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ENVIRONMENTAL MANAGEMENT OF AGRICULTURAL WATERSHEDS

A SELECTION OF PAPERS PRESENTED AT A CONFERENCE HELD IN SMOLENICE, CSSR

G. Golubev, Editor

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PREFACE

From April 23-27, 1979, a conference titled "Environmental Management of Agricultural Watersheds" was held in Smolenice, Czechoslovakia. The meeting was organized jointly by the Czechoslovakian Academy of Sciences and the International Institute for Applied Systems Analysis (IIASA).

Agriculture is one of the main factors which change the face of the earth. About 11 per cent of ice-free land in the world is cropland. In some very large river basins an area of arable land is up to 70 per cent of the whole basin, while in smaller watersheds, this ratio is even higher. It is well known now that agricultural activity has a considerable influence on hydrological processes such as run-off and its regime, erosion and sedimentation, transport of dissolved chemicals, etc. But the influence goes beyond hydrology. Water just plays the role of an agent or carrier in geoecosystems. That is why we have chosen the watershed as a natural territorial unit where the components are united by hydrological processes.

The policy usually adopted for normal agricultural development is intensification. A good deal of information is now available on various environmental consequences of such intensification, mostly of unfavorable character. Rectification of those consequences is sometimes costly or technically difficult, so that a decision to go ahead with it is made against economic or technological considerations. In many cases correction of one problem brings along new ones often related to other disciplines. To make a decision on appropriate actions, a trade-off is usually made weighing the pros and cons of the action. Hence, the management aim of maintaining environmental quality and a sustainable resource base is of a complex and multidisciplinary character which is of interest to an institute such as IIASA.

These were the criteria which led to the choice of the conference theme, as it was one of the important ones within the then Task "Environmental Problems of Agriculture." Since then, the need for development and implementation of methodologies for environmental management of agricultural units, watersheds included, has become even more urgent. Therefore, experiences accumulated in member countries of IIASA and presented at the conference in question are of interest today not only to those countries, but could be useful to the developing world as well.

It often happens that watershed management is associated with erosion control; the latter is one of the main goals but not the only one. The proceedings of this conference clearly demonstrate this.

Various reasons prevented us from publishing the full proceedings of the meeting within a reasonable time. The selected papers which appear in this volume present, to our judgement, the expertise more relevant to proper management, while others which represent aspects of understanding or assessment had to be unfortunately left out. I am grateful to all the participants at the conference, the hosts, reviewers and staff members of the Resources and Environment Area at IIASA who made this publication possible. In particular I would like to thank the Area Chairman, Dr. Janusz Kindler, whose efforts helped a great deal in finalizing this publication.

Genady N. Golubev
Task Leader (1973-1981)
Environmental Problems of Agriculture
Resources and Environment Area

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SYSTEMS ASPECTS OF ENVIRONMENTAL MANAGEMENT OF AGRICULTURAL WATERSHEDS: AN INTRODUCTION TO THE CONFERENCE

Genady N. Golubev

The problem associated with increasing agricultural production the world over may be solved in two ways: by intensification of the use of existing agroecosystems and by the development of new, currently idle lands (Figure 1). Intensification would mean expanding the use of machinery, fertilizers, pesticides, and the development of irrigation and drainage methods, among others. This leads to a number of environmental effects, for example, changes in the physical and chemical properties of soils (in many cases, unfavorable ones), an increase in soil erosion, pollution of surface water and groundwater by derivatives of fertilizers and pesticides, salinization of soils, waterlogging, and the increase of salt content in irrigation water. The fact that some land lies idle in many cases implies that the land was marginal in terms of agricultural productivity, therefore, after ploughing, it would be expected that unfavorable effects such as a high rate of erosion (when compared to natural erosion and pure drainage) and a high salt content in soils or irrigation water would manifest themselves. If the idle land was merely less fertile than other farmland, then it would require the heavy use of chemicals or the development of irrigation and drainage, or some other means, to intensify the use of its agroecosystem.

These effects which decrease the sustainability of an agroecosystem have direct, depressive feedback on agricultural production, on a short- or long-term scale. The effects on the quality of the environment outside an agroecosystem may not have a direct feedback on agricultural production. However, the need to maintain a certain standard of the quality of the environment creates some regulations which limit agricultural activity.

Therefore, we are confronted by a number of environmental effects of agriculture. Practical problems related to these effects depend very much on the time and space scale. Figure 2 shows principal classes of the environmental problems of agriculture in coordinates of space and time. Some problems require a time resolution of less than one day. In this case, intra-day variations of processes should be taken into account. For example, if we want to know in detail the water balance of a field or even of a crop, we should take note of variations of hydrometeorological factors and plant behaviour within a day. These variations are periodic, depending on the location of the sun. By superimposing periodic ones, other oscillations become aperiodic in character. For example, a variation in the rainfall at a given point is important for understanding erosion and associated fertilizer and pesticide transport.

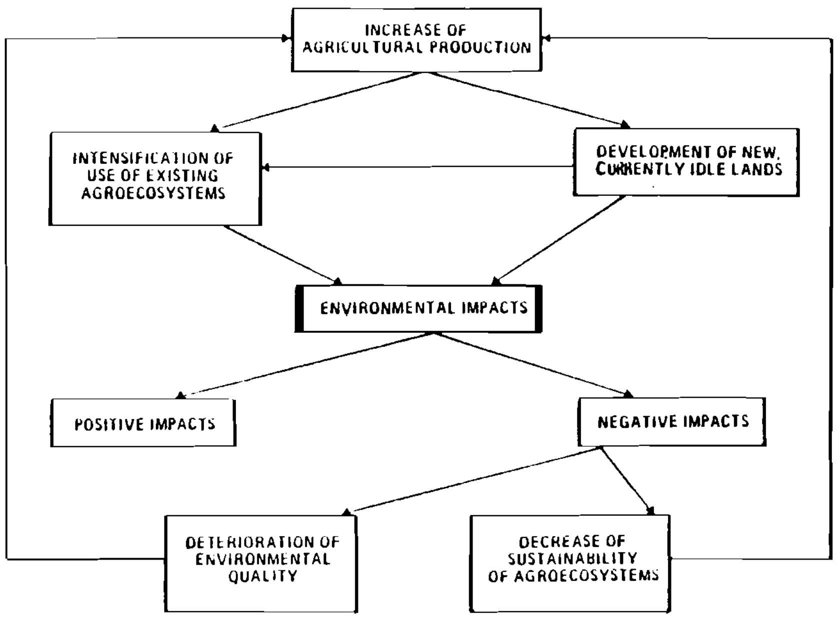


Figure 1. Environmental effects of agriculture as a function of increasing agricultural activity

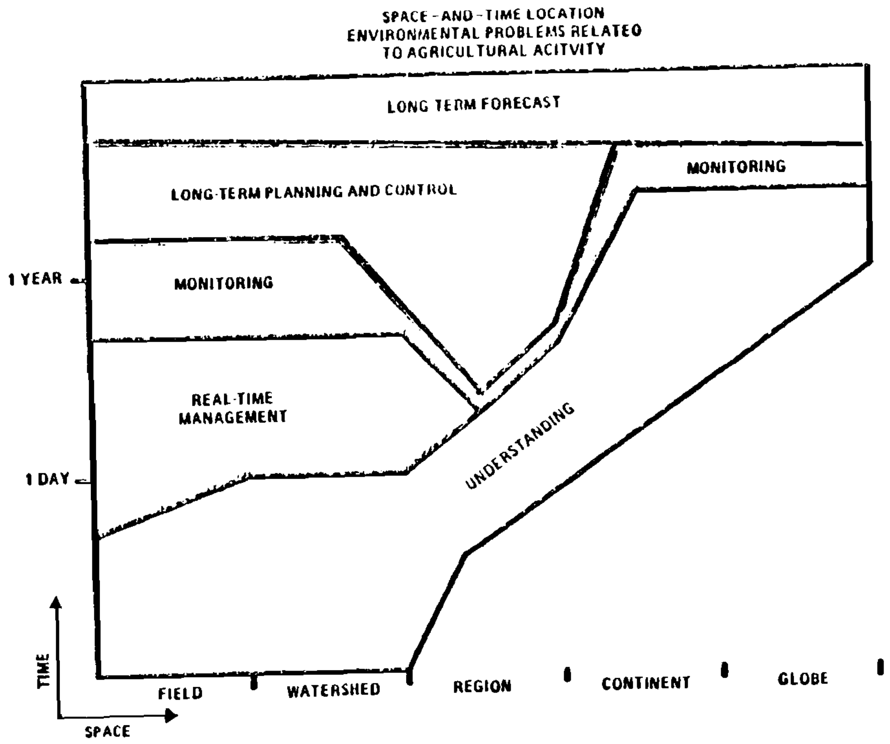


Figure 2. Space and time location of environmental problems related to agricultural activity. (The relative importance of a problem is shown by the proportions used in the figure.)

For a time scale of between one day and one year, the most important factor is the seasonal variation of processes; in many cases intra-daily variations can be disregarded. The management of fertilizer application or management of irrigation with corresponding environmental consequences are examples of this class of problems. For a time scale of more than one year, one can disregard the hourly, daily, and seasonal variations. Long-term control or forecast of soil fertility is another example of this type of problem.

In coordinates of space, a field level means mostly that we usually deal with a one-dimensional task disregarding spatial variations. At the watershed level, the spatial variation of factors and processes should be taken into account. Some solutions such as lumped parameter models do not regard this explicitly; at a conceptual stage however, the elements of space are considered. Another consideration at the watershed level is that river runoff becomes apparent. Runoff per se and as a medium of compound exchange can be studied and controlled just at this level. Many problems such as soil erosion, pollution of water bodies by agricultural chemicals, and the quality of irrigation returned water can and should be managed at this level. Some of the problems do not have an obvious relation to river runoff, thus a watershed level is not unlike the management of the quantity and quality of groundwaters or the secondary salinization of soils. However, the mere fact that groundwaters and surface waters are interrelated makes it necessary to study and manage these problems at a watershed level.

A region is regarded here as a territorial unit with common natural and socio-economic features, economic goals, and common policies. It is part of a large country, or a small country in itself. Long-term planning, control, and forecasting are the main types of environmental problems of agriculture in a region. Typical examples are the measures planned for the prevention of non-point source pollution of water bodies. Continental and global levels are of interest for understanding, monitoring, and long-range forecasting of large-scale environmental changes due to agriculture, e.g., global biogeochemical cycles.

In Figure 3 each area (field, watershed, or region) has certain explicit or implicit goals for agricultural production (1). The goals may be quite different. In some areas, the goal may be to obtain maximum benefit from agricultural production, in others, it may be to grow a certain amount of a given crop, in yet others, it is to provide self-sufficiency in agricultural products or to export a certain amount. The goal is accomplished through the adoption of appropriate agricultural practices (2). Once the goal is achieved (3), there is simultaneous impact on the environment (4) as discussed in relation to Figure 1. Usually, a farmer is not very interested in the effects represented by Block 4 in Figure 3 unless he observes immediate or short-term effects of his activity. In many cases, farmers may not realize the negative long-term consequences of their activity or they do not have

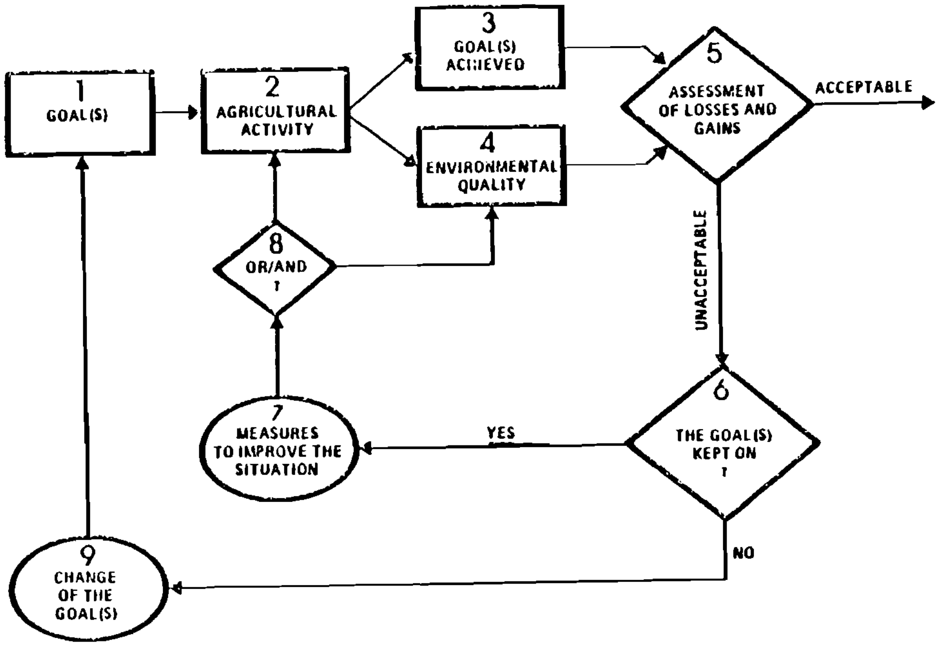


Figure 3. A concept for environmental management of agricultural areas

enough means to alter or stop these consequences. For a society living in a given region or watershed, both Blocks 3 and 4 are of interest and a proper overall assessment of the losses and gains (5), is required. If the assessment proves that the situation is acceptable, the agricultural activity continues. If it is unacceptable, the initial iteration(s) are carried out, retaining the initial goals (6), and certain measures to improve the situation are applied (7). They can be of various kinds (technological, economic, legislative, administrative, etc.), and can be applied to either or both agricultural activity and the environment (8). Many examples of such measures are known, e.g., terracing, increased charges for irrigation water, fertilizer taxes, regulations on agricultural practices, etc. In some cases, the first iteration is done mentally. For instance, design of drainage simultaneously with the design of a new irrigation project. If the output of the agriculture-environment system is still unacceptable after some iterations, the initial goal should be changed (9).

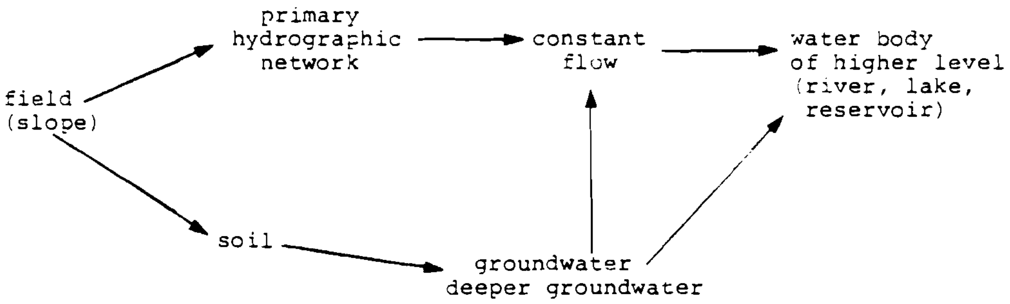
It is obvious that environmental management is not an end in itself. The main goals center on productive actions, in our case, agricultural activity. However, to achieve certain goals, control of the environment is a key factor. An important objective is to forecast environmental changes stemming from man's activities, but it would be even more important to control them. The trend in world agricultural development is toward intensification of agriculture and thus ever increasing effects on the environment are experienced. One of the fundamentals of the environmental management of agricultural areas is conflict between the goals of agriculture and those of environmental quality (Figure 3).

To solve this conflict, the state of the environment should be assessed using a system of indices comprising both physical indicators, such as $N - NO^3$ content in water, the amount of topsoil washed away, the accumulation level of pesticides in soil, etc., and the intangibles, such as the beauty of the landscape, recreation potential, human perception of certain physical indices, and human health related to environmental quality. This very important aspect of environmental science is a basic issue which should be borne in mind.

Agricultural and environmental interests are determined by a number of components, which when considered both singly and in combination, are often conflicting objectives. Therefore, delineating goals for environmental control not only entails a search for optimal goals among several criteria, but also means that an optimum for general use cannot usually be found. Instead, one should look for optimums applied at the local level, which may mean sacrificing certain objectives either in agriculture or in environmental quality. The same problem of tradeoff and compromise can be found in various aspects of the environment. For instance, successful soil conservation may lead to an increase of nitrates leaching into natural waters. In this respect, it would be useful to discuss accumulated experience in defining optimal goals for environmental management as well as methods for analyzing the goals.

In order to control the environment, the cause and efect relationships between agriculture and the environment must be known, and previous experience is of paramount importance. Some of the knowledge required can be derived from statistics, measurements over several years, and the expertise of farmers. These data, gathered incidentally or through general surveys, often stem from practical experience. However, a controlled, planned experiment is also a useful source of information. It is, furthermore, well worthwhile discussing these relationships, as the first stage in management of the complex problem of studying the environmental effects of agriculture.

In the case of a watershed, it is essential to know the cause and effect relationships for different environmental agricultural problems at various hierarchical levels, from a field to a closed water body:



The above diagram relates both to hydrologic processes and to processes where water serves as a transport medium. The processes in the links of this chain are not completely known.

Mathematical modeling is an integral part of a systems approach to the problem of using cause and effect relationships for environmental management of agricultural areas. Modeling not only helps in planning an experiment, and in using available experimental data to generate new experiments, but also can be a useful tool in assessing the effects of agriculture on the environment, thus preparing background information for solving the conflict situation between agriculture and the environment.

When the objectives of environmental management are defined, mechanisms to be used for control should be clearly stipulated. Environmental management of agricultural areas can be done through technological, economic, administrative, and legal control tools. Policy analysis is an important part of environmental management. As many of the control mechanisms are operated by man and affect mankind, social, economic, and behavioral aspects should also be taken into account.

The objective of this paper is merely to determine those problems which are important for the environmental management of agricultural watersheds. It cannot be expected that all the issues can be discussed or even mentioned in a conference. However, considerable attention should be given to understanding environmental effects as this is the first step toward environmental management.

THE HYDROLOGICAL ROLE OF AGRICULTURAL PRACTICES

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ABSTRACT

Agriculture, together with related water control, influence hydrological processes on the earth more adversely than any other interference by man in the hydrologic cycle, because the effects concentrate on a quarter of the land surface of the earth. Lengthening and intensification of the growing period, the increase of yields as compared with the natural production, installation of one-crop agriculture instead of the balancing variety of a natural composition of plants, mechanical treatment of soil, shifts in the land use, fertilization and so on, have effects which concern the distribution of water according to space and time, the quantity of water available to man, and water quality. It is an urgent task to study the geographical differentiation of these effects.

During the past few decades, the water balance on earth has changed, regionally and globally, due to man's influence, as man started to use vast areas of the land surface for economic purposes, especially for agriculture. The runoff from the continents to the sea decreased, though precipitation was almost constant. Over several decades, evapotranspiration has increased by about 10%, this number indicating the trend. The expansion of arable land and grassland at the expense of forest areas and arid areas without vegetation, and the increase of crop yields, are not the only reasons but the most important ones for the modification of water balance.

Ten percent of the land surface is arable land and settlement areas, 16% is permanent grassland, savannas and steppes. Thus, a quarter of the land surface is being used for agriculture. That is to say that on a quarter of the land surface the natural balance is influenced by man.

It is known that originally Central Europe was almost completely covered by forests of different kinds. Especially during the Middle Ages, large forest areas were cleared and claimed for arable land and pasture, known to historians and geographers as new settlement areas. In spite of these changes, water balance has not been completely unbalanced.

All the studies carried out in many countries and climatic regions of the earth proved that forests, due to the greater retention capacity of the tree tops and the ground, break most flood peaks. It cannot be clearly said whether, during the year, forested areas can supply more water than an area without forest.

In Central Europe, geomorphologists can prove that during the Middle Ages, a special sediment layer in flood plains, the so-called flood plain deposits, originated from the intensified erosion in areas of forest clearing. It is also known that in Mediterranean regions, from the Roman period to the late Middle Ages, larger areas of forest were cleared, providing space for settlements and for ship construction, etc. On account of different climatic conditions, the consequences of forest clearing in these regions are more serious than in Central Europe.

Today, in Mediterranean countries, vast areas are not only devoid of forest but there is not even soil for water storage, which could be a basis for reforestation and of course for farming. After deforestation, heavy winter rains which are characteristic of the Mediterranean climate, could easily erode the soil and spill it into the nearby sea. This process is still to be observed annually in agricultural areas of mountainous and hilly countries. During the last 150 years even more new arable land and pastures in large areas all over the world were claimed by clearing forests, than during the entire Middle Ages. The hydrological consequences of these more recent clearings are sometimes dreadful. Areas in the west of North America, in Africa and Australia, areas with a high amount of precipitation as well as semi-arid parts of New Zealand, are just a few examples. This recent clearing of land, where periods of heavy rain alternate with dry periods during the year, had catastrophic consequences. In these regions considerable erosion and sedimentation still take place every year. Large areas of arable land and pastures are still being destroyed by erosion as well as by sedimentation. During the last years, in the Mangatu Valley in NE New Zealand, the valley floor along the main river and along several tributaries has risen by 50 cm each year as a result of sedimentation. This happens along a stretch of many kilometers and extends to a width of about 200 m. Pasture claimed about a hundred years ago is being destroyed.

With deforestation, the typical climate of a forest changes, which is of particular importance in areas of fog forest. The soil is being removed. At the same time the ability of the soil to store water and the supply of soil water to the ground water decreases. The missing water-retention capacity in the soil causes the precipitation to runoff on the surface, flood peaks become higher, low water becomes more extreme; in other words: fluctuations of water levels in rivers increase and with them, the work of erosion and transport in rivers. In order to compensate these negative effects of cultivating woodlands, reservoirs have to be built to balance the fluctuation of water levels, and to decrease erosion as well as the transportation capacity of solid matter, the rising of the river bed, and sedimentation in the middle and lower part of the river.

The agrarian areas all over the world border on natural forest belts and arid belts. The natural growth of grass in semi-arid areas also protects the soil. Grass increases infiltration, transpiration and evaporation respectively. Studies have proved that grass-cover lowers the runoff peak and thereby decreases the erosion capacity and, last but not least, the water consumption of vegetation itself. A mistake most frequently observed is over-grazing, which destroys the sod, and therefore increases water and wind erosion. This causes a decreased storage of water in the soil and increased runoff fluctuations.

A further effect of pastoral farming, which may be observed in sub-alpine and alpine mountains of higher latitudes, is the following: the trampling of grazing animals causes the ground to be compacted and thereby the runoff is accelerated. In a certain area of West Colorado pasturing was not permitted between 1955 and 1961. The runoff decreased by 20%, because more water could infiltrate the soil, and the sediment load decreased by 18 to 24 % as a result of diminished erosion. At the same time the composition of the vegetation did not change radically (International Hydrological Decade, 1972).

Similar results were found in the Swiss and Bavarian Alps (Karl and Danz, 1969). The intensified erosion observed during the last decades deteriorates water resources development projects of rivers in the foreland as a result of the increased transport of solid matter. Investigations showed that pastoral farming in mountainous countries sometimes causes a rapid increase of erosion and of transport of solid matter in surface flow. There, applied infiltration tests have demonstrated that infiltration on pastures is 276 to 1080 times less as compared with infiltration on grounds which were not pastured. Therefore, the erosion encouraging surface run-off increases on pastures during frequent heavy rains in mountainous regions. These areas, which include woodland pastures, cover about 20 % of the Bavarian Alps.

In more recent hydrological research, the question of a higher water demand caused by an expansion of arable land, by intensifying cultivation, and by increasing crop yields is very important, as well as the question of modification of water quality caused by fertilization of arable land and pasture. Under varying edaphic conditions there is a different ecological evaluation of the arable land and there is, therefore, no unanimous answer to the following questions:

Does forest area need more water than farmland? Does groundwater receive more water from forest land than from arable land?

Detailed studies have shown that as a rule, more water evaporates from soil covered with vegetation than soil without vegetation; moreover, these studies have demonstrated that a dense vegetation needs more water for cultivation than sparse vegetation. Here, it must not be overlooked that in consequence of the microclimatic conditions (with more intensive radiation, a more intensive motion of the wind and thereby evaporation), the single plant in open vegetation has a relatively higher water use, i.e., the water use per gram of plant substance, than the single plant in dense vegetation. Good management of land under cultivation, improved agricultural practices, and good fertilization also saves water. However, as a rule the absolute water use increased per unit or area with a higher amount of transpirating plants. Of course, the kinds of plants are of importance; there are water-saving and water-wasting plants as well as locations. Agricultural production then, influences the surface and subsurface runoff due to the water intake of plants.

Before 1951, the question of the influence of agricultural production on evaporation and runoff did not attract any attention. Until 1951, it was believed that in Central Europe the total evapotranspiration was split up into 25 % transpiration, and 75 % evaporation. Special studies on the physiology of plants brought me to the conclusion, that 75 % of the total evapotranspiration is transpiration, and 25 % evaporation. I explained this for the first time in the first scheme of water balance of the Federal Republic of Germany in 1951. In this connection the transpiration was estimated according to a special procedure.

The water balance values for the period 1891 - 1930, which were then determined, are still used today in the Federal Republic of Germany, as a basis for the calculation of water resources. In 1970, I used the same method in recalculating the water balance for the period 1931 - 1960, whereby an interesting comparison of changes in evaporation and runoff were evident. Following this, I briefly explained the method used (Keller, R., 1951, 1952, 1961, 1965, 1970, 1971).

The basis of the method is transpiration measurements, where, simultaneously, the mass of transpiring material is also given. From botanical works, I have compiled a diagram (Fig. 1) in which the transpiration values for 62 different plants are included according to Pisek, Cartellieri, Berger-Landefeldt, Schenk, Härtel, Müller-Stoll. From the vertical scale, it may be seen that 1 gm of fresh plant matter can give off between 2 and 13 gm of water daily. This transpiration is part of an order of dimension also specified for cultivated plants.

In order to assess the water balance in a region, it is important to determine whether plants with an extremely high water-consumption can build up an entirely natural formation with full surface-coverage. Plant populations of only grasses and shrubs appear seldom as a natural phenomenon; man, however, in his fields and woodlands, cultivates plant populations of a homogeneous type. He prefers few plants. Can these plants have extreme water-requirements?

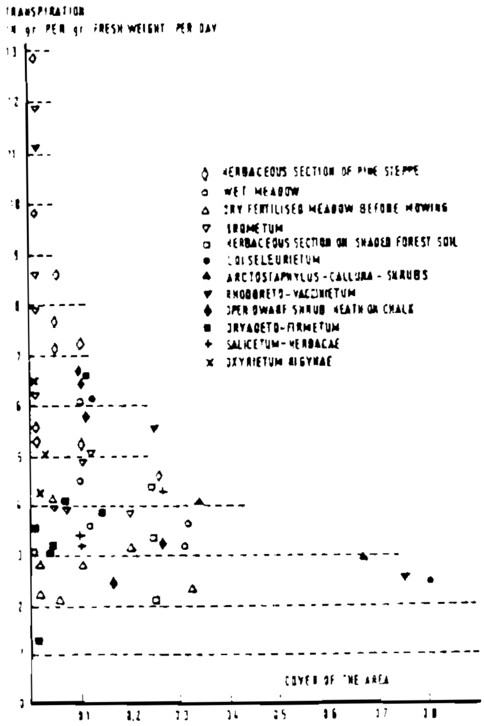


Figure 1. Transpiration by different plants in relation to areas covered by them.

Can the natural water balance be disturbed by this means? In the diagram (Fig. 1) this question is answered only for the natural plants which have been recorded here.

The larger the area covered by members of a single plant group, the lower the relative water consumption by this plant. Or, one may say: plants with extreme water consumption are always in the minority in a formation. In the following diagram (Fig. 2), not the water consumption of individual plants is portrayed, but, rather, the transpiration of natural plant formations made up of various types of plants. Thirteen characteristic plant formations and seven tree and shrub types are included. The plant formations are composed of the same plants, which were portrayed as individual plants in the previous diagram.

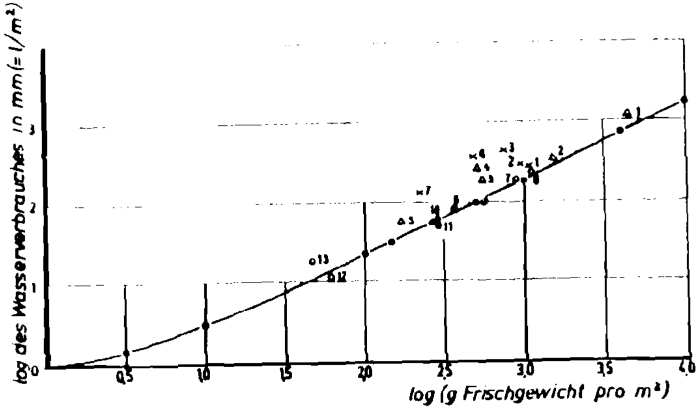
The lower limit of the arrangement of points in the diagram (Fig. 3) lies on a continuous curved graph. On this curve, all plant formations, which are to be found in the region of the alpine tree-line and above (i. e. in heights above 1800 m in Central Europe) have been investigated.

The graph curve of the water requirements of the vegetation in these altitudes, near and above the alpine tree-line, may be represented by the following preliminary equation:

$$\log W = \frac{(\log F)^2}{1+\log F} + L(t)$$

In altitudes above 1800 m $L(t) = 0$. In this equation, W represents the annual water-requirements in mm, F the annual production of fresh matter in gm/m^2, or, if the necessary data for the transpiring surfaces are lacking, the transpiring mass.

An increase in the absolute water-consumption with increasing production of fresh matter, is not to be denied. However, the relative water-consumption, that is, the water-consumption per gram of plant matter produced, decreases with increasing production. This fact, also recorded in the above formula, has long been known in agricultural botany. The transpiration values for



^{x}Trees and shrubs: 1. Picea excelsa; 2. Pinus silvestris; 3. Coryllus avellana;
4. Larix decidua; 5. Fagus silvatica; 6. Betula pendula;
7. Hippophae rhamnoides

$^{\Delta}$Plant-formations with level under 1800 NN: 1. Wet meadow; 2. Dry fertilized meadow before moving;
3. Dry meadow (Brometum); 4. Herbaceous section of pine steppe;
5. Herbaceous section on shaded forest soil

^{o}Plant-formation with level above 1800 NN: 6. Loiseleurietum; 7. Arctostaphylus-Calluna-shrub;
8. Rhodereto-Vaccinietum; 9. Open dwarf shrub heath on chalk; 10 Dryadeto-Firmetum; 11. Salicetum herbacae;
12. Oxyrietum digynae; 13. Alpine chalk scree slope.

Figure 2. Fresh weight of plant formations and water consumption

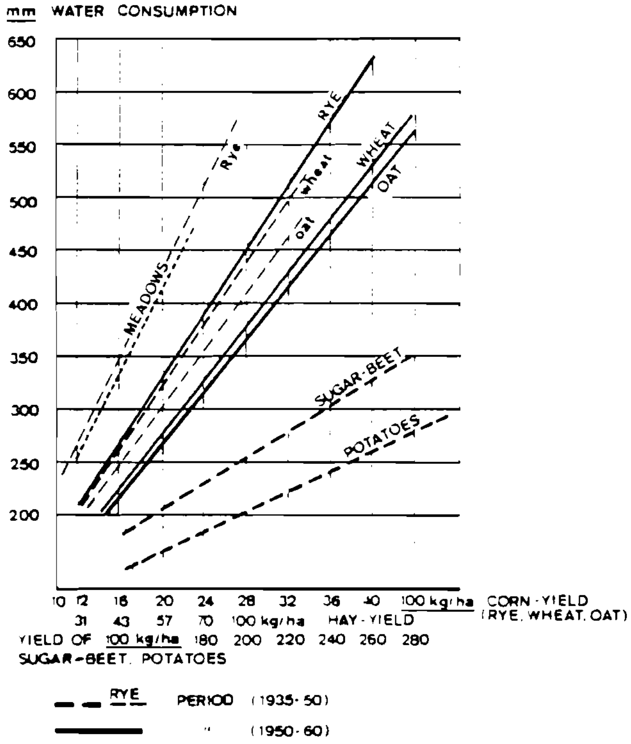


Figure 3. Water consumption by different crops (corn, hay, bulbous plants) in the Federal Republic of Germany. For oats, wheat and rye, dotted lines are for the period 1935-1950 and solid lines are for 1950-1960.

trees and shrubs exhibit the greatest variation; they doubtlessly provide the greatest difficulties in measurement, due to their varying age, the possibility of taking the samples at varying levels and from sunny or shady exposure, and, finally, in determining the production of fresh matter per m^2. The varying water requirements of plant formations in varying levels of altitude are apparent in the diagram. Although the water given off in transpiration does not exclusively function as cooling-water for the plant, there is, nevertheless, special significance in the cooling effect, which hinders the dangerous overheating of the leaves by insolation.

If it is assumed that the relationship between plant mass and transpiration, outlined here, is also applicable to cultivated plants, the result is obtained (see Fig. 3) that a rye crop with 2000 kg/ha grain yield requires more water than a wheat crop with the same yield. According to Fig. 3, the possibility exists that with increasing crop yields, the water-requirements also increase. The marked increase in crop yields in pre-war Germany and in post-war years in the Federal Republic of Germany, is illustrated in Keller, R. (1970, 1971).

The increase in crop yield is not accompanied by a proportional increase of grain and straw. It is rather success in the cultivation of plants that the increase in crop yield is achieved by improving the grain-straw ratio. Therefore, the referring lines for water-consumption of the field crops in the years from 1950 - 1960 differ from the former period (Fig. 3). The water-requirement line shown in Fig. 3 was obtained using the equation shown above.

The mean transpiration value for the agricultural area of the Federal Republic of Germany, for the period 1951 - 1960 accordingly amounts to 378 mm per annum.

The following facts may be noted:

1. There is a close relationship between the amount of water given off by the vegetation and the extent of the transpiring surface.
2. When data concerning the transpiring surface is lacking, the green weight of the transpiring material may be used as a substitute.
3. It may be inferred that trees react in a similar manner to shrubs and grasses in the transpiration of water.
4. The quantity of plant matter produced in a certain locality is dependent upon the ecological factors of that locality.
   The plant material produced is the expression of the ecological potential of the area, dependent, amongst other things, upon water, soil and radiation.
5. Fertilization and a good soil may reduce the water consumption per gram produced substance, increasing, however, the total water consumption of a surface.
6. A large amount of water available, e.g., as in the case of a high groundwater level, may lead to an increased transpiration, eventually not by means of evaporation.
7. Evaporation is not taken into consideration in the logarithmical equation of water consumption. On the basis of numerous investigations carried out in Central Europe concerning interception and evaporation, one may assume that the annual evaporation is 130 mm (see: Hydrologischer Atlas der Bundesrepublik Deutschland, 1978). In 1951, I used 100 mm, in 1978 130 mm to indicate this.
8. The logarithmic equation for water consumption may only be regarded as a preliminary equation, as the upper part of the graph curve representing water requirements (Fig. 2) cannot increase to infinity.

The final equation must make allowance for an upper limiting value for transpiration, which is dependent upon radiation. This maximum value lies within the limits of potential evaporation. In Central Europe this maximum value is not attained, except in the case of evaporation from open water surfaces and, thus, the equation under discussion is adequate for Central European conditions. It would be desirable to have a better scientific basis for the function L (t) in the logarithmic water requirements equation. This function is an expression of the differing conditions of temperature and radiation at the various altitude levels in Central Europe. At heights of 1800 m above sea level its value is zero, and, on the average, for the area of the Federal Republic of Germany, its value is about 0.15.

The comparison of water balance during the years 1891 - 1930 and 1931 - 1960, which was calculated by using the same method, encouraged hydrological research in Central Europe immensely.

The evapotranspiration value for 1931 - 1960 is 515 mm per year, or 30 mm higher than the value for the period 1891 - 1930. In both balances, the evaporation has been assessed at 130 mm. The increased evapotranspiration was calculated entirely on the basis of higher crop yields for the period 1951 to 1960. In the Hydrological Atlas of the Federal Republic of Germany (1978) the evaporation was calculated by employing the Penman, Albrecht as well as two other hydrological methods. For the period 1931 - 1960, the heat budget method resulted in 450 mm and using the other methods the values between 515 and 525 mm were estimated.

Table 1. The Water Balance of the Federal Republic of Germany 1891 - 1930 and 1931 - 1960 (mm)+)

	P	ET	Run-off		
			Total	Rivers	Ground-Water
1891 - 1930	803	434	369	330	39
1931 - 1960	837	515	322	296	26

+) Contrary to earlier publications (Keller, R., 1971 and others) the values of precipitation and evaporation have changed according to more exact and up-to-date data.

In 1931 - 1960, whilst the evapotranspiration increased, the decreased. This decrease in runoff is all the more astonishing, as the precipitation level of 837 mm for the interval 1931 - 1960 is 34 mm higher than that for the period 1891 - 1930. The total runoff was calculated as the measured annual mean precipitation minus the calculated evapotranspiration (using the above mentioned method). Subsequently, the total runoff in the period 1891 - 1930 amounted to 369 mm, 39 mm of which was groundwater runoff and 330 mm discharge in streams and rivers, recorded at gauging stations. For the period 1931 - 1960 the total runoff in the Federal Republic of Germany amounted to only 322 mm, this is 47 mm less than in the early period 1891 - 1930. 296 mm of the 322 mm flowed seawards through rivers (i. e., runoff recorded at water gauges) and 26 mm in groundwater.

All those calculations are approximate and should only indicate a trend, as the measuring accuracy and the exactness of statistical recording are inadequate in presenting precise information.

M.I. Lvovitch (1969) found out independently that water balance on the earth changes regionally and globally by the influence of man. In these studies it was demonstrated that runoff from the continents to the sea decreased, while precipitation was almost constant, and evaporation during several decades increased by about 10 %, this number only indicating the trend.

With regard to the influence on hydrological phenomena, the expansion of arable land may be of higher value than the increase of crops. For Central Europe, however, where arable area diminished rather than expanded, the decrease of runoff and the increase of evapotranspiration were mainly attributed to the considerable increase in crops per acre during the previous decades.

By observing the runoff during the period 1901 - 1970, an insignificant linear increase in the runoff of certain rivers in the Federal Republic of Germany may be mathematically detected using a trend analysis. The increase in runoff is significant in the case of certain gauging stations on the Rhine and Weser Rivers. However, for most gauging stations it is insignificant.

If one uses the same calculation for regional precipitation, one may also observe an increase, which is certainly larger than the increase in runoff and nearly reaches the significance level of 95 %. The larger precipitation increase does not affect the river runoff. This could possibly relate to the aforementioned larger water consumption by agriculture.

The trend of the total runoff contains the trend of the precipitation. Separating the precipitation trend from the runoff, an insignificant runoff trend remains, which lies, however, a great deal below the significance level than the calculated trend of the original values of runoff (according to Liebscher in Keller, 1978).

After the preceding considerations, a decrease in runoff may be anticipated, as shown by the comparison of water balance during the periods 1891 - 1930 and 1931 - 1960. If this decrease of runoff cannot be detected by the trend analysis of the observed data, it may be justified either in the choice of stations examined on the Rhine and Weser Rivers, or otherwise by a recomposition of the total runoff, distinguishing between subterranean and surface flow. In this connection, it is not yet clear what influence agriculture has, and what is traced back to industry, water engineering and other causes.

During the last decades a lowering of the groundwater level - desired or undesired - was observed in many places in Central Europe. In other words: It is quite possible that the total runoff had reduced, yet the runoff of the surface waters had increased at the expense of subterranean runoff.

In recent years, many structural measures in the transformation of cultural landscapes in Central Europe followed the trend of hastening surface runoff and drawing off flood peaks as quickly as possible. Rivers and streams were straightened and wet areas were made dry. In the Federal Republic of Germany approx. 3000 km^2 were irrigated, however 3000 km^2 were also drained (Deutsches Nationales, 1976) which could lead to a certain balance of evaporation and discharge.

In the wine-producing Kaiserstuhl region near Freiburg, loess terracing was carried out on a large scale during the period 1971 - 1973, which totally changed the cultural landscape. As a result of this, 70 % of the area was drained and a canal system provided a rapid discharge of precipitation and soil water. The newly established asphalt road system includes 8 % of the total surface, and consequently speeds up surface runoff. The Geographical Institute of the University of Freiburg has installed two hydrological experimental basins in this area and, therefore, the diversion of runoff, as a result of agricultural measures, could be quantitatively recorded:

1. The surface runoff is accelerated and intensified (Table 2 and Fig. 4).
2. The soil water storage is consequently reduced along the soil profile, which is important for vegetation; in this manner the infiltration towards groundwater decreases.
3. Replenishment of groundwater is reduced and consequently the low discharges are more pronounced in dry periods. More frequently, extremely high flood peaks emerge and remain for a short time; this causes an increase of erosion and the transport of solid matter.

I previously mentioned the attempt to hasten the surface runoff within the scope of agricultural measures. In this connection, other measures which slow down run-off in the interest of agriculture and water supply, should be discussed in detail.

No action affects hydrological processes to the extent to which irrigation does; 80% of the entire water use on earth is used for irrigation.

Since the construction of the Assuan High Dam on the river Nile the reservoir annually supplies the river with 55 milliards m^3 of water. For infiltration and evaporation in the area of Lake Nasser 10 milliards m^3 are being assumed. The 55 milliards m^3 below the reservoir are being regulated to an almost constant runoff during the year which is quite contrary to the former natural runoff. Out of 55.150 milliards m^3 which were discharged in 1972, 41.420 milliards m^3 were used for irrigation; this is about 20.000 m^3 per hectare of the irrigated area. On the other hand, only 3 milliards m^3 were used for water supply to the population (37.5 millions inhabitants) and industry, and 3.5 milliards m^3 (equal to measured discharge into the Mediterranean Sea) for navigational safety. Loss of water in irrigation channels (infiltration and evaporation) is being estimated at 11.8 milliards m^3. 75 % of the Nile water was used for irrigation purposes (according to J. Z. Kinawy, 1976).

Table 2. Changes in runoff by creating terraces in the wine-producing Kaiserstuhl area near Freiburg, Federal Republic of Germany

Flood hydrograph 30. 6. 1977	Old vine-growing landscape with small terraces (Rippach drainage basin)	Changed landscape with large terraces and land consolidation during the period 1971 - 1973 (Löchernbach drainage basin)
Total depth of precipitation	13,1 mm	18,3 mm
Duration of precipitation	140 Min.	130 Min.
Mean intensity of precipitation	0,94 mm/10 Min.	1,4 mm/10 Min.
Maximum intensity of precipitation	6,5 mm/10 Min.	8,4 mm/10 Min.
Dry-weather flow preceding the flood	2,1 l/s	2,0 l/s
Base time T	420 Min.	650 Min.
Peak discharge HSQ	20,4 l/s	742 l/s
HSq	17,1 l/s km^2	412 l/s km^2
Average flow rate during base time	5,5 l/s km^2	29,5 l/s km^2
Accumulated discharge V	165 m^3	2070 m^3
Depth of discharge AH/T	0,13 mm	1,2 mm
Coefficient of runoff	0,010	0,065

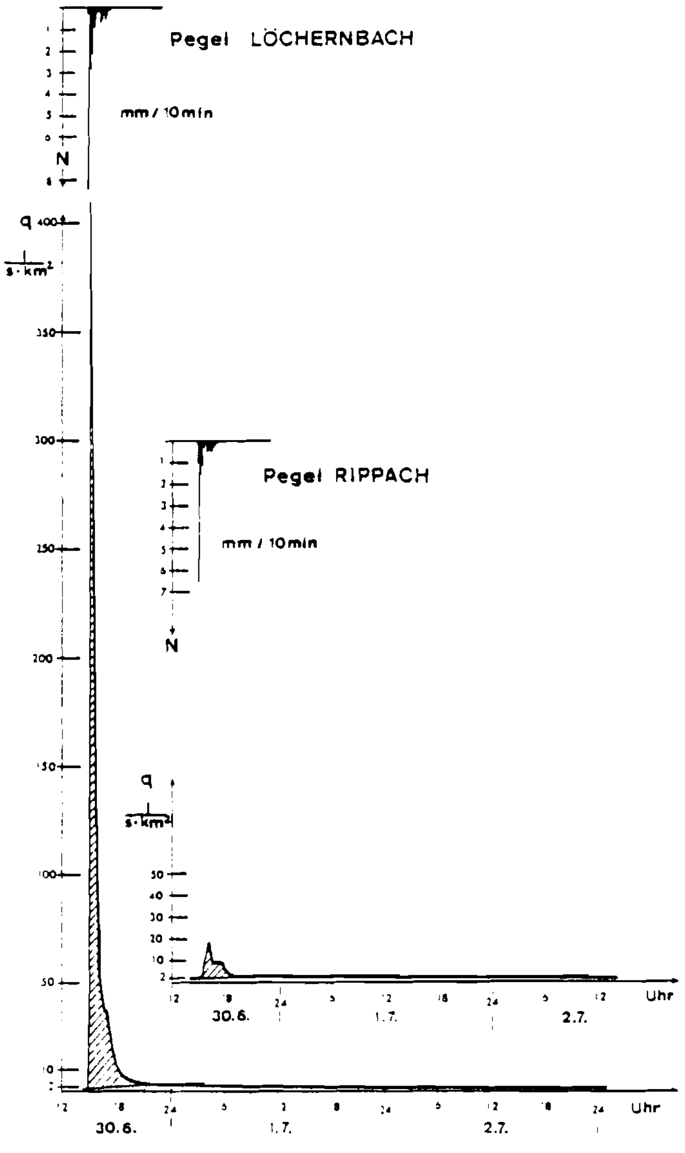


Figure 4. Changes in runoff in the vineyards of the Kaiserstuhl, near Freiburg (FRG). For additional explanation see Table 2 (after G. Luft and G. Morgenschweis, 1979)

Water demand for irrigation has increased considerably since 1966, because the rice and sugar cane growing area in the previously irrigated region was enlarged to a great extent. Rice and sugar cane need a large amount of water. That is why in Egypt about 5 milliards m^3 more water is used now than before the construction of the High Dam. During the past 25 years the rice growing area almost doubled. (National Council for Production and Economic Affairs, 1975.)

The hydrological significance of irrigation is especially extreme in semi-arid and arid areas where the natural evaporation had been very low due to lack of water. After the introduction of irrigation, evaporation increases in formerly dry areas more than ten times, in Tunisian oases, for instance, from 150 mm/year to 1680 mm/year (H. Flohn, 1970).

Irrigation management is often connected with the creation of new large water surfaces in "man-made lakes" and in a widely spread system for water distribution as well as in extensive flooded fields and meadows. The man-made lakes, channels, groundwater catchment plants, and field irrigation itself increase evaporation and influence runoff regimes. Water storage balances the runoff during the year and the supply of water to the fields across a widely spread net of channels also implies a delay of the runoff.

At the World Food Conference in Rome, 1974, it was stated that, at present, an area of 2 million km^2 of agricultural land was being irrigated. In the programmes, 230.000 km^2 of newly irrigated areas were being planned between 1976 and 1985, in order to guarantee a basis for food in developing countries. By far the highest amount of irrigation water originates from surface runoff. According to El Gabaly (1976), in the Middle East, including Egypt, Syria, Iraq, Pakistan, Iran, Afghanistan, Saudi Arabia and other countries, 261.490 km^2 is being irrigated by surface water, and 28.510 km^2 by groundwater. In many groundwater oases the reserve is being used up. In this case profitability of agriculture and the mere existence of the oasis is to be doubted within the near future. If water is taken from the surface runoff, water control takes care that the surface runoff always remains constant as far as possible. This means that flood and low water are being balanced to a great extent and flood waves which, for instance, with their fertilizing suspended loads serve as a basis for the old basin irrigation system in Egypt, are reduced or they do not occur at all. The process of erosion and sedimentation in these rivers and streams was fundamentally changed. As the transport of solid matter ceases to take place, the force of erosion is increased, the river bottom lies deeper and in estuaries, e.g., the Nile Delta, serious geomorphological changes of the coastline occur owing to the lack of sedimentation.

Agriculture, and especially field- and grassland irrigation, also influences hydrological conditions in the unsaturated zone of the soil, which is the connecting link between groundwater and the atmospheric stage of the hydrological cycle. By cultivating the soil, the natural capillary structure is modified. The infiltration of precipitation into deeper layers of soil, subsurface runoff, water flow and water retaining capacity in an unsaturated zone, levels of groundwater and capillary fringe are changed.

The modification of groundwater balance means a modification of chemical processes in the soil. By irrigation the content of soil water often reaches the maximum capacity. For vegetation this is usually not optimal, but ignorant farmers will often tolerate it. An increase of soil water content means an increase of the actual evaporation to the levels of potential evaporation and as a rule the groundwater table rises, frequently coinciding with a salinization of the soils. The rise of the groundwater level can lead to water logging or the flooding of areas used for agricultural purposes.

"Degradation of land by water logging and salinity is a common by-product of irrigation. More than 70 % of the 30 million hectares of irrigated land in Egypt, Iran, Iraq and Pakistan is moderately to seriously affected. 200.000 ha of newly irrigated land in Egypt is seriously threatened and in Pakistan it is reported that 100 hectares go out of production every day due to salinity and water logging. India has about 12 million hectares which are affected. Vast saline areas are found along the Senegal River, on the border of Lake Chad, and in most countries of northern and central Africa. They also occur in the coastal valleys and plains of Chile, Peru, Argentina, Venezuela, and Haiti, and the recent development of salinity is found in the Far East in traditional rice areas." (C. E. Houston, 1977, p. 431).

Salinized and waterlogged areas are no longer agriculturally productive, but their influence on hydrological processes still remains, because evaporation is considerably higher due to the high groundwater level, and the modification of groundwater quality is not interrupted. In dealing with the topic "The influence of irrigation on hydrological processes" we must not only pay attention to productive areas, which are being irrigated at the moment, and to areas which will be irrigated during the next decades, but attention must also be paid to the effects of vast formerly irrigated and presently lost areas. Up to now I have not yet received any exact data on abandoned irrigated areas.

The influence of hydrological processes by irrigation is not restricted to irrigated areas themselves, but it also spreads to adjacent areas. Here are some examples. From the ramified net of irrigation channels and from irrigated fields water percolates into the soil. Soil water and groundwater originating from this process follow into adjacent non-irrigated steppes or deserts. Thus, the groundwater table can rise in areas not actually irrigated and this might possibly lead to an increased evaporation and to a concentration of salts. As far as I know the expansion of these areas has not yet been registered.

In humid climates, too, there was and there still is irrigation with associated ecological problems. Here, it is true, that the rise of groundwater, due to irrigation, does not cause salinization but it influences the growth of plants, and for irrigated meadows, the composition of plant associations. In northern Switzerland and in the southern part of the Upper Rhine Valley the irrigation of meadows was abandoned 20 years ago, when this region was agriculturally reorganized. Consequently the groundwater table sank within a few years by 2 to 6 m, smaller creeks and ditches became dry, with the result that vegetation on the banks and the fauna have changed.

In humid regions of Central Europe irrigation could be used also for regulating runoff and subterranean water storage. A part of the surface runoff can be reduced in favour of groundwater by irrigation with river water, and, therefore, at least a delay of the surface runoff may be attained. In this manner irrigation is an effective measure in the regulation of runoff and groundwater recharge in water management. It is possible that the recharge of groundwater, or rather increased subterranean runoff can lead to the rise of low water in springs and rivers.

Studies in Soviet Central Asia in the Syr Darja basin showed that 30 to 36% of the runoff in the Syr Darja originates from irrigation return flow. This return water has a salinity of more than 2 gr per litre. The expansion of irrigated areas leads to a considerable increase of return water and to a fundamental modification of the runoff regime. Since 1910, river runoff decreased by 34 % and from 1971 to 1974 by 47 % as compared with the period 1910 to 1938 (recorded near Kazalinsk). This decrease in runoff is attributed to the development of irrigation and, accordingly, to the construction of reservoirs and supply channels. According to V. Dukhovny and L. Litvak (1977) losses of water from the reservoirs caused by evaporation and infiltration in the Syr Darja catchment area are at the moment as high as 1.5 km^3 and these losses will rise to 1.9 to 2 km^3 by 1990, because storage and irrigated areas are expanding. At present in the Syr Darja catchment area, within the four Central Asian republics of the Soviet Union, 27.000 km^2 are being irrigated.

