THE POTENTIAL USE OF POLLUTION INSURANCE AS ENVIRONMENTAL POLICY : AN EMPIRICAL ANALYSIS

J. Kojo Aihoon, Jan A. Groenewald and Helmke J. Sartorius Von Bach[1]

Market-based environmental policies have been forwarded as alternatives to current pollution control policies. Implementation of the "polluter pays" principle and governmental enforcement of pollution clean-up have led to astronomical environmental liabilities and clean-up costs, which may threaten the survival of many productive ventures, unless producers can spread pollution risk through insurance. An emission constrained target MOTAD LP (TMLP) model showed that pollution insurance for irrigation farmers can be a feasible and efficient solution to agricultural salinization problems in the Loskop Valley, and fairly low salinity standards with pollution insurance will still be reconcilable with profitable farming. Pollution insurance appears to hold promise for applying the "polluter pays" principles also to non-point pollution. Site specific studies are needed for pollution policy, and more research is needed on pollution standards.

SAMEVATTING : DIE POTENSIËLE GEBRUIK VAN BESOEDELINGSVERSEKERING AS OMGEWINGSBELEID : 'N EMPIRIESE ANALISE

Markgebaseerde omgewingsbeleidsopsies was voorgehou as alternatief vir huidige besoedelingsbeheerbeleid. Toepassing van die "besoedelaar betaal" beginsel en owerheidsafdwinging van besoedelingsopruiming het gelei tot astronomiese omgewingsaanspreeklikheid en opruimingskoste en dit kan die oorlewing van baie produksie-eenhede bedreig tensy produsente hul besoedelingsrisiko deur versekering kan versprei. 'n Emissie beperkende doelwit MOTAD LP model het getoon dat besoedelingsversekering vir besproeiingsboere 'n haalbare en doeltreffende oplossing vir landboukundige versoutingsprobleme in die Loskopvallei kan wees en dat redelik lae versoutingstandaarde tesame met besoedelingsversekering steeds met winsgewende boerdery versoenbaar sal wees. Dit lyk of besoedelingsversekering belofte toon vir die toepassing van "besoedelaar betaal" beginsels, ook by nie-punt besoedeling. Plek-spesifieke studies word vir besoedelingsbeleid benodig en meer navorsing oor besoedelingstandaarde is nodig.

1. INTRODUCTION

The failure of existing regulatory mechanisms to control environmental degradation satisfactorily has led to a fairly widespread call to employ market mechanisms for this purpose (Department of Environment, 1990; Kula, 1992; Moxey & White, 1994; Baumol & Oates, 1971; Pan & Hodge, 1994).

[1] Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria 0002.

In this article a specific case is used to study pollution insurance as a potential market solution to environmental degradation. The question is whether one can protect society (as the third party) and the environment through mandatory pollution insurance. This may potentially be economically the most efficient solution to pollution because it will rely on the market to arrive at the socially optimal level of environmental degradation. It aims to protect society or the environment, and also to protect producers and government from expensive pollution cleanup. As reality forces governments to make polluters pay for the clean-up of polluting emissions, astronomic environmental liabilities and clean-up costs emerge (Steuber, 1989; Gilbert, 1992). This will endanger many productive activities unless producers can spread this risk through insurance. Mandatory pollution insurance by all potential polluters is a possible approach. The feasibility of such a policy for irrigation farming was studied in the Loskop Valley

2. A THEORETICAL MODEL OF FERTILIZER POLLUTION CONTROL BY POLLUTION INSURANCE

Mineralization of the Olifants River, caused by fertilizer, irrigation and cultivation practices was investigated. Spatial differences in agriculture's potential to pollute surface and underground water stem from physical and chemical properties of the soil and underlying parent material. Leaching of minerals often does not correlate particularly closely with fertilizer applications (Pan & Hodge, 1994). A catchment should therefore be divided into land classes and zones. Land classes define areas of homogeneous agricultural productivity with an uniform opportunity cost of pollution abatement. A zone refers to the spatial juxtaposition of areas relative to the hydrological system. Fertilizer salts move downstream, but not *vice versa.* The proportion of pollution generated upstream received downstream (the delivery ratio) varies between 0 and 1, according to the transportation mechanism and biochemical processes (Donigian, 1986). The profit function of firm i in zone j may be expressed as:

$$\pi_{ij} = py_{ij} - c_{ij}\,(y_{ij}.\ m_{ij}) \qquad (1)$$

where

p is output price,
y_{ij} is output and
c_{ij} (y_{ij}, m_{ij}) is cost as a function of output and the mineralization level.

