Further reading: Wooldridge ed. 1991; Listori (WB) 1990; Mather/Bos (PEEM) 1989; Chanlett 1973

4.4 Control of Health Risks from Drainage Effluent or Surface Runoff

High fertiliser concentrations, pesticides and toxic trace element residues in drainage or surface runoff effluent may pose a health risk to downstream users if, after dilution with fresh water, the health advisory levels (HAL) are not observed (Table 4-14). Some elements are essential to human health at appropriate concentrations but at elevated concentrations cause damage to vital organs and symptoms of toxicity.

Most important are those metals which (bio-)accumulate in the food chain and thus in the human body or other organisms. Important issues regarding chemicals in wastewaters are also addressed in sections 2.1, 2.5 and 3.2.4. The same guidelines regarding quality standards are applicable for drainage effluents from agricultural lands.

Further reading: Hornsby in: Stewart ed. (ASA) 1990

5 Agronomic and other Measures for Environmental Management

Key words:

Soil and Crop Management Practices; plant manipulation; soil and crop mangement techniques for water conservation; soil tillage; crop types, varieties and cropping patterns; pollution and degradation; public intervention; nutrient management; pest management practices; heavy metal pollution; air pollution control;

Cross-references:

Part I sections 2.3; 9.1-4

Part II sections 1.3; 2.2; 2.3; 3.3; 3.4

Main Reference:

Lal ed. 1991; ISTRO 1991; Pereira 1990;

Irrigation is aimed at *mitigating drought effects* in agricultural production. Thus irrigation technology and water management practices must be seen in the context of agricultural production, and crop management must be seen in the context of land and water management techniques and options. The following chapter gives an outline of new trends in agriculture related to mitigation of drought or water stress, crop modelling in relation to water stress, soil management for soil and water conservation, and crop management in irrigated agriculture.

5.1 Soil and Crop Management Practices

There are various agronomic management options which increase or stabilise soil productivity and yields (Table 5-1). These include:

crop modelling, crop management, conservation tillage, crop rotations, improved drainage, residue management, water conservation, terracing, contour farming, organic and chemical fertilisers, pesticide use, and improved nutrient cycling.

Some of them are outlined in the following sections.

5.1.1 Crop modelling

Drought (water stress) affects the most important growth and metabolic processes of plants (Table 5-2). Understanding these processes has led to an improved recognition of the mechanisms of stress escape, avoidance and tolerance and of the related morphological and physiological characteristics (Table 5-3).

Crop modelling of water stress and water management can be an important tool in interpreting natural processes or to be utilised in irrigation scheduling:

- modelling physiological processes,
- modelling flux of water, solutes and assimilates, and quantifying the related resistances on roots, stems and leaves; this allows, for example, recognition of water stress avoidance and prediction of impacts from flux losses (eg groundwater pollution),
- modelling growth processes to manage crops and simulate the consequences of crop management options,

- modelling relationships between water use and yield, including models of agroclimatic influences, energy balances, soil-plant-water fluxes, transpiration, etc.

Source: Pereira 1990

Progress made in modelling has practical implications on agronomic (and irrigation) research and should provide the scientific background for irrigation planning and design and agronomic extension packages. Some of these models have already been treated in detail in sections 2.3, 2.4, 3.1 and 3.2.

Progress in breeding new rice varieties which transpire less **methane** into the atmosphere or produce less methane in the rizosphere are mentioned in Part I section 5.3. Efforts have also been made to breed new varieties which use **fertilisers**, namely nitrates, more efficiently, thus reducing water pollution risks and reducing nitrous oxide emissions (see Lantin 1992; Scharpenseel et al. ed. 1990; Boumans ed. 1990; Kimball ed. 1990).

Although beneficial effects may arise from genetic plant manipulation the potential negative impacts should be clearly seen. Such impacts and risks are still under debate and solutions must be found at the policy level for research activities. It will be essential to follow stricly the safety guidelines before new varieties are introduced at the field level.

5.1.2 Soil and Crop Management Techniques for Water Conservation

Conservation tillage and other soil conservation measures have positively affected the hydrological status of irrigated and rainfed fields and whole watersheds, minimising water shortage and reducing erosion in advanced agricultural farming. Some of these methods and techniques are also incorporated in 'ecofarming', a sustainable agricultural production system with low lewels of external inputs or other appropriate types of site specific farming systems in the developing countries.

A review of current options and their benefits is shown in Table 5-4, covering the following soil management and soil improvement techniques which are aimed at increasing:

- water retention on the surface and control of runoff,
- water yield and water spreading,
- water infiltration and soil storage volume,
- water retention in the soil profile.

The review shows that chemical modification of soil to improve water storage or decrease evaporative and seepage losses, faces important limits. Tillage techniques have a large potential despite small or contradictory effects for some problem soils (alkaline, saline, sodic, acid-sulphate, etc.).

In agricultural systems of semiarid and subhumid regions, options for irrigation or the adoption of drought management techniquesmay may often exist. Such options imply the needs to an economic perspective because modification of a crop system to avoid or minimise the risk of crop failure sometimes implies that farmers accept for some time a lower income although soil fertility is maintained or water resources are preserved in the long-term. Nevertheless, crop management options (Table 5-5) should be evaluated and some available techniques can be adopted in irrigated farming in order to achieve water savings in addition to water saving irrigation techniques (see section 2.3):

- drought risk management (or reducing water demand for irrigation),
- management for controlling the effects of water stress,
- cultivation techniques.

Sources: Pereira 1990; Pereira 1989. Further reading: Kotschi et al. (GTZ) 1989; Cleq/Dupriez 1988

5.1.3 Soil Tillage

Tillage forms an important component of agricultural production technology (Fig. 5-1). Tillage is aimed at preparing the desired seedbed, controlling weeds, managing crop residues, mixing fertilisers or other amendments or pesticides into the soil, improving aeration, alleviating compaction, and optimising soil temperature and soil moisture conditons. Thus, soil tillage plays an important role in achieving agricultural sustainability through its short- and long-term effects on soil processes, eg soil structure, soil organic matter content, rate and capacity for supplying or retaining water and nutrients to crops and also through impacts on soil degradation, and ground and surface water pollution. Consequently, soil productivity, economic profitability and environmental impacts are influenced by tillage operations. Adoption of appropriate tillage systems and techniques of soil surface management can facilitate attainment of agricultural sustainability by reversing degradative trends and restoring the productive capacity of soils.

Note: Aspects of labour saving through mechanisation are beyond the scope of this review.

Soil tillage techniques for improving water use efficiency and increasing nutrient use efficiency may vary for different agro-ecological zones as indicated in Table 5-6. Such technologies are based on principles of soil and water conservation (see above), preventing or minimising degradation (or over-use) of soil and water resources, restoring degraded lands (eg compacted, saline, alkaline soils), and often on reducing dependence on off-farm purchased inputs while enhancing or stabilising the productivity and profitability of the farming system.

The exact nature of tillage operations is soil and crop specific and is related to various farming systems and irrigation water management practices. Specific examples of tillage based technological packages for small and medium sized farms are listed in Tables 5-7 a-b, respectively.

Specific components relevant for irrigation include:

- mulch farming,
- minimum or no-tillage which can reduce the soil degradation which occurs with mechanical tillage in most rainfed agricultural systems; its effect under irrrigation is less clear and much depends on appropriate tillage packages and proper timing of operations; pest problems may be aggravated under no-tillage,
- soil inversion by ploughing, deep subsoiling,
- ridge tillage, raised beds, tied-ridges,
- land clearing.

Source: Lal in: Lal ed. 1991

The following regional reviews of current tillage systems and their impacts on soils are available:

Latin America - Alegre/Cassel/Amezquita (in: Lal ed. 1991),

West Africa - Aina/Lal/Roose (in: Lal ed. 1991). A regional guide to tillage methods is shown in Table 5-8,

Semi-arid African tropics - Hulugalle/Maurya (in: Lal ed. 1991),

Semi-Arid Tropics in general - Laryea et al. (in: Lal ed. 1991),

Conservation tillage in semi-arid tropics - Unger et al. (in: Lal ed. 1991).

The choice of an appropriate tillage system is a function of the natural resource endowments (soils, topography, climate, irrigation), expected crop yields, actual and anticipated erosion rates and net return. Tillage systems in turn affect the types and amounts of inputs required, as reflected in operating costs for materials, labour, and machinery. Tillage

Fig. 5-1

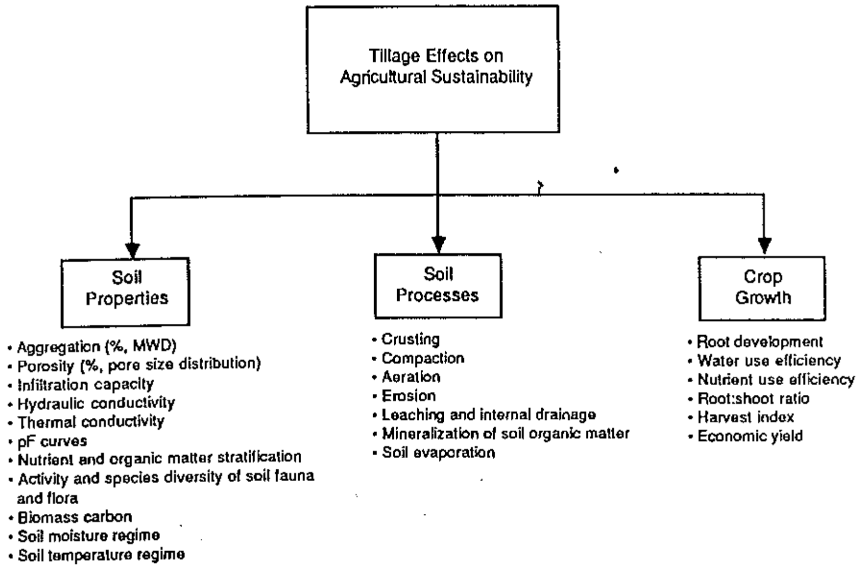


Fig. 2. Tillage effects on agricultural sustainability.

Source: Lal ed. 1991

Fig. 5-2

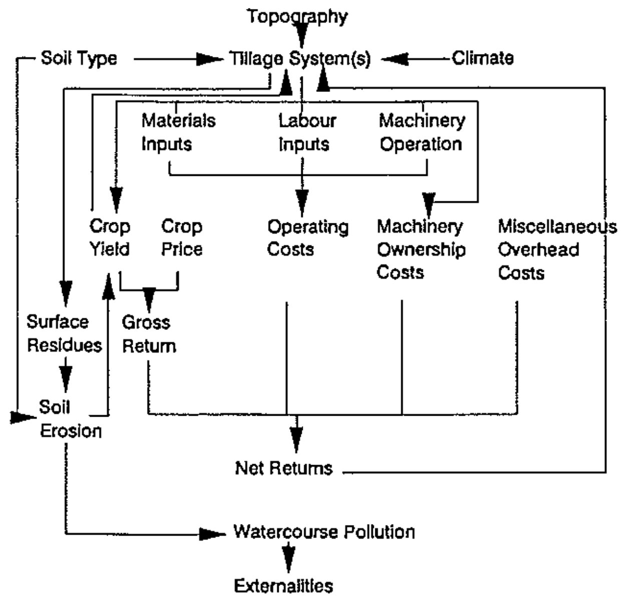


Fig. 1. An overview of the framework for economic analysis of tillage alternatives.

Source: Lal ed. 1991

Fig. 5-3

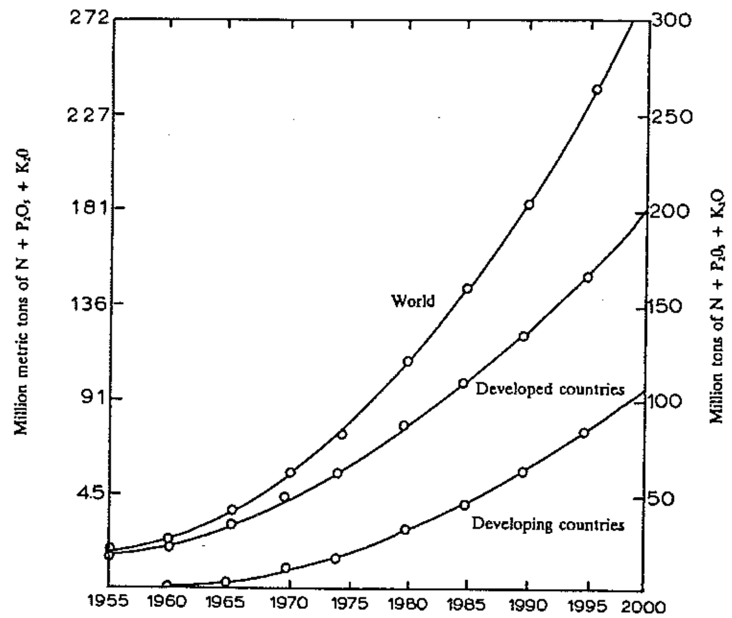


Figure 1. World fertilizer consumption, 1955-1974 (actual) and 1975-2000 (estimated) (Edwards, 1985).

Source: Edwards et al. 1990

choices are also influenced by ownership issues and types and usage rates of different tillage equipment and power units (hand, animal or tractor) available to draw them. Crop yields are a function of crop variety, tillage systems, soils, water management, climate, and management skills. These diverse interrelated factors are shown in a framework for economic analysis of tillage alternatives (Fig. 5-2).

Sources: Stonehouse in: Lal ed. 1991; Lal in: Lal ed. 1991; Laryea et al. in: Lal ed. 1991; van Doren/Triplett in: Lal (IITA) 1977

Further reading in: ISTRO 1991; Lal (IITA) 1977

5.1.4 Pollution and Degradation: Case of Public Intervention

Where there is little or no economic incentive to implement soil and water conserving measures to reduce off-farm impacts and on-farm soil degradation processes, rational farmers should not be expected to adopt conservation tillage methods. On the other hand, where such on-farm incentives do exist or they are realised by farmers, such techniques are typically adopted. External incentives may include government subsidies or mandatory controls and regulations. It has recently been recognised in industrialised countries that off-farm costs from watercourse pollution far exceed the on-farm costs, so that the expenditure of public funds as part of the intervention package would be justified. Such a targetted approach to offering financial assistance to farmers would be superior to a universal approach, and any subsidy programme should be combined with other elements such as education, extension assistance, and, if necessary, controls and penalties. However, such programmes are difficult to introduce in most developing countries due to budgetary restrictions and different perceptions or priorities. Development aid may assist to enforce such programmes in areas where control measures are required (see also sections 2.3, 2.4, 3.3 and 4.).

Source: Stonehouse in: Lal ed. 1991

5.2 Reducing Risks from Uses of Agro-Chemicals

5.2.1 Nutrient Management Practices

The use of mineral fertilisers is steadily increasing in both industrialised and developing countries (see Fig. 5-3 and Table 5-9; see also Part I section 2.3).

During the period 1973 until 1986 the total application of N-fertilisers increased from 18 to 33 M t in developing countries, mainly caused by increases in Asia with the use of high yielding varieties (FAO 1987). Further increases in the range of 4-5 % can be expected (in some countries the increase may be in the range of some 10%, eg in China and Malaysia) and a larger proportion is often used under irrigation. For example, the production of rice increased from 256 M t (1969) to 467 M t (1985) in the Far East.

The average figures of fertiliser uses in Asian countries are shown in Table 5-10.

It is expected that by 2000 the total consumption in developing countries (except CIS-states) will exceed 100 M t of N-P-K fertilisers, which is equivalent to the consumption of industrialised countries in the early 80s. Therefore, side-effects of the fertiliser use must be carefully monitored in future.

Agriculture is - with regard to salt, nutrient and sediment loads - a main polluter of groundwaters and surface waters which eventually results in the eutrophication of surface waters (see Part I section 2.3). Nutrients are derived from fertiliser applications, either as mineral or organic fertilisers, or from wastewater applications (see Part I sections 3.5

and 3.6). Some nutrient losses, either to waters or the atmosphere, are unavoidable and should be regarded as part of the natural cycling of elements. Environmental concerns are related to excessive non-productive losses of plant nutrients from the soil, particularly N and P. Although firm evidence of widespread impairments in developing countries are - to date - rare, the following losses may occur:

Nitrogen - leaching of nitrates, production of ammonia and nitrious oxides by volatisation and denitrification, soil acidification,

Phosphorus - leaching is minor, but run-off losses of soluble P and especially the transport with sediments during erosion can be of importance.

Other side-effect are related to **impurities** in fertilisers, especially those derived from the widespread use of rock phosphate. Impurities of cadmium (Cd; see Table 5-11) and lead (Pb) are known and gaseous fluoride (F) impairments occur especially during the manufacturing process. Under normal conditions and applications, these impairments do not create serious health risks to farmers, although close monitoring is recommended if such fertilisers are in use (McLaughlin 1991).

The **indiscriminate** application of fertilisers (and pesticides) in connection with over-irrigation or poor surface irrigation water management leads to the leaching or surface run-off of applied chemicals into downstream waters. There is a widespread opinion that the large scale increase in fertiliser use may be justifiable because the cost to individual farmers is less than costs for other means to increase yields. Research has revealed, however, that increased fertiliser rates are closely related to water pollution than to increased yields (Holy 1980). This indicates that it would be sensible to combine the application of mineral and organic fertilisers with other measures aimed at raising soil fertility, eg by reducing soil erosion, improving tillage practices, crop demand oriented irrigation practices etc., and that fertiliser rates should only be increased after all other agronomic techniques having less or no adverse environmental impacts had been utilised (see Fig. 5-4 a).

It is obvious that nutrient management is probably the most effective measure to prevent soil contamination and water pollution (Fig. 5-4b) with the same applying to pesticides. The easiest method, besides low application rates, is to prevent **soil erosion** and to prevent **excessive leaching** into surface and groundwaters. In irrigation it is unavoidable that some fertilisers and chemicals are leached into the deeper soil horizons or layers (see sections 2.2, 2.4 and 3.3). However, this seems less dangerous than their direct transport into the hydrological system through runoff, especially in paddy systems with continuous flow. In soils many chemicals are buffered, filtered and most of them are transformed after some time. Hence, leaching at low rates after this interactive period is less hazardous to the water system.

Major concern should be given to improving the efficiency of utilisation; for example, it is estimated that only 30-35% of the N applied to lowland rice is utilised (Uexkull/Beaton 1990). Some major management decisions to be made in the use of nitrogen fertilisers are as follows:

- selection of a realistic target yield,
- selection of the N-rate to meet this target,
- use of split applications,
- timing of N-application,
- precision placement (eg banding) especially deep placement of urea in rice fields,
- history of manure use and rate,
- history of legumes in the rotation,
- source of fertiliser N to use,
- use of nitrification inhibitors (to slow conversion of NH4-N to NO3-N),
- avoiding an imbalanced nutrient supply which restricts the net use of N,

Fig. 5- 4 a

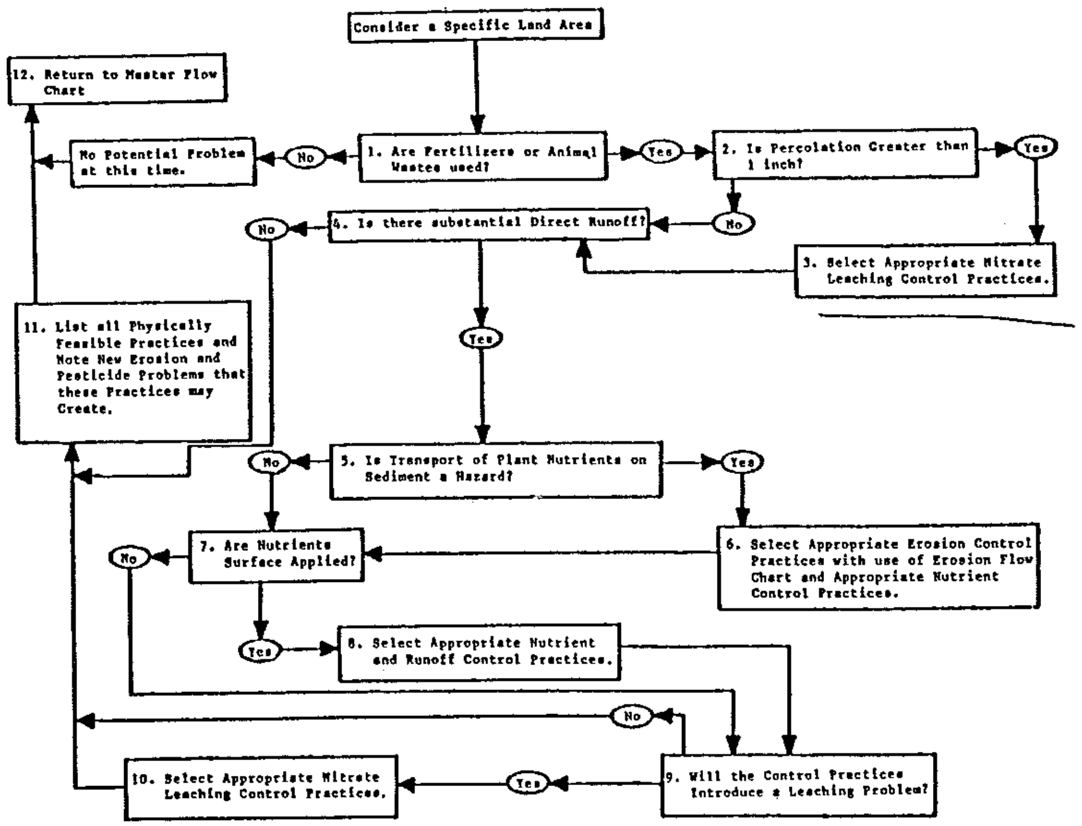
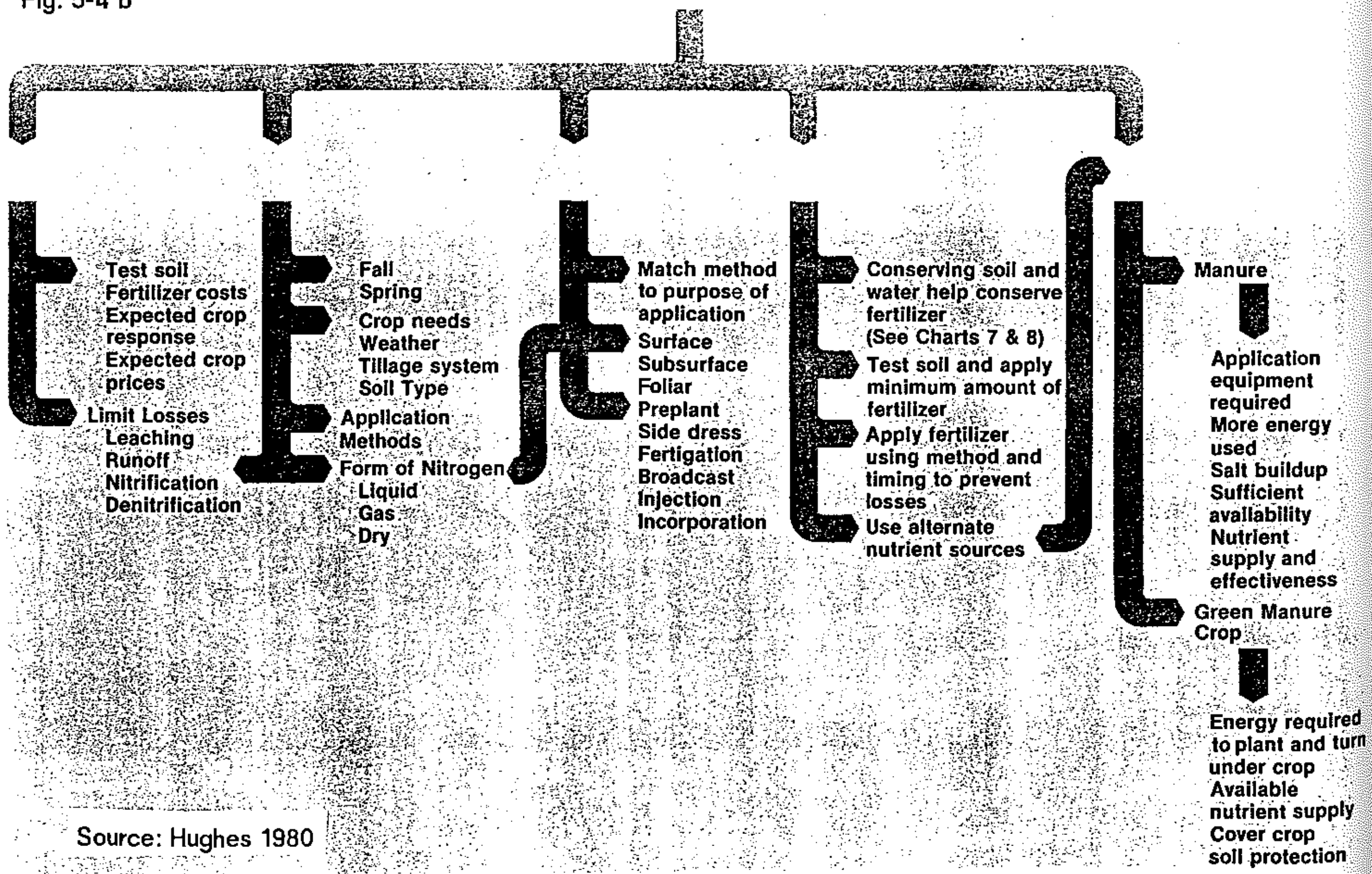


Figure 24: Flow Chart for Assessing Nutrient Pollution Problems and Controls (Frere, et al., 1977)

Source: Canter 1986

Fig. 5-4 b



Source: Hughes 1980

- avoiding unnecessary fertilisation due to incorrect diagnosis of plant deficiency symptoms,
- ensuring healthy and dense crop stands which make use of the fertilisers applied at design rates.

Source: Anderson in: USDA 1988; for rice irrigation: De Datta/Buresh 1989; further reading: Finck 1992, 1991

Various policy measures may also be applicable (see policy options; next section). To summarise, a number of agronomic practices will reduce direct runoff and erosion and, thus, reduce nutrient transport into surface waters or excessive gaseous losses. In irrigation leaching control by water management and associated agronomic methods which can control deep percolation may be used to reduce nutrient losses to the groundwater and surface water systems. A list of common practices is given in Table 5-12.

Sources: Anderson in: USDA 1988; Canter 1986; Holy 1980

Further reading: Stoy/Sattelmacher in: Blume ed. 1990; Conway/Pretty 1988; Kohlmeyer in: Nieder et al. 1987

5.2.2 Pest Management Practices for Pollution Control

Irrigation permits crops to be grown where it is not possible to grow them otherwise and it increases total biomass production, but at the same time it provides conditions conducive to high rates of population development of various pest species. Hence, the use of pesticides is typically high in irrigated agriculture, if other measures of pest control are not undertaken.

The use of pesticides to control pests is still rising sharply in most developing countries. Due to the rather indiscriminate and often inadequate use of pesticides in many localities in developing countries, potential (on-farm) environmental and direct health risks are higher (fatal incidents) than in many industrialised countries (see Part I sections 2.3, 4.3 and 8.3).

The demand for pesticides is predicted to rise from the present level of $ 2,550 M to about $ 5,000 M within a decade. It is likely that the usage of insecticides in Latin America will be 55% of the overall use in developing countries by 1993, and that of herbicides will rise from $ 730 M to $ 1,845 M over the same period. The equivalent fungicide market is likely to rise from $ 368 to $ 1,165 M over this period. The pattern of both regional and national demands, by class of pesticide and by the type of crop, will probably change very little over the period, with a few exceptions, including great increases in Africa.

Sources: Edwards 1987

Fig 5-5 shows a steady increase in the use of pesticides in both industrialised and developing countries. However, figures are often inconsistent and an UNIDO report (1987) shows that there was no increase in the use of pesticides in all developing countries between the period from 1975 to 1985 (Brader in: DSE 1989):

		total	insecticides	fungicides	herbicides	unit
global	1975	2,073	567	844	661	1000 MT
	1985	2,425	483	988	953	"
developing countries						
	1975	533	283	194	57	"
	1985	507	232	201	75	"

Fig. 5-6a shows that there are marked regional differences in the use of various pesticides (fungicides, insecticides, herbicides). In developing countries, insecticides are more important than herbicides, whereas herbicides are widely used in industrial

Fig. 5-5

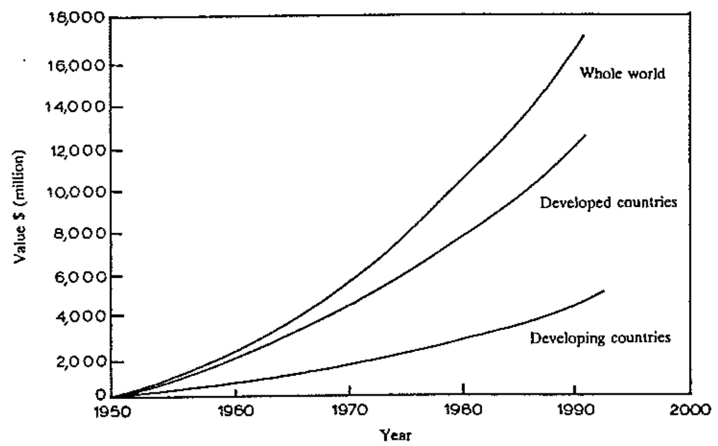
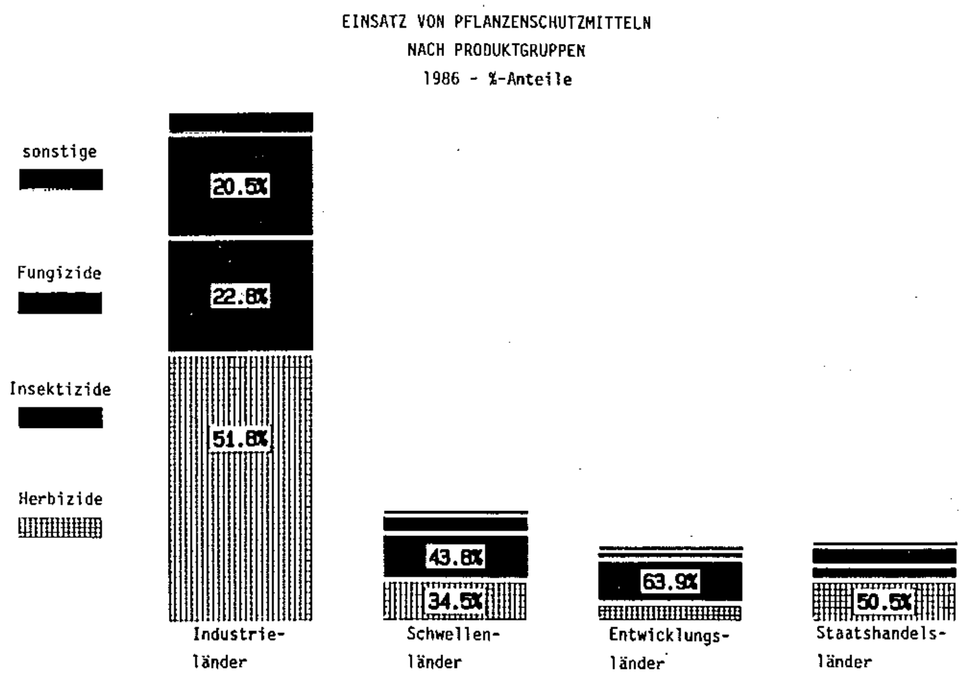


Figure 2. Predicted world pesticide use (Edwards 1986).

Source: Edwards et al. 1990

Fig. 5-6 a



Source: DSE 1989

Fig. 5-6 b

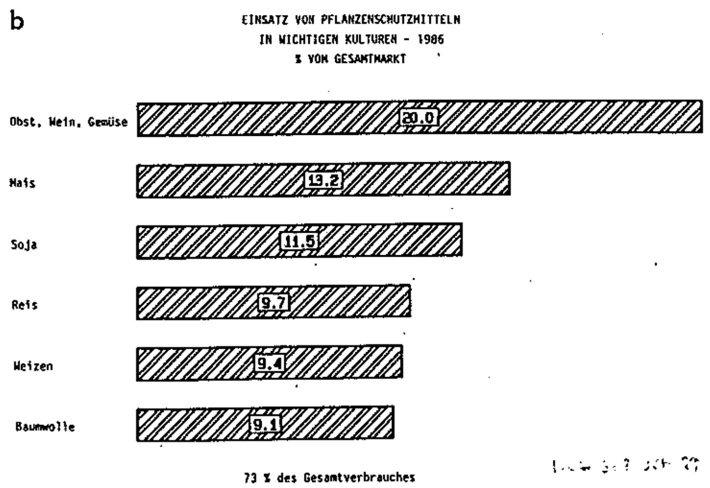


Fig. 5-6 c

- Wichtige Kulturen -
Einsatz von PSM nach Produktgruppen
% vom Gesamtverbrauch
1986

Herbizide	Soja	10.3 %
	Mais	10.3 %
	Weizen	6.8 %
	Obst, Wein	4.7 %
	Reis	4.1 %
	restl. Getreide	3.8 %
	Zuckerrüben	2.4 %
	Baumwolle	2.4 %
Insektizide	Obst, Gemüse, Wein	7.1 %
	Baumwolle	6.5 %
	Reis	3.5 %
	Mais	2.9 %
Fungizide	Obst	3.2 %
	Wein	2.6 %
	Gemüse	2.1 %

73 % des Gesamtverbrauches

countries and Eastern Europe (including CIS). These differences are also caused by different cropping patterns. Pesticides are often used for orchards and vegetables (Fig. 5-6 b), followed by maize, soyabeans and rice. The use of different pesticides for different crops is shown in Fig. 5-6c. Most pesticides in developing countries are probably used for rice cultivation (Hüttenbach in DSE 1989).

The average figures of pesticide uses in Asian countries are shown in Table 5-10.

On the other hand, there are reports from Indonesia about the successful introduction of country-wide integrated pest management practices in rice cultivation. The use of pesticides fell and rice production steadily increased at a reasonable rate (Table 5-13). The programme gives first priority to the use of non-pesticide agents for pest and disease control. For example, this involve taking into account the time of planting, the timing of irrigations, the farming pattern, the amount of fertiliser used, hand weeding, land sanitation measures, and the use of pest restistant varieties. Under such a system, insecticides are applied when the population of insects reaches a pre-dertermined limit or biologigal threshold. The number of pesticide applications per season fell from 4.5 in 1986 to 0.5 in 1988 (FAO cit. in Reus 1992) There are also measures such as mechanical, physical and biological pest control. Thus, mechanical controls seek to eliminate pests by hand, traps or by other equipment. Physical pest control uses high or low temperature, moisture, light or sound waves. Natural pest predators are used in biological pest control.

Source: Kasryna et al. in: OECD 1991d (Eröcal ed.)

The systems description of pesticide-soil-water-plant relations gives an indication about management options (Fig. 5-7). Although the transport into surface water is typically less than 1% of the total application, some agro-chemicals are extremely toxic to fish and other aquatic life so that even a small level of transport from irrigation return flow into the surface water system should be avoided or minimised. There are three general (policy) means to control soil contamination and water pollution by pesticides (and fertilisers):

- reducing **intensity** of agriculture: eg using taxes on fertilisers and pesticides; changing extension messages,
- changing **land use**: using only fertile soils for cultivation and establishing land use zones according to soil properties,
- special **restrictions**: on handling of fertilisers and pesticides; spatial restrictions on pesticide use within protected zones.

Fig. 5-8 indicates how to assess the pollution and associated problems. Generally, there are three strategies to controlling pests in agriculture to ensure that they are kept below the damage threshold:

- ensuring that the pest does not get into the field (sanitation),
- ensuring that the pest has little chance to multiply,
- eliminating the pest: mechanical methods or curative chemical or biological control.

Main advantages of most chemical control methods are speed and effectiveness of controls, flexibility in timing, easy application in comparison with many other methods, and the possible economy of control (eg if manual weed or insect controls are costly).

Main disadvantages are related to possible human health risks and environmental contamination, high costs of safe storage and disposal of containers, requirement to use special equipment for safe and efficient application and especially that the application requires technical skill which is often not available in developing countries. Local conditions must be known in order to assess risks involved in pesticide application in a given project.

Several agronomic methods are applicable for pest control which can be summarised under the headings: improved pesticide use, biological pest control techniques and integra-

Fig. 5-7

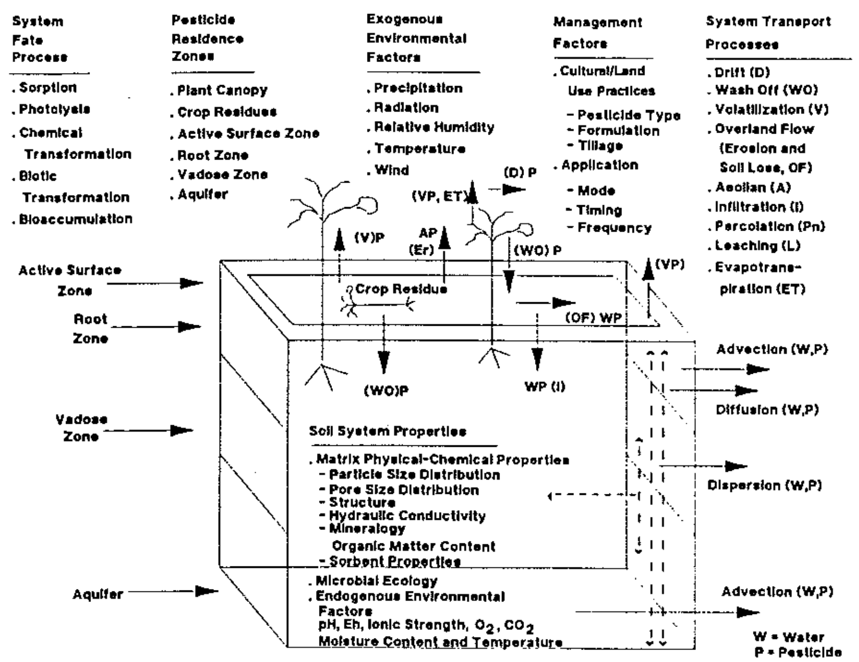


Fig. 14-1. System description of pesticide-soil/porous media-plant interactions.

source: in Cheng ed. 1990

Fig. 5-8

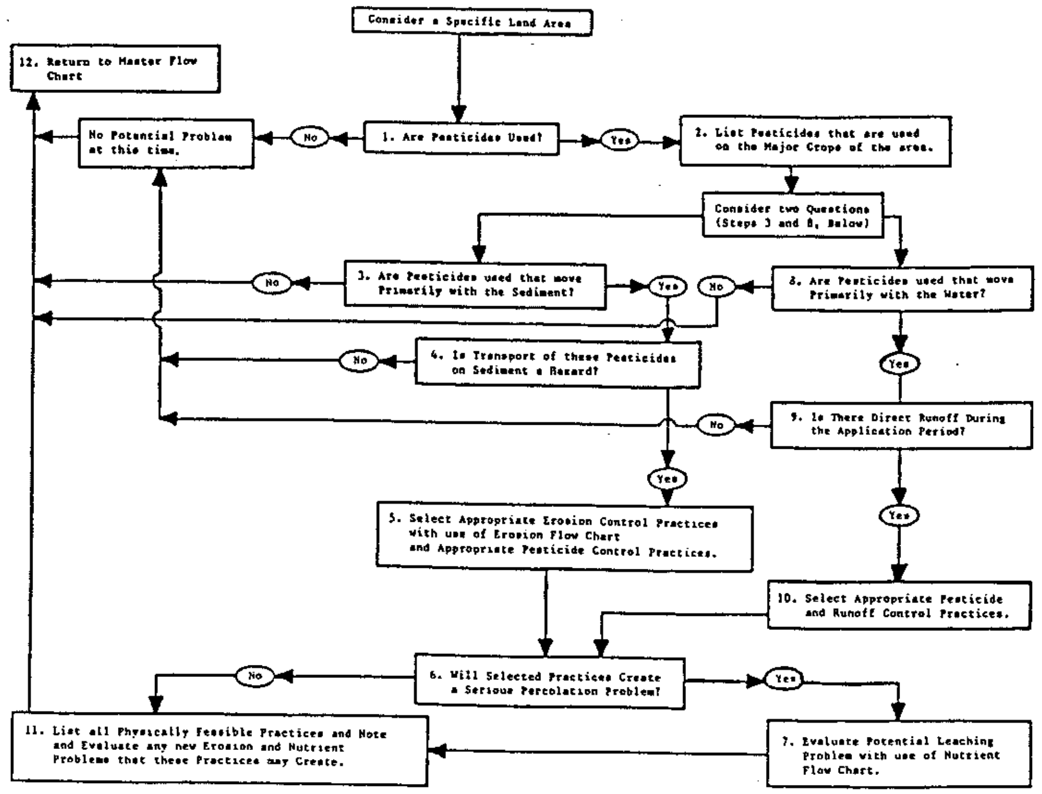


Figure 25: Flow Chart for Assessing Pesticide Pollution Problems and Controls (Frere, et al., 1977)

Source: Canter 1986

ted pest management, including cultivation methods (see also Fig. 5-9). Some important control measures are:

- adoption of **agronomic production techniques** that use methods other than agro-chemical for pest control, eg ecofarming
- strict legal **restrictions on aerial spraying,**
- use of **alternative pesticides** that are not water soluble or less toxic or less persistent and which do not accumulate: for example, use of organophosphates or carbamates instead of organochlorines; avoiding mercurial fungicides, arsenicals, highly toxic organophosphates etc.,
- use of pesticides **specific** to particular pests or groups of pests so as to have minimum side-effects on non-target species,
- optimisation of **pesticide formulation,** eg use of slow release formulations,
- treatment of **infected spots** only and avoiding **excessive treatments,**
- optimisation of application **times** and use of lower application rates,
- **biological control:** use of microorganisms or microbially produced pesticides (eg avermectins; however, the use of biotechnology/genetic engineering is controversial); use of semiochemicals (many pheromones and attractants for pests have been identified and active ingredients isolated for field use, eg in cotton); controlled use of predators and parasites of pests,
- **integrated pest control** and management: this includes any suitable technique to decrease pest populations and maintain them at levels below those causing economic injury (this differs from 'supervised control'): forecasting; scouting; use of crop varieties resistant to pest attack; use of varieties with shorter growth periods; timing of crop sowing/planting and harvesting to avoid pest attack; depth of sowing/planting; careful disposal of plant residues by grazing, burning or ploughing under,
- **cultivation methods** that increase diversity of habitat, flora and fauna: changes in cropping pattern; frequent crop rotations to avoid carrying over of pests; mixed or strip cropping etc..

Sources: Canter 1986; Edwards 1987
Further reading on integrated pest management: eg CON 1990, DSE 1987
Biological control methods are shown in Yaninek/Heren ed. 1989.

The following measures may be used to minimise <u>fungicide</u> use:

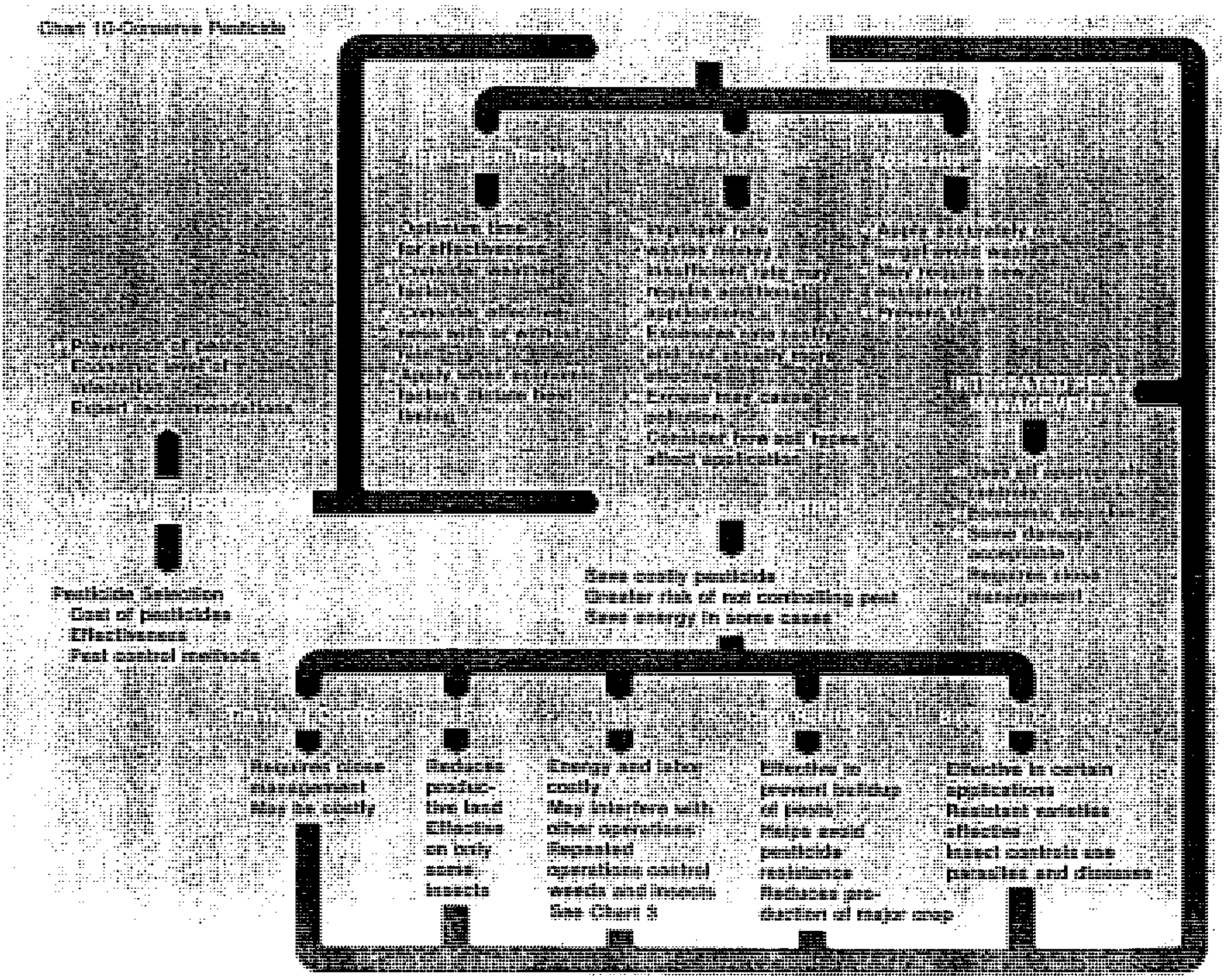
- use of minimal amounts of fungicides based on disease forecasting methods
- use of crop rotations to minimise disease attack,
- better application techniques for fungicides using small amounts and better palcement,
- timing of crop sowing to avoid the disease incidence period or climatic periods favourable to development of the disease,
- use of disease antagonists; eg a number of microorganisms inhibit growth of plant pathogens,
- use of crop varieties that are tolerant or resistant to disease,
- leaving stems dry during irrigation (eg furrow irrigation).

Source: Edwards in: Edwards et al. ed. 1990

Alternative measures for <u>weed control</u> other than herbicides may include:

- preventive measures prior to planting,
- thermal destruction of weeds prior to planting,
- mechanical measures: tillage practices for weed control; row spacing,

Fig. 5-9



Source: Hughes 1980

- agronomic measures such as crop rotation to minimise weed seed germination, or selection of uncontaminated seeds and plant materials; cover cropping to minimise weed seed germination,
- mulches to provide soil cover and inhibit weed seed germination,
- irrigation scheduling to hamper weed growth,
- use of mycoherbicides,
- release of pests of weeds,
- rotation of weed control methods.

Further reading: Loop in: Blume ed. 1990; Edwards in: Edwards et al ed. 1990; FAO 1986

A detailed list of common crop protection practices is given in Table 5-14. Any method which reduces surface runoff (soil erosion) is also effective in reducing pesticide losses into surface water (see Fig. 5-8 and Part I Fig. 3-17).

Major concern should also be given to the increase in on-field delivery efficiency. Present spray technologies are **inefficient** and do not conform to principles of spray physics. New delivery technologies must be based on efficient delivery to the target. With herbicides, control of spray drift is of overriding importance. Major components of pesticide losses in spray processes are assessed as:

- delivery losses are about 60-80%: directly to the soil and the peripheral foliage,
- primary volatilization losses to air some 3-10%: depends on volatility,
- primary particulate drift losses in the air amount to some 3-5% of most sprays.

Source: Himel et al. in: Cheng 1990

Irrigation can also be used to increase the pesticide's **efficiency** and thereby decrease the amount applied per unit of surface area, and to minimise its transport below the root-zone, thereby preventing leaching of the chemical into the groundwater. Irrigation becomes a tool in the control of pesticide **behaviour** in the soil environment (Yaron/Gerstl/Spencer 1985). This potential, however, can only be fully exploited under advanced **water mangement** systems and it requires a basic understanding of the fate of pesticides in soils (see Part I sections 2.3 and 3.4). Both preconditions are probably not yet met under prevailing conditions in many developing countries.

Irrigation may also be used to control pests by manipulating the pests' habitat. Well planned flooding and drying out for local pest control may be used prior to planting (eg rice caseworm). Temporary ponding with about 100 mm of water may also be used for weed control. On the other hand, water stress during the growing season makes most crops susceptible to a number of diseases (eg CON 1990).

Eficacy. Further improvements in the application of pesticides are also related to attempts to evaluate efficacy under field conditions. Guidance for such biological evaluations are for example given in FAO paper 'Guidelines on Efficacy Data for the Registration of Pesticides for Plant Protection' (FAO 1985b) and the FAO 'Code of Conduct' or other relevant FAO -guidelines. Other national institutions and international organisations (eg CON 1990, CTA 1989; Alebeek (CTA) 1989; GIFAP 1983) have been producing documents on the safe and effective application of pesticides.

Registration. In addition, the potential environmental risk of a given pesticide should be assessed separately for the agronomic, managerial and environmental conditions under which the pesticide is used. These conditions may differ significantly from those in industrialised countries where most pesticides are being tested for their environmental effects. **National registration authorities** and **research institutions** are urged to evaluate environmental risks implicit in the proposed use by conducting field observations and test programmes to supply specific information on application and use pattern, the fate and possible occurence of residues in relevant parts of the environment, and the effects of predicted exposures on non-target species. Such programmes and monitoring activities are outlined in FAO 'Guidelines for the Registration and Control of Pesticides' (FAO 1985a: chapter 8.5).

Waste disposal. Special attention should also be given to the handling of waste pesticides on the farm. Recommendations for methods of safe disposal are outlined in FAO 'Guidelines for the Disposal of Waste Pesticide and Pesticides Containers on the Farm' (FAO 1985c). Since most farmers in developing countries are layman in terms of handling chemicals and understanding chemical reactions, educational and training programmes for safe handling, application and disposal are essential to minimise soil and water impairments, biological imbalances and to reduce health risks.

Further reading: Loop in: Blume ed. 1990;

Monitoring. The adequate management of pests in irrigated agriculture requires a monitoring programme. Pest surveillance, a process that collects, analyses and interprets data for pest management decision-making is best suited to ensure that adverse impacts of pesticides on users, consumers and natural resources are avoided or minimised. Such a system, established by the agricultural extension service, should train farmers on the identification of pests and their natural enemies so that regular field surveys can be used in decision making on control methods by identifying economic pest thresholds levels (an example from Thailand is given in GTZ 1982; other project examples are in DSE 1987). Joint projects by UNDP/FAO and national plant protection agencies have produced documents to train the extension staff (eg the UNDP/FAO Plant Protection Project in Botswana).

Rapid assessment methods for potential hazards from pesticides to soil contamination and water pollution are shown in section 3.2.4.

5.2.3 Heavy Metal Pollution of Agricultural Lands

Most emphasis to date has been given to the conditions of disposal of sewage sludge and wastewater, but the principles involved can also apply to other metal-containing materials deposited on agricultural lands or effluents coming from agricultural lands. Guidelines for regulatory control may comprise:

- experimental approaches: need for a sound experimental base which integrates such factors as composition and application rate with agronomic and irrigation practices; evaluation of long-term effects on plants and soils must be included,
- legislative approaches: restricting applications; controlling application; defining maximum permissible contents; controls of heavy metal contents of foodstuff; combinations of these with restrictions related to land use and crop type.

Sources and further reading: Blume ed. 1990, Tiller 1985

The assessment of the behaviour of soils with regard to heavy metals is treated in section 3.2.4; further information on the reuse of sewage for irrigation is given in section 2.5.

Sources: Blume in: Blume ed. 1990; Brink in: Lessafre 1990; Himel et al. in: Cheng ed. (SSSA) 1990; Edwards 1987; Canter 1986

5.3 Control of Air Pollution

Control of emissions from irrigated agricultural lands can be achieved by several measures:

- reduction of gaseous emissions from fertilisers by careful selection of suitable N-forms, application rates and application methods,

- control and reduction of gaseous emissions during pesticide applications (eg avoiding windy days; use of low pressure spray nozzles) and selection of pesticides which are less volatile (specific information from suppliers and extension services),
- use of crop varieties which emit less gas or which are suitable to modified water management practices which allow reduced methane emissions,
- use of soil cultivation and water management methods which reduce methane and nitrous oxide emissions, especially in paddy rice,
- prohibiting burning of organic debris (by direct regulations or laws),
- prohibiting or restricting burning during land clearing activities,
- restriction of burning to limited periods (daytime/nightime or seasonal restrictions, periods with favourable weather conditions, regarding wind, temperature and humidity), or establishment of distance requirements between residents and open burning areas; or other regulations,
- control of emission standards from farm vehicles (application of control devices, regular inspections and maintenance, proper use of vehicles).

Control of emissions can be achieved by changes of individual behaviour, supported by training and information or regulations, which may be either direct or act as nuisance or hazard regulations.

Control or reduction of dust pollution can be achieved by several methods which reduce wind erosion and dust produced during tillage operations:

- use of soil preparation methods and practices which stabilise soil structure, eg aggregation,
- practicing tillage operations when soil surfaces are moist,
- cropping practices which reduce wind erosion (eg continuous cropping, strip cropping, stubble mulching),
- keeping soil surfaces moist during periods of strong winds (eg preventive watering),
- control of wind erosion on farm fields thorugh the use of windbreaks/shelterbelts,
- control or reduction of particulate pollution by crop processing and grain handling,
- all measures to prohibit or control biomass burning (see above).

Outlook. If current trends continues, a considerable increase in air pollution from fertiliser emissions is to be expected over the coming decades. Despite the fact that agricultural (and thus irrigation) pollution contributes to emissions on a global scale (eg methane, nitrous oxide, dust) it is agreed that

* their importance with regard to global warming should not be over-emphasised, eg methane and nitrous oxide respectively contribute 2.4% and 4.2% to the current mean world temperature (Schönwiese/Diekmann 1989)
* the growing world population requires the development of new agricultural land and air pollution will increase with the intensification of agriculture and increased livestock numbers. Regulations on other avoidable or unnecessary emissions of gases resulting from non-agricultural sources, especially in industrialised countries are of more importance in controlling the greenhouse effect (Schönwiese/Diekmann 1989).

Therefore, environmentally sound planning - regarding air quality - should be mainly focused on the reduction of emissions at the local level. However, there are again problems resulting from the scale effect: generally, each individual emission only contributes marginally to the overall impact. Thus, individual control measures also contribute also only marginally to improve air quality. Also, in many cases those resposible for emissions do not suffer directly from the pollution which makes progress difficult; it can probably only be achieved by changes in individual behaviour. This, in turn, depends on changed perceptions towards the protection of the environment.

Fig. 5-10

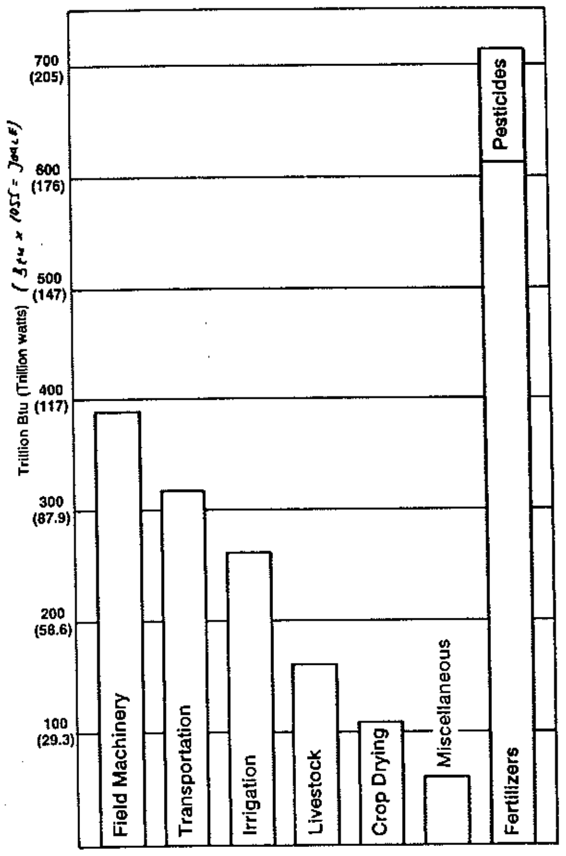


Fig. 6 — Energy use on farms

Source: Hughes 1980

Fig. 5-11

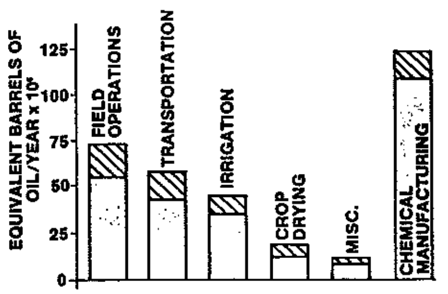


Fig. 24 — Potential for conservation of energy in crop production. Cross-hatch area indicates amount of energy that could be conserved without seriously affecting yield.

Source: Hughes 1980

Some measures can reduce costs or avoid health risk, eg in the proper use of fertilisers and the safe use of pesticides. Control measures may be possible in these fields, whereas regulations, eg regarding field burning, are often difficult to enforce by law even in industrialised countries. Therefore, efficient reduction or control of pollution from agricultural sites will remain a long term aim which should also be seen in the context of a continuous increase in irrigated areas. Some contributions to reduce air pollution may also be expected from agricultural research, especially in paddy rice cultivation where techniques are to be developed to reduce methane and nitrous oxide emissions.

5.4 Energy Conservation and Use of Non-Conventional Energy Sources

5.4.1 Irrigation and Energy Resources

Conservation of resources includes conserving on-farm energy. Irrigation is one of the main consumers of energy in modern farming systems in industrialised countries. Energy use for irrigation on farms in developing countries may even be considerably higher in relation to other activities. Direct on-farm energy use is mainly related to mechanised production, pumping of groundwater or surface water, operation of pressure systems (sprinkler, drip), transportation and post harvesting activities. An important indirect form of energy use is application of fertilisers and pesticides.

Typical energy uses on US-farms are shown in Fig. 5-10.

In China, irrigation and drainage systems account for about 5% of total electrical consumption and 25% of agricultural diesel oil consumption for the whole country (Z.Xiaoying). However, solar power in agriculture is developing in China and the use of solar power is promoted (Xin Muigyi 1991)

Irrigation may influence the demand for on-farm energy in three ways:

- intensification of agricultural production: it is obvious that irrigated agriculture is a highly intensive and specialised form of agriculture. Intensification usually implies the increased use of farm inputs, such as machines for tillage operations, weed control, application of fertilisers and pesticides, and harvesting, but also machines for post harvest operations,
- energy used for lifting water and field distribution of water,
- drainage machinery systems used for construction and maintenance works.

