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AGRICULTURAL POLICY AND THE ENVIRONMENT

Proceedings of a Conference Sponsored by

University of Minnesota
Center for International Food and Agricultural Policy

Agricultural Development Regional Agency (ESAV)

University of Padova

Motta di Livenza, Italy
June 19-23, 1989

Department of Agricultural and Applied Economics

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FORWARD

The papers in this volume are the result of the First Annual Conference on Agricultural Policy and the Environment, held at Motta Di Livenza, Italy, June 19-23, 1989. This conference resulted from the collaboration of the University of Padova, University of Minnesota and the Ente di Sviluppo Agricolo (the Veneto Regional Development Authority) which provided the lovely setting for the conference. The University of Minnesota Center for International Food and Agricultural Policy has entered into a long-term agreement with these Italian counterpart institutions to study problems of land use, land values, agricultural production and their impact on environmental quality. In both countries, the agriculture/ environment linkage is of growing importance.

The conference proceedings are divided into four volumes, according to the sessions presented.

In the fall of 1990, the Second Annual Conference on Agricultural Policy and the Environment will be held in Minnesota. We look forward to repaying the warmth and hospitality of our Italian counterparts. We would especially like to thank Danilo Agostini, Guisseppe Stellin, Cesare Dosi and the entire staff of the ESAV research station in Molta di Livenza, Veneto, and Judy Berdahl for her typing and editorial assistance.

C. Ford Runge, Director
Center for International Food and
Agricultural Policy

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Land Use and Incentive Schemes for Nonpoint Pollution Control*

by

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January 1990

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Land Use and Incentive Schemes for Nonpoint Pollution Control

I. Introduction

This paper reports an initial attempt at modeling the economic effects of policies to control agricultural nonpoint pollution in a simple spatial equilibrium setting. At this juncture, the analysis is incomplete. We discuss some general issues regarding economic analysis of agricultural pollution control policies, and present a basic equilibrium model to be used in the study of such policies. We are able to offer some tentative results, and several conjectures which give the spirit of the analysis and a notion of where further work is headed.

Some of the ideas discussed here were presented at a meeting of a group of investigators from the Universities of Minnesota and Padova in June, 1989. One purpose of writing a paper at this early stage of research is to provide a written record of the remarks given at that meeting for the benefit of meeting participants and other interested parties. The other, more important purpose is to obtain comments on the model and the potentially interesting questions that it can or cannot answer, and to solicit suggestions to assist us in our continued efforts.

The rationale for undertaking an analysis of nonpoint pollution control in a spatial equilibrium model is an interest in the effects of alternative pollution control policies on equilibrium land values. As well, we are interested in the relationship between policies designed to have an impact on the agricultural sector directly (e.g., price and/or income policies) and environmental policies in this sector.

The model studied here provides an intermediate analysis between the partial equilibrium analysis of much of the literature on environmental economics, and a full general equilibrium analysis of a large country, amenable to investigation via a computable general equilibrium model. Our analysis is tailored to a regional environmental authority within a large country, or to a small country which takes world prices as given. The former interpretation is most natural here; we have in mind specifically the Veneto region of Italy, and concern over water pollution in the Venice Lagoon and northern Adriatic Sea.

The paper is organized as follows. In the next section we begin with a brief discussion of selected issues that arise in the study of agricultural nonpoint pollution problems. This overview provides some general context within which our more detailed and stylized model can be placed. We then present an abstract model of spatial equilibrium within region with agricultural externalities. The fourth section investigates some impacts of different policies for control of agricultural pollution on aspects of the spatial equilibrium. A final section offers some thoughts on further research that might be conducted within this framework.

II. Analysis of Policies for Agricultural Nonpoint Pollution Control

In this section of the paper we discuss some aspects of the general problem of analyzing policies for nonpoint pollution control. By laying out a fairly general view of this problem, perhaps some perspective can be gained on the breadth of the task, and the manner in which the efforts of a variety of investigations help to inform the overall issue.

We illustrate the problem by considering the control of erosion from agricultural land. Sediment itself is a substantial pollutant, as are agricultural chemicals that adhere to particle of sediment as they move from the farm filed to watercourses. Moreover, policies designed to reduce erosion may have some impact on soluble chemicals that leave the filed via runoff. Note that we consider here only the off-site effects of erosion. It is presumed that profit-maximization behavior on the part of farmers leads to a consideration of the effects of erosion on crop yields (McConnell, 1983). While it may be argued that the behavior of farmers and the operation of credit markets does not lead to economically efficient rates of erosion from the on-farm (yield loss) perspective, we focus here on the more obvious external effect of off-site impacts of erosion.

Figure 1 depicts the various facets of economic analysis of erosion control policies. Note that this model takes a fairly traditional view of the policy-analysis problem in its use of a benefit-cost framework; more elaborate political-economic analytical schemes might also be invoked (see Graham-Tomasi, 1989).

Policy and Land Use

The first component of the evaluation of erosion control policies concerns the relationship between that policy and the land use practices that are undertaken by individual farmers. There is considerable research that has been undertaken in this area. Some of this work is economic in nature, assessing the private profitability of alternative farm management practices under alternative policies. Other of the research is more psycho-sociological in its orientation and is directed to determinants of adoption conservation practices.

There are two types of policies that may be of interest in this context. The first is policies that are directed explicitly to the control of erosion; e.g., cost sharing of terracing of farm fields, or land retirement schemes. The second type consists of policies directed to other concerns, but which have an impact on erosion. A leading example here is the effect of price and/or trade policies on farm management practices and the derived demand for inputs in farm production.

A second fundamental distinction may be made between i) no price effect, ii) partial equilibrium price effects, and iii) general equilibrium analyses of the impact of policy on land use practices. In the first kind of analysis it is presumed that there is no effect of changes in land use practices induced by the policy change on prices that prevail for inputs and outputs. For example, it may be assumed that a land retirement policy that leads to reduced hectares planted to maize has no impact on the price of maize. This may be because the policy is applied to a small portion of the maize market. In the second type of analysis, these direct price effects are taken into account. Thus, a reduction in maize hectares may lead to an increase in maize prices, which induces an increase in input demand on the remaining maize hectares, thereby moderating the impact of the policy. The price effects in this partial equilibrium setting are restricted, however, to those directly affected by the program under scrutiny. The final type of analysis extends the scope of the price increase to other economic sectors, with attendant shifts in supplies and demands. Continuing the example, an increase in maize price may increase wages in a region, which may shift out the demand for maize modestly, and exacerbate the moderation of the policy's effect identified in the partial equilibrium approach.

Biophysical Modeling

Having identified the effect of a set of alternative policies on land use practices in equilibrium, in order to predict the impact of these changes on environmental quality, a host of noneconomic investigations must take place. These are identified in Figure 1 in the case of erosion.

One of the key implications of this analytical stage is a recognition of the spatial variation in the impact of a given change in land use in one location on environmental quality at a different location. The ability to recognize this spatial heterogeneity in the design of policy will be of central interest in this paper.

Valuation

A defining feature of an economic policy analysis is the attempt to quantify, using a common metric, the effects of the policy under investigation. Most often, this common metric is money. Two sides of this valuation effort exist: costs and benefits.

The cost side of erosion control policy regards the cost of supplying a given change in environmental quality. These are depicted in Figure 1, and include the administrative costs of the policy, and any negative effects of the policy on producer surplus (rents) and consumer surplus. While perhaps difficult to measure in practice, the identification of the cost of supplying environmental quality is at least conceptually straightforward.

Somewhat more elusive is the measurement of the benefits of conservation policies. These benefits are derived from a demand for environmental quality on the part of consumers. Since these benefits often involve goods not traded on organized markets, there frequently do not exist ready data for the assessment of these benefits. However, in the past two decades techniques have been developed and refined for the measurement of the economic benefits of environmental enhancement.

In Figure 1, the demand for water quality is stated in terms of recreation. This is not meant to imply that all benefits of water quality improvement are realized via recreation. However, recent research in the U.S. indicates that the largest proportion of benefits of erosion control are recreational benefits. The results of two of these studies are depicted in Figure 2. More detailed analysis is available in Rodgers et al. (1990).

A large body of research has been devoted to the use of recreation demand models to assess the benefits of recreation sites. More recently, these models have been adapted to the task of measuring the benefits of altering the characteristics of recreation sites, such as the water quality. Overviews of this literature are provided by Smith et al. (1986), Bockstael et al. (1987), and Fletcher et al. (1990). Applications of these techniques to assessing the benefits of controlling agricultural nonpoint pollution are reviewed by Rodgers et al. (1990).

One aspect of this problem of some interest in this paper is the relationship between objective measures of water quality and their alteration via changes in pollutant loadings, and the perceived characteristics of recreation sites, which presumably determine the demand for recreation. Research on the linkages between these requires cross-disciplinary collaboration. In particular, it is necessary to translate measures of general ecosystem health, to which biological/chemical/physical measures of water quality are directed, into those attributes of water about which consumers care.

Policy Analysis

The final step in the policy analytic scheme depicted in Figure 1 is use of estimates of benefits and costs of erosion control in the evaluation of alternative policies to achieve it. Naturally, it is not the case that only benefits and costs so conceived matter in the formulation of policy. However, it is hoped that their careful consideration and incorporation into the policy process will lead to improved decisions regarding environmental policy.

III. A Spatial Equilibrium Model: The Competitive Equilibrium

In this section of the paper we present a highly stylized model that is designed to capture several of the effects discussed in the previous section. The model developed here is one of spatial equilibrium in a small region. Thus, it has attributes of the partial/fixed price and general equilibrium approaches outlined above. Here, we take as given the prices of produced goods and some inputs (capital/agricultural chemicals), but allow the model to determine equilibrium wages and land rents, as well as the level of environmental quality. In this section the initial competitive equilibrium is set out; in the next section the effect of policies to control water pollution will be studied.

It is important to stress that the model is not intended to incorporate an especially "realistic" description of the Veneto region. However, we have attempted to incorporate some essential features of the region and the relationship between agricultural policies and practices, environmental policies, and water quality in the Veneto.

We begin with a description of the region. For convenience, the region is assumed to be linear. At one end lies Venezia, the central business district (CBD), and a water body (the lagoon). All of the CBD lies at distance zero from the end of the region (i.e., Venezia takes up zero area). Between the CBD and distance s* along the region lies a suburban area, made up of residences of consumers/workers. Between s* and s** lies an area devoted to agriculture.

Naturally, the Veneto is spatially much more complex than this, with a great deal of fragmentation of land use (Franeschetti and Tempestra, 1989). However, the model does capture some aspects of the region.

In the CBD a good is produced using capital, K, and labor, L. As well, production of this good depends on pollution in the lagoon, denoted by Z. Hence, the production function for this good, the output of which is denoted by Y^m, is given by

[1] $$Y^m = f^m(K,L,Z).$$

The good Y^m is produced by a large number of identical firms, who take output price, p^m, the price of capital, k, and the wage rate for labor, w, as given. The production relation in [1] gives aggregate output of Y^m as a function of aggregate input use. We assume that, for any given Z, the production relation in [1] exhibits constant returns to scale (so that in equilibrium, firms make zero profits), is increasing in its arguments, and has strictly diminishing marginal products of the inputs.

The profits earned in the manufacturing sector are given by

[2] $\pi^m = p^m Y^m - kK - wL$

It is assumed that firms maximize profits. Let $L*(p^m,w,k,Z)$ and $K*(p^m,w,k,Z)$ be the profit-maximizing labor and capital demands, found by solving the first order necessary conditions for maximization of [2]. If these are inserted back into [2], the profit function $\pi^{m}*(p^m,w,k,Z)$ is obtained. Application of the Envelope Theorem shows that $\delta\pi^{m}*/\delta w = -L*(.)$, $\delta\pi^{m}*/\delta k = -K*(.)$, where the superscript * means that derivatives are evaluated at the optimal input choices. Moreover, $\delta\pi^{m}*/\delta p^m = Y^{m}*(p^m,w,k,Z)$, which is the supply function for the manufactured good.

A similar envelope argument shows that the change in profits with a small improvement in water quality is given by

[3] $\delta\pi^{m}*/\delta Z = p^m \delta f^{m}*/\delta Z.$

A comparative static exercise reveals that, if an increase in water quality increases the marginal productivity of the labor and/or capital inputs in a neighborhood of an optimum (i.e., $\delta^2 f^{m}*/\delta i \delta Z > 0$; $i=L,K$), then the demand for the input increases with an improvement in water quality, ceteris paribus.

Turning now to the agricultural sector, we need to distinguish between farms located at different distances s from the CBD. We assume that three inputs are used in production at s: land, A(s), agricultural labor $L^a(s)$, and fertilizer, N(s). Let $Y(s) = f(s) = f(A(s),L^a(s),N(s))$ be the output of the agricultural good at location s, where f(.) is the production function, assumed to be neoclassical. Let p be the price of the agricultural good, n be the price of fertilizer, and R(s) be the rental payment per unit of agricultural land. Regarding the rural labor market, we make the simplifying assumption that each farmer is endowed with one unit of labor, which he/she supplies perfectly inelastically to production on his/her farm. There is no opportunity to work off of the farm. However, farm labor can be used for two purposes: crop production or erosion control. Let b be the proportion of the labor endowment devoted to crop production. Finally, let V(s) be the cost per unit of output of transporting the agricultural good to the market at the CBD. Then the profitability of farming at s is given by

[4] $$\pi = [p-V(s)]f(b(s),N(s),A(s)) - nN(s) - R(s)A(s).$$

Note that ours is a static analysis in that soil depth does not appear as an argument in f(.), and hence that current erosion rates do not affect future production possibilities. For more on this issue, see McConnell (1983), or Shortle and Miranowski (1987).

As before, let A*(.) and N*(.) be optimal choices, and let $\pi^*(.)$ be the profit function. These are obtained via maximization of [4] with respect to the variables A and N; regarding b, we assume that the marginal product of labor is increasing at all levels of land and fertilizer application, and hence that the corner solution b=1 is obtained in this initial scenario where there is no private incentive to control erosion. These all are functions of the parameter vector (p,n,R(s),V(s)).

Turning our attention to pollution generation, we assume that the amount of pollution generated per unit of area at location s is an increasing function of $x(s) = N^*(.)/A^*(.)$, an index of the intensity of fertilizer application on a farm at distance s from the CBD, and a decreasing function of labor devoted to pollution control, $1-b(s)$. The pollution loading function per unit of area is denoted by the function $g(.,.)$; total loadings are

$$[5] \qquad z(s) = A(s)g(x(s),1-b(s)).$$

We take it that g is strictly concave. It is necessary to translate pollutant loadings at each point in space into ambient water quality at some point where water quality is demanded. We model this by assuming that water quality is demanded only at the CBD. The natural amelioration of the effect on water quality of loadings generated at one place during its transportation to another is modeled via a "distance-decay" function $c(s)$. Then $c(s)z(s)$ gives the contribution to aggregate loadings at the CBD of pollution generated by farming at location s. Total loadings of pollutants at the CBD are given by

$$[6] \qquad Z = \int_{s^*}^{s^{**}} c(s)g(s)ds.$$

As alluded to in the previous section, loadings of pollutants and attributes of water quality demanded by consumers are not the same thing. Let perceived water quality be given by $Q = Q(Z)$; it makes sense to assume that, at least over some range, Q is a decreasing function of Z.

Finally, we turn our attention to modeling the household sector. It is assumed that people live between the CBD and the boundary between the residential and agricultural sectors at s^*. Individuals demand housing services, denoted by $h(s)$, the unit cost of which is given by residential rents $r(s)$. Consumers at s also enjoy consumption of the manufactured good, $y^m(s)$, and the agricultural good, $y(s)$. Consumers are endowed with one unit of labor, which they supply at the CBD perfectly inelastically, and for which they receive wages w. While at the CBD, they purchase goods and also "consume" water quality Q. They must travel to the CBD once each period to undertake these activities; the cost of commuting is v(s), with $v'(s) > 0$. Consumers are assumed to be identical with the representative consumer having utility function $\hat{U}(h,y^m,y,Q)$. Demands of consumers located at s are assumed to be generated as the solution the maximization problem

[7] $$\max \hat{U}(h(s),y^m(s),y(s),Q(Z))$$
$$\text{s.t. } p^m y^m(s) + py(s) + r(s)h(s) = w - v(s).$$

As with input demands and supplies, we denote with an asterisk the solutions to the problem stated in [7]. These are functions of the parameter vector $(p^m,p,r(s),w,Q)$. Let the indirect utility function, obtained by substitution of the demands back into the utility function, be denoted by $U(p^m,p,r(s),v(s),w,Q)$.

Aggregation across consumers is straightforward. Since each "house" contains one consumer, the density of consumers at location s is given by $1/h^*(s,.)$, whence aggregate demands for goods are just

[8a] $$y^*(.) = \int_0^{s^*} 1/h^*(s,.)y^*(s,.)ds$$

[8b] $$y^{m*}(.) = \int_0^{s^*} 1/h^*(s,.)y^{m*}(s,.)ds.$$

Aggregate labor supply equals the total population of consumers in the region, N, i.e.,

[9] $$P = \int_0^{s^*} 1/h^*(s,.)ds.$$

Having constructed the pieces of the economy, we now are in a position to define a competitive equilibrium. Two crucial assumptions are made at this juncture: that the region of interest is small, and that it is open. By smallness it is meant that the region takes as given the prices of goods traded outside of the region. We assume that the manufactured and agricultural goods are traded, as is capital; hence, p^m, p, and k are parameters of the system. By openness is meant that individuals are free to move within and between regions. This implies that the level of indirect utility attained at all points in the region is a parameter; let this level of utility be U*. In terms of prices, these assumptions leave the wage rate and the residential and agricultural rents as endogenous variables. The overall competitive equilibrium consists of the following equations/identities.

[10] $Y^*(p,R(.)) = y^*(p^m,p,r(.),v(.),w,Q)$

[11] $Y^{m*}(p^m,w,k,Z) = y^{m*}(p^m,p,r(.),v(.),w,Q)$

[12] $L^*(p^m,k,w,Z) = P(p^m,p,r(.),v(.),w,Q)$

[13] $K^*(p^m,p,w,Z) = \underline{K}$

[14] $U(p^m,p,r(s),v(.),w,Q) = U^*$

[15] $\pi^{*u}(.) = 0$

[16] $\pi^*(.) = 0$

[17] $r(s^*) = R(s^*)$

[18] $R(s^{**}) = 0.$

Equations [10] and [11] require that aggregate supply equals aggregate demand for the two goods in the economy. Equation [12] concerns the labor market, and requires that labor demand equal the population of the region, which is labor supply by the assumption that each agent is endowed with one unit of labor. Equation [13] specifies that the demand for capital at the prevailing prices equal the region's capital endowment. Equation [14] expresses the openness condition that all agents achieve the utility level V* irrespective of their location. Equation [15] and [16] are simply zero-profit conditions generated by free entry into these sectors in the usual fashion.