The firm's cost function reflects both abatement (or pollution control) and production costs; mineralization increases with output. The firm's benefit function is defined as (Xepapadeas, 1972):

$$B_{ij}(m_{ij}) = \max_{y_{ij}} p_{ij}(y_{ij}, m_{ij}) = \max_{y_{ij}} [py_{ij} - c_{ij}(y_{ij}, m_{ij})] \quad (2)$$

This gives the maximum profit for a given level of mineralization (m_{ij}). Damage costs in zone j result from the mineral (salt) concentration which is determined by emissions from producers within the zone and emissions transported hydrologically from upstream:

$$D = d_j [h_j (\sum_k^K t_{kj} \sum_i^I m_{ik})] \quad (3)$$

where

t_{kj}	is the delivery ratio of emissions reaching zone j from source zone k,
h_j	is the mineral concentrations as a function of emissions, and
d_j	is the damage cost function.

The delivery ratios t_{kj}, are equal to 1 if k = j, 0 if zone k lies downstream of zone j, and between 0 and 1 if zone k is upstream of zone j.

Society's objective should be reflected by environmental policies and environmental agencies (eg. The Department of Water Affairs (DWA)) and may be represented as the maximization of a net social benefit function, W.

$$W = \max_{m_{ij}} \sum_J^J \sum_i^I (m_{ij}) - \sum_i^I D(m_{ij}) \quad (4)$$

This maximizes the sum of producer profits less the sum of damage costs across all zones.

The first order conditions for an optimal abatement policy, with convex benefit functions (B_{ij} (m_{ij})s) and concave damage functions are

$$\frac{B'_{11}/(m_{11})}{B'_{12}/(m_{12})} = \frac{D_{11} + D'_{12}}{D_{22}} \quad (5)$$

where

B_{ij} (m_{ij}) is the first derivative of the benefit function and
D_{kj} is the first partial derivative of damage in zone k with respect to emissions in zone j.

Thus, the ratio of marginal private benefits between the two zones is equated with the ratio of marginal social costs. The marginal social cost from fertilizer pollution generated in zone 1 includes the damage in zone 1 plus the damage caused downstream in zone 2. The second term in the numerator on the right hand side is the partial derivative of the damage function in zone 2 due to emissions from zone 1.

In downstream irrigation, the transfer of pollutants from upstream farms can be a major problem if farmers draw their water directly from the river. At Loskop, transfer among farmers is small; farmers receive water from the dam, not the river. The delivery ratio still exceeds zero; pollutants are carried to adjacent farms by run-off and sub-terranean water movements. If however, pollutant transfer to other water users downstream is considered, the effect is substantial because of return flow from farmers to the river. A situation that allows the actions of producer 1 to harm producer 2 through externalities presents problems.

Damage functions for pollutants are usually not known. With fertilizers, a maximum concentration level (in TDS) measured at one or more receptor points, may be specified as a proxy measure of the socially acceptable level of pollution. The objective becomes one of maximising total producer profits subject to limits on TDS concentrations.

$$B = \max_{m_{ij}} \sum_{j}^{I} \sum_{i}^{I} B_{ij}(m_{ij}) \tag{6}$$

subject to

$$h_j \sum_{k}^{K} t_{kj} \sum_{i}^{I} m_{ik} \leq j \tag{7}$$

This approach is adopted for pollution insurance analysis in this study. This objective function does not alter previous conclusions regarding the efficiency of zonal emission premiums, taxes or quotas (Moxey & White, 1994).

3. DATA COLLECTION AND MANIPULATION

Target MOTAD linear programming (TMLP) was used to solve the above objective function. Features of the model and data are described briefly.

3.1 Production activities

A survey revealed that land use patterns and enterprise combinations are fairly uniform at Loskop. Some beef cattle were kept on natural grazing. Farmers produced mainly the following crops under irrigation: tobacco, citrus, wheat, peas, groundnuts, soyabeans, other vegetables and cotton.

Enterprise gross margins (c_j) were determined for all enterprises. Data for gross income estimation were supplied by the Eastern Transvaal Co-operative (OTK). Yields at different fertilization levels were estimated from production functions fitted to data on fertilizer-yield responses in the area and the South African Fertiliser Society Handbook.

3.2 Constraints

The main production resources levels (a_{ij}) necessary for the production of a unit activity and limits to their availability (b_i) were based on findings from the field survey, and data from the OTK.

3.2.1 Land, water and livestock

Arable land per farm was constrained at 137 hectares, the average farm size as obtained from the OTK. These 137 hectares were available both for summer and winter crops, except if citrus orchards (perennial) were established.

The usual irrigation water quota is 770 000 litres/ha/annum (equivalent to 770 mm/annum), except when the water level at the dam is below normal. This led to an irrigation water constraint of 105 490 000 litres/ha/annum.