The diminished inflow caused the decrease in the volume of the Aral Sea and the increase of salt content in the sea water. In the period of 1910 - 1938 the mean annual inflow from the Syr Darja river to the Aral Sea was 15 km^3/year; in the period of 1961 - 1970 it was 9.78 km^3/year and in the period of 1971 - 1973 it was 8.01 km^3/year.

The increasing deficit of the water resources promoted the idea of transferring runoff of the Siberian rivers into the Syr Darja river basin (15 - 25 km^3/yr) to provide for the future development of agriculture in this area. This project is being considered for 1990 - 1995. The transfer of this volume of fresh water into the Syr Darja river basin as well as the development of irrigation systems on this basis will increase the volume of return waters by 5.8 km^3/year. It will allow a delay in the rate of lowering the Aral Sea level if all the return waters are directed to the river.

The Bhakra Canal in northern India supplies irrigation water for an area of 27.000 km^2. The channel system is 4.800 km long and has a discharge of 353 m^3/sec. Irrigation was started in 1954. From 1954 to 1963 the groundwater table rose in this area by 7 to 9 m. Salinization of soils in this area has already begun.

In oases, based on groundwater, the problems of irrigation are different. In the irrigated oasis of Phoenix, Arizona, the groundwater table was lowered by 41 m between 1948 and 1967 because of the extensive groundwater production for irrigation purposes. Groundwater production in areas used for agricultural purposes exceeds by far the natural recharge of groundwater.

Below the irrigated areas the lowering is larger than within the quickly expanding urban area of Phoenix. Consequently there are subsidences as well as the formation of fissures in the ground (Schumann, H.H. and Poland, J.F., 1970, p. 295).

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THE EFFECTS OF AGRICULTURAL LAND USE ON RIVER RUNOFF

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ABSTRACT

The following main anthropogenic factors connected with the growth of agriculture in the USSR greatly influence river runoff:
- irrigation of lands in arid regions;
- agrotechnical measures in forest-steppe and steppe zones;
- drainage of waterlogged lands and lands with surplus water.

For the quantitative evaluation of the impact of these anthropogenic factors on the river runoff, depending on the availability of initial data, physiographic features, and the extent of economic development, three groups of computation methods are used:
- methods based on the investigations of the variation of characteristics of long term river runoff at the hydraulic sites, combined with the analysis of natural variations of meteorological factors and economic activity in the river basins;
- water balance methods based on the study of water balance elements directly at the sections of watersheds subject to changes of runoff formation conditions under the influence of economic activity;
- active field experiments.

Irrigation and engineering measures greatly affect the hydrological regime and total annual runoff not only of small and mid-size river systems, but of the big ones as well. At the same time, investigations showed that in the regions of irrigated soil management, the value of river runoff reduction is not always proportional to the increase of water consumption for irrigation.

Among the problems associated with the effect of agrotechnical measures on the hydrological regime, the most complicated and moot problem is the evaluation of this effect on annual river flow variations. The evaluation of the water regime changes of some rivers in the Belorussian S.S.R., caused by drainage and land cultivation in their drainage basins, serve as a typical example of the hydrological effect of drainage.

INTRODUCTION

The necessity for a considerable increase in agricultural production to provide the ever-growing population of the world with food is the reason behind the accelerated rates in irrigation and drainage development, extensive agrotechnical measures* aimed at the increase of crop yield, intensification of livestock production, and cultivation of new lands for agricultural needs. In this connection, the role of agriculture in the transformation of the environment tends to be more important, in particular, in quantitative and qualitative changes of the hydrological cycle components within river basins and large agricultural areas. The quantitative evaluation of water regimes and water quality changes under the effect of agriculture, and a scientific examination of water regime control in agricultural watersheds, are very important for effective planning of water resources use, as well as for development and implementation of measures for the protection of the environment.

In the USSR, the following principal agricultural and related activities considerably affect the water regime:

- irrigation in arid regions;

- agrotechnical measures in forest-steppe and steppe zones;

- drainage of marshlands and high precipitation areas.

In order to study the effect of these factors on the water regime, multi-disciplinary investigations are being carried out in the USSR, mainly associated with the development of methods and regional evaluation of man-made changes in streamflow in different physiographic areas and river basins. In recent years an approximate evaluation of the changes which have occurred and are expected in annual runoff of all the main rivers, individual regions and the country as a whole, under the effect of different types of human activity (including agricultural development), has been made at the State Hydrological Institute, on a unified methodological basis. Some results of those investigations are given below.

Methodology

The quantitative evaluation of the impact of agricultural factors on the water regime is a very complicated problem, since man-made changes overlap with the natural variations of a phenomenon. Usually the range of those variations considerably exceeds that of man-made changes. Three groups of methods to evaluate man-made changes are usually applied:

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*By the term "agrotechnical measures", which is widely used in the paper, the author means a number of agricultural activities aimed at retention of water on and within a soil cover (fall tillage, snow retention, planting of forest belts, etc.). [Ed.]

- methods based on research of long-term runoff fluctuations in combination with the analysis of changes in meteorological factors and man's activity in the basin;
- water balance methods based on the study of water balance components at the locations where changes in hydrologic regime occur due to man's activity;
- methods of active field experiments.

In the USSR, the first and the second groups of methods are used most. They provide the basic information on the effect of man-made factors on the hydrological regime.

The main working hypothesis for the first group is calculation of natural streamflow characteristics, and assessment of an integral effect of the whole variety of man-made factors in the basin as the difference between the calculated and the observed flows. These methods are also applied to estimate the role of individual factors (irrigation and drainage, agrotechnical measures, channel control, urbanization, deforestation, etc.) for the basins where those factors are predominant in the change of the natural regime of streamflow.

The following methods are in the first group: method of analogy or of control basins; method of comparison of water regime characteristics for different long-term periods; and methods of streamflow modeling using natural runoff factors in the basin.

The above methods to some extent are applied to the quantitative evaluation of the effects of agriculture on streamflow in the USSR, but according to the research done by the State Hydrological Institute, the modeling of streamflow characteristics is most effective when there is no imbalance or disturbance in the watershed during the observation periods on account of interference by man. This served as the basis for the development of a technique for a quantitative evaluation of changes in annual and seasonal streamflow, applicable to individual groups of basins (Shiklomanov, 1976, 1979):

- Rivers of the southern areas of the USSR (the Caucasus, Central Asia, South Kazakhstan) which have their sources in the mountains and are used on the plains and lowlands mainly for irrigation and non-productive evaporation*. For runoff modeling, the values of inflow from the zone of runoff formation and meteorological data are used;
- Rivers of the plains, mainly for evaluation of the effects of drainage and channel control in the forest zone, agrotechnical measures and ponds in forest-steppe and steppe zones. Correlation of runoff data with the main meteorological factors (precipitation, snow storage, humidity deficit and air temperature) is used;

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*These rivers supply about 80% of the irrigated areas of the USSR with water.

- Large river systems (Volga, Dnieper) for the evaluation of the integral effect of the whole variety of man-made factors and, mainly that of the cascade of reservoirs and irrigation. Runoff of large rivers is modeled using runoff of basin-indicators and meteorological data.

The above mentioned techniques, based on the use of already available long-term hydrometeorological information, provide an objective estimation of the changes of streamflow under the effect of the whole variety of man-made factors, regardless of collection and storage of new data and avoiding complicated and costly experiments.

The general disadvantage of the methods of the first group is a limited choice of the objects under investigation because long periods of observation should be used which cover different stages of man's activity in the basin. Besides, without analysis of the physical essence of the events occurring in the basin, these methods fail to reveal the role of every man-made factor taken individually, as well as the whole variety of factors taken integrally in cases where the effect of those factors on streamflow is small and is within the limits of the accuracy of hydrological measurements at a gauging station.

To evaluate the effect of specific types of activity on the water regime, water balance methods have been widely applied, based on the study of changes in water balance components occurring in individual areas of basins and river channels, where natural physiographic features are subject to changes under the effect of man's activity (irrigated and drained areas, ploughed lands, areas inundated by reservoirs, etc.). These methods allow for an evaluation of the individual role of every man-made factor and a calculation not only of the changes which occur in hydrological characteristics, but the forecasted ones as well. Among these methods it is reasonable to mention the water balance methods for evaluation of the effect of agrotechnical measures, irrigation, drainage and channel runoff control (Shiklomanov, 1976) developed at the State Hydrological Institute during recent years. To evaluate streamflow changes under the effect of agrotechnical measures, methods have been developed on the basis of analysis of experimental data from runoff plots and small watersheds, as well as the data on groundwater levels and data on evapotranspiration from vastly different terrain. These methods permit calculation of the changes in overland flow, total streamflow and recharge of groundwaters, considering the portion of ploughed areas in the basin, the amount of water in the basin for a given year, characteristics of soils and subsoils, the gradient of slopes and depth of the groundwater table in different farm lands (Vodogretsky, 1974).

An approximate water balance method of the account of irrigation effect on annual runoff is based on the following data: irrigated areas, water consumption, efficiency of the irrigation system, depth of the groundwater table, as well as on the values of different hydrometeorological parameters typical of the regions studied. Moreover, an evaluation is made for individual groups of irrigation systems characterized by some common features of the water balance and hydrological regime, the presence or absence of a bilateral hydraulic relation between the river and the area in question as well as by hydrogeological patterns (Kharchenko, 1975; Shiklomanov, 1976, 1979).

To evaluate the effect of drainage of swamps and marshlands on the annual runoff of large rivers draining all the categories of groundwater, an approximate methodology developed at the State Hydrological Institute is used. It is based on the account of streamflow changes, i.e., depletion and drainage of groundwater storage on the one hand, and changes in evapotranspiration from the drained areas on the other hand, when swamp vegetation is replaced by agricultural crops. The first factor contributes to a temporary increase in runoff; the second factor usually causes the decrease in runoff due to some increase in evaporation losses from drained and cultivated areas (Novikov, Goncharova, 1978).

Despite quite evident advantages, the water balance methods have a number of intrinsic disadvantages. The accuracy of measurements and calculations of individual water balance components is rather low. Great difficulties arise during the translation of data from runoff plots, irrigated and ploughed areas, and small experimental watersheds to large river basins.

Considering the advantages and disadvantages of the methods developed it is expedient to evaluate runoff changes simultaneously by two independent methods, namely, by the differentiated water balance computation of irretrievable water losses in the basin caused by man's activity and by the analysis of actual long-term runoff variations and meteorological factors determining those variations. The latter method provides an integral evaluation of the role of the whole variety of man's activity simultaneously affecting the basin; this approach insures against serious miscalculations and provides reliable results in agreement with the data of actual observations of the hydrological regime.

Changes in River Runoff due to Man's Activity

Using the aforementioned methodological approaches, annual runoff changes for the main rivers of the USSR caused by man's activity have been investigated for the period to date and for the future 10-25 years. The results have been obtained for 20 large river basins most important for the national economy of the country. The computations have been made both integrally for the whole variety of man-made factors and differentially for the effects of irrigation, agrotechnical measures, drainage, channel runoff control, industrial and municipal water supply, water consumption for agricultural needs, and water transfers beyond the basin. The main results of changes in runoff due to man's activity are given in Table 1.

Considering total annual runoff of the USSR rivers as a whole, which is evaluated as 4,700 km^3/year, its decrease under the effect of man's activity is not significant. In 1940 it was 14 km^3/year, or 0.3%; by 1975 it was 92 km^3/year (2.2%);

Table 1. Changes in total runoff of the USSR rivers under the effect of man's activities from 1936-2000 (in km^3/year)

Types of man's activity and regions \ Period	1936-1940	1941-1950	1951-1955	1956-1960	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-2000
Agrotechnical measures	-5	-6	-7	-9	-10	-11	-11	-11	-12	-12	-13
Irrigation and related measures (compensation factors included)	-2	-4	-7	-8	-15	-18	-33	-51	-68	-83	-93
Drainage of swamps and marsh-ridden areas	0	0	1	1	1	2	3	4	3	2	-3
Industrial, municipal and agricultural water supply	-4	-5	-6	-7	-9	-11	-15	-19	-28	-28	-36
Losses from ponds and reservoirs (from the zones of inundation and rise of groundwater table around ponds and reservoirs)	-2	-3	-4	-7	-11	-14	-16	-18	-22	-25	-30
Accumulation of water in reservoir basin and ground-water storage	-1	-5	-6	-32	-36	-26	-20	-45	-43	-55	-62
Water diversion	0	1	2	0	-3	-7	-11	-17	-20	-25	-27
Changes in losses in river deltas	0	0	1	4	7	8	11	12	12	13	12
Total	-14	-20	-23	-58	-76	-77	-92	-145	-173	-211	-251
Excluding accumulation in reservoirs	-13	-17	-17	-26	-40	-51	-72	-100	-130	-156	-189
The same for the rivers in southern areas	-11	-14	-13	-21	-33	-42	-60	-86	-112	-134	-153
Rivers of northern European USSR	0	0	0	0	0	0	0	0	-1	-2	-3
Rivers of Siberia and Far East	-2	-3	-4	-5	-7	-9	-12	-14	-17	-20	-26

in 1985 the expected runoff decrease will equal 170-175 km^3/year (≈ 4%) and at the end of this century, 240-250 km^3/year (≈ 5.5%). The general insignificant change in total runoff of the USSR rivers is explained by the fact that the main portion of runoff (about 84%) occurs in the river basins which open into the Arctic and Pacific Oceans, where due to water surplus and low heat the effect of man's activity practically does not cause any reduction in gross water resources. The main runoff reduction is observed in the river basins of the Black Sea, Sea of Azov, Caspian and Aral Seas, Lake Balkhash, where by 1975 the runoff reduction had equaled 13% and was expected to be even greater in the future: by 1985 it will be 23% and by 2000, 30% (Table 1). At present 78% of total runoff reduction of the USSR under the effect of man's activity occurs in the rivers of the southern regions with natural water resources of about 540 km^3/year or 12% of the total river discharge of the USSR. Therefore, at present, projects are being designed in the USSR for the diversion of some portion of streamflow of northern and Siberian rivers to the southern areas.

The Impacts of Irrigation

Measures associated with the development of agriculture play an important role in the general reduction of streamflow in the USSR (Table 1). During the forties, the main role was played by agrotechnical measures, while at present and for the future, irrigation becomes the main factor of man's activity causing the major portion of runoff reduction; irrigation and agrotechnical measures cause about 60% of general reduction of streamflow (without taking into account water storage in reservoirs).

Among agricultural factors, irrigation considerably influences the hydrological cycle and total annual runoff of regions. Large new irrigated areas in arid regions result in some micro-climatic changes in the terrain and in space-time redistribution of many components of water, energy and salt balances like productive and non-productive evaporation, overland flow, temperature and humidity of air, etc. These changes are observed not only within the irrigated area but on the adjacent terrain. All these events are to some extent reflected in the changes of different streamflow characteristics including total annual runoff.

The effect of irrigation on streamflow is substantially different for small and large river systems. The latter drains all the categories of groundwater. In case of small watersheds, a complete withdrawal of water from the river for irrigation needs is possible. This, however, does not mean the exhaustion of water resources for a large basin since the major portion of water seeping from canals and coming out as return flow from irrigated fields recharges groundwater which is drained by larger rivers.

For large rivers, streamflow changes under the effect of irrigation are determined by the changes in evapotranspiration in the basin which consists of evapotranspiration from irrigated areas and non-productive evapotranspiration from other areas in the basin (assuming precipitation to be constant and neglecting additional water losses for vegetative mass production). Depending on the ratio of the last two values, river runoff due to irrigation may decrease, may be unchanged for a long period, and may even increase for some periods. Stability or increase of runoff, though hardly possible at first sight, may actually occur in large basins with diverse physiographic features, where irrigation developments and increase of water consumption happen simultaneously with the drainage of swampy areas, extermination of hydrophytes, decrease in river flooding, and reduction of the period of flood plain inundation as a result of channel runoff control, water withdrawals and removal of some surface flow to groundwater storage (Kharchenko, 1975; Shiklomanov, 1976).

In this respect, the effect of irrigation on the hydrological cycle can be illustrated by the Kura and Terek rivers (Figure 1). Their runoff is formed in the mountains of the Caucasus and is used on the plains and lowlands. The irrigated areas in the Kura basin up to Mingechaur ($F = 62,600\ km^2$) was 210,000 hectares in 1929, 520,000 hectares in 1960, 560,000 hectares in 1970 and 620,000 hectares in 1977. Consumption for irrigation needs was subject to increase respectively. Despite the increase of irrigated areas by 350,000 hectares, reliable dependences ($R = 0.94$) between runoff (annual and for a warm season, April-October) Y and natural factors have been obtained for that basin for 1929-1970:

$$Y = \varphi(\Sigma Q_{in}, X, t_a) \quad , \qquad (1)$$

where: ΣQ_{in} is characteristic of inflow from the mountainous part of the basin determined at gauging sites located in the zone of runoff formation;
x and t_a are precipitation and air temperature in the zone of runoff use.

Even during 1961-1970 runoff reduction due to irrigation and other factors of man's activity were practically not observed (the effect of additional losses for evaporation and accumulation in the Mingechaur reservoir constructed in 1953 and water diversions beyond the basin are excluded). Annual runoff during that period decreased by 1.2% only as compared with the previous period; runoff for the warm season decreased by 3.9%; the main decrease was observed during the very dry years of 1961 and 1962. Such an insignificant runoff reduction until 1970 despite an intensive irrigation development is explained by a decrease of non-productive evaporation during that time due to the above mentioned man-made factors making for significant additional water losses from irrigated areas.

During the subsequent years (1971-1977) when the possibility of compensation at the expense of non-productive evaporation was to a great extent exhausted, a further development of irrigation resulted in a considerable reduction of runoff (by 9-12%).

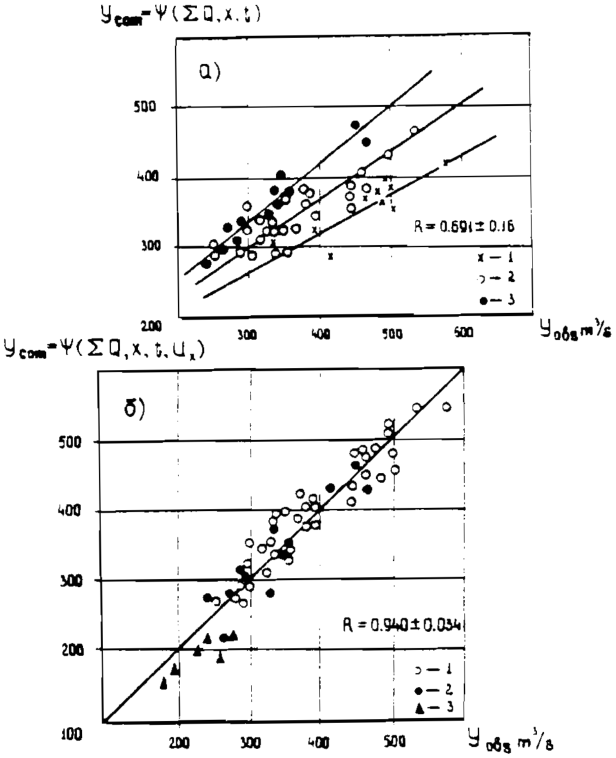

Figure 1. Dependence of runoff of the Terek river at Kargalinskaya for 1925-1977
(a) on natural factors
1 - 1925-1934, 2 - 1935-1960, 3 - 1961-1972

(b) on natural and man-made factors
1 - 1925-1960, 2 - 1961-1971, 3 - 1972-1977

Quite another situation of runoff changes caused by irrigation is observed in the Terek basin up to Kargalinskaya ($F = 37,000\ km^2$). Irrigated areas in the basin increased from 70,000 hectares in 1925 up to 600,000 hectares in 1975. It was impossible for that basin to obtain reliable dependences of type (1) accounting for natural factors only (see Figure 1a). When the anthropogenic factor U_{ir} was included in equation (1) reliable equations of regression with a high multiple correlation coefficient were computed; U_{ir} was numerically equal to the irrigated areas in the basin. For example, the following equation was obtained for annual runoff for the Terek river at Kargalinskaya for 1925-1977:

$$Y = 1.32\ \Sigma\ Q_{in} - 11\ t_a - 0.30\ U_{ir} + 144 \qquad (2)$$

$$R = 0.940 \pm 0.034$$

where U_{ir} is the area irrigated (in hectares--thousands); the remaining symbols are the same as above.

In equation (2), the partial correlation coefficient between runoff and the irrigated area is very high ($r_{YU_{ir}} = -0.88$), which shows that in this basin, unlike the Kura basin, the change in irrigated areas in fact characterizes the dynamics in the development of the whole variety of anthropogenic factors.

According to the equations of type (2), annual runoff of the Terek river under the influence of irrigation was reduced for 1960-1970 by 22% as compared with the previous period; runoff for the warm season reduced by 24%; runoff reduction was even higher (by 30-35%) during subsequent years (1971-1977).

Thus, in the areas of irrigated farming the value of river runoff reduction is far from being always proportional to the increase of water consumption for irrigation needs. In some large river basins the increase of irrigated areas and hence, water consumption for irrigation, may not cause reduction of total runoff at the river mouth due to reduction of the total non-productive evaporation in the basin.

This is especially typical of the basins where natural non-productive evaporation losses make up a great portion of total water resources (such as the Syrdarya, the Amudarya, the Kuban, the Ili and other rivers besides the Kura river).

This may be well illustrated by runoff changes affected by irrigation in the Syrdarya and Amudarya rivers discharging into the closed Aral Sea. Water resources of those rivers which are formed in the mountains of the Tien Shan and the Pamir make up 110 km^3/year on the average. This water discharges into the zone of runoff use, the latter occupies about 250,000 km^2 within the considered basins and extends over more than 1,000 km in length. In this zone, with a dry and hot climate, the major portion of water resources available and local precipitation are lost to evaporation, transpiration and for man's needs so only some of the water is discharged into the Aral Sea.

The zone of runoff of the above rivers is a region of intensive irrigation. At the beginning of this century (1910) the irrigated areas covered 3,000,000 hectares; in 1960 irrigated areas occupied about 5,000,000 hectares and at present more than 6,000,000 hectares. Despite intensive expansion of irrigated areas from 1910 to 1960 and increase of water use for irrigation, no evident increase of total runoff losses in the zone of its use $U_{z.u}$ is observed, which is illustrated in Figure 2. During the period before 1960 this relationship was quite clear, showing the increase of total water losses depending on the volume of water discharging into the zone of water use. During that period no decrease of water discharge into the Aral Sea was observed and the sea water level was stable. This is explained by the fact that for a long period of time, increasing water consumption for irrigation needs was compensated by a decrease in non-productive evaporation in the basin. Runoff control and increase of water diversions were accompanied by a decrease in river flooding downstream, reduction of evaporation and transpiration from water surfaces, and from flood plains with phreatophytes.

During subsequent years this relationship was disturbed though the water resources in the zone of runoff formation and local precipitation were the same as before. Water losses in the zone of runoff use increased greatly, i.e., diversion of some portion of the Amudarya streamflow beyond the basin down the Kara-Kum Canal, increase of water diversions for irrigation etc. On the average, during 1961-1976 discharge into the Aral Sea decreased by 16.5 km^3/year (30%) due to man's activity, which caused a fall in the water level of the Aral Sea by more than 3.5 m (plus a 1.5 m fall caused by dry years observed during the considered period). A particularly great reduction in river discharge and a drop in the water level were observed during the last three years, due to extremely limited precipitation in the mountains (Figure 2).

During recent years a considerable decrease in annual runoff at the mouths of the rivers was observed in many large rivers in the south of the USSR due to intensive irrigation development (Kura, Terek, Amudarya, Syrdarya, Sulak, Dnieper, Don, Ural and other rivers), so that the inflow into the Caspian and Aral Seas and into the Sea of Azov decreased. Moreover, as the research has shown, runoff is especially low during dry and hot years, when the natural water resources in rivers are small, which causes great difficulties in water supply.

Conclusions made on the problem of the effects of irrigation on streamflow characteristic for other river basins in similar natural conditions should be taken into account in the construction of mathematical models for water regime control, water supply and its effect on the environment.

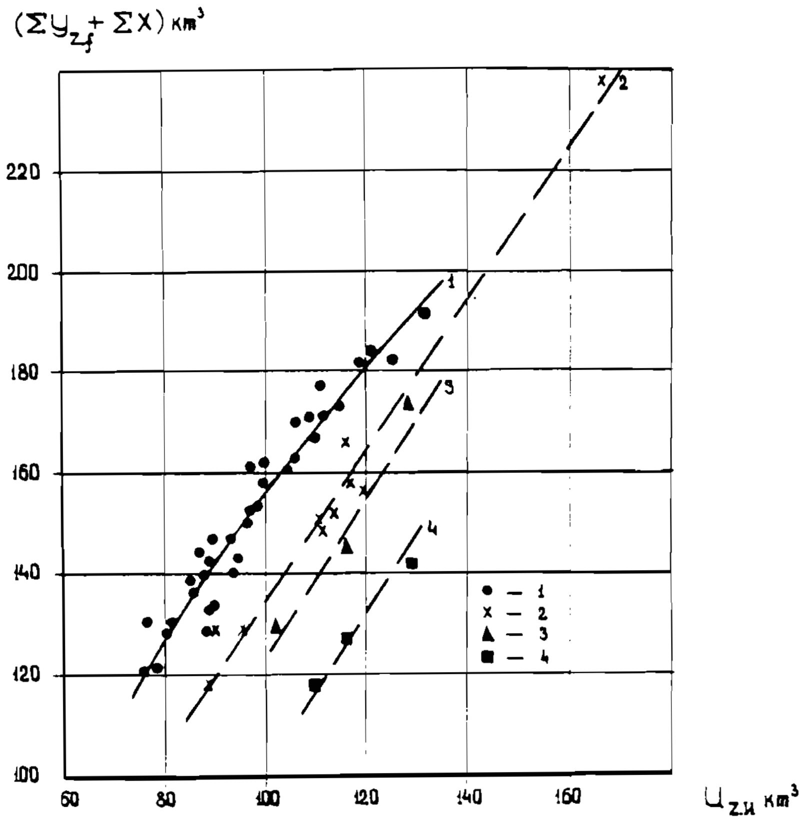

Figure 2. Dependence of total water losses in the zone of runoff use in the Aral Sea basin ($U_{z.u}$) on the amount of water resources and precipitation ($\Sigma Y_{z.f} + \Sigma X$), 1 - 1926-1960, 2 - 1961-1970, 3 - 1971-1973, 4 - 1974-1976

The Effects of Improved Agricultural Techniques

The main agrotechnical measures carried out on a large scale in the forest-steppe and steppe zones of the USSR, are as follows: ploughing of virgin and fallow lands, fall tillage, afforestation, etc. They aim at the conservation of moisture in soil to an increase in crop yields. From a hydrological point of view, agrotechnical measures primarily contribute to the increase of soil porosity and permeability and to better infiltration of snowmelt water, which results in a decrease in the overland flow and increase in filtration into the unsaturated zone and to groundwater. This general, qualitative conclusion causes no doubts. However, the quantitative evaluation of the rate of overland flow reduction, and in particular, the effect of this reduction on total river runoff, is determined by a great variety of factors, and, primarily by the amount of water resources for a given year, by soil moisture content prior to spring snowmelt, by the composition of soils and sub-soils, depth of the groundwater table, and the steepness of slopes.

Moreover, it is essential to differentiate the effect of agrotechnical measures, in particular the effect of autumn ploughing on overland flow, from the effect on runoff of small temporary water courses and especially rivers draining ground waters. The statements made above refer mainly to spring runoff formed primarily when the soils and subsoils are frozen and the intensity of water input to the surface of a basin is rather small. As to the overland flow produced by intensive rainfall, it may be much greater from steep, ploughed slopes, than from slopes which have been long fallow, or virgin lands. Moreover, an increased sediment transport is observed from ploughed slopes because of the increased water erosion rate which makes it necessary to take different measures to prevent erosion.

The intensity of the overland flow to a great extent determines maximum discharges of spring snowmelt and rainfall floods in rivers. For medium and low floods the decrease of maximum discharges of spring snowmelt floods in small watersheds under the effect of agrotechnical measures may be 10-20% or more. Maximum discharge of rainfall floods from ploughed watersheds greatly depends on the intensity of storms, local natural conditions and type of agrotechnical measures (Konovilow, Pyzhov, 1969; Sokolovsky, 1968).

As investigations show, changes in discharges of spring snowmelt and rainfall floods of rare frequency caused by agrotechnical measures are probably within the accuracy of practical calculations and usually they need not be taken into account for water management design.

The most complicated problem is the evaluation of the role of agrotechnical measures in the changes of annual runoff. Investigations made at the State Hydrological Institute during recent years (Vodogretsky, 1974; Shiklomanov, 1976) have shown that moisture accumulated in the fields due to agrotechnical measures mainly contributed to groundwater recharge and to the increase of the groundwater component of streamflow and to a lesser extent to evaporation and transpiration. The general conclusion is that the development of agrotechnical measures slightly affects annual runoff of large and mid-size rivers and cannot produce a significant depletion of water resources in vast areas. According to computations, the up-to-date decrease of runoff in large rivers on the Russian plain of the USSR flowing through the highly cultivated areas (relative to the period before 1936) is as follows: Volga, 1.7 km^3/year or 0.7%; Oka, 0.04 km^3/year or 0.1%; Dnieper, 1.2 km^3/year or 2.5%; Don, 0.68 km^3/year or 2.5%; Ural, 0.20 km^3/year or 1.8%. For the country in general, the total decrease in annual river runoff under the effect of this factor of man's activity amounted to 6 km^3/year altogether (Table 1). In future this decrease will be approximately at the same level.

Reduction of annual runoff in small and medium-sized rivers is more significant in arid steppe regions where it may attain 10-15% (when 60-70% of the basin area is ploughed). In this case a surface component of flow tends to a considerable decrease (up to 20-30%) with a simultaneous increase in the role of ground flow (up to 30-40%).

The evaluation of the hydrological role of a variety of agrotechnical measures may be illustrated by gross ploughing of virgin lands in South Kazakhstan during 1954-1966, when during the space of a few years the arable areas in some river basins increased from 5-7% up to 60-70%. From the hydrological point of view this may be considered a kind of active experiment and the results of this experiment provide a reliable conclusion on the effect of man's activity on river runoff.

Let us consider the Tobol river basin up to Kustanai (F = 44,800 km^2) located in the arid steppes of Kazakhstan. Mean annual precipitation is 320 mm, annual runoff is 17.3 mm. Before 1954 the ploughed area made up 18% of the basins, during subsequent years it increased to 67%. A water balance method developed by the State Hydrological Institute proved that this caused a reduction of the surface component of annual runoff approximately by 4.3 mm with a simultaneous increase of sub-surface component of streamflow by 1.8 mm. Total river runoff decreased by 2.5 mm or 14%. Concurrently, annual river runoff decreased under the effect of other factors: construction of ponds and reservoirs, and an increase in municipal and agricultural water consumption.

It should be noted, that the above conclusions on the effect of agrotechnical measures on runoff refer to the conditions of the continental climate of steppe and forest-steppe zones of Eurasia where river runoff is formed mainly during the period of spring snowmelt. In other natural conditions the agrotechnical measures may affect basin characteristics quite differently. For example, according to the data obtained by the US scientists (Lohson et al., 1969) in Iowa State where annual precipitation is 800 mm, with rain mainly falling during the warm season, the transformation of large areas occupied by pastures with phreatophytes into fields with tilled crops causes annual runoff increase approximately by 30% due to reduced losses by evapotranspiration.

The Effects of Drainage

The effects of drainage on the water regime and water balance is displayed immediately in reclaimed areas, on lands adjacent to drainage systems and in river basins as a whole. The creation of drainage systems primarily affects the regime of evaporation and transpiration from swamps, due to changes in the depth of groundwater tables, moisture content in soils and subsoils and transformation of vegetative cover. Detailed and complete investigations of the effects of drainage on evaporation and transpiration have been carried out by V.F. Shebeko (1970) for the conditions of the Belorussian SSR. According to these investigations soil moisture content after a drainage project is completed tends to a sudden reduction and for natural swamp grass total evapotranspiration tends to decrease by 10-15% on the average, and up to 40% during some months. As the drained swamps are cultivated for agricultural crops, evapotranspiration tends to increase again and may be even greater than prior to drainage. Evapotranspiration from perennial grass and spring cereals for a vegetative season is greater than from undrained swamps on the average by 20-25% during wet years, by 10% during the years of medium water resources, and it is about the same during dry years. The conclusions in general are supported by results obtained by scientists both in the USSR and in other countries.

Changes in water balance for swamps and marsh-ridden areas under the effect of drainage cause changes in hydrological basin characteristics (annual runoff, maximum spring snowmelt and rainfall runoff, minimum runoff, streamflow distribution during a year, etc.), which should be taken into account in the development of mathematical models of runoff formation and its use. In this case the effect of drainage on the regime of small and large rivers may differ greatly because of their different draining capacities and may be even in contradiction with each other.

For small river basins, if the depth of the river channel is comparable to the depth of the drainage network, drainage reclamation may result in a considerable decrease in annual runoff, and only a slight change or even an increase of runoff from large basins to which these small rivers relate may occur. But even when the watershed areas are similar in size, drainage reclamation may have a different effect on the water regime of rivers depending on climatic, pedological and hydrographic features of the basin, swamp area in the basin, type of swamps and the nature of reclamation. In one case this effect is insignificant, in the other one it is quite pronounced.

Many scientists come to the conclusion that drainage reclamation contributes to the increase of both mean annual runoff and discharges for low water periods, especially during the first few years after the construction of drainage systems. This is because of groundwater storage depletion, decrease in evapotranspiration, increase in river network density, reduction in the time of flood plain inundation, and some other factors.

According to data compiled by Bulavko (1971) for six reclaimed rivers in the Belorussian SSR in 4 or 5 years after realization of intensive drainage reclamation in river basins, annual runoff increased by 10-20% on the average, and summer-autumn and winter low flows grew by 1.2-1.8 times. The portion of underground flow in total river runoff increased substantially. Similar conclusions concerning drainage of swamps and marshland areas have been obtained by other scientists for the rivers of Belorussia, as well as the Ukraine, of the Baltic Republics and Central regions of the European USSR (Bulavko, 1971, 1976; Nauka i Tekhnika, 1973) where sufficiently long-term observation series are available, covering the periods with different rates of drainage development.

Figure 3 illustrates relations between specific discharges in a reclaimed basin (Belorussian SSR, the Odessa river at Andreevka, F = 3,580 km^2; the area of drained swamps in 1973 was 29% from the total basin area) and the control basin with undisturbed regime (the Ptich river at Krinka, F = 2,010 km^2) which shows a considerable increase of annual runoff after swamp drainage.

Conclusions on the increase of annual and low flows under the effect of drainage have been made by scientists from Finland, the German Democratic Republic and the United Kingdom (Bulavko, 1971; 1976; Nauka i Tekhnika, 1973).

The effects of drainage on water resources of those large river basins in humid regions where drainage reclamation covers relatively small areas (no more than 8-10%) are usually small and are within 1-5%. For example, according to calculations made at the State Hydrological Institute, the runoff of the Dnieper at Kiev (F = 328,000 km^2) due to gross drainage of swamps in the basin increased at present by 1.0-1.1 km^2/year (2-3%). For the future, when nearly all the drained lands will be used for agricultural needs, a decrease of annual runoff by approximately the same value is expected. In general, for the USSR, the changes in total annual runoff under the effect of drainage are quite insignificant (Table 1).

Some scientists note that in some basins drainage may result in a considerable decrease of annual runoff from small and mid-size rivers. For example, according to G.P. Kubyshkin (Nauka i Tekhnika, 1973), reclamation of swamps in flood plains in the basins of 12 rivers which are the tributaries of the Dnieper and the Pripiat (within the territory of the Ukrainian SSR) caused a reduction of their mean annual runoff approximately by 40%, due to some increase of evapotranspiration and multifold increase of groundwater outflow from the flood plain into mineral sub-soils.

The problem of changes in maximum discharges during spring snowmelt floods and rainfall floods under the effect of drainage is more complicated. This is explained by the fact that maximum discharges in the reclaimed swamps are formed under the contradictory effect of two factors. On the one hand, a relatively big unsaturated zone of drained swamps holds great amounts of snowmelt water, which contributes to the decrease of maximum discharges.

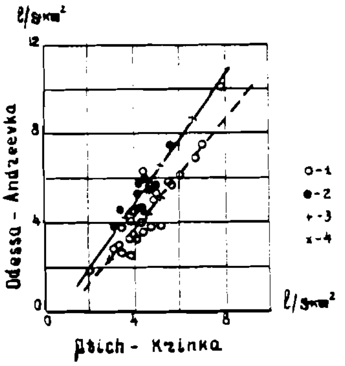

Figure 3. The relations between mean annual specific discharges of an artificially drained basin (the Odessa river) and control basin (the Ptich river)
1 - before reclamation, 2 - after reclamation,
3 - mean runoff for the period of simultaneous observations, 4 - values of equal frequencies

On the other hand, a well developed artificial hydrographic network in reclaimed areas considerably increases the velocity of flow and improves the transport of snowmelt and rainfall waters, which explains the formation of high discharges. As a result of a complicated combination of these two different factors, the maximum discharges tend to increase in some cases and to decrease in other cases. This has been noted by many scientists in the analysis of empirical data. The effect of drainage also may be quite different depending on the amount of water resources during a given year and the relative value of maximum discharge. The significant changes in ordinary maxima after drainage reclamation do not mean that maximum discharges of rare frequencies formed under extremely favourable conditions of runoff formation will be subject to changes. In this connection the corrections recommended by some scientists, for maximum discharges of rare frequency accounting for the effect of drainage are not sufficiently substantiated.

Thus, the analysis of results of numerous scientists in the USSR and in other countries provides the following conclusions on the changes of river runoff from reclaimed basins in humid zones (Bulavko, 1976; GGI, 1973; Sokolov and Vuglinsky, 1973).

During the first few years after drainage, a considerable increase of annual and seasonal runoff is usually observed. It is caused by a decrease of evapotranspiration and reduction of groundwater storage. Later, with an intensive cultivation of reclaimed areas for agricultural purposes , runoff regime stabilizes, evaporation tends to increase, annual runoff approaches its original value and may even decrease slightly. The drainage reclamation effect is most apparent in minimum discharges and in streamflow distribution during a year. Drainage contributes to a smoothing of streamflow distribution during a year; that is, it increases (often by 1.5-2 times) minimum discharges and flow during low water periods.

Maximum specific discharges under the effect of drainage may increase or decrease depending on particular physiography, meteorological conditions of flood formation, drainage type and the nature of cultivation of the reclaimed terrain. This problem requires further investigations so that the physical regularities of the above processes may be identified and practical recommendations made on drainage reclamations with the determining values of maximum discharges which are required for engineering design.

In general, reclamation of swamps and marshlands is undertaken on a scientific basis. In the majority of cases it is favourable for the streamflow regime, especially for the kinds of flow which are important for water use such as minimum flow and low water flow, which are usually increased greatly by these activities.

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WATER POLLUTION CONTROL STRATEGY FOR IRRIGATED AGRICULTURE IN THE U.S.A.

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ABSTRACT

In contrast to the use of effluent controls as part of a permit program for point sources such as municipal and industrial wastes, an Influent Control Approach (ICA) has been developed for irrigation return flows, which are non-point sources of pollution.

This approach consists of eight specific components: (1) designate areas for irrigation return flow quality management and designate the responsible area entity; (2) develop standards and criteria for beneficial use in designated areas; (3) introduce incentives to use water more efficiently; (4) include the element of water quality in new or transferred and changed water rights; (5) adopt and enforce a reporting and recording system for water rights; (6) recognize reasonable degradation from agricultural water use; (7) adopt an Agricultural Practices Act; and (8) promote close cooperation or integration of state water agencies and related functions.

INTRODUCTION

Water pollution from irrigated agriculture in the western United States has received major attention during the past five years, primarily as a result of federal and state endeavors to identify irrigation return flow quality problems and to develop a viable control strategy. The key to irrigated agricultural return flow quality control is proper utilization and management of the resource itself, and an accepted tool in our society is the law.

By legal classification, water is divided into laws for quantity control and laws for quality control. The laws on water quality control are recent, relatively uniform between states and with little exception, constrain improvement of return flows from irrigated agriculture. The laws pertaining to water resources quantity control and management are complex, voluminous, inconsistent and lack uniformity among the 17 states of the West.

Under Public Law 92-500 passed by the Congress of the United States in 1972, the U.S. Environmental Protection Agency (EPA) initiated a permit program for irrigated agriculture, thereby viewing agriculture as a point source of pollution similar to municipal and industrial wastes that are subject to effluent controls. Most agriculturalists (including the few agriculturalists in EPA) advised against the employment of a permit program for irrigated agriculture. A strong backlash quickly developed by irrigation companies and districts, and most water resource state agencies in the seventeen western states. More recently, Congress passed amendments to Public Law 92-500 that designated irrigated agriculture as a non-point source of pollution.

An approach has been formulated to incorporate the problem and the law. The Influent Control Approach is based upon the assumption that improved water management plus improved agricultural practices will significantly contribute to improved water quality, and the conclusion that best management practices plus best agricultural practices will provide irrigation return flow quality control, which in turn will contribute significantly to the national goal of cleaner water through improved water quality.

PHILOSOPHY AND CRITERIA FOR EFFECTIVE CONTROL

The Need

Water quality control from irrigation return flows has perhaps caused the greatest degree of disenchantment among state and federal personnel charged with carrying out water quality programs under P.L. 92-500 than any other category of pollution sources. Since the time that first regulations for irrigation return flows were promulgated in 1973, there has been strong and distinct differences of opinion among the various agencies dealing with water at both state and federal levels of government, and within their ranks as well. Many western states have called a stop to their programs until EPA adopts what the states consider a workable approach. The legal gyrations of the past four years have caused them to undertake minimum activity so as not to directly violate any particular law or regulation. Not one western state has completely and enthusiastically embraced a program of including irrigation return flows as a 'point source' and thus subjecting all irrigation to a permit program.

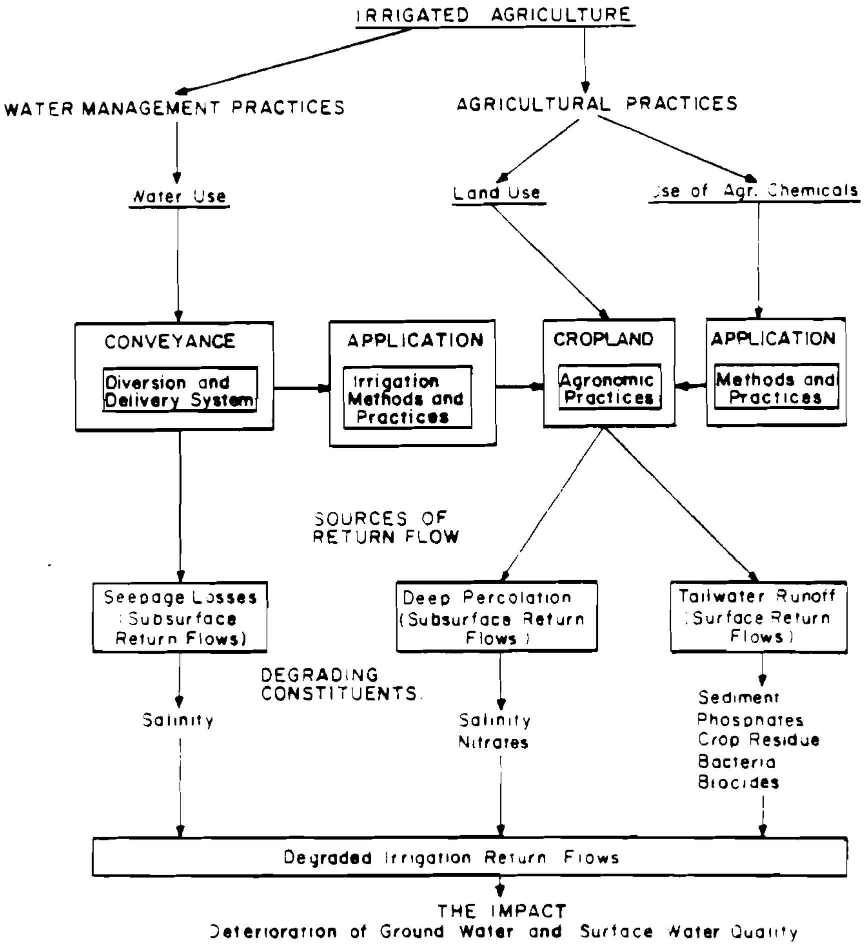
Part of the problem for the disenchantment stems from the physical difficulties in dealing with the irrigation return flow quality problem where it does exist. Equally important is the lack of a philosophical foundation and thrust to resolving a problem of this immense complexity, as well as inherent resistance to control.

Viewing the problem from both the position of water users and agency personnel charged with controlling the problem, this study attempted to be both logical and pragmatic in formulating an implementable and sustaining approach to irrigation return flow quality control. The philosophy and criteria which follow are building blocks to the proposed Influent Control Approach (ICA) set out in this paper. It is the authors' opinion that awareness, not concurrence, is essential to an understanding and acceptance of a program.

The complex situation faced by public officials and water users is illustrated in Figure 1. To achieve the highly desirable goals of cleaner water called for by the Federal Water Pollution Control Act of 1972 (P.L. 92-500), it is necessary to realistically assess the specific nature and problems caused by surface and subsurface return flows from irrigated agriculture. Present water management and agricultural practices create irrigation return flows from the conveyance system and cropland that may have a degrading effect upon water quality in the receiving waters.

Philosophy

The proposed philosophy upon which to formulate a successful program for control of irrigation return flow quality consists of four interlocking propositions. First, the ultimate goal achieved by the federal and state agencies is improved water quality by way of improved water management, with



(Radosevich & Skogerboe 1977)

Figure 1. Impact of water management and agricultural practices upon irrigation return flow quality.

this particular study focusing upon the return flow characteristics and problems of irrigated agriculture. In this context, improved water management means water quality enhancement through reductions in tailwater runoff, seepage losses, and deep percolation losses (i.e., surface and subsurface return flows, which are point and non-point sources, respectively).

Second, the program should promote social and economic well being through cooperative action. Every effort should be made to prevent polarization between state and federal agencies and local water user groups. An approach must be designated to stimulate a tripartite relationship between the water users and the state and federal agencies, while still maintaining the identity of each.

Third, only attack the problem after it has been realistically identified.

Fourth, voluntary compliance is more desirable than forced or involuntary compliance in implementing a management or control approach.

Criteria

Based upon this philosophy, the following criteria must be met for an implementable and sustaining program in irrigation return flow quality control:

1. The approach should result in improved water management practices specifically and improved agricultural practices generally. In the context of this paper, improved agricultural practices can be achieved through joint progress in two areas: (a) proper land use and (b) proper application of agricultural chemicals. As stated previously, water management includes effects upon the quantity and quality of surface and subsurface return flows.

2. The approach should prevent social disruption and polarization of water users (e.g., individuals, irrigation companies and water districts) and state and federal agencies. Maintaining separate identities is necessary, maintaining opposition is not. In most western states, water users have gone on record opposing past federal and state efforts to control irrigation return flow quality.

3. The approach should be palatable to water users. Some of the most often expressed concerns of the water users are: What is the problem and how significant is it; how am I involved; if I agree to a permit, what does that mean to me now, as well as potential control in the future (i.e., what rights and liberties am I giving up by agreeing to a nebulous program); what is it going to cost; what benefits will be achieved; and, who pays for nature's discharges?

4. The approach must be feasible, flexible and allow for state agency discretion in working with local entities. State agency concerns which must be met include: a determination of the significance of the problem; ability to implement the program because of manpower limitations; identification of pollution sources; failure of past programs to include subsurface flows; credibility with water users; conflicts with other state agencies (e.g., water quality administration and agriculture agencies); and, the ultimate impact of such a program upon water quality, flow regime of streams and water users.

5. The approach should improve the credibility of state and federal agencies. Presently, most agricultural water users feel alienated against the federal and state water quality control agencies.

6. The approach should utilize existing institutions (e.g., laws and organizations) and accepted concepts (e.g., designation of problem areas such as critical ground water basins, beneficial use, and duty of water) as much as possible.

In order to implement any approach, both the water users and the agencies must have knowledge of the resources they are 'managing.' The irrigation system is too highly integrated and complex to be subjected to a rigid unilateral control program.

AN INFLUENT CONTROL APPROACH

Irrigation Return Flow Characteristics

Irrigation return flows have few characteristics which allow them to be viewed as a typical point source pollution discharge problem. Most pollution contained in irrigation return flow occurs as a natural process of diverting and using water for a legally appropriated beneficial use. But, the pollution often occurs beyond the boundaries of the control of the water user. Thus, the first distinct feature is <u>problem identification</u>.

Because the degraded return flows may be either surface or subsurface, and most often diffused rather than collected into a discrete conveyance system from the contribution source, the second feature is <u>contributor identification</u>. From a technological standpoint, contributor identification requires an evaluation of the sources of pollution; whereas, from a legal viewpoint, contributor identification requires a determination of <u>who</u> is polluting.

Allocation of water under western states laws requires that it be for a beneficial use. Water allocated for irrigation is generally allocated to specific lands with the quantity based upon a fixed state-wide duty of water standard (e.g., 1 cfs/70 acres in Wyoming, 2 acre-feet per acre in Nebraska).[1]

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[1] In a few states, Nevada for example, discretion to determine quantity is given the State Engineer.

The right to use water is a property right to the holder, which is to be exercised according to priority with other users and availability of flow. Because there is no prorationing during shortages as under the riparian doctrine, and because this property right is one of rapidly increasing value in the West, the inherent incentive to the holder is to protect that right by diverting the full entitlement without regard to the fine line between beneficial use and waste. Thus, a third factor emerges, i.e., law and customary diversion preempt equal weight to external diseconomies.

The fourth feature gives rise to the proposed influent control approach described hereafter. This is the correlation of input to output. In addition to the possibility of controlling degraded return flows at their discharge, or effluent control, an impact can be exerted upon the quality of water discharged from irrigation uses by changes at the input stages, i.e., delivery and application of water. Because of the elusive nature of irrigation return flows, the traditional approach of effluent control is not considered adequate nor feasible in light of a more economic, simple and functional alternative within the control of the water user and influence of state water officials. That alternative is to control the influent. In the case of irrigation return flow, this includes water user discretion on the delivery and application of water (use of well known technologies such as canal lining to curb excessive seepage losses during conveyance, or improved irrigation methods and practices to reduce deep percolation losses and tailwater runoff), proper land use to retard or prevent erosion of soil and subsequent sediment pollution in tailwater, and proper application of fertilizers and pesticides.

These four features plus: a) the system of water quantity and quality administration at the state level, and b) the peculiarities of our judicial system, rules of evidence and burden of proof, require an approach which is both preventative and curative but within the parameters of a known demonstrated problem. Because end-of-pipe treatment is neither technically satisfactory, nor economically justifiable, the Influent Control Approach (ICA) is designated to get at the cause, not the consequence, of the problem and promote alternative solutions within the control and capability of irrigation water users generally. Where voluntary action to alleviate the known problem is not taken, existing laws for water quantity use and control of discharges by permit can be exercised.

Theme of Influent Control Approach

The underlying theme of the ICA can be summarized as:

1. Proof before control.
2. Proceed cautiously and positively.
3. Stimulate voluntary action based on demonstrated need to change.
4. Maintain relationship between agencies and water users.
5. Create or maintain credibility.

Assumptions

The Influent Control Approach is premised upon ten assumptions. They are:

1. Achieving the goals of P.L. 92-500 (the Federal Water Pollution Control Act of 1972) and policies of federal and state laws to improve the use of our national resources is highly desirable;
2. The concept of property rights in water and other constitutional guarantees will be maintained;
3. The legal procedures of the judiciary and agencies will be utilized;
4. Improved agricultural practices and improved water management will result in improved water quality;
5. Irrigation return flow problems and appropriate solutions to these problems are site specific;
6. Water users (farmers) will respond when it has been demonstrated that there is a problem to which they are contributing;
7. Technical and legal solutions to identify problems must be appropriate and viable (technically sound, economically feasible, legally implementable, and socially acceptable);
8. Many irrigators will respond on a voluntary compliance basis;
9. Those users who do not respond will feel a local social pressure as a result of being 'out-of-tune' with the newly evolved customs of the community; and
10. Regardless of approach, there will be some users who will not respond or will resist change, thereby requiring some mechanism for enforcement.