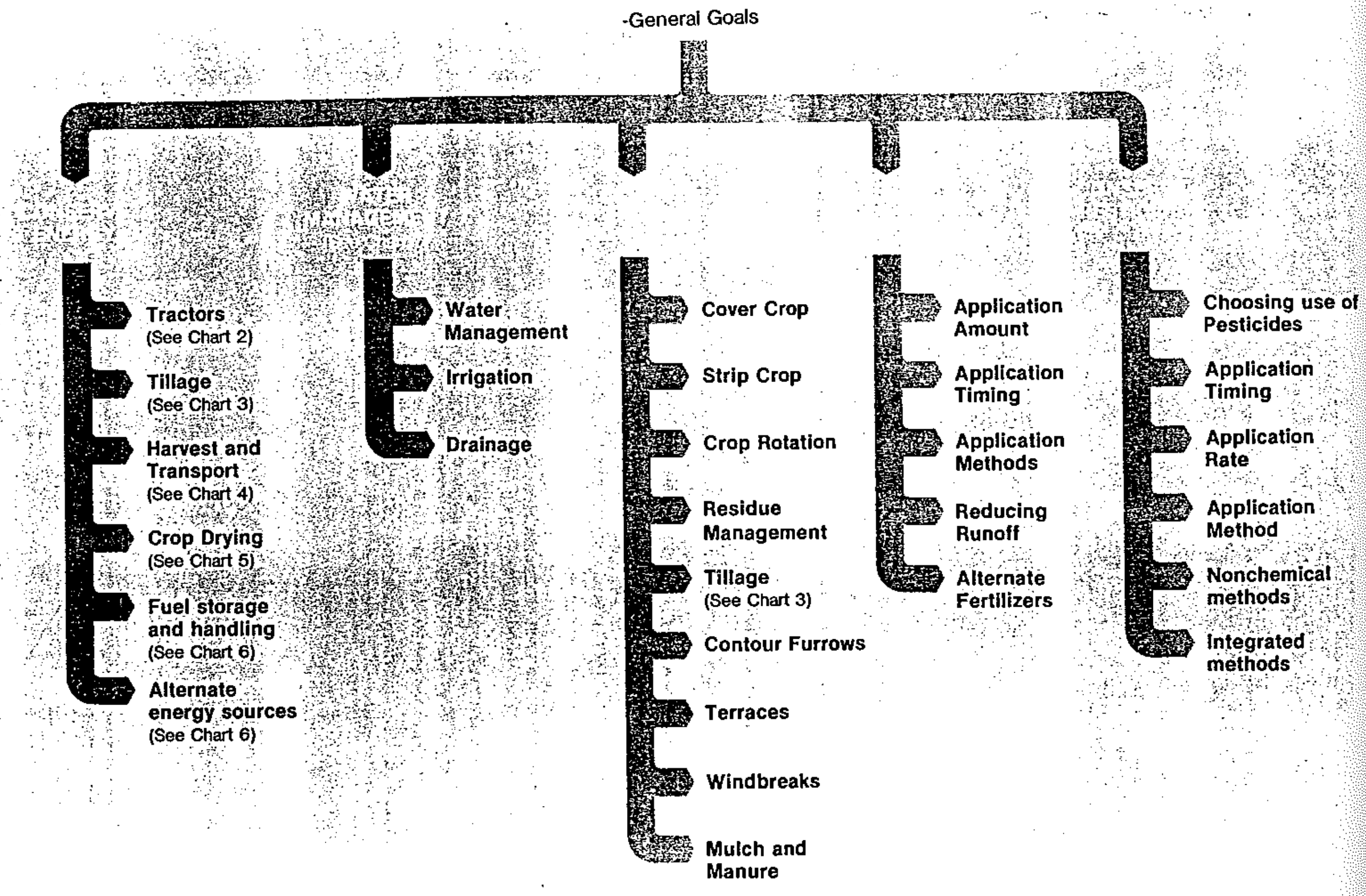
5.4.2 Energy Conservation

It is estimated that in the USA, the use of energy for irrigation alone can be cut by some 25% without seriously affecting production (Fig. 5-11). Energy audits (ie studies to measure energy use on farms) for developing countries are not at hand. For China, the utilisation ratio of agricultural energy sources and the efficiency of irrigation and drainage equipment are assessed to be low compared to international standards:

	China	other countries	
utilization ratio of agricultural energy	23	40-50	in %
irrigation/drainage - pump stations	36 *	60-65	in %
irrigation/drainage - motor pumped wells	27 *	60-65	in %

Source: Z.Xiaoying 1991 * Chinese standards for diesel engines are 54 and 45% respectively

Fig. 5-12



Source: Hughes 1980

Potentials for energy savings that reach national standards would make up about 1% of consumed electricity for the whole country.

Energy conservation measures must meet the following requirements to be accepted and applied by farmers:

- they should be cost efficient, ie costing less than current expenditures on fuel, gas etc. and the benefits should be immediate not only relaised in the long-term,
- they should be neutral to labour demand, ie a new water lifting method should not impose considerable additional labour requirements,
- they should be balanced: a new technology should not save energy at the expense of increased demands for other operations (ie switch of costs),
- they should be at least neutral to the efficiency and reliability of operations, eg sufficient wind energy must be available at times when it is needed for lifting given quantities of water.

In order to conserve energy the following measures and techniques should be adopted (see also section "conserve energy" in Fig. 5-12 and detailed Charts in Table 5-15):

(1) utilise technologies that require less on-farm energy:
  - more efficient use of chemical fertilisers and pesticides,
  - switch to crops which require less energy for production, eg during harvesting, post harvesting storage and drying,
  - more efficient use of water by increasing efficiency of conveyance systems and avoiding over-irrigation,
  - more efficient use of machines during cultivation, harvest and transport; proper maintenance of machines,
  - use of tillage systems which require less mechanization and machine operations,

(2) adoption of technologies that use renewable resources: eg for water lifting (wind power, photovoltaic power, bio-mass fuel) and drying (solar heat) etc.,

(3) use of an irrigation and drainage machinery system which has a high device efficiency index.

There are many variations and combinations of these options and an interested reader is referred to documents dealing with such systems in detail (eg Kenna and Gillet 1985).

Because labour substitution is often not a primary goal in agricultural development, a general option regarding agricultural mechanisation may exist in developing countries. For example developing animal drought power instead of introducing on-farm machinised operations or to the combined use of non-mechanised and mechanised operations.

5.4.3 Planning for Energy Conservation

An energy conservation plan may be established for an individual farm or for an entire project. The plan may, for example, be established for new farms to assess pump power requirements for various alternative lifting devices and irrigation methods. The following five steps should be undertaken:

- conducting an **energy audit** to identify the best targests for conservation efforts and to provide a basis for evaluation of the conservation effort,
- planning of the **conservation programme**; this includes general decisions about the type of water lifting device(s) to be used on the farm. After selection of the conservation target, the approach must be determined,

Fig. 5-13

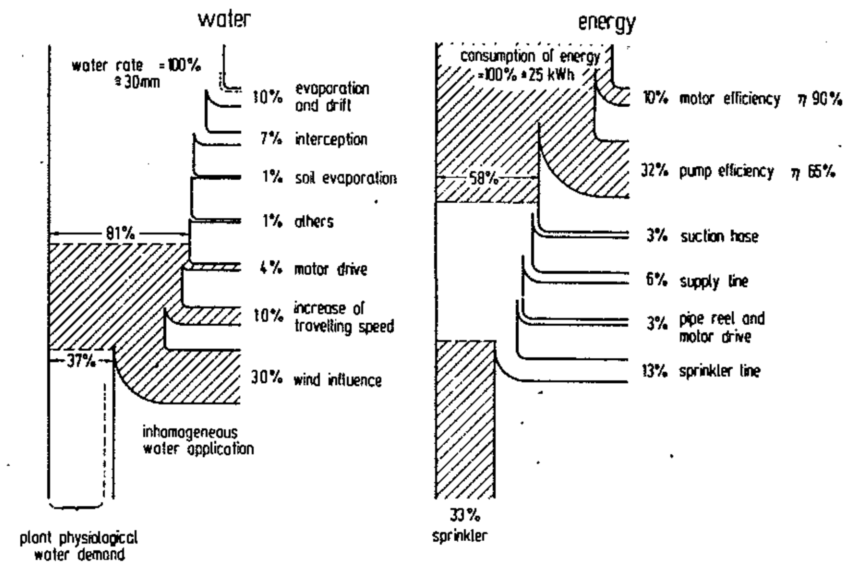


Figure 2. Water and energy balance for mobile irrigation machines

Source: Sourell in ICID 1991

Fig. 5-14

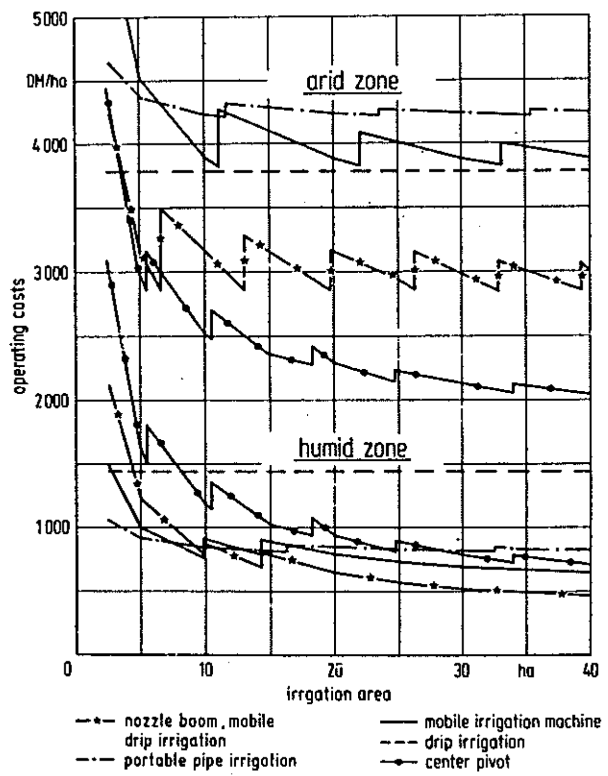


Figure 8. Variation of operating costs of the different irrigation systems depending on the irrigated area. For the calculation of water lifting and transportation costs partnership conditions are assumed.

Source: Sourell in ICID 1991

- **implementing** the plan with repeated evaluation of performance and discussion with all people involved,
- **evaluation** of effectiveness of conservation efforts at regular intervals (eg half-yearly or seasonally). The interpretation must consider that many factors, some of which are beyond the control of the individual farmer, affect energy use, for example emergency activities,
- **reassessment** of the efforts and repeating the steps above if required, for further improvements.

Source: Hughes 1980

The required <u>power</u> by a pumps depends on the pump and the power source: the discharge rate, vertical lift or head, and the efficiency of the motor pump combination. Energy conservation in pumping may be achieved by installing fuel-efficient power plants, reducing operation time by efficient water use, and by keeping the head as low as possible (eg by conjunctive use of ground- and surface waters, or the use of gravity-fed or low-pressure irrigation systems).

Increasing the device efficiencies of irrigation systems (including prime movers, transmission, water pumps, pipelines) would require the following steps during

measurement - regular calibration - calculation of energy efficiencies - analysis of the technical condition of the device - technical transformation - verification.

Measures of technical transformation are explained in ICID 1991 (STS p.262-270). Transformation programs in China resulted in the overall efficiency rising from 27% to 40% within a period less than one year (Z.Xiaojing 1991).

Energy losses in pipeline systems (ie friction and system losses) can also be greatly reduced, eg by designing various systems in undulating topography, optimum allocation of elevation differences, and the selection of optimum pipeline diameters. Energy-efficient system designs may be drawn up by linear programming or the cost potential method (Mitsuno 1991)

Possibilities for energy savings in <u>sprinkler</u> and <u>drip</u> systems are determined by incresasing reducing the pressure requirement and increasing water distribution effectiveness. Pressure losses in mobile sprinkler systems are caused by water transportation and pressure requirements (42%), friction losses in delivery hoses (25%) with the remainder being lost at sprinklers (33%) (see Fig. 5-13).

A <u>mobile drip</u> irrigation system which combines the advantages of both drip irrigation (high water application efficiency and low operating pressure) with mobile irrigation machines (lower capital and labour requirements per unit area; higher operational safety compared to stationary drippers) proved to be cost efficient thorugh savings in water and energy. Fig. 5-14 compares fixed and variable charges for a number of systems (Sourell 1991).

<u>Intake</u> works for medium and minor irrigation projects can also be designed for energy saving.

A successful example is reported from China: hydraulic flap gates retain water, creating head differences between upstream and downstream sides, and driving turbine pumps which rise water directly onto the river bank (Xionghan/Xuannian 1991 in: ICID (STS-25 1991).

Sources: T.Mitsuno in: ICID (STS-B22) 1991; Zheng Xiaoying in: ICID (STS-B21) 1991; Y.Xionghan and G.Xuannian in: ICID (STS-B25) 1991; Hughes (DEERE) 1980

Further reading: FAO (EEP 5)1985; Kenna/Gillet 1985

Table 1-1

Table 9-10

ENVIRONMENTAL MANAGEMENT: CONFLICTS IN THE HUMID TROPICS

Agricultural Activity	Conflicts Within the Agriculture Sector	Conflicts with Other Sectors	Solutions
Utilization of fertilizers and pesticides for more intensive agriculture.	Loss of predator-prey equilibria; disease and insect resistance to pesticides require increasingly-expensive control.	*Fish/Wildlife* - Direct and indirect effects because of increasing levels of biocides in the water. *Water* - Potential contamination of drinking water. *Livestock* - Potential contamination of meat and milk products. *Forests* - Reduces the need to clean forests for agriculture.	Investigation of integrated pest management techniques. Establishing regulations controlling pesticide use with training, extension services, and enforcement. Evaluation of crop mixtures and agroforestry systems to increase production and to minimize problems with weeds and plagues. Pesticides need to be properly used for both economic and health reasons.
Increasing cultivation on marginal areas because of spontaneous cultivation.	Continued subsistence production levels and standards of living because of low yield.	*Fish/Wildlife* - Habitat loss because of forest destruction. *Water* - Accelerated sedimentation, increased water volumes in rivers, water quality is adversely affected by rapid runoff and reduced infiltration. *Forests* - Additional losses due to clearing. *Social Problems* - Rapid marginalization of small farmers near new settlements and limited development potential of occupied areas.	Encouragement of intensified agriculture on the best soils, evaluation of sustained agricultural production systems adapted to the humid tropics. Emphasizing the rehabilitation of abandoned fallow lands and of degraded pastures before new forest land is cleared.
Underutilization of land resources (planting of fertile soils in grass instead of more intensive uses).	Loss of profits obtainable from more intensive uses, need for utilizing marginal lands for intensive cultivation of annual or high-value crops.	*Fish/Wildlife* - Indirect loss due to continued clearing of forests. *Water* - Indirect conflicts due to continued agricultural activity on marginal soils in watershed highlands. *Forests* - Utilization of forest lands for agricultural use; loss of forest resources.	Evaluation of land use, considering climatic, soil and economic limitations, land tenancy, market conditions, and cultural characteristics.

Source: OAS 1987

Table 1-2 a

Table 16-1

NATURAL GOODS (RESOURCES) AND SERVICES

I. Goods/Products (Resources)
1. Surface and ground water for drinking
2. Surface and ground water for industry
3. Surface and ground water for irrigation
4. Biomass for lumber
5. Biomass for firewood
6. Biomass for construction materials (posts, vigas, etc.)
7. Ornamental plants (indoor, landscaping, dry)
8. Vegetable fibers
9. Medicinal plants
10. Food for human consumption (fruits, chicle, honey, sap, shoots, etc.)
11. Plant chemical substance (dyes, stains, waxes, latex, gums, tannings, syrups, drugs, etc.)
12. Fish for human food (crustacians, finfish, mollusks)
13. Fertilizer (guano, other dung, fish meal)
14. Aquatic plants for human food (algas)
15. Aquatic precious/semiprecious materials (pearl, coral, conchas, mother of pearl)
16. Materials for artisan work (rock, wood for carving, fibers for basketmaking, etc.)
17. Metallic minerals (bauxite, ores, nuggets, etc.)
18. Non metallic minerals
19. Construction materials (sands, clay, cinders, cement, gravel, rocks, marble)
20. Food materials (salt)
21. Mineral nutrients (phosphorus)
22. Material for mineral dyes, glazes
23. Hides, leather, skins
24. Other animal materials (bones, feathers, tusks, teeth, claws, butterflies)
25. Other vegetation materials (seeds, pods)
26. Live fish (ornamental, aquaria)
27. Live animals for pets, zoos
28. Live animals for research (medical, other)
29. Fossil fuels (oil, gas, coal)
30. Other fuels (peat, other organic matter dung - biomass)
31. Livestock forage
32. Food for livestock (fish meal)
33. Pulpwood

II. Ecosystem Maintenance Services

1. Nutrient cycling
2. Nutrient storage
3. Nutrient distribution
4. Photosynthesis-Respiration (biomass-succession)
5. Population control (predator/prey)
6. Flooding
7. Sediment transport
8. Habitat for local finfish
   - feeding
   - breeding
   - nursery
   - resting (refuge)
9. Habitat for migrating finfish
   - feeding (including transient food source)

II. Ecosystem Maintenance services (Cont.)
   - breeding
   - nursery
   - resting (refuge)
   - migration route
10. Habitat for crustacea
    - feeding
    - breeding
    - nursery
    - resting (refuge)
    - migration route
11. Habitat for mollusks
    - feeding (including transient food source)
    - breeding

12. Buffering

III. Non-tangible Goods and Services

1. Windbrake
2. Shade
3. Recreation use of water (swimming, boating, waterskiing, sailing)
4. Zones for scenic tourism
5. Zones for recreation tourism
6. Zones for scientific tourism
7. Scientific values
8. Spiritual values
9. Historical values
10. Cultural values
11. Sport hunting and fishing
12. Early warning system
13. Moisture modification (humidity)
14. Temperature modification
15. U.V. filtration
16. Endangered species (fauna)
17. Endangered species (flora)
18. Gene resource (fauna)
19. Gene resource (flora)

IV. Economic Services

1. Hydroelectric power source
2. Other energy sources (wind, sun, tides)
3. Dilution of contaminants
4. Decomposition of contaminants
5. Oxidation of contaminants
6. Transportation of contaminants
7. Airshed (dilution of air contaminants)
8. Erosion control
9. Sediment control
10. Flood control
11. Groundwater recharge
12. Space for urban, industrial, agriculture, occupation, roadways, canals, airports, waste storage
13. Physical support for plants
14. Pollination

Table 1-2 b

Table 16-2

NATURAL GOODS PRODUCED BY PROTECTED AREAS IN THE AMERICAN HUMID TROPICS[a and b]

Goods	National Parks (I-II)	National Reserves (VIII)	National Sanctuaries (III-IV)	Historic Sanctuaries (V)	Protective Forest (VI)	Wildlife Areas (VIII)	Reserved Zones (VI)	Native Reserves (VII)
Water	VI	VI	S	NS	VI	S	VI	NS
Genetic bank (Flora)	VI	I	I	NS	I	S	VI	NS
Genetic bank (Fauna)	VI	I	I	NS	I	I	VI	NS
Goods from fauna		VI			I	VI		VI
Goods from fishing		I			S	NS		VI
Non-lumber vegetative goods					VI			I
Lumber vegetative goods					S			S

a. The Roman numbers (I-VIII) indicate management categories adapted by IUCN (1978).
b. VI: Very Important; I: Important; S: Significant; NS: Not Significant.

Sources: OAS 1987

Table REM 2: Goods and services available to the molapo system

Table 1-4

A Biophysical Resources (water, land, air)

inputs = floodwater, land, soils, dung from cattle/wildlife, energy/sun, nutrients from floodwaters, sediment transport from wind erosion, rainfall

outputs = crops; grazing areas for cattle; seasonal fish ponds; waterponds for cattle; birds and domestic water supply; occasionally grazing areas for wildlife; food for birds (crops).

B Ecosystems Services

B1 Physical Resources: water/land/soil/air

inputs:
- land as habitat for plants and animals (biotic functions)
- land as buffer for soil moisture (flood recession farming)
- land as filter, buffer, transformer of toxins
- land for crop production and for grazing

outputs:
- filter and storage for groundwater aquifers
- filter for air pollution (chemical spraying for control of animal health, quelea birds and public health)
- filter for soil contaminants (agro-chemicals, future uses)
- soil degradation: chemical fertility, physical status, salinity, soil phases)

B2 Biotic functions

inputs: pest predators (invertebrates, reptiles, birds, mammals), microinvertebrates, other soil fauna to control biological balances; nutrient supply (marginal importance)

outputs: potential damages due to the indiscriminate uses of agro-chemicals; impacts on forestry, wildlife, livestock, public health, biotic imbalances.

C Immaterial services

currently no special functions

Table 1-5

NATURAL SERVICES PRODUCED BY PROTECTED AREAS IN THE AMERICAN HUMID TROPICS[a]

Services[b]	National Parks (I, II)	National Reserves (VII) (VIII)	National Sanctuaries (II, IV)	Historic Sanctuaries (V)	Protection Forests (VI)	Wildlife Refuge (VIII)	Reserved Areas (VI)	Common Reserves (VII)
Recycling of Atmospheric Contaminants	VI	VI	S	NS	VI	I	I	NS
Maintenance of the Local Precipitation Regime	VI	VI	NS	NS	VI	S	I	NS
Buffering of Local Climate	VI	VI	NS	NS	VI	S	I	NS
Regulations of the Water Regime	VI	VI	NS	NS	VI	S	I	NS
Maintenance of Supply of Quality Water	VI	VI	NS	NS	VI	S	I	S
Soil Conservation	VI	I	NS	NS	VI	S	I	S
Protection from Landslides, Floods and Other Hazards	VI	I	NS	NS	VI	S	I	S
Maintenance of Genetic Diversity	VI	I	VI	NS	I	S	I	NS
Maintenance of Natural Diversity	VI	I	VI	NS	I	S	I	NS
Reservoir for Species which Offer Biological Control of Plagues	VI	I	I	NS	I	I	I	S
Reserve for Species of Interest to Science	VI	I	VI	NS	I	I	I	NS
Reserve for Species of Interest for Domestication	VI	VI	S	NS	I	I	I	NS
Genetic Bank for Future Improvement of Domesticated Species	VI	VI	S	NS	I	I	I	NS
Scenic Beauty	VI	S	I	S	I	S	I	NS
Area for Hunting	-	VI	-	-	VI	VI	-	VI
Area for Fishing	-	VI	-	-	I	VI	-	VI
Area for other Recreation	VI	I	S	I	VI	I	S	S
Area for Tourism	VI	S	I	I	S	I	S	NS
Conservation of Natural and Historic Scenery	I	NS	-	VI	NS	-	-	-
Conservation of Cultural Patrimony	I	S	VI	S	S	S	S	-

a. *The Roman numerals (I-VIII) indicate equivalent management categories adopted for IUCN (1978).*
b. *VI: Very Important, I: Important, S: Significant, NS: Not Significant, -: Not Applicable.*

Source: OAS 1987

Natural Risk Assessment for Molapo Farming

Table 1-6

elements	occurence	significance
Water		
seasonal/annual shortage of floodwater	40%	+ +
extreme variability of floodwater	predom	+ +
flooding of cropland (untimely, prolonged)	25%	+ +
low saltload (for irrigation ?)	predom.	-
Soils		
low fertility and moisture storage capacity	50% area	+
irregular pattern of soil mosaics	predom	+
partly high wind erodability	40% area	O
low infiltration rates (danger of waterlogging)	40% area	+
Air/Climate		
high windspeed causing wind erosion/moisture stress	irregular	O
heavy rainfall intensity causing erosion, pools	irregular	+ +
high erratic seasonal rainfall	regular	+ +
occurence of dry spells within rainy season	regular	+ +
Biotic risks		
vector-borne diseases	frequent	+
plant pests (birds)	40% years	+ +
pests (other)	often	+
wildlife damage to crops/structures/dangerous animals	occasional	O
weeds as competition for crops	predom	+
other		
earthquakes	frequent	O

predom = predominant, occuring in most years; percentages refer to areas or years

significance: O not or minor important; + moderately important; ++ very important

Source: Petermann

Table 1-7

Table 16-5

EXAMPLES OF NATURAL GOODS AND SERVICES PROVIDED BY TWO HYPOTHETIC ECOSYSTEMS AND THEIR USE IN CONFLICT IDENTIFICATION

	Ecosystem a	Ecosystem b
Land for Agriculture	X	
Land for Industry	X	X
Land for Grazing	X	
Wildlife Habitat	X	
Underground Water for Irrigation		X
Underground Water for Domestic Use		X

Table 1-8

Table 16-6

INTERSECTORAL MATRIX IDENTIFYING POTENTIAL CONFLICTS BETWEEN SECTORAL ACTIVITIES

	Rice Cultivation	Vegetable Cultivation	Livestock Production	Forestry
Rice Cultivation	1	2	3	4
Vegetable Cultivation	5			6
Livestock Production	7			8
Forestry	9	10	11	12

Sources: OAS 1987

Table 1-9

RESOURCE MANAGEMENT ACTIONS
- Major land-use assignments
- On-site agricultural, forestry, grazing, mining, and other resource utilization management practices
- Off-sita management practices

\+

IMPLEMENTATION TOOLS

For each category of management measure:
- Regulations
- Licenses, permits, and fines
- Prices, taxes, and subsidies
- Loans and grants
- Technical help
- Education and information
- Direct installation by public agencies

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INSTITUTIONAL AND ORGANIZATIONAL ARRANGEMENTS

For each category of management measure:

Nonorganizational:
- Tenure systems
- Legal codes
- Economic policies
- Informal arrangements

Organizational (public and private agencies):
- Planning and management
- Extension services
- Credit agencies

Figure 2.2
Watershed management as a planned system.

Table 1-10

Table 2.1
The three major activities of watershed management

Panel 1. Divide watershed into major land uses

• Agriculture Irrigated Rain-fed • Grazing • Horticulture	• Agroforestry • Forestry Commercial Mixed use Preservation	• Mining • Transportation • Urban • Lakes, reservoirs, stream channels, and wetlands

Panel 2. Develop set of resource utilization and management practices for each operating unit within each major land use

Irrigated Agriculture		Commercial Forestry	Agroforestry	
• Types of crops • Rotation of crops • Quantity and timing of water, fertilizer, pesticides, labor, animal power, and machinery inputs • Methods of tilling (e.g., contour plowing)	• Methods of application of water, fertilizer, and pesticides • Installation and maintenance of buffer strips, grassed waterways, terraces, on-farm check dams	• Types of tree species • Rotation and spatial distribution of tree crops • Quantity and timing of inputs • Methods of tree planting, thinning, and fertilizing • Harvesting methods, erosion control practices, road siting, construction and maintenance	• Types, spatial distribution, and rotation of tree and row crops • Quantity and timing of resource inputs • Methods of tilling and tree cropping • Methods of application of water, fertilizers, and pesticides	• Installation and maintenance of erosion control measures and road siting, construction and maintenance

Panel 3. Develop set of downstream management practices

• Stream bank protection by reserve buffer strips, revegetation, and riprapping	• Debris removal • Channel dredging • Harbor, estuary dredging	• Treatment of intake water • Wastewater treatment • Cheek dams

Table 1-11

Table 2.2
Examples of watershed management tasks required at the planning stage, classified by management activities and management system elements

Management Activities	Management System Elements: Resource Management	Implementation Tools	Institutional Arrangements
Land-use assignments	• Land capability analysis • Land suitability analysis • Formulation and benefit-cost analysis of alternative land-use plans	Planning for • Regulation • Economic incentives • Education	Planning for • Ownership/tenure systems • Public regulation systems • Organizational changes
On-site resource utilization and management practices	For agroforestry • Agronomic, forestry, and economic analyses of types, distribution, and rotation of tree and row crops • Planning for methods of tilling, methods of cropping, erosion control practices	Planning for • Education • Technical help • Economic incentives • Marketing assistance • Regulation	Planning for • Extension services • Credit/financial aid • Ownership/tenure systems • Soil conservation agency
Off-site management practices	Planning for • Stream bank vegetation, protection, or revegetation • Channel dredging • Riprapping • Intake water treatment	Planning for • Education • Technical help • Economic incentives • Public installation and maintenance	Planning for • Extension services • Credit/financial aid • Soil conservation agency

Source: Easter and Hufschmidt 1985.

Sources: Easter ed. 1986

Table 1-12

Table 2.3
Examples of tasks involving implementation tools, classified by stages of the management process and management activities

Management Process \ Management Activities	Land-use Assignments (1)	On-site Resource Utilization and Management Practices (2)	Off-site Management Practices (3)
Planning		Content, magnitude, and timing of • Education • Technical help • Economic incentives • Marketing assistance • Regulation	
Design		Detailed design of programs for • Education • Technical help • Economic incentives • Marketing assistance • Regulation	
Installation		• Establish special extension team • Technical help for crop planting, fertilizing, irrigation, harvesting, and erosion control practices • Economic incentives, set cost-sharing levels for practices • Marketing assistance, identify potential markets • Regulation, determine undesirable practices	
Operation		• Extension problem census and problem-solving meetings • Monitoring of performance • Technical help on changes in utilization plans • Economic incentives, adjust cost-sharing levels for practices • Marketing assistance, provide information on commodity prices by market • Regulation, check compliance	
Maintenance		• Technical help, economic incentives, and regulation for maintaining productive plant and facilities	

Sources: Easter ed. 1986

Table 1-13

Environmental Ratings of Top Ten Trends and Associated Practices: Nonirrigated Production (Unger, 1977)

Panel Rank	Trend and Subtrend
1	Runoff & Erosion Control a. Contour farming or contour strip-cropping b. Terraces and grass waterways c. Optimizing time of operations d. Narrow rows
2	Improvement of Seed and Plants a. Weather resistance b. Salt resistance c. Production efficiency d. Disease resistant crops e. Insect and nematode resistant crops
3	Conservation Tillage a. No-tillage b. Reduced tillage
4	Using Scouting and Integrated Controls a. Surface scouting b. Remote sensing scouting c. Using integrated controls
5	Developing New Biological and Chemical Pesticid[es] a. Micro-encapsulated pesticides b. Systemic pesticides c. Surfactants for herbicides d. Bio-degradable pesticides e. Alternative formulations f. Juvenile hormones g. Pheromones h. Sterile males i. Predator and parasites
6	Improving Soil-Plant Analysis
7	Methods of Nutrient Applying a. Foliar fertilization b. Multiple applications c. Fall application d. Liquid fertilizers e. Aerial and floater application f. Improved nutrient placement
8	Wind Erosion Control a. Strip-cropping b. Barrier row c. Windbreaks

Source: Canter 1986

Table 12: Description of Environmentally Related Trends and Developments: Irrigated Cropland Production (Unger, 1977)

CROP MANAGEMENT TRENDS

CONSERVATION TILLING - general reduction in cropland soil disturbance

a. No till plant: seeding without pre-planting tillage
b. Reduced tillage: weed control and soil breaking with a limited soil inversion

CROP SEQUENCING - cropping patterns

a. Mono-cropping: successive planting of one crop on the same plot of land
b. No-meadow: eliminates pastures or meadows from rotation sequence
c. Relay cropping: planting the second crop before the first crop is harvested
d. Double cropping: planting the second crop after the first crop is harvested in the same growing season

SEED/PLANT IMPROVING

a. Weather resistance: plants genetically developed to withstand winds, drought, etc.
b. Salt tolerance: developing plants capability to produce in a saline environment
c. Production efficiency: genetic development of plants which utilize nutrients and sunlight more efficiently and have desired growth characteristics of root development, growth and maturity.

SOIL WATER MANAGEMENT TRENDS

RUNOFF AND EROSION CONTROLLING

a. Contour farming: farming operations are performed according to the land elevations
b. Terracing: soil embankments which slow the downhill flow of surface waters
c. Cover crops: stubble mulching and grassed waterways to slow runoff flow
d. Optimizing time of operation: performing farm operations to minimize the time period that the soil is bare
e. Narrow rows: reducing the distance between adjoining rows of seeded crops
f. Chemical erosion-control: chemical agents applied to reduce soil erosion

Table 12: (Continued)

WIND-EROSION CONTROLLING

a. Strip cropping: dividing the field in alternate narrow bands of crop and fallow land
b. Barrier rows: use of taller crops to act as wind breaks
c. Wind breaks: planting trees and shrubs to reduce the effect of the wind and soil loss

SPRINKLER IRRIGATION -- application of water to crops dispersing droplets through the air

USING DRIP OR TRICKLE IRRIGATION -- application of water to crops by dispersing through subsurface delivery systems

REDUCING WATER APPLICATION

a. Furrow basins: small earth dams used to impound water in furrows
b. Sprinklers: dispersing irrigation water droplets through the air
c. Limited application: reducing irrigation frequency to eliminate over-irrigation
d. Recycling and controlling tailwater: using irrigation water runoff for application to other crops and improving irrigation water management

DIRECTLY MONITORING IRRIGATION NEEDS

a. Measure soil moisture content: direct field probes
b. Remote sensing of plant and water stress: by using satellite information

NUTRIENT MANAGEMENT TRENDS

IMPROVING SOIL-PLANT ANALYSIS (crop logging) - monitoring nutrient uptake, soil nutrients available, and plant condition to provide information to adjust fertilizer rates, timing, and cultural practices

METHODS OF NUTRIENT APPLYING

a. Foliar fertilization: applying fertilizer as a spray so that nutrients are taken up through the leaves of the plant
b. Fertigation: fertilizer application through irrigation systems
c. Multiple application: fertilizer is applied more than one time to realize optimum growth and crop production
d. Aerial and floater application: fertilizer is applied via airplane, helicopter, or by ground machines equipped to traverse wet or dry ground with limited soil compactions

Source: Canter 1986

Table 1-14

Table 12: (Continued)

e. Fall fertilization: application of fertilizer during the fall season prior to the crops primary growing season
f. Liquid fertilizer: application of nutrients as a liquid to enhance crop production

USING ALTERNATIVE NUTRIENT SOURCES

a. Animal wastes: solid and liquid wastes from livestock feedlots contain nutrients and organic matter
b. Municipal treatment plant wastes: use of municipal wastes as a source of nutrients
c. Green manure crops: crops grown for the intended purpose of incorporating immature plants into the soil structure

DEVELOPING BIOLOGICAL NITROGEN-FIXATION SOURCES

a. Legumes: plants capable of fixing atmospheric nitrogen and accumulating it in root nodules
b. Non-legume: soil microbacterial populations that are able to fix nitrogen from the air

DEVELOPING IMPROVED FERTILIZERS

a. Controlled-release: chemical inhibitors to delay nitrification, leaching etc. are added to fertilizers
b. High nitrogen content: use ammonia to supply a high concentration of nitrogen
c. High phosphorus content: use of polyphosphates to increase phosphorus content about 50 percent more than ordinary fertilizers

PEST CONTROL TRENDS

USING SCOUTING

a. Surface: determine types of pests and potential crop damage by visual inspection
b. Remote sensing: insect populations and locations are determined by satellite information

IMPROVING PESTICIDE APPLICATION METHODS AND TIMING

a. Aerial application: new methods to decrease pesticide drift during application by increasing an homogeneous particle size
b. Floater vehicle: can be used on wet soil for timely application
c. Dual application: herbicides, pesticides, and liquid fertilizer simultaneous application
d. Pesticide placement: using the most effective and efficient manner for applying pesticides

Table 12: (Continued)

DEVELOPING RESISTANT CROPS

a. Disease resistant: genetically developing plant species capable of resisting diseases
b. Insect and nematode resistant: genetically developing plant species capable of resisting selected insects and nematodes
c. Bird resistant: genetically developing plant species that are less accessible to feeding bird populations

DEVELOPING NEW PESTICIDES

a. Micro-encapsulated pesticides: pesticides in micro-capsule form that slowly release the pesticide over a longer time period
b. Systemic pesticides: pesticide compounds that are absorbed by the plant which make it toxic to pests
c. Surfactants: chemical materials which enhance the adsorption and absorption properties of herbicides
d. Bio-degradable pesticides: chemicals which are effective against pests and are decomposable by the environment with limited persistence
e. Alternative formulations: different methods combining chemicals which are effective against pests

DEVELOPING BIOLOGICAL CONTROLS

a. Juvenile hormones: hormonal compounds capable of preventing normal development and maturation of insects
b. Pheromones: chemical compounds containing organophosphorus insecticide used to selectively attract insects
c. Sterile males: release sexually sterile insects to decrease or control insect population
d. Predators and parasites: use of natural enemies, fungi, viruses, bacteria, to control insect populations

DEVELOPING INTEGRATED CONTROLS - integrating chemical, biological, and mechanical treatment methods to achieve desired control over cropland production

RESOURCE USE TRENDS

USING INCREASED RATES AND AMOUNTS OF CROP PRODUCTION INPUTS - increasing demands for cropland production will affect the quantity of fertilizer, animal and municipal wastes, chemicals, energy and land used for food production

Table 1-14 cont.

Table 13: Environmentally Related Trends: Irrigated Cropland (Unger, 1977)

Potential Contribution to Pollution--Major Pollutants

TRENDS	Surface Water						Ground Water			Air		Land				
	Sediment	Nitrogen	Phosphorus	Pesticides	Inorganic salt and minerals	Biodegradable organics	Nitrates	Pesticides	Inorganic salt and minerals	Gases	Particulates	Soil erosion	Salinity	Heavy metals	Pesticide residues	Biodegradable organics
CROP MANAGEMENT TRENDS																
CONSERVATION TILLING	+	+	+	-	0	-	-	-	0	0	+	+	0	0	-	-
a. No-tillage	+	+	+	-	0	-	-	-	0	0	+	+	0	0	-	-
b. Reduced tillage: chisel plowing undercutting, chemical	+	+	+	-	0	-	-	-	0	0	+	+	0	0	-	-
CROP SEQUENCING	-	-	-	-	0	0	0	-	0	0	-	-	0	0	-	0
a. Mono-crop sequencing	-	-	-	-	0	0	0	-	0	0	-	-	0	0	-	0
b. No-meadow crop sequencing	-	-	-	-	0	-	+	-	0	0	-	-	0	0	-	-
c. Relay cropping	+	+	+	+	0	-	-	-	0	0	+	+	0	0	-	-
d. Double cropping	+	+	+	+	0	-	-	-	0	0	+	+	0	0	-	0
SEED/PLANT IMPROVING (GENETIC DEVELOPMENT)	+	0	+	0	0	-	0	0	0	0	+	+	0	0	0	-
a. Weather resistance	+	0	+	0	0	-	0	0	0	0	+	+	0	0	0	-
b. Salt tolerance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
c. Production efficiency	+	+	+	0	0	-	-	0	0	0	+	+	0	0	0	-
SOIL WATER MANAGEMENT TRENDS																
RUN-OFF & EROSION CONTROLLING	+	+	+	+	0	+	-	-	-	0	+	+	0	0	-	-
a. Contour farming: contour planting, contour-strip cropping	+	+	+	+	0	+	-	-	-	0	+	+	0	0	-	-
b. Using terraces & grass waterways	+	+	+	+	0	+	-	-	-	0	+	+	0	0	-	-
c. Using winter cover crops	+	+	+	+	0	+	-	-	-	-	+	+	0	0	-	-
d. Optimizing time of operation: tillage, planting	+	+	+	+	0	0	+	+	+	0	+	+	0	0	+	0
e. Using narrow rows	+	+	+	+	0	-	+	+	0	-	+	+	0	0	+	-
f. Using chemical erosion-control agents	+	+	+	+	0	0	-	-	-	0	+	+	0	0	-	0
MOISTURE CONSERVING (STORAGE)	-	0	-	+	-	+-	+	-	+	-	-	-	0	0	-	
a. Fallow cropping: moisture storage, salt-seeps	-	0	-	+	-	+	-	+	0	+	-	-	-	0	0	-
b. Using evapo-transpiration reducing agents	+	0	+	0	0	0	-	0	-	0	+	+	+	0	0	0

Potential Contribution to Pollution--Major Pollutants

TRENDS	Surface Water						Ground Water			Air		Land				
	Sediment	Nitrogen	Phosphorus	Pesticides	Inorganic salt and minerals	Biodegradable organics	Nitrates	Pesticides	Inorganic salt and minerals	Gases	Particulates	Soil erosion	Salinity	Heavy metals	Pesticide residues	Biodegradable organics
SPRINKLER IRRIGATION	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
USING DRIP OR TRICKLE IRRIGATION	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
REDUCING WATER APPLICATION	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
a. Furrow basins	+	+	+	+	+	0	-	-	-	0	+	+	-	0	-	0
b. Sprinkler	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
c. Limited application	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
d. Recycling and controlling soil water	+	+	+	+	+	+	-	-	-	0	+	+	-	0	-	0
DIRECTLY MONITORING IRRIGATION NEEDS	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
a. Measure soil moisture content	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
b. Remote sensing	+	+	+	+	+	0	+	+	+	0	+	+	-	0	-	0
METHODS OF NUTRIENT APPLYING	+	+	+	0	0	0	0	0	0	0	+	+	0	0	0	0
a. Foliar fertilization	+	+	+	0	0	0	+	0	0	0	+	+	0	0	0	0
b. Fertigation	+	+	+	0	0	0	0	0	0	0	+	+	0	0	0	0
c. Multiple application	-	-	-	0	0	0	-	0	0	0	-	-	0	0	0	0
d. Aerial and floater application	+	+	+	0	0	0	+	0	0	0	+	+	0	0	0	0
e. Fall fertilization	+	+	+	0	0	0	-	0	0	0	-	+	0	0	0	0
d. Liquid fertilizer	+	+	+	0	0	0	0	0	0	0	+	+	0	0	0	0
USING ALTERNATIVE NUTRIENT SOURCES	+	-	-	0	0	-	-	0	0	-	-	+	0	0	0	0
a. Using animal wastes	+	-	-	0	0	-	-	0	0	-	-	+	0	0	0	0
b. Using municipal treatment plant wastes	+	-	-	0	0	-	-	0	0	-	-	+	0	-	0	0
c. Using green manure crops	-	+	+	0	0	-	-	0	0	+	-	-	0	0	0	0
DEVELOPING BIOLOGICAL NITROGEN-FIXATION SOURCES	+	+	0	0	0	-	+	0	0	0	+	+	0	0	0	-
a. Developing legume sources	+	+	0	0	0	-	+	0	0	0	+	+	0	0	0	-
b. Developing non-legume sources	+	+	0	0	0	-	+	0	0	0	+	+	0	0	0	-

Source: Canter 1986

Table 13: (Continued)

Potential Contribution to Pollution--Major Pollutants

TRENDS	Surface Water						Ground Water			Air		Land				
	Sediment	Nitrogen	Phosphorus	Pesticides	Inorganic salt and minerals	Biodegradable organics	Nitrates	Pesticides	Inorganic salt and minerals	Gases	Particulates	Soil erosion	Salinity	Heavy metals	Pesticide residues	Biodegradable organics
DEVELOPING IMPROVED FERTILIZERS	0	+	+	0	0	0	+	0	0	0	0	0	0	0	0	0
a. Developing controlled-release fertilizers	0	+	+	0	0	0	+	0	0	0	0	0	0	0	0	0
b. Developing high nitrogen content fertilizers	0	-	-	0	0	0	-	0	0	0	0	0	0	0	0	0
c. Developing high phosphate content fertilizers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PEST CONTROL TRENDS																
USING SCOUTING	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
a. Using surface scouting	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
b. Using remote sensing scouting	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
IMPROVING PESTICIDE APPLICATION METHODS AND TIMING	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
a. Improving aerial application	0	0	0	+	0	0	0	0	0	0	0	0	0	0	+	0
b. Improving floater vehicle application	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
c. Developing fertilizer and pesticide dual application	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
d. Improving pesticide placement	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
DEVELOPING RESISTANT CROPS	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
a. Developing disease resistant crops	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
b. Developing insect and nematode resistant crops	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
c. Developing bird resistant crops	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
DEVELOPING NEW PESTICIDES	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
a. Developing micro-encapsulated pesticides	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
b. Developing systematic pesticides	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
c. Developing surfactants for herbicides	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
d. Developing bio-degradable pesticides	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
e. Developing alternative formulations	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0

Table 13: (Continued)

Potential Contribution to Pollution--Major Pollutants

TRENDS	Surface Water						Ground Water			Air		Land				
	Sediment	Nitrogen	Phosphorus	Pesticides	Inorganic salt and minerals	Biodegradable organics	Nitrates	Pesticides	Inorganic salt and minerals	Gases	Particulates	Soil erosion	Salinity	Heavy metals	Pesticide residues	Biodegradable organics
DEVELOPING BIOLOGICAL CONTROLS	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
a. Developing juvenile hormones	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
b. Developing pheromones	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
c. Developing sterile males	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
d. Developing predators and parasites	+	0	0	+	0	0	0	+	0	0	+	+	0	0	+	0
DEVELOPING INTEGRATED CONTROLS (i.e., chemical-biological-mechanical)	0	0	0	+	0	0	0	+	0	0	0	0	0	0	+	0
RESOURCE USE TRENDS																
USING INCREASED RATES AND AMOUNTS OF CROP PRODUCTION INPUTS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
a. Using commercial fertilizers	-	-	-	0	0	-	-	0	0	-	-	-	0	0	0	-
b. Using other nutrient sources: livestock wastes, municipal sludges	-	-	-	0	0	-	-	0	0	-	-	-	0	0	0	-
c. Using chemical pesticides: herbicides, insecticides, fungicides, rodenticides	-	0	0	-	0	0	0	-	0	0	-	-	0	0	-	0
d. Using energy: petroleum products, electricity, sunlight	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e. Using new cropland (including set-aside lands)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 1-16

Table 15: Environmental Ratings of Top Ten Trends and Associated Practices: Irrigated Production (Unger, 1977)

Panel Rank	Trend and Subtrend
1	Improving Water Application
	a. Furrow basin
	b. Large sprinklers
	c. Recycling & controlling tailwater
	d. Timing and amount with respect to crop and soil condition
	e. Irrigation scheduling
2	Runoff & Erosion Control
	a. Contour farming
	b. Terraces & grass waterways
	c. Winter cover crop
	d. Land grading
3	Methods of Nutrient Application
	a. Foliar application
	b. Multiple applications
	c. Fall application
	d. Aerial & floater application
	e. Improved nutrient placement
	f. Irrigation application
4	Developing Integrated Controls
5	Using Soil-Plant Analysis
6	Directly Monitoring Irrigation Needs
	a. Measuring soil moisture content
	b. Remote sensing of plant or soil water stress
	c. Field soil examination
7	Using Sprinkler Irrigation
8	Seed/Plant Improving
	a. Weather resistance
	b. Salt tolerance
	c. Production efficiency
9	Developing Nitrogen-Fixation Sources
	a. Legume sources
	b. Non-legume sources
	c. Non-symbiotic non-legume
10	Developing Improved Fertilizers
	a. Controlled release fertilizers
	b. High phosphate content fertilizers
	c. Liquid
	d. Nitrate inhibitors

Source: Canter 1986

Table 1-17

Table 16: Summary of Major Environmentally Related Trends in the Agriculture Sector by Subsector (Unger, 1979)

Subsector and Trend (P or I)[a]	Panel Ratings[b] Rank	Index
Nonirrigated Crop Production		
Runoff Control (P)	1	100
Improved Seeds (I)	2	90
Conservation Tillage (P)	3	80
Integrated Pest Control (P)	4	70
New Pesticides (I)	5	65
Irrigated Crop Production		
Water Application (P)	1	100
Runoff Control (P)	2	80
Nutrient Application (P)	3	70
Integrated Control (P)	4	60
Soil-Plant Analysis (P)	5	40

[a]P=practices (primarily); I=inputs (primarily changes in quality).
[b]Ratings established by subsector panels of agriculture professionals in an EPA sponsored evaluation workshop. The rank indicates the trend cluster's rank order of environmental importance; the index is a subjective measure of each trend's relative importance compared to the top-ranked trend which has an index score of 100.

Source: Canter 1986

Table 1-18

Table 5. African agricultural systems and extent of sustainability.

Traditional and transitional systems		
1a. Shifting cultivation (Phase I)	L > 10	HS
b. Nomadic herding		SS
2. Bush fallowing or land rotation	L = 5-10	NS
3. Rudimentary sedentary agriculture	L = 2-4	NS
4a. Compound farming (shifting cultivation, Phase IV)	L < 2-4	S
b. Intensive subsistence agriculture		SU
5a. Terrace farming		SU
h. Floodland agriculture		HS
"Modern" farming systems and their local adaptations		
1. Livestock ranching		SU
2. Mixed farming		S
3. Intensive livestock production systems (poultry, pigs, and dairying)		SU
4a. Small-scale irrigated farms (lowland rice, vegetables, and arables)		S
b. Small-scale fish farming		S
5. Large-scale farms and plantations		
(a) Large-scale arable crop farms (unirrigated)		NS
(b) Irrigated crop production projects/systems		SU
(c) Tree crop plantations (oil palms, rubber)		S
6. Specialized horticulture		
(a) Market gardening		HS
(b) Truck gardening/fruit plantations		SU
(c) Commercial fruit/vegetable production for processing		SS

L = (C+F)/C where C = cropping period, F = fallow period, L = land use factor
HS = Highly sustainable
S = Sustainable
NS = Not sustainable
SS = Sometimes sustainable
SU = Sustainable only under specificied circumstances

Table 1-19

Table 1. Grain yields per hectare in four African countries with declining yields, from 1950 to 1952 and 1983 to 1985 (Brown and Wolf, 1986).

Country	Average Yields 1950-1952	Average Yields 1983-1985	Change
	Kg	Kg	%
Nigeria	760	714	−6
Mozambique	620	545	−12
Tanzania	1,271	1,091	−14
Sudan	780	479	−38

Source: Okigbe in: Edwards ed. 1990

Table 1-20

Table 2. World population growth by geographic region, 1986.

Region	Population	Population Growth Rate	Annual Increment
	—million—	—%—	— million —
Slow-growth regions			
Western Europe	381	0.2	0.8
North America	267	0.7	1.9
Eastern Europe and Soviet Union	392	0.8	3.1
Australia and New Zealand	19	0.8	0.1
East Asia*	1,263	1.0	12.6
Total	2,322	0.8	18.6
Rapid-growth regions			
Southeast Asia†	414	2.2	9.1
Latin America	419	2.3	9.6
Indian subcontinent	1,027	2.4	24.6
Middle East	178	2.8	5.0
Africa	583	2.8	16.3
Total‡	2,621	2.5	65.5

*Principally China and Japan.
†Principally Burma, Indonesia, the Philippines, Thailand, and Vietnam.
‡Numbers may not add up to totals due to rounding.

Table 1-21

Table 3. Projected population size at stabilization for selected countries.

Country	Population in 1986	Annual Rate of Population Growth	Size of Population at Stabilization	Change from 1986
	— million —	— % —	— million —	— % —
Slow-growth countries				
China	1,050	1.0	1,571	+50
Soviet Union	280	0.9	377	+35
United States	241	0.7	289	+20
Japan	121	0.7	128	+ 6
United Kingdom	56	0.2	59	+ 5
West Germany	61	−0.2	52	−15
Rapid-growth countries				
Kenya	20	4.2	111	+455
Nigeria	105	3.0	532	+406
Ethiopia	42	2.1	204	+386
Iran	47	2.9	166	+253
Pakistan	102	2.8	330	+223
Bangladesh	104	2.7	310	+198
Egypt	46	2.6	126	+174
Mexico	82	2.6	199	+143
Turkey	48	2.5	109	+127
Indonesia	168	2.1	368	+119
India	785	2.3	1,700	+116
Brazil	143	2.3	298	+108

Source: Brown et al. in Edwards ed. 1990

Table 1-22

Table 4. Measures of sustainability in seven African countries,* by ecological zone, 1980.

	Food			Fuelwood		
Zone	Agriculturally Sustainable Population	Actual Rural Population	Food Disparity	Fuelwood-Sustainable Population	Actual Total Population	Fuel Disparity
	million people					
Sahelo-Saharan	1.0	1.8	−0.8	0.1	1.8	−1.7
Sahelian	3.9	3.9	0.0	0.3	4.0	−3.7
Sahelo-Sudanian	8.7	11.1	−2.4	6.0	13.1	−7.1
Sudanian	8.9	6.6	2.3	7.4	8.1	−0.7
Sudano-Guinean	13.8	3.6	10.2	7.1	4.0	3.1
Total	36.3	27.0	9.3	20.9	31.0	−10.1

*Burkina Faso, Chad, Gambia, Mali, Mauritania, Niger, and Senegal. The five ecological zones are delineated by amounts of rainfall.

Source: Brown et al. in Edwards ed. 1990

Table 2-1

Table 2 LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 - 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 - 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 - 20	me/l
Magnesium	Mg^{++}	me/l	0 - 5	me/l
Sodium	Na^{+}	me/l	0 - 40	me/l
Carbonate	CO_3^{--}	me/l	0 - .1	me/l
Bicarbonate	HCO_3^{-}	me/l	0 - 10	me/l
Chloride	Cl^{-}	me/l	0 - 30	me/l
Sulphate	SO_4^{--}	me/l	0 - 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 - 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 - 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 - 2	mg/l
Potassium	K^{+}	mg/l	0 - 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 - 2	mg/l
Acid/Basicity	pH	1-14	6.0 - 8.5	
Sodium Adsorption Ratio[3]	SAR	$(me/l)^{1,2}$	0 - 15	

[1] dS/m = deciSiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centimetre)

mg/l = milligram per litre = parts per million (ppm).

me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l = 1 millimol/litre adjusted for electron charge.

[2] NO_3-N means the laboratory will analyse for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse for NH_4 but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.

[3] SAR is calculated from the Na, Ca and Mg reported in me/l (see Figure 1).

Source: Ayers/Westcot (FAO) 1985

Table 2-2

TABLE 31. Selection of parameters for river water-quality surveys (after McDermott)

Type of survey	Physical parameters	Chemical parameters: Inorganic	Chemical parameters: Organic	Chemical parameters: Nutrients	Biological parameters: Microbiological	Biological parameters: Hydrobiological
Proposed for inclusion in all surveys	Colour pH Specific conductance Suspended solids Total solids		Chemical Oxygen Demand (COD) Total Organic Carbon (TOC)		Coliforms, total and faecal	
Recommended for collection of baseline data	Odour	Acidity Alkalinity Calcium, Ca Chlorides, Cl Dissolved oxygen Hardness Iron, Fe Magnesium, Mg Manganese, Mn Potassium, K Selenium, Se Silver, Ag Sodium, Na	Biochemical Oxygen Demand (BOD); immediate, 5-day, ultimate	Nitrate nitrogen, NO_3	Total plate count	
Recommended additional parameters where municipal and/or industrial pollution are expected	Floating solids	Arsenic, As Barium, Ba Beryllium, Be Boron, B Cadmium, Cd Chromium, Cr Copper, Cu Dissolved Carbon Dioxide, CO_2 Fluorides, F Hydrogen sulphide, H_2S Lead, Pb Mercury, Hg Nickel, Ni Vanadium, V Zinc, Zn	Cyanide, CN Dissolved organic carbon Methylene Blue Active Substances (MBAS) Oil and grease Pesticides Phenolics	Ammonia nitrogen, NH_3 Nitrite nitrogen, NO_2 Organic nitrogen Soluble phosphorus Total phosphorus	Faecal streptococci Salmonella	Benthos Plankton counts
Optional parameters for surveys of special purpose	Bed load Light penetration Particle size Sediment concentration Settleable solids	Aluminium, Al Sulphates	Carbon Alcohol Extract (CAE) Carbon Chloroform Extract (CCE) Chlorine demand	Organic phosphorus Orthophosphates Polyphosphates Reactive silica	Shigella Viruses: —Coxsackie A&B —Polio —Adenoviruses —Echoviruses	Chlorophylls Fish Periphyton Taxonomic composition

UNESCO/WHO 1978

Table 2-3

TABLE 11. Suggested preservation techniques

Parameter	Preservation a —unnecessary b —possible c —not possible	Optimum storage time prior to analysis	Method of treatment (suggested analysis)
Acidity (pH)	c	Immediately Same day if cooled	Cap bottle, avoid bubbles and turbidity, keep cool (followed by titrimetric method to pH 4.5 and 8.3)
Alkalinity ($CaCO_3$)	c	Immediately Same day if cooled	Cap bottle, avoid bubbles and turbidity, keep cool (followed by potentiometric titration to pH 4.5 and 8.3; phenolphthalein and methyl orange indicators)
Aluminium	b	No time limit	*Rinse sample bottle with acid; add 2 ml conc. HNO_3/l (followed by Atomic Absorption Spectroscopy (AAS) after complexation with 8-quinolinol, or by colourimetric Ferron Method)
Ammonia (ammonium ions)	b	Same day	Cool and store at 3–4°C; add 0.8 ml H_2SO_4/l sample to pH 2; add 2–4 ml $CHCl_3$/l sample (followed by specific ion electrode after distillation or nesslerization after distillation or o-tolidine method)
Arsenic	a	No time limit	*No special precautions (may use colourimetric method with silver diethyl dithio carbanate; or AAS)
Barium	b	No time limit	*Add 2 ml HNO_3/l sample (followed by AAS)
Beryllium	b	No time limit	*Rinse sample bottle with acid; add 2 ml HNO_3/l (followed by AAS or by 8-quinolinol $CHCl_3$ extraction and AAS)
Bicarbonates	c	Immediately Same day if cooled	*See alkalinity (determined by methyl orange and phenolphthalein titration)
Boron	a	No time limit	*Use polyethylene or boron free glass bottles (followed by colourimetric curcumin method)
Cadmium	b	No time limit	*Rinse bottle with acid; add 2 ml conc. HNO_3/l (May absorb on bottle walls). (followed by AAS)
Calcium	a	No time limit	(Use AAS or ethylenediamine-tetraacetic acid (EDTA) titration)
Carbon dioxide	c	Immediately Same day if cooled	*Polyethylene bottle filled to overflowing; tightly capped (May be determined from alkalinity by methyl orange titration and pH)
Carbon, organic	b	Same day	*Add 1 ml H_2SO_4/l; or acidify with HCl. Cool (followed by Infra-Red (IR) analysis)
Carbonates	c	Immediately Same day if cooled	*See alkalinity
Chemical Oxygen Demand (COD)	a	Same day	*See Oxygen Demand, Chemical and also Oxidizability
Chloride	a	No time limit	(May be determined by automated colourimetric ferricyanide; mercuric nitrate, or silver nitrate method)
Chlorine	c	Immediately	Use brown glass bottles, protect from sunshine and shaking. Cooling not necessary. (followed by amperometric iodide titration)
Chlorine dioxide	c	Immediately	(May be determined by gas chromatographic method)
Chromium	b	No time limit	*See Cadmium
Cobalt	b	No time limit	*See Cadmium
Colour	c	Same day	Add 2 ml $CHCl_3$/l to suppress biochemical changes that may change colour (may be visual comparison)
Copper	b	No time limit	*See Cadmium. 5–10 ml 50% aq. HCl also suggested by some analysts. Must not be preserved in presence of cyanides
Cyanides	b	Same day	Do not add acid. Add NaOH pellets to pH 11 and cool to 3–4°C or freeze (followed by distillation—specific ion electrode; colourimetric pyrazolone or silver nitrate titration)
Dissolved gases	c	Immediately	Use gas-tight ampoules for transport to laboratory if immediate analyses is not feasible. See also: gases by name
Dissolved solids	a	Several days	Cool to 3–4°C
Extractible matters	b	Same day	Collect in wide mouth bottles; add 5 ml H_2SO_4 (50% solution)/l Do not use chloroform for conservation (followed by extraction with hexane or trichlorotrifluoro-ethane)
Fluoride	a	No time limit	Do not use bottles previously used for other halogens (may use specific ion electrode method)
Hardness	a	Immediately	Bottles should be tightly capped (may use AAS if > 0.5 ml/l heavy metals are present; or ethylenediaminetetraacetic acid (EDTA) titration)
Halogenated organics (pesticides)	a	Same day	Use glass bottles with Teflon caps. Never use plastic utensils. Cool (followed by Gas Chromatographic analysis)
Iron	b	No time limit	*See Cadmium (AAS or 2,4,6-tripyridyl-s-triazine colourimetric method)
Lead	b	No time limit	*See Cadmium
Magnesium	a	No time limit	(May be determined by AAS or by difference between total hardness and calcium)
Manganese	b	No time limit	*See Cadmium
Mercury	b	Several days	Do not use glass bottles. Filter. Acidify immediately; for dissolved mercury add 10 ml H_2SO_4/l, for suspended mercury add conc. H_2SO_4 to residue (followed by flameless AAS)
Nickel	b	No time limit	*See Cadmium. Must not be preserved in presence of cyanide
Nitrogen-Nitrate	b	Same day	Add 0.8 ml H_2SO_4/l sample or 2–4 ml $CHCl_3$/l; cool to 3–4°C (followed by cadmium reduction, brucine sulphate, automated cadmium, or hydrazine reduction method)
Nitrogen—Nitrite	b	Same day	Preserve as Nitrate (followed by manual or automated colourimetric diazotization)
Nitrogen, organic	c	Same day Several days if frozen	(May use ultra-violet oxidation method; for higher concentrations use Kjeldahl method)
Nitrogen, total inorganic	b	Same day	(Sum of nitrogen from ammonia, nitrate and nitrite)
Odour	c	Immediately	(Description)
Oxidizability	b	Immediately Same day if cooled	Cool to 3–4°C, add 35% H_2SO_4 to sample (followed by Kubel Test: 2 ml H_2SO_4 to 100 ml sample Schulze Papp Test: 2ml H_2SO_4 to 100 ml sample then neutralize Dichromate Test: 1 ml H_2SO_4/l sample) See also Oxygen Demand Chemical (COD)
Oxygen dissolved	c	Immediately	Collect in oxygen bottle (BOD bottle) (followed by modified Winkler, Probe Method or azide modification of iodometric method)
Oxygen consumed	a	Same day	*(May use potassium permanganate ($KMnO_4$) oxidation and oxalate titration method)
Oxygen Demand Biochemical (BOD)	c	Immediately	Cap bottles, Cool. Start incubation within a few hours (followed by 5-day incubation method at 20°C, then compare dissolved oxygen content at beginning and at the end of the experiment)
Oxygen Demand Chemical (COD)	a	Same day	(May use H_2SO_4 potassium dichromate digestion method back titrated with ferrous ammonium sulphate)
Ozone	c	Immediately	Cool. Acidify slightly

NOTES: Polyethylene bottles may be used unless otherwise mentioned.
* Bottles are rinsed with nitric acid (1 : 1 with distilled deionized water).

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* Bottles are rinsed with nitric acid (1 : 1 with distilled deionized water).

Source: UNESCO/WHO 1978

Table 2-3 cont.

Parameter	Preservation a — unnecessary b — possible c — not possible	Optimum storage time prior to analysis	Method of treatment (suggested analysis)
Vanadium	b	No time limit	*See Cadmium (may use AAS or AAS-solvent extraction with cupferron butyl acetate)
Zinc	b	No time limit	*See Cadmium

NOTES: Polyethylene bottles may be used unless otherwise mentioned.
b Bottles are rinsed with nitric acid (1 : 1 with distilled deionized water).