Equation [17] is an important equilibrium condition regarding the rent gradient: it must be continuous over the boundary between the residential and agricultural areas. This condition results from an elimination of arbitrage opportunities in land uses; if it does not hold profits could be made by converting land from one use to another. This condition reflects the absence of any governmental policies directed to land use practices in this initial equilibrium. In fact, it may be that current policy favors agriculture and protects, via zoning, agricultural land from conversion to nonagricultural uses. In this case, the initial "competitive" equilibrium would have [17] replaced by $r(s^*) > R(s^*)$; i.e., residential rents would exceed agricultural rents at the land use boundary, and the observed rent gradient would be discontinuous there. Absent zoning regulations, this is not a sustainable situation, since money could be made by transferring a unit of land from agricultural to residential use. Here, we abstract from this sort of circumstance and suppose that the initial equilibrium embodies no explicit government agricultural policy. Equation [18] merely defines the edge of the region.

The exogenous parameters in this model are the prices of the manufactured good (p^m) and the agricultural good (p); the input prices of capital (k) and fertilizer (n); the transport costs for agricultural goods

(V(.)) and for commuting (v(.)); and the utility level V*. The endogenous variables are the land rent schedules for residential (r(.)) and agricultural (V(.)) land uses; the wage rate (w); the input demands in manufacturing (L* and K*); the density of housing (1/h*); the input demands in agriculture, (b*, A*, and N*); total population (P); the land use boundaries (s* and s**); and the levels of pollution and water quality (Z and Q).

It is beyond the scope of this paper to deduce conditions under which an equilibrium will exist; see Miyao et al. (1980) for an analysis of this issue in a similar, though not identical, setting. Some features of the initial equilibrium are of interest, however.

The Envelope Theorem implies that

[19] $$\delta\pi^*/\delta s = -V'(s)f^*(.) - A^*(.)R'(s).$$

Now, competitive equilibrium requires that all farm firms make zero profits. Hence, $\pi^*(s) = 0$, from which it follows that $\delta\pi^*/\delta s = 0$ for all s. Then [19] shows that

[20] $$R'(s) = -V'(s)f^*(.)/A^*(.) < 0,$$

where the inequality follows from an assumption that $V'(s) > 0$, i.e., it costs more to transport crops longer distances. Thus, we have shown that agricultural land rents must fall with distance to the CBD, as one expects.

A similar result can be demonstrated for the residential sector. Since $U(.) = U^*$ by the openness assumption, the total derivative of U(.) with respect to any variable equals zero. Differentiating with respect to s and rearranging yields

[21] $$-\frac{\delta U/\delta r}{\delta U/\delta v} = \frac{v'(s)}{r'(s)}$$

By assumption, $v'(s)$ is positive. Since the left hand side is the ratio of a price derivative and the negative of an income derivative, the LHS has a negative sign. Thus, for the RHS to also have a negative sign, $r'(s)$ must be negative, which says that rents fall as one moves away from the CBD.

By Roy's Theorem, the entity on the LHS of [21] is the negative of the demand for housing services. The manner in which the demand for housing changes with distance form the CBD is ambiguous, since it depends on whether the decrease in price outweighs the decrease in income as s increases. It makes sense that as s increases the demand for housing services rises due to the price effect; in this case the population density, $1/h^*(s)$, falls with s.

IV. Pollution Control Policies

We begin this section of the paper by characterizing the Pareto efficient regional economy. This is done by appropriately specifying a social planner's maximization problem and interpreting the resulting necessary conditions for a maximum. Naturally, a comparison of the competitive equilibrium and the solution to the social planner's problem reveals that the competitive equilibrium is not Pareto efficient, due to the external effect of farming activities on water quality. We then explore the features of an optimal taxation scheme for the control of pollution. Since farmers are spatially heterogeneous, one would think that optimal taxes must be spatially heterogeneous as well. This turns out to be the case. We then examine the effects of a spatially homogeneous tax system. Such a second-best solution may be implied by an absence of information or a constitutional limitation on distinguishing among farmers in their tax rates based on their location.

Surprisingly, it is found that taxes on pollution cannot be alone to sustain the Pareto optimum in a decentralized economy. In the initial equilibrium, farm firms engage in excessively intensive production practices, and a tax on sediment can solve this distortion on the intensive margin of agriculture. But also is true that farm firms are "too close" to CBD: moving the farms farther away from the CBD will lead to an improvement in water quality due to the decay function c(s). Continuity of the rent gradient at s* therefore is inefficient. A zoning policy which can sustain a gap between the agricultural and residential rents also is needed to obtain a Pareto optimum.

The social planner's problem can be specified as maximization of one consumer's utility (or equivalently, since all consumers have the same utility function, maximization of consumers' utility at one location), subject to achieving a fixed level of utility for other consumers, and subject to production/distribution constraints implicit in the above economy. In order to accomplish this, we choose the agricultural good as the numeraire commodity for "payments" of transport and commuting costs. The Lagrangian expression for the social planner's optimization problem is

$$[22i] \qquad H = \int_0^{s^*} \lambda_1(s)\left[\hat{U}(h(s),\, y^m(s),\, y(s) - \frac{V(s)}{\delta\hat{U}/\delta y},\, Q(Z)) - U^*\right] ds$$

$$[22ii] \qquad + \lambda_2 \left(\int_{s^*}^{s^{**}} f(A(s),\, b(s),\, N(s))\, \frac{1}{A(s)}\, ds - \int_0^{s^*} \frac{1}{h(s)}\, y(s)ds \right)$$

$$[22iii] \quad + \lambda_3 \left(f^m (K, L, Z) - \int_0^{s^*} \frac{1}{h(s)} y^m(s)ds \right)$$

$$[22iv] \quad + \lambda_4 \left(\int_0^{s^*} \frac{1}{h(s)} ds - L \right) + \lambda_5 [K - \underline{K}]$$

$$[22v] \quad + \int_{s^*}^{s^{**}} \lambda_6(s)(1-A(s))ds + \int_0^{s^*} \lambda_7(s)(1-h(s))ds$$

$$[22vi] \quad + \lambda_5 \left(\int_{s^*}^{s^{**}} c(s)g(x(s), 1-b(s))ds - Z \right)$$

The first line is the constraint that utility levels achieved at all locations must be equal; without loss of generality, this line also incorporates that maximand with the understanding that the Lagrange multiplier for that location is equal to one. The second and third lines express market clearing conditions. The fourth line provides the labor constraint and the capital constraint. The fifth line ensures that quantities of land demand at each location equals supply at that location. The last line provides the tie between agricultural production and water quality.

Maximization takes place with respect to all of the choice variables in the economy, as listed in the previous section. Here, we attend only to two key elements of the model: input use in the agricultural sector, and the urban/rural boundary, s. Our presentation here is informal, since a complete derivation of the result proceeds via tedious algebraic manipulations.

Rearrangement of the first order conditions for a maximum and substitution of the appropriate prices from the competitive economy for the shadow prices represented by the Lagrange multipliers yields the following conditions for optimal input use in agriculture.

$$[23] \qquad [p - V(s)] \frac{\delta f}{\delta A} (\cdot) - R(s) - Mc(s) \frac{\delta g}{\delta A} = 0$$

$$[24] \qquad [p - V(s)] \frac{\delta f}{\delta N} (\cdot) - n - Mc(s) \frac{\delta g}{\delta N} = 0$$

$$[25] \qquad [p - V(s)] \frac{\delta f}{\delta b} (\cdot) - Mc(s) \frac{\delta g}{\delta L} = 0$$

where

$$[26] \qquad M = \int_0^{s^*} \frac{\delta \hat{U}}{\delta Q} \frac{\delta Q}{\delta Z} \left(\frac{1}{\delta \hat{U}/\delta y} \right) ds + \left(\frac{\delta \hat{U}/\delta y^m}{\delta \hat{U}/\delta y} \right) \frac{\delta f^m}{\delta Z}$$

Clearly, the expression M represents the marginal damages from an increase in water pollution in the CBD. These damages come form two sources: the aggregate effect on consumers, and the effect on the production of the manufactured good. These impacts are valued in terms of the marginal utility of the numeraire good.

A comparison between the conditions for a competitive equilibrium and those for a Pareto optimum suggests an incentive scheme for the internalization of the pollution externality. Suppose that a tax is levied on pollution generated at the edge of the farm field. Let t(s) be the magnitude of this tax at location s. The farmer's objective function becomes

$$[27] \qquad \max\ [p-V(s)]f(b(s),N(s),A(s)) - nN(s) - R(s)A(s) - t(s)A(s)g(N(s)/A(s),1-b(s)).$$

The first order necessary conditions for a solution to [27] are identical to those for Pareto efficient input use if the pollution tax t is set such that

$$[28] \qquad t(s) = c(s)M.$$

It is important to note that the optimal tax scheme is such that a different tax is levied on farmers at each location. They differ due to the decay function c(s). An alternative scheme would levy the same tax on every farmer at the rate M, but the tax would be assessed per unit of increase in Z. If the central planner and the farmer both know the decay function c(s) and the planner can distinguish pollutants by their origin, then these two schemes are equivalent. It also is possible to sustain a Pareto efficient outcome via the taxation of inputs, as long as these are taxed at the rate $c(s)M\ \delta g/\delta i$ for input i. In the case of labor, a tax on labor use in production and a subsidy on labor use for pollution control have identical effects. A tax on the output of the agricultural good is unable to achieve an efficient outcome in general, since this may induce a reduction in pollution, but not in a cost-minimizing fashion.

It is clear that the levying of a tax on pollution (or on inputs) leads to a reduction in profits in the agricultural sector, ceteris paribus. Absent any other economic adjustments, this leads to negative profits being earned at all locations. Given the assumption of constant returns to scale in agricultural production, we know that profits in equilibrium are zero. By the small/open assumptions, the price of the fertilizer input, and of output is fixed. Hence, all that can adjust to allow zero profits in the after-tax equilibrium is the rent paid at each location.

Let $R^e(s)$ denote the agricultural land rent schedule in the efficient equilibrium. By the reasoning of the preceding paragraph, $R^e(s) \leq R(s)$ for all s; with these equal only if $c(s) = 0$; i.e., only if pollution generated at s has no impact on water quality in the CBD. It also is clear that $(R(s) - R^e(s))$ is a decreasing function of s. Thus, the rent gradient in the after-tax equilibrium is flatter, if its slope is negative. It may be that the externality effect outweighs the transportation effect over some locations and that the efficient rent gradient is positively sloped.

The effect on the consumers is somewhat ambiguous. Clearly, since Z has fallen consumers may be better off, depending on the perceptions function Q(Z). If M is positive due to the consumer sector (i.e., the first term of [26] is positive), then consumers are better off, ceteris paribus. But by assumption, their equilibrium level of utility must remain unchanged at U^*. Thus, since the prices of the goods are fixed, and capital is owned by absentee capitalists (consumers only own labor), two adjustments can take place: residential rents may rise, and/or wages may fall. Note too that if tax revenues are returned to the regions residents in a lump-sum fashion, then they are better off through this effect as well, and rent increases/wage decreases are needed.

The economic mechanism for this is through in-migration. An increase in the utility level of consumers in the region above U* makes this region attractive relative to other regions in the economy. Since migration is assumed to be costless, individuals move to the region. This increases the demand for residential land, which raises land rents, and lowers utility back toward U*. This also increases the supply of labor, which acts to lower wages, which also reduces utility. The overall wage effect is ambiguous, since the demand for labor in manufacturing is affected by the change in pollution. In the case where labor demand falls with improvements in water quality, wages fall unambiguously. If the demand for labor increases, as seems likely, it is possible that wages go up in the efficient equilibrium, if the demand effect outweighs the supply effect. In this case of rising wages, residential land rents must rise by more than if the wage rate falls.

The assumptions here that the capital market in manufacturing is exogenous is untenable as a long-run proposition. If both the supply of capital and its price are fixed, then wages must rise in the after-tax equilibrium , since enhanced water quality leads to increased profits in manufacturing, and a wage increase is needed to re-equate these to zero. If the water quality improvement increases the demand for capital (as is likely, though not assured, since part of the initial capital could have be devoted to water treatment), then an increase in the supply of capital to the region will be forthcoming. In this case, the effect on wages is again ambiguous, since capital expenditures will go up, which provides an alternative means for equating profits to zero.

Since agricultural rents fall and residential rents rise, in the absence of any further intervention in land use, the urban/rural boundary will expand outwards: $s^{e*} > s^{*}$. This is based on the rent-equilibrating arbitrage activity discussed earlier in the paper, which leads to the condition $R^e(s^{e*})=r^e(s^{e*})$. However, this equilibrium condition does not characterize a Pareto optimum. When society recognizes the environmental consequences of agricultural production, the social planner wishes for the agricultural activities to be moved farther from the CBD. This holds even for the after-tax equilibrium in which inputs optimally are being used at each location.

In the efficient equilibrium, a zoning regulation is required which sets the efficient boundary even farther from the CBD that the s^{e*} determined by arbitrage behavior. The efficient rent gradient has a discontinuity, with agricultural land rents lying <u>above</u> residential rents at the boundary. Thus, the rent gradient jumps upwards at the boundary. Zoning is needed to prevent the conversion of residential land to agricultural use, since otherwise, profits could be made from such a transaction.

Naturally, if such zoning is not undertaken then too much land will be devoted to agriculture. As well, consumers will not be as well off as they might otherwise be, and it will be the case that residential rents will not rise, and/or wages fall, by as much as they should.

Finally, it is possible that the tax levied on agricultural pollution (or on input use) may be spatially homogeneous. In this case, the agricultural rent gradient will fall in the after-tax equilibrium, but it will not get flatter. The overall effect depends on how the tax is levied, i.e., whether it is set corresponding to the efficient tax at the inner boundary of agricultural production, the outer boundary, or somewhere in between. For the sake of argument, suppose that it is set equal to average marginal impacts of agriculture with the same overall amount of pollution is reduced. Farmers close to the CBD are undertaxed relative to an optimum, while those farther away are undertaxed. Thus, with the agricultural rent gradient too steep, the urban/rural boundary is too close to the CBD.

V. Discussion

This paper has presented some initial exploration of a model for the study of environmental policies directed to agricultural pollution in a regional setting. Obviously, the analysis is incomplete, and many of the more interesting questions are not addressed. However, it appears that the ability to gain insight into the issues involved is enhanced by investigation of this model. In particular, the formal model embodies many of the features of the general, schematic model proposed in section II. Our model needs improvement on two counts: the treatment of trade, and the treatment of the manufacturing sector.

The paper here did not address the trade implications of unilateral environmental policy formulation at the regional level. This was odd, since trade is what allows the fixed price assumption in the first place. Implicit in the analysis are trade activities and a balance of trade constraint balance; modification of the current paper to make this explicit is straightforward. But a detailed analysis of how trade positions change when environemtnal policies are introduced is not so straightforward. This issue is being investigated by the senior author, jointly with Amit Batabyal in a similar model.

As well, the manufacturing sector is porrly handled here. This sector has only one two variables to be determined in equilibirum: labor demand, which contributes to the determination of wages, and the impact of environmental quality in manufacturing, which effects marginal damages, as well as labor demand. The capital sector, and the possibility and price-modifying entry was circumvented by assumptions designed to make the analysis tractable. This will be improved upon in future research.

One issue which did not receive attention is the interplay between agricultural policies devoted to prices and/or incomes in the agricultural sector, or to zoning regulations which inhibit the transfer of land from agricultural to urban land uses. Clearly, these policies work in the opposite direction to those which are directed to environmental concerns. We have shown that the agricultural rents should fall relative to the competitive equilibrium; a policy which increases the price of farm products, or which transfers income to farmers leads to an increase in rents. In this case, the urban/rural boundary is even closer to the CBD than it should be if environemtnal concerns are recognized. This leads to a situation in which residential rents are too low and wages too high relative to an efficient allocation.

There are many instances in which positing a regional environmental authority is realistic, and the prices of many goods are fixed for the region. Perhaps a good example is the Veneto, and other areas within the EEC, where local authorities may set pollution guidelines to achieve regional goals, but a braoder economic milue governs equilibira that may obtain. However, it clearly would be desireable to relax some of the fixed-price assumptions invoked here. Current research by the authors is devoted to this task. Of course, the increased generaltiy reduces the specificity of the results that can be obtained.

Finally, much of this analysis by-passes what might be the defining feature of agricultural pollution: its nonpoint nature. The nonpoint attributes render untenable the assumption that the central authority can set optimal taxes for each location based on actions taken there. Segerson suggests that, in this nonpoint setting, uncertainty becomes key, and proposes a principle-agent framework for the design of policy. Her analysis does not consider land use changes (although they are mentioned briefly). A topic of future research is the recognition of true nonpoint problems addressed by Segerson, but in the spatial equilibirum model proposed here.

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LAND USE AND ENVIRONMENTAL QUALITY: A CASE STUDY

by

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1. Introduction

With laws no. 72/1980 and 40/1984 the Veneto Regional Government included the Caorle and Bibione lagoon areas in the list of areas destined to be subjected to projects of environmental and landscape conservation. Following this decision, various groups, ecologists in particular, presented the Regional Government with a number of projects for setting up a regional nature park (1). There was also a public debate in which the various local interest groups took part (farmers, hunters, fishermen, ecologists, tourist operators, etc.), culminating in a conference which, above all, highlighted the notable levels of conflicts between the various groups.

At a later date the Regional Government presented the Regional Territorial Coordination Plan (law no. 7090/1986) in which it repeated its desire to establish a regional nature park in the Caorle and Bibione lagoons, partly accepting the proposals which had been made previously. The problem, however, is far from being resolved, given that the local administrations have decided simply not to discuss it any more.

This paper presents the results from a research project aimed at evaluating alternative rural territory managerial schemes.

The opportunity of confronting a concrete problem regarding the definition of guidelines for elaborating the Park Project allowed us to check the potential of one of the methodologies elaborated for dealing with land-use

(1) According to the regional legislation, a regional nature park is defined as "...an area of the regional territory of particular natural and environmental interest in which the rigorous protection of the waters, vegetation and fauna may be accompanied by scientific activities and controlled forms of excursions and tourism" (Regional Law 40/80, art.2).

planning problems in contexts characterized by several conflicting objectives.

The approach adopted is multi-criterial (2). The methodology allows for organizing analysis in a strictly logical sequence to assess the 'overall desirability', in terms of agricultural production and environmental conservation, of the different regulatory schemes proposed for managing the protected area.

Section 2 describes the physical, economic and environmental setting for the case study, followed by a presentation of the data collection procedures and mode of model construction (par.2 and 3). The findings are then presented (par.4). The final section provides the conclusions.

2. Study Area Characteristics

The area involved in the park (approx. 15,000 hectares) is situated in the east of the province of Venice (fig.1) between the Livenza and Tagliamento rivers and borders on the Adriatic sea. It is a typical rural area where land reclamation has been carried out over the centuries; only about 10% of the the area is still part of the lagoon or "valli" (3).