Livestock was constrained at 56 livestock units (LSU); on average, farmers had 395ha of natural grazing with a stocking rate of 1 LSU/7 ha.

3.2.2 Minimum constraint on income

Pollution remediation or avoidance of production practices could cause reductions in farm income. This was constrained to a total gross margin of greater than or equal to zero. Over the short-run, a farmer will keep on producing, even at a loss, provided his gross farm income covers variable costs, as implied by zero total gross margin.

3.2.3 Pollution remediation cost

A pollution insurance premium (pollution remediation cost) was introduced in the model. Assuming an actuarially fair pollution insurance scheme, the premium per kg of fertilizer applied was equated to the mean annual remediation cost stemming from such an application. This was estimated by assuming that increases in the TDS of the Olifants River (at a specified sampling point) to levels above salinity pollution (TDS) standards would be remedied by either dilution or reverse osmosis. The data on river flow and TDS concentrations for 1981 to 1988 were obtained from the DWA data centre and those on remediation costs from the Rand Water Board. It varied between 5 and 10c/m^3 of river water using dilution, and between R2 and R2,50/m^3 of river water for reverse osmosis.

4. METHODOLOGY

4.1 Basic approach

Optimum input-output decisions and their financial income were determined with and without pollution insurance, and compared thereafter, under the assumption of a uniform land use pattern for the valley. Average yields, inputs, revenues and costs of farmers in the Loskop Valley were used. The analysis used the IBM MPSX (Mathematical Programming System Extended) package.

4.2 Estimation of the salinization indemnity (liability) charges to insurers

The proposed pollution insurance scheme limits liability to the cost of pollution remediation. Future indemnity (liability) charges to insurers are projected from historical pollution statistics, and by determining mean charges, assuming a mandatory pollution insurance scheme.

Mean pollution premium rates were based on the annual pollution remediation cost, depending on the level of water salinization, the remediation technique and the chosen pollution standard. Calculations were done for each year from 1981 to 1988 by estimating the cost of diluting river water, using either water in the Loskop Dam, excess or overflow water from the dam, or water transfer from another catchment. This will require a network of water channels to connect the dams at the point of pollution in the river. Excess water will be returned to source after dilution. The unit dilution cost is made equal to the unit cost of irrigation water supply, and the total cost of remediation is equivalent to the cost of the total volume of water required for the dilution. The concentration of the river water to be diluted is determined at the downstream sampling point.

The volume of water required for the dilution of a given volume of water depends on the salinity concentration of both the water diluted, the water used for dilution, and on the salinity standard. It was assumed that much of the dilution will be done with water from Loskop Dam. A unit dilution cost of 7,5c/m^3 was assumed. The shortcoming of this assumption was overcome by a sensitivity analysis that determined the effect of variations in remediation cost on the optimal solution.

In cases where the dilution technique could not be used for remediation, the per unit remediation cost of reverse osmosis, assumed to be R2,25/m^3, was used and also varied in the sensitivity analysis. The cost of reverse osmosis depends on the volume of water to be treated and returned to the river. This depends on the salinity concentration and the salinity standard to be met.

4.3 Salinity pollution standards

Pollution standards have been established in South Africa (Government Gazette, 18 May, 1984) for effluent discharges from point sources. Special and general standards exist for various pollutants. These standards were not applicable to the former homelands. In addition, the implementation of pollution control measures (eg. mandatory pollution insurance) for non-point source pollution will require pollution standards for underground and surface water bodies from activities of non-point source polluters. Due to differences in water quality parameters in natural water bodies, these standards on salinity, pH, nitrates, phosphates, etc. - can be established in the form of allowable increments by non-point source pollution. A standard of no increments may alternatively be adopted. This will require records of existing water quality parameters of underground and surface water over the whole country. Such record keeping will be more feasible (especially for groundwater) if restricted to regions with possible pollution problems.

Under such standardization circumstances, and until agricultural science yields production technology equally productive, profitable and simultaneously less polluting, allowance will have to be made for some pollution of underground and surface water to the point where marginal loss equals marginal gain. Net social welfare is optimised at that point. The current extent of mineralization at Loskop, as indicated by TDS and chloride masses, is too high to be ignored for "business as usual". Optimization of social welfare will require pollution control. As basis, a salinity standard of 350 mg/l TDS was assumed for the Olifants River, lower than the 450 mg/l (or 70 ms/m electrical conductivity) standard required by domestic water users and some industrial water users (Department of Water Affairs and Forestry, 1993a, b, c, d). It allows some pollution by farmers and other non-point source polluters. Since such increases in natural water quality parameters imply some cost to the natural environment, this standard is hypothetical. The sensitivity analysis done with the salinity standard in mind also examined what the optimal farm plan would be, should a different pollution standard be