Influent Control Approach Components

As was alluded to above, the distinction of this approach to irrigation return flow quality control is to indirectly correct the unreasonably degraded discharges caused by irrigated agriculture by directly affecting the influent or input to the system. This approach is based upon the assumption that improved agricultural practices (IAP) and improved water management (IWM) will contribute to improved water quality (IWQ). In specific context of this paper, it is further conduced that best management practices plus best agricultural practices will provide improved irrigation return flow quality control (IRFQC), which in turn yields improved water quality (IWQ):

$$\text{BMP} + \text{BAP} = \text{IRFQC} \longrightarrow \text{IWQ}$$

Because the nature of agricultural pollution from irrigation is too complex to rely upon end-of-pipe treatment, the cause of the problem is examined in its broader context (i.e., present water management and agricultural practices) with the emphasis upon only those elements of agricultural practices relating to or having an effect upon return flows. The concept of best management practices is currently employed by EPA and the states and refers here to improvements in local[2] water management. Best agricultural practices is used here to include proper land use and proper application of agricultural chemicals.

To reiterate, every effort in formulating this approach was made to decentralize the <u>act of control</u> to the lowest common denominator--the irrigator--because of his ability to voluntarily and directly impact the quality of return flows and because of a recognition that agriculturalists traditionally are independent people who prefer to be actors, not pawns. The components of the ICA thus provide: (1) the design and direction to irrigation return flow quality control; (2) the opportunity for voluntary compliance by water users in problem areas; and (3) the means to effectively assert involuntary compliance upon those contributing to the problem who refuse to adopt better practices by the responsible government agencies.

The Influent Control Approach is designed to improve water quality by reducing excessive seepage, tailwater runoff and deep percolation, reducing sediment in return flows through erosion control and reducing chemical concentrations in return flows through licensing and/or control resulting from over-application of pesticides and fertilizers. Since irrigation return flow quality problems differ from one irrigation system to another, the approach provides the latitude to introduce change and control according to the nature of the problem, without requiring unnecessary compliance by those irrigators outside problem areas.

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[2] Local is used to distinguish water quality control within the irrigation system or subsystem from state and national control.

Based upon this background, the Influent Control Approach (Figure 2) is designed with eight specific components. The first six components pertain to improving local water management, with components 1 and 2 having application in the problem area only and components 3 to 6 having state-wide jurisdiction. Component 7 pertains to land use and chemical applications affecting water quality and has state-wide jurisdiction. Component 8 focuses upon the functional ability of agencies to carry out the program.

The Influent Control Approach consists of the following components to be carried out by the states:

1. Designate Areas for Irrigation Return Flow Quality Management and the Responsible Area Entity.

Action. Based upon monitoring and analysis for identifying significant irrigation return flow problem areas within the state, the state agency will: a) designate the boundaries of the problem area, which may be the boundaries of an irrigation system or subsystem or watershed; b) designate an entity, i.e., legally constituted body representing water users within the area, to undertake responsibility for working with the water users, collecting data and disseminating information. The area entity may be a newly formed organization, an existing organization, i.e., irrigation district, that assumes the program or a federation of numerous existing organizations in the designated areas; and c) insure that the entity is carrying out the best management practices developed for this area, as well as best agricultural practices.

Rationale. Applying the designated area approach to controlling unreasonable degradation from irrigation return flow enables the state to focus only upon those areas within its boundaries where a problem has been identified. Thus, not all irrigators are depicted as shifting externalities (i.e., costs from use of degraded water) upon the public and downstream users; all irrigators regardless of how well they manage their water and land resources are not subjected to the time consuming procedures and implications of a permit system. Consequently, water users are not collectively polarized against the efforts of state and federal agencies to reduce and prevent water quality degradation. This first component is the cornerstone of the influent control program because it draws attention only to problem areas without the guilt insinuations or accusations that farmers are so sensitive to.

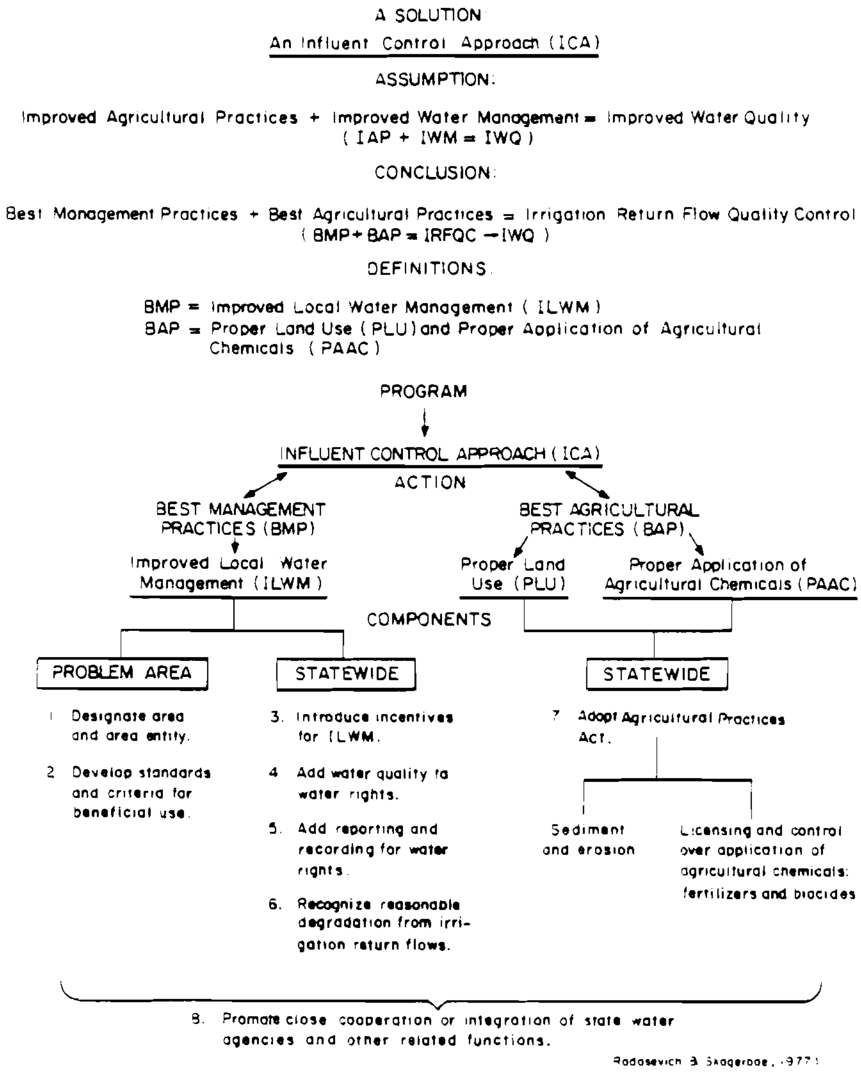

Figure 2. Influent control approach to irrigation return flow quality management

From a practical point of view, the area entity, which may be represented by an existing irrigation or water-related organization, would utilize a representative board of commissioners that would be responsible for carrying out monitoring, discussing ways to alleviate unreasonable degradation by irrigation return flows to receiving water with water users in the designated area, and encouraging voluntary improvement of agricultural practices by those users identified as contributing to the area's problem. For those users (or entities representing those users within an area) who refuse or fail to respond as recommended, the area entity would notify the state water quality control agency of the specific non-compliance, and the state would then proceed under existing federal and state law to initiate control and enforcement; that is, under the general provisions of the water pollution laws, prohibiting discharges of pollutants and violation of stream standards. In these cases, the identified and non-complying irrigator discharge can be required to obtain a permit under the regular EPA permit program. The area entity is thus responsible for assisting in managing the agricultural practices within the designated area, but control and necessary enforcement are appropriately left to the state.

Precedent. The concept of designated areas for resources control and management is well-recognized and applied in many western states for ground water and municipal water supply. In most instances, water users participate on commissions or boards having jurisdiction over the management area.

2. Develop Standards and Criteria for Beneficial Use in Designated Areas.

Action. For each designated area within a state, the water quantity and quality agencies will collaborate to arrive at standards and criteria for beneficial use of water. Such standards and criteria will not constitute an impairment or taking of water rights, but rather be the technical limits of water delivery and application under the climatic, soil and other agronomic conditions of the area. These conditions for water use would be tantamount to a calculated 'duty of water'[3] for the area in light of the return flow quality problems.

Rationale. Under the water laws of each western state, water is allocated under the concept of beneficial use. This term is generally not defined, it is normally nebulous, but does in general meet the needs for both allocating

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[3] Duty of water means the quantity of water necessary for effective use for the purpose to which it is put under the particular circumstances of soil conditions, method of conveyance, topography, climate and crop grown.

and distributing water within the state. However, in certain areas due to soil characteristics and water use practices, irrigation return flow quality problems do develop which are directly related to the delivery and application of water. Within designated areas, it is necessary to develop specific standards and criteria for beneficial use that still comply with the concept of a water right under state law.

Precedent. Under Nevada water law, the State Engineer has discretion to determine the duty of water based upon the site specific characteristics of the irrigated area, the type of use to which the water will be put, and the impact upon surrounding water users. Utah is another state that has applied the variable duty of water concept in determining the appropriate amount of water to allocate under a water right. However, the state agency in Utah has had to proceed through a judicial determination. These two states are in contrast to the standard concept of duty of water found in many states—for example, Wyoming and Nebraska--in which a fixed duty of water has been adopted that is applicable state-wide.

3. Introduce Incentives to Use Water More Efficiently.

Historically, the Agricultural Conservation Program administered under the U.S. Department of Agriculture, with technical assistance provided by the Soil Conservation Service, has provided cost-sharing funds to farmers and irrigation districts for irrigation system improvements, most of which had water quality benefits. This program has been relatively inactive in recent years because of lack of funds, however, as a result of the recent amendment to P.L. 92-500, additional funds are now being provided. This program should play a very important role in the Influent Control Approach, as a part of the federal-state-local water users tripartite.

Action. Most western states have revolving funds or low interest loan programs for water resources planning and development. Generally, these programs require the applicant to be an irrigation district or other corporate body. Where such state programs exist, changes in the legislation and/or regulations for participant qualification should be changed to allow: (1) individual irrigators to qualify; (2) broaden the use of funds to include on-farm improvement practices as well as improvement of delivery systems; and (3) include in the objectives of the program the improvement of water quality. When states have no such programs, a low or no-interest loan program containing the above three components should be adopted in order to cooperatively assist with the federal government and local water users in achieving improved water management and agriculture practices.

In addition, dissemination of information about other state and federal agency incentive programs should be carried out by the state water agencies, particularly to the designated management areas and cooperation extended to insure utilization of such programs.

Other incentive programs, which may require legislature enactments or agency regulations, could include encouragement of trading, leasing or selling of 'saved' water from more efficient practices as an inducement to improve the delivery systems and methods of application. State or local water markets, under the direction of the State Engineer (or equivalent state office), could monitor or control the uses of these waters.

To encounter the traditional attack against such an incentive program, it is highly conceivable downstream junior water rights holders would be the most likely to benefit, particularly if they were given priority to pay for this water.

Rationale. By providing incentives for water users in designated areas, the farmers will have an opportunity to voluntarily improve their water use practices, which in turn will result in improved irrigation return flow quality. This is consistent with the philosophy of encouraging voluntary compliance versus forced or involuntary compliance. Further, if states are to create standards and criteria for beneficial use, it is the opinion that some mechanism should be made available to the farmers that will facilitate compliance with the new criteria. Without it, irrigators are on solid legal grounds to continue exercising this water right as they have in the past. The legal cost to the state and water users to change this traditional practice may far outweigh devising a process and procedure by which water users can be encouraged to improve their efficiency in water use for both quantity and quality benefits, while still protecting the downstream users.

Precedent. Funds have been made available to irrigation districts and water users through the federal Department of Agriculture-Agricultural Conservation Program, with the Soil Conservation Service providing technical assistance. In addition, several states have state-wide programs in which low or no-interest monies are made available to water users for improving their delivery systems. In Wyoming, the funds may be used for improving laterals and application practices.

4. Include the Element of Water Quality in New or Transferred and Changed Water Rights.

Action. The water quality element should be a general provision added to all new water rights and requests for extensions, changes in use and transfers, in order to provide the necessary authority to state water agencies for later setting and enforcing of numerical standards (either with respect to water application or return flows, or both). Where water quality standards on streams for beneficial use have been realistically set, such standards can be incorporated by reference to water rights from that source of supply.

This action may require legislative endorsement, but under the vast majority of state law, it is conceivable that agency regulations can initiate this component.

Rationale. The element of water quality is only implicit in western state water laws, with the exception of California which has made it an explicit element in all water rights since 1969. As a consequence, water users must normally rely upon common law doctrines and private litigation to protect their water right where the quality has been degraded to levels that hinder usage. Because the quality element is not explicit, as are the other elements of a water right--quantity, source, point of diversion, type of use, and place of use--the state agency charged with administration of the water laws and rights is not in a favorable position to initiate action to prevent harm from water quality deterioration, and thus the management capability extends only to quantity control.

Precedent. In California, there is a general provision (which is added to all new water rights, extensions on water rights, and changes in ownership or type of use) that the water will be used in such a manner as not to unreasonably degrade the usage of water for downstream users. In some instances, the State Water Resources Control Board has also applied numerical water quality standards to particular agricultural water rights.

5. Adopt and Enforce a Reporting and Recording System for Water Rights.

Action. Notice would be given to all water users and water right claimants to submit a report to the water right administrative agency indicating their name, address, basis for claiming right to use water, use of water, source and beginning date for water use. Water users may be given notice by publication in local newspapers. Many states have already initiated a 'tabulation of water rights' program to acquire this data. It is necessary, however, to also adopt a system of annual reporting, indicating particularly changes in ownership since other material changes (e.g., transfer in type and place of use) require state approval.

Rationale. Although this component is more directly related to improving water management within the states rather than irrigation return flows only, it is related to the ability of the state to manage water quality because of the relationship between the diversion and application of water and the resultant return flow water quality. Most western states have inadequate knowledge of present ownership of water rights, and thus: a) have procedural difficulties in notifying water users of matters directly affecting their rights; b) are unable to effectively remove 'paper water rights' from the records that are maintained and thus making forfeiture provisions in the law nearly useless; and c) would be hampered in incorporating the element of water quality to new, extended or changed water rights.

One of the major difficulties faced in attempts to control irrigation return flow quality is 'contributor identification.' A data base of who the water right holders are will greatly facilitate efforts to encourage implementation of best management practices and best agricultural practices.

Precedent. Both Idaho and Oklahoma have a system by which the current owners of water rights are required to submit to the state water right administration agency an annual report (in the case of Oklahoma, this is done on a computer card) which specifies who the users are, where the water is used, and the approximate quantity. Failure to submit these annual reports serves as prima facie evidence of non-use and could lead to forfeiture of the water right.

6. Recognize Reasonable Degradation From Agricultural Water Use.

Action. Legislative recognition of the natural consequence of water quality degradation resulting from water use for irrigation purposes is needed at the state and federal levels.

Rationale. It is commonly accepted that any use of water for irrigated agriculture is going to result in some degradation of the quality of return flows. To pretend otherwise is to either continue a process of 'playing the game' or will ultimately remove irrigated agriculture with its obvious adverse effects. Common knowledge knows the latter will not occur, but a tremendous and unnecessary cost to prove it could be extended upon irrigators and the public through the failure of legislatures to recognize natural processes of water use.

Precedent. New Mexico has adopted a specific provision in their statutes which states that '...reasonable degradation of water quality resulting from beneficial use shall be allowed' (NM Rec. Stat. §75-39-11).

Montana has arrived at the same conclusion by defining 'naturally occurring conditions' in their water quality standards as those 'present from runoff or percolation over which man has no control or developed land where all reasonable land, soil and water conservation practices have been applied' (MAC 16-2.13(10)-S14480, Water Quality Standards, §(3) Definitions). Several state supreme court decisions also recognize certain degradation from water use, e.g., Ravndale v. North Fork Placers (91 P.2d 368 Idaho, 1939) where some contamination from a mine will necessarily occur to a stream.

7. Adopt an Agricultural Practices Act.

Action. Many of the 17 western states have laws and programs requiring the licensing of agricultural chemical distributors and applicators with the state Department of Agriculture. The laws and/or programs should be revised or new legislation adopted to include the following:

a) Sediment and erosion control.

b) Licensing and control over application of agricultural chemicals to include pesticides and artificial fertilizers.

c) Creation of an Agricultural Practices Control Board consisting of representatives from the agriculture, water quantity and quality, soil conservation (if separate) and fish and wildlife agencies, and appointed members of the public. The board's functions would primarily be establishing rules, regulations and procedures for carrying out a) and b) above and insuring functional implementation through coordination and designation of duties to appropriate state agencies.

Rationale. Due to the impact upon water quality resulting from the application of herbicides, pesticides and fertilizers in the agricultural sector, and the inability of the state to control these practices, it is highly recommended that an Agricultural Practices Act be adopted which requires licensing and monitoring of distributions and applications of such chemicals and control over harmful land management practices contributing to erosion and subsequent sediment problems in receiving waters. There may be many other agricultural practices which could be included under such an act.

It is essential to recognize the interconnection between these activities and resulting water quality problems (which may in turn contribute to ground water and downstream supply problems) and the usual division of jurisdiction and duties between various state agencies. Short of complete reorganization of state agencies to insure interrelated activities all under one agency (which may not only be impossible but highly undesirable), an Agricultural Practices Control Board (APCB) consisting of action representatives from the various involved state agencies and members of the public could insure coordination and implementation of their rules and regulations. The current local water quality planning bodies could be designated to assume local implementation.

Precedent. Again, California has led the way in licensing and monitoring of commercial applicators of herbicides and insecticides. Oregon has been considering the appropriateness of such an act to alleviate their major irrigation return flow quality problems. However, a comprehensive agricultural practices act has not been prepared in any of the western states. Iowa has adopted erosion control legislation that even authorizes imposition of a fine on those who fail to adopt approved practices.

8. Promote the Close Cooperation or Integration of State Water Agencies.

Action. To facilitate the implementation of the Influent Control Approach to irrigation return flow quality management, it is important that close cooperation and coordination exist between state water agencies through operation of a liaison board or committee, or integration of the state water agencies under one department.

Rationale. It is difficult to provide the necessary agency support to carry out any new program, but even more difficult to introduce a program of management and control over an area of activity highly sensitive to government intervention. In addition to adding duties to agencies often already burdened with heavy programs, efforts to control irrigation return flow quality meets with strong resistance from an inflexible and institutionalized system of property rights to the use of water in which the state water quantity agency often maintains a close relationship with the water users. The result is potential polarization between the state agency carrying out water quality control and the state water quantity agency. However, because of the interdependence of water quantity and quality, particularly as a natural process in water applied to irrigation, it is inconsistent to promote the goals of P.L. 92-500 and not promote the coordination or integration of agencies charged with carrying out water quantity and quality control.

Precedent. In 1969, California combined the water quality and quantity agencies under the Porter-Cologne Act in order to specifically attempt to manage the resources in a rational manner. In 1972, the state of Washington created the Department of Ecology which encompasses all three of the primary water functions; namely, water administration, water quality control and water resources development. Texas, Oregon and Kansas are contemplating an integrated approach, while Oklahoma has chosen to utilize an advisory coordinating board to interface the various water activities of numerous state agencies.

EPILOGUE

Based upon discussions with state water quantity and quality personnel from all 17 western states, it is apparent that most states feel a real credibility gap exists between the Environmental Protection Agency and the state agencies; that in those states where the state agencies attempted to implement the federal permit program, a credibility gap developed between the water users and the state agency; and, in several states the personnel expressed the opinion that EPA let them down by backing off after they attempted to carry out a control approach they did not agree with in the first place. In nearly every state, the water user organizations and individuals have polarized to combat the imposition of uncertain regulation over their possible water use. A permit concept is nothing new to them and they know that eventual control can emanate from an initially harmless permit.

ACKNOWLEDGMENTS

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AGRICULTURE AND THE HYDROLOGICAL REGIME: RECENT RESEARCH IN THE U.K.

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ABSTRACT

Recent research on the effects of agricultural practices on the hydrological regime in the U.K. are reviewed. Upland afforestation reduces water yield because of high evaporation rates applying to intercepted water. Underdrainage of fields can be very beneficial in controlling the water table and it does not exacerbate flood problems. The ecological damage done by river improvement works can be mitigated by consultation with ecologists and the use of ecological design criteria. Disturbing rises in nitrate nitrogen concentrations in streams, especially in S.E. England, derive from agricultural land. The precise source is uncertain for fertilizer leaching is not the only cause. Enhancement of natural fixation and mineralization by underdrainage and the ease of leaching in underdrained fields may be a major contributory factor.

INTRODUCTION

A desire for a great degree of national self-sufficiency in food and timber has lead the U.K. Government to propose the expansion of upland forests and increases in food production through a further intensification of agriculture. The severe drought of 1975–76 focussed the attention of scientists and the public at large onto the problems of water supply and water quality. The reorganisation of water management, to provide large multi-functional water authorities in England and Wales and strengthened River Purification Boards in Scotland, has facilitated an integrated overall view to be taken of the hydrological cycle, its use and management. Against this background, agricultural practices have been the subject of considerable research because of their hypothesized hydrological effects. This paper reviews recent U.K. work on hydrological changes consequent upon upland afforestation, on flood runoff and ecological modifications after improvements in land drainage, and on possible mechanisms to explain a disturbing rise in the concentration of nitrate-nitrogen in surface waters.

UPLAND AFFORESTATION

In 1924 there were 573,000 ha of high forest in Great Britain comprising 2.5% of the total land area. By 1976, managed forest land had risen to 1.69 mill. ha which when added to the 300,000 ha of unproductive woodland comprised 8.5% of the land area. Most of the new planting has involved coniferous plantations in the uplands; lowland forest being restricted to the old Royal forests or areas of poor sandy or chalky soil afforested in the '20s and '30s (Binns, 1979). This extensive upland afforestation, coupled with Law's (1956) finding that the annual water loss from a Sitka Spruce plantation was 290 mm greater than from grassland has led to the Institute of Hydrology's Plynlimon experiment in Central Wales reported by Clarke and McCulloch (1979).

Two small basins, the 1055 ha grass covered Wye catchment and the 870 ha Severn catchment with a 66% cover of conifers, are being used for a classic paired catchment study and as a base for process investigations. Thirty eight ground level or canopy level monthly rain gauges, six autographic rain gauges and eight flow gauging stations, including six specially designed steep stream structures, form the basic instrumentation. In addition automatic weather stations in each major domain record net radiation, total solar radiation, wet bulb depression, wind run and wind direction on magnetic tape every five minutes. Extensive networks of soil moisture access tubes facilitate monthly recording of soil moisture by neutron probe. Snowfall is recorded by terrestrial photogrammetry and snow courses.

Table 1 gives annual totals for rainfall and runoff for each catchment and the difference between water losses from the wooded Severn and grassland Wye. During the years 1970-71 there were problems with sediment accumulation in the Severn flume. The construction of an upstream sediment trap solved the problem and data for 1972-74 "were used to estimate streamflow for the ... period 1970-71" (Clarke and McCulloch, 1979). The mean value for the excess of losses in the forested Severn compared to the grass land Wye for the last four years, free of the complication of the earlier period, is 281±20 mm. This may be an underestimate of the extra losses resultant on having forests. Eighty-nine percent of the annual net radiation is used for evaporation in the Severn basin but only 65% in the Wye which suggests that the extra losses would have been greater if trees were growing on the upper 34% of the Severn catchment. It is hypothesised "that the additional water loss from the forest is the result of evaporation of raindrops intercepted by the tree canopies" (Clarke and McCulloch, 1979) and consequently it is argued that losses of a similar magnitude could occur for forests growing in regions of quite different precipitation. These findings have been confirmed by studies of an 84 m^2 lysimeter plot containing 26 Norway

TABLE 1 ANNUAL VALUES OF PRECIPITATION (P), STREAMFLOW (Q) AND P-Q FOR THE GRASSLAND WYE CATCHMENT (W) AND WOODED SEVERN (S) CATCHMENT, 1970-75.

Units: mm

Source: Clarke and McCulloch, 1979

Year	P:		Q:		P-Q:		$P_S-Q_S-P_W+Q_W$:
	W:	S:	W:	S:	W:	S:	
1970	2869	2690	2415	(1991)	454	(699)	(245)
1971	1993	1948	1562	(1328)	431	(620)	(189)
1972	2131	2221	1804	1567	327	654	327
1973	2605	2504	2164	1823	441	681	240
1974	2794	2848	2320	2074	474	774	300
1975	2088	2121	1643	1406	445	715	270
Mean	2413	2388	1985	(1698)	428	(690)	(262)

Spruce trees, 10 m in height and located in the Severn catchment. Calder (1976) found that "the annual loss recorded at the lysimeter, amounting to twice the Penman (open water evaporation rate), demonstrates the magnitude of the evaporation losses that can arise from forests in a high rainfall area". Clarke and Newson (1978) showed that "in the drought years of 1975 and 1976 losses from the Wye catchment under hill pasture were about 20% of annual precipitation; while those for the Severn were rather more than 30% of annual precipitation". They employed a simple simulation of a reservoir to show that failure to allow for a land use change (from grass to forest) could nullify a water management procedure designed to maintain supply even during a drought year.

Detailed studies of the interception process have generally supported these catchment scale findings. Rutter (1963) found interception loss in a Scots Pine plantation in Berkshire to be much higher than Penman estimates of open water evaporation and therefore higher than that to be expected from grass. Subsequently, Rutter et al. (1971, 1975, 1977) developed and validated a mathematical model for interception in a variety of forest types. The model operated on an hourly basis and computed a running water balance for the canopy. The duration of rainfall, as a measure of the time when the canopy was wet, was shown to explain much of the monthly variation in interception loss and constituted an important element in the model. The model has been extended by Calder (1977) to include both transpiration and interception. He was able to test the model over an exceptional range of conditions during 1976. Calder (1979) demonstrated the close correlation between predicted and observed losses for the Plynlimon lysimeter. He showed that, in 32 months spanning 1974-1976, transpiration losses from the lysimeter totalled 900 mm and interception losses reached 1600 mm with a gross precipitation of 5464 mm. Work with micrometeorological sensors above Thetford forest in East Anglia (e.g. Gash and Stewart, 1977) has been reviewed by Calder (1979). For 1975, rainfall was 595 mm; interception loss 213 mm; and transpiration 353 mm. This suggests a total loss less than would have occurred from grassland in spite of the high rates of evaporation observed when the canopy was wet. Calder (1979) explains this apparently anomolous result by reference to the infrequency of rain; only 350 hours in 1975. This means that the interception process operates for insufficient time to make up the difference between the low transpiration rate from the trees during dry weather and the relatively higher one from grass. Gash (1979) has used the Thetford data "to create a model of interception loss which is simpler and easier to apply than the Rutter model, but ... contains a great deal of the objectivity and physical reasoning behind that model".

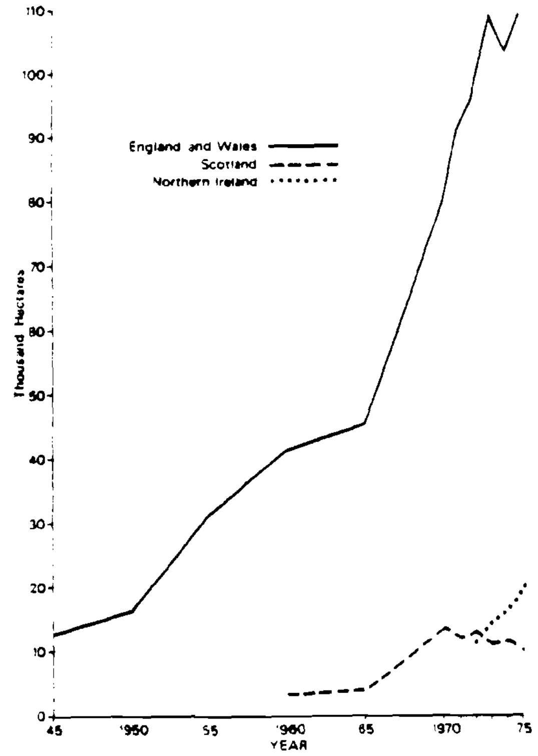
The high sediment yield of forested basins has been quantified by Painter et al. (1974). They found that the forested Tanllwyth sub-catchment at Plynlimon had four times the sediment load of the pasture land Cyff basin. Erosion of the drainage ditches, which are cut to assist tree establishement and growth, was largely responsible. Their work on the Coalburn in Northumberland revealed an increase of two orders of magnitude in sediment transport after ditching had taken place. The reduced water yield from afforested land, the high rates of erosion from forest drains and possible water quality problems from fertilizers and herbicides have been recognized by Binns (1979), a Forestry Commission scientist. His review of forestry practices shows that, whilst water quality effects can be rendered negligible and erosion limited, "the effect on water yield over the country as a whole will be determined more by policy on land acquisition and use than by the way the actual operations are done".

LAND DRAINAGE

Land drainage encompasses arterial drainage, the straightening, deepening and embanking of water courses and rivers, and underdrainage, the draining of fields by a combination of some or all of tile or plastic pipes, permeable backfill, mole drains or subsoilings (Cole, 1976; Meirs, 1974;

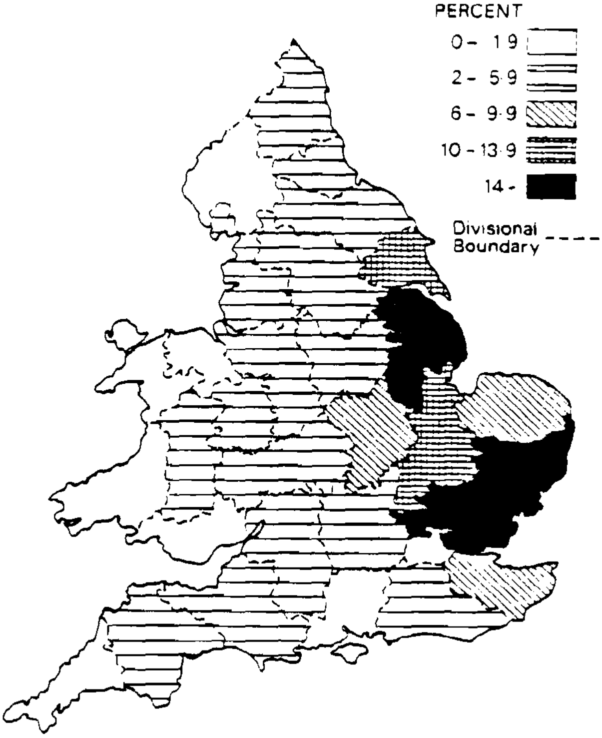
Green, 1979). Records of arterial drainage are not centralised, however the Water Data Unit (1975 and 1977) have shown that in England and Wales the capital expenditure on land drainage and flood protection (which very largely excludes underdrainage) was £17.04 mill in 1974 and £27.49 mill in 1975 with £23.47 and £30.23 being spent in the respective years on the recurrent account. Figures 1 and 2 show the extent of underdrainage in the United Kingdom in the last 30 years. Green (1979) has shown that more than 2% of some areas of Eastern England are receiving underdrainage each year in the 1970s. Essex has 15% of its whole area, but 30% of its arable area, underdrained. The prevalence of underdrainage suggests that substantial agricultural benefits accrue as a result. The Field Drainage Experimental Unit (FDEU) has used experimental sites to quantify the benefits of land drainage for watertable control (e.g. May and Trafford, 1977), crop yields (e.g. Armstrong, 1977) and soil temperature (e.g. Waters, 1977). However five years' work at the FDEU site at Abbots Ripton showed "no differences in watertable control or crop yield between the undrained control and drains at 40 metres with moling" (Kellett and Davies, 1977). This section examines the view that land drainage exacerbates flood problems and reports on the lively national debate on the relationship between land drainage and nature conservation.

Hill (1976) has summarised the effects of land drainage but he pointed out the lack of detailed evidence on specific changes. Rycroft and Massey (1975) said that "published evidence that drainage increases flooding is almost non-existent". Howe et al. (1966) demonstrated a significant increase in flooding in the Severn and Wye catchments (their studies used records from the lower reaches, not the Plynlimon headwaters) from 1911-1964. However they could not demonstrate whether this effect was the result of either a demonstrable increase in heavy rainstorms or land management by way of afforestation and land drainage. Green (1973) worked on the Willow Brook near Peterborough, where there is extensive underdrainage.



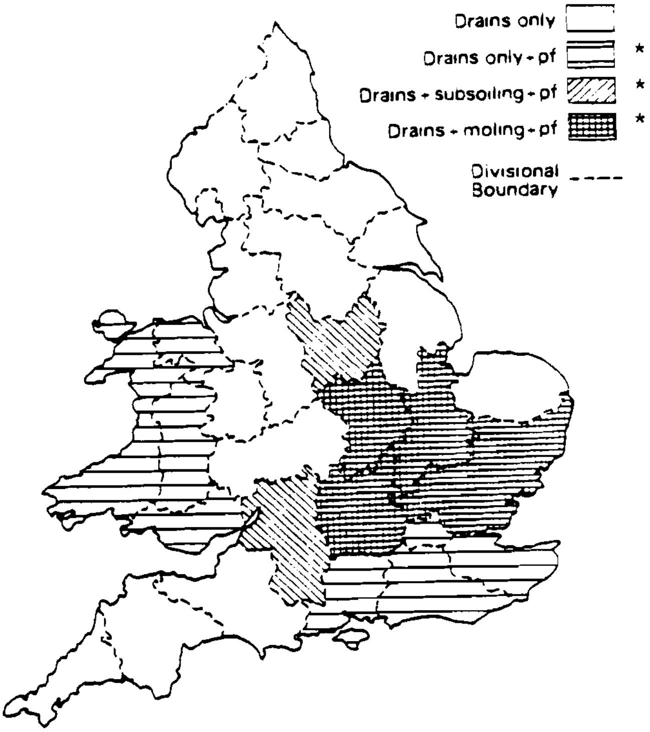
Source: Water Data Unit, 1977

Figure 1. Area in hectares underdrained in the United Kingdom



Source: Green, 1973

Figure 2a. Proportion of the total area underdrained in England and Wales 1951/2-1970/1



Source: Armstrong and Smith, 1977

*pf denotes permeable backfill

Figure 2b. Dominant drainage practices in England and Wales.

He showed that the number of days that flow exceeded 2.12 m^3/s had increased from an average of 4 days per annum for 1945-60 to 15 days per annum for 1966-71. He has also asserted (Green, 1979) that the underdrainage of 30% of the Bury Brook catchment in Cambridgeshire has increased the number of flood peaks compared to the neighbouring Harper's Brook which is only 7% underdrained. These analyses, however, say little about the effect of land drainage on the form or magnitude of significant flood hydrographs. The drainage of the 15 km^2 Glenullin catchment has received detailed attention from Wilcock (1979). This boulder clay basin, with extensive raised peat bogs, has had nearly 2 km of channel cleared and scoured alongside one bog and extensive ditches and underdrains installed in a second. Wilcock found that flood flows were reduced in magnitude and frequency during the post-drainage period. Total annual water yields and low to middle range flows were greatly increased initially, but after two years net annual replenishment restarted and he estimated that the restoration of initial storage conditions would only take twelve years. Rycroft and Massey (1975) compared recorded hydrographs from the 170 ha clay catchment at Shenley Brook End and simulated hydrographs which might have resulted if the basin had been mole drained. They concluded, from their simulation exercise and literature review, that

"1. There is no evidence to suggest that underdrainage increases flooding.

2. Mole drainage reduces the peak outflow rates from a catchment for heavy storms which are liable to give rise to flooding (because it inhibits surface runoff).

3. Mole drainage maintains watertable levels usually at 50 cm depth, the watertable rises during storms but is quickly lowered after rainfall thus creating storage space for further rainfall.

4. Undrained clay catchments have limited storage which is filled up quickly during storms. Further rainfall then results in runoff.

> 5. An undrained waterlogged clay catchment remains wet for a considerable time after rainfall thus providing no buffer against further rainfall."

The inherent conflict between land drainage and nature conservation has been succinctly put by Humphries (1978) who said:

> "there is a growing concern about increasing food production from a declining available acreage and about the incidence of higher flood levels. At the same time there is a growing awareness of the need to have regard for the preservation of the countryside and its ecological balance. ... the question (cannot) be resolved simply on economic grounds, it brings in broad social questions as well".

This concern for nature conservation is given statutory support by the Countryside Act 1968 and the Water Act 1973, both of which require Government and Water Authorities to have regard for the preservation and conservation of natural beauty. The growth in public concern is difficult to quantify but is reflected in the growth in membership of conservation-linked organisations detailed in Table 2.

The problem is not as simple as a need to assess the impact of a new development and to make recommendations for management. Land drainage is an old established procedure, it is undoubtedly highly beneficial to agriculture, many examples exist of valuable habitats created by drainage work e.g. the Ouse washes in the Fenland and the Monmouthshire Levels (Scotter et al., 1977), and there is the problem of who should pay any costs attributable to conservation work. Moreover, land drainage engineers can be rather myopic. Miers (1974), for instance, writing about "design considerations" in a paper entitled 'The Civil Engineer and Field Drainage' does not mention or allude to nature conservation or ecological changes likely to result from drainage. However, elsewhere Miers (1975) said "outside of the fens and marshes the land drainage engineer has the greatest opportunity

TABLE 2. MEMBERSHIP OF CONSERVATION BODIES IN THE U.K.

ORGANISATION	1973	1974	1975	1976	1977
British Trust for Ornithology	6,935	7,038	7,281	7,100	7,348
Royal Society for the Protection of Birds	139,000	166,000	181,000	204,000	216,000
Society for the Promotion of Nature Conservation	84,412	97,180	100,660	111,134	115,211
Wildfowlers' Association of Great Britain and Ireland	28,000	29,000*	30,815	31,664	34,412
Wildfowl Trust	11,000*	12,000*	13,000*	14,000*	15,000

Source: Water Space Amenity Commission, 1978

* Estimated

to conserve ... fauna and flora ... and improve the environment". How regrettable that he could not allude to this in his earlier discussion of drainage design. Cripps (1975) emphasised the point by saying "Miers' enlightened views contrast with some recent ... practices. Too much (land drainage) ... is still ... purely functional".

A large-scale example of the problem, but one which is typical of the hundreds or thousands of small localized schemes, are the proposed drainage improvements in the Somerset Levels (Williams, 1977). This 687 km^2 area of marshy farmland was drained piecemeal largely during the nineteenth century. Today, as a permanent pasture area, it is free of sea flooding and suffers only limited winter flooding. This habitat contains vast flocks of wintering wildfowl and waders on the soft pastures where insect food is plentiful. A high percentage of the British breeding population of certain birds and a magnificent flora add to the conservation interest. Finally, the thousands of miles of rhynes (ditches) provide a wide range of aquatic and semi-aquatic plants along with associated invertebrates. All of this is threatened by the desire of many farmers to increase productivity through a conversion to arable and improved grassland. In some areas this has begun privately and the agricultural advantages of the 1 metre lowering of the watertable are clear. Unfortunately, the ecologically detrimental effects of draining the wetlands and desiccating the rhynes are also clearly apparent.

The Somerset Levels question is far from being resolved but it is likely that worked out peat excavations will feature prominently in any agreed compromise. The proposal to form nine lakes from these pits could serve the needs of flood storage, water supply, land rehabilitation, recreation and nature conservation. In any event there is almost certain to be a public inquiry into the scheme. The conservation lobby scored a notable success when it forced a public inquiry into Southern Water Authority's scheme to drain the Amberley Wildbrooks. Moreover, the Minister ruled, after the inquiry, that the interests of conservation outweighed the potential agricultural benefit of that scheme.

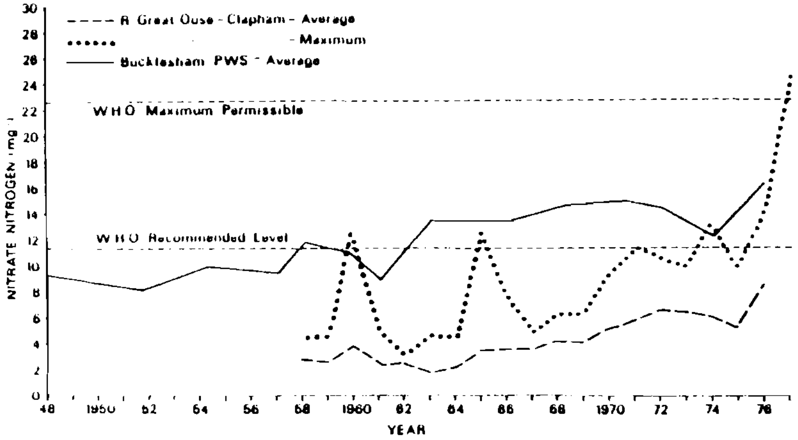
Realisation of a need for a framework within which to resolve these conflicts emerged at the 1975 Conference on Conservation and Land Drainage (Water Space Amenity Commission, 1975). Subsequently, Drummond (1977) argued that executing land drainage works and conserving our natural landscape is a matter of "management and compromise - accompanied by imagination and flair". The Working Party on Land Drainage and Conservation established by the Water Space Amenity Commission, published Draft Guidelines in 1978. They suggest "how, why and what action should be followed by those undertaking ... drainage ... to take account of ... nature conservation, landscape and amenity, fisheries and recreation". The Guidelines set out a system for consultation between engineers and conservationists and a set of practice notes for use by engineers during the design and execution of works. An example of active cooperation between land drainage engineers and conservationists is the work of Hollis and Kite (in press) on the Rivers Stort and Roding, N.E. of London. The environmental effects of conventional flood alleviation/river improvement schemes are being monitored, a model is being developed to forecast the ecological state of the rivers as it is recolonised and an ecological management plan is being prepared to maintain and enhance, where possible, the conservation interest of the rivers and their banks. There is, however, a long way to go before land drainage works are designed to satisfy hydraulic and ecological criteria. Cole (1976), Chief Engineer of the Ministry of Agriculture, Fisheries and Food, stated that "sheet steel piling has been increasingly used" for earth retaining structures, "it is just as important to remove wreeds as ... any other constriction" and herbicides "have been very effective and, in general, have done little damage to the environment". George (1975) argued that a steel lined river gives "no chance of any natural vegetation ... at the river's edge; it is aesthetically unattractive and ... it is extremely dangerous" should people need to clamber from the stream. Even Johnson (1954), a predecessor of Cole at the Ministry of Agriculture, Fisheries and Food, stated that huge amounts of tree clearance had been undertaken "without a proper appreciation ... that ... tree growth, and the shade it gave, prevented or at least discouraged the growth of water weeds".

The future ecological state of the rivers of England and Wales is uncertain because the arguments for increased indigenous food production and the desire for flood protection are especially powerful. However, the conservation lobby is growing in number and in confidence and existing publications point to the minimal cost of, and in some cases, the financial savings from, a more "environmentally aware" style of river engineering. The increasing ability of the multi-functional Regional Water Authorities to utilize research results in their catchment control function (Addyman, 1979) suggests that, perhaps, a future management strategy will be the explicit inclusion of ecological yardsticks and landscape factors as well as hydrological criteria in the design of improved river channels.

NITRATES IN SURFACE WATER

The concentration of nitrate nitrogen in surface waters in some parts of the U.K. gives grounds for concern. The WHO recommended maximum for young infants of 11.3 mg/l and absolute maximum of 22.6 mg/l are often observed in rivers and the trend appears to be upward. There is similar concern for groundwater resources (e.g. Foster and Crease, 1974) but this is discussed fully by Young and Gray, 1978; Young and Hall, 1977; and Young, 1979.

Scorer (1974) has shown that the average concentration of nitrate nitrogen in the Thames and Lee intakes of the Metropolitan Water Board rose from a long run average (1920–1940) of 2.7 mg/l and 4.0 mg/l to 12 mg/l and 17 mg/l respectively in the middle of 1974. He ascribed these changes primarily to unusually warm winters and low rainfall at the begining of the 1970s but argued that the relative importance of growing discharges of nitrate rich sewage effluent, fertilizer applications, land drainage and increased cultivation of legumes was not yet known. The nitrate problem has continued in the Thames Water Authority area, especially in the River Lee. The Thames Water Authority Annual Report (1975) says the Lee "contained high concentrations of nitrate which on occasions were so high that abstraction for public supply had to be curtailed". Thames Water Authority (1976) said the concentration of nitrate in the River Lee at the Chingford intake has been above 11.3 mg/l for the first quarter of 1976. Thames Water Authority (1977) reported low concentrations of nitrate during the 1976 drought with levels rising rapidly sometime after flows had increased. Nitrate concentrations in excess of 11.3 mg/l persisted for several months in both the Thames and Lee. The Anglian Water Authority, which covers much of Eastern England, has also had severe problems. Anglian Water Authority (1977) said "no public supplies ... exceeded (22.6 mg/l) during the year but severe problems were experienced with direct abstractions ... in Bedfordshire and Essex". Anglian Water Authority (1978) said "relatively high peaks of nitrate concentrates were recorded in four cases. The use of a chalk source in West Norfolk was discontinued due to rapidly increasing nitrate levels". Greene (1978) stated that "there is a clear upward trend in many of the major rivers in Southern and Eastern England". Figure 3 shows the steady rise in the mean annual concentration of nitrate in the Great Ouse, the spectacular rise associated with the end of the 1976 drought and the high and rising concentration in the Mill River at the Bucklesham public water supply intake. This latter example is especially important because the small catchment has no significant volume of sewage effluent discharged into it. Slack (1977) writing about nitrate levels in rivers



Source: Greene, 1978

Figure 3. Nitrate nitrogen concentrations in the River Great Ouse at Clapham and Mill River at the Bucklesham Public Water Supply abstraction

in Essex in south east England said "levels in excess of 20 mg/l of nitrate nitrogen have been recorded at times". It is important though, to note that the problem is not nationwide. The South West Water Authority (1977) said "rivers used for supply in this region normally contain very low concentrations of nitrate" and Northumbrian Water Authority (1978) do not discuss nitrate concentrations but include a table which shows that from 1972-77 the maximum nitrate/nitrogen concentration recorded in their rivers was 4.79 mg/l with a normal average of between 1.0 and 2.0 mg/l. What, then, is the cause of this disturbing rise in nitrate levels in the rivers of southern and eastern England in particular? Discussion of this question usually centres around fertilizers, sewage effluent, and natural processes being accelerated by unusual weather conditions.

At first sight the rise in the application rate of nitrogenous fertilizers, being contemporaneous with rising nitrate levels in rivers, is a powerful argument. Green (1973) has shown how the application rate for nitrogen rich fertilizer for crop and grassland in England has risen from around 4 kg/ha in 1953 to 16 kg/ha in 1972. He showed that the highest rate of application was in the south and east and in Cheshire. He showed that the greatest rate of increase in application of nitrogenous fertilizer is in the largely pastoral counties of the north and west. Most counties exhibited at least a five fold increase in application rates from 1957-72. Cooke (1976) reported that approximately 930,000 tonnes of nitrogen were added to the soil in the U.K. by fertilizers in 1973, whilst Holden (1976) in his study of Loch Leven found that nitrogen fertilizer usage in Kinross increased from under 300 tonnes/annum in 1952-54 to over 1000 tonnes/annum in 1970-72. This circumstantial evidence is not completely substantiated by small scale experimental studies nor is it proven conclusively in catchment scale studies.

Cooke (1976) reviewed three lysimeter experiments. 0.0004 ha lysimeters were made at Rothamsted by enclosing undisturbed soil blocks in 1870. The soil has since remained free of crops and fertilizers, but it has been weeded regularly. From 1878-1905 the drainage contained 9.8 mg/l of nitrate nitrogen. In 1969 the hundredth year of the experiment, the drainage from April-November averaged 5 mg/l with 18 mg/l occurring in November. This experiment reveals that drainage from land which has never received fertilizer can contain substantial amounts of nitrates released or fixed by natural processes. Similar sized lysimeters near Aberdeen, established in 1914, were planted with grasses, root crops and cereals, and given modest amounts of nitrates in manure. It was found that drainage water from grassland carried little (0.5-3 kg N/ha) nitrate whilst 4-11 kg N/ha were lost from cropland. It is significant, though, that losses were almost as great from a lysimeter not given fertilizer. A recent lysimeter study at Jealott's Hill found that, without the use of N fertilizer, drainage from a grass sward contained 1 mg/l of nitrate nitrogen, that from growing clover, 29 mg/l; that from bare soil after removel of clover, 34 mg/l, and that from bare soil 42 mg/l.

Cooke (1976) also reported studies on small (0.2 ha) plots at or near Rothamsted all growing winter wheat. In the Broadbalk experiment, a plot with contemporary commercial rates of N fertilizer application had drainage water with 7 mg/l nitrate nitrogen whilst unfertilized plots had 4 mg/l nitrate nitrogen in drainage. Water issuing from land drains at four agricultural sites in S.E. England has shown mean nitrate nitrogen concentrations of 11.7, 22.2, 20.0 and 9.8 mg/l with a range in one case of 11.5-36.5 mg/l and in another from 0.5-60.0 mg/l. Johnson (1976) showed that long-term use of N fertilizer does not produce a significant accumulation in the soil or sub-soil. He found that some crops recover 70-80 percent of the added N but the average uptake is only 46 percent. Hood (1976) studied drainage water from grassland that receives 250 and 750 kg fertilizer N/ha/annum and is stocked heavily with dairy cows.

He found that rainfall patterns affected nitrate losses but that overall less than 5 percent of the applied nitrate was leached, assuming no contribution from soil N reserves.

The evidence of these small scale studies is threefold. First, there can be substantial leaching of nitrates even when no fertilizers are used. Second, when fertilizers are used there is always incomplete uptake by the crop and therefore a high probability of leaching. Third, peak concentrations of nitrate in drainage water are related to the type of crop grown, the form of husbandry practiced, the weather, the rate of fertilizer application and the timing of fertilizer application. Cooke (1976) confirms this relative position of fertilizer in his estimates of the N involved annually in U.K. farming systems (Table 3).

Catchment scale studies, comparing agricultural, industrial, sewage effluent and rainfall contributions to nitrate in rivers, nearly all point to farmland as the major source of nitrate nitrogen. Owens (1970) examined the nutrient budget of the River Great Ouse from the headwaters to Tempsford, 16 km below Bedford. He found that the 60 sewage effluent discharges contributed only 30 percent of the total flow of N. "It was therefore concluded that in the Great Ouse Basin, land drainage was a major source of nutrients". In reconnaisance studies of thirty-three other U.K. rivers, Owens found that "the greater proportion of the nitrogen flow was derived from ... land drainage". He was, however, unable to demonstrate with his rather poor data, a clear relationship between nitrogen concentration in river water and the application rate of nitrogenous fertilizer. Moreover, using data for three Essex rivers and six Yorkshire rivers, he found that "although the amounts (of N fertilizer) applied per unit of catchment have increased substantially, no marked increases in the loads carried by the river at any given flow are apparent". Slack (1977) charted the seasonal cycle of nitrate in the Chelmer, Blackwater and Stour in Essex from 1970-74.

TABLE 3 ESTIMATES OF THE N INVOLVED ANNUALLY IN U.K. FARMING SYSTEMS.

(Source: Cooke, 1976)

		Thousands of tonnes
Soil N (natural fixation, mineralization)		1,300
Farmyard manure		300
Fertilizer		900
Excreta dropped on grass		500
	Total	3,000

High winter concentrations were associated with high flows and "as the contribution from sewage effluent (is) fairly constant, the increased nitrate can only be derived from drainage on arable land which forms the majority of the catchment area of the rivers". Greene (1978) similarly found "high nitrate concentrations are invariably associated with high flow conditions in all ... rivers in Anglia signifying that the major nitrate load is associated with land drainage". He said that "current information appears to indicate that (recent) increases (in nitrate nitrogen in river water) are primarily associated with the increasing intensity of and/or improvement in arable farming in the region in the last twenty years". The nitrate nitrogen content of rainfall is modest. Mean concentrations of 1.09 (6.8 kg/ha/annum), 0.93 (5.1 kg/ha/annum) and 1.17 mg/l (6.7 kg/ha/annum) for sites in south-east England have been reported by Williams (1976) for the period 1969-73. Troake and Walling (1975) measured a concentration of 0.25 mg/l (2.75 kg/ha/annum) for a maritime location in S.W. England and 0.1-4.5 mg/l has been quoted as the range for the U.K. (Greene, 1978).