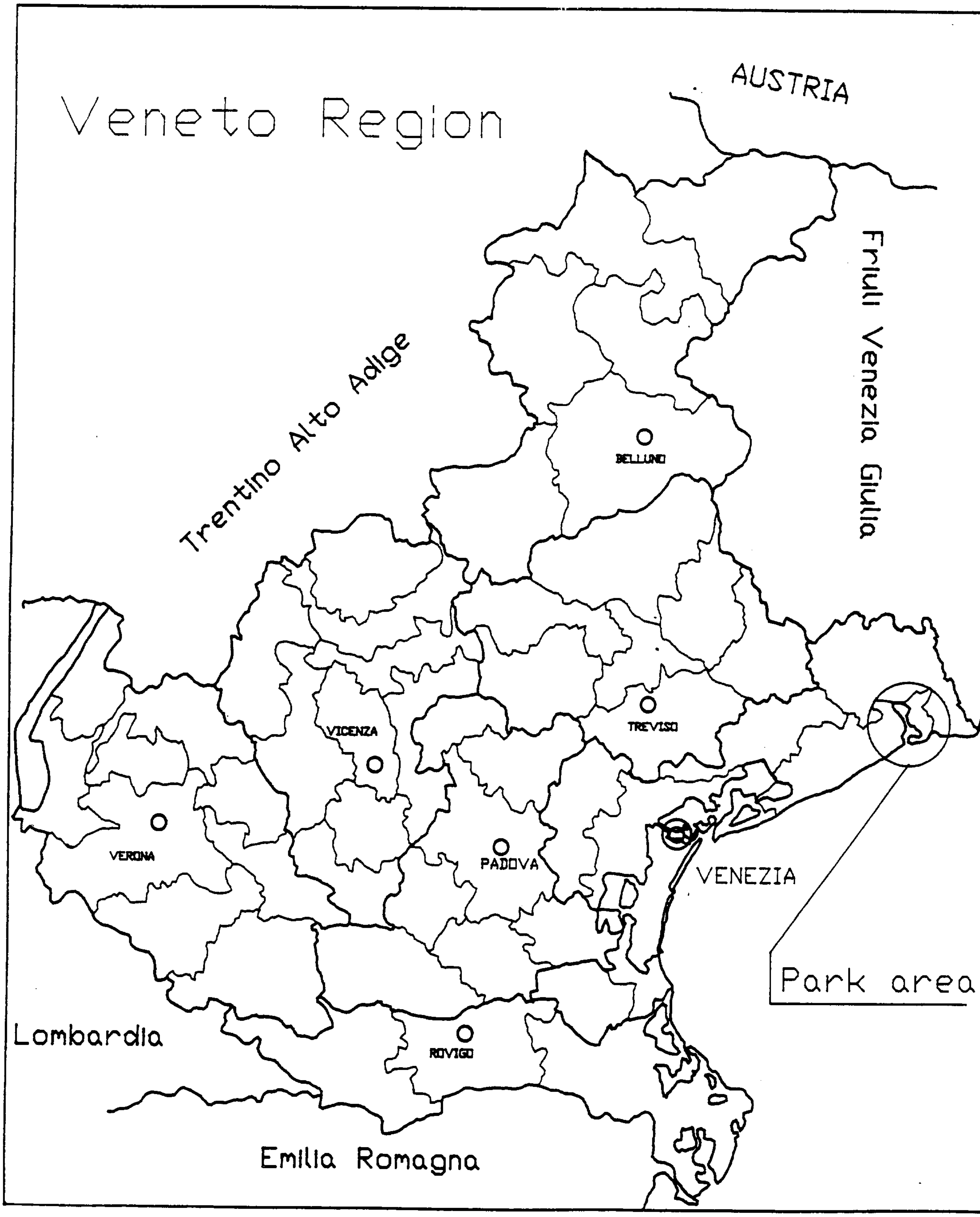
The population, living largely in small villages or isolated houses, is prevalently employed in tourism or in related occupations. The area of the park in fact borders on the tourist resorts of Caorle, Bibione' and Lignano beaches.

Agriculture is still however the most important activity within the park, if not for any other reason, because almost all the natural resources are managed by farmers. Unlike other areas of the Veneto region, here the farmers own large properties, employing hired workers. The farmland is largely used for cultivating cereals and industrial crops. There are few cattle rearing farms, though these are of notable size.

(2) The procedure adopted, known as VISPA, is that proposed by Colorni, Laniado and Rosace in the version implemented on PC (A.Colorni, E.Laniado and F, Rosace, "Valutazione integrata per la scelta tra progetti alternativi", VISPA - CLUP, Milan, 1988). It allows for rapid and easy consultation of the data collected and evaluation of all the aspects connected with the decision-making process.

(3) The term "valle" is intended to mean a salt-water lagoon varying in size between 1 and 1000 ha, sub-divided into smaller basins and surrounded by earth banks separating them from the surrounding waters, making it possible to regulate the level and volume of the water and to exploit the seasonal migration of fish which is caught when descending towards the sea.

Fig. 1 - The park area



Other significant activities here - which are usually included in the primary sector - are fish-farming and fishing. There are in fact five "valli" which, according to their distance from the sea and hence the level of saltiness in the water, produce fish of differing commercial value (mullet, eels, bass, dory, etc.), thus providing different unitary income levels; such income is often supplemented by renting the "botti" (shooting posts) during the hunting season. Alongside the fish-farming there is also fishing as such. Particularly in the spring a number of families supplement their income by catching young fish in the canals and selling it to the fish-farms where it is used for reproduction.

There are no tourist centres or seaside resorts in the park area (Caorle and Bibione are actually outside the area), even though there is a movement in favour of building hotel structures and tourist ports, as the coastline along the park is perhaps one of the few non-urbanised areas left along the coast between Venice and Trieste. The only tourist activities present in the park consist of excursions by boat in the lagoon, a small number of restaurants and a few examples of on-farm tourism. The present pattern of tourism, based entirely on the beaches and infrastructures, leads one to exclude the possibility that in the future the park should be inserted into the "package" of tourist attractions (unless it is urbanised for touristic purposes). The influence of the seaside resorts on the area should thus be considered more in terms of job-opportunities for the resident labour force, rather than as a pressure on the environment.

The lagoon areas and the stretches of land along the coast are the most significant areas from the environmental point of view, due to the abundance and variety of animal and vegetal species and the delicate dynamic equilibrium between the members of the different species. In this environment there are a number of animal and vegetal species of scientific and naturalistic interest, some of which are endemic and subject to the risk of extinction. The cultivated area is also of environmental importance, however, given the impact it may have on the lagoon and coastal area (in terms of fertilizers, pesticides, etc.) and also because it is used as a resting and grazing area by the various species of local and migratory birds.

The lagoon's ecosystem is in a somewhat precarious state today, both because the outlets to the sea have been earthed up (thus limiting the flow of water) and because of the notable quantities of pollutants carried by the rivers and canals draining the fields. The sources of water pollution are point and non-point and can be attributed to urban run-off, herbicides, livestock farms and the release of nitrogen and phosphorus from the fields (4) which in the summer cause the well-known phenomena of algae bloom.

3. The Evaluation Model

Having defined the objectives and described the various aspects of the case study (see fig.2), the following phases were carried out: a) identification of **actions** and construction of **alternative hypotheses**; b) selection of the **indicators** and measurement of the impacts; c) construction of the model.

a) Identification of the actions and construction of alternative hypotheses.

Identification of the **actions** (5) was undertaken on the basis of the indications contained in various documents such as the temporary conservation measures in the relative regional legislation; the various proposals and counter-proposals presented to the Regional Government in recent years; regional and Community legislation on this subject; publications regarding this or similar areas.

Screening was undertaken on this pool of actions on the basis of their significance (6), i.e. the impact they have on the sectors involved: agriculture, fish-farming and the environment.

By aggregating the different actions in logical patterns, the set of **alternative hypotheses** was constructed; they are differentiated in terms of the type of action and mode of application on the territory and also with respect to the size of the park area.

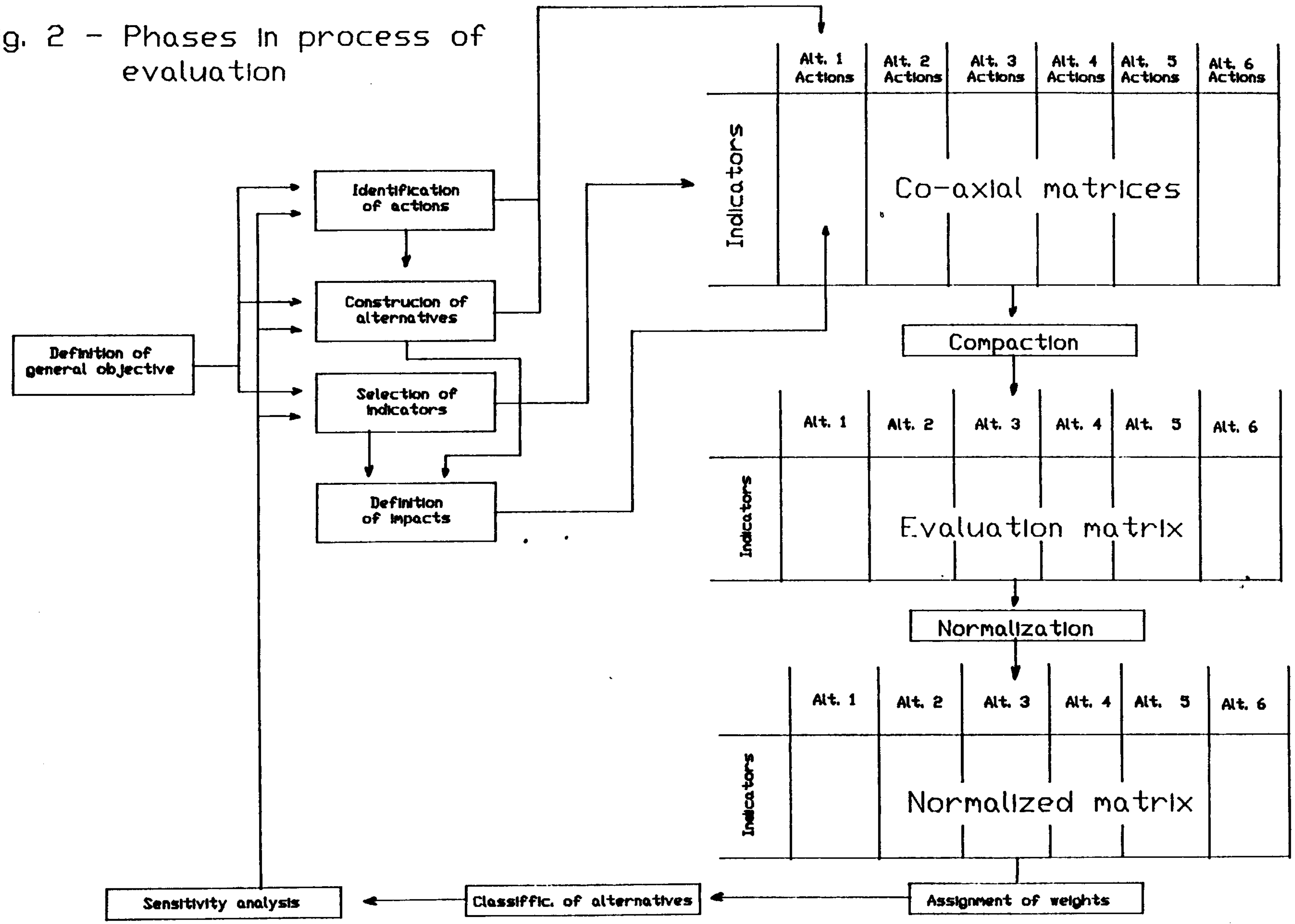
The hypotheses are as follows (see also Appendix 2):

(4) On average 25 kg/ha of N and 0.7 kg/ha of P annually (L.Giardini, C.Giupponi, 1988).

(5) Referring to the positive or negative indications (prescriptions or constraints) which may cause modifications in the present situation or behaviour according to the objectives established.

(6) An action is considered to be significant in its impact if: a) it generates an appreciable effect on at least one of the environmental indicators considered; b) it is able to modify an activity in the primary sector by reducing income and/or employment; c) it is susceptible to technical specification.
The evaluation was undertaken by assigning a score between 1 and 3 for each impact produced by the specific action on a single sector (see Appendix 1). The actions with total scores of at least 6 were chosen.

Fig. 2 - Phases in process of evaluation



Alternative no.1: maintenance of the present situation.

Alternative no.2: application of a single constraint, implying that 20% of the area would set-aside (Reg.Decree n.852/1989)

Alternative no.3: limitation in the use of herbicides over the entire area and application of alternative agronomic practices.

Alternative no.4: distinction between a nature park area (corresponding to the more fragile and environmentally interesting areas) and an external "pre-park" area (decree law 522/1984). Large-scale pig and cattle farms (with more than 1000 animals) are prohibited over the entire area, while in the park area the use of fertilizers is reduced and hunting is banned.

Alternative no.5: (decree law 172/86), the area is divided into five zones:

1) controlled urban development zone,
2) protected production zone,
3) general nature reserve zone,
4) oriented nature reserve zone
5) integral nature reserve zone.

Large-scale pig and cattle farms (with more than 1000 animals) are prohibited in the entire area, while in the protected production zone the use of fertilizers is reduced and hunting is controlled in the nature reserve zone.

Alternative no.6: on the basis of the territorial division outlined above, large-scale pig and cattle farms (with more than 1000 animals) are prohibited in the entire area; hunting is prohibited in zones 3), 4) and 5); set-aside practices are undertaken in zone 2); alternatives to herbicides are adopted in zones 1) and 2).

b) Selection of the indicators and measurement of impacts

The **indicators** in the various sectors considered were selected on the basis of the general objectives that had already been established and in accordance with the concerns expressed by the public decision-maker with respect to the activities involved.

Regarding agriculture, the indicator chosen was net income, as this is not only the parameter of reference for managerial choices, but is also likely to be an indicator relevant from the public decision-maker's point of view.

Taking a random sample of farms, stratified according to their size and type of production carried out in the area, the average unitary incomes of ten crops or activities were calculated (7). Total obtainable incomes were calculated with reference both to the current situation (i.e. Alternative 1) and the other five Alternatives (8).

With respect to fish-farming, reference was made to net income. However, as the quality of the fish caught in the various "valle" is differentiated, obtainable income was calculated for each "valle", referring both to the current situation and the other alternatives, by including rent from the "botti" (shooting positions) in this value (9).

Finally, with regard to the environment, the area was divided into four particularly significant zones from the environmental and natural point of view (10). On the basis of the available documentation and studies, the characteristic parameters or indicators of each zone were identified (e.g. water quality, state of the flora, state of the minor fauna, ornithological situation, etc.). However, given the lack of systematic studies in the area with respect to the impacts, values judgements emerging from questionnaires submitted to "particular observers" have been used (11).

c) Construction of the Model

The values calculated previously (both monetary and non-monetary) were then placed in six co-axial matrices (see fig. 2). These matrices analyse the impact of the single actions generated by the six alternative hypotheses

(7) The productions considered were: maize, wheat, soya bean, sugar-beet, pears, apples, vines, milk, beef and pork.

(8) In defining the alternative agronomic practices, reference was made to the relative literature and to specific studies carried out in the area (Giardini 1988; Giardini and Giupponi, 1988). Regarding the set-aside hypothesis, reference was made to regional decree no. 852/1989 for the mode of application and financial incentives .

(9) It was decided not to consider fishing as an autonomous activity, as it is dependent on fish-farming and was hence included in this category.

(10) These zones are: (a) agricultural areas, (b) the waterways where professional and amateur fishing is carried out, (c) the fish-farms or "valli", (d) the "garzaia" (bird nidification area) in Val Perera.

(11) These observers gave a score between 1 and 10 for the value of the different parameters (i.e. the indicators) in each situation, referring both the present situation and the various alternatives.

on the 31 **indicators** selected (11 of which were productive and 18 environmental).

The matrices were then compacted in order to obtain an **evaluation matrix** with 9 indicators, 3 of which were productive and 6 were environmental, with respect to 6 alternatives (12). The data contained in this matrix measure the performance values of each alternative on the indicators.

In order to make a comparison possible -given that the values were not homogenous- the next step was to **normalise** the data (i.e. transforming it into adimensional units) at values between 0 and 1 This operation was undertaken for each indicator on the six values, supposing a linear relationship between the value of the indicator and the parameter of evaluation (13).

4. Choice of Alternatives

In order to evaluate the alternatives the **indicators** must first of all be transformed into **objectives**. This transformation may be carried out, according to the type of objective (14), by referring to the single indicator as a measurement of the level of achievement of the objective(s), or by aggregating different indicators in order to establish a synthetic index. In our case, the synthetic indicators contained in the standardised matrix

(12) A different procedure was adopted for this operation. In order to reduce the number of indicators, the income values regarding the different livestock and crop productions were added together, while for the environmental sector, a sum was made of the scores obtained by each indicator for each zone in which it was considered. Regarding aggregation actions, it was only possible to procede in the above-mentioned manner for those indicators expressed in monetary terms. Before adding together the environmental indicators, it was necessary to correct the values with coefficients expressing the confluence of effects existing among the different actions of a single alternative with regard to the same parameter.

(13) Although this supposition involves a notable degree of approximization, it was necessary to procede in this manner as the relationships connecting the performances of the indicator with the level of utility/non-utility were unknown.

(14) The objective may in fact be expressed by a single indicator (e.g concentration of nitrogen in the waters) or by an aggregation of indicators such as the quality of the environment.

were taken as measurements of the level of achievement of the objectives (both economic and environmental).

In order to classify the alternatives on the basis of their 'effectiveness', one first has to **weigh** the relative importance of the objectives contained in them and then, after multiplying this weight by the value of the objective, carry out the "weighed sum" for each alternative.

As the studies at our disposal only contained indications of a general nature concerning the objectives to be pursued, and there was no interlocuter with whom we could discuss the relative importance to be attributed to the various objectives (an operation which in any case would involve uncertainties and subjective judgements), **different scenarios** were hypothesised, by attributing different weights to the two aggregate objectives, that is agricultural production (A) and environmental quality and conservation (E):

A: 1.0		0.9		0.8		....		0.4
	->		->		->		->	
E: 0.0		0.1		0.2		....		0.6

Given these general "value judgements", distribution of weights for the different objectives was undertaken according to their relative importance (see table 1) (15).

Sensitivity analysis was then carried out on the solutions identified by the model: this was based on identification of the "critical values" of the assigned weights, i.e. the range of weight values (considered one by one) within which the optimal solution is not modified.

If a weight has a low sensitivity, this means that the associated objective has little influence on the order of alternatives and vice-versa. In other words, in presence of low levels of sensitivity, there is a notable reduction in the conflicts connected with assignment of the weight to the specific objective, and hence the value of the unweighed objective is higher.

The arrangement of the alternatives and the sensitivity analysis conducted on the seven scenarios hypothesised above (see tables 2 and 3) allowed us to make the following considerations:

(15) With regard to economic and productive agricultural objectives (crops, livestock and fish-farming), the scores were distributed in proportion ot the contribution made by each of these to the formation of global income in the area. Regarding environmental objectives (water quality, fresh water fish, etc.), on the other hand, scores were assigned according to the relative importance of each parameter/objective as an indicator of the quality of the environment. The observers interviewed expressed their views on such importance when estimating the environmental parameters.