4.4 Estimation of the pollution insurance premium (i.e. unit pollution remediation cost)

In actuarial science, insurance premiums are estimated as a product of the probability of the occurrence of an event (normally estimated from historical data) and the indemnity charges associated with that occurrence. In this study, the important consideration is the probability of a unit remediation cost. In 1981, 1987 and 1988, the mean annual salinity of the Olifants at the downstream sampling point indicates some increases in salinity, but this was within the salinity standard laid down (350mg/l TDS); this salinization would not require remediation. Pollution remediation cost would be incurred in the remaining years, i.e. 1982-1986. Since premiums are estimated on the assumption of an actuarially fair insurance scheme, it is the mean pollution remediation cost which is considered, making it necessary to estimate mean annual pollution remediation cost for all 8 years studied.

The premium rate was calculated per kg of fertilizer applied; producers using more fertilizer will thus pay higher premiums.

This assumes fertilizer to be the only direct cause of salinity increases of the Olifants. However, an agricultural mineralization model derived for the Loskop Valley (Aihoon, 1994) indicates that other farming parameters, eg. land area cultivated to crops like tobacco and cotton as well as rainfall are also significant contributors. The linkage of fertilizer application to the premium payment is based on the assumption that increases in tillage and irrigation practices could be linked to increased fertilizer application. It implies that farming activities like groundnuts, soyabean and animal production that do not use fertilizer do not cause salinization. This assumption may not be true. However, salinization stemming from groundnut and soyabean tillage activities appears to be too small to be of significance (Aihoon, 1994). Similar research elsewhere in the world also used fertilizer input, rather than leaching potential, as basis for the assessment of the pollution potential of different land use practices (Moxey & White, 1994; Pan & Hodge, 1994).

The pollution insurance premium (i.e. the remediation cost per kg of fertilizer) was estimated as a mean for the 8 years, and the annual remediation cost per kg of fertilizer was estimated for each year by dividing the total remediation cost by total fertilizer usage in the Loskop Valley.

4.5 The empirical model

A target MOTAD LP (TMLP) model incorporating an emission constraint factor was used to determine optimum farm plans for a representative farm. An emission constraint was introduced in the form of the pollution remediation cost (per kg fertilizer). Target-MOTAD allows a simultaneous analysis of the inclusion of income risk, pollution risk and a farm management objective of ensuring a minimum expected farm income that allows the farmer to break even. This approach was followed earlier by Swinton & Clark (1994). Moxey & White (1994) used an aggregate linear programming (ALP) model in their study of alternative policy instruments for nitrogen fertilizer pollution control. Pan & Hodge (1994) used a linear programming (LP) model similar to the standard crop-mix model formulated by Johnson *et al*. (1991) to estimate costs to farmers of policies that restrict nitrogen input or nitrate leaching.

Numerous empirical studies have demonstrated that farmers are typically risk-averse (Binswanger, 1980; Dillon & Scandizzo, 1978). They often prefer plans that provide a satisfactory level of security even if this means sacrificing income on average. In a risky world, a farm plan does not have a known income each year. There are many possible income outcomes and, in the mathematical programming context, the actual outcome each year depends on the realized values of all the c_j, a_{ij}, and b_i coefficients in the model. All risks involving c_j, a_{ij}, or b_i coefficients translate into income risk. A single utility function U(Y), with Y as expected income, provides an integrated behavioural approach for selecting optimal farm plans.

To many farmers, it may be an important farm planning target to at least break even or to cover at least all variable costs in the short-term. Tauer (1983) designed a target MOTAD linear programming model, including a pollutant emission constraint for this purpose. This model is mathematically formulated as follows (Hazell Norton, 1986):

$$\max E = \sum_{j} {}_{ij} X_j \tag{8}$$

subject to

$$Y_O = \sum_{j} c_{jt} X_j - Z \leq 0 \text{ all t} \tag{9}$$

and

$$\sum_t p_t Z_t = l \qquad (10)$$

$$\sum_j a_{ij} X_j \leq b_i, \qquad \text{all } i \qquad (11)$$

$$\sum_j \phi_j X_j - \sum_j R_j = 0 \qquad (12)$$

$$X_j, Z \geq 0, \qquad \text{all, } j, t \qquad (13)$$

where

X_j = the level of the jth farm activity. Let n denote the number of possible activities, then j = 1 to n;
c_j = the forecasted gross margin of a unit of the jth activity (Rand per -ha);
a_{ij} = the quantity of the ith resource required to produce one unit of the jth activity. Let m denote the number of resources; then i = 1 to m;
b_i = the amount of the ith resource available;
ϕ_j = the pollution cost per ha for the production of the jth activity stemming from fertilizer application; and.
R_j = the total pollution remediation cost (PRC) stemming from the production of the jth activity, the given pollution standard and the given remediation technology.