The nitrate inputs to Loch Leven have been monitored by Holden (1976). He found the influent streams to be the major source of nitrogen. Their agricultural catchments produced nitrogen yields ten times those of uncultivated moorland streams. He estimated that the annual loss of nitrate of 33 kg/ha was possibly more than one third of the nitrate applied through fertilizer. Troake et al. (1976) found that for the period 1971-74 the N load of two experimental catchments which are free of sewage effluent discharges was 50 percent and 26 percent of fertilizer application; the former figure deriving from a catchment with particularly short steep slopes which would favour transmission of soil water to the stream as throughflow. An analysis of the nutrient budget of Alderfen Broad in East Anglia (Phillips, 1977) revealed that "input of nitrate nitrogen via the inflow was the most important source of nitrogen ... Maximum nitrate nitrogen input occurred during November due to a very high concentration ... (14 mg/l) combined with a high flow rate".

The evidence, therefore, points clearly to farmland as the major source of nitrate in Britain's rivers but the evidence does not pinpoint fertilizers as the major source. The efficiency of natural nitrate production by mineralization and atmospheric fixaton and the rapidity of rainwater leaching were dramatically demonstrated by studies of the effects of the 1976 drought and the subsequent wet months. The period May 1975 - August 1976 with 757 mm of rainfall over England and Wales was the driest 16 month period since records began in 1727 and has a recurrence interval of more than 1000 years. Many riverflows were lower than ever recorded before, often for 6 months or more. The estimated recharge for many U.K. aquifers has an estimated return period of 1 in 100 years (Central Water Planning Unit, 1976).

Writing about the Anglian Water Authority area, Davies (1978) said "the most notable change in the quality of river water during the (post-drought) period was the rapid increase in the concentration of nitrates ... in surface waters ... one river reached 40 mg/l nitrate nitrogen, while concentrations between 20 and 25 mg/l were not uncommon". The coincidence of sustained high nitrate concentrations with high flows gave an extremely large total discharge. Davies argued that the shortage of summer rain limited nitrate uptake by crops, and increased nitrogen fixation in the soil because of the high temperatures conspired to provide a large store of nitrate which was leached from the soil by winter rainfall. Greene (1978) provided a table of data for the Anglian area and showed for instance that at Bucklesham (Figure 3) the nitrate nitrogen was between 28.0 and 30.0 mg/l for the whole period 1:10:76 to 31:3:77. Walling and Foster (1978), working in the Exe basin in S.W. England, found that during the onset of the post-drought rainfall, nitrate levels reached levels 45 times higher than is normal for that river at that time of year. In a tile drain outlet they recorded 903.6 mg/l nitrate nitrogen. They too argued that these levels are related to the influence of the extreme drought on mineralization and nitrification processes within the soil.

The foregoing discussion provides no clear explanation of the undoubted rise in nitrate levels in many U.K. streams over the last decade although agricultural land is clearly identified as the source of the large winter concentrations of nitrate. Pereira (1976) in concluding the seminar on Agriculture and Water Quality said "agriculture does ... contribute substantial qualities of N ... to the water supply ... some of the N comes from fertilizers ... the main problem is that farmed catchments can no longer be relied on to be low enough in nitrates for use in dilution of urban sewage and industrial wastes". What other mechanisms might explain the rise in nitrates? Two have been suggested. First, Pereira (1976) argued that a major input of nitrate into the soil system is the ploughing of legumes or grass swards. He said the nitrate input was "far more than the farmer can afford to apply from the bag". Cooke (1976) reported that 2,000 kg N/ha was released in the first 12 years after ploughing very old grass. This mechanism, during the ploughing up of grassland during 1939-46, has been advanced to partially explain recently noted increases in nitrate content in groundwater (Young and Hall, 1977). However, there have been no equivalent land use changes of that scale that would explain the current rises in suface water nitrate concentrations. Second, the extension of field underdrainage has coincided with both increases in fertilizer usage and rising nitrate levels in streams. Moreover, underdrainage has been most extensive in the south and east where there is the heaviest rate of application of N fertilizer. There is evidence to support this view from soil science studies. Waters (1977) has shown how soil temperature is higher in spring on drained land than on undrained land. She showed, by means of a derived relationship between bacterial activity and temperature, that underdrainage might increase peak bacterial activity by 1.5 times. Similarly, Young and Hall (1977) concluded from a literature review that a "pronounced release of nitrogen from soil occurs with the ... improvement in the drainage of wet soils". They also found that "retention of nitrogen in soil is promoted by the absence of aeration". A final piece of circumstantial evidence is the incidence of very high nitrate concentrations, quoted above, for tile drain outlets.

There is a dearth of published studies on the nutrient effects of underdrainage. Work, though, is underway jointly between the Institute of Hydrology and the Ministry of Agriculture, Fisheries and Food (Inst. of Hydrology, 1978) with a lysimeter experiment at Plynlimon, a catchment scale study of water quality and fertilizer use at Shenley Brook End in Central England and a study of drained and undrained plots near Grendon Underwood.

CONCLUSION

Agricultural practices do, clearly, modify the hydrological regime in the United Kingdom. The high rate of evaporation observed from water held in interception storage in trees explains why afforestation reduces water yield in upland areas where rainfall is frequent and plentiful. Given the economic and silvicultural need to grow conifers there is little that can be done to mitigate this loss in yield other than to take note of it for the design of water resource systems. Land drainage does not increase the magnitude of flood flows, indeed the presence of soil storage can reduce the size of moderate floods. Field underdrainage can be very successful in reducing the water table in many soils but its beneficial effects are not large everywhere. The existence of extensive underdrainage appears to marginally increase low flows in streams. Land drainage and river improvement works reduce, and may devastate, the nature conservation interest of an area. There is a need for close consultation and liaison between engineers and ecologists. The establishment of ecological and hydraulic criteria for river improvement works would be useful.

Increasing concentrations of nitrate nitrogen in surface waters is one of the most pressing problems facing the water industry in the U.K. Heavy or ill-timed dressings of fertilizer can produce high rates of nitrate leaching. There is no conclusive proof that the ever-increasing use of nitrogenous fertilizer is directly responsible for the increase in nitrate observed in streams, but all studies of fertilizer use show an incomplete uptake by the crop. Investigations of unfertilized soils do show substantial yields of nitrate in drainage water and the wet months after the 1976 drought attested to the efficiency of natural fixation and mineralization. There is circumstantial and scientific evidence to suggest that field underdrainage is a significant factor in increasing the movement of soil nitrates into streams, but a dearth of research on this subject prevents definitive conclusions.

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THE ROLE OF FERTILIZERS IN THE POLLUTION OF WATER BY NITRATES

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ABSTRACT

The increased use of inorganic fertilizers raised not only the crop yields but also the levels of phosphorus and potassium in the soil. It was proved that nitrogen in the soil could not be increased by inorganic fertilizers alone. The rate of the nitrogen loss from the soil rose with the increasing use of nitrogen fertilizers. A particular portion of the nitrogen loss occurred through the leaching of nitrates, thus polluting groundwater.

It was proved that there was hardly any chance of preventing the water pollution by nitrates if there was nitrate present in the soil which markedly exceeded the uptake by plants. The regulation of the use of nitrates seems to be the only meaningful way of preventing their migration into deep soil horizons or into groundwater.

Three modes of possible nitrification prevention in Czechoslovakia were examined: (a) application of nitrification inhibitors; (b) application of slow-release nitrogen fertilizers; (c) biochemical nitrogen immobilization. The last-mentioned gave the highest reliability, and technological and economic efficiency.

The conditions for biochemical N-immobilization were studied in detail. Two regulatory principles were described: (1) the C: $N_{org.}$ ratio in the soil, as a regulatory factor for linkage of nitrogen to the organic carbon skeleton; and (2) the amount of free energy liberated by exergonic reactions to cover the energy demand of the endergonic amination reaction of α-oxoglutarate reactions.

INTRODUCTION

The amount of inorganic fertilizers applied in Czechoslovakia and many other countries has increased to an unforeseen extent. Along with this intensification of soil fertilization, the crop yields and the amounts of available nutrients in the soil also increased (Figures 1-3). It is possible to conclude from these figures that the increasing loads of inorganic fertilizers have been utilized either to increase crop yields or to improve soil fertility. However, this refers only to phosphorus and potassium. The overall nitrogen balance is rather bad. The amount of nitrogen not being utilized by crops and/or not being accumulated in the soil grows with increasing N-fertilizer doses. This is related to the specific agro- and biochemistry of nitrogen in soil.

Nitrogen may be readily accumulated in the soil in the form of non-soluble organic substances--soil humus. The degree to which this type of nitrogen is accumulated in the soil is limited by the proper C:N ratio. It has never been observed that the C:N ratio in soil humus exceeded the value of 10. If the ratio of the entire contents of organic carbon and total nitrogen drops below 10, a part of the nitrogen remains in an inorganic state. All the inorganic compounds of nitrogen tend to oxidize to nitrates. The anionic forms of nitrogen are not adsorbed by soil particles and move in soil as the water moves. In the water saturated state they migrate in soil solution according to the diffusion laws and their distribution corresponds to the randomization principle. Accordingly, the soil nitrate can reach the subsurface water table not only under humid conditions but also in a semi-arid climate.

The experimental results and experience to date lead one to believe that it could hardly be possible to prevent the migration of nitrates through the soil profile once nitrates have been present. Furthermore, the reduction of nitrates to a cationic form of nitrogen or to organic-N compounds is extremely difficult. This is why, for many years now, the emphasis has been on discovering methods for preventing an excess of nitrates in soil. Several methods and technologies were examined. Some promising methods, e.g. the application of slow release N-fertilizers and the application of nitrification inhibitors, failed to yield satisfactory results, because they are very expensive, produce only short-term effects, sometimes decrease the yields of crops, and furthermore introduce into the soil some foreign constituents whose effects on the environment are not known.

On the other hand, despite the large amounts of energy necessitated by the use of airplanes for fertilizer application, this treatment proved profitable for small loads of N-fertilizer when there were high crop stands. Liquid forms of N-fertilizers were preferred (nitrates + ammonia + urea). Good crop responses were achieved for the nitrogen applied and very little was leached (Figure 4). This method had the further advantage of allowing one to determine accurately the N-loads. The weather conditions usually vary markedly in different years. This is why the nitrogen transformation and its resolution from soil resources are never the same in individual years. In wet years additional N-fertilization can, therefore, be omitted. This prevents water pollution from nitrates and saves unnecessary nitrogen fertilizing (Figure 5).

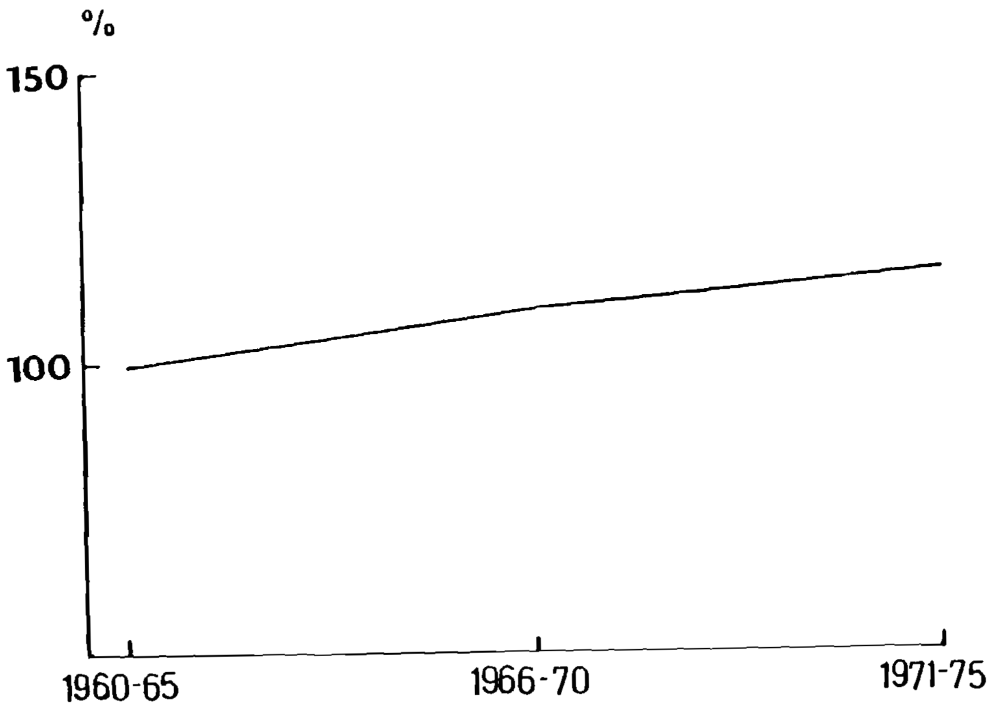


Figure 1. Gross agricultural production in Czechoslovakia in recent years - relative data

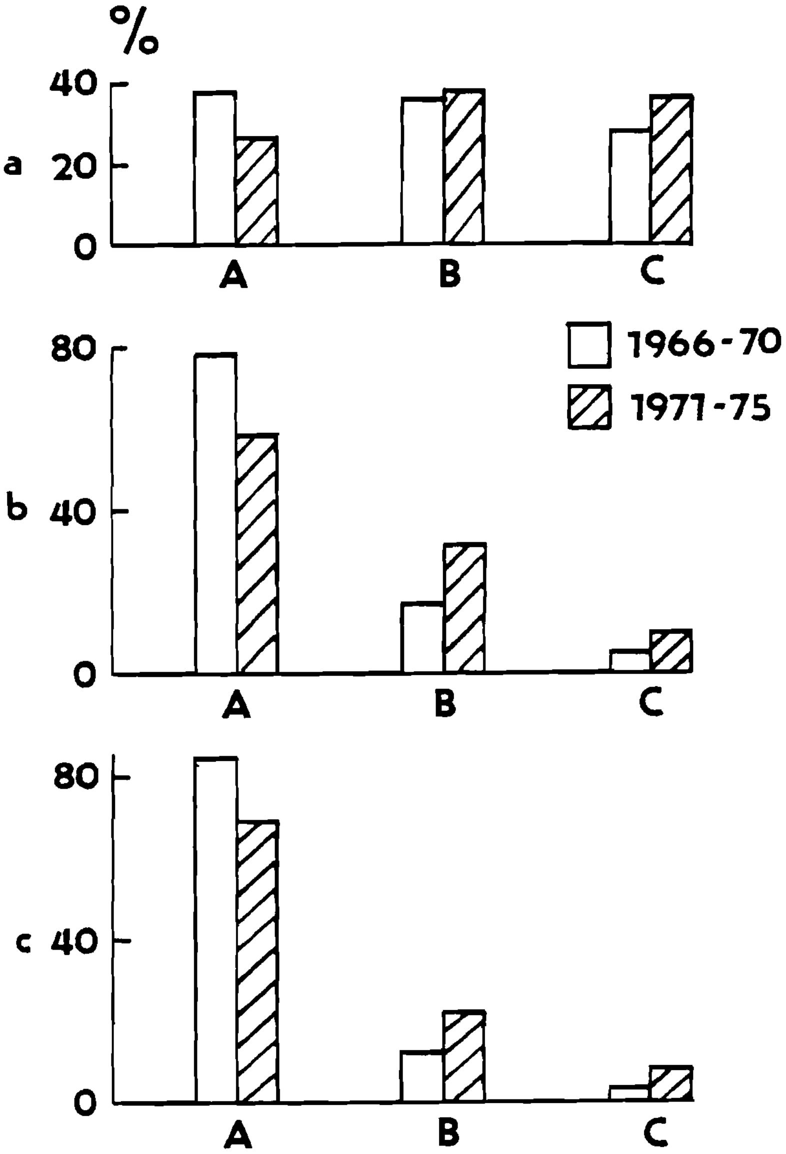


Figure 2. Phosphorus available to plants in Czechoslovakian soils. Percentage of soils: A - poor, B - good, C - rich in available phosphorus; a - maize production zone, b - sugar beet production zone, c - potato production zone

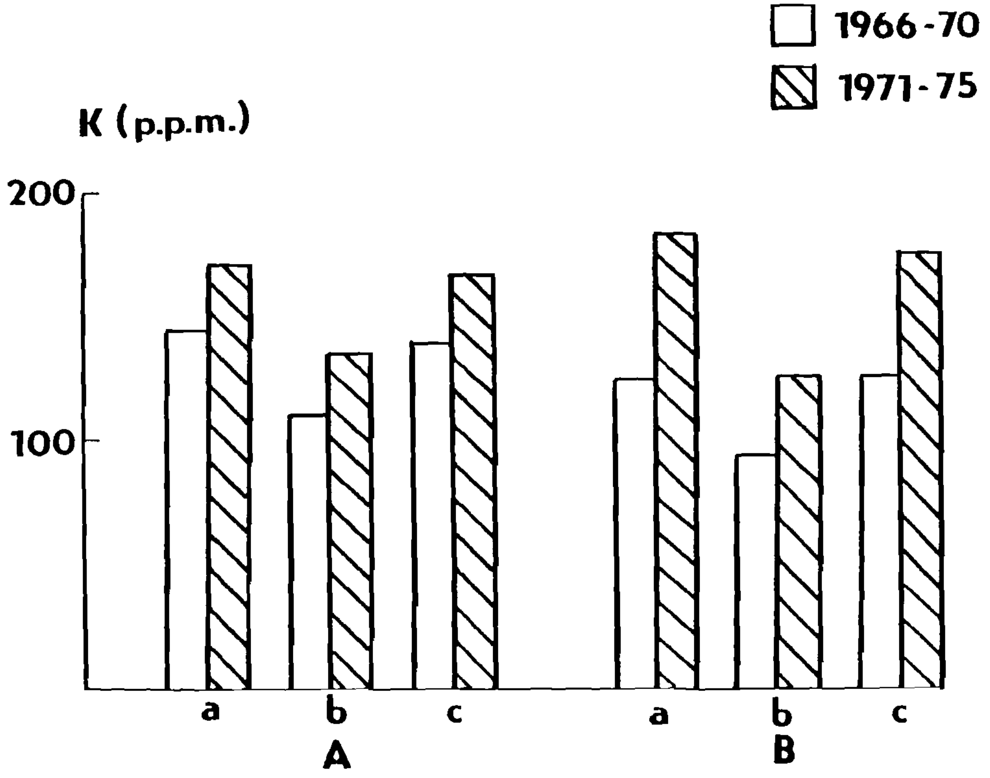


Figure 3. The content of potassium available to plants in arable (A) and grassland (B) soils: a - maize production zone, b - sugar beet production zone, c - potato production zone

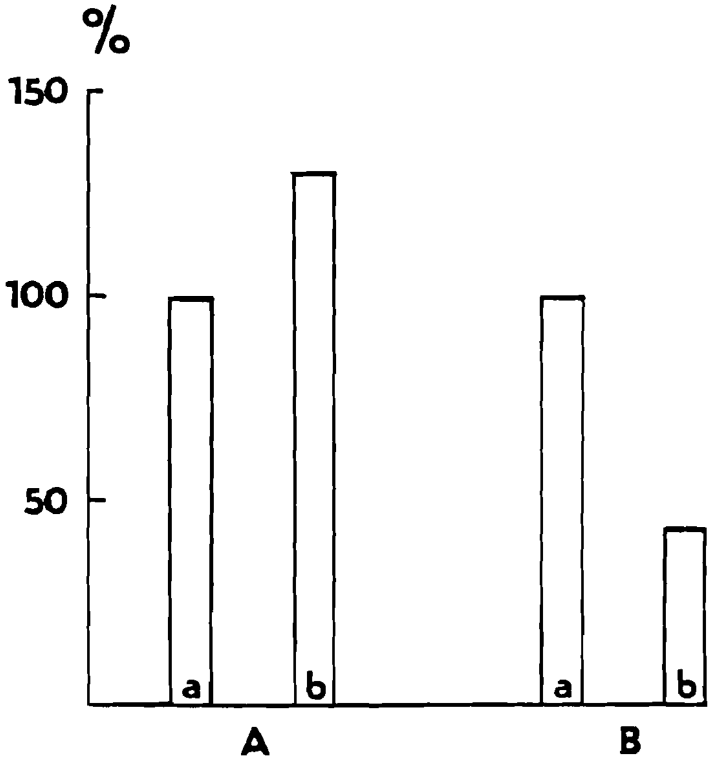


Figure 4. Yield response (A) to N-fertilizing - 150 kg. N per ha to spring wheat and leaching of N (B); (a) single load in solids, (b) divided load:

- 50% in solids before vegetation
- 50% in liquids divided in three equal portions at: stem formation, ear shooting and flowering

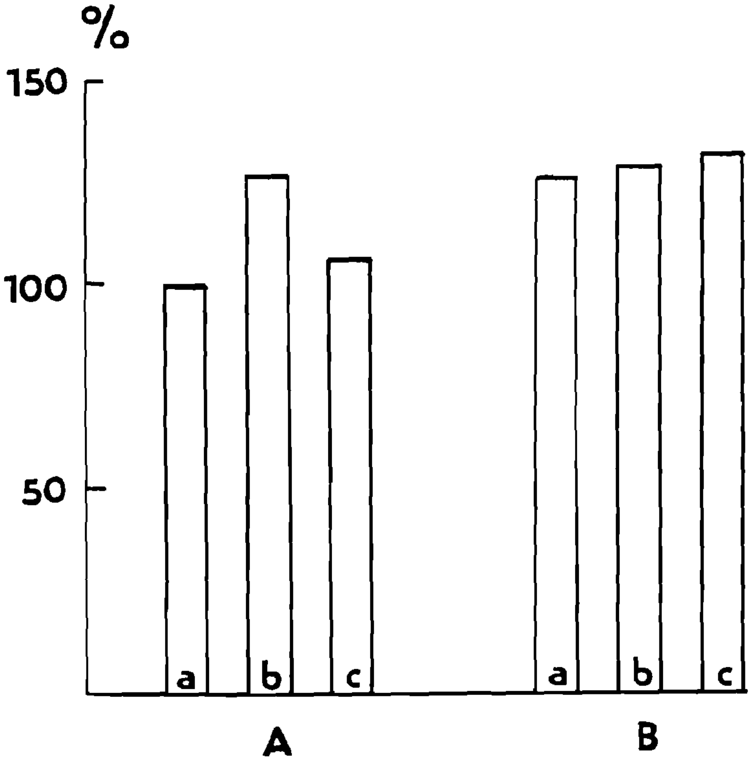


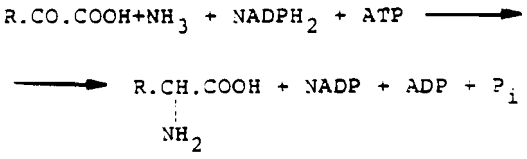
Figure 5. The effect of (a) single 150 kg, (b) divided 150 kg and (c) divided reduced 125 kg loads of nitrogen on the yield of spring wheat in "dry" (A) and "wet" (B) years

The biochemical immobilization of ammonia offered the most effective and reliable method for preventing the formation of nitrates. Organic matter can accumulate nitrogen substances in the soil and thus prevent their leaching (Figures 6-9). Crop yields have been adversely affected by the biochemical nitrogen immobilization, but on the other hand, the subsequent mineralization furnishes the roots of crops with a readily available and stable supply of nitrogen compounds. This ecological dependence of the remineralization of immobilized nitrogen is very useful for the physiological needs of growing plants.

Organic substances exert a double effect on nitrogen immobilization:

(1) They are essential for the formation of chemical bonds between the carbon chain and nitrogen. In spite of the fact that many nitrogen-rich compounds may be formed, the accumulation of organic nitrogen does not exceed 10 percent of the total carbon accumulated (Figure 6).

(2) The exergonic reactions based on the decomposition of organic matter act as fuel for the endergonic synthesis of primary nitrogenous compounds:



$$\mathrm{R.CO.COOH+NH_3 + NADPH_2 + ATP} \longrightarrow$$

$$\longrightarrow \mathrm{R.\underset{\displaystyle NH_2}{\underset{|}{CH}}.COOH + NADP + ADP + P_i}$$

where:

R.CO.COOH - any organic α-oxo acid (preferably: α-oxo glutamic or oxalacetic acids)

NH_3 - ammonia ion (NH_4^+ in fact)

$NADPH_2$ - nicotinamide-adenin-dinucleoproteide-phosphate-reduced form (briefly: coenzyme II - red.)

NADP - coenzyme II - oxidized form

ATP - adenosine triphosphate (containing energy-rich phosphate bond)

ADP - adenosine-diphosphate (with the loss of one phosphate form ATP the energy of the "energy-rich" bond is being transported)

P_i - inorganic phosphate (orthophosphate)

$\mathrm{R.\underset{\displaystyle NH_2}{\underset{|}{CH}}.COOH}$ - α-amino acid formed by the simultaneous three-step process:

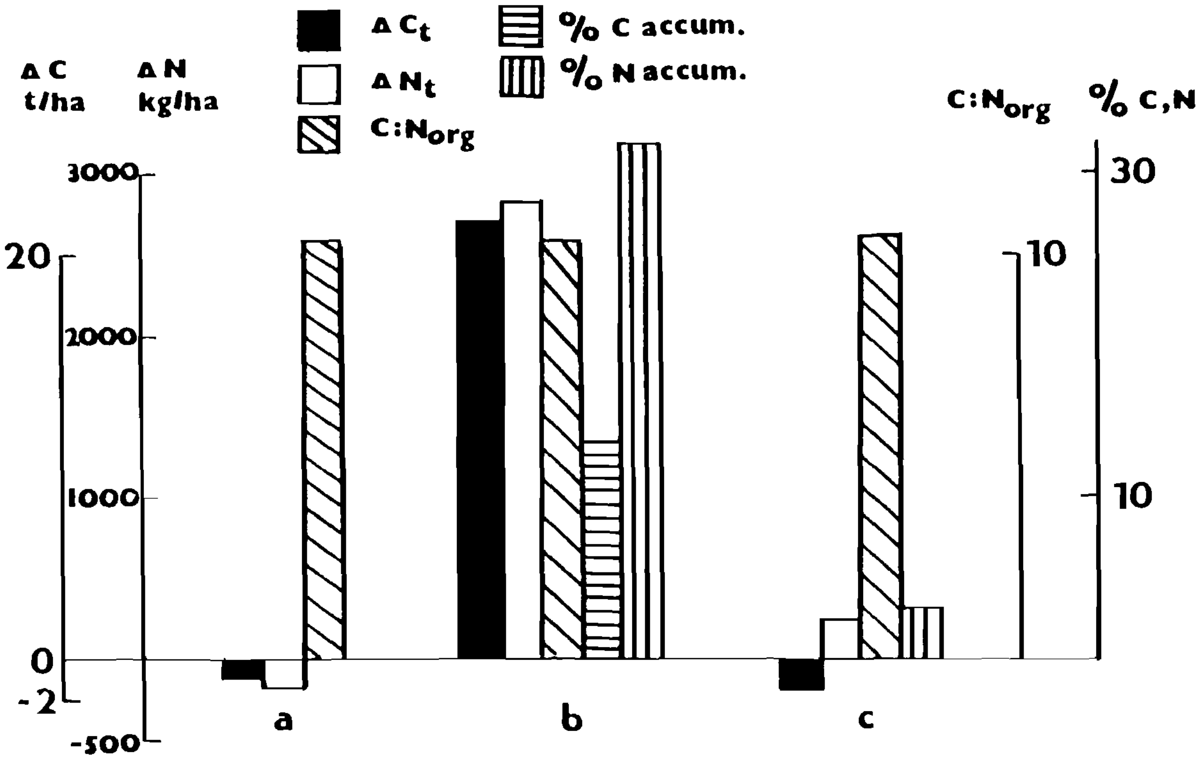


Figure 6. Extent of net accumulation of carbon and nitrogen in bare fallow soil after 20 years of annual manuring and fertilizing: (a) - not fertilized; (b) - manured; (c) - fertilized with inorganics: % C accumulated and % N accumulated were computed on the amount of element added with fertilizers (eventually N increase by precipitations or by biological non symbiotic N_2 - fixation was neglected).

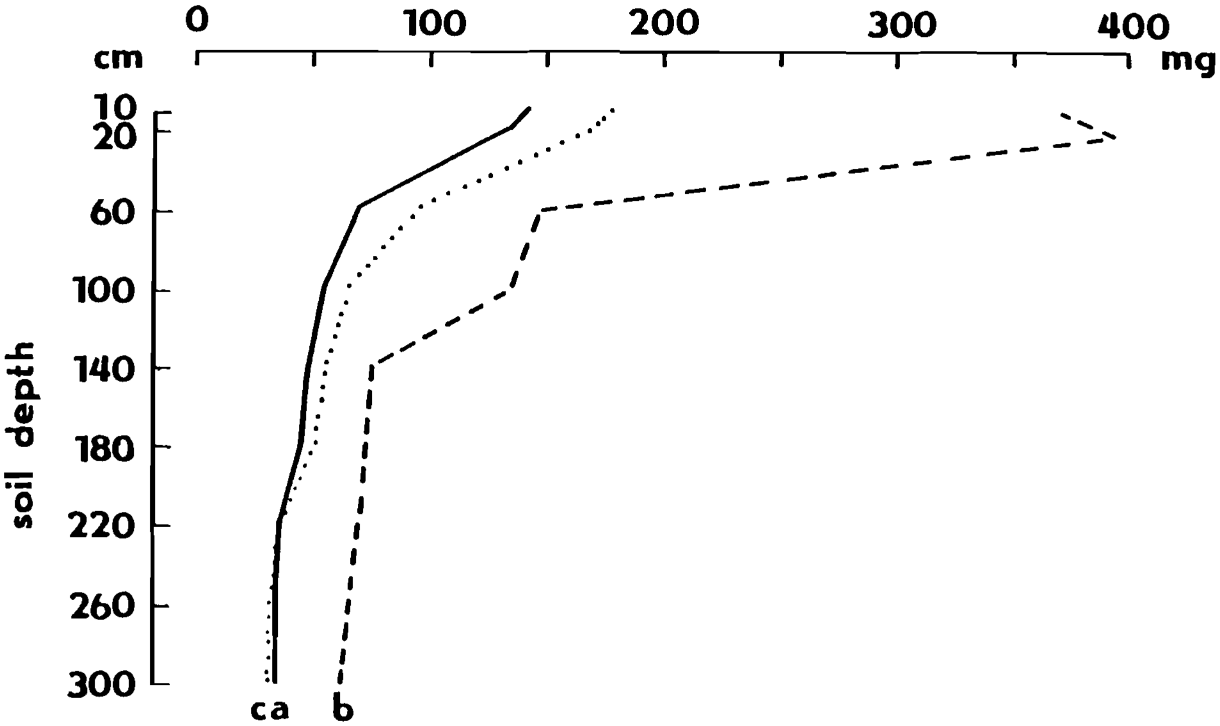


Figure 7. Distribution of entire nitrogen in the soil profile after 20 years of fertilizing of fallow soil: (a) not fertilized; (b) manured; (c) fertilized with inorganics (the entire loads of applied N in (b) and (c) were the same - 8900 kg N per ha in 20 years)

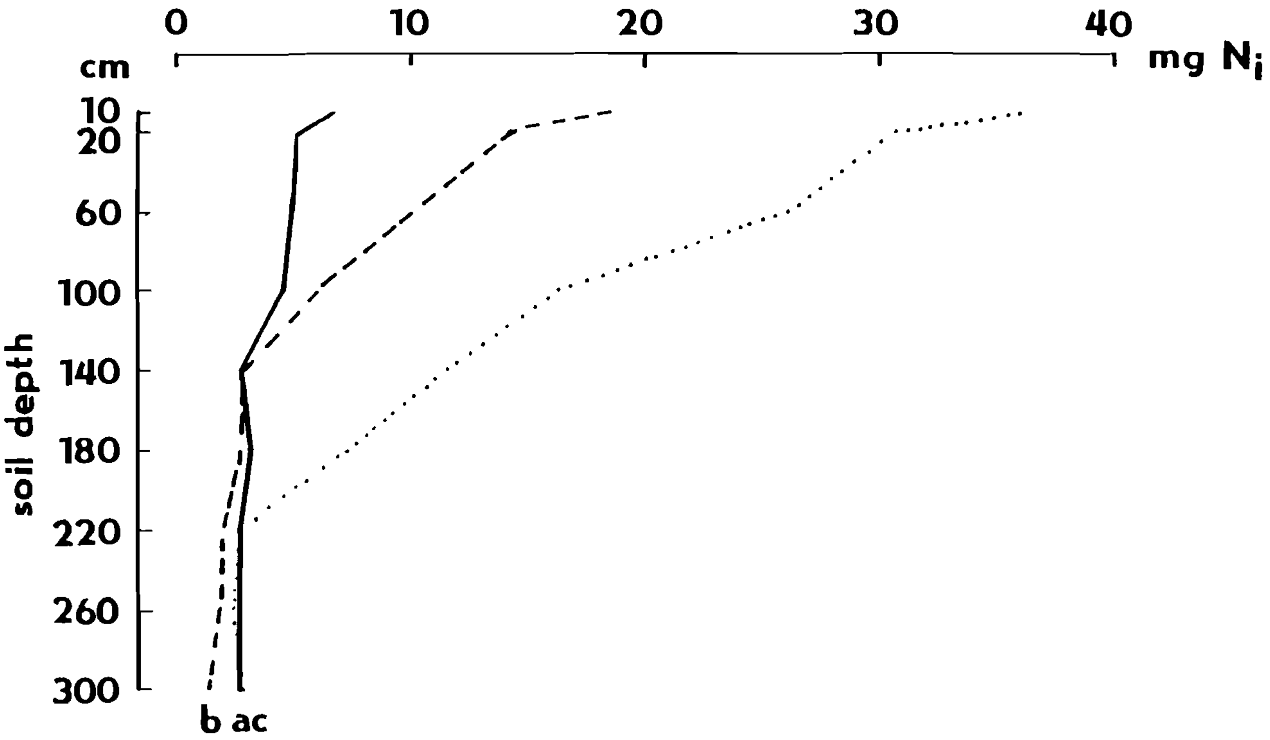


Figure 8. Distribution of inorganic nitrogen in the soil profile after 20 years of fertilizing of fallow soil: (a) not fertilized; (b) manured; (c) fertilized with inorganics

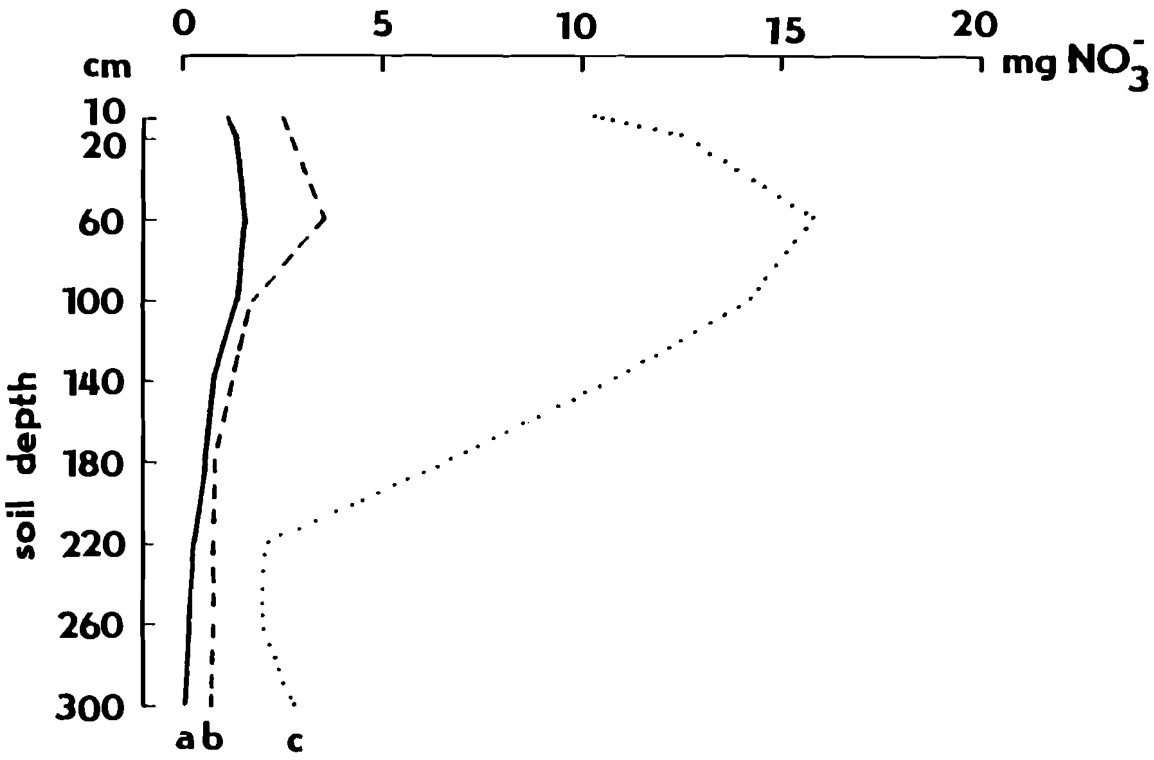


Figure 9. Distribution of the nitrate nitrogen in the soil profile after 20 years of fertilizing of fallow soil: (a) not fertilized; (b) manured; (c) fertilized with inorganics

(1) reduction of the α-ketogroup of α-oxoacid by $NADPH_2$, and partly by NH_3

(2) substitution of one H-atom in the α-position of the newly formed fatty acid by $-NH_2$ group

(3) hydrolysis of ATP by the evolved H_2O with the formation of ADP and P_i and the liberation of "free energy" needed for the incorporation of $-NH_2$ group (note: the free energy of $NADPH_2$ - reduction is not liberated; it is directly consumed in the coupled reaction of the oxo-acid reduction)

The energy input in this overall reaction may be calculated as:

$$NADPH_2 + 1/2\ O_2 \longrightarrow NADP + H_2O + 52.4\ \text{kcal}$$

$$ATP + H_2O \longrightarrow ADP + P_i + 7.3\ \text{kcal}$$

In calculating the entire free energy demand for one molecule of ammonia at 60 kcal, no more than 8 percent of the free energy for the nitrogen immobilization was ever used of the total energy liberated by exergonic processes. Generally, this percentage was much lower in our experiments, usually 2 to 3 percent under favorable conditions, or zero under less favorable conditions.

The primarily formed α-amino acids (glutamic or aspartic acids) are transformed to secondary amino acids by transamination reactions, evidently without any free energy input. But the precursors for the secondary amino acids are formed by the living cells according to their own specific regulation mechanisms. The total energy input is the controlling factor regarding the election of the alternative metabolic pathways as well as the total biomass increase.

The individual metabolic pathways vary in efficiency with regard to the energy demand for production of the same metabolite (or precursor, or intermediate). Some highly stabilized metabolites (e.g. aromatic and/or heterocyclic compounds) are linked to a very limited number of metabolic pathways (e.g. pentosophosphate pathway). This makes it clear that the energy controlling autoregulation mechanisms such as $NADH_2$: NAD (similarly: $NADPH_2$: NADP) and ATP: ADP (eventually: ATP : P_i) are very important not only for the entire process of nitrogen immobilization but also for the stability (i.e. the ability to withstand the attack of soil microorganisms) of the newly formed nitrogenous substances and, hence, for the rate of their breakdown. These facts enable us to understand easily that ecological factors are also significantly effective in the control of the extent of nitrogen immobilization and of the percentage of free energy utilization for this immobilization, as well as in the control of nitrogen mineralization.

Under comparable soil and weather conditions, the extent of N-immobilization increased with increasing amounts of organic substances entering the soil and with the consequently increased C:N ratio. The percentage of free energy utilized in nitrogen immobilization decreased with the increased amount of organic matter and increased with the increased ammonia-N content. Simple organic substances (such as hexoses) enabled rapid N-immobilization with a high content of nitrogen in the newly formed substances ($C:N_{org}$ = 5-6), but these were rather labile and were rapidly decomposed, or, if the conditions were favorable, were partly incorporated into other organic substances with a lower nitrogen content. The complex organic matter (straw, manure, etc.) yielded, with nitrogen, new and relatively stable organic compounds with a C:N ratio of approximately 10. Mineralization of soil nitrogen occurs regularly at the same rate as the mineralization of soil carbon. The production of every 35 g CO_2 is accompanied by the mineralization of one g nitrogen (C:N ratio = 10).

The application of nitrogen in the form of organic manures or the application of inorganic N-fertilizers together with straw and/or related organic matter capable of causing nitrogen immobilization, depressed nitrification and consequently, the migration of nitrogen downward in the soil profile. The proper relation between the amount of organic and inorganic fertilizers applied remains the most effective factor controlling water pollution by nitrates.

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WATER-RELATED ENVIRONMENTAL PROBLEMS OF AGRICULTURE IN FINLAND

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ABSTRACT

In Finland intensive farming is concentrated mainly on the rather dry coastal area of South and West Finland. The watercourses in this region are inherently susceptible to pollution.

The ever-increasing efficiency of agricultural practices, in particular the widespread use of fertilizers and the centralization of dairy farming into large units, emphasizes the urgent need for water pollution control in agriculture. In some cases the watercourses of agricultural areas also serve as raw water supplies for cities. Problems relating to the uptake of water occur particularly during the flood season following the spring thaw.

Research and planning in the field of water pollution control in agriculture has in recent years gained considerable importance. It is important to distinguish between natural load and the load caused by man. Research is also being carried out on the effect of non-point loading on watercourses and on the different uses of water. The role of cultivation techniques and of the reuse of waste materials is also the object of investigation. The use and drainage characteristics of pesticides is being studied.

WATER RESOURCES AND WATER POLLUTION CONTROL IN FINLAND

Finland's total area is 337,000 km^2. Soil deposit on the bedrock is thin. Thirtyfive percent of the soil is moraine, five percent sand and gravel, five to ten percent clay and silt, and five percent exposed bedrock. Peatlands cover about thirty percent of the country.

The climate is very mild compared to other countries at the same latitude. Annual precipitation is 630 mm, of which one half evaporates and the other half flows along rivers to the sea. Generally in the watercourses water flow is never broken. Further, regional precipitation is rather evenly distributed throughout the year.

A total of 9.4% of the surface area of Finland is occupied by lakes, the average depth of which is about 7 m and their total volume approximately 220 km^3. Water routes with many lakes are found mainly in central and eastern Finland. In the southern and western coastal regions the waterways are by contrast mainly small, lakeless rivers characterized by abrupt seasonal changes in flow volume. The largest river waterways are found in North Finland.

Finnish watercourses are highly susceptible to pollution. Reasons for this include the high humus content and low nutrient and salt concentrations. A long annual period of freezing over, the shallowness of Finnish lakes and slow turnover of water in the waterways, all contribute to the danger of pollution.

The majority of Finnish watercourses are still in a near-natural state. However, recent decades have seen the centralization of urbanization and considerable growth of industry and intensification of agriculture. This has in some cases resulted in pollution and consequently in reduction in the value of watercourses. Therefore, water pollution control has been important in Finland already since the sixties. The water legislation introduced in 1962 and the National Board of Waters inaugurated in 1970 comprise the legal and governmental basis for water pollution control. The central aim of water pollution control management has been to reduce the loading caused by industry and municipalities and to halt water pollution arising from these sources. Water pollution control has produced some positive results in the nineteen seventies. Due to the reduction of the load only 2% of the water area is now badly polluted. In addition, it is estimated that 19% of the water area is to some extent polluted by wastewater.

Reduction in wastewater point loading of industry and municipalities has increased the relative significance of non-point loading and also facilitated the experimental observation of this parameter. In Table 1, estimates are given of the non-point load and the nutrient load of wastewater discharge.

Table 1. Estimates of nutrient load in Finland by sources of load in 1975

	Phosphorus tons P/a		Nitrogen tons N/a	
Natural load	3,300		75,000	
Erosion		3,000		60,000
Rain and thaw water		300		15,000
Non-point load by human activities	2,500		45,000	
Settlements without sewer systems		50		1,000
Stock raising and dairy farming		600		18,000
Cultivation of land		1,700		24,000
Forestry		150		2,000
Total of non-point load	5,800		120,000	
Point load of wastewaters	2,900		22,600	
Municipalities with sewer systems		1,900		11,700
Industry		1,000		

GENERAL FEATURES OF FINNISH AGRICULTURE

Finland is the world's most northerly country in which agriculture has notable economic significance. Some basic data on Finnish agriculture is given in Table 2. Cultivated fields account for 9% of the total surface area of Finland. Agriculture is most intensive in the clay-based areas of South and West Finland, where arable land totals 30% of the surface area. As a whole, agriculture in Finland is mainly based on small holdings and crops are usually one-family produce. Average field area for the whole country is 11 ha, in the region of intensive farming 16 ha. The proportion of the total population actively engaged in agriculture is decreasing continuously, as is the number of farming units, especially small holdings. By contrast, average field area is slowly increasing, although very large farms are still the exception. Only one percent of farms have a field area over 50 ha.

Agricultural development has followed different lines in different parts of Finland. Cultivation of grain and the production of pork, chickens and eggs have become the main activities in South and Southwest Finland, whereas in central and western districts the emphasis is more on dairy farming. In the latter areas meadowland and animal feed crops are also of importance.

Dairy farming is nowadays carried out in larger units than in previous years. The total number of cows in Finland has decreased, but a growing number of dairy farms have more than 10 cows. About 25% of the total of dairy cattle are concentrated into these larger units. The size of pig-farming units has increased even more rapidly. About 65% of the total of pork production is from piggeries of over 100 pigs. The use of meadowland for ensiling fodder has increased by a factor of over 50 during the past 10 years. Almost 3,500 million kg. of fresh fodder are produced annually.

The use of artificial fertilizers is most widespread in areas of intensive farming. During the season 1977-78 nitrogen (N) was applied at a level of 80 kg/ha, phosphorus (P_2O_5) 76 kg/ha and potassium (K_2O) 64 kg/ha in Southwest Finland. For the country as a whole, the corresponding figures were 69 kg nitrogen, 59 kg phosphorus and 52 kg potassium per hectare. The use of fertilizers increased to the middle of the 1970's, after which there has been a slight decline.

Intensively cultivated fields are nowadays nearly all treated with different pesticides. In 1977, pesticides calculated as amounts of active ingredients, were used in Finland as follows: fungicides 89 tons, insecticides 115 tons, storage pest repellents 18 tons, herbicides 1,400 tons and forest herbicides 160 tons. The chemical most used, almost 1,000 tons, was the herbicide MCPA. Significant changes in the use of pesticides have taken place during the 1970s. The use of DDT as a pesticide is nowadays strictly forbidden. Biological pest control has become increasingly important (Tiittanen and Blomqvist, 1978).

Table 2. Statistical data on agriculture in Finland in 1969 and in 1977

		1969	1977	change %
Area of arable land	1000 ha	2669.1	2616.2	- 2.0
Percentage of the arable land from the total area	%	8.8	8.6	- 2.2
Percentage of subsurface drained land from total arable land	%	18.2	29.0	+ 59.3
Farms	pcs	297257	242682	- 18.4
Cattle	1000 pcs	1981.3	1762.3	- 11.1
Horses	"	101.3	29.3	- 71.1
Pigs	"	796.9	1143.3	+ 43.5
Sheep and lamb	"	158.9	104.5	- 34.2
Hens and chicks	"	7248.0	8689.2	+ 19.9
Milk received in dairy plants	mill.l	2949.30	2821.67	- 4.3
Meat production	mill.kg	208.36	251.89	+ 20.9
Silage production	1000 ha	39.6	204.3	+415.9
Silage production	mill.kg	548.9	3276.1	+496.8
Sales of fertilizers*	1000 tons			
Nitrogen N	"	160	168	+ 5.0
Phosphorus P_2O_5	"	174	142	- 18.4
Potassium K_2O	"	132	126	- 4.5
Main nutrients total	"	466	436	- 6.4
Sales of fertilizers*	kg/ha			
Nitrogen N	"	57.8	69.1	+ 19.6
Phosphorus P_2O_5	"	61.8	58.7	- 5.0
Potassium K_2O	"	47.8	51.7	+ 8.2
Main nutrients total	"	167.4	179.5	+ 7.2

*Fertilization seasons 1969-70 and 1977-78

THE EFFECT OF AGRICULTURE ON WATERCOURSES AND WATER UTILIZATION

Research into the effects and the possible reduction of discharge loading in this country has mainly been confined to wastewaters of industry and municipalities. Similar research in agricultural and sparsely populated areas has not so far been considered. However, water quality records for the whole country (Laaksonen, 1970; Laaksonen and Wartiovaara, 1973) show a slow slight increase in electrical conductivity and in the concentrations of both nitrogen and insolubles. Empirical methods have been used in an attempt to estimate the magnitude of non-point loading in the country as a whole and also in separate drainage areas (Särkkä, 1972). The most comprehensive source of research material concerning non-point loading in Finland is the observation series of small hydrological areas. Regular monitoring of water quality was commenced in the 34 small drainage basins in 1962. A requirement for research on leaching was the continuous measurement of flow rates. Observations in these areas continue unchanged.

Calculations of leaching values for the years 1962-1968 have been published for nutrients (Särkkä, 1972), alkali metals (Kohonen, 1974), and organic material (Kauppi, 1975). Kohonen (1976) has drawn up a summary of these research results. On the basis of observations made since 1965, Kauppi (1978, 1979) has investigated the dependence of non-point phosphorus and nitrogen loading on the characteristics of the drainage basin, in particular on the proportion of arable land.

On the basis of the research results from the small drainage basins, the natural rate of leaching of phosphorus in Finland is 4-6 kg/km^2. The corresponding figures for nitrogen leaching are about 200 kg/km^2 in South Finland and 100 kg/km^2 in the North.

Research shows that the effect of human activity and particularly of agriculture on the leaching of nutrients is very marked in the coastal areas of South and West Finland. Total leaching of phosphorus in South Finland is 22 kg/km^2, and that of nitrogen 400 kg/km^2. The effect of agriculture on these leaching values is very obvious: a strong correlation exists between nutrient loading and the proportion of cultivated land (Kauppi, 1978).

The effects of agriculture on watercourses and water quality are greatest in areas where the proportion of cultivated land is high and the watercourses are small. Such areas are the South, Southwest and West coastal districts of Finland, in which over one third of the total population of the country is concentrated. Particularly urgent problems arise in these areas where surface water is used as a source of water supply. The clearest example of this problem is the area around the river Aurajoki in Southwest Finland. This watercourse serves as the source of water supply for the city of Turku and its neighbouring municipalities (population 250,000). The river Aurajoki has no lakes in its course and its flow rate is subject to sharp variations. Concentrations of polluting components in the water are at their maximum during the spring flood. Taste and odour defects occurring in the drinking water of the city of Turku cannot be totally removed by the water purification technology of the waterworks. The drainage basin of the river Aurajoki is intensively farmed, and there are many large piggeries in this area.

A problem of a slightly different nature has arisen in Pohjanmaa, the coastal area of West Finland. During the time of the summer minimum flow rate the hygienic condition of watercourses becomes rather poor, and oxygen deficiencies exist. In this dairy farming area considerable amounts of fresh fodder are grown. Ensiling these fodder crops coincides with the summer flow minimum.

The use of pesticides has not been reported to have serious effects on watercourses in Finland. The use of seed dressings containing mercury compounds has not been found to increase mercury levels in fish. Amounts of MCPA and other phenoxyherbicides and also their degradation products are very small in the waters of different watercourses. However, the concentrations are significantly higher in areas in which these herbicides are used than in other areas.

WATER PROTECTION AND AGRICULTURE

Most of the activity directed towards the reduction of nonpoint loading by agriculture is economical and reasonable from the point of view of both water pollution control and agriculture itself. More efficient use of fertilizers decreases the danger of leaching of nutrients, while the utilization of wastes from cattle farming reduces the need for expensive artificial fertilizers. Nutrients discharged due to ensilage are a problem from the point of view of water pollution control, while in terms of the nutritive value of the fodder they represent an obvious loss to the farmer. These nutrients are quite acceptable as field fertilizer.