Tab. 1 - Weights attributed to the objectives in the variuos scenarious

	Scenarious						
Objectives	A/E=1/0	A/E=.9/.1	A/E=.8/.2	A/E=.7/.3	A/E=.6/.4	A/E=.5/.5	A/E=.4/.6
Agriculture	0.900	0.810	0.720	0.630	0.540	0.450	0.360
Livestock	0.020	0.018	0.016	0.014	0.012	0.010	0.008
Fish farming	0.080	0.072	0.064	0.056	0.048	0.040	0.032
Water quality	0.000	0.025	0.050	0.075	0.100	0.125	0.150
Fresh wat. fish	0.000	0.008	0.016	0.024	0.032	0.040	0.048
Flora	0.000	0.025	0.050	0.075	0.100	0.125	0.150
Minor fauna	0.000	0.009	0.018	0.027	0.036	0.045	0.054
Mammals	0.000	0.008	0.016	0.024	0.032	0.040	0.048
Wild birds	0.000	0.025	0.050	0.075	0.100	0.125	0.150

i) **Alternative no.1**, representing the present situation is obviously the best solution if little or no weight is assigned to the environment. In other words, present agricultural patterns are only able to provide environmental responses in terms of "concern". In any case, if the environment is given relatively more importance than production, this is the least efficient solution.

ii) **Alternative no.6**, involving maximum restrictions on production (no large-scale livestock holdings, set-aside practices, alternative agronomic practices, no hunting, etc.) is only significant if the environment is considered to be particularly important. In any case, this appears to be the most efficient solution with regard to environmental conservation; with environmental weights > 0.4, this is the systematically dominant alternative.

iii) **Alternative no.** 3 is a dominated solution in a Paretian sense; meaning that, independently of the weight assignment, there will always be a better solution. **Alternative no.** 2 is also systematically dominated (by no.5, for example), though not in a Paretian sense. In fact, its position as a dominated solution depends on the criteria adopted in the distribution of weights within the aggregated objectives of agriculture and the environment.

iv) With regard to **Alternative no.4**, it can be noted that, with greater specification of the territorial restrictions by means of sub-division of the area into a park zone (with greater restrictions) and an external pre-park zone (with less rigid restrictions), the solutions may be improved (see table 2), even though better alternatives may be identified in the various scenarios.

v) **Alternative no.5**, involving further diversification of the zones within the park and specification of the relative restrictions, appears to be the solution which best resolves the conflicts between agricultural production and environmental conservation. The prescriptions contained in this alternative allow one to minimise the impact of the park on the primary sector, while at the same time pursuing environmental objectives up to a certain point. As well as being the best solution, corresponding to the central values of the assigned weights, it is also the alternative which on the whole shows the greatest stability.

Sensitivity analysis (see table 3) allows one to make further considerations on the validity of alternative no. 5. Considering the scenario characterised by a weight distribution A/E 0.9/0.1, one can see how there are sufficient, even if not consistent, variations in the weights of any one of the environmental indicators, to allow one to substitute alternative no.1 with no.5 as the best solution.

Tab. 2 - Classification of the alternative hypotheses in the various scenarios

	Scenarious						
	A/E=1/0	A/E=.9/.1	A/E=.8/.2	A/E=.7/.3	A/E=.6/.4	A/E=.5/.5	A/E=.4/.6
1°	1	1	5	5	6	6	6
2°	5	5	1	4	5	4	4
3°	2	2	4	1	4	5	5
4°	3	4	2	6	2	2	2
5°	4	3	3	2	1	1	3
6°	6	6	6	3	3	3	1

Tab. 3 - Sensitivity analysis of the classification in the various scenarious

Scenarious	Objectives	Left sensitivity	Weights	Right sensitivity
A/E=1/0	Agriculture	Alt.3 <- 0.000	0.900	-
	Livestock	-	0.020	-
	Fish farming	-	0.080	-
	Water quality	-	0.000	0.252 -> Alt.5
	Fresh wat. fish	-	0.000	0.299 -> Alt.5
	Flora	-	0.000	0.095 -> Alt.5
	Minor fauna	-	0.000	0.342 -> Alt.5
	Mammals	-	0.000	0.124 -> Alt.5
	Wild birds	-	0.000	0.114 -> Alt.5
A/E=.9/.1	Agriculture	Alt.5 <- 0.518	0.810	-
	Livestock	Alt.5 <- 0.007	0.018	-
	Fish farming	Alt.4 <- 0.016	0.072	-
	Water quality	-	0.025	0.076 -> Alt.5
	Fresh wat. fish	-	0.008	0.068 -> Alt.5
	Flora	-	0.025	0.044 -> Alt.5
	Minor fauna	-	0.009	0.078 -> Alt.5
	Mammals	-	0.008	0.033 -> Alt.5
	Wild birds	-	0.025	0.048 -> Alt.5
A/E=.8/.2	Agriculture	Alt.6 <- 0.131	0.720	1.589 -> Alt.1
	Livestock	-	0.016	0.047 -> Alt.1
	Fish farming	Alt.4 <- 0.030	0.064	-
	Water quality	-	0.050	0.332 -> Alt.2
	Fresh wat. fish	-	0.016	0.254 -> Alt.4
	Flora	-	0.050	0.408 -> Alt.2
	Minor fauna	-	0.018	0.252 -> Alt.2
	Mammals	-	0.016	0.431 -> Alt.2
	Wild birds	-	0.050	0.197 -> Alt.4
A/E=.7/.3	Agriculture	Alt.6 <- 0.367	0.630	1.594 -> Alt.4
	Livestock	-	0.014	0.087 -> Alt.1
	Fish farming	Alt.4 <- 0.036	0.056	-
	Water quality	-	0.075	0.201 -> Alt.6
	Fresh wat. fish	-	0.024	0.153 -> Alt.6
	Flora	-	0.075	0.235 -> Alt.6
	Minor fauna	-	0.027	0.132 -> Alt.6
	Mammals	-	0.024	0.209 -> Alt.6
	Wild birds	-	0.075	0.163 -> Alt.4

Tab. 3 - continued

A/E=.6/.4	Agriculture	-	0.540	0.603 -> Alt.5
	Livestock	-	0.012	0.142 -> Alt.2
	Fish farming	-	0.048	0.063 -> Alt.4
	Water quality	Alt.5 - 0.070	0.100	-
	Fresh wat. fish	Alt.5 - 0.001	0.032	-
	Flora	Alt.5 - 0.062	0.100	-
	Minor fauna	Alt.5 - 0.011	0.036	-
	Mammals	-	0.032	-
	Wild birds	Alt.5 - 0.073	0.100	-
A/E=.5/.5	Agriculture	-	0.450	0.780 -> Alt.4
	Livestock	-	0.010	0.260 -> Alt.2
	Fish farming	-	0.040	0.131 -> Alt.5
	Water quality	-	0.125	-
	Fresh wat. fish	-	0.040	-
	Flora	-	0.125	-
	Minor fauna	-	0.045	-
	Mammals	-	0.040	-
	Wild birds	-	0.125	-
A/E=.4/.6	Agriculture	-	0.360	0.935 -> Alt.4
	Livestock	-	0.008	0.378 -> Alt.2
	Fish farming	-	0.032	0.200 -> Alt.5
	Water quality	-	0.150	-
	Fresh wat. fish	-	0.048	-
	Flora	-	0.150	-
	Minor fauna	-	0.054	-
	Mammals	-	0.048	-
	Wild birds	-	0.150	-

The stability and validity of this alternative are evident when observing the scenario characterised by weight distribution A/E 0.6/0.4; corresponding to this distribution, alternative no.5 is substituted by no.6 as the best solution. In particular, the sensitivity values show that even slight increases in the importance of agriculture and fish-farming are sufficient for a return to alternative no.5 as the best solution.

5. Conclusions

The opportunity of confronting a concrete problem regarding the definition of guidelines for creating a nature park in an area where the interest in agricultural production is associated with conern about the quality of the environment allowed us to check the potential of one of the methodologies proposed today in a global approach to problems characterised by the presence of several objectives of a conflictual nature.

As well as providing useful information for preparing the Park Project, analysis of the results also leads to some considerations of a general nature. Compromise solutions (such as no.3) appear to be the least effective of the alternatives. In fact, restrictions resulting from mediation between concerns and demands that are often of a general character, run the risk of creating negative effects on certain productive sectors outweighing the real environmental benefits. Solutions involving general types of intervention are efficient only if greater importance is assigned to the environment, or in other words, if greater sacrifices are accepted at the productive level. On the other hand, solutions involving detailed diversification of restrictions and prescriptions at territorial level (such as alternatives 5 and 6) appear to be more effective. More specifically, land retirement (at least in the way it is suggested today) does not appear to be particularly effective as a means for achieving environmental objectives, or rather, more precise instruments exist for achieving such objectives more effectively.

The methodology adopted is surely valid. However, it has a number of operative limitations connected with the quantitative and qualitative need for information required for formulating the model. If on the one hand it was easy to identify the alternative hypotheses (as good information was available), problems arose in defining the measure of the impact of the different actions on the environmental parameters, and also in aggregating actions and indicators together, given the presence of co-effects which may vary, in both a negative and a positive manner, aggregate evaluation of the measure of the impact. The phase of assigning weights to the different objectives also requires some delicate evaluations which may be validated to some extent by sensitivity analysis. Sensitivity analysis also makes it possible to check the validity of the indicators assumed as parameters of evaluation in the preliminary phase, and hence reformulate the model as an iterative process.

The major problem, in our view, concerns the lack of knowledge about the utility and non-utility functions, and more generally, the complex of information necessary for converting the indicator measurements into measurements of achievement of a given objective.

The limits indicated do not in any way invalidate the opportunities provided by this methodology, and particularly the possibility of considering heterogenous and at times conflicting objectives in the same model, without having to make use of a common parameter expressed in monetary terms. Finally, organisation of the procedures of analysis and evaluation in a logical sequence, allows one to identify possible contradictions and hence widens the analyst's operative scope.

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Appendix 1: Matrix for evaluating the influence of actions on the sectors present in the park area.

Action	Agri-culture	Fish farming	Eviron. quality
No large-scale livestock farms (1000 cattle)	***	*	***
No introduction of animal and vegetal species that may alter the environment	*	*	***
No new large-scale settlements (including tourist facilities), no new roads, except for agricultural purposes	*	*	***
Only construction of agricultural buildings permitted with volumes not exceeding 0.001 m3/m2	**	*	*
No motor vehicles on off-road tracks, apart from agricultural and civil protection vehicles	*	*	**
Woodland and fallow land may not be transformed into arable land	*	*	**
No felling in the woodland, apart from poplars and felling permitted by public economic plans	*	*	**
No excavations and land movements that may alter the environment	*	*	***
No land reclamation	*	*	*
No interventions modifying water flows and composition apart from those for fish-farming, irrigation, agricult. uses and drinking water	*	*	***
Closure of the lagoons prohibited	*	*	*
No navigation on the canals with motor boats > 5 hp	*	**	**
No professional fishing and limited amateur fishing	*	**	**
No hunting	*	***	***
No unauthorised hunting	*	**	***

Appendix 1: Continued

Prohibited to collect and damage wild flora, geological items and to dispose of rubbish	*	*	**
Proposed reduction of chemical fertilizers in farming	***	*	***
Proposed reduction in the use of herbicides in farming	***	**	***
Proposal to set aside a part of the farmland	***	*	***
No specific activites damaging the resources protected by regional law no. 40/1980	*	*	**
Proposed reduction of pesticides used in farming	***	**	***

*** - very significant
** - significant
* - insignificant

Appendix 2: Matrix for defining the alternatives

	Alternatives												
	1	2	3	4		5				6			
				Ambits		Ambits				Ambits			
Actions				(1)	(2)	(3)	(4)	(5)	(6)	(3)	(4)	(5)	(6)
No large-scale livestock farms (not > 1000 cattle				*	*	*	*			*	*		
No hunting					*						*	*	*
No unhauthorised hunting								*	*				
Reduction in the use of fertilizers					*		*						
Set aside (20% of the farmland)		*									*		
Reduction in the use of pesticides			*							*	*		

Ambits: (1) Pre-park zone
(2) Park zone
(3) Controlled urbanization zone
(4) Protected production zone
(5) General or oriented nature reserve zone
(3) Integral nature reserve zone

GROUND WATER QUALITY AND MINNESOTA AGRICULTURE (UNDER SITE DAMAGES)

K. William Easter and John J. Waelti

Introduction

The ground water quality problem in agriculture can be thought of as a system involving a number of important actors and resource decisions (figure 1). It starts with the farmers who are using chemicals and animal waste products that may eventually reach the ground water. Their actions are influenced by their own utility maximizing concerns and various governmental policies and institutions that constrain their decision set. At the other end of the continuum are those who use the contaminated ground water. In between are the soils, farming practices and climatic events which will influence whether or not these chemicals reach the ground water. Currently, we know too little about how soil characteristics, cropping practices and climatic events interact to affect the movement of chemicals into the ground water. In general, the nature of ground water and ground water movement below the root zone is not well understood. To illustrate this, let me quote from an 1861 decision by the Ohio Supreme Court. A suit arose where someone had a spring on his property, and a neighbor put in a well. The spring dried up--as might be expected. A justice ruled in these words:

> "Because the existence, origin, movement and course of such waters and the causes which govern and direct their movements are so secret, occult, and concealed, an attempt to administer

> any set of legal rules with respect to them would be involved in hopeless uncertainty and would therefore be practically impossible.
>
> "The man with the spring lost." (Blanchard, 1988, p. 5)

Fortunately, we do know more about ground water movements than we did in 1861, but a lot of work is still needed by those physical scientists studying chemical movements in the soil and ground water. Research on ground water pollution can make advances without knowing what happens after chemicals enter the soil, but much more is possible if these relationships are better understood.

Economists can make their major contribution by looking at the two ends of the continuum. They should be working with other agricultural scientists to study the economics of using various chemicals and animal waste products. For example, what changes in government policies, technology or fertilizer prices would it take to get farmers to make effective use of their animal waste products? Many Minnesota farmers who apply manure to their fields only reduce their use of chemical fertilizers by a small amount. The end result is that they apply as much as 60 to 100 lbs. per acre more nitrogen than their corn crop needs in a normal year. What policy or program changes might alter these practices? Can we help develop markets for this "surplus" manure?

Another serious chemical problem involves ground water pollution by herbicides. What would it cost to shift to less polluting weed control practices? If the new "less-polluting" practices provide 80% of the weed control of the old ones, how much will this reduce yields? It may be more profitable for farmers to only have 75 or 85 percent weed control. At what threshold level do weeds cause significant yield reductions and how does this change with crops and moisture conditions? Farmers do not need a perfectly clean field to obtain high yields. We also need to know the cumulative effect of partial weed control. What weeds cause special problems if they are not completely controlled?

By making some minor changes in their research design, weed scientists can collect information that will help us answer these important economic questions. This is an area where collaboration between weed scientists and agricultural economists would enrich the research efforts with only a small increase in funding. We need to know how yields respond to varying levels and types of weed control. This information would help us answer questions, such as what is the cost of less reliance on herbicides, and how might farmers react to a tax on certain herbicides?

Economists are particularly concerned about the losses caused by ground water pollution. We already know that the cost of cleaning up polluted ground water is sufficiently high to preclude clean up as an option for many aquifers. We also know that some types of pollutants are worse than others. Some degrade quickly while others are long lasting. Some cause cancer while others just taste bad. The seriousness of the pollution problem is also directly related to the use to which the ground water is or will be put in the future, and the cost of possible substitutes. If ground water is only going to be used for irrigation, there should be little concern about nitrates. The concern changes if the water is or will be for human or animal consumption. The value of high quality ground water is also much greater if the only other source of clean fresh water is 100 miles away.

Areas Sensitive to Ground Water Pollution

Two quite different parts of Minnesota areas are very susceptible to ground water pollution because of their physical characteristics and the presence of intensive agriculture. In southeastern Minnesota is the area of Karst aquifers where there is no solid bedrock (Figure 2). There are major openings in the rock and any contaminants can easily move into the openings and then through the subsurface to the ground water. It is an area with sinkholes, caves, major springs and underground streams. In Fillmore county, next to the Iowa border, dye tracing showed that one sinkhole is directly connected to the spring which flows into the Lanesboro fish hatchery.

The other area is made up of the sand and gravel aquifers of central Minnesota. Because of the sandy soils overlaying many of these aquifers, chemicals can be readily leached into the ground water. The potential pollution problem is accentuated by intensive irrigation of corn, soybeans and potatoes in the area.

Ground Water Samples

To what extent is nitrate and herbicide pollution a problem in Minnesota agriculture? The answer to this question is not completely clear, however, there are indications that it is a growing problem. For example, in a Fillmore county watershed, an area representative of southeastern Minnesota, 63% of the 52 wells tested had nitrate (NO_3-N) levels in excess of 3 ppm and 21% had levels that exceeded the state's maximum safe drinking water standard of 10 ppm (Alexander and Wheeler). If Fillmore county lowered its NO_3-N drinking water standard to 3 ppm, which one county in the region has already done, over 60 percent of tested wells would not meet the standard.

Two surveys of ground water conducted by state agencies provide a more complete picture of ground water pollution in the state. The Minnesota Department of Agriculture (MDA) did a sample of 100 shallow private wells.

> "The purpose of the MDA pesticide survey was to evaluate the possibility of pesticide movement to ground water in Minnesota. Accordingly, agricultural regions thought to be susceptible to movements of pesticides to ground water were emphasized in state selection. In addition, some wells were selected in regions or conditions that were thought to be less susceptible in order to evaluate results from several hydrologic and agronomic conditions." (Klaseus et al., 1988)

The susceptible areas were defined as:

1. unconfined, superficial aquifers, i.e., the central sand plains, and
2. the karst area of S.E. Minnesota.

The selection of individual wells within these susceptible areas was also targeted at wells with higher probabilities of contamination. In the sand plains, there was an effort to target wells in the immediate proximity of agricultural fields, wells with water tables less than 30 feet deep, wells located in the estimated down gradient direction of ground water flow from an agricultural field, or wells with a history of pesticide or nitrate contamination.

The selection of individual wells in the karst area was apparently less systematic because of the complex geology. It is unclear from the report what, if any, criteria were used to select these wells, although an attempt was made to target wells with higher probabilities of contamination.

The Minnesota Department of Health (MDH) conducted a survey of 400 public wells targeted at the two susceptible areas; the central sand plains and the karst region. There was also an attempt to sample wells with a higher probability of contamination by looking at wells with shallow depths to bedrock, a history of known problems, and wells close to irrigated cropland.

State Survey Results

In the sample of 100 private shallow wells, 23% had concentrations of nitrates over 10 ppm and 61% had concentrations over 1 ppm. For the MDH sample of 400 public wells, 125 (32%) contained between 1.0 and 10.0 ppm NO_3-N, while 28 (8%) contained over 10 ppm. The majority of wells with nitrate contamination were in the central, southeast and southwest regions (Figure 3). However, the sampling was also concentrated in this area.

In our recent study of nitrogen use in southeastern Minnesota, we showed that livestock farmers apply excessive amounts of nitrogen. Taking into account all sources of nitrogen and comparing it with normal crop needs, we found that in the six county area, 64 to 86 lbs. more NO_3-N is applied per acre than the crops needed in an average year (Legg, Fletcher and Easter, 1989). For some dairy farmers, this excess application exceeded 100 lbs. while for nonlivestock farmers, there was no excess application. Much of the excess NO_3-N applied by livestock farmers is very likely to end up in the ground water because of the soil's high permeability.