Parameter	Preservation a — unnecessary b — possible c — not possible	Optimum storage time prior to analysis	Method of treatment (suggested analysis)
pH	c	Immediately	May use tightly sealed plastic bottles. Analyse as soon as room temperature is reached (may use potentiometric method)
Petroleum hydrocarbon	c	Immediately	Cool (may use hexane extraction or trichlorotrifluoroethane extraction)
Pesticides	a	Same day	Cool sample to 3–4°C. Use all glass utensils with Teflon liners (followed by gas chromatographic method)
Phenols	b	Same day	Use glass bottle. Add 1 g $CuSO_4 . 5H_2O$/l to dry bottle; acidify to pH 4 with conc. H_3PO_4 (see text)
Phosphorous, Total (Orthophosphates and Polyphosphates)	b	Immediately Same day if cooled	Use glass Erlenmeyer for all phosphorous samples. Add 1 ml 30% H_2SO_4/100 ml sample. Cool to 3–4°C (followed by molybdenum blue colourimetric method)
Phosphorous (Orthophosphates)	b	Immediately Same day if cooled	Do not add acid. Cool to 3–4°C (followed by molybdenum blue colourimetric method)
Phosphorus Total	b	Same day	Add 1 ml 30% H_2SO_4/100 ml sample. Cool to 3–4°C (followed by persulphate digestion and molybdenum blue colourimetric metbod)
Polychlorinated Biphenyls (PCB's)	a	Same day	Cool sample to 3–4°C. Use all glass utensils with Teflon liners (followed by gas chromatographic method)
Potassium	a	No time limit	Sample into polyethylene bottles or in glass not releasing potassium (may use AAS—direct flame photometry)
Pyridine bases	b	Same day	Add 2 ml H_2SO_4 (25% by volume)
Residues	a	Immediately	(May use gravimetric method)

NOTES: Polyethylene bottles may be used unless otherwise mentioned.
b Bottles are rinsed with nitric acid (1 : 1 with distilled deionized water).

Parameter	Preservation a — unnecessary b — possible c — not possible	Optimum storage time prior to analysis	Method of treatment (suggested analysis)
Rhodanids	a	Same day if cooled	Cool
Salinity	c	Same day Several days cooled	Cool
Silica	a	Immediately Several days if frozen	Collect in polyethylene bottles. Freeze (followed by colourimetric molybdosilicate or heteropoly blue method)
Silver	b	About 10 days	Transfer sample to dry container with 4 g EDTA/ 100 ml samples added prior to collection (followed by AAS)
Sodium	a	No time limit	Use polyethylene bottle or glass not releasing sodium (may use AAS—direct flame photometry)
Specific Conductance	c	Several days	(May use conductivity meter)
Surface Active Agents (surfactants, MBAS)	b	Same day	Add 2–4 ml $CHCl_3$/l (followed by methylene blue colourimetric method)
Sugar	a	Same day	Cool 3–4°C (may use phenyl hydrazine sulphate method)
Sulphates	a	No time limit	Cool to 3–4°C (may use $BaCl_2$ titrimetric method)
Sulphides	b	Same day	Collect in special sample bottle with tube fitting. Add 10 ml of a 10% cadmium acetate or zinc acetate solution (followed by specific ion electrode or titrimetric iodine method)
Suspended solids	a	Within a few days	Cool to 3–4°C (may use filtration method)
Tannin	a	A few days	(May use colourimetric method)
Temperature	c	Immediately	(Thermometer)
Turbidity	b	Within a few days	Add 2–4 ml $CHCl_3$/l sample. Shake. Store in dark (may use turbidimeter)

NOTES: Polyethylene bottles may be used unless otherwise mentioned.
b Bottles are rinsed with nitric acid (1 : 1 with distilled deionized water).

Table 1 GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION[1]

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*[2]				
EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
(or)				
TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*[3]				
SAR = 0 – 3 and EC_w =		> 0.7	0.7 – 0.2	< 0.2
= 3 – 6 =		> 1.2	1.2 – 0.3	< 0.3
= 6 – 12 =		> 1.9	1.9 – 0.5	< 0.5
= 12 – 20 =		> 2.9	2.9 – 1.3	< 1.3
= 20 – 40 =		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*				
Sodium (Na)[4]				
surface irrigation	SAR	< 3	3 – 9	> 9
sprinkler irrigation	me/l	< 3	> 3	
Chloride (Cl)[4]				
surface irrigation	me/l	< 4	4 – 10	> 10
sprinkler irrigation	me/l	< 3	> 3	
Boron (B)[5]	mg/I	< 0.7	0.7 – 3.0	> 3.0
Trace Elements (see Table 21)				
Miscellaneous Effects *(affects susceptible crops)*				
Nitrogen (NO_3 – N)[6]	mg/l	< 5	5 – 30	> 30
Bicarbonate (HCO_3) *(overhead sprinkling only)*	me/l	< 1.5	1.5 – 8.5	> 8.5
pH		Normal Range 6.5 – 8.4		

[1] Adapted from University of California Committee of Consultants 1974.

[2] ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per metre at 25°C (dS/m) or in units millimhos per centimetre (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per litre (mg/l).

[3] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. See Figure 1 for the SAR calculation procedure. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by ECw. Adapted from Rhoades 1977, and Oster and Schroer 1979.

[4] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance tables (Tables 4 and 5). For chloride tolerance of selected fruit crops, see Table 14. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops. For crop sensitivity to absorption, see Tables 18, 19 and 20.

[5] For boron tolerances, see Tables 16 and 17.

[6] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4-N and Organic-N should be included when wastewater is being tested).

Table 1 (cont.)

Assumptions in the Guidelines

The water quality guidelines in Table 1 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgements on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield Potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain full production capability. A "restruction on use" does not indicate that the water is unsuitable for use.

Site Conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid and rainfall is low. Rainfall does not play a significant role in meeting crop water demand or leaching requirement. (In a monsoon climate or areas where precipitation is high for part or all of the year, the guideline restrictions are too severe. Under the higher rainfall situations, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement.) Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 metres of the surface.

Methods and Timing of Irrigations: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 percent or more) before the next irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction [LF]≥15 percent). The guidelines are too retrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching satisfies the leaching requirements.

Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, "more active" part of the root zone and long-term leaching is accomplished.

Restriction on Use: The "Restriction on Use" shown in Table 1 is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clearcut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Source: Ayers/Westcot (FAO) 1985

USDA classification of irrigation water salinity (sulphate-free waters) Table 8.7

Table 2-4/2

Salinity class and description	EC range (µS cm⁻¹)	Equivalent salt concentration (approximate) TDS 1/ (g ℓ⁻¹)	(ppm)	Cl (ppm)
C1 Low salinity water can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability	< 250	< 0.2	< 200	< 60
C2 Medium salinity water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control	250 - 750	0.2 - 0.5	200 - 500	60-200
C3 High salinity water cannot be used on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected	750 - 2 250	0.5 - 1.5	500 - 1 500	200-600
C4 Very high salinity water is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected	> 2 250	1.5 - 3.0	> 1 500	> 600

Note: 1/ TDS = total dissolved solids.

Source: Adapted from Richards (1954, p 76); note that further divisions based on SAR are also made; see Figure 8.2 and Table 8.8.

Source: Landon ed. 1984

Table 2-4/3

Table 9. Guidelines for interpretation of water quality for irrigation (Ayers and Tanji 1981)

SAR	EC (dS m⁻¹) No problem	Slight to moderate	Severe problem
0– 3	>0.9	0.9–0.2	<0.2
3– 6	>1.3	1.3–0.25	<0.25
6–12	>2.0	2.0–0.35	<0.35
12–20	>3.1	3.1–0.9	<0.9
> 20	>5.6	5.6–1.8	<1.8

Table 2-4/4

Table 1. Classification of irrigation water based on total salt concentration, according to five different reference sources

Salinity class	EC dAS m⁻¹ USSL[a] (1954)	Thorn and Peterson (1954)	NTAC[b] (1968)	Carter (1969)	Ayers and Westcot (1976)
C1	0.1 –0.25	<0.25	<0.75	0.4	<0.75
C2	0.25–0.75	0.25–0.75	0.75–1.5	0.4 –1.2	0.75–1.5
C3	0.75–2.25	0.75–2.25	1.5 –3.0	1.2 –2.25	1.5 –3.0
C4	>2.25	2.25–4.0	3.0 –7.5	2.25–5.0	>3.0
C5		4.0 –6.0			

[a] US Salinity Laboratory
[b] National Technical Advisory Committee, USA

Source: in Bresler et al. ed. 1982

Table 2-4/

Table 2. Permissible upper limit for conductivity of irrigation water (dS m⁻¹) for three crop tolerance groups and five soil textures

Soil texture	Crop tolerance group I, EC_e (dS m⁻¹) <4.0	II 4.0–10.0	III >10.0 Date palm	Horticultural crops	Forage crops	Field crops
Sandy	2.5	6.5	15.2	8.0	12.0	10.0
Loamy sand	1.6	4.0	6.1	4.5	7.0	6.0
Loamy	1.0	3.0	8.0	3.5	5.0	4.5
Loamy clay	0.8	2.0	6.0	2.4	3.5	3.0
Clay	0.4	1.0	3.0	1.8	1.8	1.6

Source: in Bresler et al. ed. 1982

Table 2-4/6

Table 44 GUIDELINES FOR INTERPRETATION OF WATER QUALITY FOR IRRIGATION UNDER INDIAN CONDITIONS (Bhumbla and Abrol, 1972)

Soil	Crops to be grown	Upper permissible limit of EC of water for safe use for irrigation, dS/m
Deep black soils and alluvial soils having a clay content of more than 30 percent. Soils that are fairly to moderately well drained.	Semi-tolerant Tolerant	1.5 2
Heavy textured soils having a clay content of 20-30%. Soils that are well drained internally and have a good surface drainage system.	Semi-tolerant Tolerant	2 4
Medium textured soils having a clay content of 10-20%. Soils that are very well drained internally and have a good surface drainage system.	Semi-tolerant Tolerant	4 6
Light textured soils having a clay content of less than 10%. Soils that have excellent internal and surface drainage.	Semi-tolerant Tolerant	6 8

Qualifying remarks:

1. A monsoon rainfall of 300 to 400 mm is common for most areas having a groundwater quality problem. This rainfall periodically leaches out salts accumulated in the root zone during the previous season.
2. In the above proposed limits of water quality it is presumed that the groundwater table at no time of the year is within 1.5 metres from the surface. If the water table does come up within the root zone the above limits need to be reduced to half the above values.
3. If the soils have impeded internal drainage either on account of presence of hard pans, unusually high amounts of clay or other morphologic reasons, for advisory purposes, the limit of water quality should again be reduced to half.
4. If the waters contain soluble sodium percentage more than 70, gypsum should be added to soil occasionally.
5. If supplemental canal irrigation is available, water of higher electrical conductivity could be used in periods of water shortage.

Source: Kandiah ed. (FAO) 1990

Table 1. Soil and water salinity criteria based on plant salt tolerance groupings (Maas and Hoffman 1977, at 10% yield reduction), for soils of about 60% clay content, Shaw (1988).

Table 2-5 a

Plant salt tolerance grouping [a]	Soil/ water salinity rating	Soil salinity			Irrigation water quality
		$EC_{1:5}$ [c]	EC_{se} [b]	Chloride [d]	EC [e]
		dS/m	dS/m	%	dS/m
sensitive crops	very low	<0.15	<0.95	<0.025	<0.65
moderately sensitive crops	low	0.15-0.30	0.95-1.19	0.025-0.05	0.65-1.30
moderately tolerant crops	medium	0.30-0.70	1.9-4.5	0.05-0.10	1.30-2.90
tolerant crops	high	0.70-1.20	4.5-7.7	0.10-0.18	2.90-5.20
very tolerant crops	very high	1.20-1.90	7.7-12.2	0.18-0.29	5.20-8.10
generally too saline	extreme	>1.90	12.2	>0.29	>8.10

a Groupings are statistically derived divisions based on families of linear curves representing the salt tolerance ratings of the majority of crops reported by Maas and Hoffman (1977). Terminology have been varied and extra group of sensitive crops incorporated.

b EC_{se} is the boundary EC_{se} at which 10% yield reduction occurs for these plant tolerance groups.

c $EC_{1:5}$ derived from EC_{se} divided by 6.4, that is, applicable to soils with clay content of about 60%.

d Cl% derived from $EC_{1:5}$ assuming all salts present are as chloride, EC = 6.64 x Cl%. EC of salt solution based on Marion and Babcock (1976), McNeal *et al.* (1970) and USSL (1954).

e Derived from EC_{se} on the basis that saturation extract is 2 x field capacity and a leaching fraction (LF) of 0.15 at the bottom of the root zone occurs (Ayers 1977), that is, ECwater = 2/3 EC_{se}. Conversion to other LF values can be made.

Actual plant response depends on soil, rainfall, management and the soil salinity profile shape. The boundaries should be considered as approximate divisions between groups.

Table 2-5 b

Water salinity capability rating

water salinity category	EC range dS/m	relative rating
very low	< 0.65 [1]	100%
low	0.65 - 1.3	85%
medium	1.3 - 2.9	55%
high	2.9 - 5.2	25%
very high	5.2 - 8.1	10%
extreme	> 8.1	5%

waters with a salinity below around 0.25 dS/m are more difficult to manage because of the low salt content can give reduced infiltration rates. There problems can be overcome much more easily with management practices than can the use of higher salinity waters and thus should be rated at 100%

Source: Shaw 1992

Table 2-6 a

Table 28 WATER QUALITY GUIDE FOR LIVESTOCK AND POULTRY USES [1]

Water Salinity (EC_w) (dS/m)	Rating	Remarks
< 1.5	Excellent	Usable for all classes of livestock and poultry.
1.5 - 5.0	Very Satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhoea in livestock not accustomed to such water; watery droppings in poultry.
5.0 - 8.0	Satisfactory for Livestock	May cause temporary diarrhoea or be refused at first by animals not accustomed to such water.
	Unfit for Poultry	Often causes watery faeces, increased mortality and decreased growth, especially in turkeys.
8.0 - 11.0	Limited Use for Livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for Poultry	Not acceptable for poultry.
11.0 - 16.0	Very Limited Use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
> 16.0	Not Recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

1 Adapted from National Academy of Sciences (1972; 1974).

Table 2-6 b

Table 30 GUIDELINES FOR LEVELS OF TOXIC SUBSTANCES IN LIVESTOCK DRINKING WATER [1]

Constituent (Symbol)	Upper Limit (mg/l)
Aluminium (Al)	5.0
Arsenic (As)	0.2
Beryllium (Be) [2]	0.1
Boron (B)	5.0
Cadmium (Cd)	0.05
Chromium (Cr)	1.0
Cobalt (Co)	1.0
Copper (Cu)	0.5
Fluoride (F)	2.0
Iron (Fe)	not needed
Lead (Pb) [3]	0.1
Manganese (Mn) [4]	0.05
Mercury (Hg)	0.01
Nitrate + Nitrite (NO_3-N + NO_2-N)	100.0
Nitrite (NO_2-N)	10.0
Selenium (Se)	0.05
Vanadium (V)	0.10
Zinc (Zn)	24.0

1 Adapted from National Academy of Sciences (1972).

2 Insufficient data for livestock. Value for marine aquatic life is used here.

3 Lead is accumulative and problems may begin at a threshold value of 0.05 mg/l.

4 Insufficient data for livestock. Value for human drinking water used.

Source: FAO (SB 39) 1988

EXAMPLE 6 – COMPARISON OF METHODS TO CALCULATE THE SODIUM HAZARD OF A WATER

Given: The water analysis is:

Ca = 2.32 me/l
Mg = 1.44 me/l
Na = 7.73 me/l

Sum = 11.49 me/l

CO_3 = 0.42 me/l
HCO_3 = 3.66 me/l

Sum = 4.08 me/l

EC_w = 1.15 dS/m

Explanation:

1. The Sodium Adsorption Ratio (SAR) can be calculated from equation (1):

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \qquad (1)$$

$$SAR = \frac{7.73}{\sqrt{\frac{2.32 + 1.44}{2}}} = 5.64$$

2. The adjusted Sodium Adsorption Ratio (adj SAR) can be calculated from the procedure given in Ayers and Westcot (1976):

$$\text{adj } SAR = SAR\,[1 + (8.4 - pHc)] \qquad (15)$$

where $pHc = (pk_2 - pk_c) + p\,(Ca + Mg) + p\,(Alk)$

$(pk_2 - pk_c)$ = 2.3
$p\,(Ca + Mg)$ = 2.7
$p\,(Alk)$ = 2.4

pHc = 7.4

$$\text{adj } SAR = 5.64\,[1 + (8.4 - 7.40)] = 11.3$$

3. The adjusted Sodium Adsorption Ratio (adj RNa) can be calculated from equation (14) and Table 11):

$$\text{adj } R_{Na} = \frac{Na}{\sqrt{\frac{Ca_x + Mg}{2}}} \qquad (14)$$

EC_w = 1.15 dS/m

HCO_3/Ca = 1.76

From Table 11, Ca_x = 1.43 me/l

$$\text{adj } R_{Na} = \frac{7.73}{\sqrt{\frac{1.43 + 1.44}{2}}} = 6.45$$

Table 2-7 b

Source: Ayers/Westcot (FAO) 1985

Table 11 CALCIUM CONCENTRATION (Ca_x) EXPECTED TO REMAIN IN NEAR-SURFACE SOIL-WATER FOLLOWING IRRIGATION WITH WATER OF GIVEN HCO_3/Ca RATIO AND EC_w[1,2,3]

		Salinity of applied water (EC_w) (dS/m)											
		0.1	0.2	0.3	0.5	0.7	1.0	1.5	2.0	3.0	4.0	6.0	8.0
Ratio of HCO_3/Ca	.05	13.20	13.61	13.92	14.40	14.79	15.26	15.91	16.43	17.28	17.97	19.07	19.94
	.10	8.31	8.57	8.77	9.07	9.31	9.62	10.02	10.35	10.89	11.32	12.01	12.56
	.15	6.34	6.54	6.69	6.92	7.11	7.34	7.65	7.90	8.31	8.64	9.17	9.58
	.20	5.24	5.40	5.52	5.71	5.87	6.06	6.31	6.52	6.86	7.13	7.57	7.91
	.25	4.51	4.65	4.76	4.92	5.06	5.22	5.44	5.62	5.91	6.15	6.52	6.82
	.30	4.00	4.12	4.21	4.36	4.48	4.62	4.82	4.98	5.24	5.44	5.77	6.04
	.35	3.61	3.72	3.80	3.94	4.04	4.17	4.35	4.49	4.72	4.91	5.21	5.45
	.40	3.30	3.40	3.48	3.60	3.70	3.82	3.98	4.11	4.32	4.49	4.77	4.98
	.45	3.05	3.14	3.22	3.33	3.42	3.53	3.68	3.80	4.00	4.15	4.41	4.61
	.50	2.84	2.93	3.00	3.10	3.19	3.29	3.43	3.54	3.72	3.87	4.11	4.30
	.75	2.17	2.24	2.29	2.37	2.43	2.51	2.62	2.70	2.84	2.95	3.14	3.28
	1.00	1.79	1.85	1.89	1.96	2.01	2.09	2.16	2.23	2.35	2.44	2.59	2.71
	1.25	1.54	1.59	1.63	1.68	1.73	1.78	1.86	1.92	2.02	2.10	2.23	2.33
	1.50	1.37	1.41	1.44	1.49	1.53	1.58	1.65	1.70	1.79	1.86	1.97	2.07
	1.75	1.23	1.27	1.30	1.35	1.38	1.43	1.49	1.54	1.62	1.68	1.78	1.86
	2.00	1.13	1.16	1.19	1.23	1.26	1.31	1.36	1.40	1.48	1.54	1.63	1.70
	2.25	1.04	1.08	1.10	1.14	1.17	1.21	1.26	1.30	1.37	1.42	1.51	1.58
	2.50	0.97	1.00	1.02	1.06	1.09	1.12	1.17	1.21	1.27	1.32	1.40	1.47
	3.00	0.85	0.89	0.91	0.94	0.96	1.00	1.04	1.07	1.13	1.17	1.24	1.30
	3.50	0.78	0.80	0.82	0.85	0.87	0.90	0.94	0.97	1.02	1.06	1.12	1.17
	4.00	0.71	0.73	0.75	0.78	0.80	0.82	0.86	0.88	0.93	0.97	1.03	1.07
	4.50	0.66	0.68	0.69	0.72	0.74	0.76	0.79	0.82	0.86	0.90	0.95	0.99
	5.00	0.61	0.63	0.65	0.67	0.69	0.71	0.74	0.76	0.80	0.83	0.88	0.93
	7.00	0.49	0.50	0.52	0.53	0.55	0.57	0.59	0.61	0.64	0.67	0.71	0.74
	10.00	0.39	0.40	0.41	0.42	0.43	0.45	0.47	0.48	0.51	0.53	0.56	0.58
	20.00	0.24	0.25	0.26	0.26	0.27	0.28	0.29	0.30	0.32	0.33	0.35	0.37
	30.00	0.18	0.19	0.20	0.20	0.21	0.21	0.22	0.23	0.24	0.25	0.27	0.28

[1] Adapted from Suarez (1981).

[2] Assumes a soil source of calcium from lime ($CaCO_3$) or silicates; no precipitation of magnesium, and partial pressure of CO_2 near the soil surface (P_{CO_2}) is .0007 atmospheres.

[3] Ca_x, HCO_3, Ca are reported in me/l; EC_w is in dS/m.

Table 2-7 a

Table 2-8

Table 13 AVERAGE COMPOSITION AND EQUIVALENT ACIDITY OR BASICITY OF FERTILIZER MATERIALS[1]

Fertilizer materials	Chemical Formula	Total Nitrogen (N)	Available Phosphoric Acid (P_2O_5)	Water Soluble Potash (K_2O)	Combined Calcium (Ca)	Combined Sulphur (S)	Equivalent[2] Acid or Base in kg $CaCO_3$: Acid	Base
		Percent						
Nitrogen materials								
Ammonium nitrate	NH_4NO_3	33.5-34					62	
Ammonium nitrate-sulphate	$NH_4NO_3.(NH_4)_2SO_4$	30				6.5	68	
Monoammonium phosphate	$NH_4H_2PO_4$	11	48				58	
Ammonium phosphate-sulphate	$NH_4H_2PO_4.(NH_4)_2SO_4$	13	39			7	69	
Ammonium phosphate-sulphate	$NH_4H_2PO_4.(NH_4)_2SO_4$	16	20			15	88	
Ammonium phosphate-nitrate	$NH_4H_2PO_4.NH_4NO_3$	27	12			4.5	75	
Diammonium phosphate	$(NH_4)_2HPO_4$	16-18	46-48				70	
Ammonium sulphate	$(NH_4)_2SO_4$	21				24	110	
Anhydrous ammonia	NH_3	82					147	
Aqua ammonia	NH_4OH	20					36	
Calcium ammonium nitrate solution	$Ca(NO_3)_2.NH_4NO_3$	17			8.8		9	
Calcium nitrate	$Ca(NO_3)_2$	15.5			21			20
Calcium cyanamide	$CaCN_2$	20-22			37			63
Sodium nitrate	$NaNO_3$	16						29
Urea	$CO(NH_2)_2$	45-46					71	
Urea formaldehyde[3]		38					60	
Urea ammonium nitrate solution	$NH_4NO_3.CO(NH_2)_2$	32					57	
Phosphate materials								
Single superphosphate	$Ca(H_2PO_4)_2$		18-20		18-21	12		neutral
Triple superphosphate	$Ca(H_2PO_4)_2$		45-46		12-14	1		neutral
Phosphoric acid	H_3PO_4		52-54				110	
Superphosphoric acid[4]			76-83				160	
Potash materials								
Potassium chloride	KCl			60-62				neutral
Potassium nitrate	KNO_3	13		44			23	
Potassium sulphate	K_2SO_4			50-53		18		neutral
Sulphate of potash-magnesia	$K_2SO_4.2MgSO_4$			26	1	15		neutral

[1] From Soil Improvement Committee (1975).

[2] Equivalent per 100 kg of each material.

[3] Also known as ureaform, reaction product of urea and formaldehyde.

[4] H_3PO_4, $H_4P_2O_7$, $H_5P_3O_{10}$, $H_6P_4O_{13}$ and other higher forms.

Source: Ayers/Westcot (FAO) 1985

Table 36-6. Chloride tolerance limits of some fruit-crop cultivars and rootstocks. After Maas (1986).

Table 2-9a

Crop	Rootstock or cultivar	Maximum permissible Cl^- in soil water without leaf injury
	Rootstocks	
Avocado	West Indian	15
	Guatemalan	12
	Mexican	10
Citrus (*Citrus* spp.)	Sunki mandarin, grapefruit, Cleopatra mandarin, Rangpur lime	50
	Sampson tangelo, rough lemon,‡ sour orange, Ponkan mandarin	30
	Citrumelo 4475, trifolate orange, Cuban shaddock, Calamondin, sweet orange, Savage citrange, Rusk citrange, Troyer citrange	20
Grape (*Vitis* spp.)	Salt Creek, 1613-3	80
	Dog ridge	60
Stone fruit (*Prunus* spp.)	Marianna	50
	Lovell, Shalil	20
	Yunnan	15
	Cultivars	
Berries§ (*Rubus* spp.)	Boysenberry	20
	Olallie blackberry	20
	Indian summer raspberry	10
Grape (*Vitis* spp.)	Thompson seedless, Perlette	40
	Cardinal, Black rose	20
Strawberry (*Fragaria* spp.)	Lassen	15
	Shasta	10

† For some crops these concentrations may exceed the osmotic threshold and cause some yield reductions.
‡ Data from Australia indicate that rough lemon is more sensitive to Cl^- than sweet orange.
§ Data available for one variety of each species only.

Source: Stewart ed. 1990

Table 14 CHLORIDE TOLERANCE OF SOME FRUIT CROP CULTIVARS AND ROOTSTOCKS [1]

Table 2-9b

Crop	Rootstock or Cultivar	Maximum Permissible Cl^- without Leaf Injury [2]: Root Zone (Cl_e) (me/l)	Irrigation Water (Cl_w) [3,4] (me/l)
	Rootstocks		
Avocado (*Persea americana*)	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus (*Citrus spp.*)	Sunki Mandarin, Grapefruit, Cleopatra mandarin, Rangpur lime	25.0	16.6
	Sampson tangelo, Rough lemon, Sour orange, Ponkan mandarin	15.0	10.0
	Citrumelo 4475, Trifoliate orange, Cuban shaddock, Calamondin, Sweet orange, Savage citrange, Rusk citrange, Troyer citrange	10.0	6.7
Grape (*Vitis spp.*)	Salt Creek, 1613-3	40.0	27.0
	Dog Ridge	30.0	20.0
Stone Fruits (*Prunus spp.*)	Marianna	25.0	17.0
	Lovell, Shalil	10.0	6.7
	Yunnan	7.5	5.0
	Cultivars		
Berries (*Rubus spp.*)	Boysenberry	10.0	6.7
	Olallie blackberry	10.0	6.7
	Indian Summer Raspberry	5.0	3.3
Grape (*Vitis spp.*)	Thompson seedless	20.0	13.3
	Perlette	20.0	13.3
	Cardinal	10.0	6.7
	Black Rose	10.0	6.7
Strawberry (*Fragaria spp.*)	Lassen	7.5	5.0
	Shasta	5.0	3.3

[1] Adapted from Maas (1984).

Source: Ayers/Westcot (FAO) 1985

[2] For some crops, the concentration given may exceed the overall salinity tolerance of that crop and cause some reduction in yield in addition to that caused by chloride ion toxicities.

[3] Values given are for the maximum concentration in the irrigation water. The values were derived from saturation extract data (EC_e) assuming a 15-20 percent leaching fraction and $EC_e = 1.5\ EC_w$.

[4] The maximum permissible values apply only to surface irrigated crops. Sprinkler irrigation may cause excessive leaf burn at values far below these (see Section 4.3).

Table 4 GUIDELINE TO IDENTIFY POTENTIAL INFILTRATION PROBLEM DUE TO SODIUM IN IRRIGATION WATER[1]

Table 2-10 a

Salinity levels of irrigation water	Degree of reduction in infiltration rate (SAR of irrigation water): No reduction	Slight reduction	Medium reduction	Severe reduction
Non-saline water EC_w (dS/m) = 0.7	< 1	1 to 5	5 to 11	> 11
Slightly saline water EC_w (dS/m) = 0.7 to 3.0	< 10	10 to 15	15 to 23	> 23
Medium saline water EC_w (dS/m) = 3.0 to 6.0	< 25	> 25	No effect on infiltration	No effect on infiltration
Highly saline water EC_w (dS/m) = 6.0 to 14.0	< 35	> 35	No effect	No effect
Very highly saline water EC_w (dS/m) = > 14.0	No effect by sodium on infiltration rate			

[1] Based on the results of Rhoades (1977) and Oster and Schroer (1979).

Source: Ayers/Westcot (FAO) 1985

Table 15 RELATIVE TOLERANCE OF SELECTED CROPS TO EXCHANGEABLE SODIUM[1].

Table 2-10 b

Sensitive[2]	Semi-tolerant[2]	Tolerant[2]
Avocado (*Persea americana*)	Carrot (*Daucus carota*)	Alfalfa (*Medicago sativa*)
Deciduous Fruits	Clover, Ladino (*Trifolium repens*)	Barley (*Hordeum vulgare*)
Nuts	Dallisgrass (*Paspalum dilatatum*)	Beet, garden (*Beta vulgaris*)
Bean, green (*Phaseolus vulgaris*)	Fescue, tall (*Festuca arundinacea*)	Beet, sugar (*Beta vulgaris*)
Cotton (at germination) (*Gossypium hirsutum*)	Lettuce (*Lactuca sativa*)	Bermuda grass (*Cynodon dactylon*)
Maize (*Zea mays*)	Bajara (*Pennisetum typhoides*)	Cotton (*Gossypium hirsutum*)
Peas (*Pisum sativum*)	Sugarcane (*Saccharum officinarum*)	Paragrass (*Brachiaria mutica*)
Grapefruit (*Citrus paradisi*)	Berseem (*Trifolium alexandrinum*)	Rhodes grass (*Chloris gayana*)
Orange (*Citrus sinensis*)	Benji (*Melilotus parviflora*)	Wheatgrass, crested (*Agropyron cristatum*)
Peach (*Prunus persica*)	Raya (*Brassica juncea*)	Wheatgrass, fairway (*Agropyron cristatum*)
Tangerine (*Citrus reticulata*)	Oat (*Avena sativa*)	Wheatgrass, tall (*Agropyron elongatum*)
Mung (*Phaseolus aurus*)	Onion (*Allium cepa*)	Karnal grass (*Diplachna fusca*)
Mash (*Phaseolus mungo*)	Radish (*Raphanus sativus*)	
Lentil (*Lens culinaris*)	Rice (*Oryza sativus*)	
Groundnut (peanut) (*Arachis hypogaea*)	Rye (*Secale cereale*)	
Gram (*Cicer arietinum*)	Ryegrass, Italian (*Lolium multiflorum*)	
Cowpeas (*Vigna sinensis*)	Sorghum (*Sorghum vulgare*)	
	Spinach (*Spinacia oleracea*)	
	Tomato (*Lycopersicon esculentum*)	
	Vetch (*Vicia sativa*)	
	Wheat (*Triticum vulgare*)	

Adapted from data of FAO-Unesco (1973); Pearson (1960); and Abrol (1982).

The approximate levels of exchangeable sodium percentage (ESP) corresponding to the three categories of tolerance are: sensitive less than 15 ESP; semi-tolerant 15-40 ESP; tolerant more than 40 ESP. Tolerance decreases in each column from top to bottom. The tolerances listed are relative because, usually, nutritional factors and adverse soil conditions stunt growth before reaching these levels. Soil with an ESP above 30 will usually have too poor physical structure for good crop production. Tolerances in most instances were established by first stabilizing soil structure.

Source: Ayers/Westcot (FAO) 1985

Table 2-11 a

Table 36-5. Boron tolerance limits for agricultural crops. After Maas (1986).

Common name (Botanical name not included in text)	Threshold†
	mg/L
Very sensitive	
Lemon‡	<0.5
Blackberry‡	<0.5
Sensitive	
Avocado‡	0.5–0.75
Grapefruit‡	0.5–0.75
Orange‡	0.5–0.75
Apricot‡	0.5–0.75
Peach‡	0.5–0.75
Cherry‡	0.5–0.75
Plum‡	0.5–0.75
Persimmon, Japanese (*Diospyros kaki* L.f.)	0.5–0.75
Fig, kadota‡	0.5–0.75
Grapa‡ (*Vitis vinifera*)	0.5–0.75
Walnut‡ (*Juglans regia* L.)	0.5–0.75
Pecan‡ [*Carya illinoensis* (Wangenh.) K. Koch]	0.5–0.75
Cowpea‡	0.5–0.75
Onion	0.5–0.75
Garlic (*Allium sativum* L.)	0.75–1.0
Sweet potato	0.75–1.0
Wheat	0.75–1.0
Sunflower	0.75–1.0
Bean, mung‡ [*Vigna radiata* (L.) R. Wilcz.]	0.75–1.0
Sesame‡	0.75–1.0
Lupine‡ (*Lupinus hartwegii* Lindl.)	0.75–1.0
Strawberry‡ (*Fragaria* sp. L.)	0.75–1.0
Artichoke, Jerusalem‡	0.75–1.0
Bean, kidney‡ (*Phaseolus vulgaris*)	0.75–1.0
Bean, lima‡ (*Phaseolus lunatus*)	0.75–1.0
Peanut (*Arachis hypogaea*)	0.75–1.0
Moderately sensitive	
Broccoli	1.0–2.0
Pepper, red	1.0–2.0
Pea‡	1.0–2.0
Carrot	1.0–2.0
Radish	1.0–2.0
Potato	1.0–2.0
Cucumber	1.0–2.0
Moderately tolerant	
Lettuce‡	2.0–4.0
Cabbage‡	2.0–4.0
Celery‡	2.0–4.0
Turnip	2.0–4.0
Bluegrass, Kentucky‡ (*Poa pratensis* L.)	2.0–4.0
Barley	2.0–4.0
Oat	2.0–4.0
Corn	2.0–4.0
Artichoke, globe‡ (*Cynara scolymus* L.)	2.0–4.0
Tobacco‡ (*Nicotiana tabacum* L.)	2.0–4.0
Mustard, Indian‡ [*Brassica juncea* (L.) Czerni.]	2.0–4.0
Clover, sweet‡	2.0–4.0
Squash	2.0–4.0
Muskmelon‡	2.0–4.0
Cauliflower	2.0–4.0
Tolerant	
Tomato	4.0–6.0
Alfalfa‡	4.0–6.0
Vetch, purple‡ (*Vicia benghalensis*)	4.0–6.0
Parsley‡ (*Petroselinum crispum*)	4.0–6.0
Beet, red	4.0–6.0
Sugarbeet	4.0–6.0
Very tolerant	
Sorghum	6.0–10.0
Cotton	6.0–10.0
Asparagus‡	10.0–15.0

† Maximum permissible concentration in soil water without yield reduction. Boron tolerances may vary depending upon climate, soil conditions, and crop varieties.
‡ Tolerance based on reductions in vegetative growth.

Table 2-11 b

Table 16 RELATIVE BORON TOLERANCE OF AGRICULTURAL CROPS [1,2]

Very Sensitive (<0.5 mg/1)	
Lemon	*Citrus limon*
Blackberry	*Rubus spp.*

Sensitive (0.5 - 0.75 mg/1)	
Avocado	*Persea americana*
Grapefruit	*Citrus X paradisi*
Orange	*Citrus sinensis*
Apricot	*Prunus armeniaca*
Peach	*Prunus persica*
Cherry	*Prunus avium*
Plum	*Prunus domestica*
Persimmon	*Diospyros kaki*
Fig, kadota	*Ficus carica*
Grape	*Vitis vinifera*
Walnut	*Juglans regia*
Pecan	*Carya illinoiensis*
Cowpea	*Vigna unguiculata*
Onion	*Allium cepa*

Sensitive (0.75 - 1.0 mg/1)	
Garlic	*Allium sativum*
Sweet potato	*Ipomoea batatas*
Wheat	*Triticum eastivum*
Barley	*Hordeum vulgare*
Sunflower	*Helianthus annuus*
Bean, mung	*Vigna radiata*
Sesame	*Sesamum indicum*
Lupine	*Lupinus hartwegii*
Strawberry	*Fragaria spp.*
Artichoke, Jerusalem	*Helianthus tuberosus*
Bean, kidney	*Phaseolus vulgaris*
Bean, lima	*Phaseolus lunatus*
Groundnut/Peanut	*Arachis hypogaea*

Moderately Sensitive (1.0 - 2.0 mg/1)	
Pepper, red	*Capsicum annuum*
Pea	*Pisum sativa*
Carrot	*Daucus carota*
Radish	*Raphanus sativus*
Potato	*Solanum tuberosum*
Cucumber	*Cucumis sativus*

Moderately Tolerant (2.0 - 4.0 mg/1)	
Lettuce	*Lactuca sativa*
Cabbage	*Brassica oleracea capitata*
Celery	*Apium graveolens*
Turnip	*Brassica rapa*
Bluegrass, Kentucky	*Poa pratensis*
Oats	*Avena sativa*
Maize	*Zea mays*
Artichoke	*Cynara scolymus*
Tobacco	*Nicotiana tabacum*
Mustard	*Brassica juncea*
Clover, sweet	*Melilotus indica*
Squash	*Cucurbita pepo*
Muskmelon	*Cucumis melo*

Tolerant (4.0 - 6.0 mg/1)	
Sorghum	*Sorghum bicolor*
Tomato	*Lycopersicon lycopersicum*
Alfalfa	*Medicago sativa*
Vetch, purple	*Vicia benghalensis*
Parsley	*Petroselinum crispum*
Beet, red	*Beta vulgaris*
Sugarbeet	*Beta vulgaris*

Very Tolerant (6.0 - 15.0 mg/1)	
Cotton	*Gossypium hirsutum*
Asparagus	*Asparagus officinalis*

Source: Ayers/Westcot (FAO) 1985

[1] Data taken from Maas (1984).

[2] Maximum concentrations tolerated in soil-water without yield or vegetative growth reductions. Boron tolerances vary depending upon climate, soil conditions and crop varieties. Maximum concentrations in the irrigation water are approximately equal to these values or slightly less.

Table 2-12 a

Table II.2 Recommended maximum concentrations of trace elements in irrigation water[1]

Elements	For waters used continuously on all soil (mg/liter)	For use up to 20 yrs. on fine-textured soils at pH 6.0 to 8.5 (mg/liter)
Aluminum	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.50
Boron	0.75	2.0 – 10.0
Cadmium	0.010	0.050
Chromium	0.10	1.0
Cobalt	0.050	5.0
Copper	0.20	5.00
Fluorine	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5[2]
Manganese	0.20	10.0
Molybdenum	0.010	0.050[3]
Nickel	0.20	2.0
Selenium	0.020	0.020
Vanadium	0.10	1.0
Zinc	2.0	10.0

[1] These levels will not normally have an adverse effect on plants or soils. No data available for mercury, silver, tin, titanium, tungsten.
[2] Recommended maximum concentration for citrus is 0.75 mg/liter.
[3] Only for fine-textured acid soils, or acid soils with relatively high content of iron oxide.

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Source: Shainberg/Oster 1978

Table 2-12 b

Table 21 RECOMMENDED MAXIMUM CONCENTRATIONS OF TRACE ELEMENTS IN IRRIGATION WATER [1]

Element	Recommended Maximum Concentration[2] (mg/1)	Remarks
Al (aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/1 for Sudan grass to less than 0.05 mg/1 for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/1 for kale to 0.5 mg/1 for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/1 in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/1 in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/1 in nutrient solutions.
F (fluoride)	1.0	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/1; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/1). Acts similarly to boron.
Mn (mangaoese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/1, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni (nickel)	0.20	Toxic to a number of plants at 0.5 mg/1 to 1.0 mg/1; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/1 and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Sn (tin) Ti (titanium) W (tungsten)	——	Effectively excluded by plants; specific tolerance unknown.
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH >6.0 and in fine textured or organic soils.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

[2] The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10 000 m^3 per hectare per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjnstment should be made for application rates less than 10 000 m^3 per hectare per year. The values given are for water used on a continuous basis at one site.

Source: Ayers/Westcot (FAO) 1985

Table 22 PHYSICAL, CHEMICAL AND BIOLOGICAL CONTRIBUTORS TO CLOGGING OF LOCALIZED (DRIP) IRRIGATION SYSTEMS AS RELATED TO IRRIGATION WATER QUALITY[1]

Table 2-13

PHYSICAL (Suspended Solids)	CHEMICAL (Precipitation)	BIOLOGICAL (Bacteria and algae)
1. Sand	1. Calcium or magnesium carbonate	1. Filaments
2. Silt	2. Calcium sulphate	2. Slimes
3. Clay	3. Heavy metal hydroxides, oxides, carbonates, silicates and sulphides	3. Microbial depositions: (a) Iron (b) Sulphur (c) Manganese
4. Organic matter	4. Fertilizers (a) Phosphate (b) Aqueous ammonia (c) Iron, zinc, copper, manganese	4. Bacteria
		5. Small aquatic organisms: (a) Snail eggs (b) Larva

[1] Adapted from Bucks et al. (1979).

Source: Ayers/Westcot (FAO) 1985

Table 23 STANDARD WATER QUALITY TESTS NEEDED FOR DESIGN AND OPERATION OF LOCALIZED (DRIP) IRRIGATION SYSTEMS

Table 2-14

1. Major Inorganic Salts (see Table 2)	8. Micro-organisms
2. Hardness[1]	9. Iron
3. Suspended Solids	10. Dissolved Oxygen
4. Total Dissolved Solids (TDS)[1]	11. Hydrogen Sulphide
5. BOD (Biological Oxygen Demand)	12. Iron Bacteria
6. COD (Chemical Oxygen Demand)	13. Sulphate Reducing Bacteria
7. Organics and Organic Matter	

[1] A calculated value from analyses

Source: Ayers/Westcot (FAO) 1985

Table 2.10 Clogging potential of irrigation water used in drip irrigation systems (After Nakayama 1982)

Table 2-15

Type of hazard	Extent of hazard: Slight	Moderate	Severe
Physical			
Suspended soids (mg/l)	< 50	50–100	> 100
Chemical			
pH	< 7.0	7.0–8.0	> 8.0
Dissolved solids (mg/l)	< 500	500–2000	> 2000
Manganese (mg/l)	< 0.1	0.1–1.5	1.5
Iron (mg/l)	< 0.1	0.1–1.5	> 1.5
Hydrogen sulfide (mg/l)	< 0.5	0.5–2.0	> 2.0
Biological			
Bacterial populations (maximum number/ml)	< 10000	10000–50000	> 50000

Source: Feigin et al. 1991

Table 24 INFLUENCE OF WATER QUALITY ON THE POTENTIAL FOR CLOGGING PROBLEMS IN LOCALIZED (DRIP) IRRIGATION SYSTEMS[1]

Table 2-16

Potential Problem	Units	Degree of Restriction on Use: None	Slight to Moderate	Severe
Physical				
Suspended Solids	mg/l	< 50	50 – 100	> 100
Chemical				
pH		< 7.0	7.0 – 8.0	> 8.0
Dissolved Solids	mg/l	< 500	500 – 2000	> 2000
Manganese[2]	mg/l	< 0.1	0.1 – 1.5	> 1.5
Iron[3]	mg/l	< 0.1	0.1 – 1.5	> 1.5
Hydrogen Sulphide	mg/l	< 0.5	0.5 – 2.0	> 2.0
Biological				
Bacterial populations	maximum number/ml	<10 000	10 000 – 50 000	>50 000

[1] Adapted from Nakayama (1982).

[2] While restrictions in use of localized (drip) irrigation systems may not occur at these manganese concentrations, plant toxicities may occur at lower concentrations (see Table 21).

[3] Iron concentrations > 5.0 mg/l may cause nutritional imbalances in certain crops (see Table 21).

Source: Ayers/Westcot (FAO) 1985

Table 25 PROCEDURE FOR CALCULATION OF pHc[1,2]

Table 2-17

$$pHc = (pK_2 - pKc) + pCa + p(Alk)$$

$pK_2 - pKc$ is obtained from the concentration of Ca + Mg + Na in me/l
pCa is obtained from the Ca in me/l
p(Alk) is obtained from the concentration of $CO_3 + HCO_3$ in me/l
} Obtained from the water analysis

Concentration (me/l)	$pK_2 - pKc$	pCa	p(Alk)
0.05	2.0	4.6	4.3
0.10	2.0	4.3	4.0
0.15	2.0	4.1	3.8
0.20	2.0	4.0	3.7
0.25	2.0	3.9	3.6
0.30	2.0	3.8	3.5
0.40	2.0	3.7	3.4
0.50	2.1	3.6	3.3
0.75	2.1	3.4	3.1
1.00	2.1	3.3	3.0
1.25	2.1	3.2	2.9
1.50	2.1	3.1	2.8
2.00	2.2	3.0	2.7
2.50	2.2	2.9	2.6
3.00	2.2	2.8	2.5
4.00	2.2	2.7	2.4
5.00	2.2	2.6	2.3
6.00	2.2	2.5	2.2
8.00	2.3	2.4	2.1
10.00	2.3	2.3	2.0
12.50	2.3	2.2	1.9
15.00	2.3	2.1	1.8
20.00	2.4	2.0	1.7
30.00	2.4	1.8	1.5
50.00	2.5	1.6	1.3
80.00	2.5	1.4	1.1

[1] Procedure from Nakayama (1982).

[2] pHc is a theoretical, calculated pH of the irrigation water.

Source: Ayers/Westcot (FAO) 1985

Table 27 LIMIT VALUES FOR EVALUATING THE AGGRESSIVITY OF WATER AND SOIL TO CONCRETE[1]

Table 2-18

Test	Intensity of attack: None to slight	Mild	Strong	Very Strong
Water				
pH	> 6.5	6.5–5.5	5.5–4.5	< 4.5
Lime-dissolving carbonic acid (CO_2), mg/l	< 15	15–30	30–60	> 60
Ammonium (NH_4), mg/l	< 15	15–30	30–60	> 60
Magnesium (Mg), mg/l	< 100	100–300	300–1500	> 1500
Sulphate in water (SO_4), mg/l	< 200	200–600	600–3000	> 3000
Soil				
Sulphate in soil (air-dry) (SO_4), mg/kg	< 2000	2000–5000	> 5000	

[1] Data taken from Biczok (1972).

Source: Ayers/Westcot (FAO) 1985

Table 3.6 Relative susceptibility of crops to foliar injury from saline sprinkling water[a] (After Maas 1986)

Table 2-19

Sodium or chloride concentrations (mol/m³) causing foliar injury[b]			
< 5	5–10	10–20	> 20
Almond	Grape	Alfalfa	Cauliflower
Apricot	Pepper	Barley	Cotton
Citrus	Potato	Corn	Sugar beet
Plum	Tomato	Cucumber	Sunflower
		Safflower	
		Sesame	
		Sorghum	

[a] Susceptibility based on direct accumulation of salts through the leaves.
[b] Foliar injury is influenced by cultural and environmental conditions. These data are presented only as general guidelines for daytime sprinkling.

Source: Feigin et al. 1991

Table 2-20 a

EXAMPLE 8 – BLENDING IRRIGATION WATER TO REDUCE THE SAR OF A POOR QUALITY SUPPLY

A canal water supply is available but will not meet the total crop water demand. The canal supply could be blended with a poorer quality well water to the extent of 75% canal water and 25% well water. What is the SAR of the blended water?

Given: The water analysis is:

	ECw (dS/m)	Ca (me/l)	Mg (me/l)	Na (me/l)	HCO_3 (me/l)	SAR
Canal water	0.23	1.41	0.54	0.48	1.8	0.5
Well water	3.60	2.52	4.00	32.0	4.5	18.0

Explanation: The resulting blend quality can be found by using equation (13):

(me/l of (a) x proportion of (a) used) + (me/l of (b) x proportion of (b) used) = resulting blend in me/l

$$Ca = (1.41 \times 0.75) + (2.52 \times 0.25) = 1.69 \text{ me/l (blend)}$$
$$Mg = (0.54 \times 0.75) + (4.00 \times 0.25) = 1.41 \text{ me/l (blend)}$$
$$Na = (0.48 \times 0.75) + (32.0 \times 0.25) = 8.36 \text{ me/l (blend)}$$
$$HCO_3 = (1.8 \times 0.75) + (4.5 \times 0.25) = 2.48 \text{ me/l (blend)}$$
$$EC_w = (0.23 \times 0.75) + (3.6 \times 0.25) = 1.07 \text{ dS/m (blend)}$$

$$SAR = \frac{8.36}{\sqrt{\frac{1.69 + 1.41}{2}}} = 6.7$$

Table 2-20 b

EXAMPLE 5 – BLENDING IRRIGATION WATER FOR MAIZE

A farmer is irrigating a maize crop with canal water (ECw = 0.23 dS/m) and is able to achieve a leaching fraction (LF) of 0.15 by using efficient irrigation practices. The irrigated area could be expanded but no additional canal water is available. A well is available but the water quality is marginal for maize production (ECw = 3.6 dS/m). Could these two water sources be safely blended and thus expand the irrigated area?

Given:

Canal water	EC_w	= 0.23 dS/m
Well water	EC_w	= 3.6 dS/m
Water demand (ET) for maize	ET	= 800 mm/year
Leaching fraction achieved	LF	= 0.15

Explanation:

The leaching needed for a 90% yield potential of maize is estimated using equation (9):

$$LR = \frac{EC_w}{5(EC_e) - EC_w} \quad (9)$$

$$LR_{(canal\ water)} = \frac{0.23}{5(2.5) - 0.23} = 0.02$$

$$LR_{(well\ water)} = \frac{3.6}{5(2.5) - 3.6} = 0.40$$

The calculated leaching requirement (LR) for the canal water is less than the actual leaching achieved by the farmer. Water is being lost by over leaching but a LF leas than 0.15 is not often achievable. The calculated leaching requirement of well water alone when added to ET would greatly increase the amount of water needed for production. For example, with the caoal water and a LF of 0.15, the applied water needed (Aw) is found from equation (7):

$$Aw = \frac{ET}{1 - LF} \quad (7)$$

$$Aw_{(canal\ water)} = \frac{800}{1 - 0.15} = 941 \text{ mm/year}$$

For the well water:

$$Aw_{(well\ water)} = \frac{800}{1 - 0.40} = 1333 \text{ mm/year}$$

The use of well water alone would result in a 40 percent increase in water use per hectare to achieve the same maize production as could be obtained using the canal water.

From Table 4, the maximum ECw of the blended water that will allow a 90% yield potential with a leaching fraction of 0.15 is 1.7 dS/m. The optimum blend of water can then be found by modifying equation (13):

$$EC_{w\ (canal\ water)} \cdot a) + (EC_{w\ (well\ water)} \cdot b) = \text{Maximum } EC_{w\ (blend\ water)} \quad (13)$$

where:
- $EC_{w\ (canal\ water)}$ = electrical conductivity of the canal water in dS/m
- $EC_{w\ (well\ water)}$ = electrical conductivity of the well water in dS/m
- a = proportion of canal water used
- b = proportion of well warer used
- Maximum $EC_{w\ (blend\ water)}$ = Maximum electrical conductivity of the blended water in dS/m

if a = 1 – b, then the above equation is:

$$0.23\,(1 - b) + 3.6\,(b) = 1.7$$
$$3.37b = 1.47$$
$$b = 0.44 \text{ or 44 percent well water}$$
$$a = 1 - b = 0.56 \text{ or 56 percent canal water}$$

The above shows that the area presently irrigated with canal water at Aw = 941 mm/ha/year could be expanded with no increase in Aw/ha/year if the canal water were blended with up to 44% well water. Yield potential would be maintained at about 90% and the planted area could be expanded by 44%.

Source: Ayers/Westcot (FAO) 1985

Table 2-21

Table 2.3 Inorganic constituents added to effluents through domestic use[a]

Constituent	Range of increment mg/l
Total dissolved solids	150–400
Sodium	40–70
Potassium	7–15
Calcium	15–40
Magnesium	15–40
Chloride	20–50
Carbonate	0–10
Bicarbonate	50–100
Sulfate	15–30
Silica	2–10
Alkalinity (as calcium carbonate)	100–150
Boron	0.1–0.4
Phosphate	5–15
Ammonium	15–40

[a] Metcalf & Eddy Inc. (1979); Asano et al. (1985).

Source: Feigin et al. 1991

Table 2-22a

Table 4.1 Physical and chemical characteristics of domestic wastewater

Major constituents	*Concentration* (in mg/l)		
	Strong	*Medium*	*Weak*
Total solids	1200	700	350
Dissolved solids	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chlorides*	100	50	30
Alkalinity (as $CaCo_3$)	200	100	50
Grease	150	100	50
BOD_5†	300	200	100

Source: These data are adapted from Metcalf and Eddy Inc. (1972), p. 231.

* This amount should be increased by the concentration of these constituents in the carriage water: the table shows major constituents only.
† BOD_5 is the 5-day biochemical oxygen demand at 20°C. It is a measure of the biodegradable organic content of wastewater.

Source: in Pescod/Arar ed. 1988

Table 2-22 b

Table 2.1 Typical composition of raw municipal sewage (Pound and Crites 1973[a]; Bond and Straub 1974; Thomas and Law 1977; Idelovitch 1978; Asano et al. 1985)[a]

Constituent	Concentration, mg/l[b]		
	High	Medium	Low
Solids			
Total	1300	700	200
Dissolved	1000	500	250
Suspended	350	220	100
BOD_5	350	200	100
COD	1000	500	250
TOC	290	160	80
Nitrogen			
Total	85	40	20
Ammonium	50	25	10
Organic	35	15	5
Nitrate	1.5	0.2	0
Phosphorus	36	10	4
Chlorides	650	150	10
Calcium + magnesium	150	80	25
Sodium	460	120	10
Potassium	25	10	5
Alkalinity (as calcium carbonate)	400	200	50
Grease	150	100	35
pH	8.0	7.2	7.0

[a] Tables 2.1 to 2.5 give typical data on the chemical quality of raw sewage. However, due to the great variations in quality of the original water and other factors affecting the chemical properties of sewage water, a wide range of data is found in the literature. For example, the Cl^- levels commonly reported range between 10–750 mg/l, which stresses the need for adequate local information concerning the quality of wastewater used.
[b] Except for pH.

Source: Feigin et al. 1991

Table 2-22 c

TABLE 5-1

Typical characteristics of sewage from Indian cities

Sample number	Characteristics		Ahemedabad	Bombay Dadar	Calcutta	Delhi	Hyderabad	Kanpur	Madras	Madurai	Nagpur
1.	pH		7.7	6.9	7.1	7.4	7.3	7.0	7.3	7.5	7.2
2.	Total solids	mg/l	1732	-	-	1100	1708	1500	1700	1740	1200
3.	Suspended solids	mg/l	290	220	420	470	985	600	500	420	200
4.	Dissolved solids	mg/l	1442	1375*	-	630	723	900	1200	1320	1000
5.	BOD	mg/l	196	320	-	223	339	250	350	480	350
6.	Total N	mg/l	-	47.7	40.0	28.5	37.0	73.0	60	-	60
7.	Phosphate as PO^4	mg/l	-	-	5.5	13.7	14.7	15.0	22.0	-	20.0
8.	Potassium	mg/l	-	-	15.9	15.0	26.0	40.0	55.0	-	41.6

Source: Shende et al. (1982).

Source: Shuval et al. 1986

Table 2-23

TABLE 1-1

California State Department of Health standards for the safe and direct use of reclaimed wastewater for irrigation and recreational impoundments

Use of reclaimed wastewater	Description of minimum required wastewater characteristics			
	Primary a/	Secondary and disinfected	Secondary coagulated filtered b/ and disinfected	Coliform MPN/100 ml median (daily sampling)
Irrigation				
Fodder crops	x			No requirement
Fiber crops	x			No requirement
Seed crops	x			No requirement
Produce eaten raw, surface irrigated		x		2.2
Produce eaten raw, spray irrigated			x	2.2
Processed produce, surface irrigated	x			No requirement
Processed produce, spray irrigated		x		23
Landscapes, parks, etc.		x		23
Creation of impoundments				
Lakes (aesthetic enjoyment only)		x		23
Restricted recreational lakes		x		2.2
Nonrestricted recreational lakes			x	2.2

a. Effluent not containing more than 1.0 ml/liter/hr settlable solids.
b. Effluent not containing more than 10 turbidity units.

Source: After Ongerth and Jopling in Shuval (1977), p. 230.

Source: Shuval et al. 1986

Table 2-24 a

Table 4.4 Suggested treatment processes to meet the given health criteria for wastewater reuse

	Irrigation			*Recreation*		*Industrial reuse*	*Municipal reuse*	
	Crops not for direct human consumption	*Crops eaten cooked; fish culture*	*Crops eaten raw*	*No contact*	*Contact*		*Non-potable*	*Potable*
Health criteria (see below for explanation of symbols)	A + F	B + F or D + F	D + F	B	D + G	C or D	C	E
Primary treatment	●●●	●●●	●●●	●●●	●●●	●●●	●●●	●●●
Secondary treatment		●●●	●●●	●●●	●●●	●●●	●●●	●●●
Sand filtration or equivalent polishing methods		●	●		●●●	●	●●●	●●
Nitrification						●		●●●
Denitrification								●●
Chemical clarification						●		●●
Carbon adsorption								●●
Ion exchange or other means of removing ions						●		●●
Disinfection		●	●●●	●	●●●	●	●●●	●●●*

Health criteria:

A Freedom from gross solids; significant removal of parasite eggs.
B As A, plus a significant removal of bacteria.
C As A, plus more effective removal of bacteria, plus some removal of viruses.
D Not more than 100 coliform organisms/100 ml in 80% of samples.
E No faecal coliform organisms in 100 ml, plus no virus particles in 1000 ml, plus no toxic effects on man, and other drinking-water criteria.
F No chemicals that lead to undesirable residues in crops or fish.
G No chemicals that lead to irritation of mucous membranes and skin.

In order to meet the given health criteria, processes marked ●●● will be essential. In addition, one or more processes marked ●● will also be essential, and further processes marked ● may sometimes be required.

* Free chlorine after 1 h.

Source: WHO (1973)

Source: in Pescod/Arar ed. 1988

Table 2-24 b

Table 4.5 Tentative microbiological quality guidelines for treated wastewater reuse in agricultural irrigation

Note: In specific cases, the guidelines should be modified according to local epidemiological, sociocultural, and hydrogeological factors.

Reuse process	Intestinal nematodes[a] (arithmetic mean no. of viable eggs per litre)	Faecal coliforms (geometric mean no. per 100 ml)
Restricted irrigation[b] Irrigation of trees, industrial crops, fodder crops, fruit trees[c] and pasture[d]	≤1	not applicable
Unrestricted irrigation Irrigation of edible crops, sports fields, and public parks[e]	≤1	≤1000[f]

[a] *Ascaris, Trichuris* and hookworms.
[b] A minimum degree of treatment equivalent to at least a 1-day anaerobic pond followed by a 5-day facultative pond or its equivalent is required in all cases.
[c] Irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground.
[d] Irrigation should cease two weeks before animals are allowed to graze.
[e] Local epidemiological factors may require a more stringent standard for public lawns, especially hotel lawns in tourist areas.
[f] When edible crops are always consumed well cooked, this recommendation may be less stringent.

Source: International Reference Centre for Waste Disposal (1985)

Source: Mara/Cairncross 1989

Table 2-24 c

Table 4.4 Examples of current microbiological standards for wastewater used for crop irrigation

Country	Restricted irrigation	Unrestricted irrigation
Oman	Maximum 23 TC/100 ml[a] Average <2.2 TC/100 ml Greenbelt irrigation only	Crop irrigation not permitted
Kuwait	<10 000 TC/100 ml	<100 TC/100 ml Not salad crops or strawberries
Saudi Arabia	Use of secondary effluent permitted for forage crops, field crops and vegetables which are processed and also for landscape irrigation	<2.2 TC/100 ml <50 FC/100 ml[b]
Tunisia	Fruit trees, forage crops and vegetables eaten cooked: — secondary treatment (including chlorination) — absence of *Vibrio cholerae* and salmonellae	No irrigation of vegetables eaten raw
Mexico	For recreational areas: <10 000 TC/100 ml <2 000 FC/100 ml	For vegetables eaten raw and fruits with possible soil contact: <1000 TC/100 ml
Peru	Treatment specified depending on reuse option	No irrigation of low-growing and root crops that may be eaten raw

[a] TC: total coliforms
[b] FC: faecal coliforms

Table 2-24 d

Table 4.6 Existing standards governing the use of renovated water in agriculture

	California	*Israel*	*South Africa*	*Federal Republic of Germany*
Orchards and vineyards	Primary effluent; no spray irrigation; no use of dropped fruit	Secondary effluent	Tertiary effluent, heavily chlorinated where possible; no spray irrigation	No spray irrigation in the vicinity
Fodder, fibre crops, and seed crops	Primary effluent; surface or spray irrigation	Secondary effluent, but irrigation of seed crops for producing edible vegetables not permitted	Tertiary effluent	Pretreatment with screening and setting tanks; for spray irrigation, biological treatment and chlorination
Crops for human consumption that will be processed to kill pathogens	For surface irrigation, primary effluent. For spray irrigation, disinfected secondary effluent (no more than 23 coliform organisms/100 ml)	Vegetables for human consumption not to be irrigated with renovated wastewater unless it has been properly disinfected (<1000 coliform organisms/100 ml in 80% of samples)	Tertiary effluent	Irrigation up to 4 weeks before harvesting only
Crops for human consumption in a raw state	For surface irrigation, no more than 2.2 coliform organisms/100 ml. For spray irrigation, disinfected, filtered wastewater with turbidity of 10 units permitted, providing it has been treated by coagulation	Not to be irrigated with renovated wastewater unless they consist of fruits that are peeled before eating		Potatoes and cereals – irrigation through flowering stage only

Source: California State Department of Public Health (1968); Indian Standards Institution (1965); Israel, Ministry of Agriculture, Water Commission (1969); Müller (1969); Peru, Ministry of Health, Department of Environmental Sanitation (1970); Shuval (1976).

