrate in the groundwater of the Springbok Flats. *Water SA*, 11(4):199-207.

JURY, W.A., FOCHT, D.D. & FARMER, W.J. (1987). Evaluation of pesticide groundwater pollution potential from standard indices of soil chemical adsorption and bio-degradation. *Journal of Environmental Quality*, 16(4):422-428.

KENNEDY, P. (1985). *A guide to econometrics (2nd edition)*. M.I.T. Press, Boston.

KHAN, M.A. & LIANG, T. (1989). Mapping pesticide contamination potential. *Journal of Environmental Management*, 13 (2):233-242.

KLOPFFER, W., RIPPEN, G. & FRISCHE, R. (1982). Physiochemical properties as useful tools for predicting the environmental fate of organic chemicals, *Ecotoxicological Environmental Safety*, 6:294-301.

O'KEEFFE, J.H.; UYS, M. & BRUTON, M.N. (1992). Freshwater systems. In: Fuggle & Rabie (eds.) *Environmental Management in South Africa*. Juta & Co., Cape Town.

OTK (1993). *Die Loskop besproeiingsgebied*. Unpublished document, Groblersdal.

RINALDO, A. & MARONI, A. (1984). Runoff and receiving water models for NPS discharge into the Venice Lagoon. In: A. Giorgini & F. Zingales (eds.) *Agricultural non-point source pollution : model selection and application. Developments in Environmental Modelling*. Elsevier, Amsterdam.

SAMIULLAH, Y. (1990). *Prediction of the environmental fate of chemicals*. Elsevier Applied Science, London.