Present deficiencies in water pollution control practice in agriculture stem largely from lack of knowledge or from disinterest on the part of farmers. Because of the short growing season in Finland it is often necessary to act very rapidly in spring to ensure that sowing takes place at the optimum time. In order to ease the situation in spring, many farmers spread manure in autumn, or in late winter, on the still-frozen ground, or on the snow covering. This practice of course leads to very great losses of nutrients by leaching.

Buildings and outhouses used in cattle farming are still in many areas rather old-fashioned and modernization proceeds quite slowly. The growth of cattle farming units therefore often causes increased loading of nutrients and may lead to considerable pollution of watercourses.

Advice and information is nowadays supplied by both agricultural and water authorities. Positive changes are also slowly taking place in the development and construction of farm buildings and in their financing. Land fertility research, individual planning of field fertilization and modern techniques of fertilization all serve to decrease the risk of leaching of nutrients.

The National Board of Waters has begun precise planning for the pollution control in certain important waterways in agricultural areas. The drainage basin of the river Aurajoki, mentioned above, is one such region. A water protection scheme for the Aurajoki river will be completed at the beginning of 1980. Planning is being carried out as a cooperative enterprise involving the water-consuming municipalities and representatives of agricultural activity in the area. The aim is to demonstrate systematically and in practical terms, the possibilities for reduction of nutrient loading and also the effects of the suggested actions on the quality and usability of water.

Measures are being taken for the legislative control of discharges. More specific instructions for water protection are also being drawn up for drainage areas which for reasons of nature conservation or water supply require particularly strict water protection regulations for both agricultural and other sources of non-point loading.

MAIN FEATURES OF THE RESEARCH ON WATER POLLUTION CONTROL PRACTICE IN AGRICULTURE

Non-point nutrient loading and its different components are still being investigated on the basis of the established long-term observation networks. Of particular importance in this research is the distinction between natural leaching and loading caused by human activity. Research is also being conducted on the effect of non-point loading on watercourses. Other important areas of research are the more precise analysis of eutrophication and oxygen consumption. The effect of non-point nitrogen and phosphorus loading on algae growth as compared to the effects of nutrients arriving with wastewater discharge is also important. The effects of different methods and materials for fertilization and of the use of waste materials, and also of the timing of fertilization on leaching are being examined on test plots in various parts of Finland.

The use of pesticides, as well as their occurrence and effects on watercourses, is under careful observation.

SUMMARY

Finnish climatic conditions and watercourse characteristics on the one hand reduce the harmful effects of agriculture on waterways while on the other they aggravate these problems. One of the main concerns of water pollution control in the 1980's will be the reduction of non-point loading. The necessity for action in the field of water protection will increasingly be based on observations of water quality and its changes in quality level. Field research application of mathematical models may be expected to lead to improved estimates of the consequences of non-point nutrient loading. Basic research is however first needed in order to clarify many important phenomena connected with the movement of nutrients. Only then will practical applications be possible.

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GENERAL ASPECTS OF FORESTRY MANAGEMENT AS RELATED TO AGRICULTURAL PRACTICE IN JAPAN

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ABSTRACT

Japan's entire water demand amounts to approximately 83 b.m^3 annually, which includes 57 b.m^3 for agriculture. Agricultural water demand from rivers is often higher than the minimum low flow. This means that if precipitation is low during the rainy season, serious water shortage problems often occur.

Timberland occupies an area of 25 million ha, comprising 67% of the total land area. There are many kinds of protection forests covering a total of 7.08 ha. These protection forests have been in existence since 1897; however, about the function of the protection forest, especially about its water retention function, little was known. In order to shed light on this subject, a number of experimental plots were established. The results of the past 70 years of research and observation were recently summarized as follows:

(1) Interception loss of rainfall by forest canopy ranged from about 15 to 20% of the annual net precipitation.
(2) Infiltration capacity of forest land was higher than that of other land.
(3) The increment of annual runoff water became gradually larger as the cutting progressed, and smaller as regrowth developed.
(4) After clear cutting, quick flow and peak discharge due to the heavy rainfall increased by an average of 1.30 - 1.70 times that before cutting.
(5) Nitrogen content in stream flow increased by 3.5 ppm. in the summer after clear cutting.

This paper also deals with the outline of the relationship between agriculture and forestry. Items discussed are as follows:

(1) Supply of organic material to agricultural fields,
(2) Woodland grazing,
(3) Disposal of livestock discharge,
(4) Cultivation in the forest,
(5) Production of firewood, charcoal, etc.

INTRODUCTION

The cultivation of rice, Japan's main crop, requires large quantities of water, therefore much interest has centered on forest management for the purpose of securing water resources. This paper mainly treats headwater conservation forests, protection forests, and the general relationship between agriculture and forestry; such topics as supply of organic matter, woodland grazing, and production of minor forest products (which are thought to be important factors in the system analysis of watershed management) are also dealt with.

LAND USE

Most of Japan is mountainous and there is little flat land suitable for agriculture. In addition, the population is relatively large. Because of this, almost all arable land has long been used as farmland. Location of timberland has been limited to steep slopes and poor, shallow soil. Land use areas in Japan are as follows:

Timberland	25.26 million ha	(66.9%)
Paddy field	3.14 million ha	(8.3%)
Farm field	2.39 million ha	(6.3%)
Grassland	0.46 million ha	(1.2%)
Wilderness	0.56 million ha	(1.5%)

Numbers in parenthesis represent percentage of the total land area of the country. About 40% of the total timberland area, or 9.38 million hectares, is man-made forest. One third of the total timberland is national forest.

After the war (1945-1960), timberland area was slightly reduced because lands were being reclaimed for agricultural use and farmland was being used more intensively in connection with Japan's efforts towards self-sufficiency in food. Since about 1960, due to sudden urban sprawl, farmland has diminished. As a consequence, there has been a tendency to convert wilderness into farmland. In addition, wilderness and forest land are being converted into man-made grassland in order to expand stock farming. At present, demand for firewood and charcoal is decreasing sharply. As a result, it has become a major question as to whether young, natural, broad-leaved forests, in other words, fuelwood forests, should be converted to grassland or coniferous man-made forests. Japan has a serious food and housing shortage, which in turn has led to a shortage of wood. An early solution to these problems seems unlikely, as Japan annually imports 60-70 million m^3 of log and timber, making it the largest importer of such goods in the world.

PROTECTION FOREST

As mentioned above, most of the forests are located in mountainous areas on steep slopes. Due to this geographical condition, execution of land protection, flood preservation, and water source protection are essential in Japan. For this reason, there are many protection forests in Japan, covering a total of 7.08 million ha, half of which are privately owned forests. The following is a classification of protection forests according to objective, especially where the objective relates to agriculture.

Headwater conservation	5.28 million ha
Sediment run-off prevention	1.51 million ha
Landslide protection	0.044 million ha
Shifting sand control	0.016 million ha
Windbreak	0.054 million ha
Tidal wave and salty wind prevention	0.012 million ha
Drought damage prevention	0.031 million ha
Fog prevention	0.052 million ha

Protection Forest for Headwater Conservation

In Japan, total annual precipitation is about 670 billion m^3, a relatively large quantity. An estimated 520 billion m^3 of this total flows out to rivers. The total water demand of the country at present (1975) is approximately 83 billion m^3 (57 bm^3 for agriculture, 15 bm^3 for industry, 11 bm^3 for living), of which about 60 billion m^3 are from rivers (40 bm^3 for agriculture, 10 bm^3 for industry, 7 bm^3 for living). By 1985, water demand is expected to increase by 40 bm^3. As available underground water has nearly reached its limit, this increasing demand will have to be met mainly by rivers. The increment rate of water demand for agriculture is about 10%, or about the usual rate, while the increment of water demand for industry and public supply is estimated at triple the present demand.

In order to meet future demands, it will be necessary to construct 580 dams with a total capacity of approximately 10 bm^3. However, the high construction costs will make it difficult to realize construction to this extent.

Since the land is so steep and the valleys are so narrow in Japan, the storage capacity of each dam is small. Accordingly, construction expenses per unit of volume is extremely high. Therefore, it is necessary to cover headwater area with forests in order to promote storage capacity in ways other than by the construction of water reservoirs.

For the rice crop-oriented agriculture of Japan, a large quantity of water is essential. Too much water is withdrawn from rivers for agriculture during periods of low water discharge. When precipitation is low during the rainy season, serious water shortage problems often occur. To alleviate this problem, forests around headwater areas were delineated as protection forest. Cutting in these forests has been sharply restricted by law. Many protection forests have been established since 1897, especially for headwater conservation. However, how forest type and tree species affect the volume of effluence and the water holding function had not been made clear in detail. In order to determine this relationship, a number of experimental plots were established upon which observation and research have been carried out. The results of the past 70 years' research were summarized as follows:

(1) Interception of rainfall by forest canopy ranged around 15 to 20% of the annual net precipitation. The interception by undergrowth in stand was about 1 mm for every storm, and that by litter was 2 to 4 mm. Water intercepted by the canopy ranged about 5-10% at the time of of strong storms (100 to 200 mm).

(2) The mean annual water loss by evapotranspiration of forest land ranged from 400 to 1,100 mm.

(3) Water-holding capacity of forest land was higher than that of other land: broad-leaved forest land (mean value 272 mm) > coniferous forest (246 mm) > grassland (191 mm) > cut-over land (160 mm) > terraced land (99 mm).

(4) In the watershed on which clear cutting has been practiced for 2 or 3 years, the increment in annual runoff water increased gradually as the cutting progressed, and decreased as regrowth developed. Runoff water increased by 10-50% after clear cutting.

(5) After clear cutting, quick flow and peak discharge due to 200-500 mm storms increased by an average of 1.30-1.65 times that before cutting for 200 mm storms and 1.35-1.70 times the previous amount for 500 mm storms.

(6) The average low stream flow from the watershed with superior forest was larger than that from the watershed with scanty forest.

(7) Quick flow after cutting was 1.58-2.03 times that before cutting, and flow due to heavy rains (200 to 500 mm) was 1.20-1.65 times the previous amount.

(8) Nitrogen content in streamflow increased by 3.5 ppm in the summer following clear cutting, but this increase ceased over the next several years.

(9) Application of herbicides and fertilizers increased the concentration of soluble ions and nitrogen, but this concentration rapidly decreased later.

SEDIMENT RUNOFF AND LANDSLIDE CONTROL PROTECTION FOREST

To prevent existing dams from being buried with sediment runoff during the flood season, it is very important to check soil loss and to prevent landslides by planting forests. Various experiments are being conducted to study this issue.

According to fundamental policy, large bare areas should not be created in protection forests by large scale clear-cutting: selective cutting is desirable. There is also restriction regarding thinning. Only when the density of the canopy exceeds 80% may up to 20% of the volume be cut.

In many cases, a private forest is managed to produce timber even where this forest served as a protection forest. Felling and planting costs per hectare are much higher for selective cutting and small area clear-cutting than for large area clear-cutting. How this cost should be compensated for is a major topic of discussion. On the other hand, it is assumed that the forest's preservation function will be carried out most effectively if the forest is intensively managed to obtain maximum yield. The search for a harmonic point between the preservation function and the timber production function (economic function) is an important subject for the future.

SHIFTING SAND CONTROL AND TIDAL WAVE AND SALTY WIND PREVENTION FOREST

Japan is a narrow country with a long shoreline. Sand dunes develop along the shore and shift constantly inland toward the agricultural fields. For a long time Japanese black pine (*Pinus thunbergii*) was planted on the sand dunes to stabilize the shifting sand. However, pine seedlings often suffer damages from windblown sand. Various technical methods are used to manage this problem, such as the erection of fencing when planting, or the addition of large amounts of organic matter.

Needless to say, the cutting of this type of forest is strictly prohibited. But recently, heavy infestation of the pine bark beetle in the southern part of Japan has become a serious problem. Recent research carried out to investigate the cause of the withering of the trees has revealed that the pine trees were being infested by a nematode, which is carried from place to place by a kind of long-horned beetle.

WINDBREAK AND FOG PREVENTION FOREST

Generally speaking, farmers are unwilling to establish a windbreak forest, because the practice requires the conversion of considerable areas of fertile agricultural land into forest land. Windbreak forests have been systematically established only in the eastern part of Hokkaido Island. An additional problem in this district is dense sea fog, which moves in over fields during the vegetation period of crops, and obscures the sun. Forest zones are established along the seashore for the purpose of intercepting the fog and decreasing its density.

At the felling age, when windbreak and fog prevention forests are cut, a zone at least 20 meters in width must be left untouched. As the soils in this district are volcanic and therefore easily blown away or dried out by the wind, the effectiveness of the windbreak forest is clearly recognized. However, more study is needed on the effectiveness of fog prevention.

THE MUTUAL RELATIONSHIP BETWEEN AGRICULTURE AND FORESTRY

Fallen leaves and undergrowth of comparatively young, broad-leaved coppice stands (fuelwood forest) or pine forest which regenerates naturally, have long been important sources of organic matter for agricultural fields. Occasionally, such forests were owned by farmers, individually or jointly, for the purpose of collecting fuelwood, fallen leaves and undergrass. In addition, national forests were sometimes loaned to farmers for this same purpose.

Research showed conclusively that in these forests the growth of trees and the quantity of fallen leaves and undergrass had decreased due to a deterioration of land productivity caused by the collection of fallen leaves every year. The practice makes the agricultural land more fertile, but it makes the forest less fertile. Experimentation carried out on the fertilization of such deteriorated forest land in order to recover its productivity brought successful results. However, during the last twenty years, the traditional practice of fertilizing agricultural fields with organic matter from forests has diminished because of the shortage of labor.

WOODLAND GRAZING

In Japan, raising cattle is an important activity. However, suitable land for grazing and grass cultivation is limited. There is no doubt that the expansion of man-made forests to step up wood production is also an important policy.

Woodland grazing is used to accomplish both of these objectives. Ten years after planting, a considerable amount of grass vegetates among the planted trees, depressing the growth of young seedlings. Weeding is the most labor-intensive aspect of reforestation. Grazing cattle in planted areas at a ratio of one head per 1-2 ha serves the dual purpose of clearing the grass and feeding the cattle. Of course, there is some risk that newly planted trees might be damaged by the cattle, but this risk is insignificant in comparison with the savings in manpower. Extensive forest land is required for this practice so that should forest canopy become dense and growth of grass decrease in one young plantation, the cattle may be moved to the next. Theoretically, this method is a very profitable land use system, but it has not yet been widely realized because the production of timber and the grazing of cattle are not carried out by the same farmers.

Where the ground is covered by a dense growth of bamboo grass after the destruction of forest canopy, trees can no longer infringe upon the area. Grazing such an area will decrease the amount of bamboo grass and ease the natural regeneration of beech and pine. This fact has been known since earlier times, but it has never been systematically carried out.

DISPOSAL OF LIVESTOCK WASTES

In Japan, swine, barnyard fowl, and dairy cattle are raised in narrow backyards and barns. Because of this, disposal of livestock wastes is a major problem. Nowadays, the raising of livestock has moved from the large cities to rural communities, and then to areas near forest land. Great quantities of wastes are taken into forests as fertilizers, and trials are being made to filtrate the wastes through forest soil. But these trials are still on a small scale.

CULTIVATION IN THE FOREST

As mentioned above, elimination of weeds requires the greatest amount of manpower during the reforestation stage. Cultivation in the forest was carried out to reduce this manpower requirement and to produce agricultural products in an area where the forest land is on gentle slopes, the surface of the earth is burned out and then cultivated with buckwheat, soybean, dry field rice, and various vegetables. Between these crops, *Cryptomeria japonica* and *Chamaecyparis obtusa* are planted. Usually the landowner and the cultivator are not the same farmer. Where this is the case, the cultivator is exempted from paying rent on the land and, in return, he looks after the planted trees. This method of cultivating the forest is continued for four to six years after planting, or until the trees have reached a certain size.

In times when enough cheap manpower was available to keep planting costs low, ensure the growth of trees, and ease the yield of crops, this practice was often carried out in areas with limited arable agricultural land, but now it has been largely abandoned.

PRODUCTION OF MINOR PRODUCTS

The demand for firewood and charcoal has rapidly decreased since the peak time around 1960. Today, production of charcoal and firewood has shrunk to 1/100 of what it was during peak demand. Those broad-leaved trees which were formerly used for fuel and pulp material are now being used as a bed for cultivating mushrooms. *Quercus acutissima* and *Quercus serrata* are planted for this purpose. Present total production of shiitake (*Lentinus elodes*) is about 73 thousand tonnes per year, of which about 11 thousand tonnes are dried mushrooms and 62 thousands tonnes are raw mushrooms. About 1.8 million m^3 of broad-leaved timber are used as bed logs. The cultivation of shiitake and mushrooms brings an adequate income to mountain farmers. Besides mushrooms, paulownia (*Paulownia tomentosa*) chestnut (*Castanea crenata*) and sumac (*Rhus verniciflua*) are cultivated. Paulownia is a fast-growing species and the price of its wood is very high, making it especially profitable to the farmers. In general, small farmers with little forest land must cultivate minor products to make their living, as they are not able to wait long periods for plantation yields.

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THE ROLE OF SOIL AND WATER CONSERVATION PRACTICES IN WATER QUALITY CONTROL

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ABSTRACT

Mathematical simulation and linear programming models were used to determine the site-specific effects of soil and water conservation practices (SWCPs) on farm income and losses of sediment, nutrients and pesticides from croplands. SWCPs were found to significantly reduce pollutant losses in runoff with solid-phase losses being reduced more than dissolved losses. Only one SWCP (sod-based rotations) reduced total (runoff plus percolation) losses of nitrate. Sediment control was determined not to be equivalent to erosion control since the former requires concentration of SWCPs on fields with high sediment delivery. SWCPs often have negative or marginal short-run monetary benefits to the farmer. Long-run benefits may be positive, but data is not available to estimate such benefits.

INTRODUCTION

The effects of agricultural activities on water quality result from a complex set of circumstances. Potential pollutants such as sediment, nutrients and pesticides may leave a cropped field in runoff or percolation water, be transported across or through the landscape to surface or ground waters, and depending on their effect on receiving waters, produce water quality problems. Management of agricultural water pollution requires intervention at one or more points in this causal chain. Source control implies an attempt to reduce edge-of-field loss of pollutants, delivery control focuses on measures which would prevent pollutant movement from field to stream or aquifer, and problem mitigation involves attempts to lessen the impact of pollutant discharges on potential water users. The first of these strategies (source control) is often emphasized since there are a variety of well-defined management options which can potentially reduce edge-of-field pollutant losses. In the United States, these options are referred to as agricultural "best management practices" and include practices to reduce both pollutant availability and movement. Reduction of availability can be achieved by the management of chemical applications to limit the opportunity for loss, while management of pollutant movement results from techniques such as soil and water conservation practices (SWCPs) which are designed to prevent soil erosion and retain water.

There has been a great deal of interest in the use of SWCPs for water pollution control in the U.S. Due to a long-term interest in erosion control, the U.S. has an in-place institutional delivery system to aid farmers in implementing SWCPs. This system includes local conservation districts as well as national agencies which provide technical and financial assistance to farmers. Since SWCPs can have productivity benefits due to the reduction of cropland erosion, the long-run net costs of implementation are potentially low. Thus SWCPs can be implemented using existing administrative structures, appear to be relatively inexpensive and may contribute to the control of two important national problems: water pollution and erosion.

Although it is apparent that soil and water conservation is and will continue to be a major element of agricultural pollution control in the U.S., surprisingly little is known about the effects of specific SWCPs on either edge-of-field losses of nutrients and pesticides or farm income. Data which does exist has originated from short-term experimental field studies and is sufficiently variable so that general conclusions are seldom possible. Recognizing a need for more comprehensive information on both the economic and environmental effects of SWCPs, the U.S. Environmental Protection Agency sponsored a two-year research project "Effectiveness of Soil and Water Conservation Practices for Pollution Control" at Cornell University. The project was interdisciplinary, and involved investigators from the University's Departments of Agricultural Engineering, Agricultural Economics, and Environmental Engineering as well as the U.S. Department of Agriculture's Economic Research Service (Table 1). A final project report was issued by the U.S. Environmental Protection Agency, Athens, Georgia during 1979. This paper is an attempt to summarize the principal results of the project. The research involved many different activities which cannot be adequately documented here. Of necessity, the paper focuses on results rather than methodologies, and readers must refer to the project report for the details of literature reviews, mathematical models and data analysis.

Scope and Methodology

The principal research objective of the study was to identify the potential water quality effects of SWCPs and to describe the economic implications of their use. Scope was limited to nonirrigated field crops in the Eastern U.S. The water pollutants studied were sediment, nutrients (nitrogen and phosphorus) and pesticides. Although a large number of conservation practices were studied, emphases was placed on the six SWCPs listed in Table 2. These practices were generally compared to a somewhat arbitrary definition of 'conventional' tillage, which was assumed to imply soil inversion

TABLE 1. Project Investigators and Affiliations

Agricultural Economics, Cornell	Agricultural Engineering, Cornell
George L. Casler Earl A. Lang Erick E. Smith	Hanneke D. DeLancey Douglas A. Haith Raymond C. Loehr Tammo S. Steenhuis Michael F. Walter
Environmental Engineering, Cornell	**Economic Research Service, U.S. Department of Agriculture**
Marion O. Harris Christine A. Shoemaker	Roger W. Hexem
U.S. Environmental Protection Agency Project Officer	
Lee A. Mulkey	

TABLE 2. Principal Soil and Water Conservation Practices

Practice	Description
Contouring	Field practices including soil inversion (moldboard) plowing, cultivation, harvesting, etc. follow natural field contours.
Terracing	Contouring plus embankments and channels across the field slope to divert and store surface runoff.
Strip-Cropping	Contouring with strips of close-seeded crops (sod) alternated with row crops.
Sod-Based Rotations	Rotations in which at least three consecutive years of legume sod (alfalfa) are alternated with row crops.
No-Tillage	Cropping with minimal seed bed preparation. Cultivation is eliminated, and soil surface is protected by undisturbed crop residues.
Conservation Tillage	Similar to no-tillage, with the exception that seed bed preparation by chisel or disk plowing is practiced.

by moldboard plowing, secondary tillage to smooth and pulverize the soil and mechanical cultivation of row crops for weed control. Since the project's time and resources were limited, the execution of long-term field studies was precluded. The general approach of the study included three primary elements:

1. Review and qualitative evaluation of previous and on-going field studies;
2. Use of mathematical simulation and linear programming models to quantify the effects of SWCPs at selected locations;
3. Review of research methods and results by an external panel of experts made up of professionals from universities, government agencies and consulting firms.

The following section is a qualitative description of the effects of SWCPs on pollutant losses based on the fundamental characteristics of SWCPs and pollutant constituents as well as the results of field studies. This discussion forms a basis for the succeeding sections which present research findings based on the study's quantitative (primarily modelling) analyses of sediment, nutrient and pesticide losses.

QUALITATIVE EVALUATION

Although field measurements of pollutant losses associated with SWCPs are not extensive, they have been sufficient to permit certain general observations. When these results are combined with a fundamental understanding of pollutant behavior and the effects of SWCPs on runoff and erosion, qualitative estimates of the effects of SWCPs on sediment and chemical losses from cropland are possible.

Potential water pollutants move from a cropped field in solid-phase or dissolved forms with water flows. These include both surface and subsurface lateral runoff flows and vertical percolation or deep seepage. Since SWCPs are generally designed to control erosion, they reduce losses of sediment and solid-phase nutrients and pesticides. Dissolved chemicals move with both runoff and percolation, and the surface runoff control associated with SWCPs does not necessarily reduce the total (runoff + percolation) losses of these chemicals from a field. For example, although SWCPs decrease nitrate losses in surface runoff, the same practices may increase percolation and subsurface runoff, particularly in regions where soil moisture levels are not severely depleted by evapotranspiration. The result may be an increase in nitrate movement in subsurface waters.

The classification of agricultural chemicals according to their expected dissolved and solid-phase forms can provide a basis for evaluation of a SWCP's effectiveness in controlling cropland losses of the chemicals. Since the influence of SWCPs on erosion and runoff is often predictable, qualitative estimates of chemical losses can be made by assuming movement of solid-phase constituents with eroded soil and dissolved constituents in solution with water flows. Certain chemicals may be characterized as essentially soluble (nitrate) or insoluble (organic nitrogen, fixed phosphorus). However, many chemicals may have significant solid-phase and dissolved forms, depending on their degree of adsorption to soil particles. Strongly adsorbed chemicals (organochlorine pesticides, paraquat) are lost from croplands primarily in solid-phase form. Unfortunately many of the agricultural chemicals which are of environmental concern (available phosphorus and most nonpersistent pesticides) are only moderately adsorbed, and substantial movement can occur in both solid-phase and dissolved forms. The effects of SWCPs on losses of the moderately adsorbed chemicals are difficult to estimate, since a continuous interchange between solid-phase and dissolved components is possible. For example, a reduction of surface runoff losses of dissolved phosphorus may tend to increase movement in subsurface flows. If these flows move through a soil profile with plentiful adsorption sites, losses will be minimal. Conversely, if the adsorption is minimal, the effect of runoff reduction may be to increase dissolved phosphorus in percolation and/or subsurface runoff.

Field studies have provided a reasonable basis for estimating whether a SWCP will increase or decrease losses of pollutants from croplands. However, the relative effectivenesses of the various SWCPs for control of specific pollutants are uncertain. Impacts can be expected to be site-specific and vary from year to year with weather and cropping practices. The quantification of these impacts constituted the major portion of the research project as described in the remaining sections of the paper.

CONTROL OF SEDIMENT LOSSES

Sediment is important not only as a potential pollutant of surface waters, but also as a carrier of solid-phase nutrients and pesticides. Sediment loss from croplands is readily estimated using the Universal Soil Loss Equation (Wischmeier and Smith, 1978). Predictions can be made on an annual or seasonal basis using this equation. In addition, several modifications of the equation are available which provide approximate estimates of soil loss for individual storm events. Table 3 indicates the effects of selected SWCPs on sediment losses from example corn fields in Aurora, New York, Ames, Iowa and Watkinsville, Georgia. These results were obtained from 25-year runs of the simulation model described in the next section of the paper. The results indicate that SWCPs offer substantial control of sediment losses, primarily because they reduce cropland erosion. In the case of terracing, additional sediment reduction is obtained by deposition in terrace channels. Runoff reductions are also given in the table, and it is evident that the practices are substantially less effective at controlling runoff than sediment. The differences in sediment and runoff reductions reflect variations in weather, soils and management practices at the three locations.

Although prevention of cropland erosion is an obvious way of controlling sediment, the uniform implementation of SWCPs for erosion control on the various fields within a farm or watershed may not be an efficient way of reducing sediment loading to receiving waters. This can be seen through the use of a sediment delivery ratio (SDR) which was defined for the purposes of

TABLE 3. Effects of Selected SWCPs on Runoff and Sediment Losses in Three Locations

	Reduction in Mean Annual Runoff	Reduction in Mean Annual Sediment Loss
	%	%
New York		
Contouring	40	65
Terracing	60	95
Sod-based Rotation	70	70
Conservation Tillage	20	55
Iowa		
Contouring	15	55
Terracing	30	95
Sod-based Rotation	55	60
Conservation Tillage	30	70
Georgia		
Contouring	30	60
Terracing	40	95
Sod-based Rotation	30	60
Conservation Tillage	15	40

the study as the fraction of a field's soil loss which reaches a stream. The SDR is a function of several factors, including the distance between field and stream. For example, a highly erosive field far from a stream may be unlikely to contribute sediment loadings to the stream. The use of a SWCP on such a field will reduce erosion but have little effect on stream sediment.

The relative efficiencies of SWCPs for sediment control are best illustrated by estimates of cost-effectiveness. In this study the cost-effectiveness of a SWCP was determined by comparison with conventional tillage and was defined as the reduction in annual sediment loading divided by the incremental annual monetary cost. Examples of incremental costs are given in Table 4 for grain corn. These costs are the changes in net farm income associated with the practices, and are sensitive to the effects of the practices on crop yields. Although it appears that most SWCPs have marginal impact on corn yields, no-tillage and conservation tillage are exceptions. These practices decrease yields on poorly-drained soils but can increase yields on well-drained soils. It is clear that in many cases SWCPs can be implemented only at substantial cost to the farmer and that government cost-sharing may be necessary. The incremental costs in Table 4 do not include the effects of SWCPs on long-term soil productivity. Control of soil erosion should increase farm income in the long-run, but data is not available to quantify these benefits.

Cost-effectiveness values for these practices are shown in Table 5 for two identical corn fields which have different SDRs. The fields have annual erosion rates of 32 t/ha under conventional tillage. It can be seen that it is much more cost-effective to place SWCPs on fields with high SDRs. Practices such as terracing, strip-cropping and sod-based rotations are relatively expensive ways to reduce sediment loadings, while contouring, no-tillage and conservation tillage can be highly cost-effective when they do not depress crop

TABLE 4. Typical Incremental Costs of SWCPs for Grain Corn

SWCP	% Change in Crop Yield	Incremental Cost ($/ha-yr)
Contouring	0	10
Terracing	0	110
Strip-Cropping	+4[a]	95
Sod-Based Rotation	+4[a]	90
No-Tillage	+10	-65
	0	5
	-10	75
Conservation Tillage	+5	-35
	0	- 5
	-5	35

[a] 1st year corn after sod.

TABLE 5. Cost-Effectiveness of SWCPs for Control of Stream Sediment Loadings

SWCP	% Yield Change	Erosion (t/ha-yr)	SDR = 1.0[a]		SDR = 0.3[a]	
			Sediment Loading (t/ha-yr)	Cost-Effectiveness (t/$)[b]	Sediment Loading (t/ha-yr)	Cost-Effectiveness (t/$)[c]
Contouring	0	16	16	1.60	5	0.45
Terracing	0	8	3	0.25	2	0.05
Strip-Cropping	+4	8	8	0.25	2	0.10
Sod-Based Rotation	+4	13	13	0.20	4	0.05
No-Tillage	+10	8	8	-0.35	2	0.10
	0	8	8	4.80	2	1.50
	-10	8	8	0.30	2	0.10
Conservation Tillage	+5	14	14	-0.50	4	-0.15
	0	14	14	-3.60	4	-1.10
	-5	14	14	0.50	4	0.15

[a] Sediment delivery ratio = fraction of eroded soil reaching stream.

[b] Reduction of sediment loading from 32 t/ha-yr divided by incremental cost (Table 4).

[c] Reduction of sediment loading from 32(0.3) = 9.6 t/ha-yr divided by incremental cost (Table 4).

yields. As shown in the table, the latter two practices can have negative cost-effectiveness values, indicating that they may decrease sediment loadings while increasing income.

It is somewhat misleading to compare practices based on their performance on a single cropped field. A farm consists of combinations of crops, soils and field topographies, and control of total sediment loading farm to farm generally requires a combination of practices which are consistent with a particular set of agricultural activities. A linear programming model was used to study these farm-scale effects. Representative farms were modelled in New York, Iowa and Texas. Each farm was modelled as a rectangle bisected by a stream, and SDRs were determined based on field distance from the stream. Income-maximizing plans were formulated subject to constraints of (i) 50% and 90% erosion reduction per field, and (ii) 50% and 90% sediment load reduction for the farm. These reductions were with respect to a base income-maximizing plan with no erosion or sediment constraints. The analysis consisted essentially of comparison of farm conservation plans for erosion control with those designed for water pollution (sediment) control.

The results for the Iowa farm illustrate the general findings. This farm is a 100-ha hog and cash crop operation. Total farm erosion and sediment loadings from the five conservation plans as well as costs (decreased farm income) compared to the base plan are shown in Table 6. The plan for 50% erosion reduction lowered the total farm erosion by more than 50%, since the required reduction on highly erosive soils necessitated rotations which reduced soil loss on the less erosive soils by more than 50%. It can be seen that the costs of erosion or sediment control are nonlinear. Marginal costs of control increase significantly as reductions are increased from 50% to 90%. Although farm plans designed to control erosion on all fields are very effective in reducing sediment loads, they are also quite expensive. In contrast, plans based on sediment

TABLE 6. Farm Conservation Plans to Reduce Erosion or Sediment Loading for a 100-ha Iowa Farm

Type of Farm Plan	Total Soil Erosion (t/ha-yr)	Total Sediment Load to Stream (t/ha-yr)	Cost ($/ha-yr)
Base	30.5	15.5	—
50% Erosion Reduction	10.7	5.0	$29.60
90% Erosion Reduction	3.0	1.1	$93.00
50% Sediment Reduction	15.9	7.8	$13.10
90% Sediment Reduction	6.3	1.5	$42.40

control are less costly, mainly because they concentrate SWCPs on fields with high SDRs (close to streams) and include practices such as sediment traps which are designed expressly for sediment control.

The sediment studies demonstrate that SWCPs are generally an effective way to reduce both cropland erosion and sediment loadings to streams. The short-term costs of many of these practices can be significant, although conservation tillage and no-tillage may entail little or no cost in many situations. The linear programming results demonstrate that farm plans to reduce sediment loads can be different from, and result in less costs than comparable plans to control erosion.

CONTROL OF NUTRIENT LOSSES

Research on nutrient losses carried out in the project differed substantially from the sediment work. Simple predictive equations for nutrient losses which are similar to the Universal Soil Loss Equation do not exist and in addition there are no available methods for estimating nutrient delivery to receiving waters. Thus the research was limited to the development of nutrient simulation models and the use of these models to estimate edge-of-field losses of dissolved and solid-phase nitrogen and phosphorus at the three locations mentioned earlier: Aurora, New York; Ames, Iowa; and Watkinsville, Georgia. The nutrient simulation model is based on the Soil Conservation Service's runoff equation (Ogrosky and Mockus, 1964) and on Onstad and Foster's (1975) modification of the Universal Soil Loss Equation. Soil organic and inorganic nitrogen mass balances are computed and it is assumed that solid-phase nitrogen losses are in the organic form and dissolved losses are inorganic. Soil phosphorus is divided into available and fixed inorganic forms. The partioning of available phosphorus into dissolved and solid-phase constituents is based on a linear adsorption isotherm. Model output is monthly runoff, sediment loss, dissolved and solid-phase nutrients in runoff and runoff and dissolved nitrogen in percolation. The model was validated using field data from Georgia and New York.

The effects of contouring, terracing, sod-based rotations and conservation tillage were compared to conventional tillage for 2-ha corn fields at the three locations. Soil and cropping characteristics were chosen to be typical of each location (Table 7). Twenty-five year runs of the simulation model were used for these comparisons with meteorologic data for 1952-1976. Conventional tillage was identical at each location with the exception that fall plowing was assumed for Iowa and spring plowing was considered typical in New York and Georgia. Effects of the SWCPs on 25-yr mean annual nutrient losses are shown in Table 8. Results for annual runoff and sediment losses were given in Table 3. All practices significantly reduce nutrient losses in runoff, with the highest reductions occuring on the high-runoff New York site. Solid-phase losses are generally reduced more than dissolved losses. All practices except sod-based rotations increase the amounts of dissolved nitrogen in percolation. The effects of the practices on total (runoff + percolation) losses of dissolved nitrogen are shown in Table 9. It can be seen that only sod-based rotations reduce total losses. This practice reduces all categories of nutrient losses since runoff, erosion and fertilizer nitrogen inputs are all reduced. The effects of practices on nutrient losses are obviously not uniform and vary with both nutrient form and location.

The effects of SWCPs vary from year to year with weather conditions. The size of these variations is demonstrated in Table 10 which compares annual losses of dissolved phosphorus and nitrogen in runoff for contouring and conventional tillage based on the first fifteen years of simulation model runs.

TABLE 7. Characteristics of Example Fields

	Site Characteristics		
	New York	Iowa	Georgia
Soil	Silt Loam	Silty Clay Loam	Sandy Loam
Runoff Category	High (C)	Moderate (B)	Moderate (B)
Corn Yield (kg/ha-yr)	5020	7850	4080
Fertilizer Nitrogen (kg/ha-yr)	90	200	140
Soil Organic Nitrogen (kg/ha-yr)	2500	2450	600

TABLE 8. Effects of Selected SWCPs on Mean Annual Nutrient Losses at Three Locations

Practice	% Changes in Mean Annual Runoff Losses				% Changes in Mean Annual Percolation Loss of Dissolved Nitrogen
	Phosphorus		Nitrogen		
	Dissolved	Solid-Phase	Dissolved	Solid-Phase	
New York					
Contouring	-45	-65	-50	-65	+10
Terracing	-60	-95	-70	-95	+15
Sod-based Rotation	-75	-70	-80	-70	-25
Conservation Tillage	-25	-55	-30	-55	+ 5
Iowa					
Contouring	-20	-55	-25	-55	+10
Terracing	-30	-95	-30	-95	+10
Sod-based Rotation	-55	-60	-75	-60	-50
Conservation Tillage	-35	-70	-30	-70	+10
Georgia					
Contouring	-30	-60	-35	-60	+10
Terracing	-40	-95	-50	-95	+15
Sod-based Rotation	-30	-65	-55	-60	-35
Conservation Tillage	-20	-40	-15	-40	+ 5

Table 9. Effects of Selected SWCPs on Total Dissolved Nitrogen Losses

Practice	Average Annual Losses of Dissolved Nitrogen Runoff	 Percolation	 Total
	kg/ha-yr		
New York			
Conventional	10	41	51
Contouring	5	45	50
Terracing	3	47	50
Sod-based Rotation	2	30	32
Conservation Tillage	7	44	51
Iowa			
Conventional	16	59	75
Contouring	12	64	76
Terracing	11	65	76
Sod-based Rotation	4	30	34
Conservation Tillage	11	65	76
Georgia			
Conventional	14	51	65
Contouring	9	56	65
Terracing	7	59	66
Sod-based Rotation	6	34	40
Conservation Tillage	12	54	66

TABLE 10. Effects of Contouring on Dissolved Nutrient Losses Over 15 Years in Iowa (Simulation Results)

Year	Nitrogen			Phosphorus		
	Conventional (kg/ha-yr)	Contouring (kg/ha-yr)	% Reduction	Conventional (kg/ha-yr)	Contouring (kg/ha-yr)	% Reduction
1952	4.8	1.5	69	0.12	0.06	50
1953	5.6	3.9	30	0.13	0.12	8
1954	21.4	13.6	36	0.43	0.35	19
1955	16.2	11.7	28	0.15	0.12	20
1956	1.2	1.2	0	0.01	0.01	0
1957	21.0	16.3	22	0.27	0.21	22
1958	12.6	8.2	35	0.14	0.09	36
1959	17.3	12.2	29	0.23	0.18	22
1960	31.4	26.3	16	0.41	0.35	15
1961	13.8	9.0	35	0.27	0.20	26
1962	8.2	3.9	52	0.08	0.04	50
1963	28.6	24.3	15	0.35	0.30	14
1964	26.9	22.4	17	0.28	0.25	11
1965	19.5	15.7	19	0.29	0.25	14
1966	24.9	17.1	31	0.26	0.19	27

The effectiveness of contouring changes markedly from year to year, indicating that evaluations of SWCPs cannot be based on two or three years of data. This is equally true whether nutrient losses are measured in field studies or predicted by simulation models. In either case, studies must be of sufficient duration to capture the expected range of possible losses. Long-term studies permit estimates of nutrient losses probabilities. For example, the simulation results were used to determine one-in-ten-year dissolved phosphorus losses, and the effects of contouring and sod-based rotations on these extreme losses are shown in Table 11. In general, the SWCPs are somewhat less effective at controlling large phosphorus losses than they are in reducing mean annual losses.

CONTROL OF PESTICIDE LOSSES

Pesticide losses in runoff were studied at the New York, Iowa and Georgia sites (Table 7) using a 25-year run of a simulation model similar to that used in estimating nutrient losses. As with the nutrient studies, pesticide delivery to streams could not be predicted and hence only edge-of-field losses were estimated. The pesticide simulation model was validated using Georgia field data. Since a very large number of pesticides are registered for use in the U.S., runoff losses were simulated for the general categories of pesticides shown in Table 12. The classification is based on pesticide persistence in the soil, indicated by half-life, and adsorption to soil particles. The latter property is measured by an adsorption coefficient which is equal to the ratio of equilibrium solid-phase and dissolved concentrations in the soil. Classifications of some representative pesticides are shown in Table 13, although it should be recognized that both persistence and adsorption depend on soil type, application methods and environmental conditions. For example, atrazine is relatively persistent when incorporated into organic soils but very short-lived on the soil surface.

TABLE 11. Effects of Contouring and Sod-based Rotations in Controlling Average and Extreme Annual Losses of Dissolved Phosphorus

Practice	Dissolved Phosphorus in Runoff			
	Loss Exceeded One Year in Ten (kg/ha-yr)	% Reduction	Average Annual Loss (kg/ha-yr)	% Change
New York				
Conventional	0.26		0.15	
Contouring	0.16	40	0.08	45
Sod-based Rotation	0.10	60	0.04	75
Iowa				
Conventional	0.38		0.24	
Contouring	0.32	15	0.19	20
Sod-based Rotation	0.25	35	0.11	55
Georgia				
Conventional	0.78		0.39	
Contouring	0.64	20	0.28	30
Sod-based Rotation	0.67	15	0.28	30

TABLE 12. General Pesticide Classification Based on Persistence and Affinity for Soil Particles

Category	Description	Adsorption Coefficient	Half-Life (da)
A	Weakly adsorbed, non-persistent	0.1	15
B	Moderately adsorbed, non-persistent	10	15
C	Moderately adsorbed, moderately persistent	10	100
D	Strongly adsorbed, persistent	1000	360

TABLE 13. Classification of Representative Pesticides

Pesticide	Type	Category	Major Crop	Principal Application Method
Atrazine	Herbicide	B	Corn	Broadcast or band
Carbofuran	Insecticide	C	Corn	Broadcast, band or soil incorporated
Methyl Parathion	Insecticide	B	Cotton	Foliar Spray
Paraquat	Herbicide	D	Cotton, corn	Spray
Toxaphene	Insecticide	D	Cotton	Foliar Spray

Only one SWCP, terracing, was evaluated for its effect on pesticide losses using the simulation model. This SWCP substantially reduces both runoff and sediment losses and thus provides a reasonable indication of the magnitudes of pesticide loss control which can be achieved by SWCPs. Terracing and conventional tillage of continuous corn are compared in Table 14 with respect to dissolved and solid-phase pesticide losses for the three example fields. Single pesticide applications of 3000 g/ha on May 10 of each simulated year were assumed. Except for strongly adsorbed pesticides (category D), losses in New York were negligible. At the other two locations, terracing was more effective at reducing solid-phase than dissolved losses, although dissolved losses were substantially reduced in Iowa.

Except for the strongly adsorbed pesticides, predicted runoff losses of pesticides were generally less than 5% of applications. Losses of this same magnitude have been consistently observed in field studies (Wauchope, 1978). While it seems clear that SWCPs can reduce these losses, such control may not be an efficient way of reducing environmental pollution. Pesticides may be lost from croplands by means other than runoff. For example, of the five pesticides listed in Table 13, all except for paraquat may have drift losses of up to 50% using standard application methods. Control of drift losses may have greater environmental impact than reduction of relatively small runoff losses.

CONCLUSIONS

A current assessment of the effectiveness of soil and water conservation practices (SWCPs) for control of water pollution associated with cropland sediment, nutrients and pesticides must be based on individual field studies and the predictions of mathematical models. Such an assessment must be considered preliminary and further studies of water quality and long-run economic impacts of SWCPs are urgently needed. Subject to these limitations,

TABLE 14. Effects of Terracing on Runoff Losses of Pesticides

Category/ Constituent		New York		Iowa		Georgia	
		Conven- tional	Terracing	Conven- tional	Terracing	Conven- tional	Terracing
		(g/ha-yr)					
A.	Dissolved	--	--	20	6	12	11
	Solid-phase	--	--	3	< 1	4	< 1
B.	Dissolved	--	--	40	16	26	26
	Solid-phase	--	--	5	< 1	9	< 1
C.	Dissolved	< 1	< 1	55	20	45	42
	Solid-phase	< 1	< 1	8	< 1	11	< 1
D.	Dissolved	--	--	--	--	--	--
	Solid-phase	49	27	314	64	536	140

the principal conclusions of the research described in this paper are as follows:

1. SWCPs significantly reduce edge-of-field pollutant losses in runoff. Reductions of solid-phase pollutants (sediment, strongly adsorbed pesticides, organic nitrogen, fixed phosphorus) are substantially greater than reductions of dissolved nutrients and pesticides. The magnitudes of pollutant reductions are site-specific, depending on local weather, soils and crop management.
2. SWCPs will not reduce total (runoff plus percolation) edge-of-field nitrate losses unless they also reduce fertilizer nitrogen applications.
3. Cropland erosion control may not efficiently reduce sediment loadings to streams unless they are concentrated on lands with high sediment deliveries.
4. SWCPs often have negative or marginal short-term monetary benefits to the farmer. In many cases, however, conservation tillage and no-tillage can increase farm income.
5. Although SWCPs were not extensively compared with other pollution control measures, it is apparent that efficient management of chemical applications to croplands has significant potential for reducing pesticide and nitrogen losses. Although such management is not always operationally or economically feasible, it does provide a major alternative to the use of SWCPs for pollution control.

It appears likely that for both practical and political reasons soil and water conservation is likely to be a major component of programs for control of water pollution from cropland in the United States. The results from this research project indicate that such a policy is not unreasonable. Nevertheless, the economic efficiency and water quality benefits of the policy are uncertain and should receive further study.

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THE IMPACT OF AGRICULTURAL PRACTICES ON THE NITRATE CONTENT OF GROUNDWATER IN THE PRINCIPAL UNITED KINGDOM AQUIFERS

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ABSTRACT

In the United Kingdom field studies of the unsaturated zones of 30 sites on the Chalk and 12 on the Triassic sandstone aquifers have shown a correlation between arable farming regions and high nitrate concentrations in interstitial pore water. A slow downwards movement of nitrate has been proved at two sites. A mathematical model has successfully simulated the observed nitrate profiles at a number of the investigated sites. This vertical transport model has been incorporated in a catchment model and so used to predict changes in groundwater nitrates, in some areas, to levels above 11.3 mg N/l. Rehabilitation of contaminated aquifers is slow and a number of possible engineering solutions to nitrate control are considered.

1. INTRODUCTION

About a third of the public water supplies in the United Kingdom are obtained from groundwater, the greater part of which are derived from two principal aquifers, the Chalk and the Triassic sandstones (Figure 1). Groundwater, where available, is a cheap source of supply and generally of good quality. However, an increase in the nitrate concentration of some groundwaters in the United Kingdom has been reported in recent years (Davey, 1970; Foster and Crease, 1974; Greene and Walker, 1970; Satchell and Edworthy, 1972; Severn-Trent Water Authority, 1976 a,b) Over 100 public supply boreholes now produce groundwater with nitrate concentrations intermittently or continuously above 11.3 mg N/l. High nitrate concentrations in water supplies are of concern because of potential health risks, (Comley 1945; Petakhov and Ivanov 1970; Tannenbaum, Archer, Wishnok, Correa, Cuello and Haenszel, 1977).

In 1974 the Water Research Centre initiated a programme of field investigations and laboratory studies with the objectives of

i determining the extent of nitrate contamination of the unsaturated zones of the principal aquifers in the United Kingdom.

ii evaluating the mechanisms and rates of movement of potential pollutants, derived from the land surface, through the unsaturated zone to the water table, and

iii estimating future trends in groundwater nitrate concentrations on both the local and regional scales.

Work on this major research programme is still continuing. The paper describes the techniques used and the principal results to date.

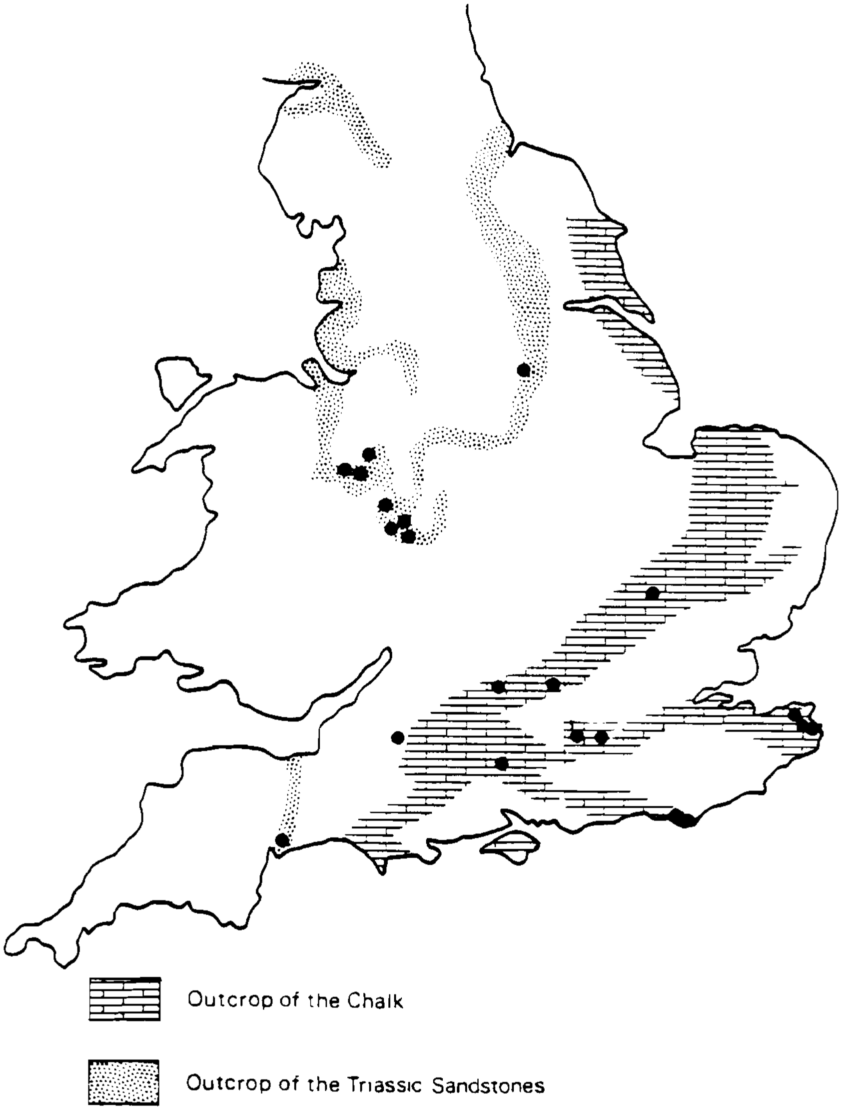


Fig. 1. Simplified geological map of England and Wales, showing the outcrops of the major aquifers and sites of WRC nitrate investigations.

2. SITE SELECTION AND RESEARCH METHODS

Sites for field investigations were selected in accordance with three criteria:

1. location on an outcrop area of the aquifer, and, thus, in a zone of natural recharge. The areas selected were free from superficial deposits (alluvium, glacial till etc) in order to ensure comparability between sites;
2. the presence of a thick (generally >20m depth) unsaturated zone, in order to allow effective determination of the vertical changes in concentrations of solvents in the interstitial water, and,
3. where applicable, the availability of detailed records of land usage, cropping and fertilizer application rates for at least the preceding ten years, together with sufficient local meterological data to permit reliable estimates to be made of infiltration rates (Grindley, 1969).

A simple classification of land usage (Table 1) has been adopted, so that different categories of use in similar hydrogeological environments may be compared. During the period October 1974 to January 1978 a total of 84 boreholes, some to depths of up to 200 m have been drilled at 42 selected sites, 30 on the Chalk and 12 on the Triassic sandstone aquifers (Figure 1).

The drilling and sampling methods employed during the field investigations and the subsampling and storage techniques used on site were designed to prevent cross-contamination of samples (Gray, Holland, Breach, and Rowland, 1977). Drive coring using a percussion drill was employed at Chalk sites, whilst air-flush rotary coring was used in the Triassic sandstone aquifer. Controlled experiments have been carried out to determine the most effective manner of preserving core samples and their interstitial water after drilling (Young and Gray, 1978). These showed

Table 1. Classification of land use types

Category	Comments
1 Fertilized arable land, including horticulture, with grass leys	Grass leys up to 7 years duration. Characteristic of arable and mixed farming districts.
2. Fertilized long term grassland	Continuous grass for more than 7 years Characteristic of dairying areas
3. Unfertilized, long term grassland	Typically common land, rough grazing, sheep folds etc.
4 Woodland	Indigenous woodland and afforested areas.

that deep freezing prevented both drainage of the interstitial fluids and changes in nitrate concentration. Water for chemical analysis was extracted from sub-samples of the cores, after thawing, by high speed centrifugation (Edmunds and Bath, 1976). Water samples were analysed using standard Auto Analyser techniques. Extraction of interstitial water by vacuum distillation and measurements of the tritium content of the waters have been carried out by the Harwell Laboratory (UK Atomic Energy Research Establishment) using the method described by Otlet (1968).