Source: in Pescod/Arar ed. 1988

Table 2-25

Table 4.6 Geometric mean bacterial and viral numbers[a] and percentage removals in raw wastewater (RW) and the effluents of five waste stabilization ponds in series (P1–P5)[b] in northeast Brazil at a mean mid-depth pond temperature of 26 °C

Organism	RW	P1	P2	P3	P4	P5	Percentage removal
Faecal coliforms	2×10^7	4×10^6	8×10^5	2×10^5	3×10^4	7×10^3	99.97
Faecal streptococci	3×10^6	9×10^5	1×10^5	1×10^4	2×10^3	300	99.99
Clostridium perfringens	5×10^4	2×10^4	6×10^3	2×10^3	1×10^3	300	99.40
Total bifidobacteria	1×10^7	3×10^6	5×10^4	100	0	0	100.00
Sorbitol-positive bifids	2×10^6	5×10^5	2×10^3	40	0	0	100.00
Campylobacters	70	20	0.2	0	0	0	100.00
Salmonellae	20	8	0.1	0.02	0.01	0	100.00
Enteroviruses	1×10^4	6×10^3	1×10^3	400	50	9	99.91
Rotaviruses	800	200	70	30	10	3	99.63

[a] Bacterial numbers per 100 ml, viral numbers per 10 litres.
[b] P1 was an anaerobic pond with a mean hydraulic retention time of 1 day; P2 and P3–P5 were secondary facultative and maturation ponds respectively, each with a retention time of 5 days. Pond depths were 3.4–2.8 m.

Source: Oragui et al. (1987)

Source: Mara/Cairncross 1989

Table 2-26

3 Indicators

In particular, the subjects studied and the indicators use were the following:

(a) Physical studies

Morphology
- Erosion and growth of the coastline
- Bathymetric sections of rivers and mouths of lagoons
- Composition of sedimentary beds

Hydrology
- Flow and distribution of river branches
- Speed direction of currents
- Salinity and temperature
- Movement of solids in suspension
- Salt-wedge intrusion
- Water and solid content of the lagoon

Oceanography
- Residual and tidal currents
- Thermocline trends
- Dispersion of the fluvial plume in the sea
- Wave intensity

Underground waters
- Ground water levels
- Salinity
- Quality of underground waters

(b) Chemical studies of the waters

General quality of water
- pH
- Alcalinity
- Inorganic ions

Pollution by toxic substances
- Ammonia
- Nitrates
- Copper
- Nickle
- Zinc
- Chrome
- Lead
- Cadmium
- Aluminum
- Arsenic
- Phenols
- Detergents

Organic substances and eutrophication
- Ammonia
- Nitrates
- Nitrites
- Silicates
- Phosphates
- Total phosphorus
- Organic nitrogen
- T.O.C.
- B.O.D.
- Dissolved oxygen

Sediments
- Bacterial dehydrogenases
- Heavy metals
- Total phosphorus
- T.O.C.

(c) Microbiology

Contamination of fecal origin
- Total bacterial counts
- Total and fecal coliforms
- Fecal streptococci
- Clostridia

Pathogenic micro-organisms
- Salmonellae
- Viruses

Contamination of sediments
- Bacterial counts
- Salmonellae
- Viruses

d) Hydrobiological studies

Phytoplankton
- Cell density
- Composition
- Chlorophyll

Zooplankton
- Density
- Composition

Macrobenthos
- Density
- Composition

Fouling
- Accumulation
- Density
- Composition
- Periods of settlement

Fish fauna
- Composition
- Feeding
- Migratory patterns along the river branches

(e) Studies of the soil and vegetation

Phyto-sociology
- Floristic catalogue
- Natural vegetation series
- Anthropic and pest vegetation series

Pedology
- Characterization and classification of soils
- Density of micro fauna
- Microbial density

Phyto-pathology
- Plant disease occurence

(f) Studies on agriculture and fishing

Land use
- Land use mapping

Production of main agriculture crops
- Record of existing farms
- Classification of crops
- Unit and total annual production
- Characterization and quantification of fertilizers and pesticides

Fish production
- Quantity of fish per catch effort
- Number of catch effort
- Estimate of production using direct methods
- Estimate of production through market research

4 Indices

The indices (indicators related to quantified limits) were used to formulate an assessment on the quality of the waters, based on scientific recommendations and existing legal regulations on the subject (Fig.G2).

Health indices	Ecological indices
Fecal coliforms	Oxygen
Salmonellae	B.O.D.
Viruses	Total phosphorus
	Ammonia
	Phenols
	Detergents
	Nickel
	Lead
	Copper
	Zinc

It was more difficult to define indices for other categories studied; the biological indices have not yet any general applicability, and the special nature of the environment limits their use. As regards hydrological quantities, it is not logical to contemplate any standardization, while, with regard to fish and agricultural production, there was no

Source: UNESCO/UNEP 1984

Table 2-27

Box 2: Individual and Group Strategies for Groundwater Management

	Individual Strategies	Group Strategies
1. increase r, the rate of recharge;	farm pond as recharge source; exploit deeper aquifer by more bores; dig larger diameter well below the recharge zone;	more check dams and percolation tanks; reduce pumping from the Dadhichi tank;
2. reduce x, the pumping rate;	reduce summer cropping; use piped conveyance and sprinklers;	group decision on extent and mix of summer cropping; cooperative exploitation of groundwater;
3. better crop and water use planning;	better understanding of one's well and its interaction with the aquifer;	better understanding of the interaction between wells; efficient water markets;

Source: Shah 1990

Table 2-28

6

Table 1: Average Yields per Hectare for Four Water Supply Situations in Pakistan (1978)*

Water Supply Situations	Average Yield per hectare (kg) Wheat No. farms	Wheat kg/ha	Paddy Rice No. farms	Paddy Rice kg/ha
1. No control (no tubewell)	170	1681	75	1308
2. Fair control (public tubewell supplies)	33	1868	13	1775
3. Good control (purchase from private tubewell)	133	1962	35	1962
4. Very good control (tubewell owners)	42	2242	9	2148
TOTAL:	378		132	

*From Lowdermilk, M. K., A.C. Early and D.M. Freeman. Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan. Water Management Research Project Technical Report 48. Fort Collins, Colorado State University, Sept. 1978.

Table 2-29

8

Table 2: Policy options for groundwater management*

Policy options	Water-logged area	Good ground-water area	Poor ground-water area	Risk of saline intrusion area
Likely impact of sustained withdrawal	++	+	–	—
Power pricing a) flat component b) pro rata component	 nil nil	 high low	 high low	 high high
Power supply regulations	very liberal	liberal	limited	very stringent
Siting regulations	very liberal	liberal	stringent	very stringent
Capital cost subsidy (+)/ tax (-) on wems	++	+ to resource poor	–	—
Surface water irrigation	Strongly discourage	discourage	strongly support	strongly support

* Table presented by Shah at Common Property Resource Workshop on Groundwater, WRDTC, University of Roorkee, February 1987.

Source: Shah 1990

Table 2-30

Table 16-1. Key features and cost estimates for several irrigation systems.

Category	Relative required water	Required labor	Initial cost	Pumping cost	Soil adapta-bility†	Terrain adapta-bility‡	Special features§	Field adapta-bility¶	Chemigation applica-ble#
		h/ha	$/ha	$/(ha yr)		%			
				Surface					
Wild flooding	1.4	30	700	35	L,C	<10	–	NL	N
Border dike	1.2	12	1150††	25	L,C	<2	SFC	NL	N
Graded furrow	1.2	35	1000	25	L,C	<3	SFC	NL	N
Corrugation	1.2		900	25	L,C	<3	SFC*	NL	N
Level basin	1.0	3	1400	15	L,C	<1	SFC*	NL	Y
				Sprinkler					
Movable set									
Hand lines	1.0	30	1000	50	All	15	--	R	N
Wheel lines	1.0	15	1200	50	Ali	10	--	R	N
Tow lines	1.0	15	1200	50	All	10	--	R	N
Stationary set									
PVC solid set	1.0	5	2650	50	All	NL	FC,C	NL	Y
Aluminum solid set	1.0	7	2550	50	All	NL	FC,C	NL	Y
Mobile									
Center pivot	1.0	3	1050	45	S,L	15	--	C‡‡	Y
Lateral	1.0	3	1150	45	S,L	15	--	R	Y
Labor assisted									
Wheel lines	1.0	15	1200	50	All	10	--	R	N
Tow lines	1.0	15	1200	50	All	10	--	R	N
Traveler	1.1	20	1000	60	S,L	10	--	N	N
				Micro					
Drip/trickle	0.9	10	1850	35	All	NL	--	NL	Y
Subsurface	0.8	10	1950	35	All	NL	–	NL	Y
Bubbler/spray	1.0	7	2300	40	All	30	SFC	NL	Y

† S: Sand, L: Loam, C: Clay.
‡ Maximum % slope (NL: No limit).
§ FC: Frost control, C: Cooling, SFC: Some frost protection is possible.
¶ C: Limited to circular shapes, R: Limited to rectangular shapes, NL: No limit.
# Y: Yes, N: No or limited adaptability to chemigation.
†† Includes $700/ha for moving 1500 m^3/ha soil.
‡‡ Some center pivots are available with adaptations to accommodate noncircular field shapes.

Source: in Stewart ed. 1990

Table 2-31

Table 2. Factors affecting the selection of different types of modern irrigation systems for use in developing countries (Facteurs affectant la sélection des divers systèmes modernes d'irrigation destinés aux pays en voie de développement)

Method and Type	Factors Affecting System Selection: Divis-ibility	Maintain by	Risk	Mgt and O&M: Skill	Mgt and O&M: Effort	Rugged-ness
Surface						
Canal-Feed						
Basin	Total*	Grower	Low	Master	5	Lasting
Border	Total*	Farmer	Low	Master	6	Lasting
Furrow	Total*	Farmer	Low	Medium	10	Lasting
Pump/Pipe-Feed						
Basin (level)	Partial*	Shop	Med	Master	3	Robust
Border	Partial	Shop	Med	Master	3	Robust
Furrow	Partial*	Shop	Med	Master	6	Robust
Sprinkle						
Lateral						
Hand-Move	Total	Shop	Med	Simple	9	Durable
End-Tow	Partial	Shop	Med	Medium	5	Durable
Side-Roll	Partial	Shop	High	Medium	6	Durable
Side-Move	No	Agency	High	Master	5	Fragile
Hose-Fed	Total*	Farmer	Med	Simple	10	Durable
Traveling Gun	Partial	Agency	High	Master	4	Sturdy
Center-Pivot	No	Agency	High	Complex	1	Sturdy
Linear-Moving	No	Agency	High	Complex	2	Sturdy
Solid-Set						
Portable	Total*	Shop	Med	Medium	5	Durable
Permanent	Total*	Farmer	Med	Medium	1	Durable
Localized						
Orchard						
Drip/Spray	Total*	Grower	High	Complex	2	Fragile
Bubbler	Total*	Grower	Low	Complex	4	Robust
Hose-Pull	Total*	Farmer	Med	Simple	9	Durable
Hose-Basin	Total*	Farmer	Low	Simple	10	Robust
Row-crop						
Reusable	Total*	Grower	High	Complex	5	Fragile
Disposable	Total*	Grower	High	Complex	3	Fragile

* well adapted for irregular shaped fields

Source: Keller in IICID 1991

Table 2-32

Table 1 . Irrigation scheduling techniques and their effectiveness for coping with droughts and water stress

Irrigation scheduling techniques	Equipment/procedure	Measured properties	Effectiveness	References
Soil water indicators				
Appearance and feel	Hand probe	Appearance and touch	Poor	Stegman et al, 1981.
Electrical resistance	Porous blocks	Electrical conductance	Limited	Stegman et al, 1981.
	Electrode probes	Electrical conductivity	High	Rhoades et al, 1981.
Soil matric potential	Tensiometers	Soil water pression	High	Peyremorte, 1985.
	Potential sensors	Idem, by temperature transducer	Promising	Phene et al, 1981
	Thermocouple psychrometers	Wet bulb or dew-point temperature	Variable	Savage & Cass, 1984.
Soil moisture	Soil sampler	Gravimetric measurement	Limited	
	Neutron probe	Reflection of neutrons	High	Hodnett, 1986.
	Time-domain reflectometry	Dielectric constant	Promising	Topp & Davis, 1985.
Water content and potential	Neutron probe/ tensiometers	Water motion parameters	High	Fernando et al, 1988.
Remote sensed soil moisture	Thermal infrared scanner	Soil surface temperature and emissivity	Limited	Jackson et al, 1981; Lo, 1986.
	Passive microwave sensors	Brightness temperature and emissivity	Limited	Newton et al, 1983.
Crop indicators				
Appearance and feel	Observation	Leaf rolling, orientation, colour	Variable	Stegman et al, 1981.
Water content	Sampling	Gravimetric measurement	Limited	Reginato & Howe, 1985.
Water potential	Pressure chamber	Tissues water pression	High	Kramer, 1983.
	Thermocouple psychrometer	Wet bulb or dew-point temperature	Promising	Savage & Cass, 1984.
Stomatal resistance	Porometer	Resistance to vapour diffusion	Limited	Kramer, 1983.
Canopy temperature	Infrared thermometer	Surface-air temperature difference	High	Jackson, 1982; Everest, 1986.
Changes in diameter of stems or other organs	Micrometric sensor	Changes in tissue water content	Limited	Huguet, 1985; Gensler, 1986.
Combinatory indicators	Combinatory procedures	Water content and temperature	High	Reginato & Howe, 1985.
		Water potential and temperature	High	Ziska et al, 1985.
		Leaf and stem responses	Promising	Schoch et al, 1987.
Vapour flux, evapotranspiration (ET)				
Evaporation	Evaporation pans	Daily rate of evaporation	High	Cardon, 1985.
	Evaporimeters	Idem	Limited	
ET estimation	Meteorologic instruments and crop coefficients	Estimated crop vapour losses from atmospheric demand	High	Doorenbos & Pruitt, 1977; Wright, 1982; 1985; Burman et al, 1983; Snyder et al, 1985.
ET measurements	Lysimeters	Rate of crop evapotranspiration	Important	Pruitt et al, 1985.
	Energy balance	Latent heat flux	Important	Rosenberg et al, 1983; Itier et al, 1985.
	Eddy correlation	Vapour flux above canopy	Important	Rosenberg et al, 1983.
Remote sensed local and regional ET	Thermal infrared and multi-spectral scanners	Surface and air temperature differences, rate of crop ET	Promising	Jackson, 1985; Nieuvenhuis, 1986; Jackson et al, 1987.
Soil - plant - atmosphere water fluxes				
Crop water stress index	Canopy temperature, vapour deficit, net radiation	Canopy responses and atmospheric demand	High	Jackson, 1982.
Plant responses and vapour fluxes	Energy balance, leaf and canopy measures	Combined explanation of vapour fluxes and crop responses	Important	Katerjiet al, 1987.
Remote sensed crop water stress	Reflective wavelengths and thermal infrared wavelengths	Canopy reflectance and surface temperature	Promising	Hatfield, 1983; Wiegand et al, 1983; Lo,1986.

Source: Pereira 1989

Table 2-33

Table 2 . Irrigation management for coping with droughts and water stress

Support for irrigation scheduling decisions	Managerial information or target	References
Appearance and feel; delaying first irrigation, increasing irrigation intervals, but avoiding stress at critical growth stages	Crop sensitivity	Stegman et al, 1981.
Observation of soil water status: irrigations according allowed soil water depletion, depending on the growth stages	Soil-crop stress parameters	Stegman et al, 1981; Peyremorte, 1985.
Observation of plant stress indicators: irrigations according the allowable stress at the different growth stages	Crop stress parameters	Hiler & Howell, 1983; Stegman, 1983.
Meteorological information and simulation of water balance with allowable stress	Crop coefficients	Doorenbos & Pruitt, 1977; Wright, 1982; 1985 Smith, 1988.
Meteorological information, water balance and relative yield simulation model	Yield response factor	Doorenbos & Kassam, 1979; Stegman, 1983; Hulsman, 1986; Teixeira & Pereira, 1988.
Monitoring of soil moisture and soil water balance model for targeted depletion levels	Acceptable yield reduction	Stegman, 1983; Jones & Bauder, 1987.
Monitoring of soil moisture and water potential, simulation of soil water balance (including water table contributions)	Acceptable yield reduction	Cambell & Campbell, 1982; Feyen, 1987.
Combined meteorological and soil water information, simulation of the soil water balance, crop growth (LAI, dry matter accumulation) and havestable yield	Targeted yield (economic decision)	Stockle & Campbell, 1985; Raju et al, 1982; Feyen, 1987; De Jong & Zeutner, 1985.
Combined meteorological, soil water and crop indicators parameters for soil water and crop modelling	Targeted yield	Feddes, 1987; Hansen, 1987.
Combining evapotranspiration, soil water, crop growth, yield modelling with economical optimization	Irrigation costs and benefits	English & Nuss, 1982; Raju et al, 1983.

Source: Pereira 1989

Table 2-34

Table 4 . Management of irrigation systems for coping with droughts and water stress conditions

Management techniques	Benefits	Effectiveness	References
Supply systems			
New sources of surface water; water transfers	Increase local water availability	High	Cunha et al, 1983a.
Increased groundwater utilization	Idem	High	Cunha et al, 1983a.
Subsurface groundwater dams	Avoidance of subsurface losses	High	Uwatoko at Tomita, 1987.
Use/reuse of low quality water	Alternative sources of water	High	See Table 9.
Conjunctive use	Maximized use of available water resources	High	Rossi et al, 1983; Morel-Seytoux, 1987.
Improved operation/management :			
. hydrological forecasting	Improved assessment of supplies	High	Yevjevich, 1983.
. application of optimization/risk/decision analysis to water systems	Optimized rules; hierarchical allocation of water resources	Promising	Duckstein, 1980; 1983a; Salas et al, 1983.
. application of optimization/decision theories to reservoirs	Idem	Promising	Duckstein, 1983b; Harboe, 1983.
. automation of reservoir releases	Real time response to downstream demand	High	Tardieu, 1988.
Control of evaporation in surface reservoirs	Water savings	Limited	Reviewed by Cooley, 1983.
Precipitation augmentation	Increased regional water availability	Controversial	Summers et al, 1983.
Regional water data-banks	Information for optimized operation and management	Promising	Francalanza et al, 1988.
Conveyance and distribution systems			
Canal lining	Avoidance of seepage losses	High	
Increased flexibility on the operation of conveyance and distribution systems	Improved responses to farm demands, decrease on operational water losses	High	Burt & Lord, 1981; Replogle & Merriam, 1981; Rijo & Pereira, 1987.
Intermediate storage (in canal, reservoirs, farm ponds)	Increase flexibility of the system, with lower water losses	Important	Replogle et al, 1981.

Management techniques	Benefits	Effectiveness	References
Avoid night irrigation : intermediate storage or improvement of conditions of night irrigation including on-farm automation	Avoidance of low efficient irrigation and improvement of social conditions	Important	Chambers, 1986.
Adapt irrigation delivery to irrigation scheduling	Improved responses to farm demands, increased overall irrigation efficiency	High	Brower & Buchheim, 1984; Clemens, 1986; El-Kady & Molden, 1987.
Application of optimization methods to schedule deliveries	Increased efficiencies, reliability and equity in responses to farm demands	Promising	Yoo, 1985; Suryaranshi & Reddy, 1986.
Develop intelligent control :			
. automation, surface systems	Adjusted response to downstream demand	Variable	Replogle & Clemens, 1987.
. remote control, surface and pressurized systems	Higher irrigation efficiencies; higher flexibility, deliveries matching demands	High	Jean, 1981; Verdier, 1986; Bolognino, & Giorgi, 1988; De Vito & De Vito, 1988; Di Nardo, 1988.
Hydraulic modelling :			
. open channels	Basic tool for improved control	Important	Hamilton & DeVries, 1986; Corriga et al, 1988; Rijo et al,1988.
. transients in pressure pipes	Idem	Important	Messina & Poggi, 1988
Operation and maintenance (O&M):			
. monitoring and evaluation, use of indicators	Improved O&M systems, identification of critical areas and solutions	Important	Reviewed by Pereira & Lamaddalena, 1988.
. vegetation and sediments control	Avoidance of delivery interruptions and water losses	High	
. water measurement	Improved O&M, water savings	High	Peri & Karmeli, 1977; Bos et al, 1984.

Source: Pereira 1989

Table 2-38

Crops	Steady state formulas		Transient flow methods	
Primary crops	Fine textured permeable soil	Light texture soil	Fine textured permeable soil	Light texture soil
Field crops	1.2	1.0	0.9	0.9
Vegetable	1.1	1.0	0.9	0.9
Tree crops	1.6	1.2	1.4	1.1

Table 1 - Suggested irrigation season watertable depths for drain spacing design (Watertable depth below ground surface in meters)

Source: in Lesaffre 1990

Table 2-50

Table 3.22 Suggested treatment processes to meet the given health criteria for wastewater reuse[a]

Wastewater use	Irrigation			Recreation		Industrial reuse	Municipal reuse	
Health criteria[b]	Crops not for direct human consumption (A + F)	Crops eaten cooked: fish culture (B + F or D + F)	Crops eaten raw (D + F)	No contact (B)	Contact (D + G)	(C or D)	Non-potable (C)	Potable (E)
Primary treatment	3	3	3	3	3	3	3	3
Secondary treatment		3	3	3	3	3	3	3
Sand filtration or equivalent polishing methods		1	1		3	1	3	2
Nitrification						1		3
Denitrification								2
Chemical clarification						1		2
Carbon adsorption								2
Ion exchange or other means of removing ions						1		2
Disinfection[c]		1	3	1	3	1	3	3[e]

[a]After WHO (1973).
[b]Health criteria: A, freedom from gross solids, plus significant removal of parasite eggs; B as A, plus significant removal of bacteria; C as A, plus more effective removal of bacteria, plus some removal of viruses; D, not more than 100 coliform organisms per 100 ml in 80% of samples; E, no fecal coliform ortanisms in 100 ml, plus no virus particles in 1000 ml, plus no toxic effects on man, and other drinking-water criteria; F, no chemicals that lead to undesirable residues in crops or fish; G, no chemicals that lead to irritation of mucous membranes and skin. In order to meet the given health criteria, processes marked 3 will be essential. In addition, one or more processes marked 2 will also be essential, and further processes marked 1 may sometimes be required.
[c]Free chlorine after 1 h.

Source: Feigin et al. 1991

Table 2-51

TABLE 2.4. Advantages and disadvantages of various sewage treatment systems

	Criteria	*Package plant*	*Activated sludge plant*	*Extended aeration activated sludge*	*Trickling filter*	*Oxidation ditch*	*Aerated lagoon*	*Waste stabilization pond system*
Plant performance	BOD removal	F	F	F	F	G	G	G
	FC removal	P	P	F	P	F	G	G
	SS removal	F	G	G	G	G	F	F
	Helminth removal	P	F	P	P	F	F	G
	Virus removal	P	F	F	P	F	G	G
Economic factors	Simple and cheap construction	P	P	P	P	F	F	G
	Simple operation	P	P	P	F	F	P	G
	Land requirement	G	G	G	G	G	F	P
	Maintenance costs	P	P	P	F	P	P	G
	Energy demand	P	P	P	F	P	P	G
	Sludge removal costs	P	F	F	F	P	F	G

FC = Faecal coliforms
SS = Suspended solids
G = Good
F = Fair
P = Poor
Source: Arthur (1983).

Source: in Biswas/Arar ed. 1988

Table 2-52

Table 3.2 Suggested treatment processes to meet the given health criteria for wastewater reuse in agriculture

Unit treatment process	*Type of agricultural reuse*		
	Crops not for direct human consumption	*Crops eaten cooked*	*Crops eaten raw*
Primary treatment	+++	+++	+++
Secondary treatment		+++	+++
Sand filtration		+	+
Disinfection		+	+++
Health criteria	A + F	D + F	

Key: +++ = Essential
+ = May sometimes be required
A = Freedom from gross solids; significant removal of parasite eggs
D = Not more than 100 coliforms per 100 ml in 80% of samples
F = No chemicals that lead to undesirable residues in crops

Source: WHO (1973)

Source: in Pescod/Arar ed. 1988

Tavle 2-53a

Table 7.1 Expected removal of excreted bacteria and helminths in various wastewater treatment processes

Treatment process	Removal (log_{10} units)			
	Bacteria	Helminths	Viruses	Cysts
Primary sedimentation				
Plain	0–1	0–2	0–1	0–1
Chemically assisted[a]	1–2	1–3 (E)	0–1	0–1
Activated sludge[a]	0–2	0–2	0–1	0–1
Biofiltration[b]	0–2	0–2	0–1	0–1
Aerated lagoon[c]	1–2	1–3 (E)	1–2	0–1
Oxidation ditch[b]	1–2	0–2	1–2	0–1
Disinfection[d]	2–6 (E)	0–1	0–4	0–3
Waste stabilization ponds[e]	1–6 (E)	1–3 (E)	1–4	1–4
Effluent storage reservoirs[f]	1–6 (E)	1–3 (E)	1–4	1–4

E—With good design and proper operation the Engelberg guidelines are achievable.
[a] Further research is needed to confirm performance
[b] Including secondary sedimentation
[c] Including settling pond
[d] Chlorination, ozonation
[e] Performance depends on number of ponds in series
[f] Performance depends on retention time, which varies with demand

Source: Feachem et al. (1983).

Source: Mara/Cairncross 1989

Table 2-53b

TABLE 2.3. Microorganism removal in wastewater treatment

Type of microorganism	*Percentage removal*	
	Primary	*Biological**
Salmonella	15	96–99.9
Mycobacterium	48–57	Slight–99.9
Amoebic cyst	Limited removal	0–99.9
Helminth ova	72–98	0–76
Viruses	3–extensive	0–84

* Biological includes trickling filter, activated sludge and waste stabilization ponds.
Source: Feachem *et al.* (1983).

Source: in Biswas/Arar ed. 1988

Table 2-53c

TABLE 2-10

Enteric pathogen removal efficiencies of wastewater treatment processes (in log_{10} units) (i.e., $4 = 10^{-4} = 99.99$ percent removal)

Treatment process	Viruses	Bacteria	Protozoa	Helminths
Primary sedimentation	0-1	0-1	0-1	0-1
Septic tanks	0-1	1-2	1-2	1-2
Trickling filters	0-1	0-2	0-1	0-1
Activated sludge	1-2	2-3	1-2	1-2
Stabilization ponds (20 day--4 cells)	2-4	4-6	4-6	4-6

Source: This table was developed for this study and is based on a review of numerous published laboratory and field studies.

Source: Shuval et al. 1986

TABLE 5-7

Table 2-54 a

Expected values of properly designed stabilization ponds in Southern Africa

Parameter (mg/l except where otherwise stated)		Effluent Composition: Stabilization ponds: for raw and settled wastewater, septic tank, and aqua privy effluent	Effluent Composition: Maturation ponds: for well-nitrified secondary effluent
Color, taste, and odor		Not objectionable	Not objectionable
pH	(range)	7.0-10.5	7.0-10.5
Temperature, °C	maximum	30	30
Dissolved oxygen, % sat.	minimum	75	75
Fecal coliform bacteria	maximum	100/100 ml (97.5% probability)	1,000/100 ml (97.5% probability)
BOD_5 (total)	maximum	16	12
BOD_5 (filtrate)	maximum	12	8
COD (total)	maximum	150	120
COD (soluble)	maximum	120	100
OA*/ (total)	maximum	20	15
OA*/ (soluble)	maximum	15	10
Ammonia nitrogen	maximum	10	10

Note: Aimed at small communities of up to 5,000 people, 800 m^3/day flow. Detention times 18-25 days, depending on temperature and plant configuration.

*/ Oxygen adsorbed from N/80 $KMNO_4$ in 4 hours.

Source: Drews (1983).

Source: Shuval et al. 1986

Table 2-54b

Table 7.2 Performance of a series of five waste stabilization ponds in north-east Brazil (mean pond temperature: 26 °C)

Sample	Retention time (days)	BOD_5 (mg/l)	Suspended solids (mg/l)	Faecal coliforms	Intestinal nematode eggs (per litre)
Raw wastewater	–	240	305	4.6×10^7	804
Effluent from:					
Anaerobic pond	6.8	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
Maturation pond 1	5.5	25	61	2.4×10^4	0
Maturation pond 2	5.5	19	43	450	0
Maturation pond 3	5.8	17	45	30	0

Source: Mara et al. (1983), Mara & Silva (1986).

Source: Mara/Cairncross 1989

Table 2-54 c

Table 7.3 Reported effluent quality for several series of waste stabilization ponds, each with a retention time > 25 days

Pond system	No. of ponds in series	Effluent quality (FC/100 ml)[a]
Australia, Melbourne	8–11	100
Brazil, Campina Grande[b]	5	30
France, Porquerolles	3	100
Jordan, Amman	9	30
Peru, Lima	5	100
Tunisia, Tunis	4	200

[a] FC = Faecal coliforms
[b] Experimental Centre for Biological Treatment of Wastewater (Extrabes).

Source: Bartone & Arlosoroff (1987).

Source: Mara/Cairncross 1989

Table 2-55

Table 3.15 Relative sensitivity of crops to sludge-applied heavy metals[a] (Logan and Chaney 1983)

Very sensitive[b]	Sensitive[c]	Tolerant[d]	Very tolerant[e]
Chard	Mustard	Cauliflower	Corn
Lettuce	Kale	Cucumber	Sudan grass
Red beet	Spinach	Zucchini squash	Smooth bromegrass
Carrot	Broccoli		'Merlin' red fescue
Turnip	Radish	Flat pea	
Peanut	Tomato		
	Marigold	Oat	
Ladino clover		Orchard grass	
Alsike clover	Zigzag, red, Kura and crimson clover	Japanese bromegrass	
Crown vetch	Alfalfa	Switchgrass	
'Arc' alfalfa	Korean lespedeza	Red top	
White sweet clover	Sericea lespedeza	Buffel grass	
Yellow sweet clover	Blue lupin	Tall fescue	
	Birdsfoot trefoil	Red fescue	
Weeping love grass	Hairy vetch	Kentucky bluegrass	
Lehman love grass	Soybean		
Deer tongue	Snapbean		
	Timothy		
	Colonial bent grass		
	Perennial ryegrass		
	Creeping bent grass		

[a]Sassafras sandy loam amended with a highly stabilized and leached digested sludge containing 5300 mg Zn; 2400 mg Cu; 320 mg Ni; 390 mg Mn; and 23 mg Cd/kg dry sludge. At 5% sludge, maximum cumulative recommended applications of Zn and Cu are made.
[b]Injured at 10% of a high metal sludge at pH 6.5 and at pH 5.5.
[c]Injured at 10% of a high metal sludge at pH 5.5, but not at pH 6.5.
[d]Injured at 25% high metal sludge at pH 5.5, but not at pH 6.5, and not at 10% sludge at pH 5.5 or 6.5.
[e]Not injured even at 25% sludge, pH 5.5.

Source: Feigin et al. 1991

Table 2-56

Category A — Protection needed only for field workers

1. Crops not for human consumption (for example cotton, sisal)
2. Crops normally processed by heat or drying before human consumption (grains, oilseeds, sugar-beet)
3. Vegetables and fruit grown exclusively for canning or other processing that effectively destroys pathogens
4. Fodder crops sun-dried and harvested before consumption by animals
5. Landscape irrigation in fenced areas without public access (nurseries, forests, green belts).

Category B — Further measures may be needed

1. Pasture, green fodder crops
2. Crops for human consumption that do not come into direct contact with wastewater, on condition that none must be picked off the ground and that spray irrigation must not be used (tree crops, vineyards, etc.)
3. Crops for human consumption normally eaten only after cooking (potatoes, eggplant, beetroot).
4. Crops for human consumption, the peel of which is not eaten (melons, citrus fruits, bananas, nuts, groundnuts)
5. Any crop if sprinkler irrigation is used (see Section 7.4.1).

Category C — Treatment to Engelberg "unrestricted" guidelines is essential

1. Any crops often eaten uncooked and grown in close contact with wastewater effluent (fresh vegetables such as lettuce or carrots, or spray-irrigated fruit)
2. Landscape irrigation with public access (parks, lawns, golf courses)

Source: Mara/Cairncross 1989

Table 2-57

Table 3.21 Wastewater treatment and quality criteria for irrigation (California) (Crook 1985)

Treatment level	Coliform limits	Type of use
Primary		Surface irrigation of orchards and vineyards, fodder, fiber and seed crops
Oxidation and disinfection	≤ 23/100 ml	Pasture for milking animals Landscape impoundments Landscape irrigation (golf courses, cemeteries, etc.)
	≤ 2.2/100 ml	Surface irrigation of food crops (no contact between water and edible portion of crop)
Oxidation, coagulation, clarification, filtration[a], and disinfection	≤ 2.2/100 ml max. = 23/100 ml	Spray irrigation of food crops
		Landscape irrigation (parks, playgrounds, etc.)

[a]The turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24-h period.

Source: Feigin et al. 1991

Table 2-58

Table 3.24 Recommended microbiological quality guidelines for wastewater use in agriculture[a] (WHO Scientific Group 1989)

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (arithmatic mean No. of eggs/l[c])	Faecal coliforms (geometric mean No. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	≤ 1000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated or, equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a]In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[b]*Ascaris* and *Trichuris* species and hookworms.
[c]During the irrigation period.
[d]A more stringent guideline (≤ 200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[e]In the case of fruit trees, irrigation should cease 2 weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Source: Feigin et al. 1991

Table 2-59

Table 7.4 Factors affecting choice of irrigation method, and special measures required when wastewater is used

Irrigation method	Factors affecting choice	Special measures for wastewater
Border (flooding) irrigation	Lowest cost, exact levelling not required	Thorough protection for field workers, crop-handlers and consumers
Furrow irrigation	Low cost, levelling may be needed	Protection for field workers, possibly for crop-handlers and consumers
Sprinkler irrigation	Medium water use efficiency, levelling not required	Some Category B crops, especially tree fruit, should not be grown. Minimum distance 50–100 m from houses and roads. Anaerobic wastes should not be used because of odour nuisance
Subsurface and localized irrigation	High cost, high water use efficiency, higher yields	Filtration to prevent clogging of emitters.

Source: Mara/Cairncross 1989

Table 2-60

TABLE 1.3. Framework for use of wastewater for irrigation and/or groundwater recharge

(1) **Nature of the problem**
a) How much wastewater will be produced and what will be the seasonal distribution?
b) At what places will wastewater be produced?
c) What will be the characteristics of wastewater that will be produced?
d) What are feasible alternative disposal possibilities?

(2) **Legal feasibility**
a) What uses of wastewater are possible under national and/or state regulations, if they exist?
b) If no regulations exist, what uses seem feasible under WHO and FAO guidelines for irrigation?
c) What are the prevailing water rights and how will these be affected by wastewater use?

(3) **Technical feasibility**
a) Is the quality of treated wastewater produced acceptable for restricted or unrestricted irrigation?
b) How much land is available or required for wastewater irrigation?
c) What are the soil characteristics of land to be irrigated?
d) What are the present land use practices? Can these be changed?
e) What types of crops can be grown?
f) How do crop-water requirements match with seasonal availability of wastewater?
g) What types of irrigation techniques can be used?
h) If groundwater recharge is a consideration, are the hydrogeological characteristics of the study area suitable?
i) What will be the impact of such recharge on groundwater quality?
j) Are there additional health and environmental hazards that should be considered?

(4) **Political and social feasibility**
a) What have been the political reactions to past health and environmental hazards which may have been associated with wastewater reuse?
b) What is the public perception of wastewater reuse?
c) What are the attitudes of influential people in areas where wastewater will be reused?
d) What are the potential benefits of reuse to the community?
e) What are the potential risks?

(5) **Economic feasibility**
a) What are the capital costs?
b) What are the operation and maintenance costs?
c) What is the economic rate of return?
d) What are the costs of development effluent-irrigated agriculture, e.g. cost of conveyance of wastewater to the irrigation site, land-levelling, installation of irrigation system, agricultural inputs, etc.?
e) What are the benefits from the effluent-irrigated agriculture system?
f) What is the benefit-cost ratio for the irrigation project?

(6) **Manpower feasibility**
a) Is adequate local manpower available for adequate operation and maintenance of:
   wastewater treatment
   irrigation and groundwater recharge works
   agricultural facilities
   health and environmental control aspects?
b) If not, what types of training programmes should be instituted?

Source: in Biswas/Arar ed. 1988

Table 2-61

TABLE 1.4. Comparison of factors relating to water and land for irrigation and groundwater recharge

Factors	*Irrigation*	*Groundwater recharge*	*Overland flow*
Treatment	Primary to secondary	Untreated to primary	Untreated to primary
Consistently good operation of treatment plants	Critical	Not critical	Not critical
Water quality	High	Medium to low	Medium to low
Land area required	High	Low	Medium
Land slope	Up to 6% for surface irrigation; up to 30% for sprinkler and drip irrigation	Not important, but difficult on steep slopes	1–12%
Soil permeability	Moderate	Rapid to very rapid	Low
Soil quality	Medium to good	Not important	Not important
Utilization of water and nutrients	High	None	Medium to low
Monitoring requirements	Extensive	Limited	Limited

Source: in Biswas/Arar ed. 1988

Table 2-62

Box 7.1 Wastewater treatment costs

A recent World Bank report gives a detailed economic comparison of waste stabilization ponds, aerated lagoons, oxidation ditches and biological filters. The data for this cost comparison were taken from the city of San'a in the Yemen Arab Republic. Certain assumptions were made, for example the use of maturation ponds to follow the aerated lagoon, and the chlorination of the oxidation ditch and biological filter effluents, in order that the four processes would have a similar bacteriological quality so that fish farming and effluent reuse for irrigation were feasible. The design is based on a population of 250 000; a per capita flow and BOD_5 (biochemical oxygen demand measured on day 5 of treatment) contribution of 120 litres/day and 40 g/day respectively; influent and required effluent faecal coliform concentrations of 2×10^7 and 1×10^4 per 100 ml, respectively; and a required effluent BOD_5 of 25 mg/litre. The calculated land area requirements and total net present worth of each system (assuming an opportunity cost of capital of 12% and land values of US$ 5/m^2) are shown in the table below. The waste stabilization pond is the cheapest option. Clearly the preferred solution is very sensitive to the price of land, and the above cost of US$ 5 per m^2 represents a reasonable value for low-cost housing estates in developing countries.

The cost of chlorination accounts for US$ 0.22 million per year of the operational costs of the last two options.

	Waste stabilization pond system	Aerated lagoon system	Oxidation ditch system	Conventional treatment (biofilters)
Costs (million US$)				
Capital	5.68	6.98	4.80	7.77
Operational	0.21	1.28	1.49	0.86
Benefits (million US$)				
Irrigation income	0.43	0.43	0.43	0.43
Pisciculture income	0.30	0.30	–	–
Net present worth (million US$)	5.16	7.53	5.86	8.20
Land area (ha)	46	50	20	25

Source: Arthur (1983).

Source: Mara/Caircross 1989

Table 2-63

There are four types of water to be analysed:

- drinking water (A_2);
- raw wastewater influent to the wastewater treatment plant (A_0);
- effluent from the primary settling tank (A_1);
- effluent from the final settling tank (A_3).

Table 26.7 Parameters analysed in A_2

Organoleptic	Aspect		
	Colour		
	Odour		
Physical	pH		
	pH 25°C		
	Conductivity		
	Turbidity		
Chemical	Alkalinity		
	Alkalinity to $CaCO_3$ saturation equilibrium		
	Total hardness		
	Carbonate hardness		
	Non-carbonate hardness		
	Oxidizability		
		Anions	*Cations*
		HCO_3^-	Ca^{2+}
		$SO_4^=$	Mg^{2+}
		Cl^-	Na^+
			K^+

Table 26.8 Parameters analysed in A_1 and A_3

Parameters analysed					
Routine				*Occasional*	
During irrigation		*After irrigation*			
BOD_5				As	(1)
COD				Hg	(1)
SS				Se	(1)
DS	(3)			CN	(1)
T					
N: NO_3	(2)				
N: NH_4	(2)				
N: org.	(2)				
pH	(3)	Cd	(1)		
Hardness	(3)	Cr	(1)		
Carbonates	(3)	Cu	(1)		
Bicarbonate	(3)	Fe	(1)		
Phosphorus		Ni	(1)		
Orthophosphate		Pb	(1)		
Chloride	(3)	Mn	(1)		
Sulphate	(3)	Zn	(1)		
Conductivity		Mo	(1)		
Calcium	(1)				
Magnesium	(1)				
Sodium	(1)				
Potassium	(1)				
Boron	(1)				

(1) Analyses to be carried out at the end of the irrigation period, on a sample composed of subsamples collected during each irrigation, suitably preserved with HNO_3 at pH = 2, kept in boron-silicate glass flasks with the stopper lined with teflon.
(2) The samples for determining the different nitrogen species will be kept in glass flasks with the stopper lined with teflon. These samples will be acidified to pH = 2 with sulphuric acid and kept at 4°C.
(3) Samples for the determination of the different ionic species cannot be chemically conserved; they have to be kept in plastic bottles at 4°C and analysed as soon as possible.

Table 26.9 Parameters analysed in A_0

pH
BOD_5
COD
TSS
FSS
VSS

Table 26.10 Microorganisms analysed

Analytical laboratory	*Microorganism*
Regional Health Administration	Faecal coliforms
Regional Health Administration	Faecal streptococci
Leeds University	*Campylobacter*
Leeds University	*Salmonella*
Leeds University	*Shigella*

Table 26.11 Surface soil parameters analysed

Parameters analysed before sowing and after harvesting	
Physical	Texture
	Structure
	Porosity
	Apparent specific density
Hydraulic	Permeability
	Rate of infiltration
	Field capacity
	Fading coefficient
Chemical	pH
	Cation exchange capacity
	Calcium
	Magnesium
	Potassium
	Sodium
	Carbonates
	Sulphates
	TOC
	Hydrogencarbonates
	Conductivity
	Chlorides
	N: total
	N: organic
	P: total
	K: assimilable
	Boron

Table 26.12 Parameters analysed in soil at 50 cm depth

Parameters analysed before sowing and after irrigation		
Sulphates	N: total	Copper
Carbonates	N: NO_3	Cadmium
Hydrogencarbonates	N: organic	Nickel
Chlorides	P: total	Chromium
Cation exchange capacity	P: P_2O_5	Mercury
Calcium	Conductivity	Lead
Magnesium	Boron	Cobalt
Potassium	Iron	
Sodium	Zinc	

Table 26.13 Surface soil parameters analysed

Iron	Manganese	Lead
Molybdenum	Cadmium	Cobalt
Zinc	Nickel	Mercury
Copper	Chromium	

Table 26.14 Chemical parameters determined in crop material

Part of plant for consumption	*Part of plant not to be consumed*
Boron	
N: total (N: Kjeldahl)	
Potassium	
Iron	
Nickel	
Zinc	Zinc
Chromium	
Copper	
Mercury	
Cadmium	Cadmium
Lead	
Cobalt	

Source: in Pescod/Arar ed. 1988

Table 3-1

Table 12 CHECKLIST OF INFORMATION NEEDS, METHODS and output at Steps 3 and 4

Information from first consultation with users	Planning goals and constraints Spatial, temporal, quantitative data: - Social: sociology, demography, land tenure - Economic: demand, consumption patterns, income and investments, land use and production - Land: topography, climate, soils, water, ecology - Infra-structure: transport, communications, services, administration and legal structure
Planner's methods	Overview existing data, identify gaps: - summarise maps, reports, agency files Rapid appraisal: - remote sensing, field survey, questionnaires, local reports Modelling land use systems
Information output for second consult-ation with users	Summary maps and statistical analysis of the existing situation Projections for the planning period Identification of land use problems and opportunities Specifications for improved land use systems

Table 3-2

What will the Land Use Plan contain?

Terms of reference

- area involved, goals, time horizon

Analysis of land use opportunities and problems

Environmental/conservation standards

- for example no cultivation on slopes greater than 15°, protection of water supplies for people and stock

What to do and where to do it

- including maps of present and planned land use and infrastructure, details of land use practices needed, performance targets

Who will do it and how

- responsibilities for action, staff, timing, budget

Procedure for assessing the performance of the plan and revising it in the light of experience

Supporting information

- so that people can understand the plan and the basis for decisions. This may include information on land resources, land use options, land suitability, economic analysis, social and other considerations.

Source: FAO 1989

Table 3-3

<u>Headings for description of land use types</u>

1. Items common to most major kinds of land use:

Name and summary of land use type - main crops and management level, for example 'rainfed rice cultivation by smallholders, traditional management with low inputs'

Main products and markets

Associated land use types

Tenure and size of management units

Capital intensity: investment required, recurrent costs

Labour and management skills needed

Power and transport requirements

Storage and processing requirements

2. For rainfed agriculture:

Cultivation practices:

- recommended varieties
- growing period
- land preparation
- planting
- fertilizer
- weed control, pests and diseases
- harvesting
- soil and water conservation

Yield, production trends

Local farming problems

3. Additional items for irrigated agriculture:

Source of water, water rights

Water management system

4. For livestock:

Pasture management and grazing practices - fencing, rotational grazing, seasonal factors, irrigation, topdressing

Supplementing forage production and conservation practices

Water sources and distribution

Soil and water conservation practices

Livestock husbandry practices:

- stock management
- pests and diseases

Forage production and trends

Livestock kind and numbers

Production and production trends

Local problems

5. For forestry:

Cultivation practices, where applicable:

- recommended species and provenance
- nursery practices
- land preparation
- planting
- fertilizing
- weed control, pests and diseases
- harvesting
- soil and water conservation

Yield, production trends

Local management problems

6. For water supply:

Catchment management practices:

- standards for forestry, grazing and agricultural use
- soil conservation
- engineering standards - road construction, drainage, flood control
- siting of settlement
- control of pollution

7. For fisheries and fish farming:

Water supply and water rights

Water management practices:

- control of water quality
- maintenance of ponds and waterways
- flood control

Pisicultural practices:

- nursery practices
- fertilizers, feeding
- pests and diseases
- harvesting

Yields and production trends

Local management problems

8. For recreation and reserves:

Facilities and services for visitors

Land management practices to maintain unique character:

- standards for parallel land uses
- policing

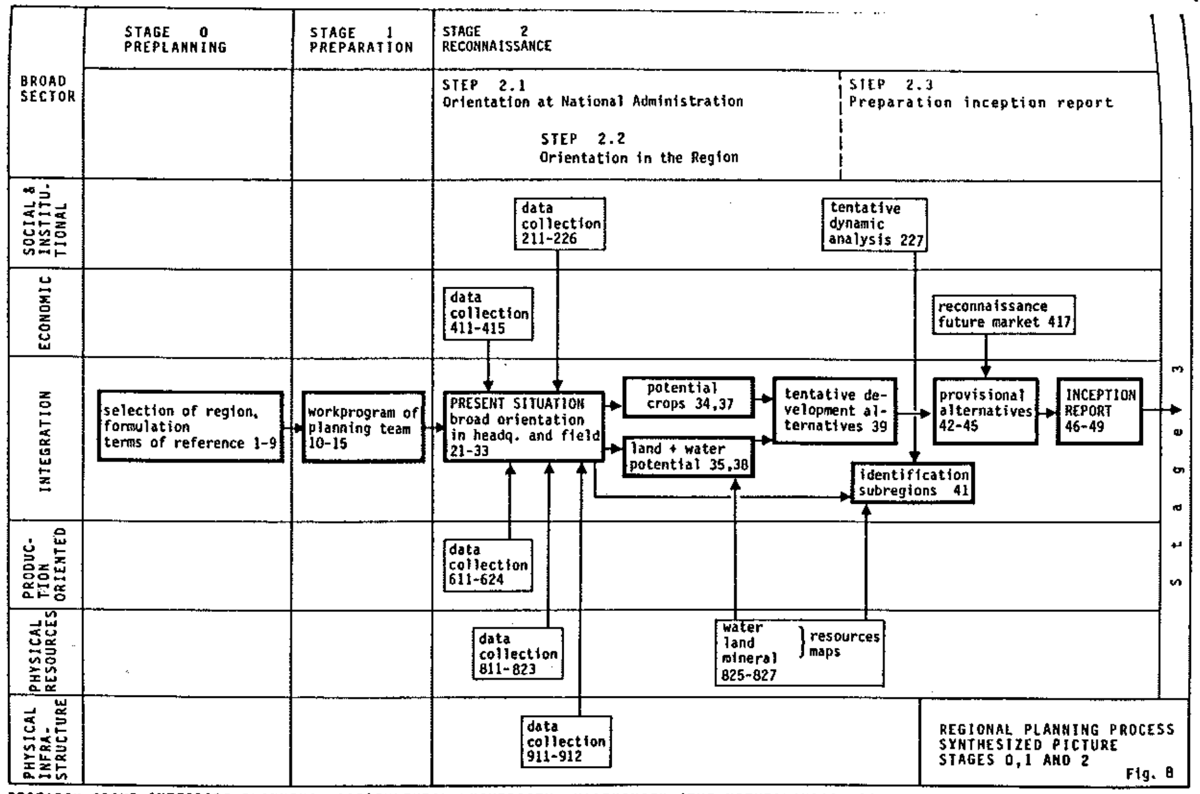
Source: FAO 1989

Table 3-4

Table 1. Possible future structures

Structure	Main elements
Economic structure	The output and employment in each sector; income distribution
Socio-economic structure	Type of production units: large factories, plantations, small-scale family-owned industries or farms, production cooperatives, or a certain combination of these units. An indication of the number of people involved in the various production units and their output.
Social structure	The various groups, based either on consanguinal or territorial criteria, and their interrelations, leadership, and power structure. Rough indication of the number of persons in the various groups.
Administrative and participation structure	Structure of the governmental organizations, their interrelations, number of people involved and their output. Organization of participation, village councils, district councils; their major tasks and functions.
Structure of the health sector	Types of service units, their interrelations, people employed in the various units and their output.
Structure of the educational sector	Types of school, their interrelations, teachers employed, the school population in the various school types and their output.
Land use pattern	What areas are used for what types of agriculture, for forestry, fishing, animal husbandry, recreation, conservation, mining, industry, housing, etc. This information should be compiled in a map, scale 1:100,000 up to 250,000.
Pattern of service centres (incl.urban)	The types of service centres (central places) and their interrelations. The services provided by the centres: schools, clinics, hospitals, shops, banks, offices of the administration, extension services, markets, industrial sites, etc. Rough indication of population living in, and served by, the centres. The information should be compiled in a map, scale 1:100,000 up to 250,000.
Infrastructure	Network of roads, canals, railroads, ports, airports, power supplies, water supplies, telecommunications, etc. The information to be compiled in a map, scale 1:100,000 up to 250,000.

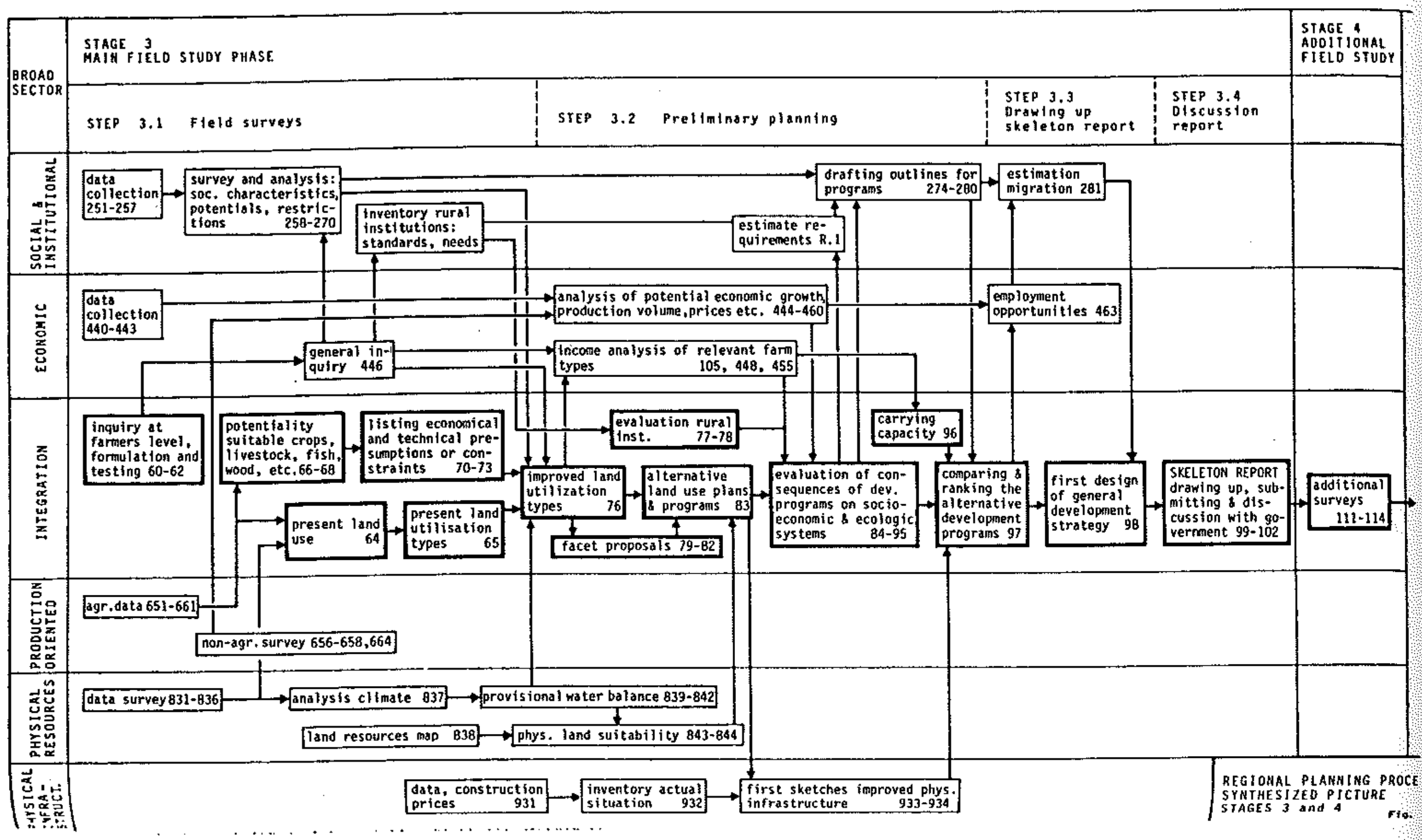
Table 3-5

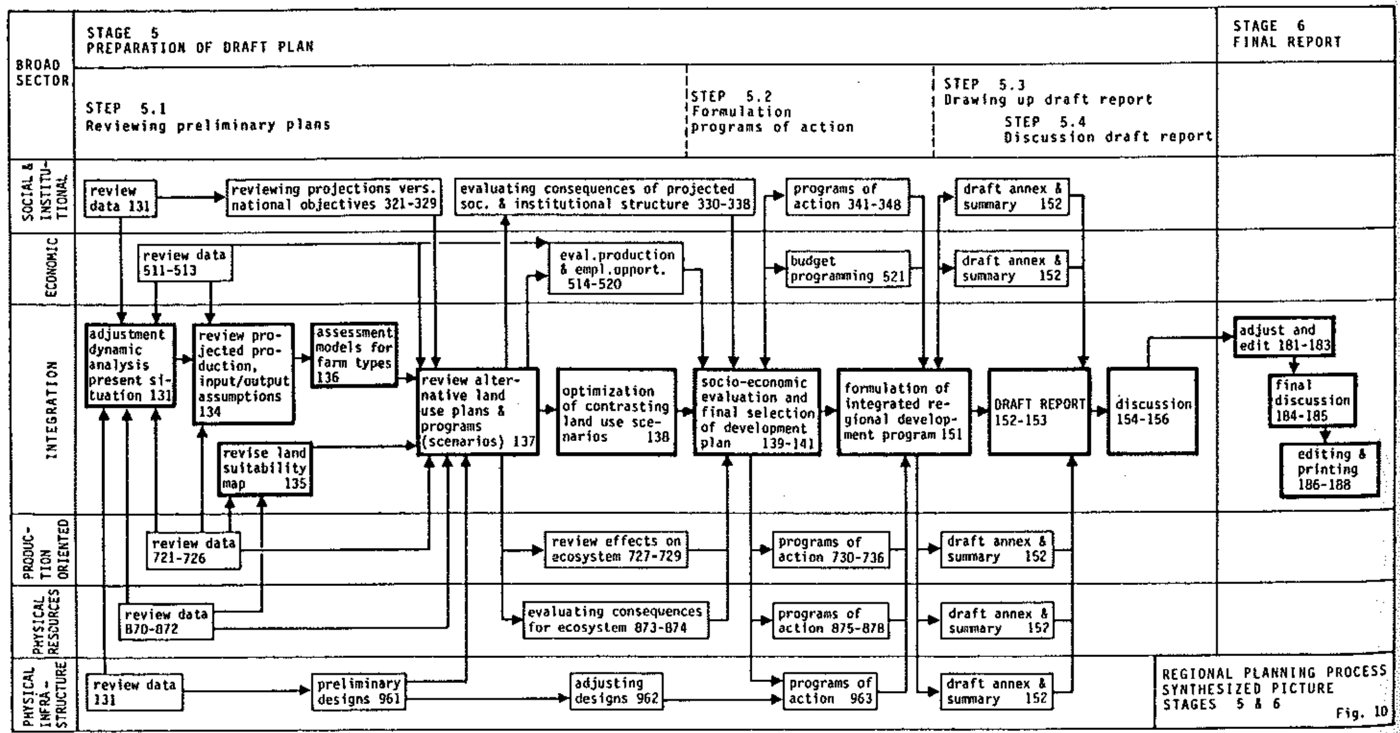


RESEARCH GROUP INTERDISC.PLANNING, AGRICULTURAL UNIVERSITY, WAGENINGEN,(THE NETHERLANDS), 1979

Source: van Staveren/Dusseldorp ed. 1993

Table 3-5 cont.





RESEARCH GROUP INTERDISC.PLANNING, AGRICULTURAL UNIVERSITY, WAGENINGEN,(THE NETHERLANDS), 1979

Source: van Staveren/Dusseldorp ed. 1993

ANNEX I. LIST OF IDENTIFIED ACTIVITIES

Table 3-6

ABBREVIATION USED

Clim	Climate
Geol	Geology
Hydr	Hydrology
Land	Land and Soils
Ecol	Ecology
Crop	Crop Production
AnPr	Animal Production
For	Forestry
Fish	Fisheries and Aquaculture
Min	Mining
Ind	Secondary & Tertiary Production Sectors (industries, etc.)
Dem	Demography
Soc	Sociology
Edu	Education
Ext	Rural Extension
Hea	Health
PubA	Public Administration
Coop	Agricultural Cooperatives
Cred	Agricultural Credit
LT	Land Tenure
MaEc	Macro Economy
AgrEc	Agricultural Economy
IndEc	Economy of non-agricultural production sectors
Infr	Physical Infrastructure
(Civ/Infr)	(incl. civil engineering)

NOTE. Each participant's degree of responsibility is indicated as follows:

(a) mainly responsible
(b) obligatorily assisting
(c) optionally assisting

Source: van Staveren/Dusseldorp ed. 1993

Table 3-7

Table 15 CHECKLIST OF SOIL QUALITIES, FIELD CHARACTERISTICS AND SPECIAL FIELD AND LABORATORY DETERMINATIONS

Quality	Field characteristic	Special determinations
Sufficiency of energy	-	Soil temperature regime
Sufficiency of water	Soil texture, depth, stoniness, salinity Rooting pattern	Soil water release characteristics and infiltration capacity
Sufficiency of oxygen	Soil drainage class, colour Depth to water table	Eh, saturated hydraulic conductivity
Sufficiency of nutrients	Soil texture, depth, stoniness, organic matter, pH Weatherable minerals, Foliar examination	Cation exchange capacity Determination of individual nutrients, eg N, P, K, Mg
Ease of water management	Landform, slope angle, microtopography Soil texture, depth Depth to groundwater	Infiltration rate and saturated hydraulic conductivity
Tilth	Soil structure, consistence	Exchangeable sodium
Strength/bearing capacity	Soil texture	Atterburg limits, shear strength
Erosion hazard/ slope stability	Landform, slope angle, slope length Soil texture, drainage, structure	Shear strength, angle of friction Particle size distribution
Toxicity	Foliar examination, pH	Determination of individual ions, e.g. HBO3-, Al3+, Se
Disease	Foliar examination Soil drainage	Microbiological and entomological examination

Table 13 CLIMATIC DATA FOR LAND USE PLANNING

Land qualities	Climatic characteristics
Sufficiency of energy	Temperature regime, sunshine hours, day length
Frost hazard	Probability of frost (local occurrence and not adequately recorded in standard data)
Sufficiency of water	Reference evaporation Eo Crop water requirement = Eo x Kc (crop coefficient) Rainfall probability, effective rainfall
Irrigation need/ Drought hazard	Rainfall probability - crop water requirement
Length of growing season	Period of energy and water sufficiency
Hazard of high winds, high temperature, hail; low humidity	Probability of occurrence in the growing season
Erosion hazard	Rainfall intensity

References: ILACO (1985), FAO (1977), FAO (1979)

Table 14 WATER RESOURCE DATA FOR LAND USE PLANNING

Present water use
- river abstraction, tanks, groundwater
- location of abstraction points, sluices, dams, wells and boreholes, with yields.