In terms of pesticide contamination of wells, the major pollutants are herbicides, particularly Atrazine. In the 100 well sample, 51 wells had pesticides of which 47 wells had Atrazine and 8 wells had Alachlor. In the eight wells sampled in northwestern Minnesota, none had pesticides; for the southwest and south central regions, 4 out of 17 wells (24%) had pesticide contamination; in the southeast region, it was 13 out of 21 wells (62%), and in central Minnesota, it was 31 out of 45 wells (63%). Thus, private well contamination was concentrated in the central and southeastern regions (figure 4). In the case of the 400 public wells, 114 wells (28.5%) tested positive for pesticides. Atrazine was found in 107 wells (27%) and Alachlor in 8 wells (2%). The next most important pesticide was 2,4-D, which was found in 7 wells. For the public wells, the southwestern region as well as the southeastern and central regions had the major concentrations of contamination (Figure 5). Thus, the wells contaminated by pesticides appear to be concentrated in the intensive agricultural areas of the state. How many wells were contamination by farmer application of chemicals that leached through the soil into the ground water is not clear. It is also not clear how serious the problem is, since only 10 of the wells exceeded pesticide health standards. Atrazine is the only pesticide widely found in Minnesota wells. This is due to Atrazine's long and extensive use as a herbicide and its water solubility and relative stability (does not break down quickly once it gets into the subsoil). Unfortunately we do not have any time series data to indicate whether or not the problem is getting worse and, if so, how rapidly.

Farmer Decisions

Since many of domestic wells polluted in rural Minnesota belong to farmers, one may ask why do farmers pollute their own wells? There are, at least, three answers to this question. One is that they lack the necessary information. In other words, they do not know that their farming practices are polluting the ground water and more specifically, "their" ground water. The second possible answer is that their neighbor or neighbors are polluting the ground water. This is the classic externality problem. Third, they may have decided that use of chemicals or disposal of manure is more important than clean ground water. They may even be willing to buy bottled water instead of reducing chemical applications. Thus, there is no simple one answer to the question. It is a combined problem of imperfect information, externalities and farmer income requirements.

Farmers make long run capital decisions such as what type of manure handling facility to install, that have important impacts on their nitrogen use. These decisions will depend on a number of uncertain variables, including future commodity and fertilizer prices. The annual chemical use decisions are then constrained by the capital investments that are in place. The farmer will decide on chemical use rates and timing based on crops selected, prices, manure available and soil conditions. These decisions may change during the growing season in response to rainfall and temperature conditions. A heavy rainfall may mean last week's fertilizer application has been lost and needs to be replaced. In contrast, dry conditions will mean that less nitrogen is needed and different weed control practices are required.

In these short and long run decisions, risk and uncertainty play an important role. Nitrogen is cheap and weed control with herbicides does not require as intense management as mechanical control. Given the uncertainty of prices and weather, farmers will tend to error on the high side of chemical use. A little extra nitrogen may increase corn yields in a good rainfall year by 20 to 30 bushels. Also, if a farmer does not control the weeds early in the season with heavy use of herbicides, wet weather may prevent him from getting into the fields and applying the needed weed control before the corn is too tall. Failure to control the weeds could result in a 25 percent reduction in crop yields.

Government Programs and Policies

Farmer decisions are very dependent on government programs and policies. Yet most government agricultural programs have been designed with little or no concern for ground water pollution. Most agriculturally related environmental concerns have focused on soil erosion, surface water pollution, bacterial pollution of domestic wells and wildlife habitat. Thus, it should not be surprising that many agricultural programs contribute to the chemical pollution of ground water. For example, the conservation reserve program (CRP) retires land and, in combination with the commodity programs, encourages more intensive farming of the acreage that remains in agriculture. This means greater use of nitrogen and herbicides which increases the potential for ground water contamination.

Another example involves some of the traditional soil conservation practices that emphasize reducing water run-off. When water is held on the land, it will drain through the soil, carrying chemicals with it. In some cases, this means increased ground water pollution.

The problem is one of changing the structure of agricultural programs. Potential impacts of agricultural program provisions on ground water pollution must be taken into account. This may mean certain areas that are susceptible to ground water pollution must be treated differently. For example, the CRP program might be banned in southeastern Minnesota, or we might require reduced fertilizer use rather than retire land, i.e., a fertilizer retirement program. In addition, certain Agricultural Conservation Program practices might not be allowed in southeastern Minnesota, since they increase chemical leaching. In other words, conservation practices should be screened according to their effects, on reducing both soil erosion and ground water pollution.

Environmental regulations could also be developed for specific areas with important ground water reserves. In designing such regulations or programs, we must consider the transactions costs, including monitoring costs and who pays the costs as well as who benefits. The distribution of costs and benefits will determine the political support obtained for such regulations.

One regulation which is being widely discussed in Minnesota is a ban on selected herbicides. Current efforts at banning herbicides is focusing on Alachlor and Atrazine. If an individual state or even a nation bans selected herbicides, what might be the impacts on farmers, the input industry and rural communities? For example, the impact of a ban on only a few herbicides might be minor if there are good substitutes that are less likely to reach the ground water, i.e., they are less water soluble or break down more quickly. However, if Atrazine is banned, the drop in net returns will depend on the weather conditions for weed control (table 1). If the weather is good for weed control, most substitutes for Atrazine provide satisfactory weed control and yields with only a fifty cent decrease in net returns. When the weather is bad for weed control, there is a significant decline in weed control and yields achieved by alternatives to Atrazine. Under bad weather, the drop in net return could be over $20 per acre. Thus farmers must decide how much risk they are willing to accept when they select their method of weed control.

Bans on Alachlor have a much smaller impact than those for Atrazine, since the range of good substitutes is better. When both Atrazine and Alachlor are banned, the drop in net returns is somewhat greater than it is for just Atrazine. If no herbicides are allowed, the drop in net returns can be as high as $72 per acre. The loss in net returns can be even higher if cropping rotations have to be changed to improve weed control. These changes might even involve substantial new capital investments.

The difference in net returns with good and bad weather shows how weather influences weed control practices. It also suggests the risk involved with different weed control practices. Thus, a risk averse farmer might select an alternative that produces a lower return in a good year, but does better in the bad year. In contrast, a risk neutral farmer might put more emphasis on high average net returns, but be less concerned about the variance in net return. Consequently, farmers are likely to have a varied response to a herbicide ban depending on their response to risk.

The ban could also have a differential impact regionally. For example, southeastern Minnesota has higher rainfall and generally good weather conditions for chemical weed control. In contrast, western Minnesota is drier and weather is not as suited to chemical weed control. This means that a ban on selected herbicides would, on average, cause a greater increase in weed control costs for Western Minnesota. Because of the dry conditions, farmers would have to shift much more to mechanical weed control. Thus, bans on herbicides may put certain regions, such as western Minnesota, at a greater comparative disadvantage.

Government regulatory actions may take place at an even lower level than a state. Just as one county lowered its standards from 10 ppm to 3 ppm of NO_3-N for domestic drinking water, it could also take action to reduce ground water pollution. A county might require that anyone applying manure in the fall would pay a fine of $X dollars. The county might also ban the sale of Atrazine in the county. In conjunction with such regulations, the county could help farmers install manure storage facilities or develop markets for their excess manure. Such combined actions would help keep the negative financial impacts to a minimum, while reducing key sources of environmental damage.

One difficulty with local or selective bans on problem areas is that they will be placed at a competitive disadvantage to other regions. This is why subsidies may have to be used extensively in such cases. Also, if a county or even a state bans the sale of certain chemicals, what is to prevent farmers from taking their business across the border? This, of course, will not please local businesses.

The U.S. government has a long history of assisting cities and firms in their adjustment to new environmental regulations. The huge investment in municipal waste treatment facilities is a prime illustration. The lesson to remember from this experience is that the U.S. invested too much in new capital intense facilities relative to improved management. We must be careful not to make the same mistake in the agricultural sector.

One final point regarding government policies. Although we are not likely to change U.S. monetary and trade policies because of their impact on ground water contamination, changes in both policies can affect ground water. An aggressive policy to expand agriculture trade will intensify U.S. agriculture and increase pollution and the use of ground water for irrigation. Monetary policy can have similar impacts by making U.S. agricultural commodities more or less competitive on international markets. Monetary policy can also influence ground water use through changes in interest rates.

Input Suppliers

When bans, taxes or regulations are discussed concerning chemical use in agricultural, local community leaders become concerned about the impacts on their communities. As one might expect, the negative financial aspect relates to how wide spread the bans are and how quickly good substitutes become available. The record on pesticide bans would suggest that the impacts are minor and the input industry, if given time, can adjust quite well. However, a complete ban on all herbicides could have a serious impact on selected chemical companies and possibly rural communities that are heavily dependent on crop agriculture. In southwestern Minnesota, about 35% of the sales and income is directly dependent on agriculture and 15% is closely related to agriculture through processing activities [Dorf and Hoppe, 1980]. Since weather conditions for weed control are not as good in western Minnesota, bans on herbicides such as Atrazine could have a significantly negative impact on economic activity in the region.

Two other aspects of such selected bans are important to consider. First, if the low cost herbicides such as Atrazine are banned, does this mean that chemical firms will be able to substantially raise the prices of the substitute chemicals? If so, the negative effects on farmers could substantially increase. Since Atrazine is the cheapest alternative currently being used, most substitutes are priced the same or slightly lower. If this price leader is eliminated, who will become the new price leader?

The second issue involves the incentive to develop new chemicals that have fewer environmental damages. What signals do chemical bans or taxes give the input industry? A lot will depend on how the regulations are structured and the likelihood of new chemicals not being banned. Care must be taken so that incentives remain to develop new safe chemicals as well as alternative methods of weed control.

Soil and Ground Water Regime

We do not want to say a lot about the soil and ground water regime except to point out some of the important relationships that need to be developed. We look to the soil scientists, the agronomists and other physical scientists to improve our understanding of the physical dimensions of ground water pollution and its prevention. Some of the specific relationships that are needed include:

(1) The rate of chemical movement through the soil under different conditions including different farming practices and rainfall and temperature levels. In other words, we need to know how farming practices change chemical movements and how these movements are affected by rainfall and temperature. One aspect of this is the role of macropores in the movement of water through the soil. How important are they, and how effective are practices that break up these macropores?

(2) What is the crop response to different rates of fertilizer application and weed density under different levels of water availability. These basic relationships have been needed for years, but are still not readily available.

(3) How do different weed control practices affect weed densities?

(4) Are there important threshold levels of chemicals in the soil and to what extent do chemicals accumulate in the soil?

(5) What happens to chemicals below the root zone and above the water table? Soil physicists deal with everything from the ground level down through the root zone, while geologists and engineers have studied water movement once it reaches the water table. However, no one has been concerned about the area in between (Blanchard, 1988).

Because we lack many of these basic soil-water-chemical relationships, we have been forced to develop expert systems to model the soil or ground water regime. For example, expert judgments have been used to develop computer models that predict the yield response to nitrogen under different rainfall conditions, i.e., how much nitrogen will be lost from leaching with different rainfall events. Such systems can be very helpful in improving input use decisions. One such system has been developed for nitrogen use in the central sandy area of Minnesota. However, it is still just a physical model and the economics has yet to be added. For example, we still do not know how labor costs and the other farming operations will affect a farmer's ability to apply nitrogen two or three times during the season or delay the first application until the crop is planted.

Health Cost of Ground Water Pollution

In rural Minnesota, 93 percent of all municipal systems rely on ground water. Virtually all private drinking supplies rely on ground water. Livestock accounts for over 70,000 acre feet of water use per year, virtually all of which is from ground water.

The most widespread known problem associated with ground water quality comes from nitrates. These have been shown to cause methemoglobinemia, or the "blue baby" syndrome in infants. More disturbing, however, is the proposition that the presence of nitrates indicates the possibilities of other chemicals having leached into the ground water. The extent of this occurring, and the potential hazard of possible pollution is the great unknown in this challenge to public policy.

A More Modest Approach

Clearly, the vast amount of information desired to make rational policy choice is insurmountable in the short run. Yet, decisions must be made -- which in the policy arena usually means "no decision" until forced by some crisis. The broad question is, "To what extent are we willing to incur visible and certain costs in the short run to prevent uncertain but potentially catastrophic costs in the future?"

In the absence of tangible evidence of the health effects, public inertia suggests that the tangible pollution control expenditures, in the short run, will not be made. This may or may not be rational, but examples of this phenomenon are:

- We are unwilling to bear the costs of worms and other pests in fruits and other foodstuffs in the absence of evidence that pesticides and preservatives have direct adverse effects on health.
- We are unwilling to sacrifice the benefits of increased energy supplies in the absence of evidence that nuclear wastes generate real health hazards.
- We are unwilling to forego the benefits of fluorocarbon use in the absence of evidence that their use damages the earth's ozone layer or causes other mischief.

So it is with ground water. We are unwilling to bear the costs in terms of more weeds, reduced yield and higher production costs in the absence of evidence that current practices pose a real threat to human health, or cause such damage that an ambitious public program is warranted.

The public pronouncements of politicians to the contrary need to be disregarded in this area. The lofty goals of a "safe environment" and a ground water aquifer with "zero pollution" are easy enough to pronounce when facing the television cameras. When not backed up with realistic policy measures, however, grandiose goals are nothing more than empty rhetoric. The exuberance for clean water and zero pollution quickly gives way when the politician is confronted by representatives of the petrochemical industries or budget constraints.

The point is that decisions need to be made with inadequate information -- much less complete information. Complete answers to questions on economics of ground water pollution are far down the road. However, a modest beginning can be made by adopting practices which are thought to reduce ground water pollution. In addition, a start can be made in measuring the benefits from preventing ground water pollution. Short of the ambitious goal of evaluating health effects, work can start on the more modest goal of estimating the costs of seeking alternative sources of water should a specific aquifer be contaminated. Work is presently underway at the University of Minnesota on just such a project. An aquifer has been identified and costs of alternative water sources for rural and municipal domestic users are being estimated. This will provide a minimum value for the benefits of ground water pollution control for a given aquifer.

Practical Policy Guidelines

What can be offered in the way of practical policy guidelines? Again, the tenuous and uncertain links between specific, identifiable practices, and ground water pollution must be stressed. Although some data exist for cause-effect relationships in aqualitative sense, the specific information linking the use of a specific cultural practice or agricultural chemical to pollution of ground water in a specific aquifer in precise quantitative terms now and in the future is lacking, and will continue to be inadequate or at least, imprecise, regardless of the effort which goes into this search. Meanwhile, policymakers will be under pressure to make decisions. (To "do nothing" is also a policy decision of sorts.) Let us review several principles of policy-making and relate them to the difficult ground water situation.

1. The efficiency in attaining the objective must be weighed against the cost of administering the policy. Certain chemicals, for example, may be more potentially damaging in one region than another. Efficiency in attaining the objective of reduced ground water pollution suggests that use of the chemical be restricted in the regions where such use poses a threat. This would allow the use where no threat is posed. However, this differentiation in allowable use would be expensive to administer as such regions are not easy to delineate. Further, such strategy gives the popular impression of arbitrariness and excessive bureaucratic intrusion. Thus, depending on the circumstances, it may be more "practical" to restrict the use of a particular chemical "across the board," rather than by region. However, as pointed out above, this type of action may have differential regional impacts and change the regional

competitive advantage. The point is that this trade-off between efficiency of attaining the goal and efficiency of administration is always a consideration in policy-making. The particular circumstances will determine which "efficiency" is of dominant importance. And, the perceived distribution of costs and benefits will affect the political viability of the policy. As described earlier, such areas as the Karst of S.E. Minnesota, with important ground water reserves, may merit the higher transactions cost of more finely tuned regulations.

2. Multiple policy objectives require multiple policy tools. In their zeal to promote a specific policy measure, advocates are often moved to promise more than a specific policy measure can deliver. A land retirement program is pushed because it promotes soil conservation, improved wildlife habitat, watershed protection, and reduced agricultural production all at the same time. While land retirement may indeed contribute to all of these objectives, it probably is more effective at achieving some goals -- in this case, soil conservation --than others. Other policy tools are more effective at attaining other goals.[1] To effectively restrict agricultural production, an explicit limitation on output, or reduced prices, would be far more effective than retiring marginal land subject to erosion. To improve wildlife habitat, specific policy tools to achieve this end, such as acquiring public rights to land crucial to certain species, would be more effective than the serendipitous effects of land retirement for the primary purpose of reducing soil

[1] See Taff, Steven J. and C. Ford Runge, "Wanted: A Leaner and Meaner CRP," Choices, 1st Quarter 1988, pp.16-17. In this article, the authors make the point that in attempting to make CRP try to do too much, its effectiveness in achieving all objectives is reduced.

erosion. While the complementary effects of a specific policy tool would be welcome, such a single tool cannot accomplish all goals with equal effectiveness. At a minimum, a policy tool (or <u>set</u> of policy tools) will be required for each policy goal. If reduction of ground water pollution is the primary goal, policies must be selected with this goal in mind -- rather than depending on tools which are aimed primarily at other targets, but which merely have ground water protection as a by-product. Yet, these by-products, or policy interactions, require that the effects of a policy on various goals be analyzed. The example cited on p.9 of the possible effects of the CRP program, both on soil erosion and on ground water pollution, is an example of a negative type of interaction.

3. <u>Select the policy tool(s) most appropriate to the target</u>. This "common sense" tenet follows closely from the previous paragraph. Sometimes policy goals are conflicting while in other cases they are complementary.

A policy goal of maximizing farm production -- the "fencerow to fencerow" cultivation advocated by the Secretary of Agriculture in the early 1970s, conflicts with the goal of soil conservation. The goal of increased wildlife habitat may be compatible with the goal of reducing farm production. However, as pointed out above, any given policy tool will be more effective in attaining one goal than another. The lesson here is to select the tool most appropriate to the expressed goal. The earlier example of a restriction on the use of atrazine or alachlor, for example, would tend to reduce both ground water pollution <u>and</u> agricultural output, but is certainly more effective at lowering pollution, than in reducing output. Farmers have time and again proven their ingenuity at substituting inputs in the production process.

4. Don't confuse policy goals (ends) with policy tools (means). Policymakers should bear in mind that their objective is to achieve a specific target, such as higher surface water or ground water quality. Specific practices are only means for achieving such targets. The classic example of the mischief that can be achieved by confusing ends with means is the EPA's requirements of "best practicable technology" for reducing surface water pollution. Such legislation requires a government agency to define what is meant by "best practicable technology" and to supervise its implementation. This requires government to get further involved in private operations than is necessary to achieve legitimate policy goals. It would be more efficient for both the private sector and the public sector for government to prescribe the amount (and perhaps strength) of effluent to be released, and to let the firm or municipality decide on the means for attaining the objective. And, for this, it is not usually necessary to prescribe the practice which is to be used.