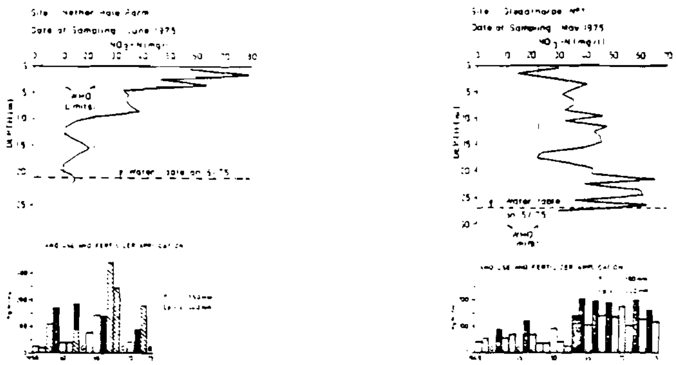
3. RESULTS OF FIELD INVESTIGATIONS

Studies in the Chalk and Triassic sandstone aquifers have revealed a correlation between high nitrate concentrations (often > 20 mg N/l) in the interstitial waters of their unsaturated zones and arable farming regimes, whilst low concentrations (often < 5 mg N/l) are characteristic of interstitial water beneath unfertilized permanent grassland and woodland. The vertical profiles of nitrate concentrations in the unsaturated zone beneath arable Chalk land are often sinuous and it is postulated in section 5 that these variations with depth reflect changes in the rate of leaching from soils under different agricultural regimes.

In addition to the nitrate and tritium profile reported in this paper, a considerable body of information has been accumulated on the vertical distribution of ammonia, nitrite, chloride, sulphate, calcium, sodium, potassium and magnesium ions in interstitial waters, whilst insoluble carbohydrates associated with the solid Chalk have been reported (Young, Hall and Oakes, 1976) at concentrations of up to 0.1 mg/g dry Chalk, at depths of between 5.0 and 55.0 meters beneath arable land. Determination of the total elemental carbon, hydrogen and nitrogen in insoluble Chalk residues is also being undertaken. Interpretation of the significance of the vertical profiles of these additional determinants is complex, due to difficulties in assessing natural, background levels and rates of external inputs.

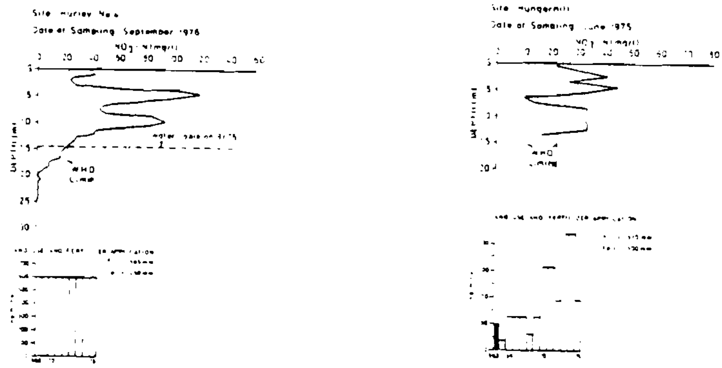
3.1 Unsaturated Zone

Fertilized Arable Land : Uniform, or relatively smoothly varying nitrate profiles were found to be characteristic of sites on the Chalk under continuous arable regimes with consistent fertilizer application rates (Young and Gray, 1978). Sinusoidal variations of nitrate concentration with depth have been found to be well developed beneath Chalk sites at which arable cropping is periodically interrupted by grass leys (Figure 2a), this being most apparent at sites with long term (4-7 years) leys (Young, Oakes & Wilkinson, 1976). The nitrate profile beneath arable and arable/ley regimes in the Triassic sandstones (Figure 2b) have been found to follow a similar pattern, but to show more rapid and irregular variations with depth. This may be attributed to the modifying effects of the greater vertical and horizontal inhomogeneity of the Triassic sandstones compared with the Chalk. Profiles obtained from drilling two or more boreholes at the same time in a single field have been found to be closely comparable with respect to variations in concentration



2(a) Arable land, Chalk.

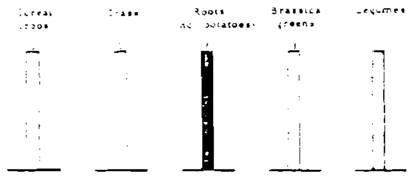
2(b) Arable land, Triassic Sandstone



2(c) Fertilized grass, Chalk

2(d) Fertilized grass, Triassic Sandstone

KEY TO FIGURES



R Estimates of average long term (1915 to 50) annual rainfall at each site derived from site or nearby rain gauges (British Rainfall, Meteorological Office, HMSO)

P Estimates of average evapotranspiration from water authority Section 14 surveys and other sources

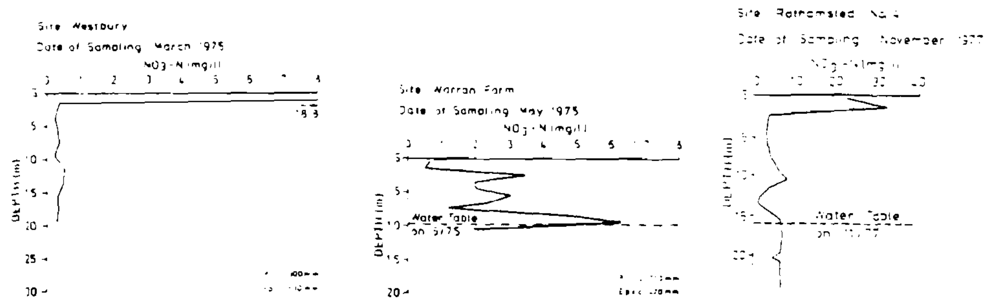
Fig. 2. (part) Nitrate profiles.

with depths below the surface (Young and Gray 1978), especially in the case of the Chalk aquifer. The quantity of nitrate stored in interstitial water in the Chalk unsaturated zone beneath arable land is large. Between 30 and 40 kg N/ha are present per 10 mg N/l interstitial concentration per meter depth of unsaturated zone, so that the profile shown in Figure 2a contains in excess of 3.0 tonnes of nitrate-nitrogen above the water table.

Fertilized Long Term Grasslands: Nitrate profiles, in the Chalk and Triassic sandstones, beneath permanent grassland receiving fertilizer applications up to about 250 kg N/ha/yr have been found to be generally uniform at between 5 and 10 mg N/l (Young and Gray, 1978) but concentrations in the range 10 to 100 mg N/l have been measured in profiles beneath grassland with fertilization rates of greater than about 400 kg N/ha (Figures 2c and d).

Unfertilized Long Term Grassland and Woodland: Profiles measured beneath unfertilized grassland have shown consistently interstitial nitrate values of less than 6 mg N/l and often less than 1 mg N/l. A similar distribution appears to be present beneath established woodland (Figures 2e, f and g).

Tritium: Tritium profiles have been determined at a large number of the Chalk sites. In all cases the peaked form of the profile was comparable with that determined by Smith, Wearn, Richards and Rowe (1970) in the Upper Chalk of Berkshire in 1968, who suggested that the peak concentrations recorded the position of infiltration during the winter of 1963/64, when thermonuclear tritium in rainfall reached maximum values (Otlet, 1978). The examples shown in Figure 3a were measured in the Upper Chalk in Surrey between 1975 and 1977, and include both permanent unfertilized grassland and arable sites. Profiles measured in the Triassic sandstone aquifers (Figure 3b) are less well defined than those from the Chalk, but provide indications of peak concentrations at depths of about 20 metres.



(e) Unfertilized grass Chalk

(f) Unfertilized grass, Triassic Sandstone

(g) Woodland, Chalk

Fig. 2. (Contd) Nitrate profiles

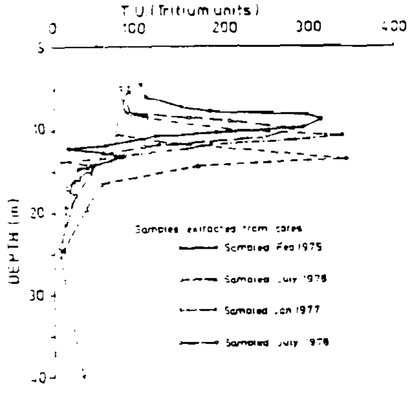


Fig. 3 (a) Tritium profiles in unsaturated Chalk in Surrey.

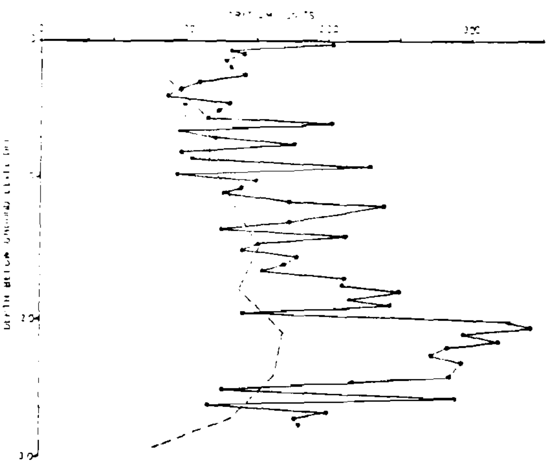
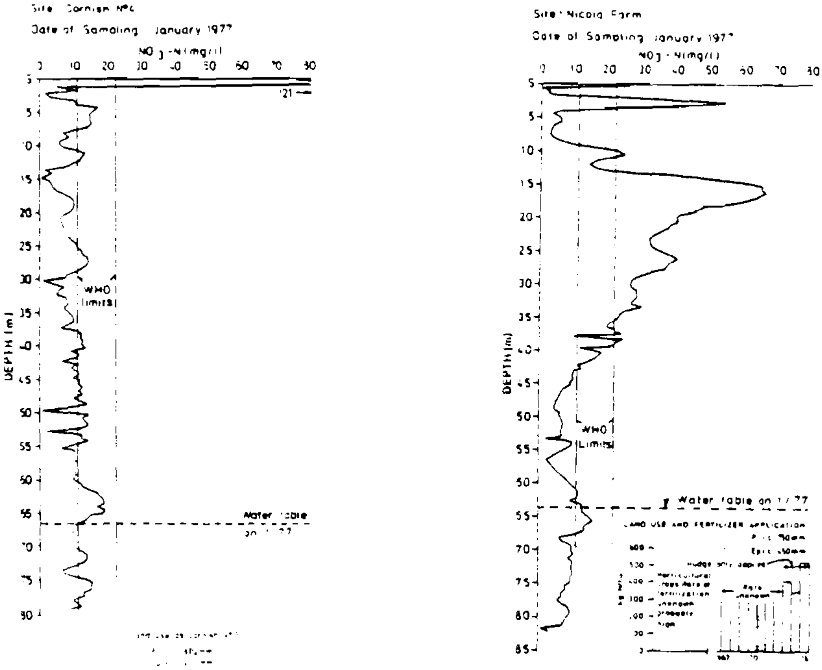


Fig. 3 (b) Tritium profiles in unsaturated Triassic Sandstone.

3.2 Saturated Zones

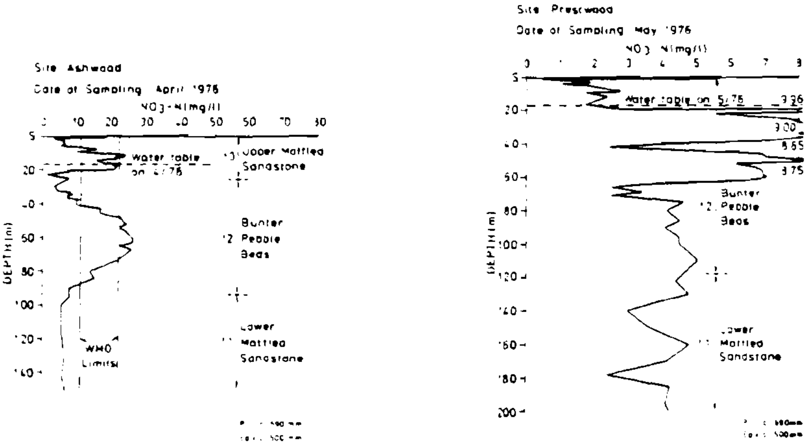
Chalk: Many of the boreholes drilled into the Chalk during the early stage of the research programmes were terminated only one or two metres below rest water level, but more recently boring has been continued to 20 metres below the water table (Figures 4a and 6). Smooth concentration gradients have been recorded within the zone of groundwater level fluctuations, indicative of washing out of interstitial water by saturated zone flows. As would be anticipated at the interface between the vertical movements of the unsaturated zone and the horizontal flows in the saturated zone, concentrations above and below the water table have been found frequently to be different.

Triassic Sandstones: Two boreholes, about 2 km apart, in the Triassic sandstone aquifer to the west of Birmingham (Figures 4c and d) were continued to depths greater than 100 metres below the water table. In both cases the division of the Triassic sandstones referred to as the Bunter Pebble Beds, a series of coarse, occasionally conglomeratic sandstones with siltstone bands, was completely penetrated and the underlying, uniform sandstone entered. Geophysical borehole logging at both sites indicated that groundwater flows were taking place predominently through the Bunter Pebble Beds, and that hydraulic head differences existed between different depths in the layered aquifer system. The tritium profiles of the saturated zones at both sites (Figures 4e and f) suggested that the higher nitrate concentrations were associated with recent recharge moving through the Pebble Beds, indicating a possible stratigraphic control on contaminant movement in that area. However, a similar study of the Triassic sandstone aquifers in North Nottinghamshire (Severn-Trent Water Authority, 1978) did not reveal a similar stratigraphic control of nitrate movement.



(a) Chalk, nitrate

(b) Chalk, nitrate



(c) Triassic Sandstone, nitrate

(d) Triassic Sandstone, nitrate

Fig. 4 (part) Nitrate and tritium profiles, saturated zones.

4. SOURCES OF NITRATE

The inputs of nitrogen to agricultural soils in the United Kingdom may be considered under three headings: atmospheric sources, human and animal waste and inorganic fertilizers.

Atmospheric: Data on the nitrate content of rainfall in the United Kingdom is limited (Stevenson, 1968, Williams 1975) but indicates that in rural areas, not downwind of conurbations, mean concentrations are on the order of 1 mg N/l, equivalent to a deposition of between 6 and 10 kg N/ha/yr over much of Southern Britain. Measured concentrations of up to 4 mg N/l have been reported from rainfall downwind of major urban areas. Fixation of atmospheric nitrogen by the free living or symbiotic soil bacteria has been assessed at about 50 kg N/ha/yr for arable crops, 75 kg N/ha/yr for permanent vegetation and up to 250 kg N/ha/yr for clover and rotational grasses (leys) (Central Water Planning Unit, 1977).

Human and Animal Wastes: The use of farmyard manure as a fertilizer in the United Kingdom is limited, but in mixed farming regions applications of between 25 and 50 tonnes/ha are typical, replacing or supplementing inorganic fertilizer, and supplying between 15 and 30 kg N/ha (Ministry of Agriculture, Fisheries and Food, 1976). Slurries from intensive stock rearing may also be spread, generally onto grasslands, at rates which provide up to 130 kg N/ha. Digested sewage sludge spreading, principally onto grassland, is practiced locally (Edworthy, Wilkinson and Young, 1978) at rates of up to 150 m^3/yr, potentially equivalent to 500 kg N/ha/yr.

Inorganic Fertilizer: The rate of inorganic fertilizer applications increased by between 5 and 10 times during the period 1944 to 1972 (Central Water Planning Unit, 1977) to the levels shown in Table 2.

Table 2. Current Ranges of Inorganic Fertilizer Annual Application

Rates in the United Kingdom
(assuming a light soil with low nitrogen residues from previous crops)

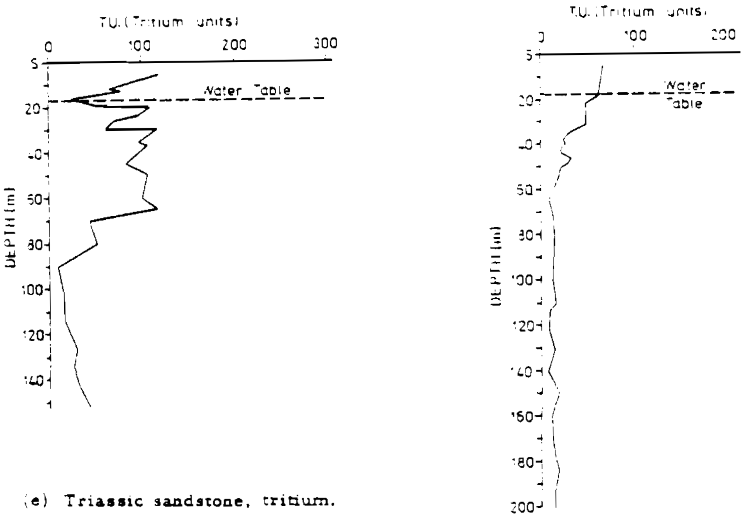
Crop category	Rate Kg N/ha	Comments
Cereals	90-150	
Roots including potatoes	120-200	Highest rate generally on potatoes
Brassica greens	150-300	Occasionally very high rates after horticultural crops
Legumes (peas & beans)	nil	Nitrogen fixing species
Grass	150-250	Occasionally higher values

Nitrogen Balance: Nitrogen losses from the soil/plant system may be divided into gaseous losses, removal by the crop and leaching. The soils developed on outcrop Chalk are characteristically shallow, well drained rendzinas and associated brown calcareous earths, whilst those in the Triassic sandstones are well drained brown earths and podsols. Under arable (tillage) regimes such soils are well aerated and losses by denitrification are considered to be insignificant whilst mineralisation of organic nitrogen is encouraged. However, it has been suggested (Young et al. 1976, a,b) that compaction of the soil under permanent grass may lead to anoxic conditions with denitrification in the lower soil layers.

The rate of removal by crops is considerable (Johnson, 1976) but a mean figure of about 50 percent of the applied fertilizer nitrogen has been estimated (Kolenbrander, 1975). Under normal climatic conditions in the United Kingdom it is probable that a high proportion of the remaining applied fertilizer is assimilated by weeds and microflora during the growing season.

Analysis of 57 lysimetric experiments in Europe and the USA (Atkins, 1976) has suggested that the rate of loss of nitrate in drainage water from lysimeters (a) supporting a grass cover, (b) those growing arable crops and (c) those maintained in a fallow condition are in the approximate ratios 1:5:30 respectively. Leaching beneath grass has been reported at only a few mg N/l (Williams, 1975), but experiments on soils developed on Upper Chalk (Garwood and Tyson, 1973) have suggested that fertilizer application rates of 500 kg N/ha on grass may lead to substantial leaching losses in normal seasons and that high leaching losses may occur from the same soils fertilized at lower rates (250 kg N/ha) following prolonged drought, as the result of abnormal mineralisation of organic nitrogen (Garwood & Tyson, 1977). The mineralisation of soil organic nitrogen following the ploughing of established grassland (Reinhorn and Avnimelech, 1974, Smith and Young, 1975, Meints, Kurtz, Melsted and Pack, 1977) has been proposed as an important source of nitrate for leaching in the United Kingdom (Young et al. 1976, a,b). It is noteworthy that the marked increase in arable hectacreage in Southern England from 1939 to 1946 (Figure 5) was concentrated principally on the thin upland soils of the Chalk recharge areas, which had previously been permanent sheep and cattle grazing. The potential quality of nitrogen available for mineralisation may be several thousand kg per hectare (Reinhorn and Avnimelech, 1974). Measurements made at Water Research Centre experimental plot on a 60 cm deep Chalk soil profile in Sussex, at which ploughing of virgin grassland first occurred in April 1978, have indicated that the soluble nitrate content of a fallow soil increased by about 200 kg N/ha, when compared with a control plot under grass, during the period April to November.

A synoptic diagram illustrating potential sources of nitrate leaching from agriculture and its possible routes to the groundwater zone is shown in Figure 6.



(e) Triassic sandstone, tritium.

(f) Triassic sandstone, tritium.

Fig. 4 (contd) Nitrate and tritium profiles, saturated zones.

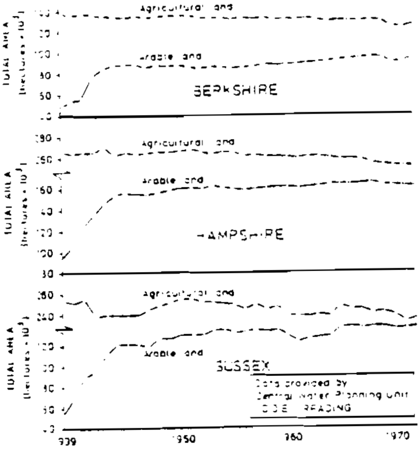


Fig. 5. Regional changes in land usage, counties in southern England.

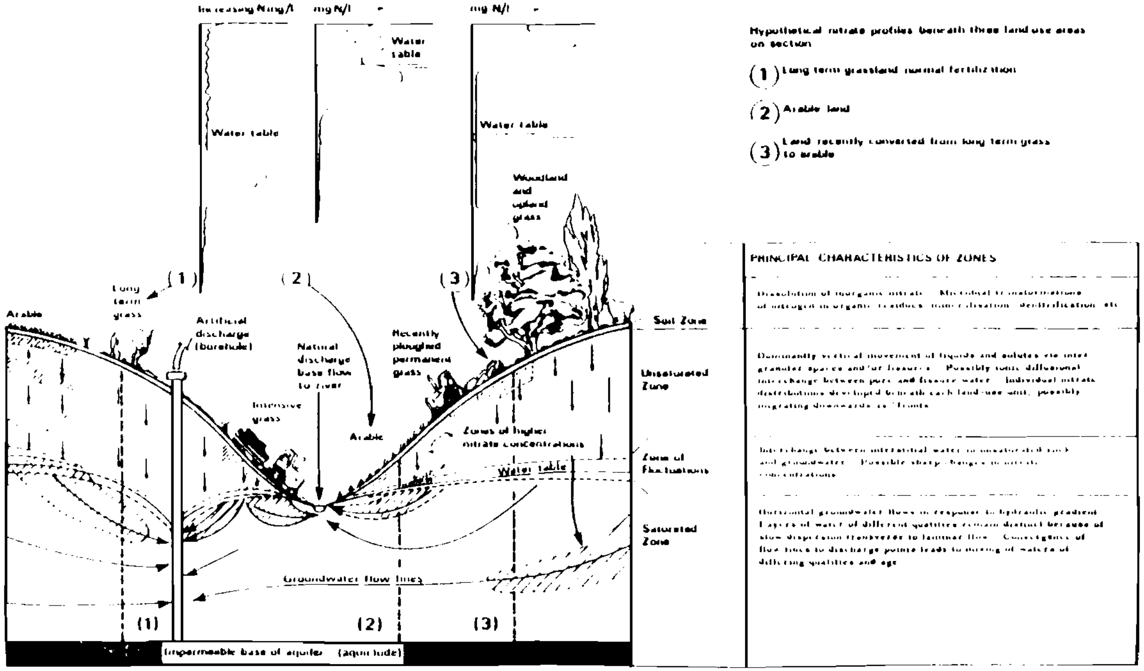


Fig. 6. Diagrammatic section of a groundwater catchment illustrating possible distribution and movement of solutes through the unsaturated zone and below the water table.

5. MOVEMENT OF WATER AND SOLUTES IN THE UNSATURATED ZONE

Basic Hydraulic Properties of the Chalk and Triassic Sandstones: The potential rates of movement of water through the unsaturated zone is controlled principally by the rate of infiltration and the hydraulic properties of the aquifer. The Chalk is composed of microscopic fossil fragments, generally less than 5 microns diameter, giving rise to a rock with high porosity (often in the range of 0.30 to 0.50) but extremely low intergranular permeability (generally below 10^{-3} m/day). As a result of this combination of characteristics the Chalk has a very high specific retention and blocks of the rock remain close to saturation, even in the unsaturated zone. The Chalk is traversed by frequent vertical and horizontal fissures, giving rise to a Chalk permeability of between 50 and 100 m/day and a storage coefficient of 0.01 to 0.05. By comparison, the coarser grain size of the Triassic sandstone aquifers gives a porosity in the range of 0.20 to 0.30 with low specific retention and intergranular permeabilities of about 1 m/day.

Infiltration Mechanisms: The distribution of tritium in the unsaturated zone indicates a downward movement rate of between 0.5 and 1 m/yr in the Chalk and about 2 m/yr in the Triassic sandstones. Furthermore, the depths of the peaks are strongly correlated to estimated infiltration rates at each of the sites where measurements have been made. It is therefore conceivable that tritium moves downwards through the pore space at the same rate as water, and in the absence of interactions with the rock matrix it is expected that other solutes will behave similarly. An alternative mechanism of water and solute movement in the Chalk has been postulated (Foster, 1975, Oakes, 1977) whereby the water moves through the fissure system and the water held in the pores is essentially static. Diffusion of solutes between the mobile and static water results in the solutes moving much more slowly than the water in the fissures. If the diffusion is sufficiently rapid for equilibrium between the fissure and pore water concentrations to be established, then the solute profile will be convected downwards with little alternation of the peak shapes and at a rate which would have obtained had water and solute moved together through the pores. The two postulated mechanisms therefore give essentially the same result and the field data collected to date have not allowed the operative mechanism to be identified. Indeed, it is likely that the real mechanism is a combination of the two, with the fissure flow component being more dominant in the Chalk and the pore flow component being more dominant in sandstone.

Despite the strong correlation of the depths of the tritium peaks with total infiltration since thermonuclear testing in 1963, the question must be posed as to whether the nitrate and tritium profiles which have been measured result from a downward migration of solutes, or whether the positions of the peaks are controlled by hydrogeological factors such as the positions of bedding planes and zones of high and low permeability. Correlations of nitrate and tritium profiles with antecedent infiltration and land use data have now been shown at 8 sites on the Chalk, supporting the concept of steady downward movement of solutes. Direct evidence of movement has come from repeat drillings at two sites on the Chalk.

Nitrate Profile Measurement: At an Experimental Husbandry Farm in Hampshire in a field which has been in a mixed arable-ley rotation since 1948, nitrate and tritium profiles were obtained from a hole drilled in October 1975, and again for a hole drilled in March 1978. The profiles shown in Figure 7 indicate a general downward movement of about 4m which is consistent with the infiltration for the intervening period. At a second site in Kent, holes were drilled in a field, which has been in arable cultivation since the early 1900's, in October 1975 and again in October 1978. Nitrate and tritium profiles are shown in Figure 8 and indicate a downward movement of about 2m which is consistent with the

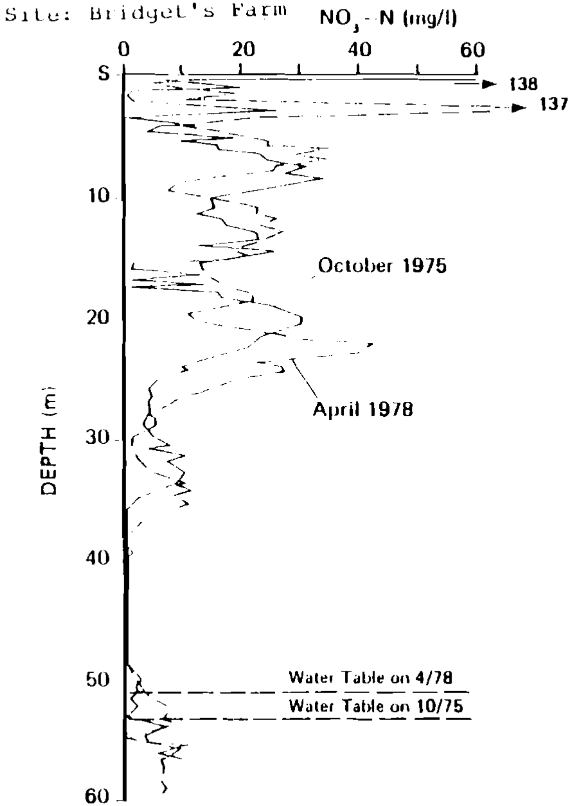


Fig. 7(a) Results of repeated drilling at an arable site on the Chalk in Hampshire. Nitrate.

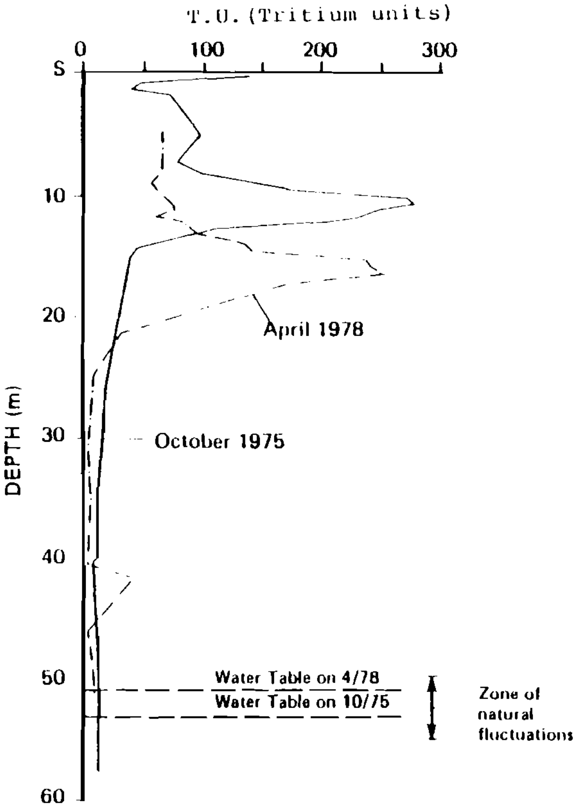


Fig. 7(b) Results of repeated drilling at an arable site on the Chalk in Hampshire. Tritium.

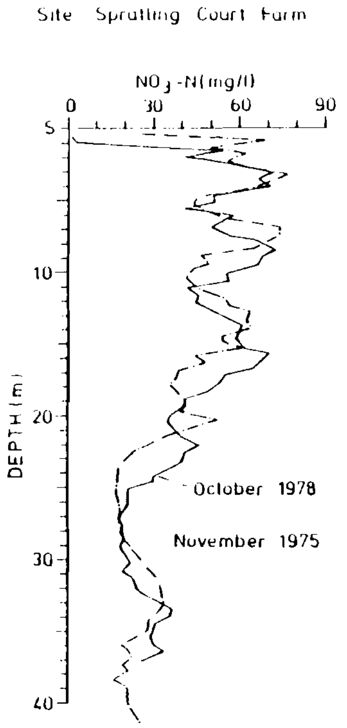


Fig. 8 (a). Nitrate profiles from repeated drilling at an arable site on the Chalk in Kent.

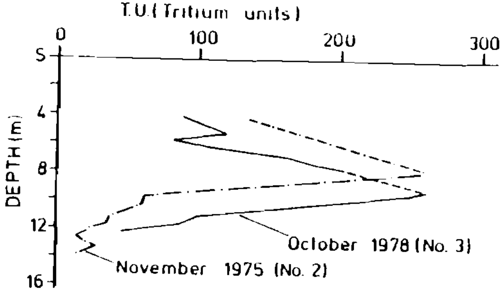


Fig. 8(b) Results of repeated drilling, Chalk arable site in Kent. Tritium.

low infiltration of this area. It is apparent therefore that solutes move downwards through the unsaturated zone of the Chalk at a rate determined by the infiltration and the total rock porosity. Similar findings are emerging from studies of nitrate and tritium movement in sandstone, but this work is not as far advanced.

6. SIMULATION OF NITRATE MOVEMENT AND PREDICTION OF FUTURE TRENDS

Models of the movement of nitrate and other solutes through the unsaturated and saturated zones have been developed to help interpret the field measurements and to provide a means of predicting future trends.

Vertical Flow Model: A vertical flow model has been developed (Young et al. 1976 b) in which solutes originating at the soil surface are leached downwards at a rate depending on the infiltration and the pore water water content of the rock. The model thus embodies the two possible mechanisms of solute transport postulated in section 5. It was assumed that a small fraction, typically 5-15% of the infiltrating water and solutes moves quickly down to the water table via the larger fissures. The remaining water and solutes fill up the pore space at the top of the unsaturated zone displacing downwards water and solutes already in the profile. Some attenuation of peak concentrations was assumed to occur and is modelled by a dispersion mechanism. The model works with a yearly time increment and requires for input:

i. annual infiltration rates for the period of simulation,

ii land use history and fertilizer application rates for the period of simulation,

iii pore water content which is assumed to be constant in time and with depth; this is a valid assumption in Chalk as shown by field measurements Young et al. 1976 a).

The mass of nitrogen released each year in the soil layers for uptake by infiltrating water was assumed to depend on present and antecedent field use and fertilizer application. Kolenbrander (1975) has estimated that for root crops and cereals 50 per cent of the applied fertilizer becomes available as organic material for mineralization and it was assumed in the model that this quantity is leached downwards. Not all of this material is available in the year of application. Using Kolenbrander's work as a basis, it was assumed that mineralization takes place over a three-year period. Table 3 gives an estimate of the nitrate available to infiltration as a fraction of the application rate.

The effect on the model results of varying the distribution in time of the mineralization rate was small as the major contribution to nitrate leaching comes from the ploughing of grassland. By matching the model results to the observed N profiles in a number of boreholes it was possible to estimate the amount of N released by ploughing grasslands of various ages. Table 4 gives the corresponding model control rules.

The model was calibrated against the nitrate profiles obtained at the Experimental Husbandry Farm in Hampshire (Young et al. 1976, a,b). Figure 9 shows the results from the same model applied to the Chalk site in Kent to simulate the nitrate profile on October 1978. Land use data were available only from 1956, which means that the top 11m only of the profile may be simulated with real data. Data for the preceding 50 years was synthesised by forcing the model to fit the lower part of the profile obtained for the earlier 1975 drilling. These data were used with real data for the years 1956-78 inclusive to generate the profile shown in Figure 9. The comparison with measured concentrations is seen to be very good over the total depth.

Table 3. Model control rules for roots and cereals

Crop	Year of application	N available as a fraction of the application rate N	
		Following year	Next following year
Roots	0.35	0.10	0.05
Cereals	0.25	0.15	0.10

Table 4. Model control rules for the ploughing of grass

Years in grass prior to ploughing	N(kg/ha) released by ploughing			
	Total	Year of ploughing	Following year	Next following year
1	120	72	36	12
2	180	108	54	18
3	310	186	93	31
4 or more	380	228	114	38

Catchment Model: A model of nitrate movement in the saturated zone has been built which has as inputs the nitrate fluxes across the water table generated by the vertical flow model. The catchment area was divided into 500 m x 500 m squares and nitrate and water routed through the system according to the prevailing hydraulic gradients. Nitrate reaching the water table during a yearly increment was assumed to mix fully with nitrate already in the saturated zone. This type of model is generally referred to as a fully mixed cell model, and is well suited to problems

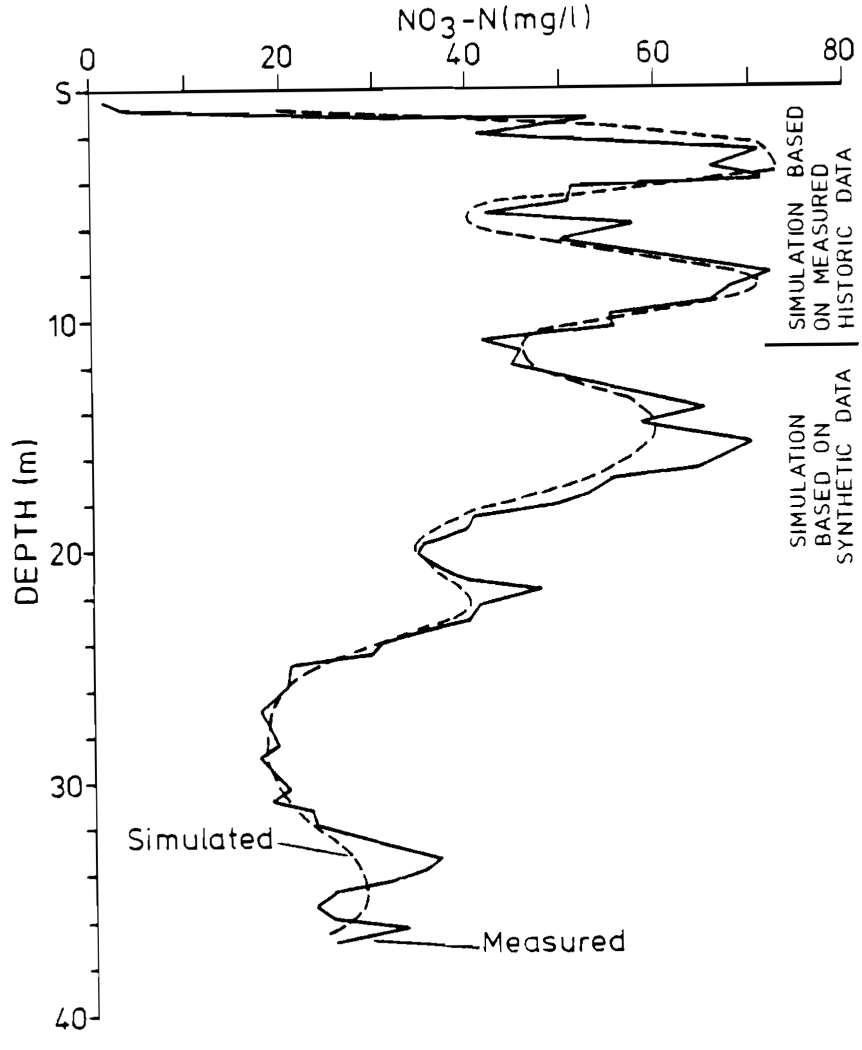


Fig. 9 Unsaturated zone model simulation and comparison with measurement.

with diffuse source inputs. The model was run from the year 1800 up to the year 2100. Early data on land use and fertilizer application rates were obtained from parish and ministry of Agriculture, Fisheries and Food records and by matching the vertical flow model to measured distributions of nitrate in the unsaturated zone. Present levels of fertilizer use were assumed to be maintained in the future. Figure 10 shows a typical model output, giving nitrate concentrations in pumped groundwater discharge. There are a few measured values with which to compare the simulations and these are shown in Figure 10. The predictions suggest that in this catchment nitrate concentrations will exceed 20 mg N/l within the next two decades and will stabilise at about 33 mg N/l. The model predictions are relatively insensitive to future trends in land use and fertilizer application rates because of the long transit time through the unsaturated zone, in this catchment being typically 25-30 years.

Similar models have been applied to other Chalk catchments and their application to Triassic sandstone catchments will be relatively straightforward once the vertical flow models for the sandstone have been calibrated.

7. POSSIBLE SOLUTIONS TO GROUNDWATER SUPPLY PROBLEMS ARISING FROM HIGH NITRATE CONCENTRATIONS

The Centre's investigations have shown that the vertical movement of nitrate carried by infiltrating rainwater through the unsaturated zones of the principal aquifers in the United Kingdom is generally relatively slow and that a considerable quantity of nitrate is present in these zones. Measures to decrease the rate of leaching losses from soils, for example by the use of slow release fertilizers or by improved synchronisation of fertilizer applications and plant demands will ultimately reduce the nitrate content of groundwater but this may take many years, or possibly decades to achieve. Other methods of meeting World Health Organisation (1971) or EEC drinking water quality regulations may therefore be necessary.

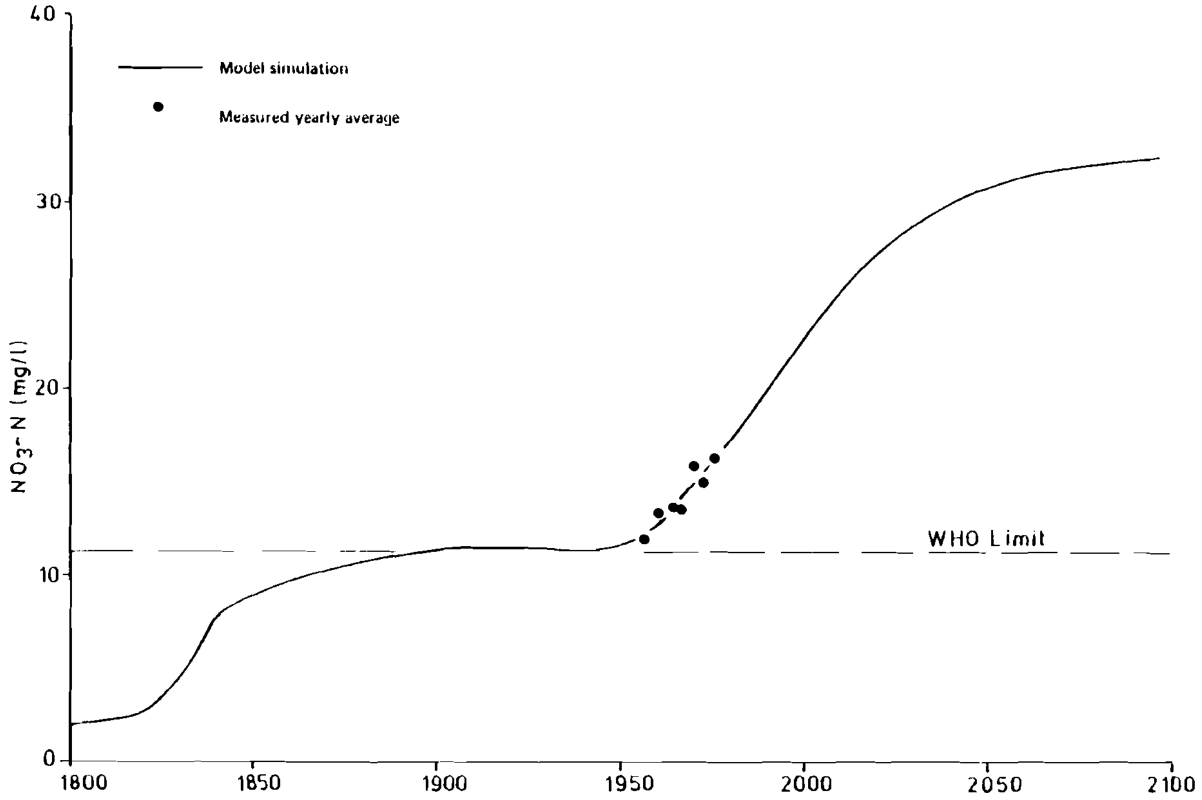


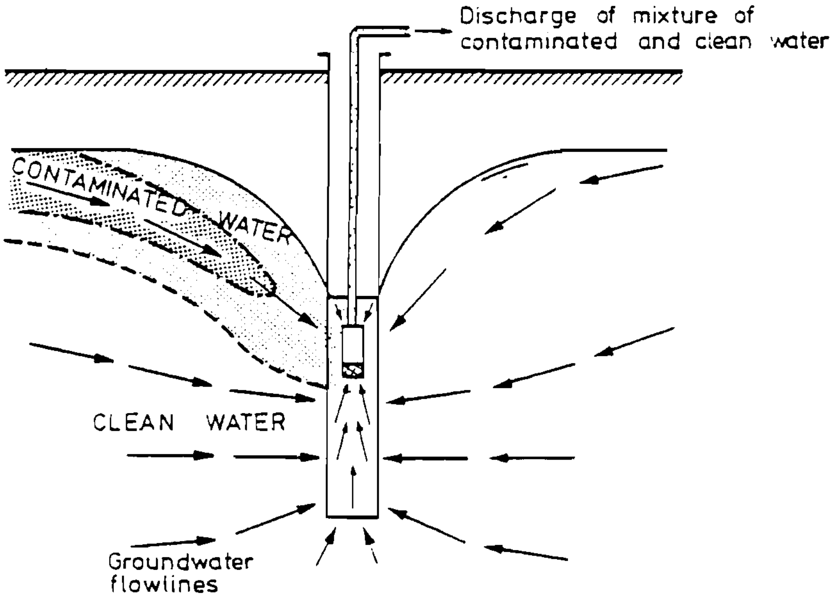
Fig. 10. Catchment model simulation - prediction of nitrate concentrations in pumped discharge and comparison with measurement.

Blending low nitrate water from surface or groundwater sources with a high nitrate content, before injection into the public supply system is already carried out in certain parts of the United Kingdom. This method remains satisfactory so long as a suitable source of diluting water is available, but increased difficulties may be anticipated if nitrate concentrations in both surface and groundwater continue to rise. Particular problems may arise in the case of rural mains networks supplied by only one to two boreholes and not linked to external mains networks. The supply of low nitrate bottled water to infants may partially alleviate the problem, but it is doubtful whether such a practice could be extended to the adult population if other health risks were to be confirmed.

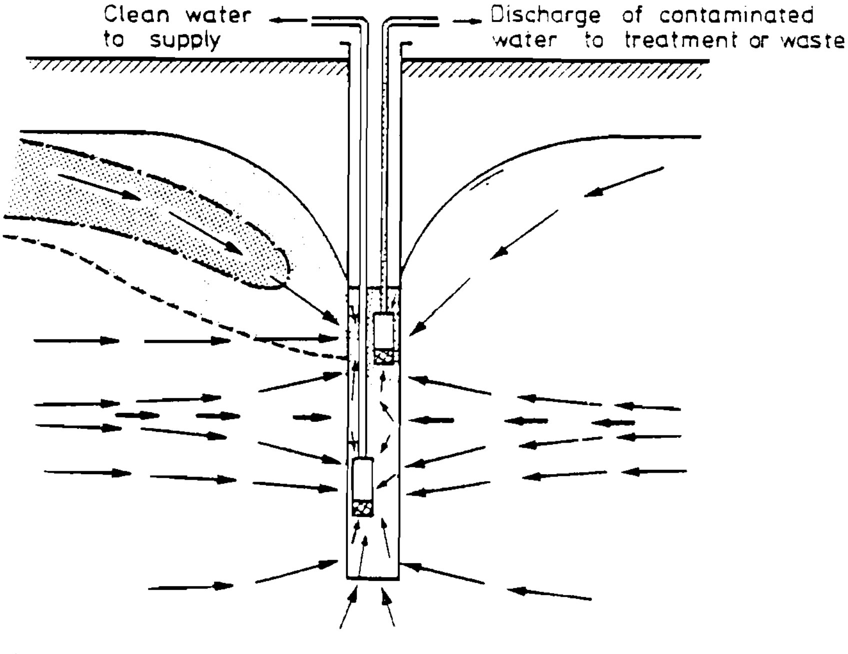
When the nitrate-rich groundwater can be shown to be moving at well defined horizons, scavenge pumping of the contaminated water to waste may allow extraction of relatively uncontaminated groundwater (Figure 11). This technique has been successfully applied to the removal of connate saline water within the Triassic sandstone aquifer in Shropshire. (Tate and Robertson, 1971). If, however, the nitrate rich groundwater is composed principally of recent recharge, progressive removal of older, less contaminated groundwater may lead to overpumping of the aquifer and a permanent decline in groundwater levels.

An alternative approach would be to reduce nitrate concentrations in the groundwater by artificially recharging the aquifer via basins or boreholes with high quality water. Successful control of groundwater quality by basin recharge in California has been demonstrated by Nightingale and Bianchi (1977), and consideration is being given by the Water Research Centre to the use of such techniques in the United Kingdom.

In these cases where engineering solutions prove impracticable or unsuccessful, consideration may be given to treatment by ion-exchange processes to reduce the nitrate levels in the pumped water. The development



a) Normal abstraction



b) Scavenge pumping

Fig 11. Scavenge pumping to control groundwater contamination.

of nitrate-specific recharge resins is being undertaken by the Water Research Centre (Gauntlett, 1975), but some problems of contamination of the exchange media by sulphates, and of the disposal of the regenerative effluents remain.

8. CONCLUSIONS

i) Field investigations have established that large quantities of nitrate are present in the unsaturated zones of the principal aquifers in the United Kingdom. A strong correlation between high interstitial water nitrate concentrations and arable farming regimes in the unsaturated zones has been found. Low nitrate leaching losses are associated with moderately fertilized, and unfertilized, grassland.

Experimental and field observations indicate that very large nitrate leaching losses are associated with the ploughing up of established grassland or long-term grass leys, as a result of the mineralisation of soil organic material.

ii) Correlation of nitrate and tritium profiles through the unsaturated zone of the Chalk with historical variations in nitrate leaching rates due to changing husbandry practices and with the thermonuclear tritium content of rainfall suggests that a high proportion of both solvents move slowly downwards.

iii) The use of mathematical models has allowed satisfactory simulations of measured tritium and nitrate profiles to be achieved. The rate of downwards movement is dependent on the local hydraulic properties of the aquifer and infiltration rates, but in the Chalk velocities of between 0.5 and 1.0 m/yr are indicated. Successful simulation of Triassic sandstone profiles has not yet been completed, but greater rates of movement, perhaps 2 m/y, are anticipated. Slow downwards movement of nitrate and tritium profile through the Chalk unsaturated zone has been confirmed by sequential sampling at two sites.

iv) The mathematical model of vertical movement has been incorporated in a catchment model for groundwater flows in the saturated zone, allowing predictions to be made of future nitrate concentrations in groundwater in well defined catchments. The results of such models, validated by comparison with historical groundwater quality data, indicate that in some areas nitrate concentrations may continue to rise to levels in excess of 11.3 mg N/l before stabilizing.

v) The slow rates of groundwater movement in both the unsaturated and saturated zones preclude a rapid response in groundwater quality to changes in nitrate leaching rates from the soil zone and other actions including engineering solutions and treatment of borehole water may become necessary in some areas in order to meet drinking water quality standards.

9. ACKNOWLEDGEMENTS

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UTILIZING AQUIFERS FOR SUBSURFACE STORAGE OF IRRIGATION WATER, ESPECIALLY INFILTRATED SEWAGE

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Republik

ABSTRACT

The extension of irrigation in the German Democratic Republic requires the utilization of groundwater for irrigation purposes and the effective management of groundwater resources in irrigation areas. Problems arise above all from the quality parameters set for irrigating vegetable crops and fruit plantations and from the potential risk of groundwater contamination in the case of sewage and slurry irrigation. Using typical examples, an outline is given of the models and strategies that were developed for groundwater management with due consideration to the specific conditions of irrigated crop production already used. The model described here couples water and matter dynamics, and is currently being tested at the field level.

PROBLEMS

In 1971, the irrigated area in the German Democratic Republic came up to about 350,000 hectares. It was extended to 1,100,000 hectares by 1982. The latter figure includes some 428,000 hectares under sprinkling irrigation. These high rates of increase are part of intensification measures taken, according to plan, with a view to improving soil fertility and stabilizing crop yields. This goes hand in hand with the intensification of fertilization, plant protection, and improved tillage.

Surface water, mostly from rivers, lakes, and reservoirs is used for irrigation purposes. Sewage irrigation has become common practice on more than 40,000 hectares of irrigated land. This means that every year, 80 million cu.m. of the 1.2 thousand millions of cu.m. of domestic sewage produced are utilized. During the winter, sewage is applied mainly to land with intensive infiltration, i.e., with infiltration rates of more than 3000 mm. Slurry is used for irrigation on 25,000 hectares of farmland (Kappes and Schwarz, 1979).

Until a few years ago, only a very small portion of groundwater was used for irrigation since groundwater is reserved primarily for drinking water supply. Meanwhile, groundwater is being used for sprinkling about 35,000 hectares of land.

Figure 1 shows the trend of water demand in the GDR (Albrecht, 1977). The water demand of the agricultural sector exhibits a particularly high rate of increase. That means a very heavy load on the water resources, since in dry years the supply of water comes up to no more than 9 thousand million cu.m. It is obvious that there is a need for the effective control of irrigation, for setting up special reservoirs for irrigation water, and for maximum sewage utilization for agricultural purposes. While considering more intensive groundwater utilization and better groundwater management, the following objectives have to be met:

- maintaining the quality of water required for fruit, vegetables, and other special crops;
- improving the reliability of water supply during dry periods;
- relieving the surface water balance during the summer;
- limiting the contaminating effect in areas with agricultural sewage utilization;
- subsurface storage of infiltrated sewage in winter to be utilized for irrigation during the growing season;
- reducing the investment expenditure compared with expensive facilities for water supply.