The Z variables in equation (9) measure the value of deviations in income below the target. These deviations are collected in equation (10) and multiplied by the probability of them occurring (p_t) to give the expected sum of the deviations below the target income.

The model is set up to maximise E, (expected farm gross margin) subject to achieving a satisfactory level (determined by l) of compliance with the target income and the salinity pollution standard, which determines the level of the pollution remediation cost (PRC), i.e f_j per unit activity.

It was important to capture two aspects of farm planning in the model. If a premium is levied for every unit of fertilizer used, the profit-maximising level of fertilizer and yield changes. To handle this, five points were chosen on the production function for every fertilizer-using crop. Gross margins at those particular points and the corresponding fertilizer quantities entered the model as a_{ij} levels.

The objective function included gross margins per hectare for the various levels of crop enterprises, the gross margin per LSU for beef cattle and the pollution remediation cost per kg of fertilizer.

The constraint rows included limitations on the use of arable land, irrigation water requirements, the limit on beef cattle, fertilizer applications for crops, the expected short-fall from target income, and the risk rows. The risk rows consisted of six years' historical gross margin data for the various enterprises, except beef cattle. The total of enterprise gross margins was specified to be greater or equal to the target (zero). Beef cattle were not included in the income risk analysis because it does not compete with other enterprises, being produced on natural grazing.

5. RESULTS

The TMLP model yielded primal solutions and the `internal' sensitivity analyses obtained by activating the `Range' option in the MPSX package. This 'internal' sensitivity analysis provides information about the stability of the optimal solution. Stability is tested *ceteris paribus*; the effect of change in a single coefficient is considered with all other coefficients held constant.

The results are presented and discussed in two steps. The first step involves a comparison of optimum farm plans and revenues without and with pollution insurance. The second step involves `external' sensitivity analyses, in which values of some coefficients are varied in the model with pollution insurance. The purpose is to evaluate the effect of such changes on optimum results.

5.1 Farm plans with and without of pollution insurance

The target MOTAD LP model was run with and without pollution remediation cost (PRC). Results appear in Table 1.

The primal solutions for the two scenarios indicated no change in optimum input-output use or in the level of resource application. The additional cost for pollution insurance reduced expected total gross margin by R45 237 from R1 282 751 to R1 237 514.

Without PRC, the most efficient production plan involves keeping the maximum beef cattle allowed by the available natural grazing, i.e. 56 LSU, plant all available land in summer (137 ha) to tobacco at its highest fertilizer-yield level considered, and to plant 116 ha in winter to peas at the highest considered fertilizer and yield level. According to the `internal' sensitivity analysis, water availability prevents planting more than that in winter.

Table 1: Optimal farm plans with and without pollution remediation cost (PRC) in the Loskop Valley - at a salinity standard of 350 mg/l TDS

Scenario	E(R)	Activity	Level of Activity	Upper cost (R) Lower cost (R)	Limiting process (activity)
Without PRC	1 282 751	Tobacco 5	137 ha	5 533 Infinity	Citrus 5 None
		Peas 5	116 ha	2424 6169	Peas 4 Summer Arable land
		Beef Cattle	56 LSU	Infinity	None
With PRC	1 237 514	Tobacco 5	137 ha	4687 Infinity	Tobacco 4 None
		Peas 5	116 ha	2460 6118	Peas 4 Summer Arable land
		Beef Cattle	56 LSU	Infinity	None
		PRC	R0,65	12,40 0,57	Peas 1 Citrus 5

Scenario	Resources	Shadow price of resources (R)	Limiting resource
Without PRC	Summer arable land Irrigation water	3293 7,77	Summer arable land (UL)
With PRC	Summer arable land Irrigation water	3238 7,41	Irrigation water (UL)

The primal solution excluded citrus which, being a perennial enterprise, cannot compete with a combination of summer tobacco and winter peas, notwithstanding its high gross margin per hectare. Peas also have a relatively low water requirement.

The stability of the primal solutions can be judged from the last two columns of Table 1. Upper and Lower costs indicate the range of activity gross margins over which the primal solution will remain unchanged. Beyond these limits, these activities would be replaced by the corresponding activities in the Limiting process (activity) column. For example, if the gross margin of Tobacco 5 becomes less than R5 533 it will be replaced by Citrus 5; a reduction of gross margin of Peas 5 to less than R2 424 will cause its replacement by Peas 4, i.e. peas with less fertilizer.