Present storage capacity of tanks and reservoirs.

Reliable yield of water for each river catchment - 75% and 90% probability low flow, from hydrograph records, or 75% and 90% probability rainfall - Eo over 7/10 day periods x area of catchment.

Safe yield of groundwater, from test pump data or well records.

Depth below surface of useful groundwater

Location of aquifers

Water quality

Location of irrigable land

Legal and customary rights

Source: FAO 1989

Table 3-8b

Summary of types of land resource surveys

Table 2.1

Type of survey 1/	Nearest FAO equivalent nomenclature and final map scale 2/	Aim and level	Site intensity and survey method	Approximate proportion of time input (%) API	Literature	Field work and sampling	Preferred scales Aerial photos	Final maps 3/
Exploratory	Exploratory to low intensity < 1:1 000 000 to 1:100 000	Resource inventory Project location Prefeasibility	Free survey of variable intensity usually much < 1 per 100 ha	60 (Probable averages, very variable)	20	20	< 1:60 000 < 1:100 000	Variable
Reconnaissance	Medium intensity 1:100 000 to 1:25 000	Prefeasibility Regional planning Project location	Free survey of variable intensity usually < 1 per 100 ha	50	25	25	1:40 000 to 1:20 000	< 1:50 000
Semi-detailed	High intensity 1:25 000 to 1:10 000	Feasibility Development planning	Flexible or rigid grid. Intensity 1 per 15 to 50 ha	20	20	60	1:25 000 to 1:10 000	1:25 000 to 1:10 000
Detailed	Very high intensity > 1:10 000	Development Management Special purpose	Rigid grid. 1 per 1 to 25 ha	5	20	75	1:10 000 to 1:5 000	1:10 000 to 1:5 000

Notes:
1/ These terms are loosely used for a wide variety of intensities and final map scales: see Young (1973), Stobbs (1970) and Western (1978, Chapter 3).
2/ See FAO (1979a, p 88).
3/ For many integrated projects the final map scale may be chosen to conform to civil engineering or project development requirements, rather than to the most appropriate scale for the survey intensity and complexity of the soil pattern (see Subsection 9.5.1).

Table 3-8a

Summary of mapping units used in land resource surveys

Table 2.2

Types of survey	Final mapping unit	Landscape components 1/ Geomorphology	Soil	Vegetation	Land use
Exploratory	1. Physiographic units/ land systems 2. Potential development areas	Major relief units	Orders 2/ to associations	Soil/climate-related types	Agro-ecological groups
Reconnaissance	1. Physiographic units/ land systems 2. Soil associations 3. Land capability units 4. Potential development areas	Relief units, major landforms	Associations	Soil/climate-related types, plant associations	Land use systems, cultivation density
Semi-detailed	1. Geomorphic units 2. Soil series/ associations 3. Land suitability/ management classes 4. Major constraints or development parameters	Detailed landforms and elements, slope units	Series, complexes or associations; soil phases and selected parameters	Plant associations and distribution	Land use and farming systems, specific parameters, cropping patterns
Detailed	1. Soil phases and/or land parameters 2. Land management units	Slope units	Soil phases and selected parameters	Specific crop or natural vegetation variables related to soil parameters - eg drainage or salinity effects	

Notes:
1/ After Baulkwill (1972).
2/ ie the highest level of soil classification (see Annex C); not to be confused with the USDA term 'order of soil survey' which refers to the kind of survey (see Orvedal, 1977).

Source: Landon ed. 1984

Table 3-9

Table 14 INVENTORY OF SOILS DATA

	DATA ITEM	PURPOSES FOR WHICH MAY BE REQUIRED
A.	PHYSICAL	
1.	Effective soil depth	Root room, water and nutrient retention; land levelling; drainage; aligning and design of irrigation and drainage channels.
2.	Presence of organic or histic horizons	Special problems or opportunities.
3.	Grain size distribution (texture)	For establishing homogeneity of land units and for deriving many characteristics.
4.	Soil structure and porosity Bulk density. Pore space volume and distribution. Air-filled pore space at field capacity. Structure stability.	Root environment, nutrient, water and soil management. Drainage and permeability especially of sodic soils. Leaching of excess salts. Tilth and workability for seedbed and land preparation. Ability to puddle riceland. Erodibility.
5.	Infiltration rate	Rainfall and irrigation intake or run-off. Selection of irrigation method. Furrow lengths or basin size. Sprinkler nozzle selection. Erodibility.
6.	Hydraulic conductivity or permeability	Soil drainage, removal of excess water and salts.
7.	Available water capacity (field capacity and permanent wilting point)	Soil water balance, residual water between and following irrigations. Choice of irrigation method and schedules.
8.	Plastic and liquid limits	Indicative of mineralogy and physical behaviour.
9.	Soil strength, linear extensibility	Mechanical strength for construction works; swelling and shrinking; root penetration.
B.	CHEMICAL	
1.	Soil reaction (pH)	To identify very alkaline, sodic and acid sulphate soils; nutrient deficiencies and toxicities.
2.	Carbon and nitrogen	Organic matter content and management.
3.	Gypsum and calcium carbonate	Hardpans, gypsiferous layers liable to subside, gypsum requirements for sodic soils.
4.	Electrical conductivity of saturation extract (ECe)	Salinity hazard.
5.	Soluble salts (Na, K, Ca, Mg, Cl, SO_4, CO_3 and HCO_3)	Interpretation of salinity hazard.

Table 14 (contd.) INVENTORY OF SOILS DATA

	DATA ITEM	PURPOSES FOR WHICH MAY BE REQUIRED
6.	Cation exchange capacity (CEC), total exchangeable bases (TEB) and base saturation %	Nutrient retention and chemical fertility status.
7.	Exchangeable sodium percentage (ESP) or adjusted sodium adsorbtion ratio of saturation extract(adj.SAR)	Sodicity or alkalinity problems.
8.	Exchangeable cations (Na, K, Ca, Mg)	Base saturation, ESP, potassium status.
9.	Available phosphorus	See Table 35, Part Two.
10.	Total contents of P, K, Mg, Na, Cu, Mn, Zn, B, Fe, Al, As, Ni, Cr	Macro and micronutrient content. Toxic elements.
C.	MINERALOGICAL	
1.	Sand and silt fraction	Indicates parent material and degree of weathering.
2.	Clay fraction and iron and aluminium oxides	1:1 clay minerals less sticky, swell and shrink less and have a smaller surface area (and less CEC) than 1:2 clay minerals. 1:1 clay minerals with Fe and Al oxides predominating may prove excessively well-drained for wetland rice, and often physically favourable but chemically less fertile for non-rice crops.
3.	Calcium and magnesium carbonates	Hardpans restricting rooting depths. Large amounts decrease nutrient retention and fertility; but soils with 60% $CaCO_3$ can be successfully irrigated but with a restricted choice of crops. Deposition under saline conditions of fine grained material blocks pores and reduces permeability. Surface crusting interferes with seedling emergence and infiltration. Lime-induced nutrient deficiencies. Magnesium carbonate soils often very fertile. High exchangeable Mg leads to sodic-like impermeable profile.
4.	Gypsum	Gypsiferous hardpans restrict rooting and make installation of drains and channels difficult. Dissolution may lead to land subsidence after irrigation. Gypsum crystals in soil may offset sodicity tendency. If too high, causes nutrient problems due to unfavourable K/Ca, Mg/Ca ratios and extra costs in fertilizers and soil management.

Note: The characteristics in Table 14 should be evaluated in the context of morphological and geographical considerations.

Source: Landon ed. 1984

Table 3-10a

Summary of routine soil physical measurements and their interpretation — Table 6.2

Measurement	Recommended method(s)	Preferred units	Range of values and comments	
Infiltration rate	Basin, furrow or ring at site	cm h^{-1}		Rating for surface irrigation:
			< 0.1	Unsuitable (too slow) except for rice
			0.1–0.3	Unsuitable (too slow); marginal for rice
			0.3–6.5	Main suitable range (> 0.3 unsuitable for rice)
			6.5–12.5	Marginal (too rapid)
			12.5–25.0	Only suitable in special conditions (small basins)
			> 25.0	Only suitable for overhead irrigation Note: Values from ring infiltration may be high because of lateral seepage
Hydraulic conductivity	Auger hole or inverse auger hole	m day^{-1}	< 0.2	Very slow
			0.2–1.4	Slow to moderate
			1.4–3.0	Moderately rapid to rapid
			> 3.0	Very rapid Note: both horizontal and vertical components should be considered
Bulk density	Replacement at site and/or undisturbed core in laboratory	g cm^{-3}	0.9–1.2	Recently cultivated soil
			1.1–1.4	Main range uncultivated, uncompact soil
			1.6–1.8	Sands and loams) Ranges that
			1.4–1.6	Silts) restrict
			Very variable	Clays) roots
Porosity	From bulk density tests	% by vol	30–70	Usual range in soils
			10	Limiting value for air-filled pores
Field capacity (FC)	In situ tests	mm m^{-1} (% by vol)	100–450	High values for clays; low values for sandy soils
Permanent wilting point (PWP)	Pressure membrane method at 15 bar	mm m^{-1} (% by vol)	50–250	High values for clays; low values for sandy soils
Available water capacity (AWC)	FC – PWP	mm m^{-1} (% by vol)	50–230 but mostly 70–190	Approximate range for stone-free tropical soils. High values (> 180 mm m^{-1}) for soils with very fine sandy and silty textures; moderate values (120–180 mm m^{-1}) for clayey soils; low values (< 120 mm m^{-1}) for sandy soils
Water content	Gravimetric	% by vol or by mass	See ranges above	Tensiometers and neutron probe methods need careful calibration; former unsatisfactory on gravel soils
Structure	Water immersion	-	Class 1–8	Class 1 (least stable) to Class 8 (most stable); may be great variation within classes. Limited use in routine surveys
Strength	Penetrometer	kg cm^{-2}	Highly variable	Careful calibration and operation needed; highly dependent on water content; limited use in routine surveys
Stone content, and particle size distribution	Wet and dry sieving; sedimentation	Stones: % by vol Fines: % by wt	) See) Section 6.9	Note variation due to different pretreatments

Source: Landon ed. 1984

Table 3-10b

Brief summary of recommended routine soil chemical analyses and their interpretation

Table 7.4

Analysis	Recommended method(s)	Units	Rating	Range	General interpretation	Section reference
pH	1:2.5 soil:water suspension	-	Very high	> 8.5	Alkaline soils: Ca and Mg liable to be unavailable; may be high Na; possible B toxicity; otherwise as below:	7.5
			High	7.0–8.5	Decreasing availability of P and B to deficiencies at higher values. Above 7.0 increasing liability of deficiency of Co, Cu, Fe, Mn, Zn	Interpreta-ation 7.5.3
			Medium	5.5–7.0	Preferred range for most crops; lower end of range too acidic for some	
			Low	< 5.5	Acid soils: possibly Al toxicity and excess Co, Cu, Fe, Mn, Zn; deficient Ca, K, N, Mg, Mo, P, S (and B below pH 5)	
CEC	a) Unbuffered 1 M KCl at pH of soil b) Na or NH_4 acetate at pH 8.2, 7.0	me/100 g soil	Very high	> 40	Normally good agricultural soils – only small quantities of lime and K fertilisers required	7.6
			High	25–40		
			Medium	15–25	Normally satisfactory for agriculture, given fertilisers	Interpreta-tion 7.6.3
			Low	5–15	Marginal for irrigation (FAO (1979a) quoted low is 8-10 me/100 g soil)	
			Very low	< 5	Few nutrient reserves. Usually unsuitable for irrigation, except rice	
BSP	Calculation: total exchange-able bases/CEC	%	High	> 60	Generally fertile soils	7.6.4 Table 5.7
			Medium	20–60	Generally less fertile soils	
			Low	< 20		
			Eutric	> 50		
			Dystric	< 50		
Exchangeable cations						7.7
Ca	As CEC	me/100 g soil	High	> 10	Response to Ca fertiliser expected at levels < 0.2 me/100 g soil. If high Na levels, response occurs with higher Ca levels	7.7.3
			Low	< 4		
Mg	As CEC	me/100 g soil	High	> 4.0	Mg deficiency more likely on coarse, acidic soils. With high Ca, Mg is less plant available	7.7.4
			Low	< 0.5		
K	As CEC	me/100 g soil	High	> 0.6	Response to K fertiliser unlikely. High K effects often similar to high Na, but depends on soil type – especially texture	7.7.5
			Low	< 0.2	Response to K fertiliser likely	
EPP	Calculation: K^+/CEC	%	High	> 25%	Very approximate upper limit (cf ESP > 15%) 1/	
			Low	< 2%	Very approximate lower limit 1/	
Na	As CEC	me/100 g soil	High	> 1	Alkali or sodic soils 1/	7.7.6
ESP	Calculation: Na^+/CEC	%	High	> 15%	Alkali or sodic soils 1/	
		%	High	> 15%	50% yield reduction for sensitive crops 1/	
				15–25%	50% yield reduction for semi-tolerant crops 1/	
				35%	50% yield reduction for tolerant crops 1/	
Al:CEC	1 M KCl unbuffered	%	High	< 85	Tolerated only by few crops	7.7.8
			Medium	30–85	Generally toxic	
			Low	> 30	Sensitive crops affected	

cont

Notes: See page 114.

Source: Landon ed. 1984

Table 3-11

Table 44 GROWTH LIMITING CONDITIONS FOR RICE ON SUBMERGED SOILS OF VARIOUS TYPES

KIND OF SOIL AND MAIN LIMITATIONS	OTHER GROWTH LIMITING CONDITIONS
Saline soils	
Arid saline soils	Alkalinity, Zn deficiency, N & P deficiencies
Acid coastal saline soils	Iron toxicity, P deficiency, deep water
Neutral and alkaline coastal and saline soils	Zn deficiency, deep water
Deltaic and estuarine acid sulphate soils	Iron toxicity, P deficiency, deep water
Coastal histosols	Nutrient deficiencies, H_2S toxicity, toxicity of organic substances, deep water, Fe toxicity
Acid sulphate soils	
Coastal soils	Salinity, Fe toxicity, N & P deficiencies, deep water
Old inland soils	N & P deficiencies
Histosols	Fe toxicity, H_2S toxicity, nutrient deficiencies, deep water, salinity
Iron-toxic soils	
Acid sulphate soils	Salinity, N & P deficiencies, deep water
Acid oxisols and ultisols	P deficiency, low base status, low Si content
Histosols	H_2S toxicity, toxicity of organic substances, macro-nutrient deficiencies, Zn and Cu deficiencies, deep water
Phosphorus deficiency in wetland rice	
Acid sulphate soils	Strong acidity, iron toxicity, low nutrient status, base deficiency, salinity
Acid oxisols and ultisols	Iron toxicity, base deficiency
Vertisols	Zinc deficiency, iron deficiency, salinity, alkalinity
Zinc deficient soils	
Saline-sodic and sodic soils	Salinity, N & P and Fe deficiencies
Vertisols	P and Fe deficiencies, salinity, alkalinity
Calcareous soils	K deficiency
Wet soils	Cu deficiency
Histosols	N, P, K, Si, Cu, deficiencies; H_2S toxicity, deep water

Source: after Ponnamperuma 1976.

Source: Landon ed. 1984

LANDEVALUIERUNG FÜR DEN BEWÄSSERUNGSFELDBAU IM FEZZAN

Anhand der "Grenzwert- Methode" für einen kleinbäuerlichen Familienbetrieb mit kombinierten Oberflächen- und Beregnungsmethoden;

FACTOR OF LAND AND SOIL QUALITY OR CHARACTERISTICS	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5+6
Effective soil depth	>150 cm	150-75 cm	75-50 cm	30-50 cm	<30 cm
Topography/Slope	<0.5%	<1%	<2%	2-4%	>4%
Microrelief	level uniform	slighly homogeneous	moderately homogeneous	homogen.	undulating homogeneous
Permeability	40-100cm/d	>20cm/d	>10cm/d	<1cm/d	any
Drainage class	3 + 4	2 - 5	1 - 6	all	all
Infiltration class	12-48 cm/d	12-144 cm/d	1-300 cm/d	any	any
Topsoil texture 0-30 cm	sL,scL,L	lS to sC/cL/siC	clay<65% sand <90%	all	all
Subsoil texture 30-100 cm	ls to sC/cL/siC	clay <65% sand <90%	all	all	all
Available water capacity	>140 mm	>90 mm	>50 mm	all	all
Potential fertility	high	moderate	low	low	any
Actual fertility status	high	moderate	low	low	any
$CaCO_3$-content	2-20%	<35%	<65%	any	thick petrocalcic
$CaSO_4$-content	0.5 - 5%	<25%	<40%	any	thick petrogypsic
Soil toxicity (B etc.)	low	moderate	mod. high	high	any
Salinity of topsoil 0-50 cm	<4m S/cm	4-15 mS/cm	15-50 mS/cm (< 1% salts)	any	any
Salinity of subsoil 50-150 cm	<8 mS/cm	<30 mS/cm (< 1% salts)	any	any	any
Alkalkinity of topsoil	pH < 8.0	pH <9.0	pH <10.0	any	any
Alkalinity of subsoil	pH < 8.5	pH <9.5	pH <10.0	any	any
Wind ersoion hazard	low	moderate	high	high	extremely high shifting sands

Land Class specifications according to USDI (1953) (in:Klingebiel & Montgomery 1961)
C 1: soils/land with few or no limitations ; C 2:soils/land requiring moderately intensive treatment;
C 3: severe limitations that require special practices; C 4: severe limitations that restrict choice of land use and require very careful management; C 5+6: severe limitations requiring further studies or problems which are consideres to be non-correctable at an economic rate.
Classes C1-C3: *Irrigable* ; Class C4: *Restricted Irrigable;* Classes 5+6: *Provisionally Non-Irrigable.*

LANDEVALUIERUNG FÜR DEN BEWÄSSERUNGSFELDBAU IM FEZZAN

Anhand der "Grenzwert- Methode" für ein großflächiges Center-Pivot-Projekt

FACTOR OF LAND AND SOIL QUALITY OR CHARACTERISTICS	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5+6
Effective soil depth	>100 cm	>75cm	>50cm		<50cm
Topography/Slope	<0.5%	<2%	<4%		>4%
Microrelief	level uniform	slightly homogeneous	moderat. homogeneous		homogeneous
Permeability	40-100cm/d	<10cm/d	>2cm/d	>0.5cm/d	<0.5cm/d
Drainage class	3 + 4	2 to 6	1 to 6	all	all
Infiltration	12-144cm/d	12-300cm/d	>1cm/d	any	any
Topsoil texture 0-30 cm	sL,scL,L	clay<40% sand<90%	clay <65%* sand >90%	any	any
Subsoil texture 30-100 cm	clay<40% sand<85	clay <65%	any		
Available water capacity	>140 mm	>50 mm	any		
Potential fertility	high	moderate	low		
Actual fertility status	high	moderate to low	any		
$CaCO_3$-content	2-20%	<40	any		
$CaSO_4$-content	0.5-10%	<25%	<45%	any	
Soil toxicity (B etc.)	low	moderate	mod. high	any	
Salinity of topsoil 0-50 cm	<4mS/cm	<15mS/cm	>15mS/cm <2% salts	any	
Salinity of subsoil 50-150 cm	<8mS/cm	<15mS/cm	>15mS/cm	any	
Alkalkinity of topsoil	pH <8.0	pH <9.0	pH <10.0	any	
Alkalinity of subsoil	pH <8.5	pH <9.5	pH <10.0	any	
Wind ersoion hazard	low	moderate to mod. high	high	high	extremely high; shifting sands

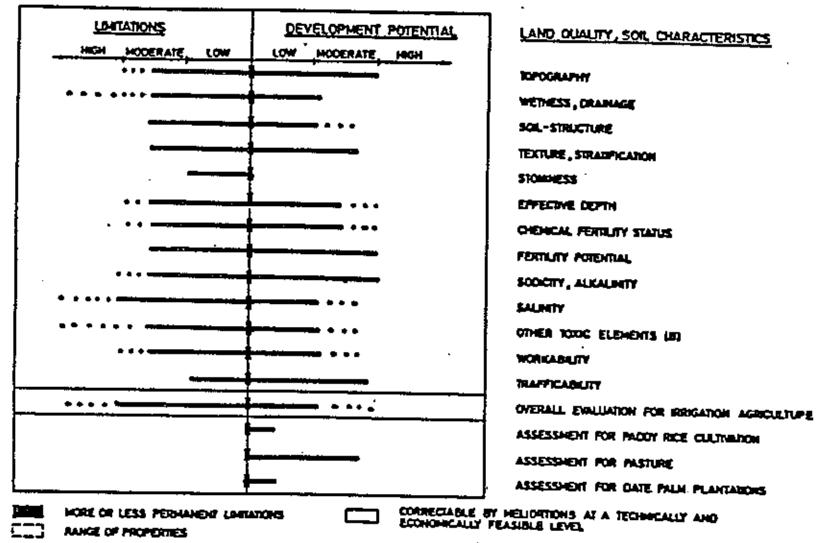
* Bei gutem Management können auch tonreiche Substrate in die Class C2 eingestuft werden.

DIRECTIVES DE GROUPEMENT DE SOLS EN CLASSES D'APTITUDE POUR LA CULTURE DU RIZ IRRIGUE (NIVEAU D'EXPLOITATION MOYEN)

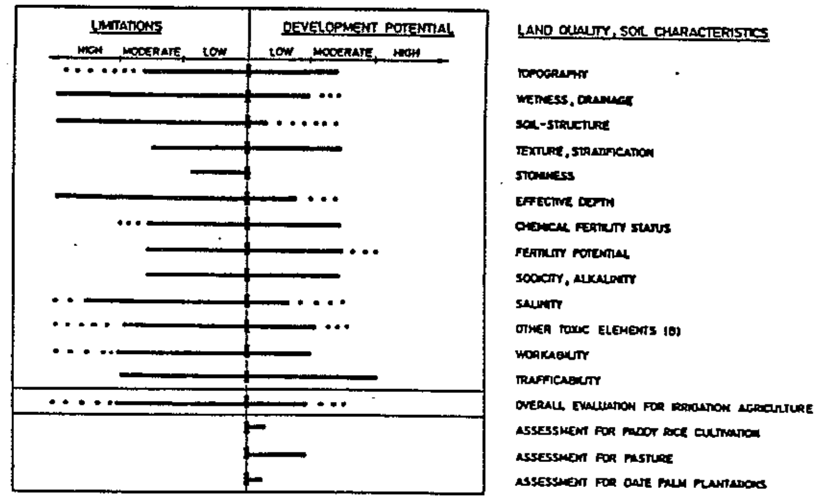
Guideline for grouping soils in current suitability classes for paddy rice (medium level of management)

Land and Soil Quality	P1	P2	P3	P4	N
Topography	< 0.5%	< 1%	< 3%	≤ 5%	–
Microrelief	smooth plan	smooth	levelling required	levelling required	–
Drainage (class*)	8, 9	6, 7, 10	5, 10	4 to 10	4
Water table	shallow < 20 cm	mod. deep 20-50 cm	deep (> 50 cm)	deep (> 50 cm)	deep
Risk of damage by flooding	Seldom < 1 in 10 years	occasional	moderate damage	damage may be frequent	–
Texture	very fine	v. fine to fine	v. fine to medium	v. fine to coarse	v. coarse
Hydraulic cond. of subsoil	1-10 cm/d	10-40 cm/d < 1 cm/d	40-100 cm/d	100-600 cm/d	> 600 cm/d
Sulphuric horizon	no	no	no or deeper than 50 cm	–	–
Effective soil depth	> 100 cm	> 75 cm	> 50 cm	> 25 cm	< 25 cm
Exchange Capacity	> 24 me %	12-24 me %	7-12 me %	< 7 me %	< 4 me %
Base saturation	> 50%	35-50%	15-35%	< 15%	–
Nutrient status	high to mod.	high to mod. low	high to low	high to low	–
Organic matter	> 2%	1-2 %	< 1%	< 1%	–
Salinity groundw. / Soil extr.	< 0.3 mS/cm / < 1.0 mS/cm	0.3-1.0 / 1-3	1.0-3.0 / 3.0-5.0	> 3.0 / 5-8	– / > 8
Alkalinity/Acidity	pH 5.5-6.5	pH 5.0-8.0	pH 4.5-8.5	pH 4.0-9.0	< 4
Presence of toxic elements x1	slight	moderate	moderate	severe	–
Calcium carbonate %	< 15%	< 15%	15-25%	> 25%	–
Absence of specific deficiencies x2	slight	moderate	moderate	severe	–
Exchangeable sodium	< 20%	< 40%	< 60%	≥ 60%	–
Infiltration rate	< 3 mm/d	3-30 mm/d	30-60 mm/d	60-100 mm/d	> 100 mm/d

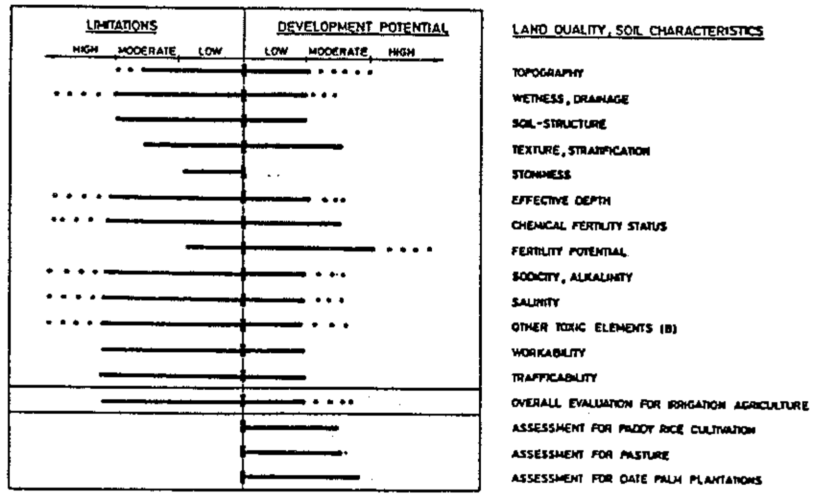
ASSESSMENT OF GENERAL SOIL SUITABILITY
(ALL CROPS, WITHOUT PADDY RICE)



Graphik 7.7
ARIDIC (HAPLIC-) CALCIC SOLONCHAKS



Graphik 7.8
ARIDIC (PETRO-) CALCIC SOLONCHAKS



Graphik 7.9
ARIDIC (TAKYRIC-) SODIC SOLONCHAKS

Table 3-14

Table 11 LAND UTILIZATION TYPES IN BALI (IRRIGATED) 1/

1.	IRRIGATED LANDS
1.1	Irrigated rice only
	1.1.1 Two crops of local 140-160 day varieties per year 2/
	1.1.2 Five crops of short duration 120 day varieties per two years
	1.1.3 One crop of 140-160 day local variety followed by one crop of 120 day local or new variety per year (where dry season water is limited)
	1.1.4 One irrigated rice crop (wet season) and land fallow in dry season (where soil is unsuitable for palawija crops and there is insufficient water for second rice crop)
1.2	Irrigated rice (wet season), irrigated or rainfed palawija (dry season) 3/
	1.2.1 Rice, rice, palawija per year 4/
	Irrigation of palawija dependent on water availability; often grown on residual moisture, e.g. rice, rice, soybeans (relay planted)
	1.2.2 Rice, palawija, palawija per year
	The palawija is usually irrigated. Many combinations of crop are planted, e.g. rice, maize, groundnuts
	Rice, groundnuts, red onion Rice, soybean, soybean Rice, soybean, green gram Rice, groundnut, groundnut Rice, tobacco, red onion Rice, soybean, cucumber
	1.2.3 Rice followed by one relay-planted soybean crop per year
	The irrigation of the soybean crop depends on rainfall and availability of stream water. Land is only recultivated once each year
	1.2.4 Rice followed by one palawija crop other than soybeans.
	Rice, melons Rice, cucumbers
1.3	Irrigated rice under coconuts
	1.3.1 Rice (wet season), palawija or fallow (dry season)
	1.3.2 Rice, rice per year
1.4	Irrigated palawija crops only
	Palawija crops rarely irrigated because of serious weed problems
1.5	1.5.1 Pure stand citrus
	1.5.2 Citrus under-planted with maize, groundnuts and red onions

1/ Eavis and Walker 1976.

2/ Rice is usually transplanted under groups 1.1, 1.2 and 1.3 but direct seeding is a possible future variant. Days refer to time from transplanting to harvest.

3/ Palawija is an Indonesian term that collectively refers to crops grown in rotation with rice, e.g. maize, groundnuts, green gram (mung), tobacco, red onion, soybeans, sweet potato, melon, cucumber etc.

4/ Generally relay-planted, i.e. sown in rice stubble or before rice is harvested, without any cultivation.

Source: FAO (SB 55) 1985

Table 3-15

Table 4 FORMAT 1: SPECIFICATIONS OF LAND USE REQUIREMENTS AND LIMITATIONS

LUT Name:	LUT Description							
CLASS-DETERMINING REQUIREMENTS OR LIMITATIONS (Delete factors that are not selected as class-determining)	REVELANT LAND QUALITY OR LAND CHARACTERISTIC	INPUTS AND LAND IMPROVEMENTS REQUIRED	UNIT OF MEASURE-MENT	CRITICAL LIMITS OR RANGES				
				s1	s2	s3	n1	n2
A. Crop (agronomic) requirements or limitations								
1. Growing period requirement								
2. Radiation requirement								
3. Temperature requirement								
4. Rooting requirement								
5. Aeration requirement								
6. Water requirement								
7. Nutritional requirements (NPK)								
8. Water quality limitation								
9. Salinity limitation								
10. Sodicity limitation								
11. pH, micronutrients and toxicities								
12. Pest, disease, weed limitations								
13. Flood, storm, wind, frost, hail limitations								
B. Management requirements and limitations								
14. Location								
15. Water application management requirements								
16. Pre-harvest farm management requirements								
17. Harvest and post-harvest requirements								
18. Requirements for mechanization								
C. Land development or improvement requirements or limitations								
19. Land clearing requirements								
20. Flood protection requirements								
21. Drainage requirements								
22. Land grading requirements								
23. Physical, chemical, organic aids and amendments								
24. Leaching requirements								
25. Reclamation period								
26. Irrigation engineering needs								
D. Conservation and environmental requirements and limitations								
27. Long-term salinity, sodicity hazard								
28. Ground or surface water hazard								
29. Long-term erosion hazard								
30. Environmental hazard								
E. Socio-economic requirements or limitations								
31. Farmers' attitudes to irrigation								
32. Others that are class-determining								

Note: s1, s2, s3, n1 and n2 denote decreasing suitability levels for single factors or their interactions. See Table 12 and Section 6.5 Example 2.

Table 5 FORMAT 2: LAND QUALITIES AND LAND CHARACTERISTICS DESCRIBING A LAND UNIT WITH AN ASSESSMENT OF INPUTS AND LAND IMPROVEMENTS REQUIRED

CLASS DETERMINING FACTORS: - land quality or characteristic - inputs or improvements	UNIT OF MEASUREMENT	LAND CHARACTERISTIC OR QUALITY VALUE		INPUTS AND IMPROVEMENTS ASSUMED FOR LUT A, B, C etc.
		PRESENT	FUTURE UNDER IRRIGATION	
e.g.				
7. NUTRITION (NPK)				
- Total N depth 0-25 cm	%	0.05	0.5	
- Available P (Olsen)	mg/l	10		
- Exchangeable K	me/100 g	0.6		
Fertilizer requirement	kg/ha			
N				200 kg/ha
P				nil
K				nil

Source: FAO (SB 55) 1985

Table 3-16

Table 12 LIST OF CLASS-DETERMINING FACTORS (i.e. AS LAND USE REQUIREMENTS OR LIMITATIONS OR AS LAND QUALITIES) WITH SOME LAND CHARACTERISTICS, INPUTS AND LAND IMPROVEMENTS FOR CONSIDERATION IN SETTING CRITICAL LIMITS

	CLASS-DETERMINING FACTORS: 1/ - land use requirements or limitations - land qualities (where applicable)	REPRESENTATIVE LAND CHARACTERISTICS, INPUTS, LAND IMPROVEMENTS AND OTHER RELEVANT CONSIDERATIONS (see Part Two for full explanations)
A.	**AGRONOMIC:** - crop requirements or limitations - the crop environment	
1.	GROWING PERIODS: - growing period requirement - growing periods	Growing cycle of crops. Dates and duration (days).
2.	RADIATION: - radiation requirements - radiation regime	Day length, extra-terrestrial radiation; solar radiation (Rs); photosynthetically active radiation (PAR); actual sunshine hours (n); possible number of sunshine hours (N); net shortwave radiation Rns; total net radiation (Rn); mm of evaporation (Rn = 1 cal/cm^2/min approximate equivalent to 1 mm water/hr).
3.	TEMPERATURE: - temperature requirement - temperature regime	Temperature data. Heat units. Frost free periods.
4.	ROOTING: - rooting requirement - rooting conditions	Effective soil depth for roots. Root room. Volume percent of stones. Penetration resistance or soil strength.
5.	AERATION: - oxygen & aeration requirement - oxygen supply and soil aeration	Periods with or without adequate aeration during the growing period. (Depth and fluctuation of groundwater)
6.	WATER QUANTITY: - water requirement - water supply	Water balance, water storage. Yield vs. evapotranspiration relationships; deficient periods. Run-off, run-on, seepage and percolation, groundwater contribution, effective precipitation. Stream flows, diversions, storage releases, aquifer safe yields.

1/ Evaluate only selected factors i.e. those that are class-determining in a given evaluation.

Source: FAO (SB 55) 1985

Table 12 (contd.)

	CLASS-DETERMINING FACTORS: - land use requirements or limitations - land qualities (where applicable)	REPRESENTATIVE LAND CHARACTERISTICS, INPUTS, LAND IMPROVEMENTS AND OTHER RELEVANT CONSIDERATIONS (see Part Two)
7.	NUTRIENTS (NPK) - nutritional requirement - fertilizer requirement, etc. - nutrient supply - fertilizer supply	NPK uptake by crops and responses to NPK. Losses of NPK (leaching, volatilization, fixation, etc.). Nitrogen fixation. Soil nutrients and their retention, cation exchange capacity, etc. Fertilizer requirements and availability including manures, etc.
8.	WATER QUALITY: - crop tolerance to water quality - water quality	Total salt concentration. Ionic composition. Electrical conductivity dS/m at 25°C. Sodium adsorption ratio (SAR). pH, carbonates and bicarbonates. Suspended solids, BOD, COD, etc.
9.	SALINITY: - crop tolerance to salinity - salinity regime (salt balance)	Plant salt tolerances, present and future soil salinity, inputs of salt through water supply, losses of salt by leaching, salt balance. Seasonal salt movement in profile, salt from groundwater.
10.	SODICITY: - crop tolerance to sodicity - sodicity regime	Predicted pH, ESP and or SAR of soil solution, predicted effects on soil structure, infiltration and permeabilities. Sodium toxicity.
11.	pH, MICRONUTRIENTS AND TOXICITIES: - crop tolerances, susceptibilities - toxicity or micronutrient regimes	On non-rice cropland, pH effects and crop tolerances and susceptibilities to excesses or deficiencies of Ca, Mg, Zn, Fe, S, B, Cu, Mn, Mo, Al. On submerged soil effects of pH, salts, Fe, Si, Mo, Zn, Cu, H_2S. Soil and plant composition, relevant inputs.
12.	PEST, DISEASE, WEEDS: - crop tolerances, susceptibilities - pest, disease, weed hazard.	Crop tolerances and susceptibilities. Wild animals, birds, arthropods etc. Fungal, bacterial, viral pathogens. Weeds. Pesticides, fencing, inputs.
13.	FLOOD, STORM, WIND, FROST: - crop tolerances, susceptibilities - flood, storm, wind, frost, hail hazard	Adaptations of rice to flooded conditions. Frequency and severity of flood, storm, wind, frost and hail.

Table 3-16

Table 12 (contd.)

	CLASS-DETERMINING FACTORS: - land use requirements or limitations - land qualities (where applicable)	REPRESENTATIVE LAND CHARACTERISTICS, INPUTS, LAND IMPROVEMENTS AND OTHER RELEVANT CONSIDERATIONS (see Part Two)
B.	**MANAGEMENT:** - management requirements and limitations - conditions affecting management	
14.	LOCATION: - location requirements - location	Closeness to markets, processing units. Access to inputs and services. Access to water (gravity, pumped). Travel & transport problems & cost. Day-to-day management problems. Accessibility of machinery.
15.	WATER APPLICATION MANAGEMENT: - limitations of irrigation method - conditions affecting water application management	Size, shape of management units. Labour requirement availability. Conditions affecting uniformity of water application, rate, frequency and duration of application.
16.	PRE-HARVEST FARM MANAGEMENT: - pre-harvest farm management requirements and limitations - conditions affecting pre-harvest farm management	Effects on timing of pre-harvest operations (e.g. of soil workability) including land preparation, nurseries, seeding, transplanting, fertilizer application, irrigation, weeding, spraying, etc.
17.	HARVEST AND POST HARVEST MANAGEMENT: - requirements or limitations - conditions affecting	Atmospheric wetness, dryness, wind. Soil wetness, dryness. Effects of soil or humidity on the quality of the crop produce.
18.	MECHANIZATION: - requirements for mechanization - conditions affecting potential for mechanization and on-farm transportation	Slope angle, rock hindrances, stoniness, soil depth, soil texture, shape and size of fields. Effects of soil compaction. On-farm transportation.

Table 12 (contd.)

	CLASS-DETERMINING FACTORS: - land use requirements or limitations - land qualities (where applicable)	REPRESENTATIVE LAND CHARACTERISTICS, INPUTS, LAND IMPROVEMENTS AND OTHER RELEVANT CONSIDERATIONS (see Part Two)
C.	**LAND DEVELOPMENT AND IMPROVEMENTS** - land development requirements - factors affecting cost of land development and improvement	
19.	LAND CLEARING: - land clearing requirements - conditions affecting cost of land clearing	Forest: underbrushing, felling, burning, stacking; costs, value of timber, charcoal; time period to development. Persistent weeds: mechanical cultivation, flooding, chemical control; costs, time period to development. Rocks and stones: removal costs.
20.	FLOOD PROTECTION: - flood protection requirements - conditions affecting cost of flood protection	Earthmoving costs for embankments, costs of structures.
21.	DRAINAGE: - drainage requirements - conditions affecting cost of drainage	Watertable depth, depth to barrier of low permeability, vertical resistance to flow through soil and barrier, slope angle, need for salt removal; size, spacing, depth of surface or pipe-drainage and cost of drainage.
22.	LAND GRADING AND LEVELLING: - grading and levelling requirements - conditions affecting land grading and levelling costs	Slope, microrelief, macrorelief, cover. Field size and shape, cut and fill, earthmoving costs.
23.	PHYSICAL, CHEMICAL AND ORGANIC AIDS AND AMENDMENTS: - requirements - conditions affecting costs	Need for deep ploughing, subsoiling, profile inversion, sanding, marling; gypsum, lime, organic matter, costs.
24.	RECLAMATION LEACHING: - leaching requirement - conditions affecting leaching	Primary or one-time reclamation leaching requirements mm of water; continuous or intermittent, costs.

Table 3-16 cont.

Table 3-16 cont.

Table 12 (contd.)

	CLASS-DETERMINING FACTORS: - land use requirements or limitations - land qualities (where applicable)	REPRESENTATIVE LAND CHARACTERISTICS, INPUTS, LAND IMPROVEMENTS AND OTHER RELEVANT CONSIDERATIONS (see Part Two)
25.	DURATION OF RECLAMATION PERIOD: - period required to reclaim by drainage and leaching, etc. - conditions affecting leaching periods	Number of project years to full production, project year in which field drainage is installed, rate of rise in watertable.
26.	IRRIGATION ENGINEERING: - irrigation engineering requirements - conditions affecting engineering works and costs	Earthwork and other structures for diversion, storage, conveyance, and regulation of water. Topography, substratum conditions, permeability of channels, access to construction sites, costs of engineering works.
D.	CONSERVATION AND ENVIRONMENTAL: - conservation and environmental requirements and limitations - conditions affecting conservation and the environment	
27.	LONG-TERM PREVENTION OF SALINITY AND SODICITY: - requirements and limitations - conditions affecting long-term salinity and sodicity hazards	Long-term inputs and outputs of salts, (see Fig. 18), water quality, groundwater depth, permeability, drainage, tidal swamp conditions, intrusion of saline water into an aquifer, control measures and their cost.
28.	LONG-TERM CONTROL OF GROUNDWATER AND SURFACE WATER: - requirements and limitations - conditions affecting long-term control	Protection of catchment areas, degradation of catchment, sedimentation of reservoirs, control of groundwater, and their costs.
29.	EROSION HAZARD: - requirements and limitations - conditions affecting erosion	Erosion control. Maximum acceptable soil loss and effects of climate, soil, topography, land use factor, costs.
30.	ENVIRONMENTAL HAZARDS: - environmental control requirement and limitations - conditions affecting long-term environmental risks	Wildlife, water-borne human diseases, need for environmental control of vectors.
E.	SOCIO-ECONOMIC: - socio-economic requirements and limitations - socio-economic conditions	
31.	FARMERS' ATTITUDES TO IRRIGATION	Will the farmers utilize the irrigation facilities?
32.	OTHER SOCIO-ECONOMIC LIMITATIONS THAT MAY BE CLASS-DETERMINING	Water rights, tenurial and land-ownership complications, disincentives of taxation, fragmentation, etc.

Source: FAO SB 55 1985

Table 3-17a

Table 13 RATINGS OF CLASS-DETERMINING FACTORS (FACTOR RATINGS)

FACTOR RATINGS	GUIDELINES FOR SETTING CRITICAL LIMITS
s1	The critical limits indicate that in terms of the given factor, the land is highly suitable for the specified land use.
s2	The critical limits indicate that in terms of the given factor, the land conditions are slightly adverse for the specified land use.
s3	The critical limits indicate that in terms of the given factor, the land is marginally suitable for the specified land use.
n1	The critical limits indicate that in terms of the given factor, the land is marginally not suitable for the specified land use (usually for adverse benefit/cost reasons).
n2	The critical limits indicate that in terms of the given factor, the land is permanently unsuitable for the specified land use.

Note: Critical limits to define factor ratings should reflect benefit/cost or other economic indices that indicate the influence of the factor on the value of production, costs of production, land development costs, etc.

Table 3-17b

Table 29 FACTORS THAT MAY DETERMINE LAND SUITABILITY CLASS FOR LOWLAND RICE IN INDONESIA 1/

DESCRIPTION OF THE LAND USE TYPE:
Crop: Lowland rice

Land Characteristic or Land Quality	Units	CRITICAL LIMITS s1	s2	s3	n
Length of growing period	days	120	105-120	95-105	95
Average temperature over the growing period	°C	24-26	26-28 22-24	28-30 20-22	30 20
Water requirements (rainfall and irrigation)	mm/yr	>1 600	1 300-1 600	1 000-1 300	<1 000
Soil drainage class 2/		1, 2	3, 4	5	
Soil texture 3/		8, 9 10, 11	6, 7 12, 13 14, 15	5 16, 17	1,2,3,4 18
Rooting depth	cm	25	25	25	25
Soil pH		5.5-6.5	6.5-7.5 5.0-5.4	7.6-8.2 4.5-4.9	8.2 4.5
Soil salinity	dS/m	3	3-5	5.1-6.5	6.6-8
Nutrient uptake/ N (nutrient removal P in brackets) K	kg/ha	160 32 250	110 24 170	75 18 110	48 (30) 14 (9) 60 (10)

Adapted from Bunting 1981.

1/ Note that not all the above land characteristics would be class-determining. Land suitability class is based on those that are, taking into account their 'Interactions' (Section 6.2) and 'Significance' (see Section 6.3).

2/ Key to drainage classes: 1 = very poorly drained, 2 = poorly drained, 3 = imperfectly drained, 4 = moderately well drained, 5 = well drained, 6 = somewhat excessively drained, 7 = excessively drained.

3/ Key to texture classes: 1 = gravel, 2 = coarse sand, 3 = medium sand, 4 = fine sand, 5 = loamy sand, 6 = sandy clay loam, 7 = loam, 8 = sandy clay loam, 9 = silt loam, 10 = silt, 11 = clay loam, 12 = silty clay loam, 13 = sandy clay, 14 = kaolinitic clay, 15 = silty clay, 16 = mixed clays, 17 = structured montmorillonitic clay, 18 = massive montmorillonitic clay.

Sources: FAO SB 55 1985

Soil requirements and limitations for selected tropical and subtropical crops 1/

Table 3-18a

Crop	TEXTURE				DRAINAGE					MINIMUM ROOTING DEPTH CLASS 4/	MOISTURE			EROSION HAZARD 2/5/	REACTION		NUTRIENT NEEDS		SALINITY TOLERANCE 2/
	Fine	Medium	Coarse	Very coarse tolerated	Free essential or desirable	Imperfect well tolerated	Poor tolerated or needed	Tolerance to short periods of waterlogging 2/	Minimum groundwater depth (cm) 3/		Drought resistance 2/	High AWC important	Low AWC well tolerated		Optimum pH	Range of pH tolerance for satisfactory yield 5/	General level of requirements 2/	Specific requirements	
Cereals																			
Barley		+	+					M	60	M							H		G
Maize		+			+			L	75	M	L	+		H	5.5-7.0	5.0-8.0	H	High N	L
Millet (bulrush)		+	+	+	+						H		+	H					
Millet (finger)		+	+		+			M	60	S	M		+	M		5.0-6.0	M		L
Millet (panicum)		+	+								H		+	M					
Rice (paddy)	+						+				L	+		L	5.0-6.5	4.0-8.0	M	High N	
Rice (upland)	+	+						H		S	L			M		4.5-7.5	M		M
Rice (hungry)	+	+									M		+	H		4.5-7.5	L		
Sorghum	+	+	+			+		M/H	50	M	M		+	H	5.5-6.5	5.0-8.5	M	High N	L
Wheat	+	+						M	60	M					6.0-7.0		H		M
Fibre crops																			
Cotton	+	+			+			M/L	100	M	M				5.2-6.0	4.8-7.5	H		H
Hemp	+	+						M/L	75	D						6.0-7.0	H		L
Jute	+	+						H/M	10-75	M						6.0-7.0	M		L
Kenaf		+	+					M/L	75	M						6.0-7.5	M		L
Rosella		+	+					M	60	M						6.0-7.5	H		L
Sisal			+	+				L	150	D						6.5-8.0	M		L
Fruit crops																			
Banana		+	+		+			M	100	D	L	+		H	6.0-7.5	4.0-8.0	M/H	High N, K	L
Cashew			+					M	100	D						5.5-7.0	M		M
Citrus		+	(+)		+			L	130	D	M			L	5.5-6.5	5.0-8.0	M	High N, K	L
Date palm		+	+			+		H	100	D	H			H		6.5-8.0	M		H
Grape	+	+								D						6.0-7.0	M		L
Mango		+						M	60	D						5.5-7.5	H		L
Olive			+	+						D	H		+		7.0		M		M
Papaya		+								D					6.0-6.5		H		L
Pineapple		+	+		+			L	60	S	M			H		5.0-6.5	M		L
Oil crops																			
Coconut		+	+	+		+		H	50	D	L		+	L	6.0-7.5	5.0-8.0	L		M
Groundnut		+	+	+	+			L	50	M	M		+	M	5.3-6.6	5.0-7.0	M		L
Oil palm		+	+		+			H	100	D	L	+		M	5.5-6.0	4.0-8.0	H	Very high K	L
Safflower		+	+		+			M/L	75	M						5.5-6.5	H		L
Sesame		+	+		+			M/L	100	M						5.5-7.0	H		L
Soyabean		+	+			+		M	50	M				M	6.0-7.0	4.5-7.5	M		M
Sunflower		+	+		+			M	75	M	M		+	M		6.0-7.5	M		M
Pulses																			
Bean		+	+		+			M/L	30-50	M	L	+		M	6.0-7.0		M		L
Cowpea		+	+					M/L	40	M						5.5-7.5			L
Gram	+	+						M/L	30-50	M									M
Root crops																			
Cassava		+	+	+	+			L	50	D	H		+	M		5.5-6.5	M	(Low tolerated)	L
Cocoyam	+	+					+	H			L			L			H	High K	
Potato		+	+		+			L	30	M	L			M	5.0-5.8	4.5-7.0	M	High K	M
Sweet potato		+	+		+									M	5.8-6.0		H	High K	
Yams		+	+		+			L	50	D	M	+		M		5.5-6.5	H	High K, Mg	L
Sugar																			
Sugarbeet	+	+						M/H	45	M							H		H
Sugarcane	+	+				+		M/H	40	D	L	+		H	6.0-7.5	4.5-8.5	H	High N	M/L
Tree and shrub perennials																			
Cocoa		+	+		+			L	150	(D)	L	+		M	6.0-7.0	4.5-8.0	M/H		L
Coffee (arabica)		+	+		+			L	100	D	L	+		M	5.0-6.0	4.5-7.0	M/H		L
Rubber		+	+			+		H	75	D	L			H	4.0-6.5	3.5-8.0	L	N when young	L
Tea		+	+		+			L	100	D	L	+		H	4.0-5.5	4.0-6.5	M	High N	L
Coconut, Oil palm	see under oil crops above																		
Banana, Citrus	see under fruit crops above																		
Vegetables																			
Cabbage		+			+			L	50	S						6.0-7.5	H		M
Cucumber		+			+			L	50	M						6.5-7.5	H		L
Onion		+			+			L	50	S						6.0-7.5	H		L
Tomato		+			+			L	50	M						5.0-7.0	H		L
Others																			
Alfalfa		+	+			+		L	50	D	M	+		L	6.5-7.5	6.0-8.0	M/H	Low N, high Ca,S	M
Tobacco																			
air-cured			+		+													High N, K	
fire-cured	+				+			L	100	M	L			M	5.5-6.0	5.0-7.5	M	High N, K	L
flue-cured			+		+													Low N, high K	

+ = Desirable condition or attribute.

Notes: 1/ See also Table F.5. Note that CEC and OM criteria omitted because of lack of data; in general the higher the better - the latter up to at least 5%.
2/ L = low; M = medium or moderate; H = high.
3/ Minimum depth during growing period; this level produces about 25% reduction in optimum yield.
4/ D = deep (> 90 cm); M = medium (60 to 90 cm); S = shallow (30 to 60 cm).
5/ For conditions before full canopy development and/or without cover crop; note that at maturity sugarcane, tea and rubber have low erosion hazards.

Sources: ILACO (1981, p 569); Young (1976, p 308), including figures from Jacob and Uexküll (1963) and Richards (1954). Sugarcane figures from R A Yates (personal communication).

Source: Landon ed. 1984

Table 3-18b

Indicative soil requirements and tolerances of selected crops

Table F.5

Crop	Requirement for					Tolerance of				
	Water	Clayey texture	Good structure	Calcium	Acid conditions	Water-logging	Drought	Clayey texture	Acid conditions	Salinity
Apple	M/H	M	H	M	L	L	L/M	L	L	L
Barley	L/M	L	L	L	L	L	M/H	M	M	H
Beans	M	M*	M*	M*	L	L/M*	L*	M/H	L	L*
Cherry	M/L	L	M	L	L	L	M	L/M	M	L
Citrus	M	M	H	H	L	L	M	M*	M	L/M*
Cocoa	M	M	H	M	L	L	M	L	L	L
Coffee	M	L	H	M	L	L	M	L	L	L
Date palm	M	L	H	H	L	L	M	L	L	H
Flax	M	M	H	M	L	L	L	L	L	L
Maize	L/M	L	M	L	L	L	M/H	L	L	L/M
Mangolds	H	L	M	L	L	H	L	H	H	M
Oats	M	L	L	L	L	H	L	H	H	L
Oil palm	H	M	H	L	M	L	L	H	M	L
Pear	H	L/M	H	M	L	M	L	M	L	L
Peas	M	M	H	M	L	L	M	M	L	L*
Potatoes	M/H	L	H	L	H	M/H	L	L	H	L
Rice	H	M	L	L	L	H	L	H	H	L/M
Rubber	H	H	L	L	M	H	L	H	M	L
Rye	L	L	L	L	L	L	L/M	H	H	M
Sisal	M	M	L*	M	L	M*	M	H*	M	M
Sugarbeet	H	M	H	M	L	M	L	H	M	M/H
Tapioca	M	M	M	M	L	L	M	M	M	L
Tea	H	L	H	L	H	M	L	L	H	L
Tobacco	M	L	H	M	L	L	M	L	L	L
Wheat	L/M	H	H	H	L	L	M	M/H	L	M

Notes: 1. L = low, M = medium, H = high, * = depending on variety.
2. See also Table F.4.

Sources: McRae and Burnham (1981) after Vink (1975); see also ILACO (1981, p 569).

Source: Landon ed. 1984

Indicative climatic and soil requirements for selected crops

Table 3-18c

Crop	Total growing period (days)	Mean daily temperature for growth (°C) optimum (and range)	Day length requirements for flowering	Specific climatic constraints/requirements 1/	Soil requirements 2/	Sensitivity to salinity 3/
Alfalfa (Medicago sativa)	100-365	24-26 (10-30)	Day neutral	Sensitive to frost; cutting interval related to temperature; requires low RH in warm climates	Deep, medium-textured, well drained: pH 6.5-7.5	Moderately sensitive
Banana (Musa spp)	300-365	25-30 (15-35)	Day neutral	Sensitive to frost; temperature < 8°C for longer periods causes serious damage; requires high RH, wind < 4 $m\ s^{-1}$	Deep, well-drained loam without stagnant water: pH 5-7	Sensitive
Bean (Phaseolus vulgaris)	Fresh: 60-90 Dry: 90-120	15-20 (10-27)	Short day/ day neutral	Sensitive to frost, excessive rain, hot weather	Deep, friable soil, well drained and aerated: optimum pH 5.5-6	Sensitive
Cabbage (Brassica oleracea)	100-150+	15-20 (10-24)	Long day	Short periods of sharp frost (-10°C) are not harmful: optimum RH 60-90%	Well drained: optimum pH 6-6.5	Moderately sensitive
Citrus (Citrus spp)	240-365	23-30 (13-35)	Day neutral	Sensitive to frost (dormant trees less), strong wind, high humidity; cool winter or short dry period preferred	Deep, well aerated, light- to medium-textured soils, free from stagnant water: pH 5-8	Sensitive
Cotton (Gossypium hirsutum)	150-180	20-30 (16-35)	Short day/ day neutral	Sensitive to frost, strong or cold winds; temperature required for boll development: 27-32°C (20-38°C range); dry ripening period required	Deep, medium- to heavy-textured soils: pH 5.5-8 with optimum pH 7-8	Tolerant
Grape (Vitis vinifera)	180-270	20-25 (15-30)		Resistant to frost during dormancy (down to -18°C) but sensitive during growth: long, warm to hot, dry summer and cool winter preferred/required	Well-drained, light soils are preferred	Moderately sensitive
Groundnut (Arachis hypogaea)	90-140	22-28 (18-33)	Day neutral	Sensitive to frost; for germination temperature > 20°C	Well-drained, friable, medium-textured soil with loose topsoil: pH 5.5-7	Moderately sensitive
Maize (Zea mays)	100-140+	24-30 (15-35)	Day neutral/ short day	Sensitive to frost; for germination temperature > 10°C; cool temperature causes problem for ripening	Well-drained and aerated soils with deep water-table and without waterlogging: optimum pH 5-7	Moderately sensitive
Oil palm (Elaeis guineensis)	365	27 (24-30)		Sensitive to frost; requires high RH, > 1 500 mm well-distributed rainfall and > 1 300 h sunshine	Well-drained, aerated soils with good water-holding capacity and unrestricted rooting medium	Moderatoly sensitive
Olive (Olea europaea)	210-300	20-25 (15-35)		Sensitive to frost (dormant trees less); low winter temperature required (< 10°C) for flower bud initiation	Deep, well-drained soils free from waterlogging	Moderately tolerant
Onion (Allium cepa)	100-140 (+30-35 in nursery)	15-20 (10-25)	Long day/ day neutral	Tolerant to frost; low temperature (< 14-16°C) required for flower initiation; no extreme temperature or excessive rain	Medium-textured soil: pH 6-7	Sensitive
Pea (Pisum sativum)	Fresh: 65-100 Dry: 85-120	15-18 (10-23)	Day neutral	Slight frost tolerance when young	Well-drained and aerated soils: pH 5.5-6.5	Sensitive
Pepper (Capsicum spp)	120-150	18-23 (15-27)	Short day/ day neutral	Sensitive to frost	Light- to medium-textured soils: pH 5.5-7	Moderately sensitive
Pineapple (Ananas comosus)	365	22-26 (18-30)	Short day	Sensitive to frost; requires high RH; quality affected by temperature	Sandy loam with low lime content: pH 4.5-6.5	Sensitive
Potato (Solanum tuberosum)	100-150	15-20 (10-25)	Long day/ day neutral	Sensitive to frost; night temperature < 15°C required for good tuber initiation	Well-drained, aerated and porous soils: pH 4.5-6	Moderately sensitive
Rice (paddy) (Oryza sativa)	90-150	22-30 (18-35)	Short day/ day neutral	Sensitive to frost; cool temperature causes head sterility; small difference in day and night temperature is preferred	Heavy soils preferred for percolation losses, high tolerance to O_2 deficit: pH 5.5-6	Moderately sensitive
Rubber (Hevea brasiliensis)	365	28 (26-30)		Sensitive to frost; wide range in temperature unfavourable, strong winds harmful. Pronounced dry season reduces yield	Deep, well aerated, permeable, acid soils. Shallow and peaty soils to be avoided	Very sensitive
Safflower (Carthamus tinctorius)	Spring: 120-160 Autumn: 200-230	Early growth: 15-20 Later growth: 20-30 (10-35)		Tolerance to frost; cool temperature required for good establishment and early growth	Fairly deep, well-drained soils, preferably medium textured: pH 6-8	Moderately tolerant
Sorghum (Sorghum bicolor)	100-140+	24-30 (15-35)	Short day/ day neutral	Sensitive to frost; for germination, temperature > 10°C; cool temperature causes head sterility	Light to medium/heavy soils relatively tolerant to periodic waterlogging: pH 6-8	Moderately tolerant

Source: Landon ed. 1984

Table 3-18c cont.

Crop	Total growing period (days)	Mean daily temperature for growth (°C) optimum (and range)	Day length requirements for flowering	Specific climatic constraints/requirements 1/	Soil requirements 2/	Sensitivity to salinity 3/
Soyabean (Glycine max)	100-130	20-25 (18-30)	Short day/ day neutral	Sensitive to frost; for some varieties temperature > 24°C required for flowering	Wido range of soil except drought susceptible and poorly drained: pH 6-6.5	Moderately tolerant
Sugarbeet (Beta vulgaris)	160-200	18-22 (10-30)	Long day	Tolerant to night frost; towards harvest mean daily temperature < 10°C for high sugar yield	Medium- to slightly heavy-textured soils, friable and well drained: pH 6-7	Tolerant
Sugarcane (Saccharum officinarum)	270-1 200	22-30 (15-35)	Short day	Tolerant of only very light frost; during the harvest period cool (10-20°C), dry, sunny weather is beneficial	Deep, well aerated with ground water deeper than 1.5-2 m but relatively tolerant to periodic high water-tables and/or flooding and O_2 deficit: pH 4.5-8.5; optimum pH 6.5	Moderately sensitivo
Sunflower (Helianthus annuus)	90-130	18-25 (15-30)	Short day/ day neutral	Sensitive to frost	Fairly deep soils: pH 6-7.5	Moderately tolerant
Tobacco (Nicotiana tabacum)	90-120 (+40-60 in nursery)	20-30 (15-35)	Short day/ day neutral	Sensitive to frost	Quality of leaf depends on soil texture: pH 5-6.5	Moderately sensitive
Tomato (Lycopersicon esculentum)	90-120 (> 25-35 in nursery)	18-25 (15-28)	Day neutral	Sensitive to frost, high RH and strong wind; optimum night temperature 10-20°C	Light loam, well drained without waterlogging: pH 5-7	Sensitive
Watermelon (Citrullus vulgaris)	80-110	22-30 (18-35)	Day neutral	Sensitive to frost	Sandy loam is preferred: pH 5.8-7.2	Moderately sensitive
Wheat (Triticum spp)	Spring: 100-130 Winter: 180-250	15-20 (10-25)	Day neutral/ long day	Spring wheat: sensitive to frost; winter wheat: resistant to frost during dormancy (> 15°C), sensitive during post-dormancy period; requires a cold period for flowering during early growth. For both, dry period required for ripening	Medium texture is preferred; relatively tolerant to high water-table: pH 6-7	Moderately sensitive

Notes:
1/ Temperatures quoted are optimal, with ranges in parentheses.
2/ Indicative rooting depths and soil-water tension are given in Table F.8.
3/ See also Tables 7.12, 7.13 and 8.2 to 8.4.