PRINCIPLES FOR THE PREPARATION AND OPERATION OF GROUNDWATER-BASED IRRIGATION SYSTEMS

(1) Only those aquifers must be used that are neither required nor suitable for drinking water supply.

(2) Hydrological restrictions for minimum discharge in dry periods and the effects on neighbouring waters must be complied with.

(3) On controlling the groundwater tappings in the course of one year, the differentiated operation and water pumpage of the wells in coordination with the technology (e.g., intermediate storage; running time of the pumps) have to

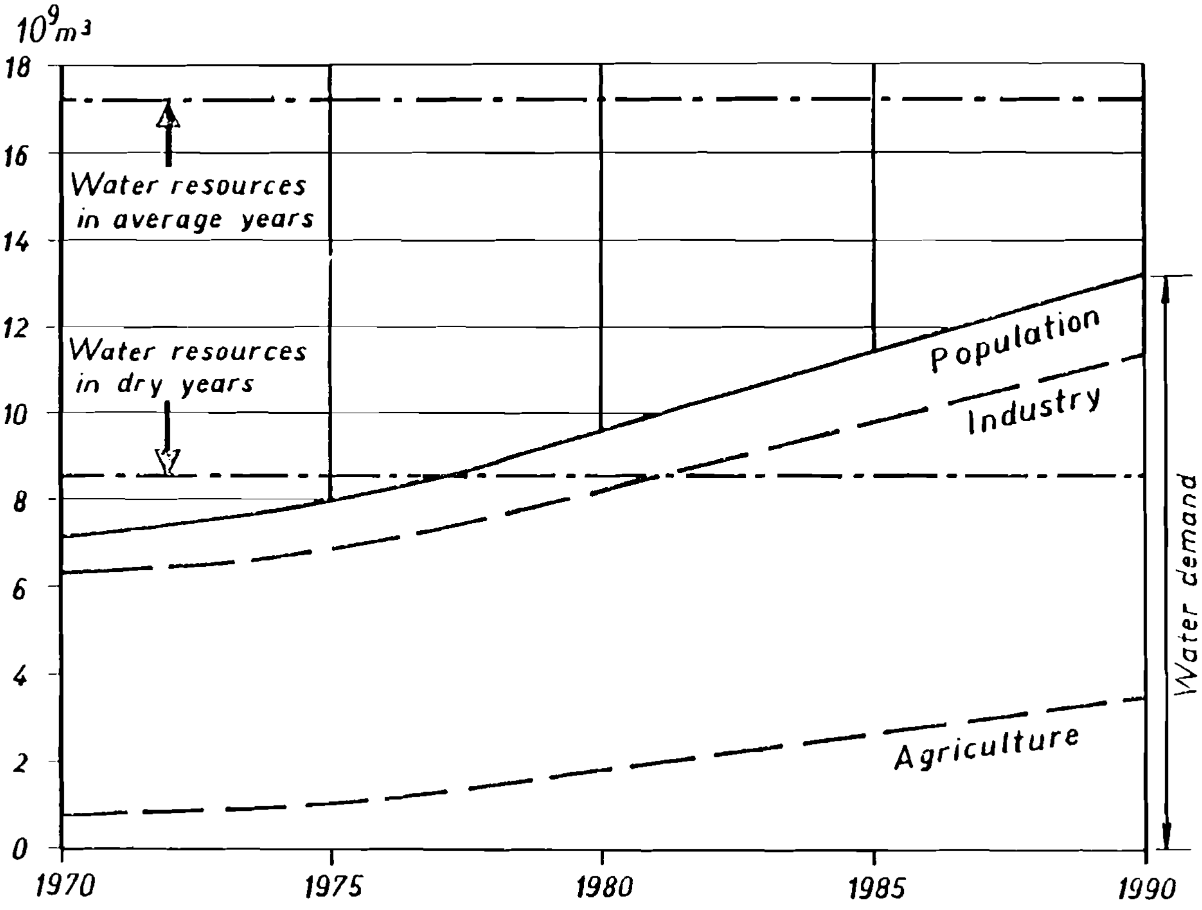


Figure 1. Development of water demand in the German Democratic Republic (after Albrecht, 1977)

be arranged in a specific way for each individual system so that the actual storage lamina would guarantee maximum reserves from the groundwater reservoir, thus meeting peak demands and supplying water in critical situations.

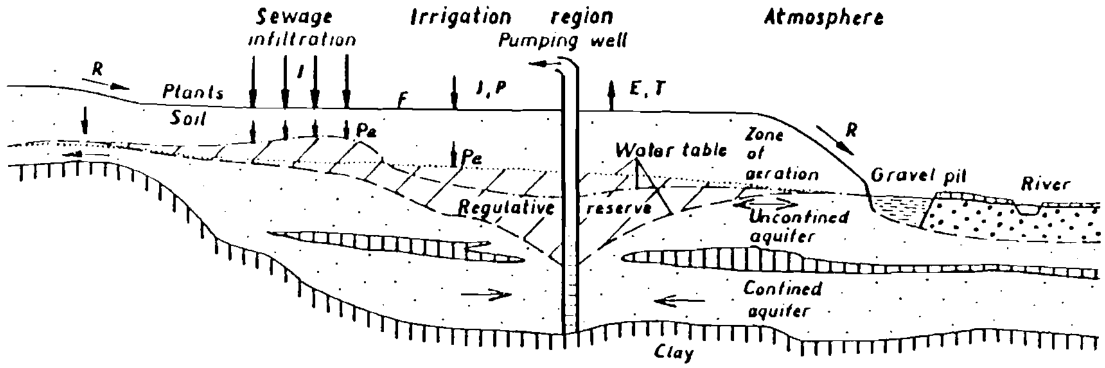
(4) Optimum management of the groundwater storage over several years presupposes that the mean annual uptake is small compared with the total storage lamina (regulative reserve) of the aquifer. The static parameters for annual uptakes and replenishment of the groundwater storage have to be considered on the basis of meteorological and hydrological time series analyses.

(5) For effective irrigation system control to manage the groundwater storage, it is necessary to analyze the results of at least a one-year test, along with extended hydrological programs.

(6) On suitable sites, the technology of intensive sewage utilization should be coupled with that of storing infiltrated sewage in the aquifer.

DISCUSSION OF TYPICAL VARIANTS AND OF THE DECISION AIDS USED FOR PROBLEM SOLUTION

The aquifer shown in Figure 2 is of the valley type. It is unconfined and consists of fluviatile sands and coarse gravels. Tertiary clays are found in the understratum. The thickness of the aquifer is between ten and twenty metres. Hydrological boundary conditions include (on the right) the river or the



Quantity (ground-water balance)

Input:
- Infiltration from precipitation P
- Infiltration from surface water
- Infiltration of artificial discharge (sewage infiltration in the non-irrigational season, return of irrigation water, etc.)
- Subsurface inflow

Outgo:
- Natural discharge to the surface water
- Artificial discharge (wells, drains)
- Subsurface outflow
- Evapotranspiration direct from ground-water

Quality (balance of chemical species)

Input:
- Sewage infiltration
- Chemical addition (fertilizers, pesticides)
- Rainfall addition
- Runoff addition
- Subsurface inflow
- Fixation

Outgo:
- Plant uptake
- Return flow (wells, drains)
- Runoff erosion
- Subsurface outflow
- Interactions and transfers (sorption, denitrification)

Figure 2. Cross section of an aquifer used for irrigation purposes.

gravel pit, and (on the left) the subsurface watershed divide which is not stationary when operating the groundwater sprinkling plant or employing sewage infiltration. Irrigation sprinkling is used on agricultural land.

Variant 1: Clean-water sprinkling

The land is to be used primarily for vegetable growing. In the given location, sprinkling water of adequate quality can only be obtained from the groundwater. Sprinkling water is delivered to the sprinkling machine either by means of a central battery of wells through an intermediate storage with capacity for one day and an automatic pumping station, or the wells are decentralized in a way that they feed immediately into the sprinkling machines. Positioning and arrangement of the wells, as well as water pumpage, comply with the requirement that, adhering to the projected water demand indices, the pumping depression cone reaches the river only by the end of the growing season. During periods of peak demand, additional water can be taken from the gravel pit. Replenishment of the groundwater storage takes place mainly over the winter by way of

- infiltration from precipitation;
- bank-filtered river water;
- inflow from the subsurface watershed.

On the basis of the results of geohydrological and hydrogeological exploration (and of pumping tests), the digital computer program, HOREGO (Luckner and Schestakow, 1975) is used for planning such an irrigation system, for dimensioning the wells, and for effective storage management. HOREGO solves the two-dimensional differential equation of the groundwater movement (with Dupuit assumptions) by means of a finite difference scheme with rectangular elements and linear parameters of transmissibility. Boundary conditions of the first, second and third kind can be realized at any point of intersection in the scheme. The HOREGO program was developed by Luckner for the Soviet computer BESM-6. The program has been used with good results since 1976 for handling practical problems. Therefore this program was used for geohydraulic simulation tests during preparations for groundwater sprinkling plants. The geohydraulic regime up to the maximum storage lamina was calculated for several practice plants sprinkling between 1000 and 2000 hectares each. The possible annual pumping rates, the extent of the pumping depression cone, and the dynamics of the storage lamina were indicated.

Variant 2: Sewage sprinkling

Sprinkling water quantities applied are generally much higher than the water requirement of the plants. Sewage infiltration and groundwater contamination may result. The situation will be even more acute if in critical areas intensive infiltration is practiced because the sewage has to be accepted all the year round.

It has become necessary to determine the dynamics, in time and space, of contamination in the aquifer. For the time being, technological solutions are in their testing stage in the GDR, combining sewage utilization and the reuse of the contaminated groundwater for irrigation purposes. With that, an additional water resource can be opened up, and the extensive groundwater contamination will be largely confined if we succeed in continuously inducing a depression cone in the aquifer between the infiltration area and the surface water (ditch, river, lake), i.e., water flow in the aquifer must always be directed to the wells.

The HOREGO program was also used with good results for simulating the geohydrological regime in that specific case. Regarding the simulation of the coupled water and matter dynamics, the practical use of models has not yet reached that advanced stage. At present, one model for the dynamics in the saturated aquifer is being tested. The following problems are being investigated:

- spread and disintegration of a contamination trail in the groundwater under a sewage utilization area;
- forecast of the quality of the sewage infiltrate pumped away from the aquifer.

Recording of percolation from the unsaturated zone of the soil is done on the basis of test data (Figure 3). No separate model calculations of matter translocation for test problems in the unsaturated zone have, as yet, been available.

The following model concept is being used for the saturated range of the aquifer (e.g., Pinder, 1973; Pickens and Lennox, 1976; Prakash, 1976; Taylor and Huyakorn, 1978).

The spread, in time and space, of chemicals in the groundwater range under review is described by means of the dynamic equations of a miscible binary fluid system:

- matter conservation of the fluid system

$$S \frac{\partial h}{\partial t} + n (\rho V_i)_{,i} = Q \qquad (1)$$

- conservation of momentum (equation of motion) of the fluid system

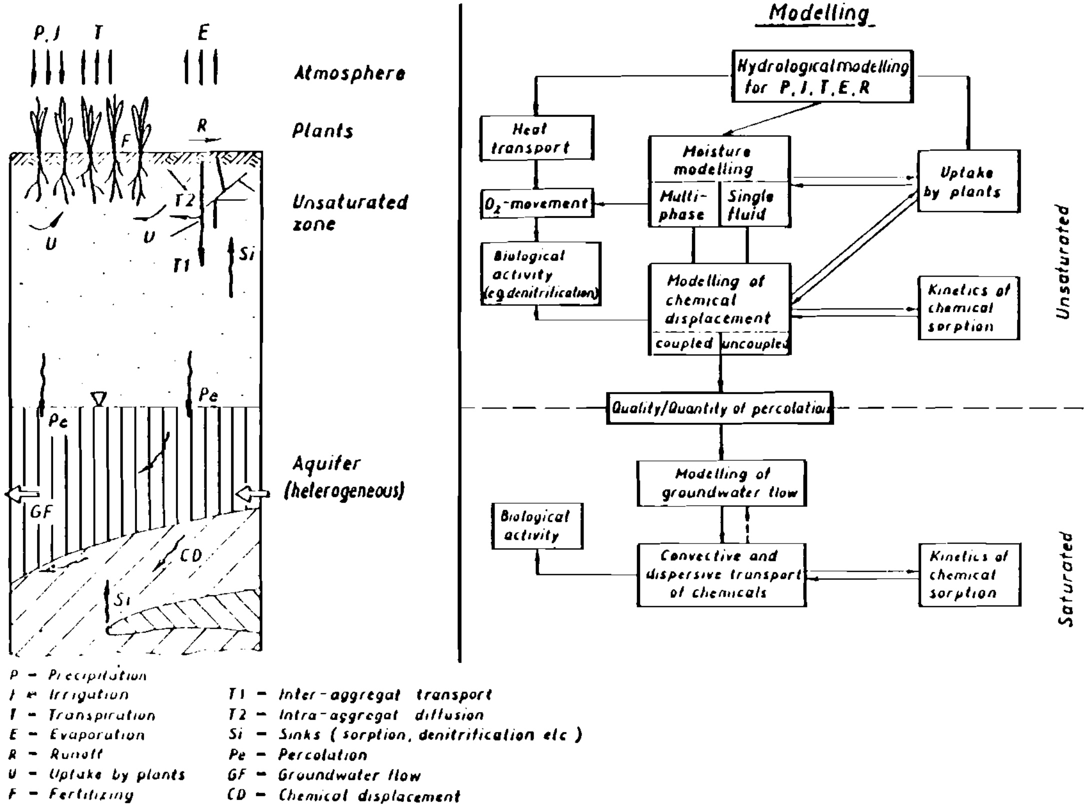


Figure 3. Process elements and elements coupling in the modeling of transport and exchange processes.

$$V_i + K_{ij}\left(h_{,j} + \frac{\rho - \rho_0}{\rho_0} e_j\right) = 0$$

$$K_{ij} = k_{ij}\frac{\rho_0 g}{\mu\ n} \qquad h = \frac{p}{\rho_0 g} + x_3 \tag{2}$$

- matter conservation of the chemical species (convection - dispersion equation)

$$\left(1 + \frac{1-n}{n}\varkappa\right)\frac{\partial C}{\partial t} + (V_i C)_{,i} = (D_{ij} C_{,j})_{,i} + Q_c \tag{3}$$

with

$$\left.\begin{aligned} D_{ii} &= D_L \frac{V_i\ V_i}{V^2} + D_T \frac{V_j\ V_j}{V^2} + D_d\ ; \\ D_{ij} &= (D_L - D_T)\frac{V_i\ V_j}{V^2} \end{aligned}\right\}\quad i \neq j$$

- equation of state

$$\rho = \rho_0\ (1 + \alpha C/C_{max}) \qquad \alpha = \left[\ \rho(C_{max}) - \rho_0/\rho_0\ \right] \tag{4}$$

The equation system is solved within the frame of a finite element model (FEFLOW programming system) for two-dimensional problems. These are some of the characteristics of the model:

- discretization of the flow field by means of isoparametric finite elements (linear, quadratic, cubic);
- linear time approximation (implicit or mixed schemes);
- Galerkin finite element approximation of equations (1), (2) and (3);
- determination of the velocity distribution either as a

derivative field from the hydraulic head (1 nodal degree of freedom, discontinual velocity) or directly through coupled solution of equations (1) and (2) (3 nodal degrees of freedom, continual velocity);

- frontal solution of the equation systems;
- fluid density correction by means of simple relaxation, equation (4);
- use of modified numerical methods (upwind formulation) for convective-dominant transport processes;
- boundary conditions of the first and second kind for any field configurations.

This model has been validated for theoretical problems and was tested on a model problem. It offers good simulation results, good quality with regard to stability and convergence, and to the effects in terms of numerical dispersion. At present, the finite element model is undergoing tests in a sewage infiltration area in the northern part of the GDR.

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Notation

The following symbols are used in this paper:

C = concentration of chemical species (M/L^3);
D_d = molecular diffusion coefficient (L^2/T);
D_{ij} = components of dispersion tensor (L^2/T);
D_L = effective longitudinal dispersion coefficient (L^2/T);
D_T = effective transverse dispersion coefficient (L^2/T);
e_j = components of gravitational unit vector;
g = gravitational acceleration (L/T^2);
h = hydraulic head (L);
K_{ij} = components of hydraulic conductivity (L/T);
k_{ij} = components of permeability tensor (L^2);
n = effective porosity of porous medium;
p = pressure (M/LT^2);
Q = fluid mass source or sink (M/L^3T);
Q_c = concentration source or sink (M/L^3T);
S = specific storage capacity (M/L^4);
V_i = components of average pore velocity (L/T);
V = resultant average pore velocity (L/T);
x_3 = height above a datum (L);
α = fluid density difference ratio;
$\varkappa$ = sorption coefficient;
μ = dynamic fluid viscosity (M/LT);
ρ = fluid density (M/L^3);
ρ_o = reference density (M/L^3);
τ = tortuosity of porous medium.

SIMULATION OF RUNOFF QUALITY FROM RURAL WATERSHEDS

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ABSTRACT

Described is a distributed parameter model which simulates runoff quantity and quality from the agricultural, forested and urban portions of rural watersheds. Direct runoff is deterministically simulated while interflow is described with a transfer function. The quality portion of the model simulates the runoff of sediment, organics, nutrients and heavy metals.

Example applications of the model are referenced in conjunction with describing how the model is used in investigations of the influence of changing rural land uses on the environment. Presented, also, are the problems associated with the use of such deterministic, distributed parameter models. The difficulties and meaningfulness of model calibration are discussed, along with the theoretical problems associated with the selection of design precipitation events for planning simulations.

INTRODUCTION

The significance of runoff from rural watersheds on downstream aquatic ecosystems has only recently been recognized. One approach to the analysis of the water quality problems arising from these catchments is to use predictive simulation models. Through simulation, unknown inputs to downstream systems can be determined or the response to various constructive measures or cultural activities can be predicted. Problems exist with such simulation techniques, but the power of their systematic analysis of solutions to complex water quality problems cannot be overlooked. Described here is a deterministic approach to simulating runoff water quality, the advantages of such an approach, and the associated problems and weaknesses.

In the hydrologic cycle, between precipitation and instream water quality below a rural watershed, lie numerous interrelated steps, all of which are complicated and difficult to describe accurately. Water moves overland as direct runoff or through the soil and deeper aquifers as interflow and base flow. Sediment is removed with the direct runoff by washoff and erosion. The base and interflow pick up dissolved constituents through solution and desorption. Once in channels, solids and dissolved constituents form a dynamic physical-chemical-biological system as they move downstream.

For the sake of mathematical representation, these processes have been represented at the largest level as a runoff system and a transport system. The transport system, not described here, is necessary when the hydrodynamics become complicated, e.g. constrictions with backwater or hydraulic structures for storage or diversion, or when the nonconservative instream water quality aquatic biology reactions begin to become significant. In such cases the runoff simulated from the described model is routed through more exact transport models to provide simulated flows and water quality at the desired downstream location.

The runoff system is further subdivided into an overland flow component, a groundwater flow component, and a channel routing component. The hydrodynamics and the water quality constituent pick-up and transport of these systems has been deterministically described. Once calibrated and verified against historical data, such a deterministic description allows for the predictive simulation of various planning alternatives or scenarios.

MODEL DESCRIPTION

The runoff system is simulated with a dynamic deterministic model, very unimaginatively named RUNOFF. This model is based on a relatively simple distributed parameter characterization which divides the watershed into several subcatchments drained by a tree-shaped network of channels. It is capable of simulating single events or continuous sequences, depending on the user's requirements. The state variables are water depths and constituent concentrations. Development of this model began nearly a decade ago. The model has been applied successfully to a great variety of watersheds and a number of program versions have been written for specific application requirements. Complete mathematical formulations of various model sections have been described by Roesner et al. (1971), Metcalf and Eddy, Inc. et al. (1971), Shubinski and Roesner (1973) and Lyons (1978).

For overland and channel flow, the Lighthill and Whitham (1955) kinematic wave assumption has been utilized to simplify the Saint-Venant general momentum equation of motion. Combining with the continuity equation, the resulting nonlinear differential equations for subcatchment overland flow and channel flow are:

Subcatchments ($\ell=1, \ldots L$):

$$\underbrace{\frac{da_\ell}{dt}}_{\text{storage change}} + \underbrace{I_\ell}_{\text{infiltration}} + \underbrace{f(a_\ell)}_{\text{overland outflow}} - \underbrace{R_\ell}_{\text{precipitation}} = 0 \qquad (1)$$

Channels ($m=1, \ldots M$):

$$\underbrace{\frac{db_m}{dt}}_{\text{storage change}} + \underbrace{g(b_m)}_{\text{channel outflow}} - \underbrace{\sum_{j=1}^{J} f(a_j) + h(c_j) + i(e_j)}_{\text{influent subcatchment flows}} - \underbrace{\sum_{k=1}^{K} g(b_k)}_{\text{tributary channel inflows}} = 0 \qquad (2)$$

The model states a_ℓ and b_m are the overland and channel flow depths, respectively, and the functions $f(\cdot)$ and $g(\cdot)$ represent flows computed from Manning's equation.

Interflow and baseflow are computed through a conceptualized system of overlying one-dimensional elements. The equations of continuity and motion give the following set of nonlinear differential equations for interflow and base flow:

Subcatchment soil system ($\ell=1, \ldots L$):

$$\underbrace{\frac{dc_\ell}{dt}}_{\text{storage change}} + \underbrace{I'_\ell}_{\text{deep percolation}} + \underbrace{ET_\ell}_{\text{evapotranspiration}} + \underbrace{h(c_\ell)}_{\text{interflow}} - \underbrace{I_\ell}_{\text{infiltration}} = 0 \quad (3)$$

Subcatchment groundwater system ($\ell=1, \ldots L$):

$$\underbrace{\frac{de_\ell}{dt}}_{\text{storage change}} + \underbrace{i(e_\ell)}_{\text{base flow}} - \underbrace{I'_\ell}_{\text{deep percolation}} = 0 \quad (4)$$

The model state c_ℓ and e_ℓ are, respectively, the effective water storage depths of the soil and groundwater systems. The functions $h(\cdot)$ and $i(\cdot)$ represent flows computed from Darcy's law.

Equations 1 to 4 are solved in RUNOFF with their appropriate functions, $f(\cdot)$, $g(\cdot)$, $h(\cdot)$ or $i(\cdot)$, through an implicit Newton-Rapnson scheme. Once depths and flow rates have been calculated, it is possible to compute the runoff quality.

Surface washoff of settled dust and dirt is simulated as a first order rate process:

$$\frac{dm}{dt} = -km \quad (4)$$

where m is the mass of the simulated constituent and k is a constant. See Metcalf and Eddy, Inc. et al. (1971) and Lyons (1978) for a discussion of the analytical and numerical methods used in RUNOFF to solve Equation 4. Several methods are used to determine the build up of dust and dirt on the catchment surface between precipitation events, which gives the initial conditions needed to solve Equation 4. Agricultural and forested areas are usually computed with a constant build up factor dependent on land use, while in urbanized areas a build up rate dependent on total catchment street length has proven most effective.

Erosion resulting from rainfall dislodgment and overland flow removal has been described to date with the well known Universal Soil Loss Equation (Wischmeier and Smith 1958). This empirical equation was originally derived from statistical analyses of soil loss data to give an estimate of average annual soil erosion from rainstorms. The Universal Soil Loss Equation has been modified for use in RUNOFF to predict event erosion and deliveries to the receiving channel.

$$A = R \cdot K \cdot LS \cdot C \cdot P \cdot SDR \qquad (5)$$

where

A = soil loss per unit area,
R = the rainfall erosive energy factor,
K = the soil erodibility factor,
LS = the slope length gradient ratio,
C = the cropping management factor or crop cover index factor,
P = the erosion control practice factor, and
SDR = the sediment delivery ratio.

Dissolved water quality constituents are picked up by interflow and groundwater as ions move into solution from equilibrium and ion-exchange reactions. While these complicated physico-chemical reactions can be mathematically represented and simulated, it has not been felt necessarily productive enough to use such a deterministic procedure in RUNOFF. The pick-up of dissolved constituents is simulated with transfer functions dependent on flow rate:

$$c_{i\ell} = \alpha_i(q_\ell) \qquad (6)$$

where $c_{i\ell}$ is the concentration of constituent i leached from subcatchment ℓ and $\alpha_i(\cdot)$ is a transfer function relating concentration to flow rate q_ℓ.

The constituents removed from the subcatchment are routed downstream through a one-dimensional channel system. Water quality reactions are assumed conservative in the channels and movement is by convection only:

$$\left(A_x \frac{\partial c}{\partial t} + c \frac{\partial A_x}{\partial t} \right) = \pm s \qquad (7)$$

where A_x is the cross-sectional area in the x-direction and s represents sources or sinks of constituent c. This equation is integrated using a mixed implicit-explicit scheme (Lyons 1978).

Normally, a limited number of constituents are simulated. When sufficient water quality data are available to calibrate RUNOFF, numerous constituents can, however, be simulated. Table 1 presents a list of the constituents already simulated with RUNOFF.

MODEL APPLICATION

The use of distributed parameter deterministic models requires a large amount of initial effort. Once calibrated and verified, however, they become quite versatile and powerful as planning and analysis tools. Predictive simulation is the last in a three-step process. The model must first be calibrated against measured historic data, preferably collected within the watershed to be studied. Once the model parameters have been calibrated against a set of historical data, the model's predictive capabilities must then be verified against another set of historical data. Such a validation gives the user a direct measure of the model's accuracy in making predictions.

The predictive simulation of runoff quality can be applied in many different ways in the analysis of environmental problems. Simulation can be used simply to compute imputs to downstream water quality -- aquatic ecology investigations, for example, reservoir water quality management (McLaughlin et al. 1975), or estuary water quality management (Metcalf and Eddy, Inc. and Resource Management Associates 1978). The impacts of proposed land-use changes can very effectively be predicted (Roesner et al. 1972). Proposed constructive measures, such as terracing or land leveling, or changes in agricultural cultural practices, can similarly be studied with predictive simulations (McLaughlin et al. 1975).

Deterministic models are not, however, particularly suited to real-time simulation. Adaptive state/parameter models are superior due to their speed in calculation and their ability to continually adapt to changing conditions and improve their predictions (Todini et al. 1976; Bras 1976). Adaptive models are primarily useful in real-time control problems, while deterministic models have their main value in simulating various planning alternatives.

DATA REQUIREMENTS

The set up and calibration of RUNOFF requires a large amount of data. The deterministic formulation of the model implies immediately a large number of rate or transfer-function coefficients. For example, the overland flow function $f(\cdot)$ in Equation 1 in its simplest form contains five parameters:

Table 1. Simulated runoff water quality constituents

SOLIDS

- Settleable
- Suspended
- Total dissolved

INORGANIC

- Chloride
- Sulfate

ORGANIC

- Biochemical oxygen demand
- Chemical oxygen demand
- Grease
- Total coliforms
- Fecal coliforms

NUTRIENTS

- Organic nitrogen
- Ammonia
- Nitrate plus nitrite
- Total hydrolized phosphorus
- Orthophosphate

HEAVY METALS

- Mercury
- Copper
- Zinc
- Lead
- Chromium
- Cadmium
- Arsenic

$$f(a_\ell) = \frac{k_\ell \; w_\ell}{A_\ell} \; \sigma_\ell^{1/2} \; (a_\ell - \delta_\ell)^{5/3} \qquad (8)$$

Several parameters in Equation 8 can be directly interpreted from subcatchment geometry, w_ℓ, A_ℓ and σ_ℓ, width, area and slope; while in spite of their physical bases, the other two parameters, k_ℓ and δ_ℓ, overland flow roughness and surface detention, can only be estimated and their values finalized through calibration. As a distributed parameter model, spatial discretization gives a rapid growth to the total number of parameters to be determined.

To calibrate a deterministic model, measured historical and simulated values of the state variables for the same event are compared and model parameters are adjusted until the minimum difference is achieved between measured and simulated. A meaningful data collection program for model calibration is a significant activity in itself. Spatial and temporal distribution of measurements in a meaningful pattern, as well as repetition, is needed to be able to identify uniquely all of the model parameters. Such a data collection program must be designed for model calibration rather than vice versa. Often it is unwisely decided to make the best of inappropriate, existing data collected for other purposes to calibrate a model.

RUNOFF must be calibrated in steps. First, data are needed to calibrate the model flow parameters, and second, data are needed to calibrate the quality portions of the model. Coordinated precipitation and flow measurements are relatively easy and cheap to make in comparison with water quality measurements. There is much to be done in developing effective techniques for collecting and analyzing the quality data needed to properly calibrate runoff quality models. Micro-processors and mini-computers are proving effective in supervising the collection and storage of runoff quality samples (Marr and Pieper 1977), and in the future we will definitely see their greater use in field constituent determination.

CALIBRATION

Virtually all runoff models incorporate unknown parameters that are difficult, if not impossible, to measure in the field or laboratory, for example, the overland flow roughness coefficient. Often, precise parameter values are difficult to specify in advance. At best, the model user has only a rough idea of the range of plausible values. Model parameters that cannot be measured directly must be inferred from observations of related variables that are more readily available.

Indirect estimation procedures suffer from two fundamental sources of error: 1) the measurements used for estimation may be uncertain or corrupted by extraneous disturbances, and 2) model inputs or boundary conditions which are assumed to be well known may, in fact, be inaccurate. These error sources directly effect the quality of the parameter estimates. For a runoff model, errors of the first type include such sources as using uncertain, dynamically varying water level measurements to calculate flow hydrographs with a rating curve which, in itself, is a smoothed set of uncertain velocity-discharge measurements. Errors of the second type are exemplified by using precipitation rates, measured at a few point locations, often not within the catchments being calibrated, to estimate the dynamic areal distribution of precipitation. Experience has shown that the measurements used in calibrating runoff models, quantity and quality, contain very significant uncertainties and these measurements should always be viewed very skeptically, and, when possible, estimates of these uncertainties should be directly incorporated into the parameter estimation process.

Originally, the calibration of deterministic predictive models was carried out by a trial-and-error process. An event was simulated and the calculated runoff rates and concentrations were compared with the measurements; parameter adjustments were manually made according to the modeler's judgment and understanding of the model; and the system resimulated with the new parameters. This cyclical process was repeated until a satisfactory calibration was achieved.

Trial-and-error calibration becomes more difficult, as those who have tried it will know, as more parameters are adjusted and as the relationship between these paramaters and the performance index becomes more complex. In such situations, the search for "good" parameter adjustments can usually be made more efficiently with numerical optimization algorithms which are able to assimilate and process very quickly the information obtained from sequential performance evaluations. This numerically oriented approach is commonly called automatic model calibration.

At least two different parameter estimation techniques are available for the practical automatic calibration of runoff quality models, weighted least-squares and maximum likelihood. The weighted least-squares estimation algorithm (a Fisher estimator) essentially ignores input errors, while the maximum likelihood estimation algorithm (a Bayesian estimator) accounts for these errors in a systematic way. Performance differences between these estimators are negligible when input errors are minor. When input errors are large, however, the maximum likelihood estimator appears to give significantly better estimates.

Consideration of the model equations reveals the following important points:

- The number of unknown parameters tends to grow rapidly as the watershed discretization becomes more detailed. Each subcatchment and channel contributes several uncertain coefficients.
- All of these unknown parameters normally must be estimated with flow and quality measurements from a limited number of events at downstream locations receiving runoff from numerous subcatchments.
- Uncertain rainfall values have a dominant effect on both runoff predictions and parameter estimates.

Experience indicates that most of the parameter estimates of finely discretized systems computed by techniques such as least-squares or maximum likelihood are, in fact, only weakly coupled to measurements of individual events. This has important statistical implications, the Rao Cramer bound on estimate covariance (Schweppe 1973), which imply that the parameters will be only marginally identifiable.

This tendency can be countered in several ways:

- Spatial distribution of sampling sites should be selected to reduce the number of parameters estimated during calibration. More emphasis should be given to upstream sites with subcatchments of uniform land use.
- Within individual runoff events, more effort should be given to shorter sampling intervals when the runoff processes are most rapidly changing, i.e. for quality, at the beginning of the events.
- Greater effort should be made to describe more accurately the temporal and spacial distribution of precipitation.
- Repetition of sampled events and sampling locations is important.
- Only those parameters should be estimated which are significantly involved in the sampled hydrological process. In other words, during calibration the insensitive parameters should be sequencially dropped until only those parameters remain which are sensitive to the measurements.

Prior to model calibration, the complete set should be divided. With the first sample subset, the model is calibrated and with the second it is verified. In the verification, events are simply simulated and the model results compared with the measurements. Verification gives a statistical measure of the predictive accuracy of the runoff model. This important step is often unwisely left out by modelers.

PREDICTIVE SIMULATIONS

We analyze runoff quality from rural watersheds to be able to solve some downstream water quality problem arising from or accentuated by the runoff. It is common to specify an objective which should not be exceeded more often than a given frequency of occurrence: mass discharge rates or instream concentrations are not to exceed some critical level more often than once every "n" years. Such a statistical approach to solving environmental problems is realistic: it is delusional to say that so-and-so event will *never* occur.

Several techniques are available for using predictive simulation models in planning studies:

- Event simulation of planning alternatives with data from critical historical events.
- Event simulation of planning alternatives with independent variables determined from statistical analyses.
- Long-term simulation of planning alternatives with a historic or stochastic input sequence. The results of the simulation are then statistically analyzed to give a measure of project effectiveness.

The first two approaches, as normally applied, contain an implied assumption:

> *The occurrence frequency of a simulated event is the same as the occurrence frequency of the independent variables (precipitation).*

This assumption is incorrect for two reasons. First, the probability distribution function of a sequence of independent precipitation events does not remain constant in the transformation to the probability distribution function of runoff, as the runoff process is not linear. Second, while precipitation can usually be seen as a sequence of independent events, runoff events are sequentially correlated; in other words, it is a Markov process. It is, therefore, not possible to specify a single precipitation event that will give a runoff event of a unique occurrence frequency.

The third approach to predictive simulation is the only one through which the effectiveness of a planning alternative can be statistically quantified. The first two approaches give the response to specific boundary conditions,but say nothing quantitative over the statistical effectiveness of a project. One can only take steps to guarantee that the boundary conditions of an event oriented predictive simulation are as physically (statistically) representative as possible of what could occur in the study watershed (Abraham et al. 1976).

CONCLUSIONS

The deterministic simulation of runoff can effectively depict the quality of water originating from rural watersheds, and it is a very versatile tool in water quality management planning. The quantity prediction algorithms are more advanced in their development and more reliable than those for quality. Experience has shown that the amount and reliability of data available for calibration plays a significant role in the model's accuracy in making predictions. More needs to be done in quantifying input data and prediction uncertainties and in improving individual quality functions in the model.

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TRACE ELEMENT CONTENT IN ORGANIC FERTILIZERS AND RELATIVE SUPPLIES TO SOIL

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ABSTRACT

Thirty-two commercial fertilizers collected from eight different manufacturers and distributors have been analyzed by atomic absorption spectrophotometry to determine how much of the following elements they contain: As, B, Bi, Cd, Cl, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sn, and Zn.

Fifteen of the eighteen investigated trace elements are detectable in all fertilizers; B is not present in two fertilizer types and Bi does not show up in three types; Se is present only in two samples.

The elements present in the largest amount in all fertilizers are Fe and Cl, whereas Li, Hg, Cd and Bi are present in the smallest amounts.

Fertilizers originated from phosphate rocks contain the highest quantities of trace elements, whereas synthetic nitrogen fertilizers and potassium sulphate samples contain much smaller quantities.

Calculations show that As, Cd, Hg, Sn and Mo provided by common dressings with almost all examined fertilizers may affect the micronutrient status of soil, thus leading to potential contamination; the risk from Co, Cr, Cu, Ni, Pb, Zn, Li, B, and Cl appears to be limited only to the case when phosphate fertilizers are added to soils commonly poor in that element; in no case are Fe, Mn and Bi contributions by fertilizers expected to vary appreciably the natural soil content.

INTRODUCTION

Fertilizers have been recently indicated [11, 14, 18, 20] to be among the principal factors of the trace element contamination of the environment, as they affect the trace element composition of soils and often lead to soil contamination.

Application of inorganic fertilizers frequently involves the addition of small quantities of heavy metals and other elements that are present in the natural parent materials or are derived as impurities from many other sources. Although the amounts may vary widely in materials of different origins and different processing, such additions may be regarded as a modification of the natural geochemical distribution.

Whether or not results may be highly beneficial rather than adverse when fertilizers containing metals (that are essential nutrients) are added to soils naturally deficient in these elements, potential problems could arise when the concentration of undesirable elements have increased too much.

Comprehensive information on the trace element contents of fertilizers has been published by Swaine in 1962 [25]; further studies on this subject have been performed to date by some other authors [1, 2, 4, 8, 9, 12, 16, 17, 21, 27], but concerning only a limited number of trace elements and fertilizer formulations.

In order to have a more complete and current evaluation of the soil contamination hazard related to commercial inorganic fertilizers management in agriculture, 32 samples from 8 manufacturers and distributors, representing the major types of fertilizers used in Italy and elsewhere, were collected in the last six years [15, 22, 23] for the detection and determination of the contents of the following trace elements: As, B, Bi, Cd, Cl, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sn, and Zn.

The supply of these trace elements to soil per hectare/year from common rate application of fertilizers to a wide variety of crop plants, has been calculated.

MATERIALS AND METHODS

The elements are extracted from ground fertilizers by absorption for 24 hours in a water bath with concentrated mineral acids of high purity (HCl/HNO_3 = 3/1; $HNO_3/H_2SO_4/HClO_4$ 70% = 10/2/4; HNO_3 conc., HCl conc. 6 N), following when possible, the official methods of A.O.A.C. [3].

The concentrations of the elements in the acid extracts are determined by atomic absorption spectrophotometry, except for chlorine. The operating parameters and equipment used are summarized in Table 1.

Table 1. Atomic absorption equipment and operating parameters

Equipment and Parameter	Elements																
	As	B	Bi	Cd	Co	Cr	Cu	Fe	Hg	Li	Mn	Mo	Ni	Pb	Se	Sn	Zn
Spectrophotometer	I.L. 251	P.E. 305A	I.L. 251	P.E. 306	P.E. 305A	P.E. 305A	P.E. 305A	P.E. 305A	P.E. 306	P.E. 306	P.E. 305A	P.E. 305A	P.E. 305A	P.E. 306	I.L. 251	I.L. 251	P.E. 305A
Atomizer	Hydr. syst. I.L.	Burn.	Hydr. syst. I.L.	HGA 72 P.E.	Burn.	Burn.	Burn.	Burn.	Hg system P.E.	Burn.	Burn.	Burn.	Burn.	HGA 72 P.E.	Hydr. syst. I.L.	Hydr. syst. I.L.	Burn.
Wave length (Å)	1937	2497	2231	2288	2415	3579	3251	2488	2536	6708	2800	3133	2320	2170	1960	2246	2141
Lamp current (mA)	12	34	10	✱5	31	31	34	34	7	15	34	34	31	✱10	10	7	22
Slit (nm)	1.0	0.7	0.3	0.7	0.2	0.7	0.7	0.2	0.7	1.4	0.2	0.7	0.2	0.7	2.0	1.0	0.7
Oxidant	air	N_2O	air	--	air	air	air	air	--	air	air	N_2O	air	--	air	air	air
Fuel	H_2	C_2H_2	H_2	--	C_2H_2	C_2H_2	C_2H_2	C_2H_2	--	C_2H_2	C_2H_2	C_2H_2	C_2H_2	--	H_2	H_2	C_2H_2
Carrier gas	argon	---	argon	argon	---	---	---	---	air	---	---	---	---	argon	argon	argon	---
Flame	oxid. (blu)	reduc. (yellow)	oxid. (blu)	---	oxid. (blu)	reduc; (yellow)	oxid. (blu)	oxid. . (blu)	---	oxid. (blu)	oxid., (blu)	reduc. (yellow)	oxid. (blu)	---	oxid. (blu)	oxid. (blu)	oxid. blu)

✱: power (watt) ; oxid.: Oxidant ; reduc.: Reducent.

Arsenic, bismuth, selenium and tin are determined by the gaseous hydride generated by reduction with sodium borohydride and swept by a flow of argon into an argon-hydrogen-air flame [10]. Mercury is determined by the Hatch and Ott method [13], using the special Hg-System by Perkin Elmer: an airstream swept by the metallic mercury vapors in a quartz tube, where the maximum of absorbance is detected. Cadmium and lead are analyzed by atomization in a graphite furnace, Perkin Elmer HGA-72, using a Deuterium Background Corrector. All the other elements are determined by burner atomization of the extracts.

Hollow cathode lamps are employed for all elements, except for Cd and Pb, for which discharged non-electrode lamps are used. The method of addition is used to eliminate matrix interference.

RESULTS AND DISCUSSION

The average contents of trace elements in the fertilizers examined are summarized in Table 2. Fifteen of the eighteen elements investigated are detectable in all fertilizer types; B is absent in ammonium sulphate and urea samples; Bi in ammonium nitrate, calcium cyanamide and potassium sulphate ones; Se is present only in triple superphosphate and ammonium nitrate.

Fe and Cl are the elements present in the largest amounts in all fertilizers, followed by Mn, Cr, B, Cu, Zn, As and then by Ni, Co, Mo, Pb, Sn, whereas Li, Hg, Cd, and Bi are present in the smallest quantities. Se is detectable at significant levels in the present two samples.

Table 3 shows the variations and Figure 1, the range of trace element contents analyzed in fertilizers. It appears that some elements, such as Pb, Ni, Li, Mo, Cl, Hg, and Co show relatively limited variations, whereas the others such as B, Bi, Se, Fe, etc., vary in a wide, or relatively wide range.

In Table 4 the scale of abundance of analyzed trace elements for each fertilizer type is presented. Cl and Fe almost always occupy the first two places, followed by the other elements which are distributed throughout the intermediate positions, except for Cd, Li, Hg, Bi and Se, which are localized virtually everywhere in the last places.

Fertilizers originating from natural raw materials contain the highest amounts of trace elements.

All the phosphate fertilizers (triple superphosphate, superphosphate, NP and NPK compounds) contain high levels of Cl and Fe (> 1,000 ppm), appreciable amounts of Mn, B, Cr, Zn, Cu, and As (321-9 ppm), followed by Ni, Co, Mo, Pb and Sn (44-6 ppm), and significant quantities of Li, Cd, and Hg (4-0.4 ppm) and Bi (0.5-0.03 ppm); apparently they come from the parent rock phosphates, as indicated by the comparison of the relative abundance of trace elements in phosphate fertilizers (Table 4) and rock phosphates (Table 5).

Table 2. Average trace element amounts in fertilizer samples (ppm)

Fertilizers	Number of samples	Trace Elements																	
		As	B	Bi	Cd	Cl	Co	Cr	Cu	Fe	Hg	Li	Mn	Mo	Ni	Pb	Se	Sn	Zn
Ammonium Sulphate	4	15.67	0	0.06	2.96	1,600	9.4	2.4	<1.0	34	0.59	1.5	3.2	2.2	29.6	6.01	0.00	4.32	2.5
Ammonium Nitrate	3	60.52	tr.	0.00	4.46	1,500	8.7	2.6	3.0	547	1.46	1.7	25.0	5.7	20.2	14.44	3.33	9.36	4.7
Calcium Nitrate	2	6.16	tr.	0.10	1.43	600	10.7	17.3	10.0	158	1.18	2.1	27.5	6.0	26.7	5.22	0.00	6.12	22.0
Urea	2	16.71	0	0.05	1.71	550	1.2	1.2	<1.0	24	0.74	4.0	5.0	2.0	8.7	27.15	0.00	11.70	<1.0
Calcium-Cyanamide	1	2.22	tr.	0.00	0.03	n.d.	22.0	23.0	14.0	4,140	0.40	1.7	14.0	9.0	48.8	5.92	0.00	0.36	4.0
Superphosphate	4	9.06	160	0.04	0.65	1,100	15.1	108.6	51.0	2,262	0.86	1.7	60.0	11.0	30.2	8.70	0.00	10.62	120.0
Triple Superphosphate	1	321.55	172	0.51	3.25	2,000	16.7	190.0	138.0	8,980	3.20	3.3	197.0	21.0	44.2	13.92	13.25	7.20	138.0
Potassium Sulphate	3	4.33	25	0.00	1.31	1,500	6.3	2.3	1.7	130	0.25	0.7	4.7	6.3	13.1	11.48	0.00	1.92	3.7
NP Compounds	3	46.89	73	0.03	3.15	4,200	13.7	83.8	15.3	4,640	0.44	2.5	161.0	16.3	33.6	5.05	0.00	17.44	74.0
NPK Compounds	9	58.97	100	0.08	4.03	6,100	13.1	60.2	11.4	3,438	0.86	2.3	84.0	11.0	33.0	9.86	0.00	6.08	43.5

Table 3. Trace element variation in analyzed fertilizers (in ppm)

Element / Value	As	B	Bi	Cd	Cl	Co	Cr	Cu	Fe	Hg	Li	Mn	Mo	Ni	Pb	Se	Sn	Zn
Maximum	321.55	172	0.51	4.46	6,100	22.0	190.0	138	8,980	3.20	4.0	197.0	21.0	48.8	27.15	13.25	17.44	138.0
Minimum	2.22	0	0	0.03	550	1.2	1.2	< 1	24	0.25	0.7	3.2	2.0	8.7	5.22	0	0.36	< 1.0
Maximum/Minimum	145	∞	∞	149	11	18	158	> 138	374	13	6	62	10	6	5	∞	48	> 138

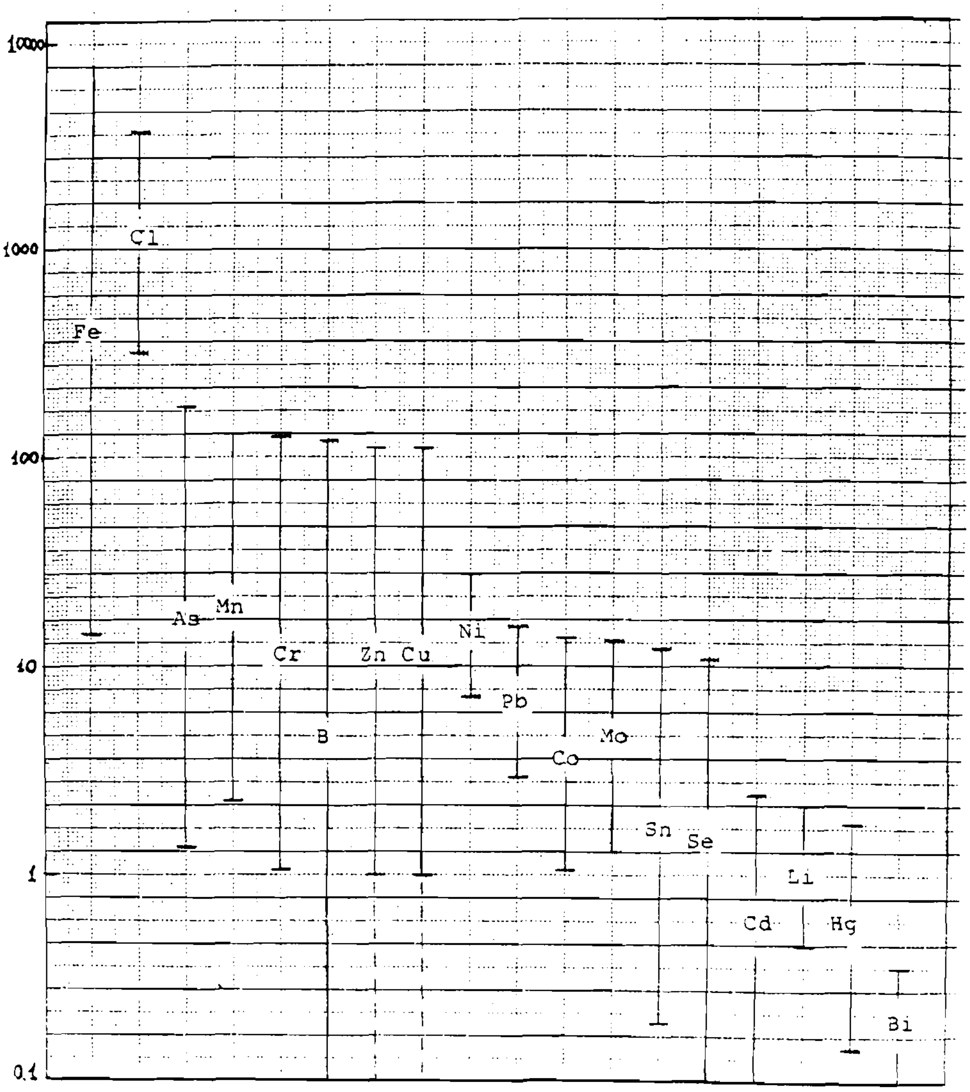

Figure 1. Range of contents of investigated trace elements in fertilizers

Table 4. Decreasing order of analyzed trace elements abundance for fertilizer types analyzed

Fertilizers	Number of samples	Scale of Elements Abundance																	
Ammonium Sulphate	4	Cl	Fe	Ni	As	Co	Pb	Sn	Mn	Cd	Zn	Cr	Mo	Li	Cu	Hg	Bi	B	Se
Ammonium Nitrate	3	Cl	Fe	As	Mn	Ni	Pb	Sn	Co	Mo	Zn	Cd	Se	Cu	Cr	Li	Hg	B	Bi
Calcium-Nitrate	2	Cl	Fe	Mn	Ni	Zn	Cr	Co	Cu	As	Sn	Mo	Pb	Li	Cd	Hg	Bi	B	Se
Urea	2	Cl	Pb	Fe	As	Sn	Ni	Mn	Li	Mo	Cd	Co =	Cr	Cu =	Zn	Hg	Bi	B =	Se
Calcium-Cyanamide	1	Fe	Ni	Cr	Co	Mn =	Cu	Mo	Pb	Zn	As	Li	Hg	Sn	Cd	B	Bi =	Se	Cl
Superphosphate	4	Fe	Cl	B	Zn	Cr	Mn	Cu	Ni	Co	Mo	Sn	As	Pb	Li	Hg	Cd	Bi	Se
Triple Superphosphate	1	Fe	Cl	As	Mn	Cr	B	Cu =	Zn	Ni	Mo	Co	Pb	Se	Sn	Li	Cd	Hg	Bi
Potassium Sulphate	3	Cl	Fe	B	Ni	Pb	Co =	Mo	Mn	As	Zn	Cr	Sn	Cu	Cd	Li	Hg	Bi =	Se
NP Compounds	3	Fe	Cl	Mn	Cr	Zn	B	As	Ni	Sn	Mo	Cu	Co	Pb	Cd	Li	Hg	Bi	Se
NPK Compounds	9	Cl	Fe	B	Mn	Cr	As	Zn	Ni	Co	Cu	Mo	Pb	Sn	Cd	Li	Hg	Bi	Se

Fertilizers derived from carbonate rocks (calcium nitrate and calcium cyanamide) show a wide distributional range of the amounts of various elements with significant quantities of Fe, Ni, Co, Cu, and Mn (4,000-14 ppm) for calcium cyanamide and Cl, Fe, Ni, Mn, Zn, Cr, Co, Cu (600-10 ppm) for calcium nitrate. In almost all cases the trace element contents of the fertilizers derived from carbonate rocks are quite below the phosphate ones (Table 5). Comparing Tables 4 and 5, there is a good correlation between the relative abundance order of trace elements in the calcium containing fertilizers and parent carbonate rock.

Synthetic nitrogen fertilizers (ammonium sulphate, ammonium nitrate and urea) and potassium sulphate contain much smaller quantities of all the analyzed elements, excepting Fe, Pb, As, Sn, and Li in urea samples; Cl, Fe, As, Mn, Pb, Cd, and Sn in ammonium nitrate; Cl, Fe, Ni, As, and Co in ammonium sulphate and Cl, Fe, B, Ni, and Pb in potassium sulphate. The presence of small amounts of trace elements in synthetic fertilizers could be ascribed mainly to impurities from sulphuric and nitric acids, catalysts, raw materials used as conditioners or fillers for their commercial dilution (i.e. gypsum, calcium carbonate, kaolin, limestone, etc.,) and corrosion of equipment.