The wide ranges between upper and lower costs indicate a high level of stability in the primal solution. The shadow prices of recoures indicate how much the farmer can pay for an extra unit of those resources that were exhausted by the primal solution. The farmer can pay up to R3 293 for an extra ha of arable land in summer and R7,77/mm/annum for extra water. The situation remains almost unchanged with introduction of PRC.

The introduction a pollution insurance premium (pollution remediation cost) of 65 c/kg fertilizer usage did not cause a basis change in the primal solution; total fertilizer usage (69 596 kg) remains the same. This confirms previous findings (Babcock, 1992; Swinton & Clark, 1994) that under conditions of financial risk, risk aversion justifies heavy nitrogen fertilization. The salinization effect of fertilizer usage is controlled by the remediation (i.e., clean-up) of the pollution insurance. The 'internal' sensitivity analysis (Table 1) shows that, should the premiums increase to R12,40/kg fertilizer, (almost 20 times the present cost), the basis would change, introducing Peas 1 (without fertilizer), reducing fertilizer usage by 25 619 kg. Extrapolating this to the whole Loskop Valley yields a total reduction of 4 956 248 kg per annum of fertilizer at Loskop. Such a reduction will reduce salinization in the Olifants, but will also have a social cost in the form of reduced income to farmers (R61 457 475 per annum less the value of the unused fertilizer). This may lead to a decline in agricultural employment in the region. This illustrates the need for economic analysis of environmental degradation before new policies are adopted. Since the social cost of externalities caused by salinization of the Olifants could be equally high (though not yet estimated), control of mineralization is necessary. However, regulations that cause fertilizer usage to decline drastically may be socially expensive. A pollution insurance scheme that is able to control mineralization by the remediation techniques suggested may be socially more desirable and deserves further investigation: For example, what is the technical feasibility of these remediation techniques?

Moreover, if such restrictive policies are adopted on a national scale, reduced supply of some products may induce rising food prices, thereby inducing additional social costs for the population. This underlines the necessity of research on ways to control pollution as economically as possible.

Insurance premium payments represent income transfers and not a social cost, while reduction in output caused by reductions in fertilizer use involves a social cost. If insurance would succeed to control salinization without reductions in output, it will represent an additional gain to society. It will be more attractive than environmental policy instruments like pollution tax, input quotas, pollution permits, etc., all of which reduce production to control pollution. There is a need to re-examine the traditional concept that pollution should be prevented rather than treated. This convention probably holds true with many forms of pollution because of the high externality costs and the irreversibility of effects. However, there is no scientific or economic justification to insist on this convention in cases where the pollutants are not harmful to the environment at the quantities of emission and where technically, remediation is relatively simple and cheap.

Environmental degradation should be analyzed, diagnosed and addressed case by case. What is an efficient solution in one case may not be so in another, and *vice versa.*

5.2 'External' sensitivity analysis of the optimal farm plan with pollution insurance

The optimal farm plan with pollution insurance was subjected to sensitivity analysis in terms of pollution standards and cost of remediation technology. Results appear in Table 2.

An arbitrary salinity standard has hitherto been used in the study. Pollution insurance as government policy will require research to determine standards that will ensure eco-efficiency in the management of natural resources. The first sensitivity analysis was aimed at the effect of different salinity standards on the optimal farm plan. Absolute non-pollution by non-point source polluters is one possibility that presently applies to point-source polluters. For example, the pollution standards for effluent (Government Gazette, May 18, 1994) require that when these effluents mix with surface water, change in the quality of the receiving water must be imperceptible. The existing attitude appears to imply

Table 2: Sensitivity of the optimal farm plan with pollution insurance to changes in various model coefficients

Sensitivity test	Expected Income E(R)	% Decrease from (a)@	% Decrease from (b)@	Activity level			
				Beef cattle (LSU)	Tobacco 5 (ha)	Peas 5 (ha)	Peas 1 (ha)
Remediation cost/kg fertilizer*							
i) Reverse Osmosis - R3,32							
ii) 100% increase in dilution cost - R1,30	1051692	18,01	15,02	56	137	116	
iii) 200% increase in dilution cost - R1,95	1192276	7,05	3,66	56	137	116	
iv) 500% increase in dilution cost - R3,90	1147039	10,58	7,29	56	137	116	
v) 1000% increase in dilution cost - R7,15	1011327	21,16	18,28	56	137	116	
	785140	38,79	36,56	56	137	116	
Pollution standard							
i) Zero increases in river salinity - R15,36/kg fertilizer by Reverse Osmosis	289589	77,42	76,60	56	137	116	
ii) 250 mg/l Tds - R1,50 by dilution	1178357	8,14	4,78	56	137	116	
iii) 450 mg/l TDS - R0,32 by dilution	1260480	1,74	-1,86	56	137	116	
Original Results							
(a)@ Absence of PRC	1282751			56	137	116	
(b)@ Presence of PRC	1237513			56	137	116	

* The variation in remediation cost was done assuming salinity pollution standard at 350 mg/l TDS

** The variation in irrigation water availability was done assuming salinity pollution standard at 350 mg/l TDS and PRC at 65 c/kg fertilizer usage

@ Original results introduced for comparison

that non-point source polluters, including agriculture, could alter the quality of underground and surface water without any limit because pollution cannot be legally traced to them.