Sources: Adapted from Doorenbos and Kassam (1979); see also ILACO (1981, pp 562ff) and Tables 7.12 and 13, 8.2 to 4. Sugarcane figures amended according to R A Yates (personal communication).

Table 3-18d

Indicative nutrient and water requirements for selected crops — Table F.7

Crop	Nutrient requirements 1/ N : P : K (kg ha^{-1}/growing period)	Ideal water requirements 2/ (mm/growing period)	Sensitivity to water supply (and ky value) 3/	Water utilisation efficiency for harvested yield (Ey) 4/ kg m^{-3} (and % moisture of product)
Alfalfa (Medicago sativa)	0-40: 55-65: 75-100	800-1 600	Low to medium-high (0.7-1.1)	1.5-2.0 Hay (10-15%)
Banana (Musa spp)	200-400: 45-60: 240-480	1 200-2 200	High (1.2-1.35)	Plant crop: 2.5-4 Ratoon: 3.5-5.6 Fruit (70%)
Bean (Phaseolus vulgaris)	20-40: 40-60: 50-120	300-500	Medium-high (1.15)	Fresh: 1.5-2.0 (80-90%) Dry: 0.3-0.6 (10%)
Cabbage (Brassica oleracea)	100-150: 50-65: 100-130	380-500	Medium-low (0.95)	12-20 Head (90-95%)
Citrus (Citrus spp)	100-200: 35-45: 50-160	900-1 200	Low to medium-high (0.8-1.1)	2-5 Fruit (85%, lime: 70%)
Cotton (Gossypium hirsutum)	100-180: 20-60: 50-80	700-1 300	Medium-low (0.85)	0.4-0.6 Seed cotton (10%)
Grape (Vitis vinifera)	100-160: 40-60: 160-230	500-1 200	Medium-low (0.85)	2-4 Fresh fruit (80%)
Groundnut (Arachis hypogaea)	10-20: 15-40: 25-40	500-700	Low (0.7)	0.6-0.8 Unshelled dry nut (15%)
Maize (Zea mays)	100-200: 50-80: 60-100	500-800	High (1.25)	0.8-1.6 Grain (10-13%)
Olive (Olea europaea)	200-250: 55-70: 160-210	600-800 (per year)	Low	1.5-2.0 Fresh fruit (30%)
Onion (Allium cepa)	60-100: 25-45: 45-80	350-550	Medium-high (1.1)	8-10 Bulb (85-90%)
Pea (Pisum sativum)	20-40: 40-60: 80-160	350-500	Medium-high (1.15)	Fresh: 0.5-0.7 Shelled (70-80%) Dry: 0.15-0.2 (12%)
Pepper (Capsicum spp)	100-170: 25-50: 50-100	600-900	Medium-high (1.1)	1.5-3.0 Fresh fruit (90%)
Pineapple (Ananas comosus)	230-300: 45-65: 110-220	700-100	Low	Plant crop: 5-10 Ratoon: 8-12 Fruit (85%)
Potato (Solanum tuberosum)	80-120: 50-80: 125-160	500-700	Medium-high (1.1)	4-7 Fresh tuber (70-75%)

Notes: See page 288.

cont

Source: Landon ed. 1984

Table 3-18d cont.

Crop	Nutrient requirements 1/ N : P : K (kg ha^{-1}/growing period)	Ideal water requirements 2/ (mm/growing period)	Sensitivity to water supply (and ky value) 3/	Water utilisation efficiency for harvested yield (Ey) 4/ kg m^{-3} (and % moisture of product)
Rice (paddy) (Oryza sativa)	100-150: 20-40: 80-120	350-700	High	0.7-1.1 Paddy (15-20%)
Safflower (Carthamus tinctorius)	60-110: 15-30: 25-40	600-1 200	Low (0.8)	0.2-0.5 Seed (8-10%)
Sorghum (Sorghum bicolor)	100-180: 20-45: 35-80	450-650	Medium-low (0.9)	0.6-1.0 Grain (12-15%)
Soyabean (Glycine max)	10-20: 15-30: 25-60	450-700	Medium-low (0.85)	0.4-0.7 Grain (6-10%)
Sugarbeet (Beta vulgaris)	150: 50-70: 100-160	550-750	Low to medium-low (0.7-1.1)	Beet: 6-9 (80-85%) Sugar: 0.9-1.4 (0%)
Sugarcane (Saccharum officinarum)	100-200: 20-90: 125-160	1 500-2 500 (per year)	High (1.2)	Cane: 5-10 (80%) Sugar: 0.6-1.2 (0%)
Sunflower (Helianthus annuus)	50-100: 20-45: 60-125	600-1 000	Medium-low (0.95)	0.3-0.5 Seed (6-10%)
Tobacco (Nicotiana tabacum)	40-80: 30-90: 50-110	400-600	Medium-low (0.9)	0.4-0.6 Cured leaves (5-10%)
Tomato (Lycopersicon esculentum)	100-150: 65-110: 160-240	400-600	Medium-high (1.05)	10-12 Fresh fruit (80-90%)
Watermelon (Citrullus vulgaris)	80-100: 25-60: 35-80	400-600	Medium-high (1.1)	5-8 Fruit (90%)
Wheat (Triticum spp)	100-150: 35-45: 25-50	450-650	Medium-high (Spring: 1.15 winter: 1.0)	0.8-1.0 Grain (12-15%)

Notes:
1/ Rough figures under irrigation; actual values will obviously depend on soil, climate, cultivar etc; also note that:
1 kg P = 2.4 kg P_2O_5
and 1 kg K = 1.2 kg K_2O
2/ Indicative rooting depths and soil-water tensions are given in Table F.8.
3/ ky = yield response factor = ratio of relative yield decrease (1 - actual yield/maximum yield) to relative evapotranspiration deficit (1 - actual ET/maximum ET)
ie ky = (1 - Ya/Ym):(1 - ETa/ETm)
ky of the total growing period: low: ky < 0.85; medium: ky 0.85-1.0; medium-high: ky 1.0-1.15; high: ky > 1.15
4/ Ey = water utilisation efficiency = kg of produce m^{-3} of water supplied.

Source: Adapted from Doorenbos and Kassam (1979); sugarcane figures amended according to R A Yates (personal communication).

Table 3-19

Table 3. Major criteria used in assessing the soil suitability for crops.

Crop Group / Crop	Slope	Effective Soil Depth	Soil Texture Structure	Drainage	Water Release	Salinity mmhos/cm at 25°C	pH	Depth to Acid Sulphate	Thickness of Peat (drained)	Workability
				Soil Criteria						
A. Rubber										
Rubber	0–20°	>125 cm	Exclude LS or coarser	Exclude poorly drained	All Year	<2 mmhos in top 150 cm	4.0–6.0	>150 cm	<50 cm	N.I.*
B. Oil Palm										
Oil Palm	0–16°	>125 cm	Exclude SL or coarser	Some temporarily poorly drained	All year	<2 mmhos in top 150 cm	4.0–6.5	>100 cm	<100 cm	N.I.
C. Sago Palm										
Sago Palm	0–2°	>100 cm	Exclude SL or coarser	Very poorly to poorly only	—	<2 mmhos in top 150 cm	4.0–6.0	>125 cm	<50 cm	N.I.
D. Tapioca										
Tapioca	0–6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3–7.3	>50 cm	No restriction	No restrictions allowed
Sweet Potatoes	0–6°	>50 cm	Exclude clays and poor structures	Exclude poorly drained	All year	<2 mmhos in top 100 cm	4.3–6.0	>50 cm	No restriction	No restrictions allowed
Soyabeans	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly only	Growing season	<4 mmhos in top 50 cm	5.5–6.5	>50 cm	<25 cm	No restrictions allowed
Chilies	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	5.0–6.8	>50 cm	<25 cm	No restrictions allowed
Vegetables	0–6°	>25 cm	Exclude clays and poor structures	Well to imperfectly	Growing season	<4 mmhos in top 50 cm	4.5–6.5	>50 cm	No restriction	No restrictions ellowed
E. Tea										
Lowland Tea	0–20°	>100 cm	Exclude sands, clays	Well to imperfectly	All Year	<2 mmhos in top 150 cm	4.0–6.0	>25 cm	No peat	N.I.
F. Grass										
Grasses (Cut)	0–12°	>25 cm	Exclude LS end coarser	Well to poorly	All year	<4 mmhos in top 50 cm	4.3–7.0	>50 cm	No restriction	No restrictions ellowed
Stylo	0–12°	>25 cm	Exclude sands	Well to poorly	All year	<4 mmhos in top 50 cm	4.3–7.0	>50 cm	Not known	No restrictions allowed
G. Citrus										
Citrus	0–20°	>125 cm	Exclude sands and heavy clays	Well, some imperfectly	All year	<2 mmhos in top 150 cm	5.0–7.0	>150 cm	<50 cm	No stones
Chiku	0–20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
Mangosteen	0–20°	>125 cm	Exclude sands and heavy clays	Well to imperfectly	All year	<2 mmhos in top 150 cm	Not known	>150 cm	<50 cm	No stones
H. Papaya										
Papaya	0–12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	>2 mmhos in top 100 cm	5.0–6.5	<100 cm	No peat	No stones
Pineapple	0–6°	>25 cm	All textures	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–5.5	>50 cm	No restriction	No stones
Passion fruit	0–12°	>50 cm	Exclude sands and heavy clays	Well to imperfectly	All yeer	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<50 cm	No stones
Guava	0–12°	>50 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<100 cm	No stones
Salak	0–12°	>50 cm	Exclude LS or coarser	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	No stones
I. Bananas										
Bananas	0–12°	>125 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	5.0–7.0	>125 cm	<25 cm	No stones
Durian	0–12°	>100 cm	Exclude LS or coarser; firm soils; oxisolic soils	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	No peat	N.I.
Rambutan	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 100 cm	4.5–6.5	>100 cm	<100 cm	No stones
Langast	0–12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.
Duku	0–12°	>100 cm	Exclude clays and sands	Well drained	All year	<2 mmhos in top 100 cm	Not known	>100 cm	No peat	N.I.
Avocado	0–12°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	5.5–6.5	>125 cm	No peat	N.I.
Kundangan	0–12°	>100 cm	Exclude clays	Well drained	All year	<2 mmhos in top 150 cm	Not known	>125 cm	No peat	N.I.
J. Cashew										
Cashew	0–20°	>100 cm	Exclude clays	Well to imperfectly	9 months	<2 mmhos in top 150 cm	4.0–7.3	>150 cm	<100 cm	N.I.
K. Cocoa										
Cocoa	0–12°	>150 cm	Exclude LS or coarser	Well to imperfectly	High all year	<2 mmhos in top 150 cm	5.0–7.5	>150 cm	<50 cm	N.I.
Coffee	0–12°	>125 cm	Exclude sands	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5–6.5	>100 cm	<125 cm	N.I.
L. Coconut										
Coconut	0–6°	>100 cm	Exclude LS or coarser	Well to imperfectly	All year	<2 mmhos in top 150 cm	4.5–7.5	>100 cm	<100 cm	N.I.
M. Maize										
Maize	0–6°	>50 cm	Exclude sands and clays	Well to imperfectly	Good in growing season	<2 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Sorghum	0–6°	>50 cm	Exclude sands	Well to imperfectly	Good in growing season	<4 mmhos in top 50 cm	>5.0	>125 cm	No restriction	No restrictions allowed
Groundnut	0–6°	>25 cm	Exclude sands and clays	Well to moderately well	Good in growing season	<4 mmhos in top 50 cm	5.5–7.0	>50 cm	No peat	No restrictions allowed
N. Rice										
Lowland Rice	0–2°	>25 cm	SCL or finer	Drainage control necessary	Dry during harvest	<4 mmhos in top 25 cm	>4.0	>25 cm	No peat	No restrictions allowed

*N.I.—Not important.

Source: USDA-SMSS 1981

Table 3-20

Table 8

SOIL REQUIREMENTS OF RAINFED CROPS

CROPS	SLOPE (PERCENT)				DRAINAGE		FLOODING		TEXTURE				DEPTH (cm)	
	High Inputs		Low & Int. Inputs		All Inputs		All Inputs		High & Int. Inputs		Low Inputs		All Inputs	
	Optimum	Marginal	Optimum	Marginal	Optimum	Range	Optimum	Marginal	Optimum	Range	Optimum	Range	Optimum	Marginal
Wheat	0 - 8	8 - 16	0 - 8	8 - 24	MW-W	I-SE	F_o	F_1	L-MCs	SL-MCs	L-SC	SL-KC	>50	25 - 50
Barley	0 - 8	8 - 16	0 - 8	8 - 24	MW-W	I-SE	F_o	F_1	L-MCs	SL-MCs	L-Sc	Sl-KC	>50	25 - 50
Pearl millet	0 - 8	8 - 16	0 - 8	8 - 24	MW-SE	I-E	F_o	F_1	L-CL	LS-KC	L-CL	LS-KC	>50	25 - 50
Sorghum	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-C	LS-MCs	L-SC	LS-KC	>50	25 - 50
Maize	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-C	SL-MCs	L-SC	LS-KC	>50	25 - 50
Upland rice	0 - 8	8 - 16	0 - 8	8 - 24	MW-W	I-SE	F_o	F_1	L-C	LS-KC	L-SC	LS-KC	>50	25 - 50
Bunded rice (paddy)	0 - 4	4 - 8	0 - 4	4 - 8	I-MW	VP-W	$F_o-F_1-F_2$	F_3	L-SiCL	SL-MCs	L-SiCL	SL-KC	>100	50 - 100
Cassava	0 - 8	8 - 16	0 - 4	4 - 16	W	MW-SE	F_o	F_1	L-SiCL	SL-KC	L-SiCL	LS-KC	>100	75 - 100
Sweet potato	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-SiCL	SL-C	L-SiCL	LS-KC	>75	50 - 75
White potato	0 - 8	8 - 16	0 - 8	8 - 20	W	MW-SE	F_o	F_1	L-SiCL	LS-MCs	L-SiCL	FS-KC	>75	50 - 75
Yam/cocoyam	0 - 8	8 - 16	0 - 4	4 - 16	W	MW-SE	F_o	F_1	L-SiL	SL-KC	L-SiL	LS-KC	>75	50 - 75
Chickpea	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-SC	SL-MCs	L-SC	MS-KC	>75	50 - 75
Phaseolus bean	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-CL	SL-KC	L-CL	LS-KC	>75	50 - 75
Soybean	0 - 8	8 - 16	0 - 8	8 - 20	MW-W	I-SE	F_o	F_1	L-SC	SL-KC	L-SC	LS-KC	>75	50 - 75
Groundnut	0 - 8	8 - 16	0 - 8	8 - 20	W-SE	MW-E	F_o	F_1	SL-SCL	LS-KC	SL-SCL	MS-KC	>50	20 - 50
Cotton	0 - 8	8 - 16	0 - 8	8 - 20	W	MW-SE	F_o	F_1	L-MCs	SL-MCs	L-SC	SL-KC	>100	75 - 100
Sugar cane	0 - 8	8 - 16	0 - 8	8 - 24	MW-W	P/I-SE	F_o	F_1	L-C	SL-MCs	L-KC	SL-SiC	>75	50 - 75
Banana	0 - 16	16 - 30	0 - 16	16 - 50	MW-W	I-SE	F_o	F_1-F_2	L-C	SL-MCs	L-KC	SL-SiC	>100	50 - 100
Oil palm	0 - 16	16 - 30	0 - 16	16 - 50	MW-W	I-SE	F_o	F_1-F_2	SCL-KC	L-C	L-KC	SL-SiC	>100	50 - 100
Cocoa	0 - 16	16 - 30	0 - 16	16 - 50	W	MW-SE	F_o	F_1	SCL-SC	L-C	L-KC	SL-SiC	>150	75 - 150
Coffee	0 - 8	8 - 16	0 - 8	8 - 30	W	MW-SE	F_o	F_1	L-SC	SL-KC	L-KC	SL-SiC	>150	75 - 150
Rubber	0 - 16	16 - 30	0 - 16	16 - 50	W	MW-SE	F_o	F_1	L-KC	SL-C	L-KC	SL-SiC	>150	75 - 150
Tea	0 - 16	16 - 30	0 - 16	15 - 50	W	MW-SE	F_o	F_1	L-CL	SL-SiC	L-KC	SL-SiC	>150	75 - 150
Citrus	0 - 8	8 - 16	0 - 8	8 - 30	W	MW-SE	F_o	F_1	LS-L	MS- SiCL	L-KC	SL-SiC	>150	75 - 150
Pasture	-	-	0 - 16	16 - 30	W-MW 1/	SE-I 1/	$F_o - F_1$ 1/	F_2			SL-C	FS-MCm	>50	10 - 50

Source: Sys/Riquier 1979

Table 8 (Cont.) SOIL REQUIREMENTS OF RAINFED CROPS

$CaCO_3$ (PERCENT)		GYPSUM (PERCENT)		pH		FERTILITY REQUIREMENT	SALINITY (mmhos)		ALKALINITY	
All Inputs		All Inputs		All Inputs		All Inputs	All Inputs		All Inputs	
Optimum	Marginal	Optimum	Marginal	Optimum	Range		Optimum	Marginal	Optimum	Marginal
0 - 30	30 - 60	0 - 5	5 - 20	6.0-8.2	5.2-8.5	moderate/high	0 - 5	5 - 10	0 - 30	30 - 45
0 - 30	30 - 60	0 - 5	5 - 20	6.0-7.5	5.2-8.5	moderate	0 - 8	8 - 12	0 - 35	35 - 50
0 - 25	25 - 50	0 - 3	3 - 15	5.5-7.5	5.2-8.2	low	0 - 4	4 - 6	0 - 30	30 - 45
0 - 30	30 - 75	0 - 5	5 - 20	5.5-8.2	5.2-8.5	low/moderate	0 - 5	5 - 10	0 - 20	20 - 35
0 - 15	15 - 30	0 - 3	3 - 15	5.5-8.2	5.2-8.2	moderate	0 - 4	4 - 6	0 - 15	15 - 25
0 - 15	15 - 30	0 - 3	3 - 15	5.5-7.5	5.2-8.2	low	0 - 2	2 - 4	0 - 20	20 - 40
0 - 15	15 - 30	0 - 3	3 - 15	5.5-7.5	5.2-8.2	low	0 - 2	2 - 4	0 - 20	20 - 40
0 - 1	1 - 10	0 - 0.5	0.5- 3	5.2-7.0	4.5-8.2	low	0 - 2	2 - 4		
0 - 15	15 - 30	0 - 3	3 - 15	5.2-8.2	4.5-8.5	moderate	0 - 3	3 - 6		
0 - 10	10 - 25	0 - 1	1 - 5	5.5-7.0	5.2-8.2	moderate	0 - 3	3 - 6		
0 - 1	1 - 10	0 - 0.5	0.5- 3	5.5-7.5	5.2-8.2	moderate	0 - 2	2 - 4		
0 - 25	25 - 50	0 - 3	3 - 15	6.0-7.5	5.5-8.2	low/moderate	0 - 3	3 - 6	0 - 8	8 - 15
0 - 20	20 - 35	0 - 0.5	0.5- 3	5.5-7.5	5.2-8.2	moderate	0 - 1	1 - 2	0 - 5	8 - 12
0 - 20	20 - 35	0 - 3	3 - 15	5.5-7.5	5.2-8.2	moderate	0 - 3	3 - 6	0 - 8	8 - 15
0 - 25	25 - 50	0 - 3	3 - 15	6.0-7.5	5.5-8.2	moderate	0 - 3	3 - 6		
0 - 25	25 - 40	0 - 3	3 - 15	6.0-7.5	5.5-8.2	moderate/high	0 - 8	8 - 12	0 - 20	20 - 35
0 - 25	25 - 50	0 - 5	5 - 20	5.5-8.2	4.5-8.5	moderate	0 - 5	5 - 8	0 - 8	8 - 15
0 - 5	5 - 15	0 - 1	1 - 5	5.5-7.5	5.2-8.2	moderate/high	0 - 2	2 - 4	0 - 4	4 - 10
0 - 1	1 - 10	0 - 0.5	0.5- 3	5.0-6.5	3.5-7.5	low/moderate	0 - 2	2 - 4		
0 - 1	1 - 10	0 - 0.5	0.5- 3	6.0-7.0	5.2-8.2	high	0 - 1	1 - 2		
0 - 1	1 - 10	0 - 0.5	0.5- 3	5.3-6.0	4.5-6.5	moderate/high	0 - 1	1 - 2		
0	0 - 1	0	0 - 0.2	5.0-6.0	4.0-6.5	low	0 - 1	1 - 2		
0	0 - 1	0	0 - 0.2	4.5-5.5	3.0-6.0	low	0 - 1	1 - 2		
0 - 10	10 - 25	0 - 1	1 - 5	5.5-7.0	5.2-8.2	moderate/high	0 - 4	4 - 8	0 - 4	4 - 10
0 - 30	30 - 50	0 - 5	5 - 25	5.5-8.5	4.5-9.5	moderate/low	0 - 16	16 - 25	0 - 35	35 - 50

Drainage classes

VP = very poor
P = poorly drained
I = imperfectly drained
MW = moderately well drained
W = well drained
SE = somewhat excessively drained
E = excessively drained

Textural sequence

MCm = montmorillonitic clay, massive
MCs = montmorrillonitic clay, structured
C = clay (mixed unspecified)
SiC = silty clay
KC = kaolinitic clay
SC = sandy clay
SiCL = silty clay loam
CL = clay loam
SiL = silt loam
SCL = sandy clay loam
L = loam
SL = sandy loam
LS = loamy sand
FS = fine sand
MS = medium sand
CS = coarse sand

Grassland

1/ Grazing in dry season

Table 44 GROWTH LIMITING CONDITIONS FOR RICE ON SUBMERGED SOILS OF VARIOUS TYPES

KIND OF SOIL AND MAIN LIMITATIONS	OTHER GROWTH LIMITING CONDITIONS
Saline soils	
Arid saline soils	Alkalinity, Zn deficiency, N & P deficiencies
Acid coastal saline soils	Iron toxicity, P deficiency, deep water
Neutral and alkaline coastal and saline soils	Zn deficiency, deep water
Deltaic and estuarine acid sulphate soils	Iron toxicity, P deficiency, deep water
Coastal histosols	Nutrient deficiencies, H_2S toxicity, toxicity of organic substances, deep water, Fe toxicity
Acid sulphate soils	
Coastal soils	Salinity, Fe toxicity, N & P deficiencies, deep water
Old inland soils	N & P deficiencies
Histosols	Fe toxicity, H_2S toxicity, nutrient deficiencies, deep water, salinity
Iron-toxic soils	
Acid sulphate soils	Salinity, N & P deficiencies, deep water
Acid oxisols and ultisols	P deficiency, low base status, low Si content
Histosols	H_2S toxicity, toxicity of organic substances, macro-nutrient deficiencies, Zn and Cu deficiencies, deep water
Phosphorus deficiency in wetland rice	
Acid sulphate soils	Strong acidity, iron toxicity, low nutrient status, base deficiency, salinity
Acid oxisols and ultisols	Iron toxicity, base deficiency
Vertisols	Zinc deficiency, iron deficiency, salinity, alkalinity
Zinc deficient soils	
Saline-sodic and sodic soils	Salinity, N & P and Fe deficiencies
Vertisols	P and Fe deficiencies, salinity, alkalinity
Calcareous soils	K deficiency
Wet soils	Cu deficiency
Histosols	N, P, K, Si, Cu, deficiencies; H_2S toxicity, deep water

Source: after Ponnamperuma 1976.

Source: FAO SB 55 1985

Table 3-22a

Table 48 FEATURES OF IRRIGATION APPLICATION TECHNIQUES FOR EVALUATING CHOICE OF SYSTEM AND SUITABILITY OF LAND
A. SURFACE APPLICATION TECHNIQUES (page 1)

FEATURE	SMALL BASINS	(MEDIUM) 1/ LARGE BASINS	BORDER STRIPS	SHORT FURROWS	(MEDIUM) 1/ LONG FURROWS
1. Land development costs	Low	Often high, precision grading required	Low to medium depending on topography	Low	Often high, precision grading required
2. Capital intensity (field equipment)	Low	Low	Low	Low	Low
3. Labour intensity	High	Low	Medium	High	Low
4. Energy intensity	Low (gravity) High (pumped)	Low (gravity) High (pumped)	Low (gravity) High (pumped)	Low (gravity) High (pumped)	Low (gravity) High (pumped)
5. Size and shape of fields	Very flexible, often small and irregular	Large and regular shaped fields required	Long, rectangular, can be narrow	Very flexible, often small and irregular	Medium to large, regular shape
6. Topography	Important but generally not critical	Often critical if graded or level basin	Suitable slope and absence of cross slopes	Important but generally not critical	Often critical both for graded and dead level furrows
7. Soils	Intake rates often critical for efficient use of water and uniformity of application; influences size of basins, lengths of furrows or border strips in relation to the rate of water delivery, slope and uniformity of microrelief.				
8. Management skills	Suitable for small farmers in LDCs	Sophisticated management required	Suitable for middle level management	Suitable for small farmers in LDCs	Sophisticated management required
9. Cropping limitations and mechanization	Wide range of crops, but not mechanized	Suitable field crops planted on the flat or ridges and mechanized	Suitable field crops planted on the flat and mechanized	Wide range of crops, but not mechanized	Row crops, not those planted on the flat; mechanized
10. Scheduling by frequency, rate and duration of the water supply	Continuous (rice); Intermittent, generally fixed by water agency; often 10-30 l/s, limited, fixed duration	Usually intermittent, by arrangement or fixed by water agency; high delivery rates, short duration possible	Intermittent, by arrangement or fixed by water agency; rate must be matched by labour, cutbacks to flow important	Intermittent, by arrangement or fixed by water agency; often 10-30 l/s, limited, fixed duration	Intermittent, by arrangement or fixed by water agency; delivery rate must match labour, cutbacks to flow important
11. Factors affecting uniformity of application	Topography, soils management, size and shape of fields, water supply, labour skills	Levelling and grading of land, soils, management, size and slope of basin, in-field variability	Uniformity of grade, absence of cross slope, rate and duration, cut-back stream size, labour skills	Topography, soils, management, size and shape of fields, water supply, labour skills	Uniformity of grade or level, rate and duration, cutbacks to stream flow, or use of return flows, variability
12. Mechanical problems	None	None	None	None	None
13. Security problems	None	None	None	None	None
14. Leaching and salts problems	Salty patches on underwatered high spots	No special problems	No special problems	Salt accumulation on ridges, salty patches on high spots	Salt accumulation on ridges, otherwise no special problems
15. Location	If water in short supply distance from source is important	Usually adequately serviced	No special problems	If water in short supply distance from source is important	No special problems
16. Field water use efficiencies	Inherently low on permeable soil; minimum application is 50 mm per irrigation	Can be very high in very accurately levelled basins	Very dependent on the water control, cross slope, can be high and low	Inherently low on permeable soil; minimum application is 50 mm per irrigation	Very dependent on the water control, rate, duration, slope, high or low
17. Main problems generally encountered	Poor uniformity of application, overwatering, land wasted in bunds and channels	Very high land levelling costs. Exposure of subsoils	Poor uniformity of application, erosion, crop damage	Poor uniformity of application, overwatering, land wasted in channels	Poor uniformity of application, excessive run-off, erosion
18. General remarks	Easily administered water schedules, at expense of efficient water use. Good for third world farmers	Suitable for large mechanized units where labour is costly and energy/water use efficiency is important	Suitable for medium sized farms not growing row crops, especially for forage	Easily administered water schedules at expense of efficient water use Good for third world farmers	Suitable for large mechanized units where labour is skilled

1/ This indicates that there are intermediate conditions to be considered.

Source: FAO SB 55 1985

Table 3-22b

Table 48 FEATURES OF IRRIGATION APPLICATION TECHNIQUES FOR EVALUATING CHOICE OF SYSTEM AND SUITABILITY OF LAND
B. SPRINKLER AND LOCALIZED IRRIGATION TECHNIQUES (page 1)

	SPRINKLERS: LOW OUTPUT	SPRINKLERS: MEDIUM 1/ HIGH OUTPUT	MINI-SPRINKLERS	ORIFICE AND LONG PATHWAY EMITTERS (ON-LINE OR IN-LINE)	BIWALL TUBING
1. Land development costs	Low or nil	Low or nil	Low or nil	Low or nil	Low or nil
2. Capital intensity (field equipment)	High	High	High	High	High
3. Labour intensity	Hand move systems, high labour need, mechanized and mobile systems low.		High need for labour in laying and removing tubing, low labour need during period of irrigation and/or automatic control of water supply		High labour for installation, low for operating, often ploughed in
4. Energy intensity	Medium-high water pressures required	Medium to very high pressures	Low pressures (losses on filtration)	Low pressures (no advantage if pressure for filtration is high)	Low pressures but losses over filters
5. Size and shape of fields	Not suitable for very small fields. Hand move systems are flexible; and mobile, mechanized systems inflexible requiring large, regular shaped fields.		Very adaptable; limited length of laterals	Very adaptable; limited length of laterals	Very adaptable; Limited length of laterals
6. Topography	Not suitable for very steep land. Some limitations for mobile and mechanized systems but less so than for surface irrigation systems		Very adaptable	Very adaptable	Very adaptable
7. Soils	Suitable for soils with high intake rates. Sometimes problems with low intake soils. Problems with high rate of application, mobile systems and rainguns		No intake problems. Some lateral water spreading	No intake problems. Lateral spread is limited especially on sandy soils	No intake problems. Lateral spread is limited especially on sandy soils
8. Management skills	Not suitable for farmers in the third world who cannot get spares or manage the operation effectively		Intermediate level of management but fairly simple	Sophisticated management to prevent malfunction	Sophisticated management to prevent malfunction
9. Cropping limitations and mechanization	Apart from some tall crops and rice no problems. Highly mechanized wheel mounted laterals, centre pivots, cable systems, or permanent systems reduce labour requirements		Better for tree crops and widely spaced row crops; automated control possible	Intensive high value crops; unsuited for seedbed irrigation, reel-in systems, automation	Wide row crops, can be subsurface (e.g. sugarcane), mechanized laying
10. Scheduling by frequency, rate or duration of the water supply	Usually on demand. Intervals are days or weeks, medium to high rates, 3-15 mm per hour	Usually on demand. Intervals are days or weeks, medium to high rates, 3-15 mm per hour	Usually on demand. 1-3 day intervals. Low-medium rate, medium-long duration	Usually on demand. 1-3 day intervals or continuous. Low rate, long duration	Usually on demand. 1-3 day intervals or continuous. Low rate, long duration
11. Factors affecting uniformity of application	Wind is the major problem of hand-mover sprinkler systems. Drop in pressures along lines, distances of throw and spacing between sprinklers		Not uniform when used as localized irrigation; pressure regulators can be used to improve uniformity	Not uniform when used as localized irrigation, variation along laterals is a design factor	Not uniform when used as localized irrigation, variation along laterals is a design factor
12. Mechanical problems	Moving parts wear, nozzles may block, some filtration and servicing needs		Nozzle blockages	Filtration critical aspect to stop clogging; a major limitation	
13. Security problems	Not vandal proof; pipe and metal fittings must be removed from field at night in some countries		Not very vulnerable to damage or theft. Needs attention	Not particularly vulnerable and equipment can be left operating in field for long periods unattended	
14. Leaching and salt problems	Under-watering can be a problem on very impermeable soils; uniformity problems; scorch on wetted leaves especially important e.g. citrus		No special problem. Low level avoids leaf scorch in tree crops	The major advantage is better yields with salty water due to the soil never drying out, frequent irrigations. Salt encrustations on soil surface	
15. Location	Distance and elevation major cost factors in pressure head losses and requirements		Intermediate costs for pressurizing	Long duration irrigation results in smaller head losses but note pressure head loss across filters	
16. Field water use efficiency	Much affected by wind and distribution uniformity, can be high or low		Very high	Very high	Very high
17. Main problems generally encountered	Costly equipment, high pumping costs, operational difficulties, hand move problems on wetted land, application rates too high with moving systems, wind drift and uneven application		Excessive lengths of piping, especially for closely spaced crops. High labour for unblocking nozzles	Clogging, installation and removing long lengths of tubing. Weeding. High cost. No use for seedbeds	Clogging, installation, no use for seedbed irrigation and therefore may need sprinklers as well
18. General remarks	Suitable for high intake soils and uneven topography for a wide range of crops and extensive farming or intensive systems		Low pressure requirements suitable for small to medium-scale farmers	Better yields and water use efficiency justifies high capital costs on unintensive farms	Better yields and water use efficiency can justify high capital costs

Source: FAO SB 55 1985

Table 3-22 c1

TABLE 16. Qualification of the grades in land use types qualities

Characteristics	Grade		
	High	Fair	Low
1. Soil nutrients availability	1	2	3
2. Soil water availability	1	2	3
3. Soil oxygen availability	1	2	3
4. Salts and/or sodium presence in soil	3	2	1
5. Soil salinization and/or sodization risk	3	2	1
6. Soil surface crusting risk	3	2	1

Table 15. Qualification of the grades of irrigation management qualities

Characteristics	Grade			
	High	Fair	Low	Very Low
1. Availability and water qualities for irrigation	1	2	3	4
2. Soil topography	1	2	3	4
3. Soil compaction risks	4	3	2	1
4. Drainage possibilities	1	2	3	4
5. Salts and/or sodium management in soil	4	3	2	1
6. In depth water losses risk	4	3	2	1
7. Flooding and/or puddling risk	4	3	2	1
8. Possibility of applying mechanization practices	1	2	3	4

Source: in ICID 1989

C.32

Table 3-22 c2

TABLE 9. Characteristics which define "Soil nutrients availability"

Characteristics	Grade		
	High	Fair	Low
1. Fertility	Very high to high	Moderate	Low to very low
2. (Ca+Mg)/K	< 40	40 - 150	>150
3. Ca/Mg	2 - 4	1 - 2 or	< 1 or
Relation		4 - 10	> 10

TABLE 10. Characteristics which define "Soil water availability"

Characteristics	Grade		
	High	Fair	Low
1. Availability water (cm/m of soil)	> 15.1	15 - 5.1	< 5
2. Infiltration Family	Fair	High	Low
Basic Infiltration (mm/h)	37.5 - 12.5	> 37.5	< 12.5
3. Hydraulic conductivity (cm/h)	< 1.5	7.6 - 2.5	> 7.6
4. Water table level in the irrigation time (cm)			
If:			
- Moderate texture soils	80 - 120	120 - 150	> 150
- Coarse and clayey texture soils	100 - 60	100 - 120	> 120
- Sodium or salts soils	40 - 60	80 - 100	> 100

TABLE 11. Characteristics which define "Soil Oxygen availability"

Characteristics	Grade		
	High	Fair	Low
1. Natural drainage	Excessively to well	Well to moderately	Somewhat poorly or less
2. Color soil	Reds, yellows, fort yellow whites	Values more than 1	Gray, values less than 1 or mottles
3. Air porosity in 30cm first in depth	> 120	10 - 20	< 10
4. Water table level (cm)	More depth than 120 all year	60 - 120 some time in year	Less than 60 some time in year
5. Unpermeability layer position (cm)	> 300	300 - 150	< 150
6. Flooding or puddling risk	< 1 in 5 years	1 in 3 years	1 in a year

TABLE 12. Characteristics which define "Soil salinization and/or sodization risk"

Characteristics	Depth (cm) in which there are salts and/or sodium			
	Suitability Grade			
	High	Fair	Low	Very Low
1. Salts (dS/m)				
> 16	< 25	25 - 50	50 - 100	> 100
16 - 8		< 25	25 - 50	> 50
8 - 4			< 25	> 25
4 - 2				< 25
< 2	There isn't limitation			
2. Sodium E.S.P. (%)				
> 50	< 25	25 - 50	50 -100	> 100
50 - 15		< 25	25 - 50	> 50
15 - 7			< 25	> 25
< 7	There isn't limitation			

TABLE 13. Characteristics which define "Soil salinization and/or sodization risk"

Characteristics	Grade		
	High	Fair	Low
1. Soil			
a) Basic Infiltration (cm/h)	< 5	5 - 12.5	> 12.5
b) Hydraulic conductivity (m/day)	< 0.5	0.5 - 3	> 3
2. Water Table depth (cm)			
a) If normal water:			
- Fine or coarse textures	< 60	60 - 90	> 90
- Medial textures	< 100	100 - 150	> 150
b) If water quality isn't normal:			
- Fine or coarse textures	< 120	120 - 150	> 150
- Medial textures	< 150	150 - 200	> 200
3. Drenability			
Layer between 50 - 100 cm			
a) CE (ds/m)	> 4	4 - 2	< 2
b) ESP (%)	> 15	15 - 8	< 8
4. Water irrigation quality (USDA System)			
Salinization risk	C_4 and C_3	C_2	C_1
Sodization risk	S_4 and S_3	S_2	S_1
6. Effective precipitation > Evapo-transpiration (month/year)	< 2	2 - 6	> 6

TABLE 14. Characteristics which define "Soil surface crusting risk"

Characteristics	Grade		
	High	Fair	Low
IF: % Organic Matter is more than 3% and surface layer have:			
(1) Texture*	CL.SC.SL.S	SCL. C	Sa.LS.SaL.L
(2) Silt % if pH>7	> 30		
(3) Clays kind	Montmorillonite	Kaolinate	Mice
(4) % Carbonate as $CaCO_3$	> 18		
(5) ESP %	> 40	40 - 15	< 15
IF: % Organic Matter is less than 3% and surface layer is:			
(1) Texture*	SCL.SC.CL.SL	SaL.L.C	Sa.Ls
(2) Silt %	> 30		
(3) Clays kind	Montmorillonite	Kaolinate	Mice
(4) % Carbonate as $CaCO_3$	> 25	25 - 18	< 18
(5) ESP %	> 15	15 - 8	< 8

* CL = Clay loam. SC = Silty clay. SL = Silt loam. S = Silt. SCL = Silty clay loam. C = clayly. Sa = Sand. Ls = Loamy sand. SaL = Sand loamy. L = Loam

TABLE 17. Irrigation System Requirements in Quality Terms

Irrigation System	Availability and water qualities for irrigation				Soil Topography				Soil Compaction risk				Drainage Possibilities			
Suitability grade	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
1. Basin listing	1	2	2	3	3	4	4	4	2	3	4	4	1	2	3	4
2. Basin Irrigation	1	1	2	3	2	3	3	4	2	2	3	3	2	3	4	4
3. Border	1	1	2	3	1	1	2	3	1	1	2	3	1	2	3	4
4. Contour border																
- wide interval dikes	1	1	2	3	2	2	3	4	1	1	2	3	1	2	3	4
- short interval dikes	1	2	3	4	1	2	3	4	1	2	3	3	1	2	3	4
5. Pool	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
6. Corrugation	1	2	3	4	2	2	3	3	1	1	2	3	1	2	3	4
7. Furrows	1	2	3	4	2	2	3	3	1	2	3	4	1	2	3	4
8. Contour furrows	2	2	3	3	2	2	3	4	2	3	4	5	1	2	3	4
9. Sprinkler Irrigation	2	3	3	4	3	4	5	5	2	3	3	4	2	3	4	5
10. Drip Irrigation	3	4	4	4	5	5	5	5	5	5	5	4	3	4	5	5

Irrigation System	Salts and/or sodium management in soil				In-depth water losses risk				Flooding and/or puddling risk				Possibility of applying mechanization			
Suitability grade	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4	A_1	A_2	A_3	A_4
1. Basin listing	1	2	2	3	2	2	3	4	2	3	3	4	2	3	3	4
2. Basin Irrigation	2	3	3	4	1	1	2	3	2	3	3	4	1	2	3	4
3. Border	1	2	2	3	1	2	3	4	2	2	3	4	1	1	2	3
4. Contour border																
- wide interval dikes	1	2	2	3	1	1	2	3	2	2	3	4	1	1	2	3
- short interval dikes	1	2	2	3	1	1	2	3	2	2	3	4	1	1	2	3
5. Pool	1	2	3	4	2	2	3	4	1	2	3	4	1	1	2	3
6. Corrugation	1	2	2	3	1	2	3	4	1	2	3	4	1	1	2	3
7. Furrows	1	1	2	3	1	2	3	4	1	2	3	4	1	1	2	3
8. Contour furrows	1	1	2	3	2	2	3	4	1	2	3	4	2	3	4	4
9. Sprinkler Irrigation	3	3	4	4	2	3	3	4	1	1	2	3	2	3	4	5
10. Drip Irrigation	4	5	5	5	4	5	5	5	1	2	3	4	5	5	5	5

Source: in ICID 1989:321

Table 3-23

Table 1

LAND EVALUATION CRITERIA FOR TECHNICAL SELECTION OF SPRINKLER IRRIGATION SYSTEMS

LAND CONDITIONS	Type of aspersion 1/			Type of sprinkler (and pressure)			Type of system				Type of cooperative distribution system	
	High rain intensity	Medium rain intensity	Low rain intensity	Long range 2/	Medium range	Short range	Fixed	Stationary	Semifixed mobile	Mechanized	By "shifts"	Without shifts
SOIL												
- sticky, clayey	-	-	xx	-	-	xxx	x	x	x	-	-	xx
- gravelly, sandy	x	x	-	x	x	-	xx	x	-	-	xx	-
- medium texture	x	xx	-	x	x	-	x	x	x	x	x	x
TOPOGRAPHY												
- sloping terrain	-	x	xx	x	xx	x	x	x	x	-	x	x
- flat terrain	x	x	-	x	x	x	x	x	x	xxx	x	x
CROPS												
- corn	xx	x	-	xx	x	-	-	xx	x	x	-	xx
- alfalfa	x	x	-	x	xx	-	-	7	xx	x	-	xx
- orchards or vineyards	-	x	xx	-	x	xx	xx	x	x	-	-	xx
- citrus grove	xx	xx	x	-	-	xxx	xx	x	-	-	x	x
- vegetables	-	x	xx	-	x	xx	x	xx	-	-	x	xx
PROPERTY HOLDINGS												
- small farms (and small fields)	x	x	x	-	x	x	x	xx	xx	-	-	xxx
- medium size farms	x	x	x	x	x	x	x	xx	x	xx	x	xx
- large farms (and large fields)	x	x	x	xx	x	-	x	x	xx	xxx	xx	x
CLIMATE												
- windy	xx	x	-	-	-	xxx	xx	xx	-	x	x	x
- humid or subhumid	x	x	x	x	x	-	-	x	xx	xx	-	xxx
- arid	xx	x	-	-	x	xx	xx	xx	-	x	xx	x

NOTES: 1/ high intensity 12 mm/hr; medium intensity 6-12 mm/h; low intensity 6 mm/h.
2/ jet length: long range 40 m (4-10 atm); medium range 25-40 m (2,5-4 atm); short range 25 m (2.5 atm).

Source: FAO. WSSR 50. 1979

Table 3-24

Table 1: Natural metal contents of important parent materials of soil*) (X = order of magnitude)

	Cd	Mn	Ni	Co	Zn	Cu	Cr	Pb	Hg	Fe	Al
	mg/kg									mg/g	
Ultrabasic rocks	0.X	1600	2000	150	50	10	1600	1	0.0X	90	20
Basalt	0.2	1500	130	50	100	90	170	6	0.09	90	80
Granite, rich in Ca	0.1	500	15	7	60	30	20	15	0.08	30	80
Granite, poor in Ca	0.1	400	5	1	40	10	4	20	0.08	15	70
Syenite	0.1	900	5	1	130	5	2	10	0.0X	40	90
Shale	0.3	900	70	20	100	50	90	20	0.4	50	80
Sandstone	0.0X	X0	2	0.3	15	X	30	7	0.03	10	25
Limestone	0.04	1000	20	0.1	20	4	10	10	0.04	4	4
Loess			10	10	40	10		30		20	50
Marl	0.2	400			50	20		30		20	30
Flurvoglacial sand	0.1							10		1—2	6

*) TUREKIAN, K.K. and WEDEPOHL, K.H., 1961: Distribution of the elements in some major units of the earth's crust: The Geological Society of America, Bulletin vol. 72, 175—192: with supplements by BLUME and FLEIGE

Table 3: Relative binding strength1) for metal ions depending on soil constituents for a given pH limit

Metal	pH limit	sustrate-dependent binding strength below threshold pH2) through: humus	clay	sesquioxides3)
Cd	6	4	2	3
Mn	5.5	2	3	3
Ni	5.5	3—4	2	3
Co	5.5	3	2	3
Zn	5.5	2	3	3
Al	5.5	5	4	4
Cu	4.5	5	3	4
Cr(III)	4.5	5	4	5
Pb	4	5	4	5
Hg	4	5	4	5
Fe(III)	3.5	5	5	

1) rating: 1 = very weak, 2 = weak, 3 = medium, 4 = strong, 5 = very strong
2) Above threshold pH considerable accumulation through formation of oxides (Al, Fe, Mn) and binding of hydrocomplexes (others)
3) Sesquioxides = Fe-, Al- and Mn-oxides

Table 2: Metal contents frequently occurring in soils as well as legal threshold values for sewage sludge application (after German sewage sludge decree)

Metal		total content in air-dry soil (mg/kg): normal values	threshold values1)
Cd	cadmium	0.01 — 0.7	3
Mn	manganese	20 — 3000	
Ni	nickel	2 — 50	50
Co	cobalt	1 — 10	25[1]
Zn	zinc	3 — 100	300
Al	aluminium	5000 — 10^5	
Cu	copper	1 — 40	100
Pb	lead	0.1 — 20	100
Cr	chrome	2 — 50	100
Hg	mercury	0.01 — 0.5	2
Fe	iron	10^3 — $5 \cdot 10^4$	

1) Swiss sewage sludge decree

Table 4: Influence of soil acidity on the relative binding strength for metals (FSM) in sandy soils (texture class S, Su2) with low humus content (<2%)

Metal	Relative binding strength FSM for pH ($CaCl_2$) values of: 2.5	3	3.5	4	4.5	5	5.5	6	6.5	7—8
Cd	0	0—1	1	1—2	2	3	3—4	4	4—5	5
Mn	0	1	1—2	2	3	3—4	4	4—5	5	5
Ni	0	1	1—2	2	3	3—4	4	4—5	5	5
Co	0	1	1—2	2	3	3—4	4	4—5	5	5
Zn	0	1	1—2	2	3	3—4	4	4—5	5	5
Al	1	1—2	2	3	4	4—5	5	5	5	5
Cu	1	1—2	2	3	4	4—5	5	5	5	5
Cr (III)	1	1—2	2	3	4	4—5	5	5	5	5
Pb	1	2	3	4	5	5	5	5	5	5
Hg	1	2	3	4	5	5	5	5	5	5
Fe (III)	1—2	2—3	3—4	5	5	5	5	5	5	5

Evaluation of FSM: 0 = none, 1 = very weak, 2 = weak, 3 = medium, 4 = strong, 5 = very strong

Table 5: Additions to take the ratings of Table 4 for metal binding in relation to differences in humus content (mean of the upper 30 cm)

Humus-range h1)	Humus-content %	binding strength of humus acc. Table 3: 2	3	3—4	4	5
1—2	< 2	0	0	0	0	0
3—4	2— 8	0	0—1	0—1	0—1	1
5	8—15	0—1	0—1	1	1	1—2
6	> 15	0—1	1	1	1—2	2

1) according to Water Management Standards No. 115

Table 6: Additions to the ratings of Table 4 for metal binding (FMSo) in relation to differences in the clay content or texture (mean of upper 30 cm)1)

Clay content %	German texture class	US-Soil Taxonomy2)	binding strength of clay according to Table 3: 2	3	4	5
<5(8)	S, Su2	sand	0	0	0	0
5—15(17)	St2, Sl2, Sl3, Su, Us, U	loamy s., s. loam1), silt loam1), s. clay loam, loam	0	0	0—1	0—1
17—25	Sl4, Ul, Uls, Ls, Lu, St3, Ts4	s. loam2), silt loam2)	0	0—1	0—1	1
25—45	T1, Ts2, 3, Tu, Lts, Lt	s. clay, clay loam, silty clay (loam)	0	0—1	1	1—2
>45	T	clay	0	1	1—2	2

1) For 25 weight % gravel or stones, each addition is to be reduced by 0.5
2) s. = sandly, 1 = 10% clay, 2 = > 10% clay

Source: Blume ed. 1992

Table 3-24 cont.

Table 7: Additions to the ratings of Table 4 for metal binding (FMSo) in relation to elevated iron oxides

Sesquioxide influence acc. Table 3	Influence of higher iron-oxide content on FSM at Hue ≦7.5 YR and Chroman: value 0—1	1—1.5	>1.5
3	0	0—1	1
4	0	1	1—2
5	0	1—2	2

Table 8: Additions to the ratings of Table 4 for metal binding in order to take into account the humus content and texture of the subsoil (at least 30 cm thick) layer

Subsoil property	addition
h 3—6 or >2 % humus	up to 1
>17 % clay	up to 1

Table 9: Influence of the climatic water balance (infiltration rate) and metal binding on metal retention in soils (FSMt)1)

Climatic water balance2): Symbol (class)	mm/year	Binding strength FSMt according to Tables 4—8: 0	1	2	3	4	5
1	0—100	0—1	2	3—4	4—5	5	5
2	100—200	0	1—2	3	4	4—5	5
3—4	200—400	0	1—2	2—3	3—4	4—5	5
5—6	>400	0	1	2	3	4	5

1) FSMt scale:
0 = none, 3 = medium,
1 = very weak, 4 = high,
2 = low, 5 = very high
2) Climatic water balance as the difference of annual precipitation and evaporation (DVWK Water Management Standards No. 116)

Table 10: Influence of metal retention in the groundwater free soil (FSMt) after Table 9, and of the mean groundwater table (groundwater scale in line with DVWK Water Management Standards No. 115, Table 6) on the risk of groundwater pollution FSMw1)

FSMt	groundwater scales (class): 1 <0.2	2 −0.4	3 −0.8	4 −1.3	5 −1.6	6 −2	>2 2)
0—1	5	5	5	5	5	5	5—4
2	5	5	4	4	4	4	3
3	5	5	4	3	3	3	2
4	5	5	4	3	3	2	1
5	5	5	3	2	2	1	1

1) FSMw scale:
1 = very low, 4 = high,
2 = low, 5 = very high
3 = medium,
2) mean groundwater table in m below surface

5.2 Soil unit : Gleysol from debris marl under a meadow near Ravensbruck (Upper Swabia), climatic water balance 4 (+350 mm/a)

Ah (0—30 cm): Lt, very dark brown (7.5 YR 2.5/4), strongly humus (h4), pH 5.1

Go (30—50 cm): Ls, reddish brown (5 YR 4/6), poor in humus (h1), ph 5.1

Gr (below 100cm): Ls, green-grey (5 BG 6/1)

Groundwater scale Gw 3 (mean groundwater level 38 cm)

Diagnosis of immobilization of heavy metals in topsoil:

	Cd	Zn	Cu
Influence of pH (Table 4)	3	4	5
Influence of humus (Tables 3 and 5)	+1	0	+1
Influence of texture (Tables 3 and 6)	0	+1	+1
Fe-oxide influence (Tables 3 and 7)	+1	+1	+1
Deduction for temporary waterlogging	−1	−1	−1
Binding strength FSMo	4	5	5
Evaluation	high	- very high -	

Diagnosis of groundwater pollution risk:

	Cd	Zn	Cu
Influence of pH (Table 4)	3	4	5
Influence of humus (Tables 3, 5 and 8)	+1	0	+1
Influence of texture (Tables 3, 6 and 8)	0	+1	+1
Fe-oxide influence (Tables 3 and 7)	+1	+1	+1
Deduction for temporary water logging	−1	−1	−1
Binding strength in total soil FSMt	4	5	5
Influence of the climate 350 mm and the binding strength (Table 9)	4	5	5
Groundwater pollution risk (Table 10)	4	3	3
Evaluation	high	- medium -	

Table 11: Recommended measures depending on the binding strength FSMo and groundwater risk scale FSMw of a soil with regard to heavy metals

Binding strength FSMo	Risk to ground water FSMw	Recommended measures	heavy metal measures scale
1 very weak	5 very high	Discharge of any type of waste products is prohibited. Where the presence of former contaminated sites is suspected, immediate investigation of the heavy metal load is requested. For former contamination, the binding strength of the soil is to be increaaed and the pH value in the aoil and displacement of the heavy metals is to be controlled annually.	5
2 weak	4 high	Discharge of wastes is prohibited if there is suspicion even of low heavy metal load. Where the presence of former contamination or potential contamination from the environment is suspected, the heavy metal contamination must be investigated immediately. Provided there is a heavy metal contamination the binding capacity of the soil must be increased and the pH values in the soil controlled annually. Control is required also in case of heavy metal displacements in the soil profile if pH values decrease, otherwise at least every three years.	4
3 medium	3 medium	Avoid, if possible, the discharge of waste products even if occasionally with low heavy metal content. At any rate investigation of previous pollution. In the case of discharge or where former contamination is present, control of the pH values in the soil every 3 years. Control of heavy metal displacement in the profile where pH values decrease, otherwise at least every 6 years.	3
4 strong	2 low	Discharge of waste pursuant to valid legal provisions possible after investigation of other previous load. In the case of discharge or the presence of former contaminated sites, control of pH values in soil every five years, control of heavy metal displacement in the case of falling pH values, otherwise every 10 years.	2
5 very strong	1 very low	In case of discharge measures must be taken as under 2. In case of discharge or former contaminations, control of pH values in the soil every 7 years, control of heavy metal displacement in soil profile in the case of falling pH values otherwise every 10 years.	1

Source: DVWK 1991

Tab. 2.7.5/2: Eigenschaften organischer Biozide und Verhalten in Böden bei praxisüblicher Dosis und günstigen Abbaubedingungen bei 11 – 16 °C in lockeren, lehmigen Ackerböden (pH 5.5 – 6.5, 2 – 4 % Humus) (n. HELLING u.a. 1971, HAMAKER 1972, PESTEMER 1975/77, KENAGA 1980, Anonym 1982 u. 1990, OTTOW 1982, BAIER u.a. 1985; K. DOMSCH u. H. NORDMEYER, freundl.mündl.Mittlg.)

Bewertungsstufen: 0 praktisch nicht; 1 sehr gering, sehr schwach; 2 gering, schwach; 3 mittel bis erhöht; 4 hoch, stark; 5 sehr hoch, sehr stark; ( ) Unsichere Angaben

Löslichkeitsstufen (mg/l H_2O bei 20 °C): 1 < 1; 2 1 – 50; 3 50 – 500; 4 > 500

Bindungsstufen: Sorptionskoeffizient nach FREUNDLICH von Humus bzw. Ton:
k_{oc}: 1 1 – 100; 2 100 – 300; 3 300 – 1 000; 4 1 000 – 10 000; 5 > 10 000
k_{Ton}: 1 0.5 – 50; 2 50 – 150; 3 150 – 500; 4 500 – 5 000; 5 > 5 000
pH-Einfluß: Bindung steigt mit zu- (+) oder abnehmendem (–) pH; 0 ohne Einfluß

Abbaustufe (> 75 %): 1 > 3 Jahre; 2 1 – 3 Jahre; 3 18 Wochen bis 1 Jahr; 4 < 18 Wochen; 5 < 6 Wochen

Flüchtigkeitsstufen (Dampfdruck in hPa bei 20 – 25 °C): 1 < 10^{-3}; 2 10^{-3} – 100; 3 100 – 5 x 10^3; 4 > 5 x 10^3 (orientierende Daten für die reine Substanz)

Mobilitätsstufen (Jährl. Verlagerungstiefe durch 1 500 mm N bei 25 °C in Lehmbod..m. ca. 2 % Humus u. pH 6 im A_p): 1 < 10; 2 5 – 20; 3 15 – 40; 4 > 35 cm

Alphabetische Ordnung der Pflanzenschutzmittel:

Aldicarb 60, Aldrin 32, Amitrol 11, Anilazin 9, Atrazin 6, Benomyl 77, Bentazon 4, Bromacil 91, Bromoxynil 85, Butylat 52, Captafol 82, Captan 81, Carbaryl 44, Carbenazin 79, Carbofuran 45, Carboxin 62, Chloramben 23, Chlordan 35, Chloridazon 3, Chlormequat 90, Chlortoluron 72, Chloropropham 49, DDT 37, 2.4-D 16, D(e)iquat 1, Dicamba 22, Diallat 50, Diazinon 43, Dichlobenyl 83, Dichlorprop 21, Dichlorpropen 38, Dieldrin 33, Dinoseb 26, DNOC 27, Diuron 67, Endosulfan 31, EPTC 53, Ethofumesat 92, Fenpropimorph 89, Fenuron 65, Fluazifop-butyl 20, Glyphosat 86, Heptachlor 34, Hexachlorbenzol 30, Ioxynil 84, Isoproturon 71, Lindan 36, Linuron 7, Malathion 40, Mancozeb 54, Maneb 59, MCPA 17, Mecoprop 18, Metaldehyd 88, Metam 55, Metamitron 15, Metazachlor 64, Metalachlor 63, Methabenzthiazuron 69, Metalaxyl 87, Metoxuron 70, Methylbromid 39, Metribuzin 14, Monolinuron 68, Monuron 66, Nitralin 74, Paraquat 2, Parathion 41, Pendimethalin 76, Pentachlorphenol 28, Phenmedipham 47, Phorat 42, Picloram 25, Propazin 8, Propanil 58, Prochloraz 80, Prometryn 5, Propachlor 61, Propham 48, Propiconazol 12, Propoxur 46, Quintozen 29, Simazin 7, Terbutylazin 10, 2.4.5-T 19, 2.3.6-TBA 24, Thiophonatmethyl 78, Thiram 57, Triadimenol 13, Triallat 51, Trifluralin 75, Zineb 56.