Table 6 shows a comparison between the range of content of trace element found in this study and the average content reported in the literature [25, 26]. Cobalt, copper, molybdenum, nickel and often lead and zinc content detected in our samples are higher than average, whereas iron and lithium content are always below the average given by other authors at present.

Regarding the other elements analyzed, our data rarely fit in with the values in the literature, ranging at random below or above them. This is not surprising if one considers how the purification and treatment of the parent materials and their origin vary with time and place; moreover, the differing and variable grades of purity of reactants and catalysts used and the variability of materials used as conditioners and filters must be considered.

Table 7 shows the contributions of trace elements per hectare/year to the top layer of cultivated soils, following fertilizer applications at common rates. The last four lines in the table refer to the extreme and usual range of trace element loads to soils [7, 11, 24].

Calculations show that As, Cd, Hg, Sn, and Mo, found in almost all examined samples, can be significant sources of soil contamination despite the generally very low contents of these elements. They may considerably affect the micronutrient status of soil with regard to the uptake by crop plants.

The risk from Co, Cr, Cu, Ni, Pb, Zn, Li, B and Cl additions by phosphate fertilizers will probably be limited to those soils commonly poor in that element and for crops with low tolerance limits.

In no case would Fe, Mn, and Bi contributions by fertilizers be expected to increase the natural soil content appreciably.

Table 5. Trace element content in world phosphate deposits [5] and carbonate rocks [26] (in ppm)

Phosphate rocks	Fe	Mn	Cl	Zn	Cr	Mo	Cu	Se	B	Ni	Sn					
	24,480	2,322	700	201	192	139	80	78	45	24	16					
Carbonate rocks	Fe	Cl	Ni -	Zn -	B	Cr	Pb	Li	Cu	As	Sn	Se	Mo	Co	Hg	Cd
	–	150	20	20	20	11	9	5	4	1	<1	0.8	0.4	0.1	0.04	0.035

Table 6. Range of contents (ppm)of trace elements detected in this work (1st line) and average contents (ppm) reported in the literature [6, 25] for simple fertilizers

Trace Element	Principal Element		
	K (3 samples)	N (12 samples)	P (5 samples)
As	2.44 - 8.02 15	2.18 - 119.66 100	2.45 - 321.55 10 - 1000
B	20 - 30 20	0 - tr. 0.2 - 20	140 - 185 30
Bi	0.00 0.01	0.00 - 0.13 --	0.00 - 0.51 --
Cd	0.06 - 3.80 1	0.03 - 8.50 --	0.10 - 3.25 38 - 48 *
Cl	1500 --	500 - 2500 --	600 - 2000 --
Co	5.8 - 7.0 <1	1.0 - 22.0 0.1	8.8 - 21.0 3
Cr	2.0 - 2.8 10	tr. - 23.0 <5	36.6 - 190.0 200
Cu	1 - 2 1	tr. - 15 1	20 - 138 5
Fe	97 - 163 5000	8 - 4140 5000	910 - 8980 20000
Hg	0.00 - 0.40 --	0.30 - 2.88 --	0.40 - 3.20 --
Li	0.1 - 2.0 10	0.3 - 4.6 30	1.0 - 3.3 5
Mn	4 - 5 8	2 - 65 40	10 - 197 150
Mo	4 - 9 0.2	1 - 9 0.1	8 - 21 4
Ni	11.0 - 16.0 0.5	7.0 - 48.8 1	19.2 - 44.2 5
Pb	1.39 - 17.40 0.2	1.91 - 48.72 0.5	3.13 - 17.40 5 - 100
Se	0.00 <0.5	0.00 - 10.00 5	0.00 - 13.25 1
Sn	1.80 - 2.16 5	0.36 - 21.60 0.1	2.16 - 19.08 5
Zn	2 - 6 2	tr. - 42 5	55 - 235 150

*: from Williams and David (1973) [27].

Table 7. Minimum and maximum amounts (g/ha) of trace elements supplied by fertilizers applied at common rates (Kg/ha) to cultivated soils (1st line: min. rates; 2nd line: max. rates). The last four lines show the extreme and usual ranges of soil trace element contents [7, 24].

Fertilizer Supplies (Kg/ha)		As	B	Bi	Cd	Cl	Co	Cr	Cu	Fe	Hg	Li	Mn	Mo	Ni	Pb	Se	Sn	Zn
		Element Supplies (g/ha)																	
Ammonium Sulphate	100	1.6	--	<0.01	0.3	160	0.9	0.3	<0.1	3.3	0.1	0.15	0.3	0.2	2.9	0.6	--	0.4	0.3
	350	5.5	--	0.02	1.1	560	3.3	0.8	0.4	11.7	0.2	0.52	1.2	0.8	10.4	2.1	--	1.5	0.8
Ammonium Nitrate	60	3.6	tr.	--	0.3	90.0	0.5	0.2	0.2	33.0	0.1	0.10	1.5	0.3	1.2	0.9	0.20	0.6	0.3
	300	18.1	tr.	--	1.4	450	2.6	0.8	1.0	164.0	0.4	0.51	7.4	1.8	6.0	4.3	1.00	2.8	1.4
Calcium Nitrate	100	0.6	tr.	0.01	0.1	60.0	1.2	1.7	1.0	16.0	0.1	0.21	2.7	0.6	2.7	0.5	--	0.6	2.2
	300	1.9	tr.	0.03	0.4	180.0	3.2	5.2	3.0	48.0	0.4	0.63	8.2	1.8	8.0	1.6	--	1.8	6.6
Urea	75	1.2	tr.	<0.01	0.1	41.0	<0.1	<0.1	<0.1	2.0	<0.1	0.30	0.4	0.2	0.7	2.0	--	0.9	<0.1
	150	2.5	tr.	<0.01	0.3	83.0	0.2	0.2	<0.2	4.0	0.1	0.60	0.7	0.3	1.3	4.1	--	1.8	<0.2
Calcium Cyanamide	100	0.2	tr.	--	tr.	n.d.	2.2	2.3	1.4	414.0	<0.1	0.17	1.4	0.9	4.9	0.6	--	<0.1	0.4
	400	0.9	tr.	--	tr.	n.d.	8.8	9.2	5.6	1636.0	0.2	0.68	5.6	3.6	19.5	2.4	--	0.1	5.6
Superphosphate	300	2.7	48	0.01	0.2	220	4.5	32.6	15.0	679.0	0.3	0.51	18.0	3.3	9.1	2.6	--	3.2	15.0
	800	7.2	128	0.03	0.5	280	12.1	86.9	41.0	1810.0	0.7	1.36	48.0	8.8	24.2	7.0	--	8.5	41.0
Triple Superphosphate	200	64.3	34.4	0.10	0.6	400	3.3	38.0	28.0	1796.0	0.6	0.66	39.0	4.2	8.8	1.7	2.65	1.4	28.0
	800	257.2	137.6	0.41	2.6	1,600	13.4	152.0	110.0	7184.0	2.6	2.64	158.0	17.0	35.4	7.0	10.60	5.8	110.0
Potassium Sulphate	100	0.4	2.5	--	0.1	150	0.6	0.2	0.2	13.0	<0.1	0.07	0.5	0.6	1.3	1.1	--	1.7	0.4
	400	1.7	10.0	--	0.5	600	2.5	0.9	0.7	22.0	0.1	0.28	1.8	2.5	5.2	4.6	--	7.0	1.5
NP Compounds	70	3.3	7.0	<0.01	0.2	294	1.0	5.9	1.1	325.0	<0.1	0.17	11.0	1.0	2.4	0.3	--	1.2	5.2
	500	23.4	36.4	0.01	1.6	2,100	6.8	41.8	7.6	2320.0	0.2	1.25	80.0	8.0	16.8	2.5	--	8.7	37.0
NPK Compounds	100	5.9	10,0	<0.01	0.4	610	1.3	6.0	1.1	344.0	0.1	0.23	8.0	1.1	3.3	1.0	--	0.6	4.4
	800	47.2	8,0	0.06	3.2	4,800	10.5	48.2	9.1	2750.0	0.7	1.84	67.0	8.8	26.4	7.9	--	4.9	35.0
Soils contents (ppm) Extreme range	min	<0.1	<0.2	<3	0.01	30	0.001	<0.01	<1.0	2,560	0.01	<1.0	1	0.1	0.5	0.1	0.01	0.03	6
	max	1000.0	1000.0	13	45.0	3,000	1,000	35,800	14,000	150,000	1.14	5,000	70,200	224.0	6,560.0	10,000	225	300	30,000
Usual range	min	1.0	2.0	--	0.01	--	1.0	5.0	2,0	--	0,03	<1.0	200	0.2	5.0	2.0	0.1	0.1	10
	max	50.0	100.0	--	0.70	--	4.00	1000.0	100,0	--		<100.0	3,000.0	5.0	500.0	200.0	2.0	5.0	300

CONCLUSION

Even if the trace element contents of commercial fertilizers are often quite low and the quantities added to ordinary soil are seldom sufficient to affect the total content in the soil, they may on occasion affect the soluble and available fraction.

It seems necessary to point out that the actual hazard for accumulation of these elements in the soil and for uptake by plants will clearly depend on many other factors, chiefly on solubility of the element, climatic conditions, chemical and physical properties of the soil, and types of cultivated plants.

Moreover, trace element addition through fertilizers has to be considered not only in relation to their natural content in the soil and to the specific needs and toxicity levels of plants, but also to the requirements and health hazard for animals that consume these plants.

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ASSESSING THE WATER QUALITY IMPACTS OF AGRICULTURAL PRACTICES: SOME METHODOLOGICAL COMPARISONS

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ABSTRACT

Two methods addressing the relationship between agriculture and water quality are reviewed. Meta Systems (1978) has investigated for the U.S. Environmental Protection Agency the feasibility of a methodology which permits the assessment of both the water quality and socio-economic impacts of agricultural practices and specific government policies aimed at encouraging environmentally sound agricultural practices. Bogardi and Duckstein (1978) elaborated a stochastic model of non-point nutrient loading into a waterbody. Common elements as well as specific features of both models are underlined, and recommendations are given for further research.

1. INTRODUCTION

The purpose of this paper is to compare two models (Meta Systems, 1978; Bogardi and Duckstein, 1978) serving for the analysis of the relationship agriculture-water quality. Both models consider the same problem: (a) watershed(s) with various human activities such as agricultural practice; (b) a river network collecting and transporting runoff water, sediment and pollutants, into (c) an impoundment (reservoir or lake) or a downstream river section. A trade-off or best policy is sought for agricultural management and pollution control. Among the various types of pollution, eutrophication is considered a world-wide danger for natural water-bodies (Edmonson, 1969). The problem can be solved with the help of two submodels: an impact model simulating water-quality conditions as related to agricultural management alternatives, and a decision model leading to the best compromise among conflicting interests. Since both models considered contain impact models, these submodels are compared and the decision model is briefly referred to.

The paper consists of two main parts. First, principal elements of both models are reviewed, then a comparison is made, emphasizing common features and specific aspects. Also, a recommendation is given for a composite model.

2. REVIEW OF MODELS

2.1 The Meta System Model

Figure 1 is a flow chart of the proposed methodology showing: (1) the farm model, which accepts as inputs alternative agricultural practices available to the farmer and estimates the net revenues resulting from each alternative; (2) the watershed/water quality model, which analyzes the water quality impacts of the selected agricultural practices; and (3) a qualitative approach for the assessment of the socio-economic impacts of water quality changes on downstream water users.

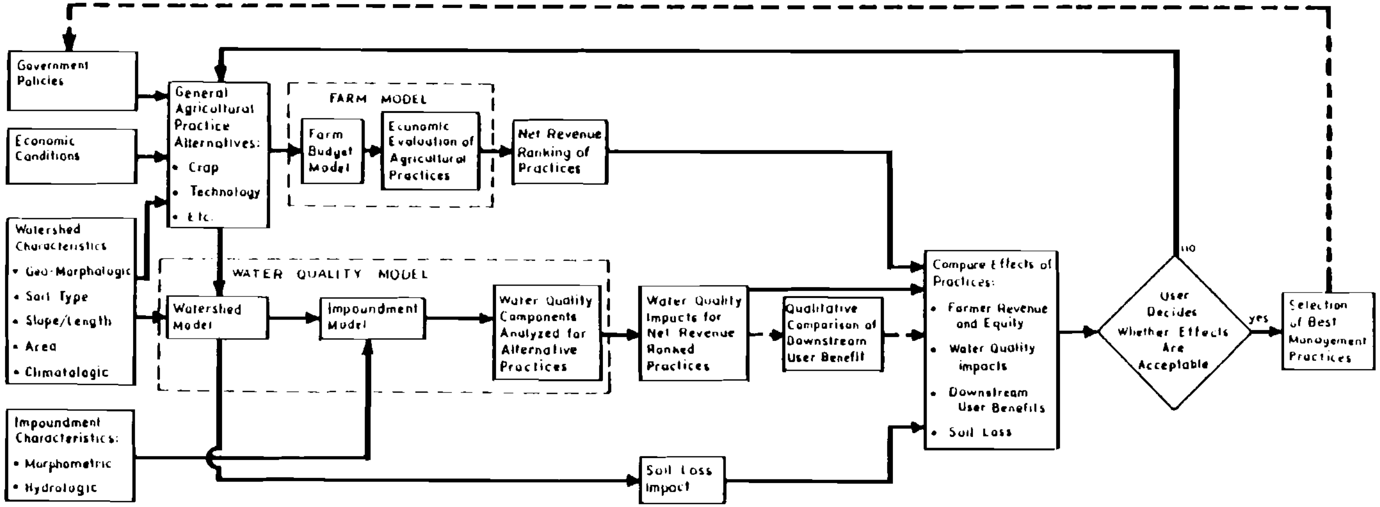

Figure 1. Flow chart of the Meta System model

An illustrative example was selected throughout model formulation and solution. In order to minimize required field work and maximize data available for the example, a well-studied agricultural watershed with a downstream impoundment was sought. A locality meeting all these requirements was not to be found; therefore, to implement the illustrative example, the Black Creek watershed in Northeastern Indiana (a U.S. EPA, USDA demonstration project) was used, and a downstream impoundment was synthesized with characteristics typical to those found in the Corn Belt. Data from impoundments in this region were obtained from the EPA's National Eutrophication Survey and other sources that permitted regional calibration of the impoundment water quality models. The work done on the Black Creek watershed (Lake and Morrison, 1977) provided a good source for some of the economic, soils and water quality data needed for calibration and illustrative application of the methodology.

Agricultural Practices and Farm Budgets

A farm budget that assumes the current agricultural structure is developed. A set of agricultural practices representative of the options available to a farmer in a particular watershed is selected. In the example, eleven practices are selected, and farm budgets are developed for a uniform farm of 250 acres on each of the three predominant soils in the Black Creek watershed. The farmer chooses a set of agricultural practices that include: crop rotation, tillage practices, structural erosion and drainage control practices, and levels of chemical application (Table 1).

Water Quality Impacts of Agricultural Practices

To judge the water quality effects of the agricultural practices, the water quality impacts of each practice/soil combination are analyzed as the second step. The following water quality parameters are considered.

1. impoundment sedimentation (kg/m^2-yr),

   a measure of the amount of sediment deposited on the bottom of the impoundment per year and thus of the impoundment's useful lifetime;

Table 1. Major features of a selected set of farm practices in the Black Creek area

Crops	Tillage Practice	Soil Conservation Practice	Abbreviated Designation of Farm Practice
Continuous Corn	Conventional tillage, fall turn plow (CV)	without terracing	CC-CV
Continuous Corn (CC)	Conventional tillage, fall turn plow (CV)	with terracing	CC-CVT
Continuous Corn (CC)	Fall shred stalks, chisel plow, spring disk (CH)	without terracing	CC-CH
Continuous Corn (CC)	Fall shred stalks, chisel plow, spring disk (CH)	with terracing (T)	CC-CHT
Continuous Corn (CC)	Fall shred, no till planting (NT)	without terracing	CC-NT
Corn-Soybean Rotation (CB)	Conventional tillage, fall turn plow (CV)	without terracing	CB-CV
Corn-Soybean Rotation (CB)	Fall shred, chisel plow, spring disk (CH)	without terracing	CB-CH
Corn-Soybean Rotation (CB)	Fall shred, no-till planting (NT)	without terracing	CB-NT
Corn-Soybean Rotation (CB)	Fall shred, no-till planting (NT)	with terracing (T)	CB-NTT
Corn-Soybean-Wheat-Hay Rotation (CBWH)	Conventional tillage, fall turn plow for corn; no-till planting for soybean, wheat, hay	without terracing	CBWH* CBWH
Corn-Soybean-Wheat-Hay Rotation (CBWH)	Fall shred stalks, no-till planting for all crops, increased use of herbicides (NT)	without terracing	CBWH*-NT CBWH-NT

Note: Entry in parentheses used where needed to distinguish specific component of farm practice

* indicates farmer-owned equipment for wheat and meadow planting and for hay mowing, raking and baling, rather than custom hiring for these operations

2. impoundment sediment outflow concentration (kg/m^3),
   a measure of the amount of sediment suspended in waters withdrawn from the impoundment;
3. river and impoundment nitrogen concentrations (g/m^3),
   an indication of nitrate levels in the waters;
4. river light extinction coefficient (m^{-1}),
   a measure of the resistance to light penetration in the river due to turbidity and color;
5. impoundment light extinction coefficient (m^{-1}),
   a measure of the resistance to light penetration in the surface waters of the impoundment due to turbidity, color and algal growth;
6. impoundment biomass (g chl-a/m^3),
   a measure of the concentration of suspended algae in the surface waters of the impoundment during the summers and thus a measure of the degree of eutrophication.

For each practice, the watershed models predict <u>average</u> loadings of sediment (sand, silt and clay fractions), nitrogen, phosphorus and color as functions of field/soil characteristics. Transport of water quality components from the watershed is represented in two phases (dissolved and sediment-bound) and in two streams (surface runoff and sub-surface drainage). The water quality models estimate the impact of these loadings on the average concentrations of the respective components in the downstream river and impoundments. Impoundment water quality response is also assessed with regard to mean summer transparency and chlorophyll-a concentration, which are important indices of eutrophication.

Figure 2 depicts the separation of the water quality analysis into two major sections:

1. the <u>watershed</u>, or runoff model, which is characterized as generating different loadings of pollutants depending on agricultural activities and watershed characteristics;

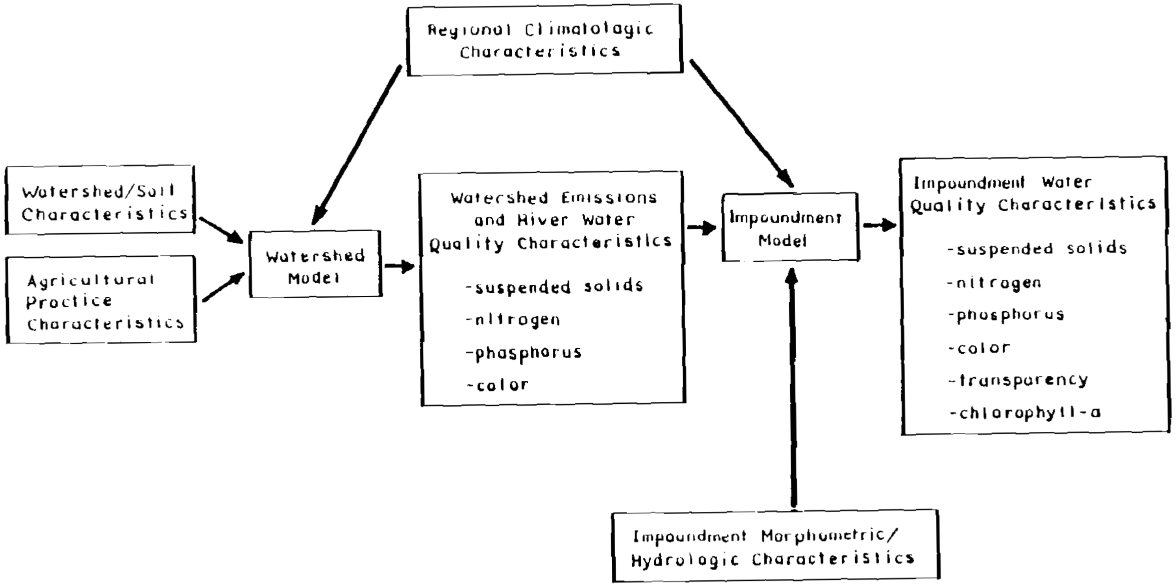

Figure 2. Main elements of the Meta System model

2. the impoundment, where water quality is dependent upon the type and quantity of loadings from the watershed and upon impoundment characteristics.

Watershed emissions or loadings are computed as functions of the following characteristics:

1. Surface soil properties
    a. Erodibility - K factor in the Universal Soil Loss Equation (Wischmeier and Smith, 1972)
    b. Texture - sand, silt and clay content
    c. Hydrologic Soil Group (SCS/USDA, 1971)
    d. NH_4F/HCl extractable phosphorus content - in each texture class
    e. Phosphorus distribution coefficient (g extractable P/Kg soil)/(g dissolved P/m^3 soil solution)
    f. Organic matter content - in each texture class
2. Watershed/field properties
    a. Slope
    b. Slope length
    c. Surface area
    d. Total flow (runoff and drainage)
    e. Rainfall erosivity (R factor in Universal Soil Loss Equation)
3. Agricultural practices
    a. Cropping factor (C in Universal Soil Loss Equation)
    b. Practice factor (P in Universal Soil Loss Equation)
    c. Nitrogen and phosphorus fertilization rates
    d. Tillage depth
    e. Crop residue management.

Some Results of Model Application

Table 2 shows the ranking of the eleven selected farm practices in terms of net revenues for the three farms; further results can be found in the Meta Systems report (1978).

For ridge farm, comparison of practices is shown in Figure 3. Besides soil loss, values of the other six water-quality parameters are also given.

2.2 Stochastic Model of Non-point Nutrient Loading

Model Description

Main specifications of a P loading model designed for decision-making in the lake eutrophication problem are: (1) to account for uncertainty in hydrologic events, i.e., precipitation events causing transport of dissolved and absorbed P into the lake; this uncertainty is encoded as a probability density function (pdf) of P loading per event for each type of P; (2) to utilize existing precipitation data plus the few data bits available for calibration on chemistry of dissolved and adsorbed P, and on runoff and sediment yield; (3) to enable us to keep track of both types of P in the lake, given the net release rate of P from sediments and the residence time of water in the lake; (4) to predict the effect of fertilizer control on the pdf of P loading, hence the pdf of eutrophic state of the lake.

The elements of this model include: (a) the source of P for a given subcatchment; (b) random precipitation events which lead to transport of P by the two mechanisms described previously and modelled in (c) and (d) below; (c) dissolved P loading, a function of runoff volume; (d) sediment or sorbed P loading, a function of sediment yield; (e) total seasonal loading of dissolved P and sorbed P. These elements which are sketched in Figure 4 are described below.

P-loading events are triggered by precipitation events X_1, X_2, T, in which X_1 is the rainfall amount, X_2 the duration and T the interarrival time between

TABLE 2. Net revenue -- 1977 Dollars.

Farm Practice	Uplands Farm		Ridge Farm		Lowlands Farm	
	$	Rank	$	Rank	$	Rank
CC-CV	12,800	4 (Tie)	23,600	5	22,300	4
CC-CVT	9,600	9	20,300	10	19,100	6
CC-CH	13,400	3	24,100	4	22,900	3
CC-CHT	10,200	8	20,900	8	19,600	5
CC-NT	6,900	11	20,100	11	6,500	11
CB-CV	13,500	2	25,300	2	24,400	2
CB-CH	13,700	1	26,100	1	24,600	1
CB-NT	12,200	7	25,100	3	16,600	9
CB-NTT	8,600	10	21,500	6	13,000	10
CBWH	12,400	6	20,300	9	18,100	7
CBWH-NT	12,800	4 (Tie)	21,100	7	17,600	8

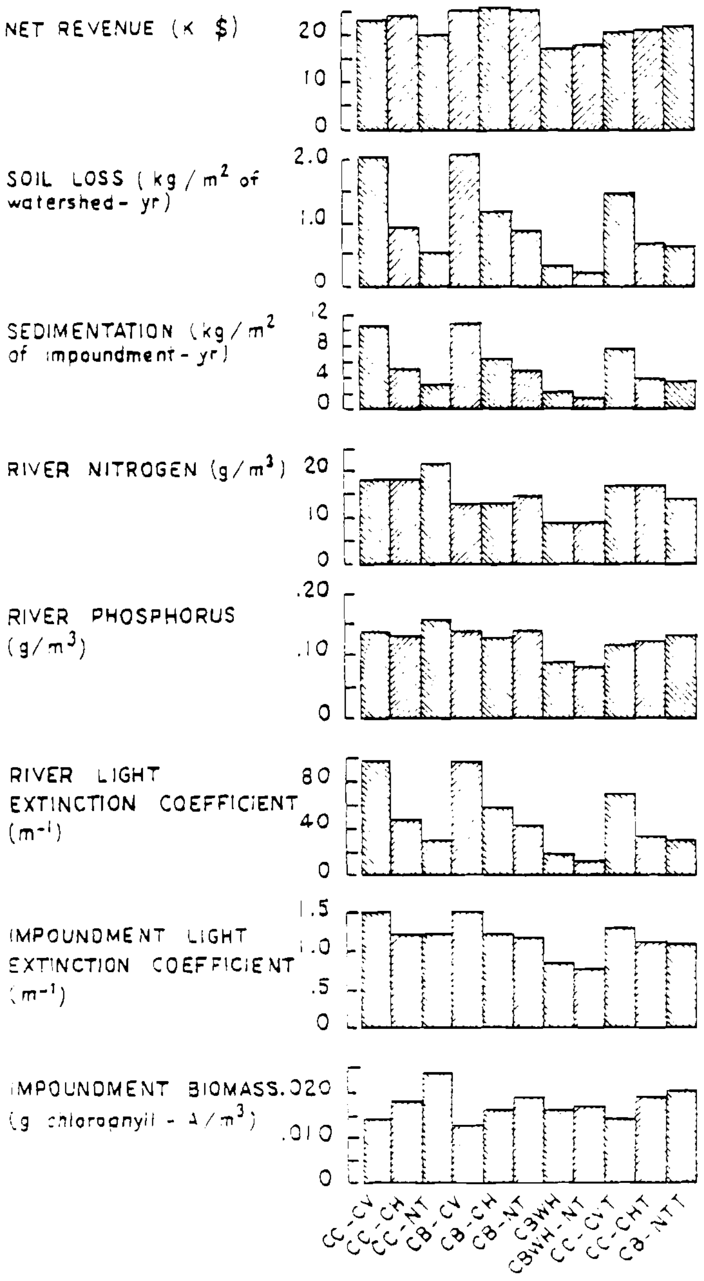

Figure 3. Impacts of farm practices on net revenue and water quality

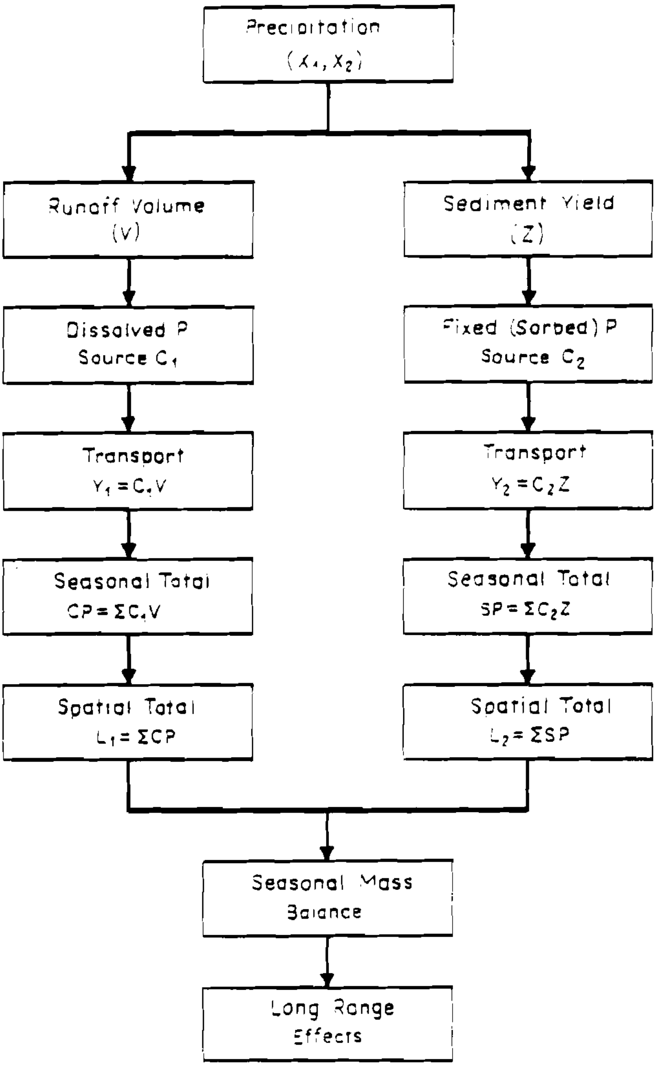

Figure 4. Elements of the stochastic phosphorus (P) loading model

events. X_1, X_2 are dependent random variables, while T is assumed to be exponentially distributed. The precipitation event causes runoff, which carries dissolved P into the lake with a concentration C_1 and sediment yield Z, which carries fixed or sorbed P into the lake in a fraction C_2 of Z. Seasonal loading of P is calculated by adding random numbers of random variables. The model accounts separately for dissolved P and sorbed P. Explicit expressions are given for the mean and variance of each type of P-loading. Then a simulation method is used to estimate complete pdf of these random variables.

Model application (Duckstein et al., 1978)

Results of the model are shown for a subwatershed (Figure 5) of Lake Balaton, Hungary. Specifications of the watershed are given in Table 3.

Hydrological observations have been made by the Hungarian Research Institute for Water Management (VITUKI) on the Tetves subwatershed. Specifically, daily amounts of rainfall are available for the years between 1964 and 1975 at four stations in the watershed while 43 runoff events were recorded between 1964 and 1970 at the outlet of the subwatershed.

In 1975, when the eutrophication process in the lake appeared to be accelerating, VITUKI started new observations in two forms: point measurements of discharge, concentration of sediment of dissolved P and of fixed P (Jolankai, 1975). For this paper, only one year of such data, amounting to 49 points, was available to calibrate preliminary models for C_1 and C_2.

Table 4 compares first order analysis and simulation results; the expected values are within a few percent of each other, but the variances of simulation runs are several times higher than those of first order analysis. This may be explained by the very skewed pdf of P-loading per event and the small number of events per season (mean = 7.43). Some results of simulation runs, each of which was performed with 500 sample points, are shown in Figures 6 and 7.

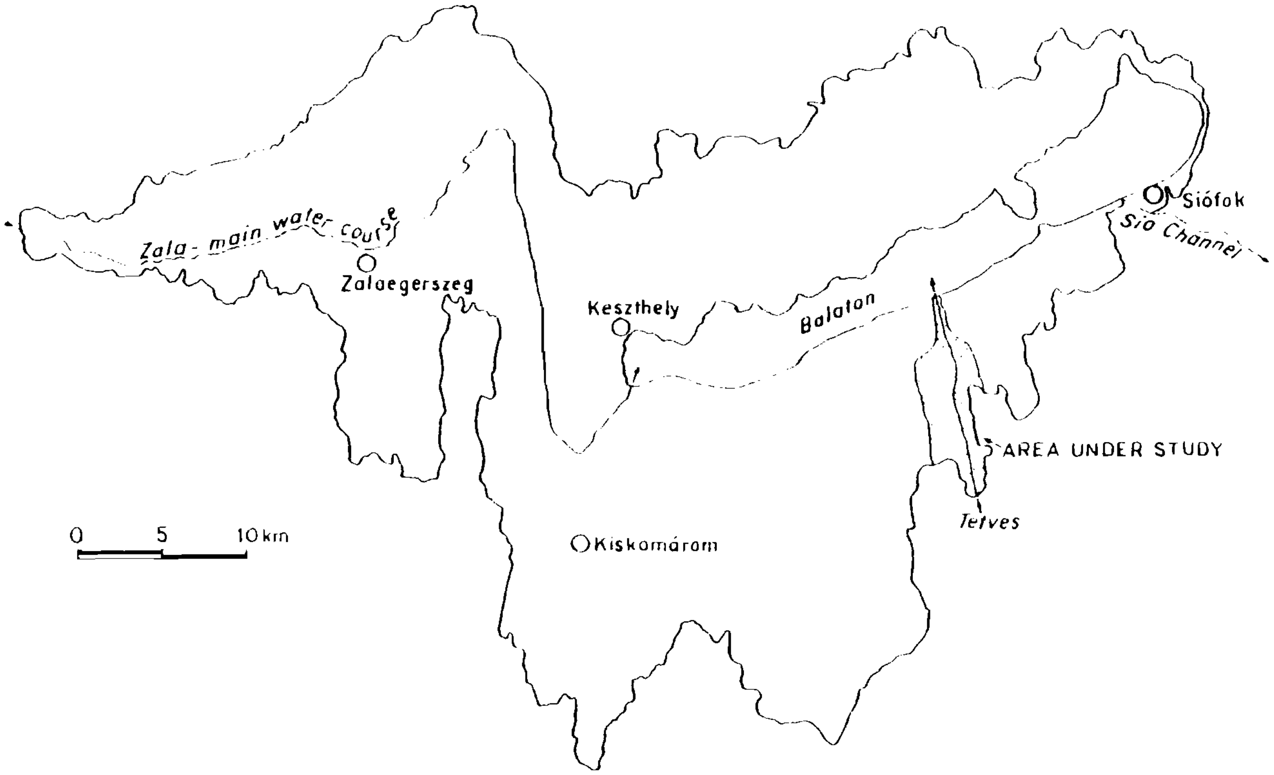

Figure 5. Watershed of the Lake Balaton and the Tetves subwatershed

Table 3. Specifications of the Tetves watershed

Geographical data:

Watershed area: 70 km^2

Watershed length: 15.2 km

Watershed average width: 5.1 km

Average slope of the main water course: 4.1%

Soil data:

Loess: 39%; sandy loam: 30%; gravel and sand: 27%; other: 4%

Land use data:

Agricultural land: 70%; meadow: 20%; forest: 6%; vineyard and orchard: 4%

Slope categories:

0-5%	5-12%	12-25%	25-35%	Average
30%	30%	34%	6%	11%

Table 4. Comparison of first order analysis (FO) and simulation (SI) statistics

		Dissolved (CP)		Sorbed (SP)		pdf fit to CP*		pdf fit to SP*	
		FO	SI	FO	SI	a	b	a	b
Per event	mean, tons	0.105	0.110	0.700	0.688	0.280	2.54	0.216	0.314
	variance	0.0105	0.0435	0.73	2.19				
Seasonal	mean, tons	0.780	0.748	5.20	4.63	1.63	2.17	1.30	0.271
	variance	0.190	0.344	10.20	16.5				

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*The gamma pdf fitted to the simulation results has the form:

$$f(x) = \frac{a^b x^{b-1}}{\Gamma(b)} e^{-ax}$$

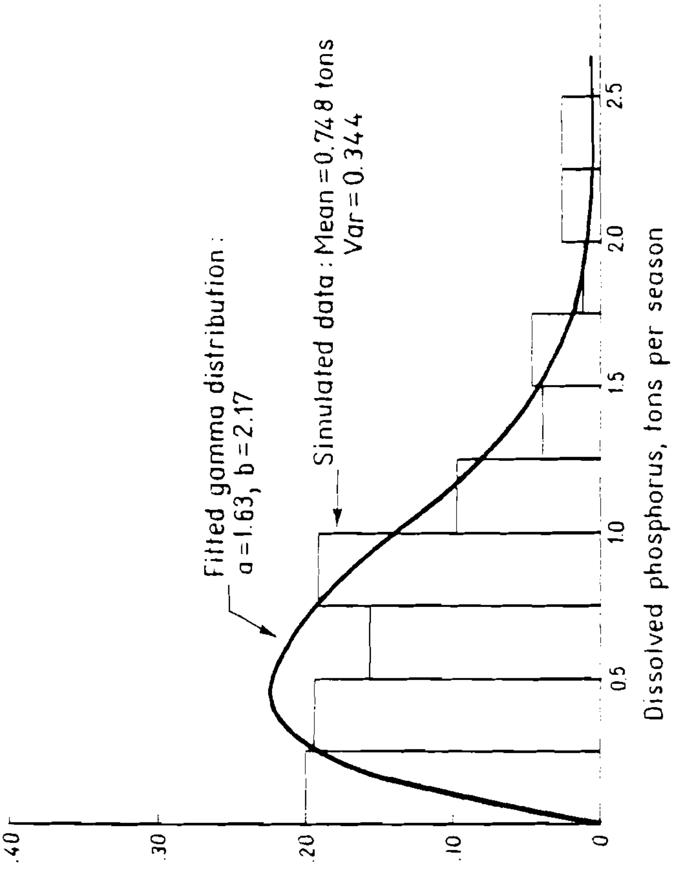

Figure 6. Simulated seasonal loading of dissolved P

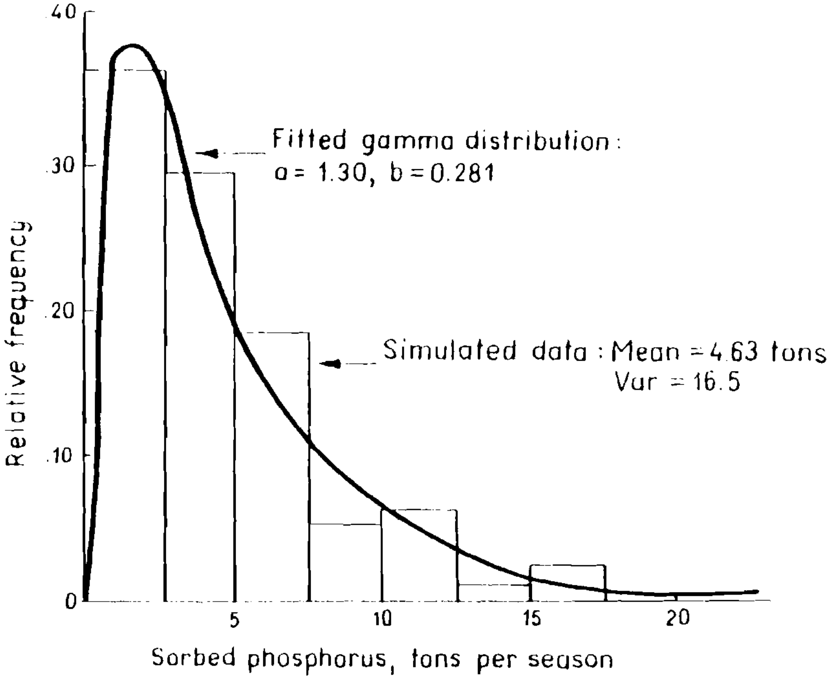

Figure 7. Simulated seasonal loading of sorbed P

3. DISCUSSION: COMPARISON OF THE MODELS

Both models analyze the following pathway of processes: watershed - management alternatives - conveyance of the pollutants - impoundment water quality. Being engineering models, they can readily be used for eutrophication control planning, as recommended by Bogardi and Duckstein (1979). Table 2 and Figure 3 show that generally there is no single optimal solution concerning net revenue and water quality parameters. Sometimes the best policy corresponding to one of the criteria, such as economics, is even not feasible as far as another criteria, such as algae biomass is concerned. As a result, we claim that the evaluation of agricultural practices is a multiobjective or multicriteria problem and current research is directed in that line.

Both models acknowledge the fact that there is a general lack of data to serve as a direct basis for estimating the model parameters associated with several types of practices. Subjective estimates must often be relied upon, particularly in the watershed submodel.

The Meta Systems model endeavors to tackle the watershed, the river network and the impoundment in equal depth. In order to keep the model operational, long-term average loadings are calculated. In contrast, the stochastic loading model, in its present form, considers mostly the watershed, while processes in the river network and the impoundment are simplified. As a result, statistical inferences can be reached; specifically, preliminary results show that there is considerable variance in P loading and that the pdf of both forms of P loading are very skewed gamma distributions. Thus, it is important to consider the effects of uncertainties associated with model parameter estimates and climatologic variations in developing realistic assessments. On the other hand, results of the Meta Systems model also reveal that in order to properly evaluate practice impacts, it is necessary to go beyond an edge-of-field analysis of pollutant loadings and to consider instream pollutant transformations and interactions which are responsible for water quality changes.

ACKNOWLEDGEMENTS

Research leading to this paper was partly supported by the Hungarian Research Institute for Automation and Computer Techniques. The participation of L. Duckstein in the research was greatly appreciated. Also, IIASA, by initiating cooperation between groups of researchers, gave us the right sort of stimulus.

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APPENDIX A: AGENDA OF THE CONFERENCE

SMOLENICE CASTLE, ČSSR APRIL 23-27, 1979

INTERNATIONAL CONFERENCE
ON
ENVIRONMENTAL MANAGEMENT OF AGRICULTURAL WATERSHEDS

AGENDA

Monday morning, April 23

Opening Session

10:00-10:15	Welcoming Address - J. Janovic, Minister of Agriculture, CSSR
10:15-10:30	Welcoming Address - R. Levien, Director of IIASA
10:30-10:50	Addresses by Czechoslovak IHP Committee, WMO, ICID
10:50-11:20	O. Vasiliev, Deputy Director of IIASA and Leader of the Resources and Environment Area (IIASA)
11:20-11:50	G. Golubev (IIASA), Systems aspects of environmental management for agricultural watersheds
11:50-12:30	D. Pimentel (U.S.A.), Land use policies: Environmental degradation and energy resources

Monday afternoon, April 23

Land Use and its Impact on Water Resources

14:00-14:40	M. Holý (ČSSR), Land use and its impact on water regime
14:40-15:10	I. Shiklomanov, (U.S.S.R.), Agricultural land use effect on river runoff
15:10-15:25	V. Vaníček, (Č.S.S.R.), Water as the dynamic indicator of the ecological valency of the rural landscape structure and integrity of its environment
15:25-15:40	W. De Man, (Netherlands), Some remarks on the element of space in environmental management of agricultural watersheds
15:40-15:55	L. Rex, (U.S.S.R.), Influence of agricultural land use on river runoff
15:55-16:15	Coffee Break
16:15-16:30	J. Balek, J. Skořepa, (Č.S.S.R.), Land use impact on the hydrological and hydrogeological regime of representative catchments of the Czech-Moravian Hills
16:30-16:45	T. Pačes, B. Moldan, (Č.S.S.R.), Differences between the runoff of eleven chemical elements from agricultural and forested watersheds

16:45-17:15	H. Liebscher, (F.R.G.), Results and experiences of studies in small watersheds on the influence of forestry and agriculture on the runoff regime of rivers in the F.R.G.
17:15-17:30	H. Takehara, (Japan), Forestry management in its relation to agricultural practice
17:30-18;00	Discussion

Tuesday morning, April 24 — Agricultural Management Practices and their Impact on Water Resources

08:30-09:10	R. Keller, (F.R.G.), The hydrological role of agricultural practices
09:10-09:40	G. Hollis, (U.K.), Man's effect on the hydrological regime in rural areas of the United Kingdom
09:40-10:10	A. Voronin, F. Zaidelman, L. Karpachevsky, (U.S.S.R.), Effect of agricultural activity on hydrological regime of landscape
10:10-10:25	M. Kutílek, (Č.S.S.R.), The influence of soil surface quality upon water regime of the region
10:25-10:45	Coffee Break
10:45-11.00	P. Warmerdam, (Netherlands) Hydrological effects of drainage improvement in the Hupselse Beek Catchment Area in the Netherlands"
11:00-11:40	D. Zachar, (Č.S.S.R.), Ecological consequences of water erosion on watersheds
11:40-12:30	Discussion

Tuesday afternoon, April 24 — Management of Groundwaters for Agricultural Production

14:00-14:30	J. Benetin, (Č.S.S.R.), Care for underground water regime in agricultural practices
14:30-15:10	S. Antontsev, O. Vasiliev, S. Rybakova, V. Sabinin (U.S.S.R.), Mathematical modeling of soil and groundwater regimes
15:10-15:40	G. Kovacs, (Hungary), Flow and storage of soil moisture
15:40-15:55	I. Ladunga, (Hungary), AQUALIBRA 1.0: A model characterizing the occurrence of low soil moisture
15:55-16:10	I. Mucha, P. Pospíšil, L. Melioris, (Č.S.S.R.), Three-dimensional modelling of groundwater flow: a tool for solving groundwater problems in agricultural areas

16:10-16:30	Coffee Break
16:30-17:00	C. Young, (U.K.), The impact of agricultural practices on the nitrate content of groundwater in the principal U.K. aquifers
17:00-17:15	B. Novák, (Č.S.S.R.), The effect of fertilizers on the pollution hazard of water with nitrates
17:15-17:30	P. Rijtema, (Netherlands) The offset of grassland farming on nitrogen leaching
17:30-17:45	N. Senesi, M. Polemio, (Italy), Trace element contents of inorganic fertilizers and relative supplies to soils
17:45-18:00	J. Streďansky, J. Benetin, J. Antal, (Č.S.S.R.), Complex of agrotechnical measures in agricultural utilization of soils in the protective zones of underground water sources

Wednesday morning, April 25 — Management of Groundwaters for Agricultural Production (continued)

08:30-08:45	J. Hraško, A. Môcik, O. Sustykevičova, T. Repka, (Č.S.S.R.), Some dependences between intensity of fertilization and amounts of nitrates in ground waters of the Zitny Ostrov area
08:45-09:00	M. Malý, J. Šálek, (Č.S.S.R.), Effects of irrigation with wastewater and septicized sewage sludges on the environment in agricultural watersheds
09:00-09:15	J. Czysewski, M. Furmanska, M. Nawalany, E. Trykoźko, (Poland), The concept of simulation model of the agricultural pollution in soil- and groundwater
09:15-09:30	J. Quast, H. Diersch, (G.D.R.), Use of confined aquifers for underground storage of irrigation water, especially for infiltrated sewage
09:30-09:45	J. Stibral, J. Vavra, (CSSR), Underground water contamination with Nitrogen
09:45-10:15	Discussion
10:15-10:35	Coffee Break

Wednesday morning, April 25 (continued) — Environmental Management of Irrigated Agriculture

10:35-11:15	G. Skogerboe, G. Radosevich, (U.S.A.), Water pollution control strategy for irrigated agriculture in the U.S.A.
11:15-11:55	I. Stepanov, A. Sabitova, (U.S.S.R.), Control of the melioration state of irrigated lands by chemical composition of drainage waters

11:55-12:25	A. Hornsby, (U.S.A.), Management of water quality impacts of irrigated agriculture

Wednesday afternoon, April 25 **Excursion**

Thursday morning, April 26 **Environmental Management of Irrigated Agriculture** (continued)

08:30-09:00	P. Wierenga, C. Duffy, J. Hernandez, (U.S.A.), Effects of irrigation on return flow quality in the Rio Grande
09:00-09:15	G. Skogerboe, W. Walker, R. Evans, (U.S.A.), Application of salinity control planning framework to the Colorado River
09:15-09:45	S. Nerpin, (U.S.S.R.), Physical fundamentals of Mathematical models of water- and salt transfer in soils
09:45-10:15	I. Szabolcs, G. Varallyay, (Hungary), Soil salinity problems in watersheds
10:15-10:35	Coffee Break
10:35-11:05	B. Rozanov, (UNEP), Management of water-salt regimes under irrigation in arid lands
11:05-11:20	L. Kadry, (FAO), Soilwater-salinity relationship in the Hilla-Diwamiya (Iraq) drainage study
11:20-11:35	V. Bobschenko, (U.S.S.R.), Water and salt balance control and groundwater regulation by means of drainage, agricultural engineering and reclamation methods
11:35-11:50	V. Penkovsky, V. Aemich, (U.S.S.R.), Mathematical models of salt motion in soils
11:50-12:30	Discussion

Thursday afternoon, April 26 **Surface Water Quality Under Fertilizer and Pesticide Usage**

14:00-14:40	D. Haith, (U.S.A.), Land use and water quality - a review of North American empirical studies
14:40-14:55	A. Bredihina, V. Moskovkin, Yu. Yurkov, (U.S.S.R.), Methodology to estimate transport of poisonous chemicals under intensive farming taking into account standards to protect water bodies
14:55-15:10	V. Zajíček, B. Válek, (Č.S.S.R.), Water contamination by agricultural practices in peneplain-type watersheds

15:10-15:25	V. Kudeyarov, V. Bashkin, (U.S.S.R.), The nitrogen balance in small river basins under agricultural and forestry land use
15:25-15:40	P. Valpasvuo, (Finland), Water-related environmental problems of agriculture in Finland
15:40-15:55	F. Massantini, F. Caporali, (Italy), Inorganic nitrogen contents of streams draining agricultural and forested watersheds in central Italy
15:55-16:15	Coffee Break
16:15-16:45	V. Ladonin, (IAEA), The behavior of herbicides in soil under different levels of fertilizer application
16:45-17:15	T. Lyons, (U.S.A.), Simulation of runoff quality from rural watersheds
17:15-17:30	M. Holý, J. Vaška, K. Vrána, (Č.S.S.R.), The deterministic model of nutrient transport at a catchment area level
17:30-18:00	Discussion

Friday morning, April 27 — Environmental Management of Complex Agricultural Systems

08:30-09:10	D. Haith, R. Loehr, (U.S.A.), The role of soil and water conservation practices in water quality and non-point source pollution control
09:10-09:40	I. Bogárdi, (Hungary), W. Walker, J. Keuhner, (U.S.A.), Assessing the water quality impacts of agricultural practices--some methodological comparisons
09:40-09:55	L. David, (Hungary), Watershed development approach to control the eutrophication of shallow lakes
09:55-10:10	K. Frohberg, (IIASA), C. Taylor, (U.S.A.), Optimal agricultural erosion-sedimentation control
10:10-10:30	Coffee Break
10:30-11:30	Short reports of the chairmen and/or rapporteurs of the sessions
11:30-12:30	General Discussion

APPENDIX B: LIST OF PARTICIPANTS

LIST OF PARTICIPANTS

Dr. Emil BOGDANOV
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APPENDIX C: LIST OF THE CHAIRMEN AND RAPPORTEURS

Chairmen and Rapporteurs

MONDAY, 23 April (Afternoon)

Land Use and its Impact on Water Resources

Chairman: Prof. Dr. Reiner KELLER (FRG)
Rapporteur: Prof. David PIMENTEL (USA)

TUESDAY, 24 April (Morning)

Agricultural Management Practices and their Impact on Water Resources

Chairman: Prof. Istvan SZABOLCS (Hungary)
Rapporteurs: Prof. Gaylord SKOGERBOE (USA)
Prof. Jan BENETIN (CSSR)

(Afternoon)

Management of Groundwaters for Agricultural Production

Chairman: Prof. John HERNANDEZ (USA)
Rapporteurs: Prof. Miroslav KUTILEK (CSSR)
Dr. George HOLLIS (United Kingdom)

WEDNESDAY, 25 April (Morning)

Environmental Management of Irrigated Agriculture

Chairman: Prof. Milos HOLY (CSSR)
Rapporteurs: Dr. T. Clark LYONS (FRG)
Prof. Franco MASSANTINI (Italy)

THURSDAY, 26 April (Morning)

Environmental Management of Irrigated Agriculture (contd.)

Chairman and Rapporteurs: same as Wednesday morning

(Afternoon)

Surface Water Quality Under Fertilizer and Pesticide Use

Chairman: Dr. L.T. KADRY (FAO)
Rapporteurs: Prof. Sven JANSSON (Sweden)
Dr. Geoffrey MANCE (United Kingdom)

FRIDAY, 27 April (Morning)

Environmental Management of Complex Agricultural Systems

Chairman: Prof. Douglas HAITH (USA)
Rapporteurs: Ing. Zdenek KOS (CSSR)
Prof. Gyorgy KOVACS (Hungary)