A policy that forbids non-point source pollution and asks non-point source polluters not to pollute at all will render reverse osmosis to be the only suitable technology for recovery of the salinity quality. This will cost R15,36/kg of fertilizer usage and reduce total expected gross margin from R1 282 751 (in the absence of pollution insurance), to R289 589, thus a revenue loss of R993 162,32 (77,4%) to the farmer. With average annual financial commitments (including short, medium and long term liabilities, depreciation and operators earnings) currently estimated at R285 000 (University of Pretoria, 1993) this will cause financial ruin for many farmers, resulting in high social costs. Therefore, other salinity standards also have to be considered, eg 250 mg/l TDS, 450 mg/l TDS and the original 350 mg/l TDS. A requirement of zero increases in salinity would cause introduction of Peas 1 (no fertilizer) into the primal solution, reducing fertilizer application on the representative farm by 25 619 kg per annum. Such a policy might render it necessary for government to consider subsidization of pollution remediation cost (or pollution premiums). Subsidization should however, be at a level just enough to allow profitable production, otherwise the cost to society could be high enough to negate the moderating effect on pollution (Swinton & Clark, 1994; Shortle & Laughland, 1994).

The other salinity standards considered did not lead to basis changes in the primal solution, and led to moderate reductions in expected income. The final decision on salinity standard will have to depend on economic as well as ecological, social and other considerations.

The effect of changes in the cost of the remediation technology adopted was also considered, once again assuming a salinity pollution standard of 350 mg/l TDS. Reverse osmosis was considered for a situation where water for dilution was not available from the Loskop Dam or any other source. The other remediation technology costs considered were 100, 200, 500 or 1000 percent increases in the cost of dilution. A doubling in remediation costs would only have a moderate effect on expected income, which however becomes severely affected by further increases, including reverse osmosis.

6. IMPLEMENTATION OF A POLLUTION INSURANCE SCHEME

Pollution insurance may potentially be used in the control of environmental degradation from both point and non-point sources. This study demonstrates that research into individual pollution cases creates the potential to apply pollution insurance pollution problems, including non-point source pollution. Premium rate determination will require specific studies at the location of pollution, aimed at the polluters concerned. Implementation will require specific premiums for specific cases.

Some legal aspects that will need to be addressed: Non-point source polluters should firstly also be made legally responsible for their actions under the "polluter pays" principle. This is achievable if a group of non-point source polluters at given definable location becomes jointly responsible. Responsibility should be linked to individuals' polluting actions. In the case of agricultural polluters, liability could be linked to the leaching or as in this analysis, to fertilizer usage. This will require determination of fertilizer usage by field.

Experience elsewhere furthermore suggests that the insurance industry will be more willing to participate if their liability is limited to what is necessary to keep the environment clean. For example, like the EIL policies in the US, it could be made a claims-made-and-reported policy. This can eliminate the threat of long-tailed claims, a major problem for the insurer. This form of policy requires a claim to be filed during the policy period, and reporting of the claim insured during the same policy period (Epstein *et al.*, 1989). With non-point source pollution, such legal requirements could be modified to require the monitoring government agency (eg. DWA) to notify such claims directly to the insurer, and not the insured, thereby reducing transaction cost and speeding up remediation action.

7. CONCLUSIONS

Results of this analysis indicate that a market-based scheme to control agricultural pollution is possible and may be rather efficient. The possibility to control agricultural mineralization problems, eg. in the Loskop Valley through a cost-effective mechanism, means that the present non-action against non-point source polluters is unacceptable.

Some widely held traditional concepts of environmental economics become questionable by the mere possibility of this study. Is the notion that prevention or control of non-point pollution is possible only through regulation and policing a mistake of generalization? Is the notion wrong that because non-point source pollution liabilities cannot be sourced to individual polluters, the "polluter pays" principle cannot be applied? Is the notion also a mistake of generalization that once a water body is polluted the pollution cannot be remedied? These questions can only be answered by research; some methodologies adopted in this study may be useful in research on other non-point source pollution problems.

If a standard of zero increases in river salinity becomes government policy, it will lead to very expensive pollution control and many insolvencies. A salinity pollution standard that provides for some level of non-point salinization will still allow profitable operation of farms, together with a pollution insurance scheme.