A second illustration is the above example of the subsidized investment in municipal waste treatment facilities, as if treatment facilities were the objective: In fact, such facilities are the means to the greater objective of improved surface water quality. The final result of this confusion between means and ends was an over investment in facilities and an under investment in management. With ground water, it may be necessary to prescribe practices, even though this is generally undesirable for surface water. As a general rule, the policy goal, and the regulations necessary to attain that goal, should be aimed as closely as possible at the ultimate objective. In the case of ground water pollution, protection of those supplies is the ultimate objective. However, simply to legislate "high ground water quality," is not feasible. What is required is a legislated policy focused on some identifiable action, such as a change in discharge or, in the case of ground water, a change in percolation. As technology changes, the policy prescribing specific practices may need to change. Again, this shows why the policy prescription needs to be focused as closely as possible toward the ultimate objective.[2]

These four broad principles of public policy do not tell us what to do. But they do provide some guidelines when drafting policy legislation in the absence of the information needed for anything remotely approaching the ideal. Each policy objective and proposal needs to be examined in the context of these principles.

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[2] Examples from farm policy and macroeconomic policy may serve to further illustrate the above points. If the ultimate policy objectives are a given level of farm income and prosperous rural communities, a policy focusing on farm prices as a means to these ends is practically sure to be inadequate, as it misses the ultimate target (point 4 confuses ends and means). Further to the extent that supported prices (rather than income), promotes fewer but larger farms, it is in conflict with the goal of prosperous and stable rural communities. We saw from point 2 that this separate goal of prosperous rural communities will require separate though perhaps complementary policies focused on this goal. Similarly, in macroeconomic policy, a law mandating a balanced federal budget confuses means and ends (point 4). The ultimate target is not a balanced budget, but full employment, stable prices, and economic growth. A balanced Federal Budget may be a <u>means</u> to this end, depending, of course, on economic conditions. Legislation restricting the budget to balance would not only be unworkable and wasteful of administrative effort, but restricts the use of the budget -- which at times should be brought toward balance, and at other times purposefully unbalanced -- to achieve these broader goals. And again, (after point 2), the goals of full employment, stable prices, and economic growth will require at least 3 sets of economic tools; fiscal policy, monetary policy, and specific policies on saving, investment, and research and development. Focusing on the budget as an end, or target, restricts the options for attaining the more important targets.

To paraphrase John Kenneth Galbraith, "Economic development guarantees the reduction of physical drudgery. No such claim can be made for economic development with respect to the need for mental effort."

The effort required to attain information for soundly based policy will indeed be monumental. In the meantime, the effort devoted to formulate policy in the absence of information will tax the ingenuity of policymakers and advisors for years to come.

Summary and Conclusions

The intractable problems of ground water pollution will continue to challenge policymakers for some time to come. In the absence of defensible information on the many aspects of the problem, policies will be made at best on sketchy and incomplete information combined with good judgement, or at worst, on a see-saw alternative between neglect and fear. The following are an attempt to represent common points of agreement.

- While information is sketchy, pollutants from agricultural and domestic sources have entered certain aquifers in Minnesota. In addition, they will continue to enter these and other aquifers as long as the current farming practices are continued.
- While it is not certain as to the physical extent of these pollutants, nor of their potential physical and economic damage, there is sufficient cause for alarm that research backup is needed to back up the inevitable push for rational public policy.
- The costs of ground water pollution (benefits of pollution control) tend to be uncertain, sometimes intangible, and in the future. These types of costs (benefits) generally get short shrift in the market

mechanism, and they are generally omitted early on in the policy process, short of tangible evidence or, more likely, public scare. The latter is a poor, not to mention an ephemeral, basis on which to make policy.

- The costs of ground water pollution control would impose real costs in the near term. These costs may involve changing agricultural practices and the discharge of animal wastes. Surely changes would involve the political system and bureaucratic procedures which are generally interpreted as "interference" in the price and market system. Such changes are difficult to impose and will generally be opposed by individuals who perceive their rights to be interfered with and by the petrochemical industry.
- Because of the short-term, immediate nature of costs of pollution control, and the long term, intangible and uncertain nature of the damages of ground water pollution, the free market mechanisms cannot be depended upon to yield a socially optimum solution.
- Yet, economic principles can yield useful insight into public policy. Zero pollution is not economically feasible, and the costs of pollution must be balanced with the costs of pollution control, as difficult as this may be to accomplish.
- With all this, public policy may best error on the side of caution--that is, in favor of too much pollution control--in view of the potential risks to human health.
- The effects of a policy tool on various objectives must be considered. Multiple policy goals of high farm income, reduced soil erosion, improved ground and surface water quality, and improved

wildlife habitat will require specific policy tools to attain those goals. Specific policy measures will be required to attain the objective of maintaining ground water quality.

- Research which is needed to formulate rational public policy for controlling ground water pollution is only in its beginning stages. And if history is any guide, the nature of this and related problems, along with information requirements, are certain to become more complex -- rather than less.

Table 1. CHANGES IN NET RETURNS DUE TO HERBICIDE BANS ON SOUTHEASTERN MINNESOTA FARMS USING CONVENTIONAL TILLAGE PRACTICES

BAN & DECISION RULE	GOOD WEATHER	BAD WEATHER
BAN ATRAZINE	(per acre)	
Same Yield	-$7.73(3%)	-$7.73(4%)
Maximum Net Returns, Good Weather	-$0.51(0%)	-$20.50(10%)
Maximum Net Returns, Bad Weather	-$7.73(3%)	-$7.73(4%)
Maximum Average Net Returns	-$7.73(3%)	-$7.73(4%)
No Herbicide	-$11.62(4%)	-$71.76(35%)
BAN ALACHLOR		
Same Yield	-$2.64(1%)	-$2.64(1%)
Maximum Net Returns, Good Weather	-$0.10(0%)	-$20.15(10%)
Maximum Net Returns, Bad Weather	-$2.64(1%)	-$2.64(1%)
Maximum Average Net Returns	-$2.64(1%)	-$2.64(1%)
BAN ATRAZINE AND ALACHLOR		
Same Yield	-$9.53(3%)	-$9.53(5%)
Maximum Net Returns, Good Weather	-$0.51(0%)	-$20.56(10%)
Maximum Net Returns, Bad Weather	-$9.53(3%)	-$9.53(5%)
Maximum Average Net Returns	-$11.62(4%)	-$71.76(35%)