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Löslichkeit	Flüchtigkeit	Bindung durch Humus	Ton Fe-Ox	pH Einfl.	Abbau aerob	anaerob	Mobilität
1.	Kation-aktiv										
	Bipyridylderivate										
1	Deiquat (H)	1,1'-Ethylen-2,2'-bipyridylium	+	4	1	5	4 – 5	+	3		1 – 2
2	Paraquat (H)	1,1'-Dimethyl-4,4'-bipyridylium	+	4	1	5	4 – 5	+	1		1
2.	Basisch (schwach)										
	Diazine										
3	Chloridazon (H)	5-Amino-4-chlor-2-phenyl-(2H)-pyridazinon	+	3	1	3	2	(–)	4 – 5		2
4	Bentazon (H)	3-Isopropyl-2,1,3-benzothiadiazin-4-on-2,2-dioxid	(+)	4	1				4 – 5		

[1]) (A) Akarizid, (F) Fungizid, (H) Herbizid, (I) Insektizid, (N) Nematizid, (R) Rodentizid, (M) Molluskizid

[2]) Seit 19.. in der BRD verbotene, + zugelassene, ( ) aber in Wasserschutzgebieten seit 1. 9. 88 verbotene Präparate (n. Pflanzenschutzanwendungsverordnung)

Source: Blume ed. 1992

Table 3-25

Forts. Tab. 2.7.5/2

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Löslichkeit	Flüchtigkeit	Bindung durch Humus	Ton Fe-Ox	pH Einfl.	Abbau aerob	anaerob	Mobilität
	S-Triazine										
5	Prometryn (H)	4,6-Diisopropylamino-2-methylthio-s-triazin		4	1	3	2	(–)	4		2
6	Atrazin (H)	4-Ethylamino-2-chlor-6-isopropylamino-s-triazin	(+)	2 – 3	1	2	1	–	3 – 4	3 – 4	3
7	Simazin (H)	4,6-Diethylamino-2-chlor-s-triazin	(+)	2	1	2	2	(–)	3 – 4		3
8	Propazin (H)	2-Chlor-4,6-diisopropylamino-s-triazin	(+)	2	1	2		(–)	3 – 4		3
9	Anilazin (F)	2,4-Dichlor-N-(6-chlor-phenyl)-1,3,5-triazin-2-amin	+	2	1			(–)	5		
10	Terbuthylazin (H)	4-Ethylamino-6-ter.-butylamino-2-chlor-s-triazin	+	2	1	2 – 3	2	(–)	3 – 4		
	S-Triazole										
11	Amitrol (H)	3-Amino-1,2,4-triazol	(+)	4	1	2	2	(–)	4		4
12	Propiconazol (F)	1-[2-(2,4-Dichlorphenyl)-4-propyl-1,3-dioxolan-2-y [methyl]-1 H-1,2,4-Triazol	+	3	1			(–)			
13	Triadimenol (F)	1-(4-Chlorphenoxy)-3,3-dimethyl-(1H-1,2,3-triazol-2-yl)-butan-2-ol	+	3	1	(1)		(–)	(1)		
	Triazinone										
14	Metribuzin (H)	4-Amino-6-tert.-butyl-3-methylthio-1,2,4-triazin	(+)	4	1	2	(2)	(–)	4		
15	Metamitron (H)	4-Amino-3-methyl-6-phenyl-1,2,4-triazin	+	4	1			(–)	5		
3.	Sauer										
	Phenoxyfettsäuren										
16	2,4-D (H)	2,4-Dichlorphenoxyessigsäure	+	4	1	1 – 2	1	–	4		4
17	MCPA (H)	4-Chlor-2-methylphenoxyessigsäure	+	3	1	2	1	–	4		4
18	Mecoprop (H) CMPP	2-(4-Chlor-2-methylphenoxy)-propionsäure	+	4	1	2	1	–	4		3
19	2,4,5-T (H)	2,4,5-Trichlorphenoxyessigsäure	+	3	1	2 – 3	1	–	4	3	3
20	Fluazifop-butyl (H)	Butyl-2-[4(5-trifluormethyl-2-pyridyloxy) phenoxy] propionat	(+)	1 – 2	1	2		(–)	5		
21	Dichlorprop (H)	2-(2,4-Dichlorphenoxy)-propions.	(+)	3 – 4	1			(–)	4 – 5		
	Benzoesäuren										
22	Dicamba (H)	3,6-Dichlor-2-methoxybenzoesäure	(+)	4	1	2	1	–	5		4
23	Chloramben (H)	3-Amino-2,5-dichlorbenzoesäure	(+)	4	2			(–)	2		4
24	2,3,6-TBA (H)	2,3,6-Trichlorbenzoesäure		4	2	2	1	–	3		4

Forts. Tab. 2.7.5/2

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Löslichkeit	Flüchtigkeit	Bindung durch Humus	Ton Fe-Ox	pH Einfl.	Abbau aerob	anaerob	Mobilität
	Picolinsäureabkömmling										
25	Picloram (H)	3-Amino-3,5,6-trichlor-picolinsäure	(+)	3 – 4	1	2	1	–	2 – 3		3
	Phenole, Benzole										
26	Dinoseb (H)	2-(1-Methylpropyl)-4,6-dinitrophenylacetat	(+)	4	2	2		(–)	5		4
27	DNOC (H)	2-Methyl-4,6-dinitrophenol	(+)	3	1	2 – 3		–	4		3
28	PCP (I)	Pentachlorphenol	86	2	1	4	2	–	3 – 4	4	1
29	Quintozen (F)	Pentachlornitrobenzol (PCNB)	+	1	2			0	2 – 3	4	1
30	Hexachlorbenzol (F)	Hexachlorbenzol	77	1	1	4	2	0	2	1	1
4.	Nicht Ion-Aktiv (apolar)										
	Halogenierte Kohlenwasserstoffe										
31	Endosulfan (I)	6,7,8,9,10-Hexachlor-1,5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepin-3-oxid	+	1	2	4		0	3	(2)	1
32	Aldrin	1,2,3,4,10,10-Hexachlor-1,4,4a,5,8,8a hexahydro-1,4-endo, exo-5,8-dimethannaphthalen	81	1	1	(5)	(3)	0	3	(2)	1
33	Dieldrin (I)	1,2,3,4,10,10-Hexachlor-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, exo-5,8-dimethannaphthalen	71	1	1	5	3	0	1 – 2	1 – 2	1
34	Heptachlor (I)	1,4,5,6,7,8-Heptachlor-3a,4,7,7a-tetrahydro-4,7-methanoinden	86	1	2	5	3	0	2 – 3	2 – 3	1
35	Chlordan (I)	1,2,4,5,6,7,8,8-Heptachlor-3a,4,7,7a-tetrahydro-4,7-methanoinden	71	1	2	5		0	3		1
36	Lindan (γ-HCH) (I)	γ-1,2,3,4,5,6-Hexachlorocyclohexan	(+)	2	1	3 – 4	3	0	2 – 3	5	1
37	DDT (I)	1,1,1-Trichlor-2,2-bis (p-chlorphenyl) ethan	77	1	1	5	4	0	1 – 2	3	1
38	Dichlorpropen (N)	1,3-Dichlorpropen	(+)	2	2	2	2	0	5	4	4
39	Methylbromid (I,N)	H_3C-Br	(+)	4	3			0			

[1]) (A) Akarizid, (F) Fungizid, (H) Herbizid, (I) Insektizid, (N) Nematizid, (R) Rodentizid, (M) Molluskizid

[2]) Seit 19.. in der BRD verbotene, + zugelassene, ( ) aber in Wasserschutzgebieten seit 1. 9. 88 verbotene Präparate (n. Pflanzenschutzanwendungsverordnung)

Forts. Tab. 2.7.5/2

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Löslichkeit	Flüchtigkeit	Bindung durch Humus	Ton Fe-Ox	pH Einfl.	Abbau aerob	anaerob	Mobilität
	Organische P-Ester										
40	Malathion (I)	0,0-Dimethyl-dithiophosphat-diethylmercaptosuccinat	+	3	2	2 – 3		0	3	3 – 4	2
41	Parathion (I,A)	0,0-Diethyl 0-4-nitrophenyl-thiophosphat	+	2	2	4 – 5	2 – 3	0	4 – 5	4	2
42	Phorat (I,A)	0,0-Diethyl-S-((ethylthio)-methyl) phosphodithioat		2 – 3	2	4	2	0	4		2
43	Diazinon (I)	0,0-Diethyl-0-(2-isopropyl-6-methylpyrimidin-4-yl)-thiophosphat		2	2	3	2	0	4	4	2 – 3
	Carbamate										
	a) Methylcarbamate										
44	Carbaryl (I)	N-Methyl-1-naphthylcarbamat	86	2 – 3	2	2 – 3		0	3 – 4	4	2 – 3
45	Carbofuran (I,A,N)	2,3-Dihydro-2,2-dimethyl-7-benzofuranylmethylcarbamat	(+)	3	1	3		0	4	3 – 4	2 – 3
46	Propoxur (I)	2-Isopropoxyphenyl-N-methylcarbamat	(+)	4	2	2		0	(4)		
47	Phenmedipham (H)	Methyl-3-m-tolycarbamoyloxy-phenylcarbamat	+	2	1	3 – 4		0	4		–
	b) Phenylcarbamate										
48	Propham (H)	Isopropyl-N-phenylcarbamat	+	2	1	2	1 – 2	0	4 – 5		3
49	Chlorpropham (H)	Isopropyl-N-(3-chlorphenyl)-carbamat	+	3	1	3	1 – 2	0	4		2
	c) Thiocarbamate										
50	Diallat (H)	S-2,3-Dichlorallyl-N,N-diisopropylthiocarbamat		2	1	4		0	4 – 5		2
51	Triallat (H)	2,3,3-Trichlorallyl-diisopropylthiocarbamat	+	2	1	4	2	0	3 – 4		2
52	Butylat (H)	S-Ethyl-N,N-diisobutylthiocarbamat	+	2	2	3		0	4		2
53	EPTC (H)	S-Ethyl-N,N-dipropylthiocarbamat	+	3	2	2		0	4		2
	d) Dithiocarbamate										
54	Maneb (F)	Mangan(II)-1,1-ethylen-bis-dithiocarbamat	+	1	1			0	5	5	
55	Metam-Na (F,N,H)	N-Methyldithiocarbamat	(+)	4	1	1 – 2		0	4		3
56	Zineb (F)	Zink-ethylen-bis-dithiocarbamat	+	2	1	3 – 4		0	4 – 5		2
57	Thiram (F)	Tetramethylthiuramdisulfid	+	3	1	3		0	4 – 5		
58	Propanil (H)	N-(3,4-dichlorphenyl)-propionamid		3	1 – 2	2	1 – 2	0	4		
59	Mancozeb (F)	Ethylen-bis-dithiocarbamat	+	1	1			0	4 – 5		

Table 3-25 cont.

Table 3-25 cont.

Forts. Tab. 2.7.5/2

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Lös-lich-keit	Flüch-tig-keit	Bindung durch Hu-mus	Bindung durch Ton Fe-Ox	Bindung durch pH Einfl.	Abbau ae-rob	Abbau an-aerob	Mobili-tät
	c) Oxicarbamate										
60	Aldicarb (I,N)	2-Methyl-2-(methyl-thio)propion-aldehyd-0-methylcarbamoyl-oxim	(+)	4	1	2	1	0	3–4	4	4
	Acetanilide										
61	Propachlor (H)	2-Chlor-N-isopropyl-N-phenyl-acetamid	(+)	4	1	2	1–2	0	4		3
62	Carboxin (F)	5,6-Dihydro-2-methyl-1,4-oxathiin-3-carb-oxanilid	+	3	1	5	3	0	4–5		2
63	Metalachlor (H)	Chloracetanilid	+	4	1	2–3		0	4		
64	Metazachlor (H)	Chlorazetanilid	(+)	3	1	2–3		0	4–5		
	Harnstoffderivate										
65	Fenuron (H)	1,1-Diemethyl-3-phe-nylharnstoff		4	1	2–3	2	0	3		3
66	Monuron (H)	3-(4-Chlorphenyl)-1,1-dimethylharn-stoff	+	3	1	3	2	0	4		3
67	Diuron (H)	3-(3,4-Dichlorphenyl)-1,1-dimethylharnstoff	+	4	1	3	2	0	3		2
68	Monolinuron (H)	3-(4-Chlorphenyl)-1-methoxy-1-methyl-harnstoff	+	3–4	1	3	2	0	4		2
69	Methabenz-thiazuron (H)	1-(Benzthiazol-2-yl)-1,3-dimethylharnstoff	+	3	1	3	2	0	3		2
70	Metoxuron (H)	3-(3-Chlor-4-methoxy-phenyl)-1,1-dimethyl-harnstoff	+	4	1	2	(2)	0	4–5		2
71	Linuron (H)	3-(3,4-Dichlorphenyl) 1-methoxy-1-methyl-harnstoff		3	1	3–4	2	0	4		2
72	Chlor-toluron (H)	3-(3 Chlor-4 methyl-phenyl)-1,1-dimethyl-harnstoff	+	3–4	1	2–3		0	4–5		
73	Isoproturon (H)	N-(4-isopropyl-phenyl)-N',N'-dime-thylharnstoff	+	3	1	2		0	5		
	Dinitroaniline										
74	Nitralin (H)	4-(Methylsulfonyl)-2,6-dinitro-N,N-dipropylanilin	+	1	1	3–4	(3)	0	3–4		1
75	Trifluralin (H)	2,6-Dinitro-N,N-dipropyl-4-trifluor-methylanilin	+	1	1	4–5	(3)	0	3–4		1

[1]) (A) Akarizid, (F) Fungizid, (H) Herbizid, (I) Insektizid, (N) Nematizid, (R) Rodentizid, (M) Molluskizid

[2]) Seit 19.. in der BRD verbotene, + zugelassene, ( ) aber in Wasserschutzgebieten seit 1. 9. 88 verbotene Präparate (n. Pflanzenschutzanwendungsverordnung)

Forts. Tab. 2.7.5/2

Nr.	Name (Wirkung)[1]	Chemische Bezeichnung	BRD[2]) verb. zug.	Lös-lich-keit	Flüch-tig-keit	Bindung durch Hu-mus	Bindung durch Ton Fe-Ox	Bindung durch pH Einfl.	Abbau ae-rob	Abbau an-aerob	Mobili-tät
76	Pendimetha-lin (H)	N-(3-phenyl)-3,4-dimethyl-2,6-dini-troanilin	+	1	1			0	4		
	Benzimidazole										
77	Benomyl (F)	Methyl-1-(butylcar-bamoyl)-2-benzimi-dazolcarbamat	+	2	1	5	3	0	4		1
78	Thiophanat-methyl (F)	1,2-bis-((3-Methoxy-carbonyl)-2-thiourei-do)-benzol	+	2	1			0	4–5		1
79	Carbendazim (F)	Methyl-2-benzimi-dazolcarbamat	+	2	1	4		–	3–4		1
80	Prochloraz (F)	N-Propyl-N-2,4,6-tri-chlorphenoxy-ethyl-imidazol-carboxamid	+	2	1						
	Phthalimid-Derivate										
81	Captao (F)	N-Trichlormethylthio-4-cyclohexen-1,2-di-carboximid	+	1	1	1–2		0	4–5		2
82	Captafol (F)	N-(1,1,2,2,2-Tetra-chlorethylthio)-3,6,7,8-tetrahydrophthalimid	+	1–2	1	1–2		0	4–5		
	Aromatische Cyanide										
83	Dichlo-benil (H)	2,6-Dichlorbenzo-cyanid	+	2	2	2		0	3		2
84	Ioxynil (H)	3,5-Dijod-4-hydroxy-benzonitril	+	2	1	2		0	5		
85	Bromoxynil (H)	3,5-Dibrom-4-hydro-xybenzonitril	+	3	1	2		0	4–5		
	Aminosäurederivate										
86	Glyphosat (H)	Aminomethylphos-phorsäure	+	4	1	3			3–4		
87	Metalaxyl (F)	D,L-N-2,6-Dimethyl-phenyl-N-(2'-methoxy-acetyl-alanin-methyl-ester	(+)	4	1	3			4		
	Aldehydoligomere										
88	Metaldehyd (M)	2,4,6,8-Tetramethyl-1,2,3,5,7-tetraoxacy-clooctan	+	3	2	2					
	Morpholinderivate										
89	Fenpropi-morph (F)	cis-4-[3-(4-tert-Butyl-phenyl)-2-methylpro-pyl]-2,6-dimethyl-morpholin	(+)	2	1						
	Quartäre Ammoniumverbindung										
90	Chlormequat (H)	2-Chlorethyl-trime-thyl-NH_4Cl	+	4	1						

[1]) (A) Akarizid, (F) Fungizid, (H) Herbizid, (I) Insektizid, (N) Nematizid, (R) Rodentizid, (M) Molluskizid

[2]) Seit 19.. in der BRD verbotene, + zugelassene, ( ) aber in Wasserschutzgebieten seit 1. 9. 88 verbotene Präparate (n. Pflanzenschutzanwendungsverordnung)

Nr.	Name (Wirkung)	Chemische Bezeichnung	BRD verb. zug.	Löslichkeit	Flüchtigkeit	Humus	Ton Fe-Ox	pH Einfl.	aerob	anaerob	Mobilität
	Uracilderivate										
91	Bromacil (H)	5 Br-3-sec-butyl-6-methyl-uracil	+	4	1				3		
	Benzofuranderivate										
92	Ethofumesat (H)	2-Ethoxy-2,3-dihydro-3,3-dimethyl-benzofu-ran-5-yl-methansulfo-nat	+	3	1	2			3–4		

[1]) (A) Akarizid, (F) Fungizid, (H) Herbizid, (I) Insektizid, (N) Nematizid, (R) Rodentizid, (M) Molluskizid

[2]) Seit 19.. in der BRD verbotene, + zugelassene, ( ) aber in Wasserschutzgebieten seit 1. 9. 88 verbotene Präparate (n. Pflanzenschutzanwendungsverordnung)

Table 3-26

Tab. 2.7.5/10: Einfluß von Humus, Bodenart und pH-Wert auf die relative Bindungsstärke[3]) von Wirkstoffen in Böden (0 (fast) nicht bis 5 sehr stark)

% Humus[1]) (Mittel 0–3 cm)	Bodenart[2])	Bindung nach Tab. 2.7.5/2: 1	2	3	4	5
0.5–1	S, Su2	0	0.5	1	1.5	2
1 –2	Sl, St, Su, Us, U	0.5	1	1.5	2	3
2 –8	Uls, Ul, Lu, Ls, Lt, Ts4, Ut2,3	0.5	1	2	3	4
8 –15	Ts2, Tl, Tu, Lts, Ltu, Ut4	1	1.5	2.5	3.5	4.5
> 15	T	1	2	3	4	5

Zu-/Abschlag (+ od. –, n. Tab. 2.7.5/2): ± 0.5 0 ∓ 0.5 ∓ 1
bei pH ($CaCl_2$) > 6.5 – 5.5 – 4 >

[1]) Nach Blume und Helsper (1987) [2]) Nach AG BODENKUNDE (1982)
[3]) Stufe der bodenbezogenen Sorptionskonstanten (k_f) n. Freundlich

Tab. 2.7.5/11: Beurteilung einer Eliminierung von Wirkstoffen in Böden, 0 (*fast*) *nicht* bis 5 *sehr stark*

(a) Einfluß der Temperatur auf den Abbau

Abbau n. Tab. 2.7.5/2	a) Mitteltemp. d. Sommerhalbj. 21 – 16	16 – 11	11 – 6 °	b) Jahresmitteltemperatur 12 – 9	9 – 6	6 – 3 °C
1	1.5	1	0.5	0.5	0.5	0
2	2.5	2	1.5	1.5	1	0.5
3	3.5	3	2.5	2.5	2	1.5
4	4.5	4	3.5	3.5	3	2.5
4.5, 5	5	4.5	4	4	3.5	3

(b) Einfluß der Wasser-, Luft- und Nährstoffverhältnisse auf den Abbau

Abschlag:	1	0–1	0
bei Standortkundl. Feuchtestufe SF[1])	01.11	*02 12 21 31 41	übrige
Effektiver Durchlüftung (DL[1])	1	2–3	4–5
S-Wert in mval/100 ccm[2])	< 4	4–12	> 12

[1]) Nach AG BODENKUNDE (1982) [2]) Nach Tabelle 4 in Blume u. Brümmer 1987

(c) Einfluß starker Bindung auf den Abbau

Abschlag bei:	Bindungsstufe (n. Tab. 2.7.5/10) 1 u. 2	3	4 u. 5
Seemarsch, Tschernosem	0	0	–0.5
Übrige	0	–0.5	–1

(d) Einfluß möglicher Verflüchtigung auf Eliminierung

Zuschlag bei:	Verflüchtigung n. Tab. 2.7.5/2: 1	2	3	4
Temperatur > 10 °C oder langes Verweilen an Bodenoberfläche	0	1	1.5	2
Temperatur < 10 °C oder kurzes Verweilen an der Oberfläche	0	0	1	1.5

Tab. 2.7.5/12: Einfluß von Bindung, Eliminierung und klimatischer Wasserbilanz auf die Bewegung eines Wirkstoffs im grundwasserfreien Bodenraum

KWBa[1])	Sickerung[2]) mm/Jahr	Bindung[3]) + Eliminierung[4]):2: 5	4	3	2	1	0
1	0–100	0	1	2	3	4	5
2	100–200	0	1.5	2.5	3.5	4.5	5
3–4	200–400	0	2	3	4	4.5	5
5–6	> 400	0.5	2	3.5	4.5	5	5

[1]) Klimat. Wasserbilanz als Differenz von Jahresniederschlag und Verdunstung n. Tab. 3 in AG Bodenkunde 1982
[2]) Bei Acker mit Winterung 50 mm Zuschlag
Bei Acker mit Sommerung 100 mm Zuschlag
Bei Forst 50 mm Abschlag
[3]) n. Tab. 2.7.5/10
[4]) n. Tab. 2.7.5/11

Tab. 2.7.5/13: Einfluß von Grundwasserstand (mittl. Hochstand) und Bewegung (n. Tab. 2.7.5/12) org. Chemikalien im grundwasserfreiem Bodenraum auf die Grundwassergefährdung (1 sehr gering, 5 sehr hoch)

Bewegung	Grundwasserstufen[1]): 1	2	3	4	5	6	7[2])
0–1	5	5	3	2	2	1	1
2	5	5	4	3	3	2	1
3	5	5	4	3	3	3	2
4	5	5	4	4	4	4	3
5	5	5	5	2	5	5	4.5

[1]) n. Tab. 53 in AG BODENKUNDE 1982
[2]) mittl. Grundwasserhochstand tiefer 2 m

Tab. 2.7.5/14: Bewertung des Verhaltens eines Wirkstoffs im Boden

	1	2	3	4	5
Bei Bindung n. Tab. 2.7.5/10 von: Anreicherung im Boden:	sehr gering	gering	mittel	stark	sehr stark
Bei Bindung (Tab. 2.7.5/10) + Eliminierung (Tab. 2.7.5/11) geteilt durch 2 von: Aufnahme durch Pflanzen, Schädigung von Bodenorganismen:	sehr wahrschein.	wahrscheinlich	wahrschein.	weniger wahrschein.	unwahrschein.
Bei Grundwassergefährdung n. Tab. 2.7.5/13 von:	sehr gering	gering	mittel	stark	sehr stark
Mitteleinsatz:	möglich		begrenzt mögl.	nicht möglich	

Das Verfahren soll im folgenden kurz erläutert werden (DVWK 1989).

Eine negative Nebenwirkung auf Bodenorganismen und eine Pflanzenaufnahme sind dann zu erwarten, wenn der Wirkstoff im Hauptwurzelraum wenig gebunden und langsam abgebaut wird und sich gleichzeitig kaum verflüchtigt.

Die zu erwartende Bindungsstärke des nach Tab. 2.7.5/2 klassierten Stoffes ergibt sich nach Tab. 2.7.5/10 für Humus aus dem mittleren Humusgehalt und für Ton aus der mittleren Bodenart (der oberen 3 dm). Bei verminderter (oder verstärkter) Bindung infolge niedrigen (oder hohen) pH-Wertes nach Tab. 2.7.5/2 ist bei der Bindungsstärke durch Humus und der durch Ton ein Abzug (oder Zuschlag) nach Tab. 2.7.5/10 vorzunehmen. Die Gesamtbindung wird dann durch die Summe der humus- und der tonbezogenen Bindungsstärke charakterisiert, wobei höchstens die Stufe 5 anzusetzen ist.

Der während der Vegetationsperiode (April bis September) zu erwartende Abbau des nach Tab. 2.7.5/2 klassierten Stoffes wird nach Tab. 2.7.5/11 a aus der Mitteltemperatur des Sommerhalbjahres abgeleitet. Bei einer Kontamination zwischen Oktober und März wird die Jahresmitteltemperatur herangezogen, weil sich dann der Abbau meist bis in das nächste Frühjahr verlängert. Bei Wasser-, Luft- und/oder Nährstoffmangel sind Abschläge um maximal 1 nach Tab. 2.7.5/11 b vorzunehmen. Bei Wirkstoffen, die unter anaeroben Bedingungen besser als unter aeroben abgebaut werden, erfolgt bei Luftarmut (DL 1–3) nach Tab. 2.7.5/11 b kein Abschlag sondern ein entsprechender Zuschlag. Wurde eine hohe, den Abbau hemmende Bindungsstärke nach Tab. 2.7.5/2 und 2.7.5/10 prognostiziert, erfolgt ein Abschlag nach Tab. 2.7.5/11 c. Der Einfluß der Flüchtigkeit nach Tab. 2.7.5/2 auf die Gesamteliminierung wird durch einen Zuschlag nach Tab. 2.7.5/11 d berücksichtigt. Die erreichbare Höchststufe beträgt 5.

Bei einer Abschätzung der Grundwassergefährdung sind neben Bindung und Eliminierung im (aus dem) Oberboden auch die Vorgänge im Unterboden zu berücksichtigen, außerdem die Sickerungsraten und der Grundwasserstand. Die Bewegung des Wirkstoffs im grundwasserfreien Bodenraum wird nach Tab. 2.7.5/12 aus dem Mittel von Bindung (Tab. 2.7.5/10) und Eliminierung (Tab. 2.7.5/11) sowie der klimatischen Wasserbilanz (KWBa) abgeleitet. Dabei ist die Bindung nach Tab. 2.7.5/10 um bis zu 1 Stufe zu erhöhen, wenn auch der Unterboden bis zum Grundwasserspiegel eine mindestens 4 dm mächtige, humose (> 2 % org. S.) Lage aufweist und/oder eine mittlere Bodenart von Sl4 oder toniger besitzt. Die klimatische Wasserbilanz gilt für Grünland in ebener Lage; bei Acker ist sie um 50–100 mm zu erhöhen, bei Wald um 50 mm zu erniedrigen. Senken- und Unterhanglagen weisen eine stärkere, Kuppen- und Oberhanglagen eine geingere Sickerung auf, was entsprechend zu berücksichtigen ist. In Böden mit hoher Wasserdurchlässigkeit (kf durchgehend > 40 cm/d: Schätzung n. AG Bodenkunde 1982) kann die Sickerung um bis zu 100 mm höher liegen. Die Grundwassergefährdung ergibt sich dann nach Tab. 2.7.5/13 aus der nach Tab. 2.7.5/12 prognostizierten Bewegung und dem mittleren Grundwasserhochstand; 1 bedeutet sehr geringe, 5 sehr starke Gefährdung. Ist zu erwarten, daß lateral abziehendes Stauwasser (gilt bei geringer Wasserdurchlässigkeit, d.h. bei kf < 10 cm/d des Unterbodens) einen benachbarten Vorfluter kontaminiert, ist Tab. 2.7.5/13 entsprechend anzuwenden.

Eine Bewertung der Befunde erfolgt nach Tab. 2.7.5/14.

Ein ähnliches Verfahren zur Prognose einer möglichen Grundwasserkontamination, das auf dem Abbau- und Perkolationsverhalten eines Pestizids unter Laborbedingungen fußt, wurde von Herzel (1987) entwickelt.

Source: Blume ed. 1992

Table 6

RELATIVE MOBILITY OF PESTICIDES IN SOILS[1]
(CAST 1985)

Very Mobile	Moderately Mobile	Slightly Mobile	Nearly Immobile	Immobile
TCA	Picloram	Propachlor[3]	Siduron	Neburon
Dalapon	Fenac	Fenuron	Bensulide	Chloroxuron
2,3,6 TBA[2]	Pyrichlor	Prometone	Prometryn	DCPA
Tricamba	MCPA	Naptalam	Terbutryn	Lindane
Dicamba	Amitrole	2,4,5-T	Propanil	Phorate
Chloramben	2,4-D	Terbacil	Diuron	Parathion
	Dinoseb	Propham	Linuron	Disulfoton
	Bromacil	Fluometuron	Pyrazon	Diquat
		Norea	Molinate	Chlordimeform
		Diphenamid	EPTC	Dichlormate[3]
		Thionazin[3]	Chlorthiamid	Ethion
		Endothall	Dichlobenil	Zineb
		Monuron	Vernolate	Nitralin
		Atratone	Pebulate	Fluorodifen
		Cyanazine	Chloropropham	ACNQ[3]
		Atrazine	Azinphosmethyl	Morestan
		Simazine	Diazinon	Isodrin[2]
		Ipazine		Benomyl
		Alachlor		Dieldrin[2]
		Ametryn		Chloroneb
		Propazine		Paraquat
		Trietazine		Trifluralinh
				Benefin
				Heptachlor[2]
				Endrin[2]
				Aldrin[2]
				Chlordane
				Toxaphene[2]
				DDT[2]

[1] Ranked according to estimated order of decreasing mobility within each class
[2] Most or all uses cancelled by the Environmental Protection Agency as of November 1984
[3] Not used at present in the United States

Source: Kandiah FAO 1990

TABLE 6. The various salts influencing the formation of salt-affected soils

Group of salts	Occurrence	Origin	Solubility	pH in solution	Toxicity to plants	Effect on soil
Carbonates	All regions. In: soil, subsoil, ground water, surface water, marine deposits.	Predominantly weathering products.	Varies.	Alkaline.	Varies, depending on solubility.	Varies, depending on mobility and solubility.
$CaCO_3$	In: fresh river water, ground water, soils (5–80 per cent). Mostly in steppe and desert soils.	Predominantly weathering products in sedimentary rocks and from ground water.	Low, depending on: CO_3 conceutration, CO_2 concentration, pH values in solution $L = 9{\cdot}3 \times 10^{-9}$ $9{\cdot}8 \times 10^{-3}$ g/l. [illegible]	Alkaline.	No toxicity.	Different form of $CaCO_3$ medium concretions hardpan.
$MgCO_3$	As $CaCO_3$.	Predominantly weathering products.	Low, but higher than $CaCO_3$. $L_{MgCO_3} = 2{\cdot}10^{-4}$ $1{\cdot}2$ g/l. Dolomite dissolution is poor.	Alkaline.	Toxicity due to alkaline hydrolysis.	Rare in free form, mainly dolomite or dolomitized $CaCO_3$ concretions.
Na_2CO_3	In: surface and ground waters at mineralization 0·5–3 g/l, soils (mainly in absence of gypsum), deposits.	Weathering products (in CO_2-containiug water), Hilgard, Gedroitz, sulphate reduction, from plants.	Highly soluble $CO_3 \leftrightharpoons HCO_3$ reaction.	Alkaline, up to pH 12.	Very toxic, due to high solubility and alkaline hydrolysis.	Peptization of soil, low water permeability, poor water-physical properties, non-leachable.
K_2CO_3	Similar to Na_2CO_3. Its occurrence in soils is very rare.					
Sulphates	In: deserts and steppes, deposits, soils, ground waters.	Sometimes weathering products, sometimes magmatic origin.	Varies, but higher than carbonates.	Neutral or slightly acidic.	Different, depending on solubility and concretions.	Effect on soils varies, depending on compounds.
$CaSO_4$	In: deserts and semi-desert regions, ground water, deposits soils.	Sometimes weathering products, partly formed secondarily from SO_4 having magmatic origin in sediment due to reaction $Na_2SO_4 + CaCl_2$ $CaSO_4 + 2NaCl$.	$L_{CaSO_4 \cdot 2H_2O} = 1{\cdot}3 \times 10^{-4}$ $C = 2$ g/l $L_{CaSO_4} = 6{\cdot}1 \times 10^{-5}$ $C = 1$ g/l.	Slightly acidic.	No toxicity.	Forms transparent mottles; compact layer used for soil amelioration.
$MgSO_4$	In: desert and semi-desert regions, saline soils, saline ground water.	As $CaSO_4$.	High: $C = 262$ g l.	Slightly acidic.	Very toxic.	Accumulates always in combination with other soluble salts. Reclamation by leaching.
Na_2SO_4	In: desert and semi-desert regions, saline ground water, saline lakes, saline soils.	Partly weathering products, partly magmatic origin.	High solubility, 280 g/l (25° C). Depends very much on temperature.	Nearly neutral.	Two or three times less than $MgSO_4$.	Accumulates together with other easily soluble salts. In warm periods dehydration. Reclamation by leaching in dry season.
Chlorides	In: desert and semi-desert regions, saline ground water, saline lakes, saline soils, sea water, seashores, marine deposits.	Partly magmatic origin, partly weathering products.	High solubility.	Nearly ueutral or slightly acidic.	High toxicity.	Saline soil. Physiological effect.
$CaCl_2$	Waters of saline lakes (at salinity 400–500 g/l), deep-lying ground water.	Partly magmatic origin, partly weathering products.	High solubility.	Slightly acidic.	Toxic in high concentration.	Seldom present in soil (form $CaCO_3$ or $CaSO_4$) only at very high salinity.
$MgCl_2$	Common in saline ground waters, lakes, soils. Only at very high salinity.	Partly magmatic origin, partly weathering products.	High solubility, 353 g/l.	Nearly neutral.	Very toxic.	Together with $CaCl_2$ very hygroscopic. Saline soils with $CaCl_2$ and $MgCl_2$ remain humid for a long time after rain. Reclamation: intensive leaching.
NaCl	Sea water, marine sediments, coastal area, saline surface waters, saline ground waters, saline soil, desert and semi-desert regions.	Magmatic. Only partly weathering product.	High solubility, 264 g/l.		Very toxic from 1 g/l.	In saline soil together with Na_2SO_4 and $MgSO_4$. Amelioration: leaching of soil containing gypsum. In absence of gypsum, alkalization.

Source: Darab and Ferencz (1969).

Source: Szabolcs 1979

Table 3-29

TABLE 19. Classification of saline soils by degree and type of salinity in relation to field crops

Condition of agricultural crops with medium salt resistance	Degree of soil salinity	Type of salts dominating in soils: Soda	Chloridic soda and soda chloridic	Sulphatic soda and soda sulphatic	Chloridic	Sulphatic-chloridic	Chloridic-sulphatic	Sulphatic
Good growth and development (no bare patches, crop normal)	Practically non-saline (or only very slightly saline)	0.10	0.15	0.15	0.15	0.20	0.25	0.30
Slight withering (bare patches and decrease of crop by 10–20 per cent	Slightly saline	0.10–0.20	0.15–0.25	0.15–0.30	0.15–0.30	0.20–0.30	0.25–0.40	0.30–0.60
Medium withering (bare patches and decrease of crop by 20–50 per cent	Medium saline	0.20–0.30	0.25–0.40	0.30–0.50	0.30–0.50	0.30–0.60	0.40–0.70	0.60–1.0
Marked withering (bare patches and decrease of crop by 50–80 per cent	Strongly saline	0.30–0.50	0.40–0.60	0.50–0.70	0.50–0.80	0.60–1.0	0.70–1.20	1.0 –2.0
A few scattered plants survive (virtually no crop)	Solonchaks	>0.50	>0.60	>0.70	>0.80	>1.0	>1.20	>2

Source: Kovda, Hagan and van den Berg (eds.) (1973, p. 70).

Source: Szabolcs 1979

Table 3-30

A) STUDY AND PLANNING

Environmental issues:

- sources and current processes of salinization
- the geochemical characteristics of the area
- salinization and/or alkalization of soils resulted by primer (natural) and secondary (man-made) effects
- environmental possibilities of removal of excess salts (place of disposal, drainage systems, etc.)
- environmental changes to be expected by reclamation (short and long term)

Socio-economical issues:

- cost and possibilities of reclamation project (purpose, area, time limit, etc.)
- possibilities of agri-, sylvi-, horticultural as well as other productions of the area before and after the reclamation. Cost and benefit analysis.
- combination of meliorative measures with application of by-products of industry, mining as well as of sludge
- public projects, colonization, employment and production on reclaimed territories

Feasibility studies, reports and plans for action

↓

B) REALIZATION

1) Strategy for restauration
2) Alternatives, scenarios, preferences
3) Decision making
4) Implementation
5) Maintaining the rehabilited ecosystems
6) Protection of the rehabilited ecosystems from new degradation and deterioration

Tab. 1: *Scheme of amelioration of salinized areas.*

Source: Shaw 1992

Table 3-31

(A) Before construction of irrigation system	Preliminary survey	
	Landscape	Planned irrigation
	climate	available irrigation water quality and quantity
	hydrology	groundwater depth and quality
	hydrogeology	technology of irrigation
	geomorphology	cropping pattern tolerance
(B) During irrigation	Monitoring	
	salinity and alkalinity of soil and groundwater table	
	chemical composition of groundwater	
	chemical composition of irrigation	
	water filtration	
	physical soil properties toxic elements, if any, in soil and water	

Tab. 5: *Scheme of methods recommended for the control of salinity and alkalinity in irrigated areas.*

Source: Shaw 1992

TABLE 2

Engineering measures for salinity control in the Shapur and Dalaki basin (Yekom, 1980).

Table 3-32

	Engineering measures	Applicability	Proposed salt-disposal projects (Ref. Fig. 4)
Salt disposal	Collecting, diverting and evaporation in natural or artificial ponds	Applicable	Shur river project Shekastian river project
	Collecting and desalting	Not applicable	–
	Sealing of springs through grouting with cement, etc.	Not applicable	–
	Recharge through wells into deep aquifers	Not applicable	–
	Evaporation of salty tributaries by use of sequence of dykes and mining the salt	Not applicable (too costly)	–
	Disconnect the recharge (limestone) from the polluting source (salt plugs) by pumping	Applicable	Cerezak spring project
	Diverting the polluting source to a point downstream	Applicable	Tol-Kharaki drain project
	Use of salt water in the chemical industry	Not applicable (too costly)	–
Salinity mitigation	Construction and management of storage reservoirs	Applicable	Jarreh storage res. project
	Desalination	Not applicable (too costly)	–
	Partial storage of saline or fresh water	Not applicable	–
	Blending or cyclic use	Applicable (costly)	Shapur and Zohreh river water blending project

Source: Shiati 1991

Table 3-33

Table 2. Provisional listing of suitable situations and desirable management practices for each of the major salinity management options.

	Manage existing situation	Minimise recharge	Intercept water	Increase water use in discharge area
Situations most suitable to the proposed control option	. affected land not of high value or productivity . control of recharge area too costly or recharge area of much higher productivity . current vegetation is surviving on most of the affected area . vegetation can be enhanced and/or area fenced for grazing control . seepage of fair quality water represents a majority of the affected area . erosion not a problem or can be stabilised with vegetation . downstream water quality not significantly affected by salting . only moderate salt load in discharge area	. Identifiable recharge area for treatment . agroforestry is an option . winter rainfall regime . shallow rooted pastures main vegetative cover . cropping practices could be more water use efficient . rainfall periods not aligned with crop high water use . high recharge rates . value of discharge area greater than recharge area . sodicity of water in discharge area low and soil structure not severely affected	. transmission zone is relatively well defined . recharge area is large and not well defined . groundwater quality acceptable . can identify good aquifers in transmission zone . aquifers can be pumped or are accessible by tree roots . pumped water can be discharged into stream, evaporated or used for irrigation . discharge area under upward hydraulic pressure through clay confining layer . recharge areas and discharge areas are high value lands . large quantities of water are involved . major salt loads &/or high sodicity in discharge area	. diffuse and extensive recharge area . recharge areas distant from discharge area . discharge area extensive in area . economic value of recharge areas is high . economic value of discharge area lands are high or low . diffuse transmission zone . finite salt loads in discharge area . generally acceptable groundwater quality or saline water and evaporation basins are cost effective . drainage, pumping or use of high water use trees are options . waterlogging is an important component
Desirable management practices	. enhance salt tolerant vegetation in worst areas . fence and manage grazing pressures . maintain adequate vegetative cover at all costs . stabilise against erosion but do not prevent seasonal flooding of area where it would normally occur . improve surface drainage . plant trees or other perennial deep rooted vegetation	. avoid summer fallow in summer rainfall areas and use double or opportunity cropping . revegetate stock routes, fencelines etc . mix pasture species with deeper rooted ones or more perennial species . agroforestry . reduce ponded areas where possible if leakage is significant	. pumping with pumps or windmills from single or linked tubewells. Need a minimum of flow of at least 3 L/sec . plant dense vegetation belts in groundwater accessible areas with high water use vegetation . subsurface drainage . irrigation on adjacent areas	. pumping with pumps or windmills from single or linked tubewells. Need a minimum flow of at least 3 L/sec . revegetate area with perennial high water use and salt tolerant vegetation . subsurface &/or surface drainage . use of pumped water for irrigation on adjacent areas . plant halophytes which take up salts

Source: Shaw 1992b

Table 3-34 a

Table 36-1. Salt tolerance of herbaceous crops.†

Crop		Electrical conductivity of saturated soil extract		
Common name	Botanical name‡	Threshold§	Slope	Rating¶
		dS/m	% per dS/m	
	Fiber, grain, and special crops			
Barley#	*Hordeum vulgare* L.	8.0	5.0	T
Bean	*Phaseolus vulgaris* L.	1.0	19.	S
Broadbean	*Vicia faba* L.	1.6	9.6	MS
Corn	*Zea mays* L.	1.7	12.	MS
Cotton	*Gossypium hirsutum* L.	7.7	5.2	T
Cowpea	*Vigna unguiculata* (L.) Walp	4.9	12.	MT
Flax	*Linum usitatissimum* L.	1.7	12.	MS
Guar	*Cyamopsis tetragonolaba* (L.) Taub			MT
Millet, foxtail	*Setaria italica* (L.) Beauvois	–	–	MS
Oat	*Avena sativa* L.			MT*
Peanut	*Arachis hypogaea* L.	3.2	29.	MS
Rice, paddy††		3.0‡‡	12.‡‡	S
Rye	*Secale cereale* L.	–	–	MT*
Safflower	*Carthamus tinctorius* L.	–	–	MT
Sesame	*Sesamum indicum* L.	–	–	S
Sorghum	*Sorghum bicolor* (L.) Moench	6.8	16.	MT
Soybean	*Glycine max* (L.) Merrill	5.0	20.	MT
Sugarbeet§§	*Beta vulgaris* L.	7.0	5.9	T
Sugarcane	*Saccharum officinarum* L.	1.7	5.9	MS
Sunflower	*Helianthus annuus* L.	–	–	MS*
Triticale	*X Triticosecale*			T
Wheat#	*Triticum aestivum* L.	6.0	7.1	MT
Wheat (semidwarf)¶¶	*T. aestivum* L.	8.6	3.0	T
Wheat, durum	*T. durum* Desf.	5.9	3.8	T
	Grasses and forage crops			
Alfalfa		2.0	7.3	MS
Alkaligrass, Nuttall	*Puccinellia airoides* (Nutt.)	–	–	T*
Alkali sacaton	*Sporobolus airoides*	–	–	T*
Barley (forage)#		6.0	7.1	MT
Bentgrass	*Agrostis stolonifera* L., *palustris*	–	–	MS
Bermudagrass##	*Cynodon dactylon* L.	6.9	6.4	T
Bluestem, Angleton	*Dichanthium aristatum* (Poir) C.E. Hubb.	–	–	MS*
Brome, mountain	*Bromus marginatus* Nees ex Steud.	–	–	MT*
Brome, smooth	*B. inermis* Leyss	–	–	MS
Buffelgrass	*Cenchrus ciliaris* L.	–	–	MS*
Burnet	*Poterium sanguisorba*	–	–	MS*
Canarygrass, reed	*Phalaris arundinacea* L.	–	–	MT
Clover, alsike	*Trifolium hybridum* L.	1.5	12.	MS
Clover, berseem	*T. alexandrinum* L.	1.5	5.7	MS
Clover, hubam	*Melilotus alba*	–	–	MT*
Clover, ladino	*Trifolium repens* L.	1.5	12.	MS
Clover, red	*T. pratense* L.	1.5	12.	MS
Clover, strawberry	*T. fragiferum* L.	1.5	12.	MS
Clover, sweet	*Melilotus* Mill.	–	–	MT*
Clover, white Dutch	*Trifolium repens* L.	–	–	MS*
Corn (forage)		1.8	7.4	MS
Cowpea (forage)		2.5	11.	MS
Dallisgrass	*Paspalum dilotatum* Poir.	–	–	MS*
Fescue, meadow	*F. pratensis* Huds.	–	–	MT*
Fescue, tall	*Festuca arundinacea* Schreb.	3.9	5.3	MT
Foxtail, meadow	*Alopecurus pratensis* L.	1.5	9.6	MS
Grama, blue	*Bouteloua gracilis* (HBK) Leg.	–	–	MS*
Harding grass	*Phalaris stenoptera* L.	4.6	7.6	MT
Kallargrass	*Diplachne fusca*	–	–	T*
Lovegrass†††	*Eragrostis* sp. n.m. Wolf	2.0	8.4	MS
Milkvetch, cicer	*Astragalus cicer* L.	–	–	MS*
Oatgrass, tall	*Arrhenatherum elatius* Beauvois, Danthonia	–	–	MS*
Oats (forage)		–	–	MS*
Orchardgrass	*Dactylis glomerata* L.	1.5	6.2	MS
Panicgrass, blue	*Panicum antidatale* Retz.	–	–	MT*
Rape	*Brassica napus* L.	–	–	MT*
Rescuegrass	*Bromus unioloides* HBK	–	–	MT*
Rhodesgrass	*Chloris gayana* Kunth	–	–	MT
Rye (forage)	*Secale cereale* L.	–	–	MS*
Ryegrass, Italian	*Lolium italicum* L. *multiflorum*	–	–	MT*
Ryegrass, perennial	*L. perenne* L.	5.6	7.6	MT
Saltgrass, desert	*Distichlis stricta*	–	–	T*
Sesbania††	*Sesbania exaltata* (Raf.) V.L.Cory	2.3	7.0	MS
Siratro	*Macroptilium atropurpureum* (DC.)	–	–	MS
Sphaerophysa	*Sphaerophysa salsula*	2.2	7.0	MS
Sudangrass	*Sorghum sudanense* (Pipee) Stapf	2.8	4.3	MT
Timothy	*Phleum pratense* L.	–	–	MS*
Trefoil, big	*Lotus uliginosus* L.	2.3	19.	MS
Trefoil, narrowleaf birdsfoot	*L. corniculatus* L., *tenuifolium*	5.0	10.	MT
Trefoil, broadleaf birdsfoot‡‡‡	*L. corniculatus* L., *arvenis*	–	–	MT
Vetch, common	*Vicia sativa* L.	3.0	11.	MS
Wheat (forage)¶¶		4.5	2.6	MT
Wheat, durum (forage)	*T. durum*	2.1	2.5	MT
Wheatgrass, standard crested	*Agropyron desertorum* A.	3.5	4.0	MT
Wheatgrass, fairway crested	*A. cristatum* (L.) Gaertn.	7.5	6.9	T
Wheatgrass, intermediate	*A. intermedium* (Host) Beauv.	–	–	MT*
Wheatgrass, slender	*A. trachycaulum* (Link) Malte	–	–	MT
Wheatgrass, tall	*A. elongatum* (Hort) Beauv.	7.5	4.2	T
Wheatgrass, western	*A. smithii* Rydb.	–	–	MT*
Wildrye, Altai	*Elymus angustus* Trin.	–	–	T
Wildrye, beardless	*E. triticoides* Buckl.	2.7	6.0	MT
Wildrye, Canadian	*E. canadensis* L.	–	–	MT*
Wildrye, Russian	*Psathyrostachys juncea* (Fisch.)	–	–	T
	Vegetable and fruit crops			
Artichoke, Jerusalem	*Helianthus tuberosus* L.	–	–	MT*
Asparagus	*Asparagus officinalis* L.	–	–	T
Bean	*Phaseolus vulgaris* L.	1.0	19.	S
Beet, red§§	*Beta vulgaris* L.	4.0	9.0	MT
Broccoli	*Brassica oleracea* B., *Botrytis*	2.8	9.2	MS
Brussels sprouts	*B. oleracea gemmifera* B.	–	–	MS*
Cabbage	*B. oleracea capitata* B.	1.8	9.7	MS
Carrot		1.0	14.	S
Cauliflower	*Brassica oleracea* B., *botrytis*	–	–	MS*
Celery	*Apium graveolens* L.	1.8	6.2	MS
Corn, sweet		1.7	12.	MS
Cucumber	*Cucumis sativus* L.	2.5	13.	MS
Eggplant	*Solanum melongena* L.	–	–	MS*
Kale	*Brassica oleracea* B., *acephala*	–	–	MS*
Kohlrabi	*B. oleracea gongylode*	–	–	MS*
Lettuce	*Lactuca sativa* L.	1.3	13.	MS
Muskmelon	*Cucumis melo* L.	–	–	MS
Okra	*Abelmoschus esculentus* (L.) Moench	–	–	S
Onion	*Allium cepa* L.	1.2	16.	S
Parsnip	*Pastinaca sativa* L.	–	–	S*
Pea	*Pisum sativum* L.	–	–	S*
Pepper	*Capsicum annuum* L.	1.5	14.	MS
Potato	*Solanum tuberosum* L.	1.7	12.	MS
Pumpkin	*Cucurbita pepo pepo* L.	–	–	MS*
Radish	*Raphanus sativus* L.	1.2	13.	MS
Spinach	*Spinacia oleracea* L.	2.0	7.6	MS
Squash, scallop	*Cucurbita pepo melopepo*	3.2	16.	MS
Squash, zucchini		4.7	9.4	MT
Strawberry	*Fragaria* sp. L.	1.0	33.	S
Sweet potato	*Ipomoea batatas* (L.) Lom.	1.5	11.	MS
Tomato		2.5	9.9	MS
Turnip	*Brassica rapa* L.	0.9	9.0	MS
Watermelon	*Citrullus lanatus* (Thunb.)	–	–	MS*

Source: in Stewart ed. 1990

Table 3-34b

† These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions, and cultural practices.
‡ Botanical and common names follow the convention of *Hortus Third* where possible.
§ In gypsiferous soils, plants will tolerate EC_e's about 2 dS/m higher than indicated.
¶ Ratings are defined by the boundaries in Fig. 36-1. Ratings with an * are estimates. For references consult the indexed bibliography by Francois and Maas (1985).
# Less tolerant during emergence and seedling stage. EC_e at this stage should not exceed 4 or 5 dS/m.
†† Less tolerant during emergence and seedling stage.
‡‡ Because paddy rice is grown under flooded conditions, values refer to the electrical conductivity of the soil water while the plants are submerged.
§§ Sensitive during germination. EC_e should not exceed 3 dS/m.

Table 36-2. Salt tolerance of woody crops.†

Crop		Electrical conductivity of saturated soil extract		
Common name	Botanical name‡	Threshold§	Slope	Rating¶
		dS/m	% per dS/m	
Almond#	*Prunus dulcis* (Mill.)	1.5	19	S
Apple	*Malus sylvestris* Mill.	–	–	S
Apricot#	*Prunus armeniaca* L.	1.6	24	S
Avocado#		–	–	S
Blackberry	*Rubus* spp.	1.5	22	S
Boysenberry	*Rubus ursinus* Cham. and Schlechtend	1.5	22	S
Castorbean	*Ricinus communis* L.	–	–	MS*
Cherimoya	*Annona cherimola* Mill.	–	–	S*
Cherry, sweet	*Prunus avium* L.	–	–	S*
Cherry, sand	*P. besseyi* L.	–	–	S*
Currant	*Ribes* sp.	–	–	S*
Date palm	*Phoenix doctylifera* L.	4.0	3.6	T
Fig	*Ficus carica* L.	–	–	MT*
Gooseberry	*Ribes* sp.	–	–	S*
Grape#	*Vitis* sp.	1.5	9.6	MS
Grapefruit	*Citrus paradisi* Macfad.	1.8	16	S
Guayule		–	–	T
Jojoba#	*Simmondsia chinensis* (Link) C. Schneid.	–	–	T
Jujube	*Ziziphus jujuba* Mill.	–	–	MT*
Lemon#	*Citrus limon* (L.) Burm. f.	–	–	S
Lime	*C. aurantiifolia* (Christm.) Swingle	–	–	S*
Loquat	*Eriobotrya japonica*	–	–	S*
Mango	*Mangifera indica* L.	–	–	S*
Olive	*Olea europaea* L.	–	–	MT
Orange	*Citrus sinensis* (L.) Oab.	1.7	16	S
Papaya#	*Carica papaya* L.	–	–	MT
Passion-fruit	*Passiflora mollissima* (HBK) L.H. Bailey	–	–	S*
Peach	*Prunus persica* (L.) Batsch	1.7	21	S
Pear	*Pyrus communis* L.	–	–	S*
Persimmon	*Diospyros virginiana* L.	–	–	S*
Pineapple	*Ananas comosus* (L.) Merr.	–	–	MT*
Plum; Prune#	*Prunus domestica* L.	1.5	18	S
Pomegranate	*Punica granatum* L.	–	–	MT*
Pummelo	*Citrus grandis* C.	–	–	S*
Raspberry	*Rubus idaeus* L.	–	–	S
Rose apple	*Syzygium jambos* (L.) Alston	–	–	S*
Sapote, white	*Casimiroa edulis* Llave	–	–	S*
Tangerine	*Citrus reticulata* Blanco	–	–	S*

† These data are applicable when rootstocks are used that do not accumulate Na or Cl rapidly or when these ions do not predominate in the soil.
‡ Botanical and common names follow the convention of *Hortus Third* where possible.
§ In gypsiferous soils plants will tolerate EC_e's about 2 dS/m higher than indicated.
¶ Ratings are defined by the boundaries in Fig. 36-1. Ratings with an * are estimates. For references consult the indexed bibliography by Francois and Maas (1985).
# Tolerance is based on growth rather than yield.

Table 1. Salinity Threshold Values and Yield Decreases

Crop	Threshold Value EC_{ex} in mmhos/cm	Yield Decrease per mmhos/cm in kg/feddan
Cotton	6.5	150
Wheat	4.5	200
Barley	5.0-5.0	180
Clover	2.5-3.0	650
Rice	3.5	250

Table 3-35a

Table 2. Expected Yield Decrease for Certain Crops due to Salinity of Irrigation Water

Crop	Salinity of Irrigation Water (ppm)	Yield Decrease
Cotton	2 000	0
	4 000	18%
	6 000	25%
	8 000	50%
	10 000	75%
Wheat	3 000	20%
	4 000	35%
	6 000	70%
	8 000	100%
Barley	3 000	10%
	5 000	40%
	7 000	50%
	12 000	75%
Clover	1 000	6%
	2 000	20%
	4 000	60%
Rice	1 500	15%
	2 000	45%
	4 000	60%

Table 3-35b

Source: El-Guindi/Abu Bakr in ICID (STS-C16) 1991

Table 36-4. Relative salt tolerance of various crops at emergence and during growth to maturity. After Maas (1986).

Common name†	Electrical conductivity of saturated soil extract: 50% Yield‡	50% Emergence‡
	dS/m	dS/m
Barley	18	16–24
Cotton	17	15
Sugarbeet	15	6–12
Sorghum	15	13
Safflower	14	12
Wheat	13	14–16
Beet, red	9.6	13.8
Cowpea	9.1	16
Alfalfa	8.9	8–13
Tomato	7.6	7.6
Cabbage	7.0	13
Corn	5.9	21–24
Lettuce	5.2	11
Onion	4.3	5.6–7.5
Rice	3.6	18
Bean	3.6	6.0

† Common names follow the convention of *Hortus Third* where possible.
‡ Emergence percentage of saline treatments determined when nonsaline control treatments attained maximum emergence.

Source: in Stewart ed. 1990

Table 3-36

Table 2 RELATIVE TOLERANCE OF SPRINKLER CROPS TO SALINITY IMPINGING ON THE LEAVES OR ROOTS. SALINITY LEVELS ARE EXPRESSED AS THE ELECTRICAL CONDUCTIVITY OF THE IRRIGATION WATER (EC_i) (from Maas 1985)

Crop	Salinity threshold: Max. EC_i without injury from foliarly-absorbed salts[1] (dS/m)	Max. EC_i without detrimental soil salinity effects[2] (dS/m)
Almond	< 0.5	1.0
Apricot	< 0.5	1.1
Citrus	< 0.5	1.1
Plum	< 0.5	1.0
Grape	0.5-1.0	1.0
Pepper	0.5-1.0	1.0
Potato	0.5-1.0	1.1
Tomato	0.5-1.0	1.7
Alfalfa	1.0-2.0	1.3
Barley	1.0-2.0	5.3
Maize	1.0-2.0	1.1
Cucumber	1.0-2.0	1.7
Safflower	1.0-2.0	
Sesame	1.0-2.0	
Sorghum	1.0-2.0	4.5
Strawberry	2.0-4.0	0.7
Cauliflower	3.0-6.0	
Cotton	3.0-6.0	5.1
Sugarbeet	3.0-6.0	4.7
Sunflower	3.0-6.0	

[1] Saline water (primarily NaCl) with EC_i values higher than the threshold is expected to cause foliar injurt on crops sprinkled 5 hours or more each week during the irrigation season. The degree of injury is influenced by the cultural and environmental conditions.

Table 3-37

Source: Kandiah ed. 1990

Table 3-38

3.5. Management Practices to Control Soil Salinity and Water Quality

i. On-farm management

Management measures should not be considered in isolation but should be developed in an integrated manner to optimize water use, minimize drainage and increase crop yields within the limits of the physical and social environment.

Three general management strategies seem practical: (i) control salinity within permissible levels, (ii) change conditions to improve crop response, (iii) change management to maintain yield at the field level when salinity causes damage at the plant level. All three can be used together. The first is the most commonly used.

Crop management

1. In the near future, crop management with respect to salt tolerance should concentrate on the choice of appropriate crop species rather than on major conventional breeding efforts within species. In the longer term, wide crosses and genetic engineering methods might give more promising results in terms of improved cultivar tolerance within a species.

2. Appropriate seed placement in respect to irrigation methods can minimize salt accumulation around the seed and improve germination and seedling establishment.

3. Increasing seeding rates can compensate for reduced crop establishment resulting from salt stress or surface crusting.

4. Increased crop density can compensate for the effect of reduced plant size on the field level yield.

5. The crop response function can be changed through reducing the stress level in the plant under a given salinity by growing the crop in a region of milder climate, using protected environments, changing irrigation method or enhancing CO_2 enrichment, etc.

Water management

1. Issues of irrigation water application and of leaching should be considered as distinct.

2. Irrigating with water of different qualities separately offers more benefit compared with traditional blending. Higher efficiency can be achieved by using non-saline water at sensitive growth stages or for sensitive crops in alternation with saline water during the remainder of the growing period or tolerant crops in a rotation.

3. For each kind of saline irrigation water, coupled with the availability of fresh water, appropriate crop rotations need to be worked out in order to: (a) make optimal use of both fresh and saline water; (b) periodically, restore the soil to its original state; (c) minimize the volume of unusable drainage effluent that must be disposed of; and (d) optimize crop yields under the given situation.

4. The temporal and spatial average salinity in the actual root zone may be considered as a first approximation of effective salinity at each stage of plant growth. When starting with a low salt profile, management of the saline water should concentrate on minimizing drainage volumes by delaying leaching, allowing salinity to build up to permissible values (physical or economic) before it is removed from the soil by seasonal or annual leaching.

5. Seasonal leaching should control salinity to the desired depth. It is more effective with respect to salt removal, and it can be applied at optimal timing with respect to crop requirements, physical conditions for leaching and water value.

6. When seasonal rainfall can leach the soil profile, a no-leaching irrigation strategy within the season may be optimal.

7. The benefit of increased irrigation frequency for saline water is still controversial; it was found effective in sands but not on medium textured soils. Further research is required on this aspect of water management.

8. Where irrigation systems such as drip or furrow accumulate salts in upper layers, rainfall or changing irrigation position may result in significant damage by washing salt into the root zone.

9. Even with high-efficiency irrigation, a certain leaching fraction is essential over the long term. Wherever there is shallow groundwater or a perched water table, this will require on-farm drainage. Effluent from on-farm drainage, whether by surface or subsurface drains, without or with mole drains, can be reused on appropriately tolerant crops. This would reduce the effective net drainage volume to be dealt with at system level.

Source: Kandiah ed. 1990

Table 3-38 cont.

Fertility management

1. Normal soil analysis guidelines also apply to land irrigated with saline water. For soils affected by sodium bicarbonate water, pH is of particular importance. Salinity tends to lower fertilizer efficiencies, increase rates of fertilizer loss and decrease the efficiency of rhizobium nodulation. Appropriate timing and placement of fertilizers, adjusting the timing of leaching treatments, as well as choice of slow-release fertilizers can improve efficiency of fertilizer use.

2. Organic manures, where it is practical to use them, are beneficial through increasing structural stability and infiltration rates, slow release of nutrient elements and some lowering of pH and calcium release from $CaCO_3$. However, they do not appear to counteract sodication in all cases; further research is required in this regard.

3. There is no clear evidence that damage through salinity can be overcome by the addition of K or NO_3. The salinizing effect of heavy applications of soluble fertilizers should be recognized.

Soil management

1. Precision levelling in basin or furrow systems is essential for uniform water application, leaching and efficient salinity control.

2. Appropriate tillage is needed to prepare for seeding, to improve soil permeability, to break up surface crusts and to improve water infiltration. Sub-soiling may be beneficial on soils having an impermeable layer, hard pan or compacted layer in the root zone. Deep ploughing may be harmful where saline or sodic soil is brought up to the surface.

3. Where there is a rainy season or where non-saline water is used following irrigation with saline water, special management is needed to prevent problems from slaking, crusting, slow infiltration and poor seedling emergence. Options include (a) a first application of water with intermediate salinity, (b) application of gypsum or other amendments with irrigation water either on the soil surface, or by mixing in the topsoil and (c) possibly, very small applications of soil conditioners in nonswelling soils. Further research is needed to evaluate soil conditioners that might be effective in swelling soils.

4. Use of highly alkaline water cannot be sustained, except with the use of appropriate amendments and good management practices. Further research is needed to develop criteria and standards for assessing hazards from use of alkaline water.

5. After harvest, immediate shallow cultivation with crop residues left on the surface where feasible and other mulching practices minimize wasteful evapotranspiration and the accumulation of salts in the surface.

ii. System level management

1. In the design of new irrigation areas prior questions should be asked including (a) whether different water qualities should be made available to farmers and if so, in fixed sequence or on demand; and (b) if certain drainage waters are to be reused or if all drainage water is to be safely disposed of.

2. The drainage water from sensitive crops could be reused for progressively more tolerant crops, until no further use is possible, in order to maximize crop production and income, to optimize water use efficiency, to keep drainage volume minimal and to minimize disposal or treatment costs.

3. Halophytic crops could be produced using water too saline for conventional agricultural crops, this would at the same time further reduce final drainage volume. The choice of crops for the less saline water would be somewhat wider, including some eucalypts.

4. If horizontal drainage is used effectively to skim off effluent for reuse, as in the case of perched water tables, the natural groundwater quality would be protected from salinization and pollution. However, if this water is not intercepted but allowed to mix with deeper water, as in the case of tubewells, then quality problems may be greater.

5. Options to manage drainage effluents include: on-farm reuse for a variety of salt-tolerant crops, use on halophytic crops or vegetation, 'harvesting' of toxic ions by certain plants (toxic ion scavengers), disposal into evaporation ponds, direct discharge into the ocean or into rivers at high stages with surplus flow.

iii. Basin level management

Strategies for the efficient use of water supplies in a drainage basin including saline and non-saline water should aim to:

- conserve usable water supplies;
- maximize effectiveness of using each water resource;
- minimize drainage volume and maximize salt concentration of drainage water from agricultural land;
- leave unusable saline groundwaters undisturbed as far as possible.

These strategies will minimize off-site impacts of irrigation.

Water quality management policies and programmes should take into consideration the drainage basin as a whole. Policies at the level of canal commands and management at the level of individual farms should be as compatible as possible within this overall drainage basin policy.

Table 3-39

Table 36-10. Equivalent amounts of common amendments for reclaiming sodic soils.