Thus, while the option of non-point source pollution control via remediation (or cleaning) is not feasible at the individual polluter level, the pollution insurance scheme makes it feasible for a group of farmers in a subcatchment, because of the economies of scale involved in large-scale pollution remediation. This makes possible a market-based, economically efficient pollution control measure that maximizes net social gain and welfare. Pollution remediation which does not require cuts in production then becomes an alternative mechanism to all others that depend on reduced production.

REFERENCES

AIHOON, J.K. (1994). *Pollution insurance for the agricultural sector : a study in the Loskop Valley*. M.Sc(Agric) thesis. University of Pretoria.

BABCOCK, B.A. (1992). The effects of uncertainty on optimal nitrogen application. *Rev. Agr. Econ.*, 14:271-280.

BAUMOL, W.J. & OATES, W. (1971). The use of standards and prices for the protection of the environment. *Swedish J. Econ.*, 73:42-54.

BAUMOL, W.J. & OATES, W. (1988). *The theory of environmental policy, 2nd Edition,* Cambridge University Press, Cambridge.

BINSWANGER, H.P. (1980). Attitudes toward risk : Experimental measurement in rural India. *Amer. J. Agr. Econ.*, 62:390-407.

DEPARTMENT OF ENVIRONMENT. (1990). *This common inheritance : Britain's environmental strategies*. CM1200, HMSO, London.

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

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1993). *South African water quality guidelines, Vol 2 - Recreational use*. DWAF, Government Printer, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1993). *South African water quality guidelines, Vol 3 - Industrial use*. DWAF, Government Printer, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1993). *South African water quality guidelines, Vol 4 - Agricultural use.* DWAF, Government Printer, Pretoria.

DILLON, J.L. AND SCANDIZZO, P.L. (1978). Risk attitudes of subsistence farms in northeast Brazil : A sampling approach. *Amer. J. Agr. Econ.*, 60:425-35.

DONIGIAN, A.S. (Jnr.) (1986). *Integration of run-off and receiving water models for comprehensive watershed simulation and analysis of agricultural management alternatives.* In Giogini, A., and Zingales, F. (eds.), Agricultural non-point source pollution : Model selection and application. Elsevier Developments in Environmental Modelling No. 10. Elsevier.

EPSTEIN, H.B., NEUMAN, S. & BARNES, J. (1989). Pollution liability coverage under the claims-made- and-reported form. In: Miller, L.M. & Mallonee, M.J. (eds.) *Insurance claims for environmental damages.* Executive Enterprises Publications Co., Inc., New York.

GILBERT, E. (1992). Pollution woes prompt new policies. *National Underwriter*, 96, Iss 2: 9, 24-25.

HAZELL P.B.R. & NORTON, R.D. (1986). *Mathematical programming for economic analysis in agriculture.* MacMillan Publishing Company, New York.

JOHNSON, S.J., ADAMS, R.M. & PERRY, G.M. (1991). The on-farm costs of reducing groundwater pollution. *Amer. J. Agr. Econ.*, 73:1063-1073.

KULA, E. (1992). *Economics of natural resources and the environment.* Chapman & Hall, London.

MOXEY, A. & WHITE, B. (1994). Efficient compliance with agricultural nitrate pollution standards. *J. Agr. Econ.*, 45(1):27-37.

PAN, J.H. & HODGE, I. (1994). Land use permits as an alternative to fertiliser and leaching taxes for the control of nitrate pollution. *J. Agr. Econ.*, 45(1):102-112.

SHORTLE, J.S. & LAUGHLAND, A. (1994). Impacts of taxes to reduce agrichemical use when farm policy is endogenous. *J. Agr. Econ.*, 45(1):3-14.

STEUBER, D.W. (1989). Overview of environmental claims and insurance coverage litigation. In: Miller, L.M. & Mallonee, J. (eds.) *Insurance claims for environmental dagames.* Executive Enterprises Publications, New York.

SWINTON, S.M. & CLARK, D.S. (1994). Farm-level evaluation of alternative policy approaches to reduce nitrate leaching from midwest agriculture. *Econ. Rev.*, 23(1):66-74.

TAUER, L.W. (1983). Target MOTAD. *Amer. J. Agr. Econ.*, 65:606-10.

UNIVERSITY OF PRETORIA (1993). *Agricultural Development Plan : Loskop Valley. Report on Ph ase II : Step 1.* Unpublished Report, Department of Agricultural Economics, University of Pretoria.

XEPAPADEAS, A.P. (1972). Environmental policy design and dynamic non-point-source pollution. *J. Environmental Econ. and Mgt.*, 23:22-29.