Source: Craig A. Cox

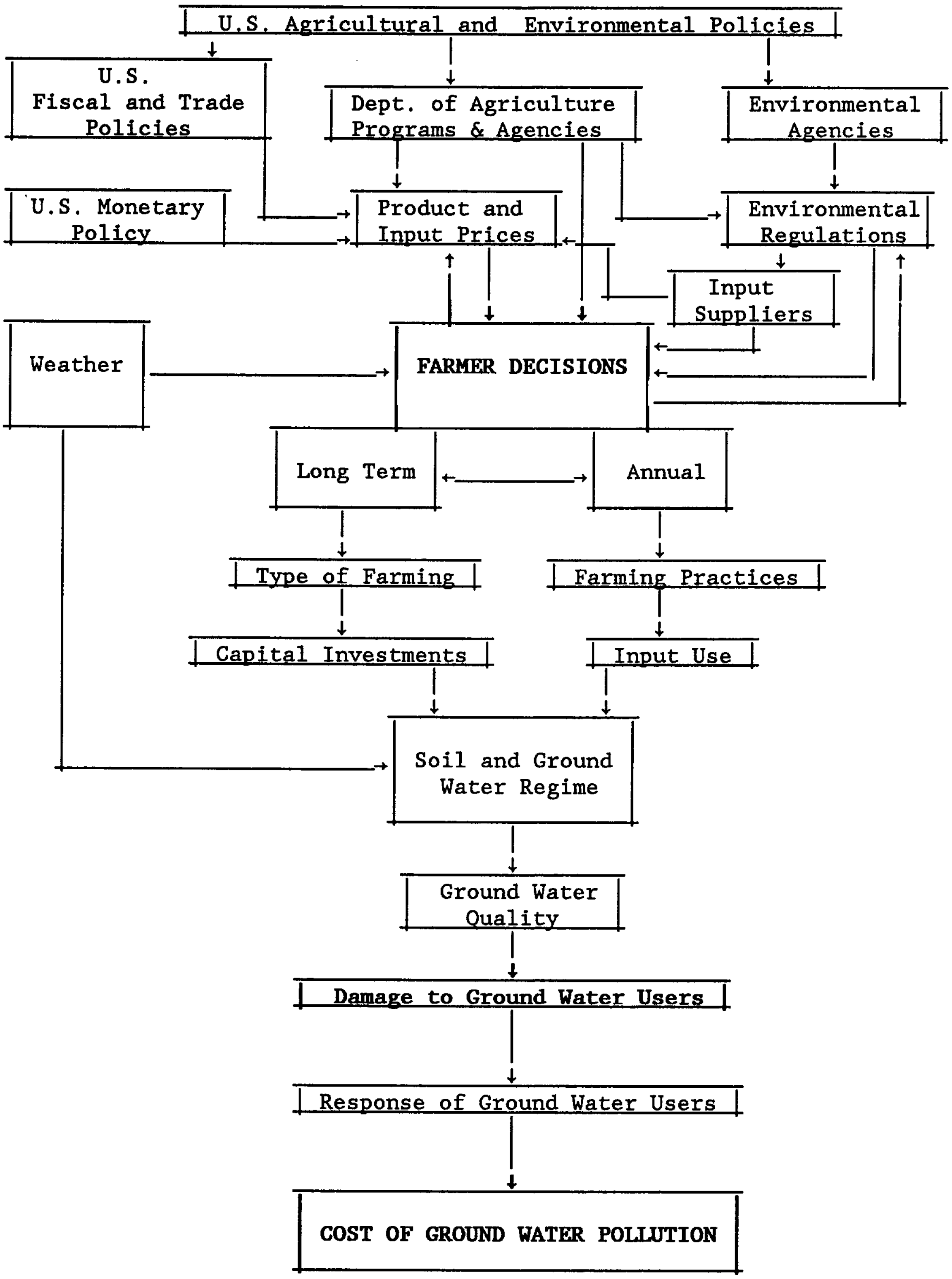

FIGURE 1. GROUND WATER QUALITY SYSTEM

Figure 2

SUSPECTED SENSITIVE AREAS

TO CHEMICAL GROUND WATER CONTAMINATION

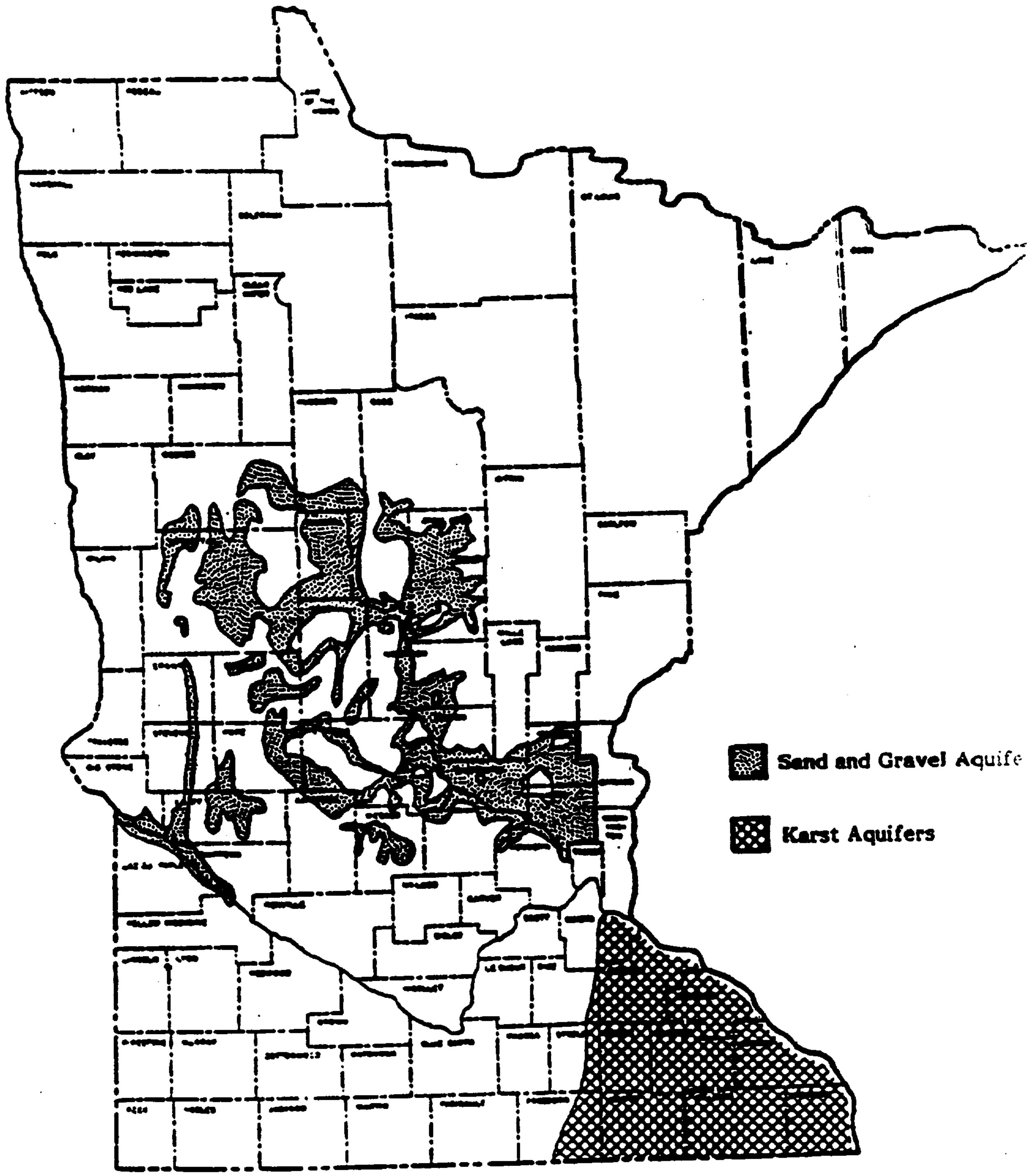

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FIGURE 3

OCCURRENCE OF NITRATES

PUBLIC WELLS, MDH SURVEY

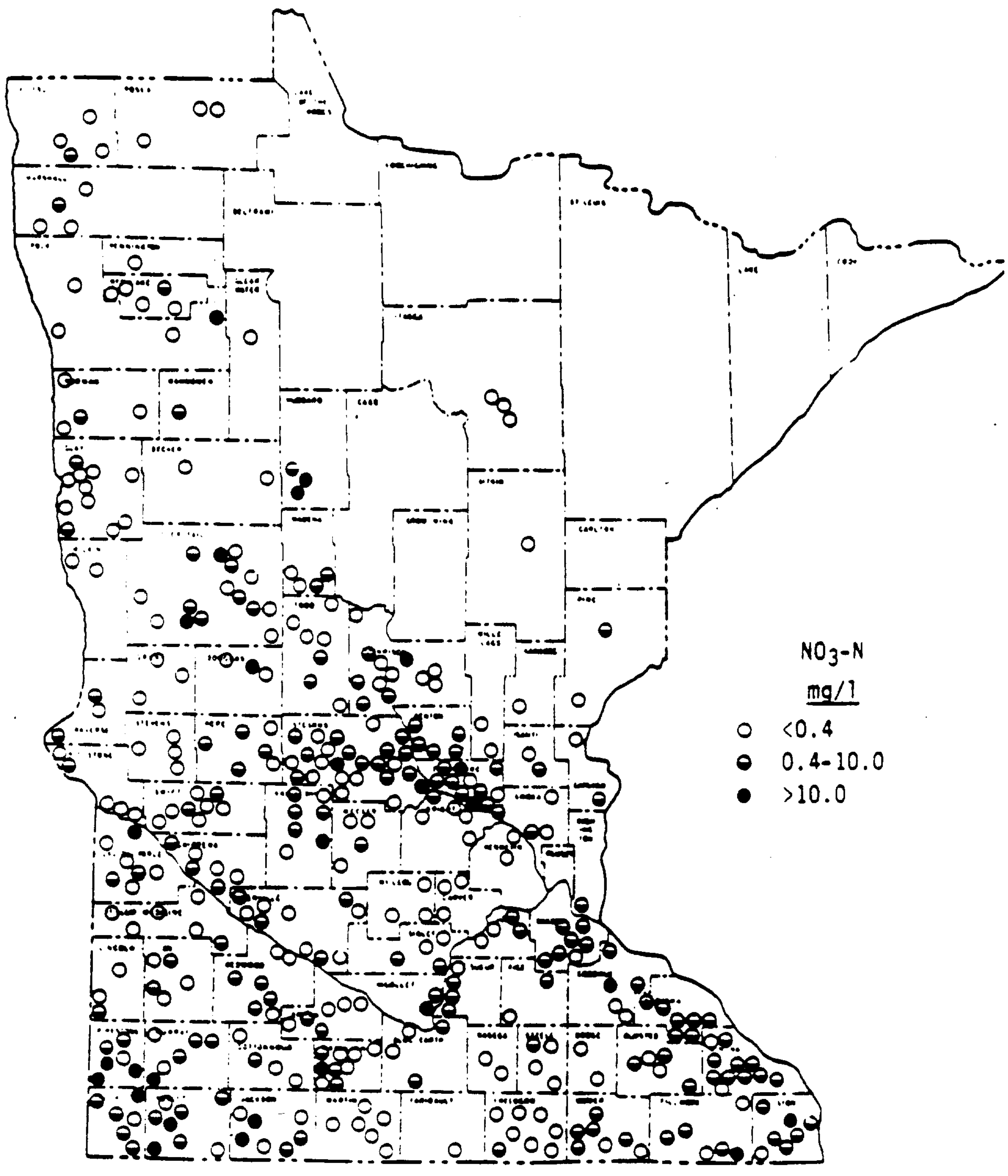


FIGURE 4

OCCURRENCE OF PESTICIDES

MDA SURVEY

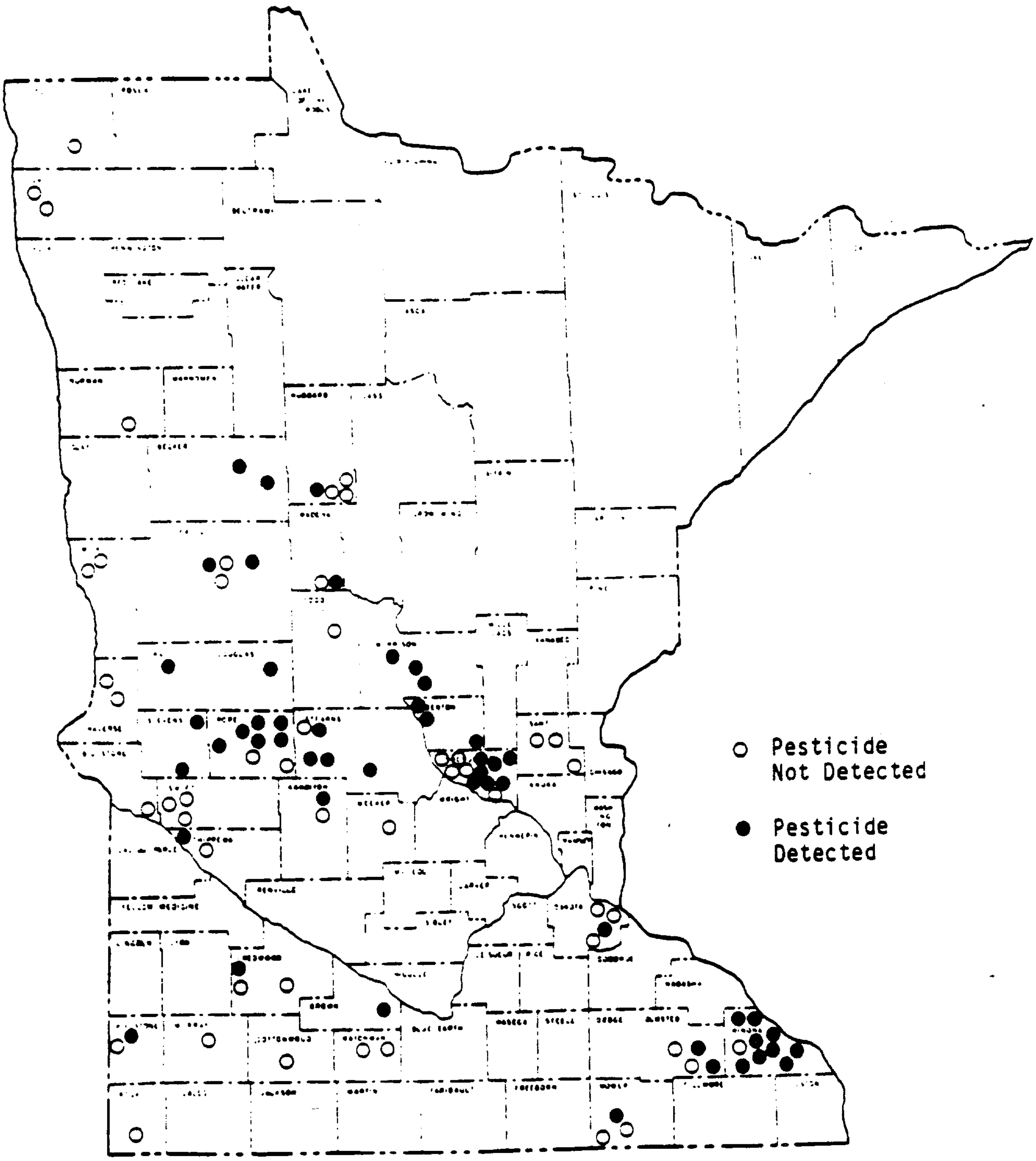
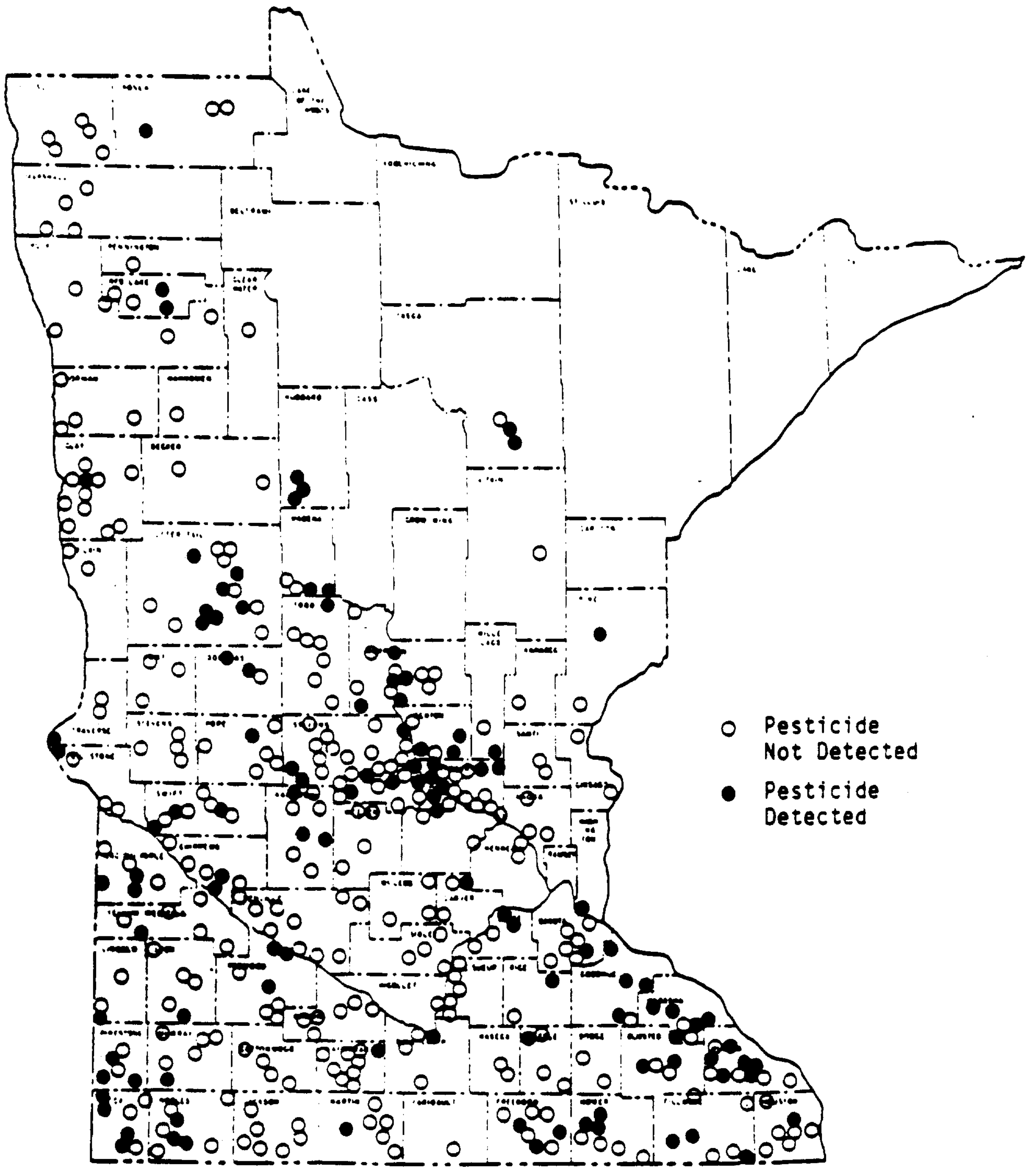


FIGURE 5

OCCURRENCE OF PESTICIDES

PUBLIC WELLS, MDH SURVEY



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Modelling Pesticide and Herbicide Health Impacts:

Is an Agricultural "Superfund" Coming?*

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The agricultural sector as a whole is increasingly under fire as a source of pollution. This article explores the technical, health and public policy implications of extending the "polluter pays principle" to agriculture and to individual farmers, based on an agricultural "superfund". The superfund concept arises from P.L. 94-580, which effectively spreads the costs of industrial pollution by imposing fees on industry, the proceeds of which are available to pay for hazardous waste cleanup at "superfund sites".

If agriculture were to be included in the superfund, or a separate such fund were established for the agricultural sector, the costs of agricultural pollution would effectively be spread to all those paying into the fund. Who will pay, of course, is an issue likely to prompt debate, as is the magnitude of the problem itself. Regardless of who pays and how

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much, such cost spreading may be preferable to allowing full liability to be borne in agriculture by a few companies producing chemicals found to have adverse effects, or by farmers found to have used these chemicals over time.

In this article, we focus on the type of information that will be demanded in characterizing the risks associated with agricultural pollution, based on methods currently in use in connection with the superfund. These risks are at present largely unknown. If, as we conjecture, the public increasingly demands information on the human health impacts of agricultural pollution, the framework developed under superfund legislation in the non-agricultural sector can be useful in agriculture as well. Here we describe the types of information that will be needed. After considering this information, we close with a discussion of the public policy issues involved in implementing an agricultural superfund.

Chemicals and fertilizers used in crop production have, until recently, been regarded as less significant causes of pollution than more localized hazards resulting from landfills, industrial disposal and other "point sources". Yet recent evidence implicates agricultural contributions over wide areas as significant "non-point sources" of pollution, which despite the lack of a single source, are nonetheless identifiable. Broadly speaking, the two main sources are pesticides and fertilizers.

Pesticides are generally synthetic organic chemicals used to kill or inhibit the growth and reproduction of species viewed as pests. Crop fertilizers encompass a broad range of commercially available and indigenous sources, including animal wastes and plant nutrients (nitrogen, potassium, phosphorus). Both pesticides and fertilizers can have impacts on distant non-target organisms. Pesticides, because of their pervasive use and negative public perception, provide a focal point for an analysis of the linkage between potential adverse health effects associated with agriculture-induced by environmental pollution.

In the jargon of pollution control technology, agricultural businesses can be viewed as "source generators" that either continuously or intermittently release contaminant material into both air and water. Traditionally, these releases have been viewed as non-point source pollution, as opposed to industrial point source pollution. This non-point versus point source distinction provides a partial basis for the exemption from the Clean Water Act currently enjoyed by U.S. agriculture. Yet, increasing analytic and environmental engineering sophistication coupled with changing public perception may blur the distinction between point and non-point source contaminators.

Sites polluted with by-products of agricultural land-use such as California's Kesterson Reservoir and Italy's Bay of Venice have focussed national and international attention on the agricultural industry. As the ability to track the fate and transport of agricultural chemicals improves, it is reasonable to foresee a superfund process specifically directed towards agriculture.

Obviously, such an "agricultural superfund" program would have long-term economic impacts on agricultural policy, land valuation, property transfers and farmland conversion associated with urban development. For example, lending institutions are already beginning to consider potential and existing environmental liabilities associated with agricultural properties. Under an agricultural superfund, this practice would become a normal part of doing business in agriculture, similar to the current scrutiny applied to the industrial and commercial sectors.

Although no "agricultural superfund" exists, it is appropriate to consider how one might be constructed and what types of information might be demanded of the agricultural sector, specifically concerning the fate, transport, and health risks of agricultural practices. The Superfund Human Health Evaluation process (EPA 1989) provides a framework for developing the risk information necessary to assist in this process. There are four primary objectives of this assessment:

(1) to provide an analysis of baseline risks;

(2) to generate data which provides a basis for determining what levels of chemicals are environmentally acceptable;

(3) to provide a basis for comparing potential health impacts of various remediation strategies;

(4) to provide a consistent process for evaluating and documenting public health threats associated with a given polluting source.

The analysis of agricultural use of pesticides fits well into this overall framework. Typically, the baseline risk assessment of potentially widespread contamination utilizes a four part approach:

(1) Historical Overview, Data Collection and Evaluation

(2) Exposure Assessment

(3) Toxicity Assessment

(4) Risk Characterization

Each of these categories is further subdivided into specific tasks (Figure 1) which will produce an overall conceptual evaluation model (Figure

2). Here, we consider pesticides in terms of this four-part process.

Historical Overview, Data Collection and Evaluation

Since World War II, the widespread and intensive use of pesticides has been associated with persistent and broad spectrum agents such as DDT. DDT and its related chlorinated compounds have been associated with residues throughout the environment, including accumulation in both the food chain and living systems. Although DDT was banned in the U.S. in 1972, it continues to be used widely outside of North America. However, new nonresidual chemicals and agents that can be specifically targeted to certain pests have been developed in response to environmental concerns. These newer chemical agents, despite substantial improvements, still generate concern because of their potential impacts on soil fertility and their long term effects on ground and surface water.

Chemical pesticides reach the soil by direct application and from aerial and ground sprays. Overall, there are three main processes which affect the efficiency and ultimate fate of pesticides in soil: (1) absorption-desorption; (2) transformation via biological and chemical degradation; and (3) transport into the soil, atmosphere, surface water and groundwater. Research reported by Easter and Waelti demonstrates that ground water can suffer contamination attributable to the widespread application of agricultural chemicals. Specific chemicals, such as atrazine, can now be measured in aquafiers and wells. The problem is to determine the origin of these chemicals, which have been widely applied over periods of decades.

This non-point source problem involves both time sequence and location. Recent work by the Tennessee Valley Authority involving stereoscopic infrared color aerial photography has begun to demonstrate that source and time sequence problems may no longer be insurmountable (Perchalski and Higgins, 1988). Computer data bases can be constructed that include land use category, site number, surface area and topography, and hydrogeologic codes for both aquafier and stream systems. As this technology becomes more sophisticated, the quality and specificity of the data base will improve such that the term "agricultural non-point source pollution" may become an anachronism.

Exposure Assessment

Exposure assessment is the determination or estimation of the magnitude, frequency, duration and route of exposure to a particular chemical pollutant. These estimations can be based on long duration real-time measurement or a variety of mathematical models. Typically, these "fate and transport" models provide conservative estimates of the amount of chemical available at the human exchange boundaries (lungs, gastrointestinal tract, skin) during a specified time period. There are several specific instances where real-time monitoring data is not adequate and fate-transport models must be utilized. These include:

(1) Cases in which potential exposure points are spatially separate from the monitoring point. Examples of this situation include groundwater transport and air dispersion of chemicals.

(2) Cases in which time-series data is lacking. Long term site specific data is generally unavailable; therefore, even though there may be situations where it is reasonable to assume constant conditions, it is necessary to predict future exposure employing a model.

(3) Cases in which monitoring data are difficult to quantify. Examples are the case of a groundwater plume discharging into a river or other surface water body. The dilution in the river water can result in concentration of the chemical below limits of detection, despite the fact that the chemical can bioaccumulate and ultimately raise health concerns.

Fortunately, while much could be done to improve our knowledge of agricultural chemical use, a reasonably large and well-documented data base exists for the environmental fate and transport of pesticides in soil.

Soils possess a large and physio-chemically active surface area. This surface area provides a site for multiple surface reactions and a reservoir for the retention of pesticides; in addition, the chemical character of pesticides affects the extent and nature of pesticide absorption by soils. The overall distribution of pesticides in soil phases is influenced not only by intrinsic soil properties, but also by external factors, including climactic conditions and agricultural practices (Saltzman and Yaron, 1986).

Fate-transport models have been devised to incorporate both these external factors and various physio-chemical factors to address the following seven fundamental questions:

(1) What are the principal mechanisms for change or removal in each soil type and horizon?

(2) How does the chemical degrade or accumulate in air, water, soil, and other biological material?

(3) Does the agent react with other compounds in the soil environment?

(4) Is there transfer from the soil surface to groundwater, and if so, what are the mechanisms, rates and reactions of this process?

(5) What is the long-term (air, water, soil) environmental persistence of each chemical?

(6) Are potentially toxic by-products produced, and, if so, how are they to be analyzed?

(7) Is a stead-state concentration distribution achieved?

Each of these questions are applicable to the general transport of chemicals in ground and surface water, air, soil and the food chain.

The Superfund Exposure Assessment Manual (EPA, 1988) provides specific guidance for the selection of contaminant release and fate analysis models; in addition, there is a large selection of situation specific models. Two particularly well-documented models relevant to pesticide fate and transport are the Pesticide Root Zone Model (PRZM) and the Seasonal Soil Compartment Model (SeSoil).

PRZM simulates the vertical movement of pesticides in the unsaturated soil and within and below the plant root zone. Simulations can also be extended to the water table where ground water models can be utilized. The PRZM model analyzes runoff, erosion, plant uptake, leaching, decay, foliar washoff/volatilization vertical movement, dispersion and retardation (Figure 3). Predictions can be made daily, monthly or annually. The cumulative frequency distribution wave of a given pesticide leaving the root zone is illustrated in Figure 4. Extensive documentation including modeling specifics and limitations are available for PRZM and other pesticide models from the EPA (EPA, 1988).

SeSoil is a general water and sediment transport model that allows specific analysis of pesticide and sediment transport on water sheds (Figure 5). This model has particular utility because it merges with pre-existing long-term climate files and it is integrated into the Graphical Exposure Modeling System (GEMS) family of air and water models. GEMS is user friendly and allows the complete fate and transport analysis of most chemicals. There are, of course, many limitations to these models; however, they are increasingly improved, and provide an initial screening tool with wide applicability to pesticide use in agriculture.

Toxicity Assessment

The primary hazard of pesticide exposure is the development of acute toxic reactions associated with dermal contact or inhalation. The medical literature is replete with studies of pesticide related illness (Kahn, 1976). The health effects of low-level or prolonged pesticide exposures via drinking water is less clear. Controlled epidemiologic studies of long-term exposure to pesticides has generally been focused on farmers and pesticide production workers (Council on Scientific Affairs, 1988). Qualitative and quantitative risk assessment suggests the possibility of incremental increased cancer risk although human epidemiologic data is less clear. Specific health based recommendations for acceptable pesticide levels in groundwater have been formulated (Zaki, 1982). The ability to recommend no adverse effects levels for pesticides in groundwater is controversial, although the limit setting process and methodology is well established by the EPA. Risk based toxicity assessments for pesticides are common despite the lack of strong evidence to support or negate a causal relationship between low-level exposure and disease. This scientific uncertainty does not effect the increasing public pressure to monitor and regulate low doses of pesticide exposure in food and water.

Risk Characterization

Risk characterization combines toxicity and exposure assessments into quantitative and qualitative expressions of risk. Risks are estimated as projected excess rates of cancer for chronic disease associated with a set of chemical exposures. Risk characterization also provides key information for policy makers. Pesticide risk methodology involves the same assumptions and calculations as for other chemical exposures. Those are (1) standard intake assumptions; (2) EPA potency factors (carcinogenic risk) and reference doses (non-carcinogenic); (3) risks combined across exposure pathways; (4) carcinogenic risk is assessed and analyzed; (5) non-cancer hazard quotients are calculated; and, (6) sensitivity and uncertainty analysis of all assumptions are performed. The current risk assessment guidance manual for Superfund, (EPA, 1989) provides further detail and documentation of the entire process.

Conclusion: Implications for Policy

Overall, traditional non-point source pollution problems such as agriculture, in fact, appear highly amenable to the Superfund Risk Evaluation process. As the distinction between point and non-point source pollution becomes harder to sustain, non-point source pollution in agriculture may well become subject to regulations under existing superfund laws, or through creation of a separate agricultural superfund. An agricultural superfund would no doubt be controversial, since it would involve major shifts in liability assignment for farmers and suppliers of farm chemicals. Yet, members of the U.S. Committee on Irrigation and

Drainage (USCID) have suggested that some members of industry might be happy to see the focus and costs for cleanup of contaminated water shifted in part to an additional sector of the economy that has heretofore escaped responsibility (Fairweather, 1988). As the technology of chemical detection and fate-transport improves, agriculture may well become the new emperor with no clothes - exposed and vulnerable to the increasing regulatory and financial pressure associated with environmental contamination.

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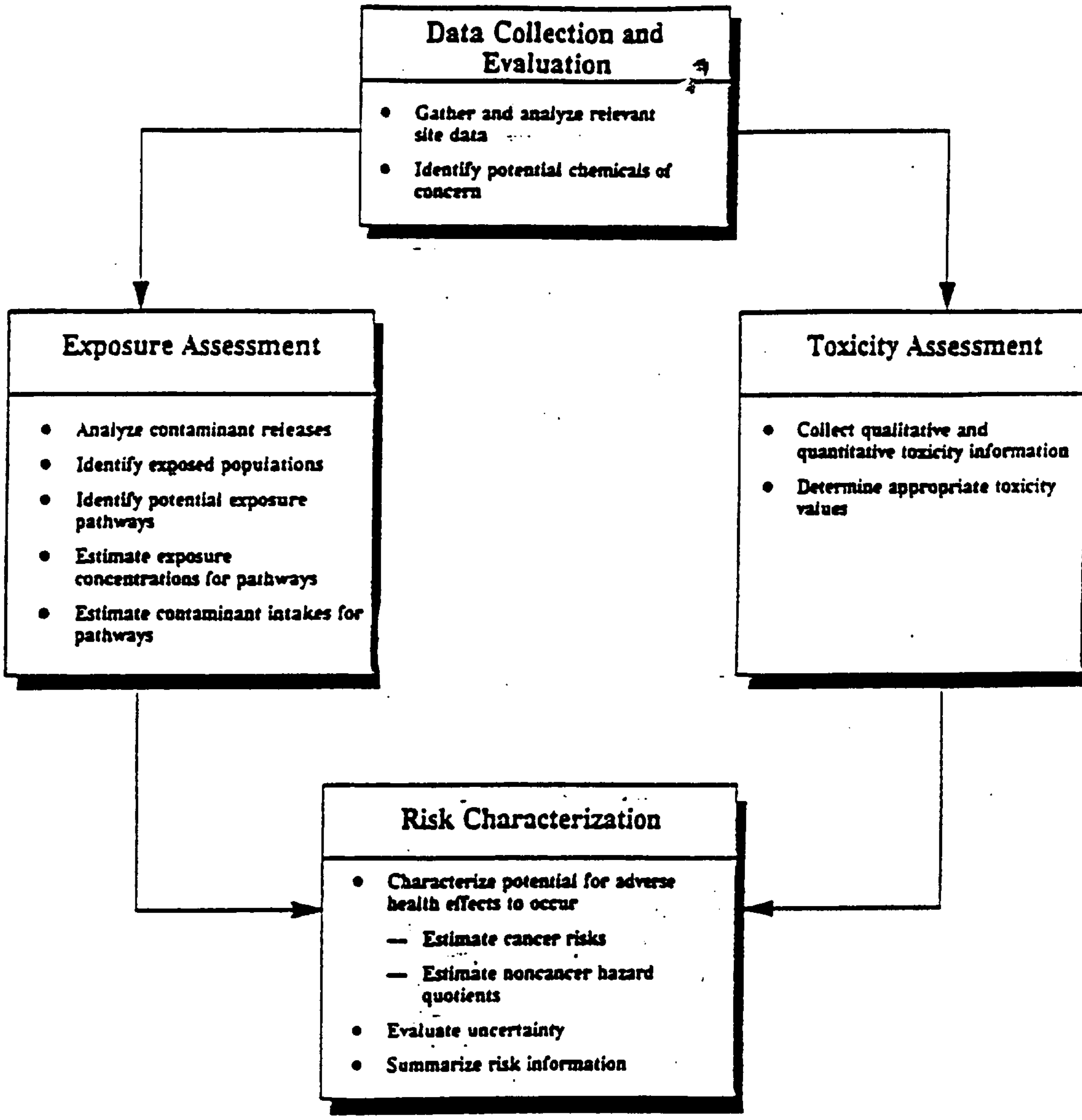
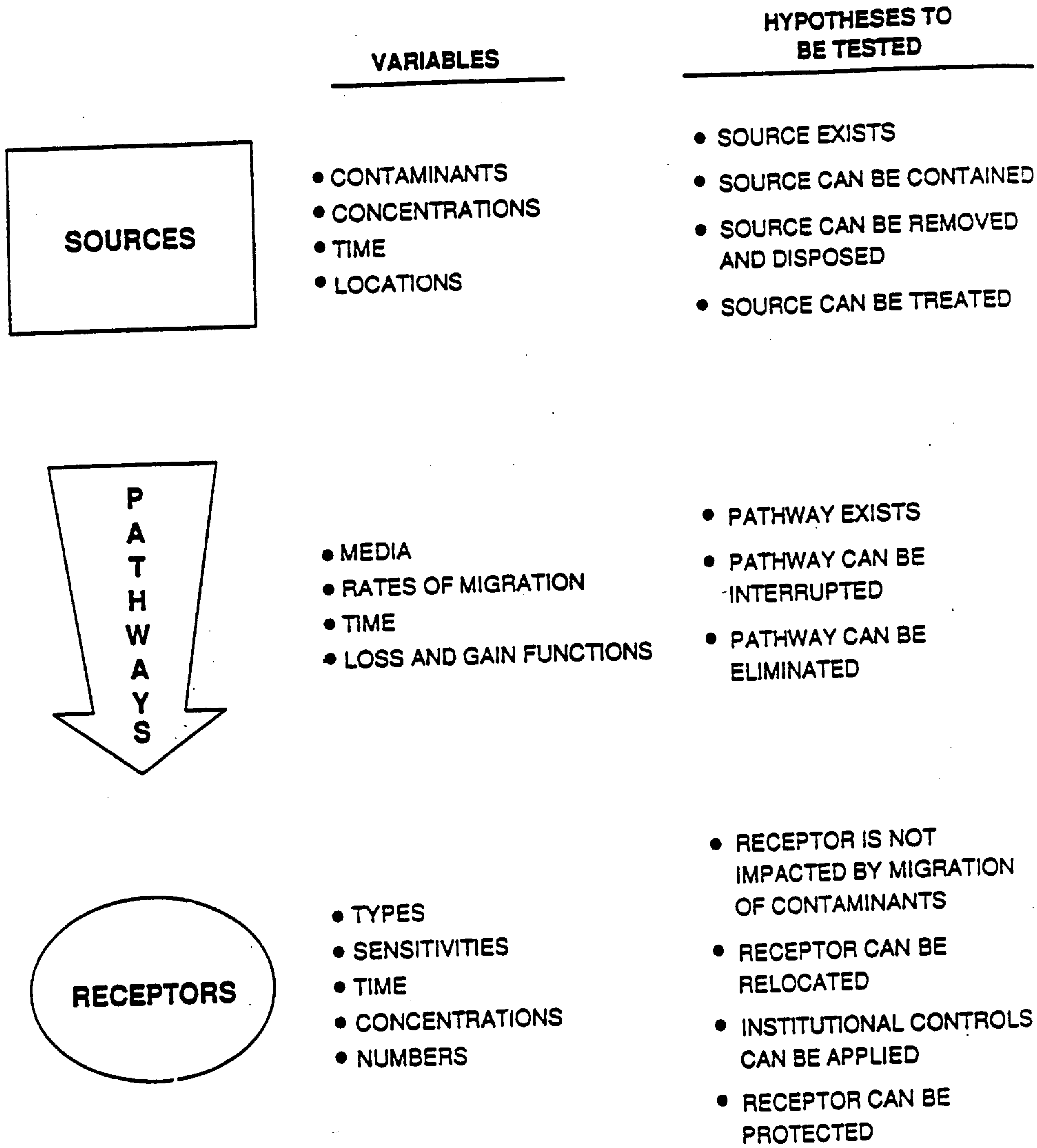
FIGURE 1



SOURCE: EPA 1989

FIGURE 2

ELEMENTS OF A CONCEPTUAL EVALUATION MODEL



SOURCE: EPA 1987a

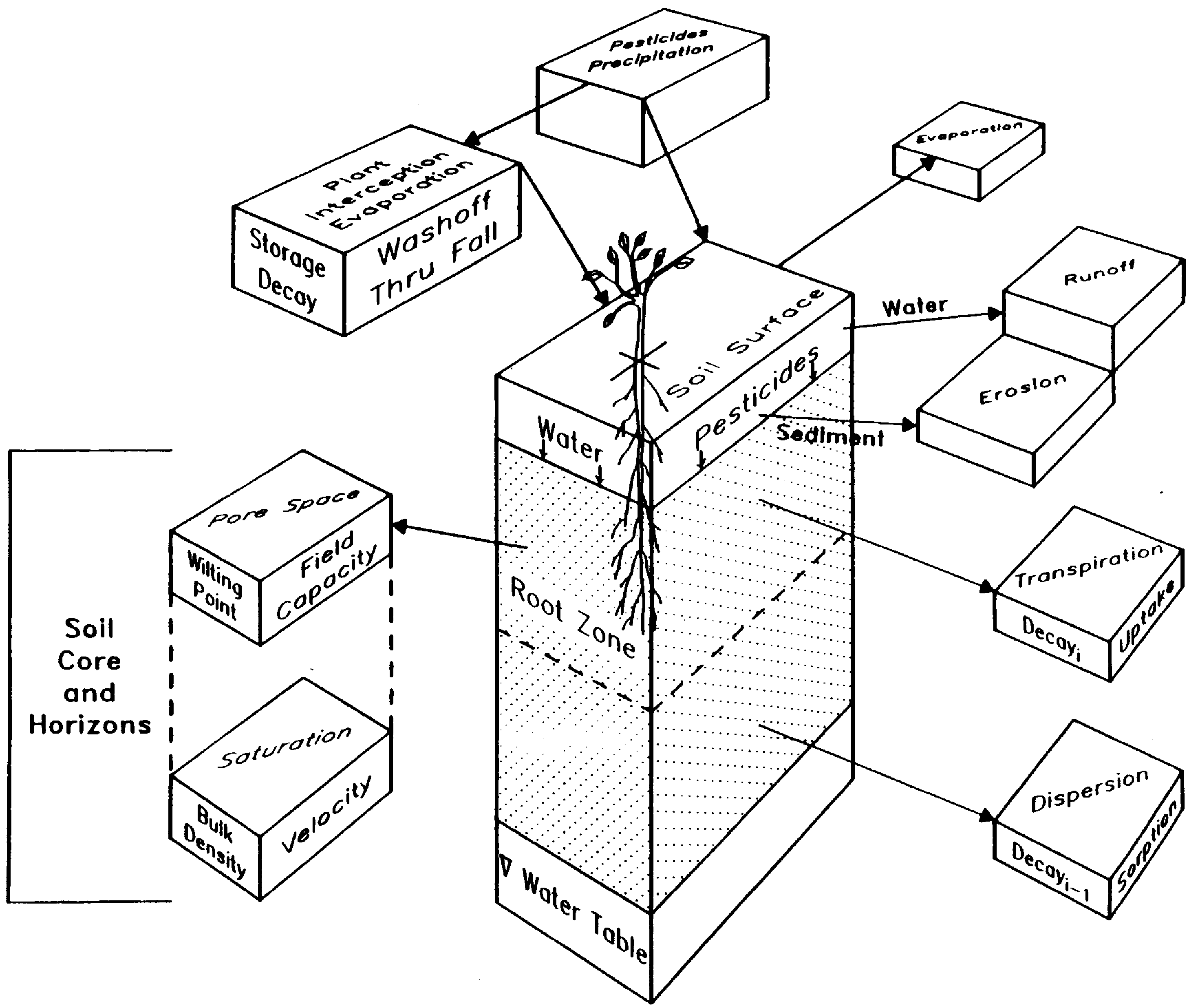


Figure 3 Pesticide Root Zone Model.

SOURCE: EPA 1984

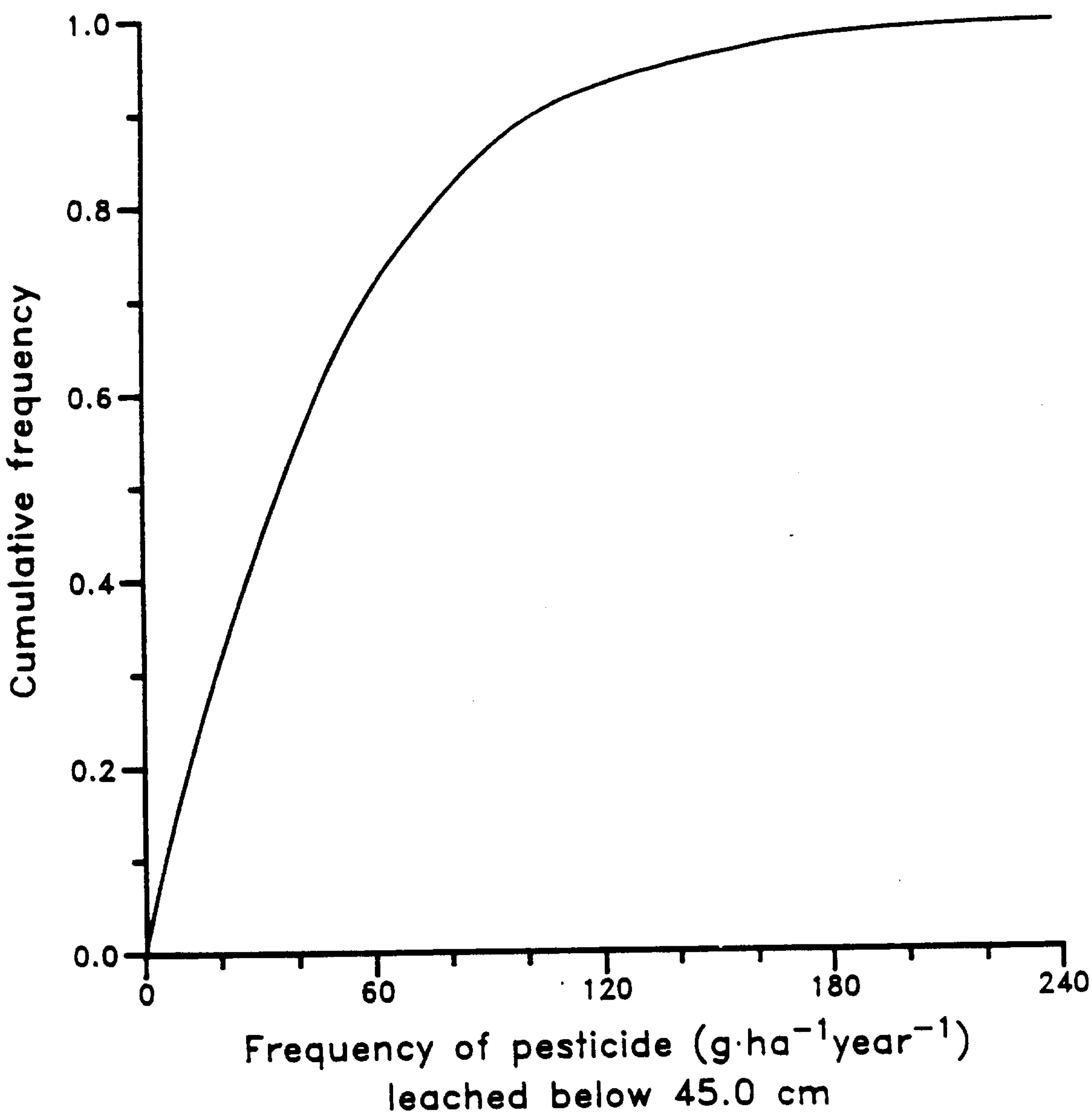


Figure 4 Cumulative frequency distribution of pesticide leaving root zone.

SOURCE: EPA 1984

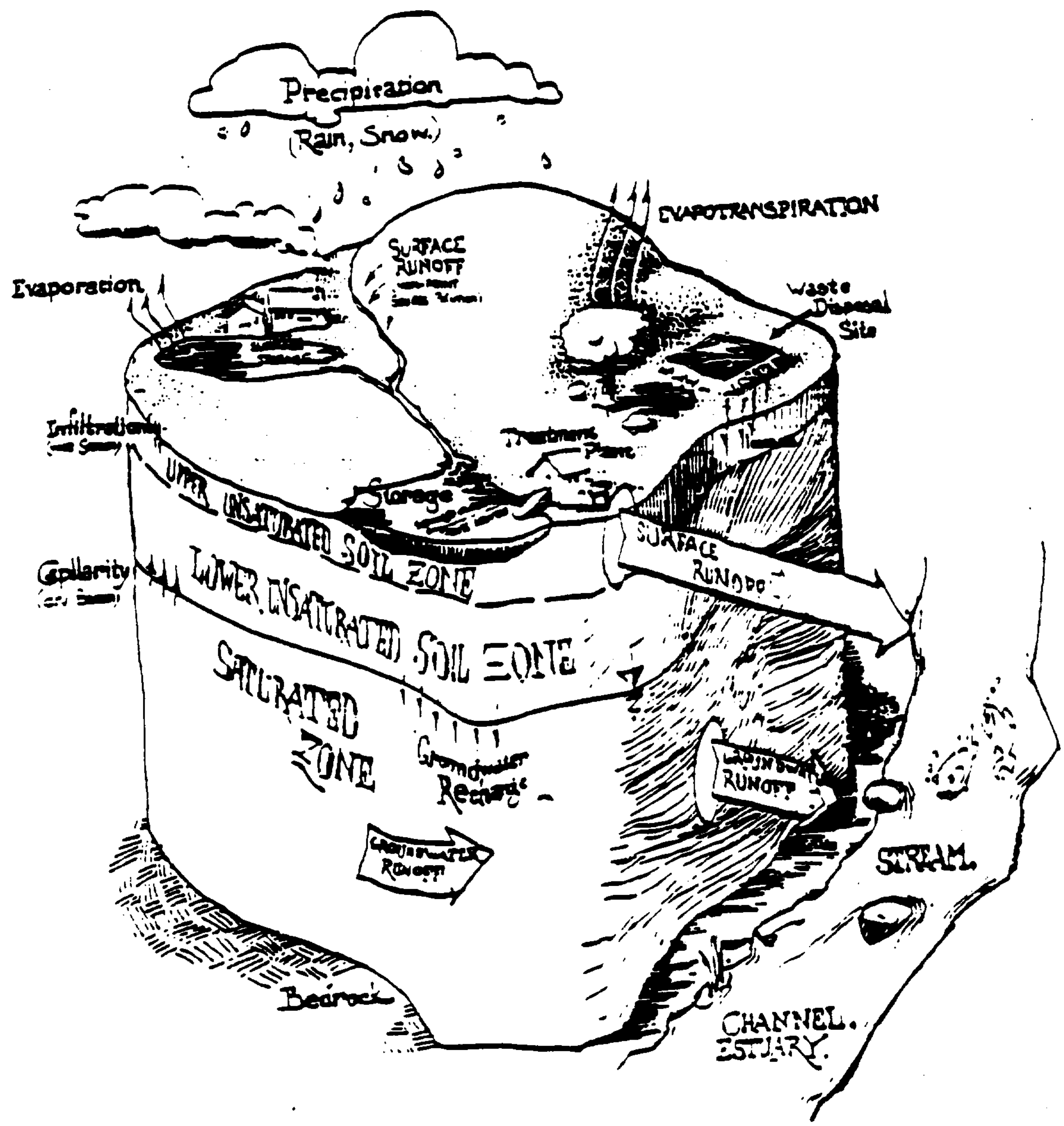


Figure 5 SCHEMATIC PRESENTATION OF THE SESOIL COMPARTMENT

SOURCE: EPA 1984