Amendment	Amount equivalent to 1 kg gypsum
	kg
Gypsum	1.00
S	0.19
H_2SO_4	0.57
CaS_5 (24% S)	0.77
$CaCO_3$	0.58
Calcinm chloride dihydrate ($CaCl_2 \cdot 2H_2O$)	0.85
Ferrous sulfate ($FeSO_4$)	1.61
Aluminum sulfate [$Al_2(SO_4)_3$]	1.29

Source: in Stewart ed. 1990

Table 3-40a

Genetic type	Relation with groundwater	Water soluble salt content in the surface layers in saturation extract	Amelioration*
1 solonchak-solonetz meadow solonetz meadow solod (shallow and middle)	permanently linked	more than 0.2% (about 4 mmhos/cm)	drainage and chemical amendments
2 meadow solonetz and solod soils turning into steppe formation	temporarily linked	about 0.2% (about 4 mmhos/cm)	chemical amendments, deep ploughing and drainage if necessary
3 deep solonetz and solod soils, solonetz-like meadow soils	not linked	less than 0.2% (about 4 mmhos/cm)	low amount of chemical amendments proper agrotechnics and suitable crop (deep ploughing, alfalfa, etc.)

* The necessity of irrigation depends on local conditions

Tab. 2: *A schematic grouping of solonetz and solod soils with regard to their amelioration.*

Source: Szabolcs 1989

Table 3-40b

TABLE 21. Schematic grouping of solonetz and solod soils and suggested methods of amelioration.

Genetic type	Relation with ground water	Water-soluble salt content in the surface layer	Amelioration[1]
1. Solonchak-solonetz Meadow solonetz Meadow solod (shallow and middle)	Permanently linked	More than 0.2 per cent (about 4 mmhos)	Drainage and chemical amendments
2. Meadow solonetz and solod soils turning into steppe formation	Temporarily linked	About 0.2 per cent	Chemical amendments, deep ploughing and drainage if necessary
3. Deep solonetz and solod soils Solonetz-like meadow soils	Not linked	Less than 0.2 per cent	Low amount of chemical amendments, proper agrotechnics (deep and suitable crop (alfalfa, etc.) ploughing)

1. The necessity for irrigation depends on local conditions.

Source: Szabolcs 1979

Table 3-41

Table 8.3. Soil conservation practices

Practice	Control over					
	Rainsplash		Runoff		Wind	
	D	T	D	T	D	T
Agronomic measures						
Covering soil surface	*	*	*	*	*	*
Increasing surface roughness	–	–	*	*	*	*
Increasing surface depression storage	+	+	*	*	–	–
Increasing infiltration	–	–	+	*	–	–
Soil Management						
Fertilizers, manures	+	+	+	*	+	*
Subsoiling, drainage	–	–	+	*	–	–
Mechanical Measures						
Contouring, ridging	–	+	+	*	+	*
Terraces	–	+	+	*	–	–
Shelterbelts	–	–	–	–	*	*
Waterways	–	–	+	*	–	–

– no control; + moderate control; * strong control (adapted and enlarged from Voetberg, 1970)
D = Detachment, T = Transport.

Source: Kirkby/Morgan ed. 1980

Table 4-1

Table 2 Health Protection Measures: Overview of the Practice

Country/Location	Kind of Reuse	Health Protection Measures Practised
MEXICO Mezquital Valley	Irrigation of alfalfa, maize, cereal crops, tomatoes and beans mostly with untreated wastewater	Crop restriction, some exposure control for agricultural workers
CHILE Santiago	Irrigation of raw-eaten vegetables, cereal crops and grapes with untreated wastewater	None (treatment being planned)
INDIA Kanpur	Irrigation of rice, wheat, forage and flowers with diluted untreated wastewater	None
Calcutta	Fish growing in ponds receiving untreated wastewater at low loading rates	Cooking of the fish
PERU Lima (S. Martin de P.)	Irrigation of vegetables and non-food crops with raw wastewater	None
Ica (Cachiche)	Irrigation of maize and cotton with primary pond effluent	Partial wastewater treatment and crop restriction
Tacna	Irrigation of maize, alfalfa and fruit trees with effluent from overloaded WSP	Partial treatment and crop restriction
ARGENTINA Mendoza	Irrigation of raw-eaten vegetables with settled sewage	Partial treatment
TUNISIA Tunis	Irrigation of non-vegetable crops and fruit trees with secondary effluent	Partial treatment and crop restriction
SAUDI ARABIA Riyadh	Irrigation of wheat, forage and date palms with tertiary (filtered and chlorinated) effluent	Full treatment and crop restriction
SOUTH KOREA Pusan	Use of sludge from nightsoil treatment plants in agriculture	Dewatering and composting of the sludge
JORDAN Wadi Dhuleil area	Indirect use of the Al-Samra/Amman WSP effluent for the irrigation of trees, fodder and industrial crops	Full wastewater treatment, seasonal dilution and crop restriction
Zarqa Valley (downstream of Jerash bridge)	Indirect use of WSP and STP effluent for unrestricted vegetable irrigation	Full/partial treatment and seasonal dilution
Salt (Wadi Shu'eib)	Indirect use of STP effluent for the irrigation of vegetables eaten cooked	Partial treatment, seasonal dilution and crop restrictions

Source: Shuval (WB) 1991 (?)

Table 4-2/1

Figure 1-4. Example of a summary assessment.

Project Title	An example
Project Type	Commercial Irrigation
Location	Somewhere in Africa
Date of Assessment	month/year
Community Group	Construction workers
Project Phase	Construction phase

Disease	Vulnerability of community	Receptivity of environment	Vigilance of health services	Health Hazard
Malaria (*falciparum*)	high	moderate	treatment only	high
Schistosomiasis (*mansoni*)	low	moderate	none	low
Filariasis (onchocerciasis)	low	none	none	none

For example

The accompanying worksheet (figure 1-4 on page 1- 11) indicates how the assessment might have been completed for the construction phase of an irrigation scheme somewhere in Africa. The summary could be interpreted as follows:

Malaria is expected to represent a health hazard during the construction phase because susceptible people will be exposed to the vector and no preventative measures are planned. A large percentage of the workforce may be incapacitated.

Schistosomiasis does not occur near the project site but a potential vector is present. The health hazard is moderate but will increase unless immigrants or construction workers and their families are screened on arrival for infection, or other preventative measures are instigated.

Onchocerciasis occurs in the region but there is no vector at the project site and none is expected to become established during construction.

Such a summary assessment is insufficient in itself. Each conclusion must be justified by reference to the answers obtained to the questions in the flowchart.

Source: Birley 1992

Table 4-2/2 to 6

see next pages

Table 1-5

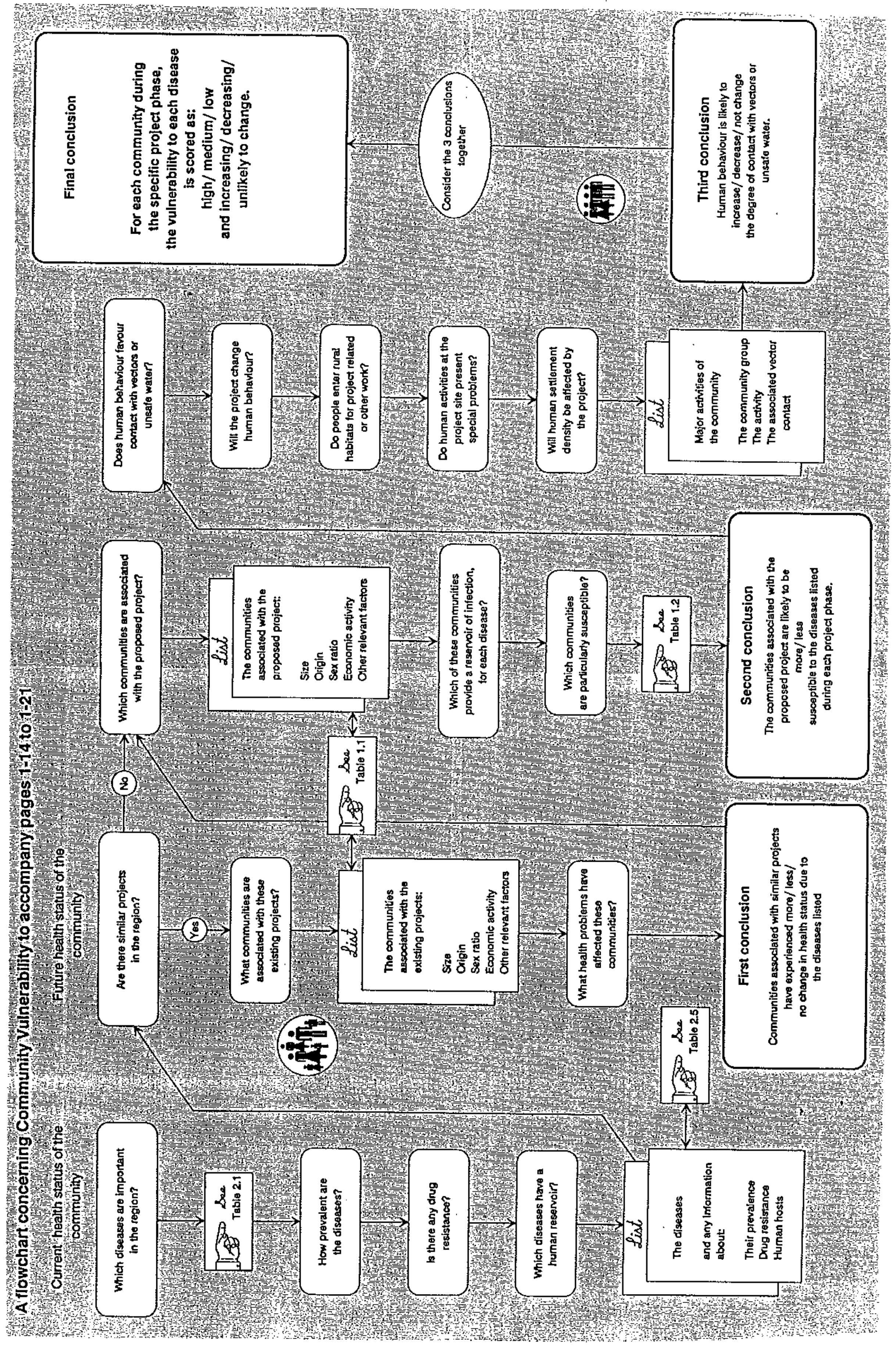
The flight range of vectors (kms). Migratory flights are often aided by prevailing winds and occasionally much longer flights have been recorded. Local movement is indicated as a guide to settlement siting. Where a range is indicated, the majority of vectors will only travel the shorter distance.

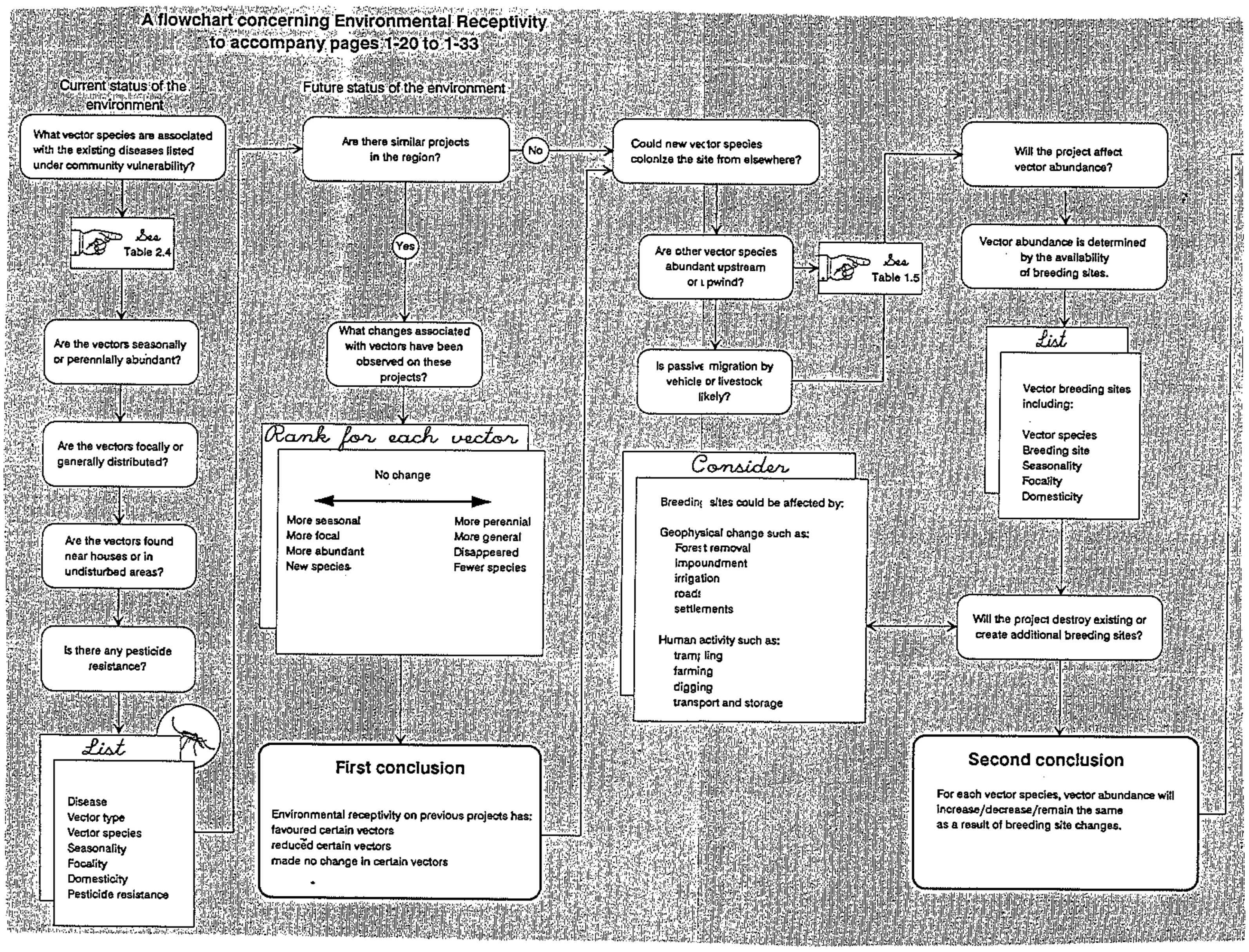
Vector	Local movement	Migration
Simuliid blackflies	4-10	400
Anopheline mosquitoes	1.5-2.0	50
Culicine mosquitoes	0.1-8.0	50
Tsetse	2.0-4.0	10
Phlebotomine sandflies	.05-0.5	1

Source: Birley 1992

Table 4-3

Table 4-2/2




A flowchart concerning Environmental Receptivity
to accompany pages 1-20 to 1-33
Current status of the environment
Future status of the environment
What vector species are associated with the existing diseases listed under community vulnerability?
See Table 2.4
Are the vectors seasonally or perennially abundant?
Are the vectors focally or generally distributed?
Are the vectors found near houses or in undisturbed areas?
Is there any pesticide resistance?
List
Disease
Vector type
Vector species
Seasonality
Focality
Domesticity
Pesticide resistance
Are there similar projects in the region?
Yes
No
What changes associated with vectors have been observed on these projects?
Rank for each vector
No change
More seasonal
More focal
More abundant
New species
More perennial
More general
Disappeared
Fewer species
First conclusion
Environmental receptivity on previous projects has:
favoured certain vectors
reduced certain vectors
made no change in certain vectors
Could new vector species colonize the site from elsewhere?
Are other vector species abundant upstream or upwind?
See Table 1.5
Is passive migration by vehicle or livestock likely?
Consider
Breeding sites could be affected by:
Geophysical change such as:
Forest removal
impoundment
irrigation
roads
settlements
Human activity such as:
tramping
farming
digging
transport and storage
Will the project affect vector abundance?
Vector abundance is determined by the availability of breeding sites.
List
Vector breeding sites including:
Vector species
Breeding site
Seasonality
Focality
Domesticity
Will the project destroy existing or create additional breeding sites?
Second conclusion
For each vector species, vector abundance will increase/decrease/remain the same as a result of breeding site changes.

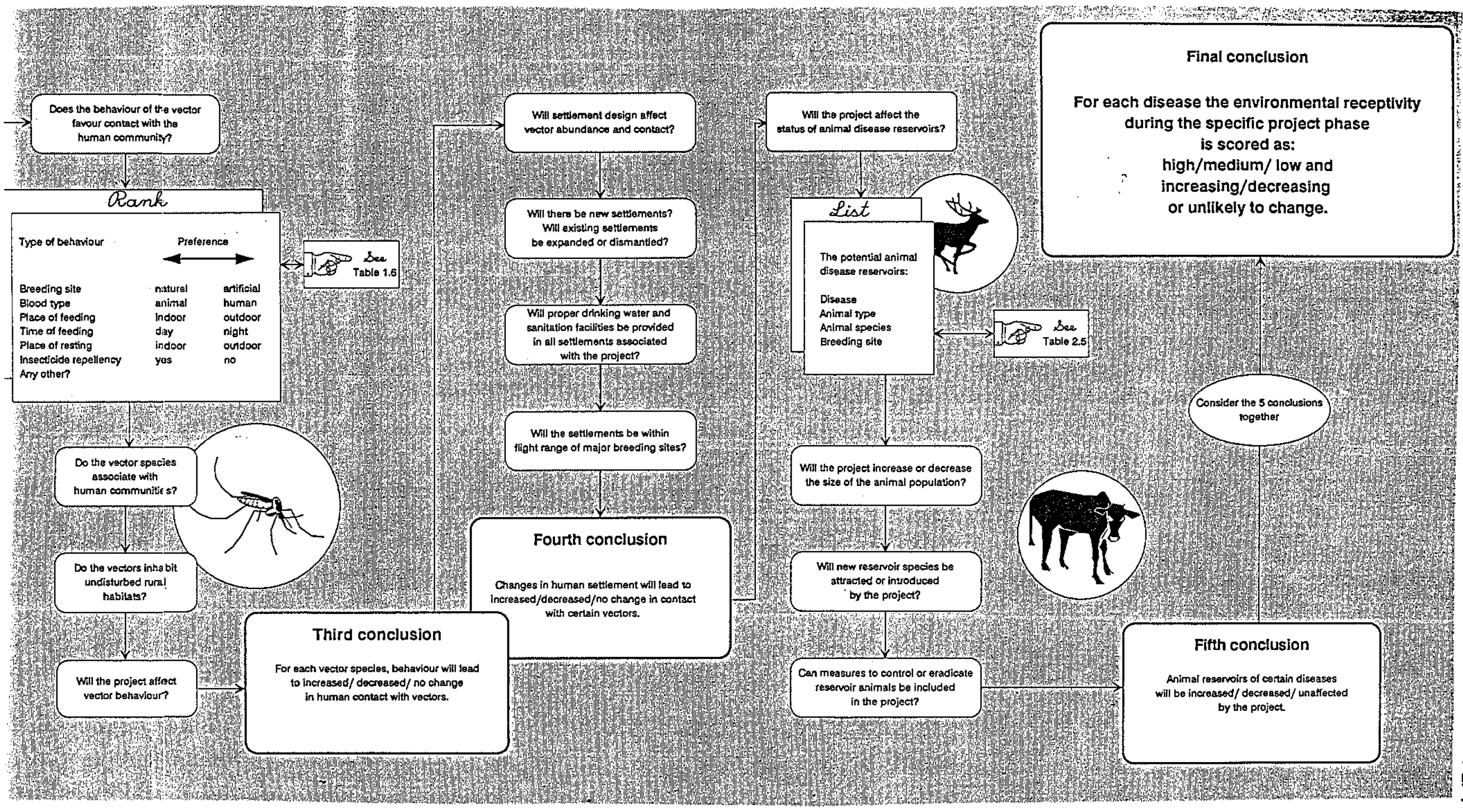

Does the behaviour of the vector favour contact with the human community?
Rank
Type of behaviour
Preference
Breeding site natural artificial
Blood type animal human
Place of feeding indoor outdoor
Time of feeding day night
Place of resting indoor outdoor
Insecticide repellency yes no
Any other?
See Table 1.6
Do the vector species associate with human communities?
Do the vectors inhabit undisturbed rural habitats?
Will the project affect vector behaviour?
Third conclusion
For each vector species, behaviour will lead to increased/ decreased/ no change in human contact with vectors.
Will settlement design affect vector abundance and contact?
Will there be new settlements? Will existing settlements be expanded or dismantled?
Will proper drinking water and sanitation facilities be provided in all settlements associated with the project?
Will the settlements be within flight range of major breeding sites?
Fourth conclusion
Changes in human settlement will lead to increased/decreased/no change in contact with certain vectors.
Will the project affect the status of animal disease reservoirs?
List
The potential animal disease reservoirs:
Disease
Animal type
Animal species
Breeding site
See Table 2.5
Will the project increase or decrease the size of the animal population?
Will new reservoir species be attracted or introduced by the project?
Can measures to control or eradicate reservoir animals be included in the project?
Fifth conclusion
Animal reservoirs of certain diseases will be increased/ decreased/ unaffected by the project.
Consider the 5 conclusions together
Final conclusion
For each disease the environmental receptivity during the specific project phase is scored as:
high/medium/ low and
increasing/decreasing
or unlikely to change.

Table 4-2/5

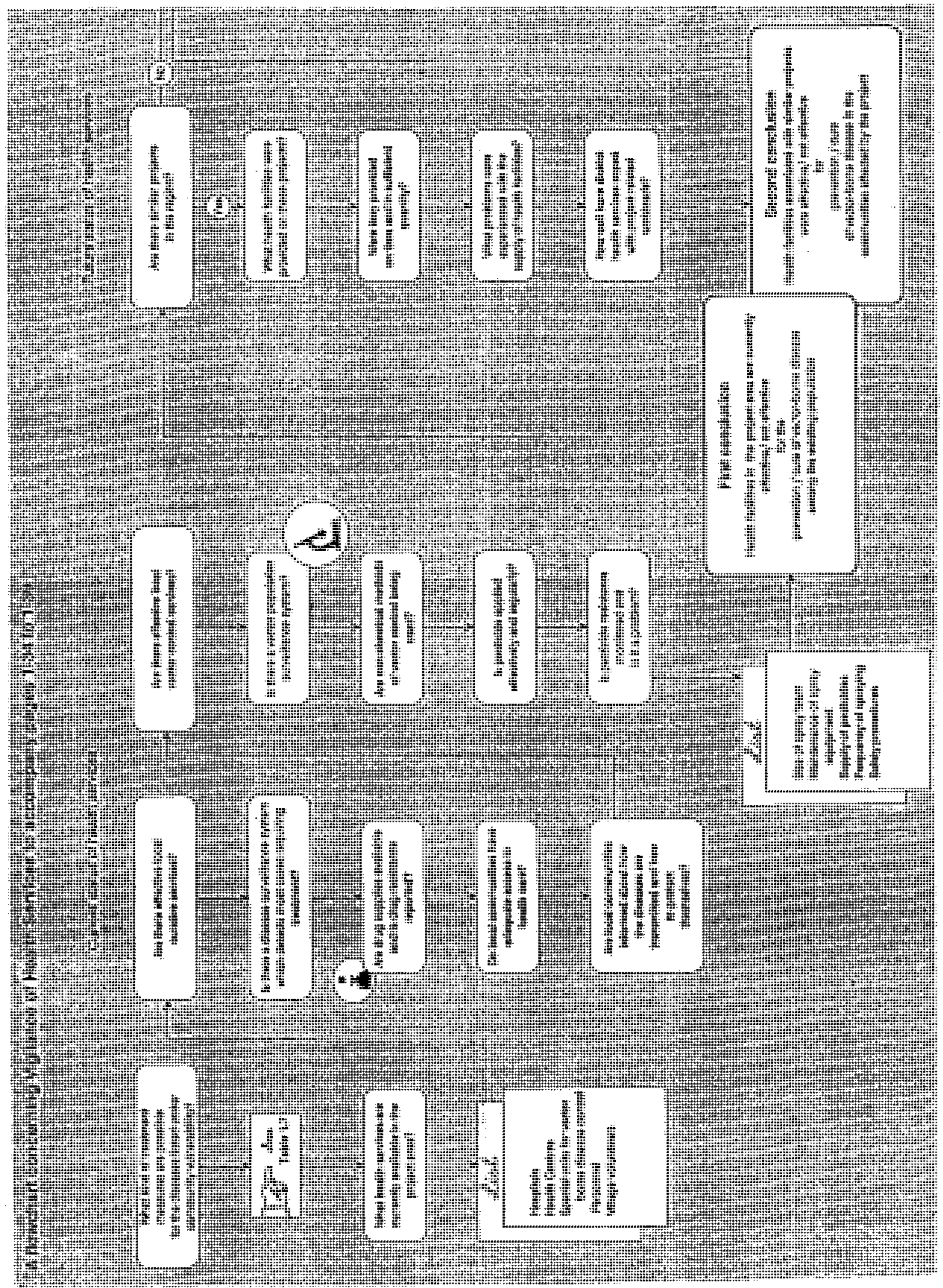
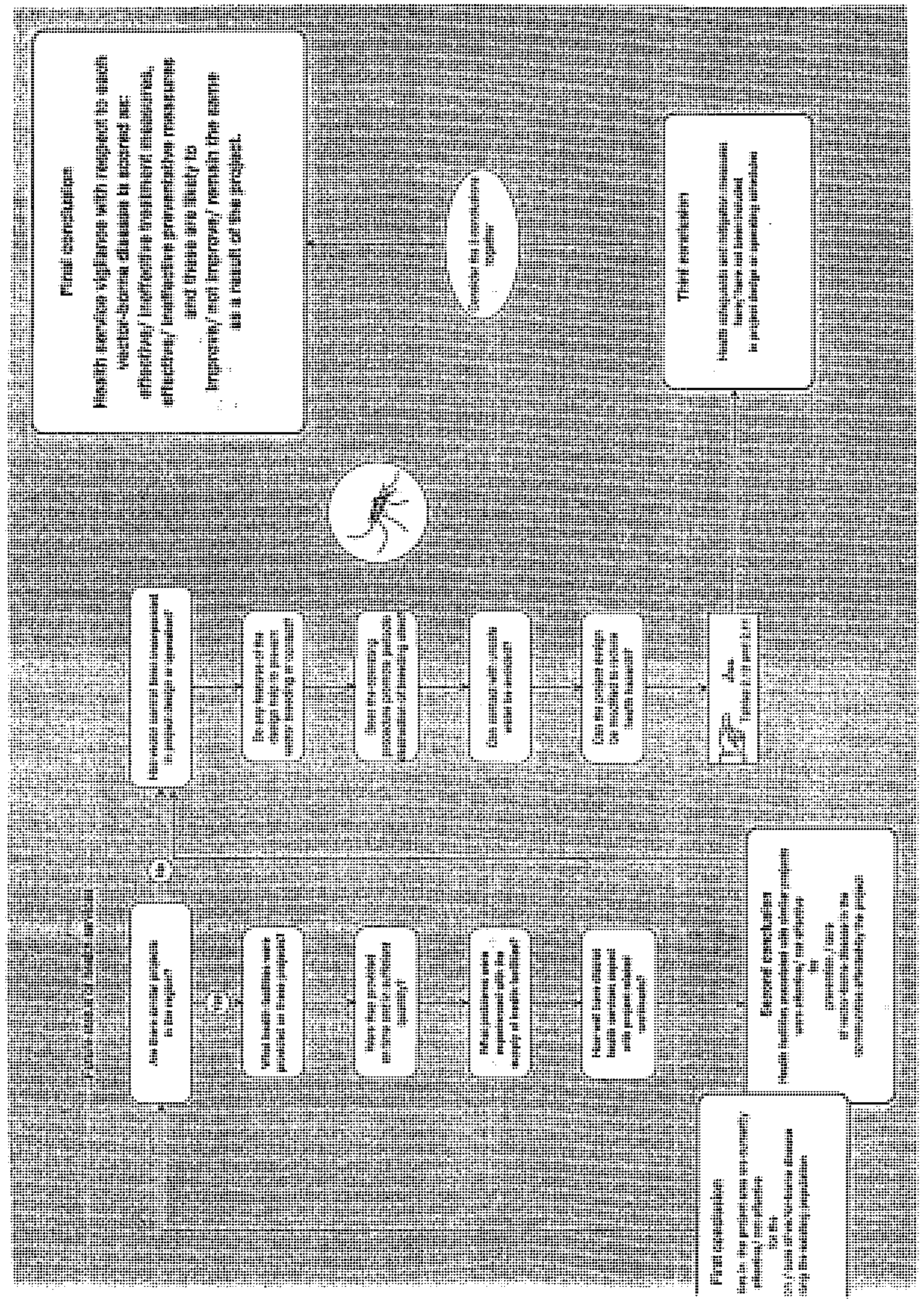


Table 4-2/6



Source: Birley 1992

Geophysical

Table 4-4

Soil type

If soil is compacted or ground cover is removed or soil is exposed to excessively dry conditions then soil loses its permeability or porosity and rainpools last longer.

If ground cover is removed then soil is eroded.

If soil is eroded then shallow pools are created by silt deposition.

If there are loess soils and semi-arid conditions then rodent reservoirs of leishmaniasis may be abundant.

If the soil is structurally poor then shallow latrine pits will collapse and provide vector breeding sites.

If the soil type is ferralsol or acrisol then there may be a lower incidence of malaria as compared with luvisols (because deep, free draining soils provide fewer pools for mosquitoes to breed).

Water Scarcity

If water is scarce or supply is irregular then there will be domestic water storage.

If tap water is too hot then it may be stored in domestic containers to cool.

If water is stored in domestic containers without good covers then container breeding mosquitoes such as *Aedes aegypti* will increase in abundance.

If there is a piped water supply and inadequate waste water disposal then there will be muddy surrounding water (in which mosquitoes and snails may breed).

If water pipes leak then mosquito breeding sites are created.

Irrigation Schemes

If an irrigation scheme is sited in a previously semi-arid region then health hazards are created because major ecological changes occur.

If molluscicide treatment is required then focal application can be very effective.

If old irrigation ditches are filled and new ones constructed alongside then snail populations are eradicated (oncomelanian snails were controlled in China by this method).

If canals are lined then the recurrent cost of vegetation and erosion control is reduced.

If water is piped then capital, maintenance and pumping costs are higher but health hazards are removed.

If sprinkler or drip feed irrigation is used then mosquitoes and snails are deterred.

If irrigation schemes are managed to provide the minimum of standing water for the minimum consecutive period then breeding can be controlled.

If canals and night stores are drained in a 7 day rotation with 2 days dry then mosquito breeding is reduced.

If a scheme is surrounded by afferent canals then the invasion of rodent populations is reduced.

Canalisation

If canal linings are imperfect then seepage pools will provide important breeding foci.

If rivers are crossed by fords, causeways or bridges then vector blackflies may be provided with new breeding sites.

If damage to canal banks is to be avoided then overpasses should be provided.

If the project is in West Africa then crossing points may attract tsetse flies.

If the mean flow rate is greater than 0.6 m/s and the channel is free of vegetation then snails are deterred (but erosion of unlined channels may occur).

If fast flow rates are to be maintained then regular desilting, bank repair and deweeding is necessary.

If the water is relatively clean and aerated and flowing then blackfly vectors may breed (Preferred habitats range from tiny streams and irrigation ditches to large rivers, to a depth of 0.15m. In W. Africa preferred flow rates are 0.7-1.2 m/s)).

If channels are designed for rapid draw-down and adequate drying-out then pooling during periods of low flow rate may be avoided.

If miracidia and cercaria are released in moving water then they cause infection downstream.

If solid waste collection facilities are inadequate then drains will be blocked by domestic waste.

If water is channeled through numerous small ditches then maintenance is more difficult than for a few large canals.

If an irrigation system contains night storage dams or canals then snail breeding should be expected (these habitats are difficult to treat with molluscicide).

If night storage dams become infested with aquatic vegetation then *Mansonia* mosquitoes should be expected.

Water Collections

If there are numerous small collections of clean water (such as are found in discarded cans, tyres, containers, leaf axils, tree holes, bamboo and rock pools) then *Aedes* mosquitoes may be abundant.

If borrow pits result from construction activities and fill with water then snails and mosquitoes may breed in them.

If borrow pits are deliberately planned as water holes then they should be enclosed and/or treated with larvicides or molluscicides.

Source: Birley 1992

Geophysical

Table 4-4 cont

Season

If the climate is seasonal then vectors may vary in abundance through the year.

If malaria is stable then additional vectors may not affect the incidence of the disease significantly.

If there is a season during which vectors and snails are unable to breed then disease transmission may be interrupted during that season.

If the seasonal abundance of standing water is increased then the period of interrupted transmission is reduced.

If domestic animals such as cattle, buffaloes and pigs are seasonally abundant then they may divert vectors away from human hosts.

If a development project alters the abundance of domestic animals then the diversionary effect is altered.

If people sleep outside during hot weather then they may attract outdoor biting mosquitoes.

If there are seasonal food shortages then there may be a seasonal increase in susceptibility to infection.

If there is a water development scheme then seasonal food shortages may be reduced.

If there is increased contact with limited dry season water supplies then intense focal transmission of schistosomiasis may occur.

Temperature and Altitude

If the mean temperature is below 17°C then parasite development in the vector or intermediate host ceases (20°C for *falciparum* malaria, 14°C for schistosomiasis).

If the temperature is very high then parasite development ceases and the activity of vectors is reduced.

If a development project is planned at altitudes at which pathogen transmission is rare then the potential increase will be negligible.

Wind

If the project is in West Africa and there are blackfly vectors breeding within 400 km upwind then recolonization of seasonal streams may be expected.

If wind assists the drift of floatage then the dispersal of snail vectors may be increased.

If the site is generally windy then insect biting activity will be greatly reduced.

If there are exposed shores subject to wave action then the breeding of snails and mosquitoes will be greatly reduced.

Humidity

If the microclimate humidity is low then insect lifespans may be low.

If the insect lifespan is low then it is less effective at disease transmission.

If humidity is low then the survival of filarial parasites may be reduced when they escape from the insect proboscis and transmission of this disease is reduced.

If the development project is in an area of low humidity and there will be a large scale increase in surface water then microclimate humidity will increase.

If the region is arid or semi-arid then schistosomiasis due to *S. mansoni* or *S. haematobium* is a potential health hazard.

Topography

If a river has a steep gradient then stream flow exposes bedrock (which provide breeding sites for various vectors).

If there is a flood plain and slowly meandering streams deposit silt then more permanent pools and marshes are created.

If there are fast currents and an unstable stream bed then the site is unfavourable for snails.

If bedrock is non-sedimentary then it is more suitable for blackfly breeding.

If land is levelled for road construction then borrow pits will be created.

If borrow pits fill with water then mosquito and snail habitats are created.

Rainfall

If there is plenty of rain then water contact may be reduced but snail breeding rates may be increased.

If an area has distinct dry and wet seasons then both insect vector density and disease prevalence are likely to have seasonal patterns.

If rainfall is plentiful in the river basin and hydrological conditions promote stream flow then stream margin breeding mosquito larvae will be flushed out but blackfly breeding sites may be enhanced.

If hydrological conditions cause rapid alterations in stream depth then rock pool breeding sites will be created as the stream falls and blackfly breeding sites may be created as the stream rises.

If there is plenty of rainfall and the soil is not too porous then temporary rainpools will be abundant.

If the vectors breed in temporary rainpools then their breeding sites will be very difficult to control.

If rainfall is less than expected then dried up river beds may serve as mosquito breeding sites.

Surface Water

If there is an abrupt margin between land and water then breeding sites are minimised.

If there is wave action and a steep shore or an unstable shore then mosquitoes and snails are deterred.

Table 4-4 cont

Geophysical

Water Chemistry

If surface water is subject to high evaporation rates then salinity increases.

If a coastal site is occasionally inundated with seawater then saline pools are abundant.

If salinity is high then some species of mosquitoes are attracted and other mosquito species are repelled.

If nitrogen content is high then culicine mosquitoes may be more abundant than anophelines (exceptions include *An. vanma* and *An. annularis* in India).

If insecticide spraying kills non-target organisms then algal blooms may stimulate vector production.

If there is a lake outflow and algal blooms provide high nutrient levels then vector blackfly larvae may be abundant at the outflow.

If the calcium content is about 80ppm and there is a balance of calcium, potassium and magnesium and pH is slightly acid then aquatic snails may be abundant.

If stream nutrient content and chemistry is suitable then vector blackflies may be abundant.

If the water is turbid then important malaria vectors may be attracted but snails may be deterred (eg: by puddling soils in ricefields).

Drainage and Sullage

If domestic water is supplied without adequate provision for waste water disposal then a major public health hazard is created.

If an irrigation system has better maintained water supply ditches than drainage ditches then excess standing water may create a public health hazard.

If water is moderately polluted then snail populations are favoured.

If water is heavily polluted with human or animal faeces then culicine mosquitoes will be abundant.

If an approved latrine design is used then mosquito breeding may be minimised (recommended designs include ventilated improved pit latrines, vault latrines and pour-flush latrines).

Ground Water

If the water table is close to the surface then latrine pits will fill with water and promote culicine mosquito breeding.

If trees with high evapotranspiration potential are planted then the level of the water table may be reduced.

If the water table is very deep then vertical drainage may be used.

Impoundments

If a reservoir floods a stream course then blackfly breeding sites may be destroyed but new breeding sites may be created at the spillway.

If the spillway is constructed of undressed stone then blackfly breeding is likely.

If the spillway is vertical or overhung or siphoned then blackflies are deterred.

If the spillway flow is interrupted for at least 1 day in 7 by using twin spillways then blackfly breeding is unlikely.

If continuous discharge from a reservoir scours the stream bed then new blackfly breeding sites may be created downstream.

If blackflies disrupt dam construction then larvicide should be applied upto 20km up- and down-stream during periods of rising and falling flood.

If the water level of a reservoir can be varied then the breeding of mosquitoes and snails can be reduced (but fluctuating water levels favour some species of mosquito).

If a reservoir is deep then mosquitoes and snails will be deterred (they rarely occur in lakes and large ponds, except at shallow margins).

If land can be cleared before it is flooded then breeding sites may be much reduced (because there is more exposure to wave action).

If complete land clearance is too costly then clearance should be restricted to the vicinity of human habitation or water margins (clearance should extend above the projected shore-line).

If land is flooded then wild rodent populations are displaced and may be brought into closer contact with human communities.

If a dam is constructed for hydroelectricity generation then its water may not be available for irrigation when it is most required and water level variation is likely to be unpredictable.

If a dam is constructed without adequate vegetation clearance then rotting organic material will pollute downstream water and make it unsuitable for domestic use.

If habitations adjacent to water margins are sited facing prevailing on-shore winds then wave action renders the margin unsuitable for vector breeding.

If land is newly flooded then old mosquito breeding sites are flushed out but new breeding sites are eventually created (so mosquito abundance may initially fall before rising to new levels).

Table 4-4 cont

Biotic

Vegetation on site

If the banks of water courses are covered in vegetation then water flow rates are reduced and refuges provided for mosquitoes and snails.

If water is shaded or partly shaded by vegetation then certain mosquito species will be attracted (eg: *An. minimus* in Asia and *An. funestus* in Africa).

If water is not shaded then certain mosquito species will be attracted (eg: *An. gambiae* in Africa).

If there is tropical rain forest vegetation and shaded or partly shaded margins of forest pools and streams then *Anopheles* mosquitoes should be abundant.

If tropical rain forest is clear felled then shade breeding species are eliminated (but soil erosion and loss of resources occurs).

If tropical rain forest is selectively felled then disturbance of the ground creates additional breeding sites.

If crop production simplifies the vegetation environment then more dangerous vector and snail species may be encouraged.

If emergent or floating vegetation grows in deep water then vector breeding sites are created. (*Mansonia* mosquito larvae only breed in association with rooted or floating vegetation, especially *Eichhornia*, *Pistia* and *Salvinia*).

If the species of vegetation provide natural water containers then mosquitoes will breed in them (eg: Bromeliads including pineapples; bananas; bamboo; Colocacia and rotting tree stumps).

If there is halophytic[1] vegetation then there may be reservoir hosts of leishmaniasis (eg: the rodent *Psammomys obesus*).

Bird fauna

If wild ardeid birds such as herons are attracted to an irrigation project then there is a risk of arbovirus transmission such as Japanese encephalitis.

Aquatic and terrestrial succession

If land or water is cleared of vegetation during the construction process then an orderly process of vegetational succession (regrowth) will occur.

If there is succession then vegetation will increase in size, density, cover and shade area (each phase in the succession will favour different species of animals, including vectors and their natural enemies).

If there are dense stands of vegetation then there are relatively humid resting places which are favoured by vectors.

Farming systems

If oxen are replaced by tractors then mosquitoes which were feeding on oxen may be forced to bite people (a resurgence of malaria in Guyana was attributed to this factor).

If water buffaloes are replaced by tractors in a rice production system then removal of their bathing pools may affect dry season vector density.

If agricultural insecticides are used on a large scale then vectors may develop resistance to a wide range of insecticides (eg: *An. sinensis* in China, *An. sacharovi* in Turkey and *An. albimanus* in Central America).

Rodent fauna

If an irrigation scheme is under development then rodent species which are closely associated with human settlements and are potential disease reservoirs will increase in abundance (eg: at Hola in Kenya abundance increased 10-50 times).

If an irrigation project raises the water table then rodents such as gerbils may become less abundant but associated sandflies may become more abundant (eg: a reservoir of cutaneous leishmaniasis which affected construction workers in Uzbekistan).

If previously unpopulated areas are settled then increased human contact with wild fauna may promote zoonoses.

If land is ploughed then colonial rodents such as *P. obesus* and *R. opimus* are eliminated but secondary reservoirs of leishmaniasis such as *Meriones* spp. may become more abundant.

If fodder crops are irrigated and it is a semi-arid region then rodents may increase in abundance.

Rice cultivation

If human settlements are close to rice fields then high rates of mosquito-borne disease may occur.

If a belt of dryland crops is established around a village then people are protected from rice-field breeding mosquitoes.

If paddy rice has been transplanted and is less than 75cm tall then malaria mosquitoes which prefer sunlit water will breed (eg: *An. arabiensis* in Africa, *An. freeborni* and *An. albimanus* in Central America).

If the paddy rice is taller than 75cm then shade loving malaria mosquitoes will breed (eg: *An. funestus* in Africa, *An. umbrosus* in S.E. Asia, *An. punctimaculata* in S. America).

If insecticides are used to kill rice pests and they kill aquatic predators then abundant mosquito breeding may result (eg: use of Dimecron at Ahero in Kenya).

If old plant debris is allowed to rot in newly flooded rice fields then mosquito breeding may be promoted (eg: *C. tritaeniorhynchus* in Sarawak).

If rice is planted in trenches through which water flows then mosquito breeding may be prevented (eg: *An. pseudopunctipennis* in Mexico).

Large fauna

If a settlement is planned and the settlers keep domestic animals then hygienic animal pens should be included in the settlement design.

If domestic animals are penned between human communities and mosquito breeding sites then mosquito vectors may bite the animals instead of the people and disease transmission is reduced.

Aquatic fauna

If natural predators such as dragonfly nymphs and fish are numerous then they will contribute to the control of vectors.

If natural predators are contributing to vector control then they should be protected by careful choice of vector control measures such as insecticide and application schedule.

If certain fish are introduced into irrigation schemes then they can contribute to the control of vectors.

If fisheries are drained or rotated periodically then schistosomiasis hazards may be reduced.

Source: Birley 1992

Demographic and socio-cultural factors

Table 4-5

Settlements

If there is inadequate provision for maintenance then piped water supplies and village pumps will be unreliable.

If the water supply is unreliable then water will be stored in the home (see water scarcity).

If water sources are far from the home then water will be stored in the home.

If water points are fitted with self-closing taps or handpumps then excess water discharge will be avoided.

If water supply and sanitation facilities are communal then there may be no incentive to maintain them properly.

If domestic waste water is not disposed of properly then vector and snail breeding sites are created.

If there are septic pools or surface grey water drainage or poorly maintained latrines then the mosquito vector of lymphatic filariasis may flourish.

If houses are designed to prevent mosquito ingress then much potential disease transmission can be avoided.

If house construction materials are absorbent then residual insecticide sprays will be less effective.

If settlements are sited 2km from swamps and forest margins then they are outside the flight range of most mosquitoes.

If settlements are sited far from agricultural zones then watchmen will be required to deter theft.

If there are locally breeding blackflies in a savannah or forest habitat then settlements should be sited at least 10km from the river.

If a dry-crop zone is sited around a settlement then contact with vectors which breed in irrigated sites is reduced.

If cultivation sites are far from permanent settlements then temporary settlements without proper sanitation will develop there.

Water contact

If small children bathe in irrigation systems where there are snails then schistosomiasis transmission will be intense.

If the climate is hot then the desire to bathe will outweigh any health education.

If snail-free bathing areas are provided and they are more convenient to use and their use is promoted by health education then schistosomiasis transmission can be reduced.

If bathing areas are sited in the centre of the village and they are closer to the home than irrigation canals then they are more likely to be used.

If bathing areas are to be kept free from snails then they should be refilled periodically and treated with molluscicide.

If the use of water sources near settlements is deterred by fencing, culverts, bridges and steep-sided canals then water contact is reduced.

If the daily cycle of water-related activities coincides with peak cercarial densities (the peaks are often during the middle of the day) then the risk of schistosomiasis infection is intensified.

If the seasonal cycle of activity (such as farming or fishing) coincides with peaks of vector or cercerial density then the risk of disease transmission is intensified.

Susceptibility to infection

If the demographic characteristics of the population are known then potential disease problems can be forecast with greater precision.

If a new settlement is developed then there will be more young fertile women and young children than in the rest of the population.

If there is a large population of children then schistosomiasis transmission is particularly favoured.

If future settlers are screened for parasitic disease then the chances of introducing new strains of parasites can be reduced.

If future settlers are screened on arrival, rather than at their place of origin, then anxiety, evasion and corruption may be reduced.

If the community has a high frequency of certain blood types such as haemoglobin S positive or Duffy group negative then malaria infections will be less severe.

If the population is largely immune to malaria then children and immigrants will be the main groups to suffer clinical illness.

If a labour force is assembled then the epidemic potential is increased.

If a susceptible community are translocated to a region with Japanese encephalitis and pig production is encouraged near to irrigation systems or reservoirs then there is a potential hazard of an epidemic (this has happened in Sri Lanka).

If use of antimalarial drugs is widespread then results of parasite surveys can be misleading.

If immigrants have no previous exposure to filariasis then clinical symptoms should be expected sooner than in communities from endemic areas (within 2 years in Indonesia).

If economic activities force certain people to expose themselves to the risk of infection then their health should be carefully monitored.

Vector contact

If mosquito nets and screens are badly maintained then they are not effective.

If the climate is hot, humid and windless then mosquito nets and screens are unbearable.

If the farms are within 15km of a blackfly breeding site then farm workers will be bitten.

If a vector is largely confined to feeding on animals and it is not very abundant then it does not pose a major health hazard.

If a biting insect cannot support development of parasite then it may be a nuisance but it is not a health hazard.

If there are no local blackfly breeding then seasonal migration of potentially infected blackfly may cause a hazard within at least 1.5km of the river bank.

Social categories

If there are large groups of construction workers then up to ten times as many spontaneous immigrants may be attracted informally to provide goods and services.

If communities are displaced then they may be exposed to hazards to which they have no prior experience.

Customs

If rights to use a water source are traditionally vested in different interest groups then development of the water source may produce intergroup conflicts leading to the destruction of the project.

If anal cleansing customs involve wiping and a waste disposal system is designed which assumes washing then wiping materials may block the system.

Source: Birley 1992

Table 4-6

CHECKLIST OF MAJOR STEPS FOR THE PREVENTION AND CONTROL OF VECTORBORNE DISEASES AT EACH PHASE OF WATER RESOURCES DEVELOPMENT PROJECTS

Planning phase

(1) Review of existing information on health and related subjects

(*a*) Epidemiology: morbidity and mortality rates, geographical distribution, vector ecology.
(*b*) Health and medical services: facilities, staff, special projects and programmes; degree of development, capacity and coverage.
(*c*) Human population and its characteristics: agricultural, migrant, nomadic, etc.; population growth, importance of migratory movement, displacement within the project area.
(*d*) Cattle: numbers and economic importance, prevalent diseases.
(*e*) Community and housing patterns: location, design, construction materials.
(*f*) Water supply, excreta and wastes disposal facilities.
(*g*) Climatic patterns: temperature, rainfall, humidity, wind, etc.
(*h*) Water: surface water and groundwater, quality, pollution, abundance and seasonal variation, floods and droughts, seasonal variation in temperature.
(*i*) Soil: physical and chemical characteristics, including permeability, stability, salt content, etc.
(*j*) Natural and cultivated aquatic and land vegetation; domestic and wild animals.
(*k*) Economy: national and local, sources and levels of income.
(*l*) Topographical maps: contour lines, roads, villages, etc., of the region and the watershed, design plans of proposed project, etc.

(2) Surveys: To check existing information or fill in gaps in knowledge; assessment and collection of basic data by specialists

(*a*) Detailed epidemiology of major existing diseases and biology and ecology of principal vectors.
(*b*) Health and medical services, disease and vector control programmes and activities, evaluation of effectiveness and resources.
(*c*) Human and cattle movement: migratory currents, their origin and paths.
(*d*) Sanitation: actual and potential sources of water supply, investigation of groundwater sources, actual and potential sources and routes of pollution, practices involving water contact, and methods of excreta disposal, cattle watering and manure disposal.
(*e*) Existing and proposed agricultural crops and practices: irrigation methods, suitable crops, rotation in cultivation and irrigation, use of pesticides and fertilizers, their kind and amount.
(*f*) Local economy: present status and prospects for future development.
(*g*) Sociocultural patterns: present level and possible disturbance produced by the project.
(*h*) Engineering and operational reconnaissance and mapping for ecological, hydrological, and geological or soil studies.
(*i*) Contact with agencies operating in the project area, their type of activities and possibility of assistance and coordination.

(3) Decision-making for the prevention and control of diseases

(*a*) Review of project proposals and preliminary designs and options.
(*b*) Identification of existing health problems.
(*c*) Prediction of possible future problems and of their health effects.
(*d*) Determination of the importance and extent of actual and potential health problems to establish an order of priority in prevention and control operations.
(*e*) Feasibility studies of control measures, including cost-effectiveness and cost-benefit analyses.
(*f*) Selection of village sites and types of water supply and excreta disposal installations.
(*g*) Selection of methods of vector and disease control and estimates of manpower and organizational requirements.
(*h*) Organization of field trials and pilot projects.
(*i*) Settlement of displaced and immigrant population and estimates for the provision of water supply, sanitation and other health facilities.

Design phase

(1) Establishment of design criteria to minimize health hazards and to achieve the objectives of the health programme.

(2) Evaluation of preliminary project designs and alternatives.

(3) Establishment of proposed practices of water-system management and their effects on vector habitats.

(4) Preliminary design and options for canal lining overpasses and other health structures.

(5) Final detailed design of works in the reservoir

(*a*) Shoreline modification and improvement.
(*b*) Clearance and disposal of trees and brush, of man-made structures and fences.
(*c*) Relocation of roads, villages, cemeteries, shrines, etc.
(*d*) Discharge structures sized for water-level regulation and downstream flushing.

(6) Final detailed design of works in irrigation schemes

(*a*) Equalizing reservoirs and night-storage ponds, when necessary.
(*b*) Canals and drains.
(*c*) Regulating structures, gates, sluices, etc., and distributing chambers.
(*d*) On-farm water use.
(*e*) Groundwater use and control.
(*f*) Potential for incorporating domestic water supply.

(7) Final detailed design of measures and works in communities

(*a*) Selection of sites for new communities distant from water sources.
(*b*) Provision of safe, adequate and convenient water supply and sewage disposal systems.
(*c*) Recreation: provision of safe ponds as alternative to infected water bodies, sports grounds, etc.
(d) Other protective measures, such as house-screening, surface-water drainage, general sanitation, and public laundry installations.

(8) Provisions for maintenance activities and their financing.

(9) Environmental management

(*a*) Regulating structures for measurement and control of water discharge and velocity.
(*b*) Gates required for rapid drying and flushing of irrigation subsystems.
(*c*) Adjustment of water salinity in coastal breeding-sites through the installation and operation of gates.
(*d*) Water-level regulation in small reservoirs by means of automatic siphon spillways.
(*e*) Safe crossings and bridges over canals and drains.
(*f*) Lining of canals and drains, closed or subsurface conduits.

(10) Enhancement and simplification of chemical and biological control

(*a*) Design of dispensers for chemical application attached to or incorporated into regulating structures, metal rakes and screens against snails.
(*b*) Access roads and paths for surveillance and spraying, clear water lanes and landings for boats.

(11) Health education of the public and development of community participation.

(12) Health facilities: dispensaries and hospitals.

Source: WHO 1980

Construction phase

(1) Health protection of the construction labour force.

(2) Special facilities for disease control and treatment at the construction site.

(3) Adequate housing and sanitary facilities for construction workers and their families.

(4) Surveillance of infections in imported manpower and local population.

(5) Monitoring, vaccination, treatment of local population and elimination and control of endemic diseases, especially those with potential for intensification with project operation.

(6) Environmental protection, erosion, spillage, air and water pollution, disposal of wastes, aesthetic alterations, etc.

(7) Inspection to ensure that construction is carried out according to health designs.

(8) Health education of the public and development of community participation.

Operations phase

(1) Allocation of funds, assignment of staff and implementation of disease control programmes.

(2) Surveillance, screening and treatment of infected persons.

(3) Establishment of rule curves and schedules for the control of mosquitos, snails, flies, weeds, etc.

(4) Establishment of practices and schedules for water-level regulation.

(5) Maintenance and modernization of structures and other works.

(6) Application of chemical and biological methods for vector and weed control.

(7) Drainage of all water collections around the reservoir.

(8) Prevention and correction of excessive seepage.

(9) On-farm water management.

(10) Operation, maintenance, improvement and development of water supply and sewage disposal systems, general sanitation.

(11) Health education of the public and development of community participation.

(12) Evaluation of vector and disease pattern changes, efficacy of control programmes, study and implementation of amendments or alterations to improve results.

(13) Preparation of periodic and special reports for information purposes.

Annex 3

LIST OF ENVIRONMENTAL MANAGEMENT MEASURES WHICH HAVE PROVED TO BE USEFUL IN THE PREVENTION AND CONTROL OF MALARIA AND SCHISTOSOMIASIS

The following environmental management measures have been applied for the prevention and control of malaria and schistosomiasis. They serve to create conditions unfavourable to the breeding and propagation of vectors and intermediate hosts, to reduce opportunities for man/mosquito contact or man/cercaria-infested water contact, and to assist in the application of insecticides and molluscicides. Although specifically addressed to water resources development projects, the measures are equally applicable to other situations.

The letters (M) or (S) indicate that the measure is particularly applicable to malaria or schistosomiasis control respectively. No indication is given where the measure is equally applicable to the control of both diseases.

During the design and construction phases

A. In reservoirs and surrounding areas

1. Removal of all trees, bushes and other plants that would emerge at maximum drawdown water level of the reservoir.

2. Selective clearing of vegetation in the zone of water level fluctuation about 8 m beyond the normal full reservoir contour at heads of bights for stranding of drifts (see subchapter IIIA), and much further on open shorelines.

3. Straightening of margins through cutting, deepening and filling of the reservoir edge.

4. Construction of dikes and levees to separate shallow bays from the reservoir and dewatering of the low areas behind the dikes by the operation of gates, so that the water flows by gravity when the reservoir is at low level or by pumping. Dewatering of runoff from drainage areas behind the dikes.

5. Removal of earth from higher areas that would protrude as small islands at maximum drawdown water level of the reservoir.

6. Filling of natural or man-made depressions in the vicinity of the reservoir, or draining of these depressions by ditches leading to the reservoir.

7. Provision in the dam design for the periodic fluctuation of water level. Large size crest gates (Tainter gates).

8. Paving or lining of spillways and diversion channels where they are exposed to wave action and erosion.

9. Use of waterproof membranes of clayey or plastic material at the base and surroundings of the dam to reduce water seepage, and provision of drainage for possible seepage water.

10. Building of boat operating bases, either by the construction of jetties or by the digging of small channels for the docking of boats. Ramps for launching of boats.

11. Provision of paths and other means of access to the reservoir edge for vegetation clearance and pesticide application.

(S)12. Extension into the reservoir of the drawout structure or outlet conduit so that water is not taken from the edge.

(S)13. Screening of intakes to prevent the passage of snails.

(S)14. Locating intakes of large lakes and reservoirs below the euphotic zone. Below this zone, where sunshine does not penetrate, there should be no snails.

(S)15. Fencing of the reservoir in the vicinity of villages to discourage people from using the reservoir.

Source: WHO 1982

B. In irrigation systems

1. Design of main canals, laterals and sublaterals to follow straight lines with the minimum number of bends; any necessary bends should be of ample curvature.

2. Design of canal gradients and cross-sections to ensure water velocities that prevent both silting and scouring.

3. Design of canal grids without interconnexions so that water enters at the head (or upper) end and flows in one direction only.

4. Provision of a gate, siphon or other water control device at the tail (or lower) end of canals so that they can be flushed and emptied to the nearest drain when necessary.

5. Provision of an effective drainage system to collect and dispose of surface and ground surplus water.

6. Elimination of disused canals and drains, and of natural streams intercepted by the new system.

7. Filling or draining of borrow pits along canals and roads. Land levelling.

8. Paving or lining of canals as extensively as possible; this is an irrigation improvement as well as an effective health protection measure.

9. Consideration in the design to using covered conduits or pipes for water distribution to cultivated plots and for surplus water drainage.

10. Provision of a sufficient number of bridges across canals so that the villages are not isolated from the main roads; this will also help the maintenance work and the application of insecticides and molluscicides.

11. Protection of the canal section at the entrance and exit of culverts, drops, chutes, control structures, etc. against scouring that may form depressions.

12. Designation of "dry belting" areas around villages, and land occupancy and restriction measures.

During the maintenance and operation phases

A. In reservoirs and surrounding areas

1. Clearing of submerged, emerging and floating vegetation to keep a bare zone of water level fluctuation and a clean shoreline.

2. Dredging of the reservoir margin to deepen it and produce steeper slopes.

3. Repair of dikes and levees to keep them in proper condition.

4. Filling or draining of natural and man-made ground depressions of recent formation or those that were unnoticed at the time of construction.

5. Straightening of courses and rectification of gradients of natural streams conveying water from the catchment area to the reservoir.

6. Provision of proper management for the punctual operation of water level fluctuation.

7. Repair of spillways, diversion channels and other structures scoured by water, and paving of the damaged sections.

8. Repair of drains that collect and convey the seepage water coming from the dam or other structures.

(S) 9. Repair of grids and screens at the intake structures or suction pipes.

(S)10. Fencing of the reservoir may be advisable when the communities have been provided with a proper water supply.

11. Repair of roads and paths of access to the reservoir edge.

B. In irrigation systems

1. Dredging of canals and drains to bring them back to their original dimensions and correct gradients, reshaping of cross-sections, and filling of bed depressions that may retain water when empty.

2. Frequent clearing of vegetation to ensure that the canals and drains are free from aquatic plants, weeds, etc.

3. Avoidance of the use of canals for night storage.

4. Repair of control structures and gates to ensure their proper functioning.

5. Repair of culverts, siphons and bridges, and filling of bed depressions formed by scouring at their entrances and exits.

6. Effective control of water quantity at the intake of the irrigation reservoir and at the gates to prevent over-irrigation.

7. Levelling and grading of cultivated land, particularly where it is exposed to flooding, or provision of drainage when levelling and grading is too extensive.

8. Gradual lining of canals, starting in the sections most exposed to scouring and those where seepage losses are greatest.

9. Gradual transformation of open channels to covered conduits and pipes, starting in the sublaterals and feeding canals. Promotion of subsurface drainage.

10. Gradual improvement of irrigation practices and methods (intermittent irrigation, localized sprinkler irrigation, etc.); gradual improvement in agricultural practices.

(M)11. Restriction of land use to daytime work in order to reduce the opportunities for mosquito biting.

12. Periodic flushing of canals and drains.

Table 4-8

Table 8.2 Properties of some molluscicides (Source: WHO 1965; 1973; 1980; 1983)

Characteristics	Niclosamide (Bayluscide)	N-trityl-morpholine (Trifenmorph)	NaPCP (Sodium penta-chlorophenate)	Yurimin	Copper sulfate	Nicotinanilide
Physical properties						
- Form of material	Crystalline solid	Crystalline solid	Crystalline solid	Crystalline solid	Crystalline solid	Crystalline solid
- Solubility in water	230 mg/l	very low	300 mg/l	Very low	320 mg/l	?
Toxicity						
- Snail LC_{90} (mg/l·h)*	3-8	0.5-4	20-100	4-5	20-100	5
- Snail eggs LC_{90}*	2-4	240	3-30	.	50-100	20-50
- Cercaria LC_{90} (mg/l)	0.3	No effect	–	..	–	?
- Fish LC_{90}(mg/l)	0.05-0.3	2-4	–	0.16-0.83	–	>30
Stability (affected by)						
- U.V. light	No	No	Yes	No		–
- Mud, turbidity	Yes	No	No	Yes		–
Formulations	70% W.P. 25% E.C	16.5% E.C. 4% granules	75% Flakes 80% Pellets 80% Briquettes	5% Granules	980 g/kg Pentahydrate crystals	Not yet formulated
Field dosage						
- Aquatic snails (mg/l·h)*	4-8	1-2	50-80	?	20-30	?
- Amphibious snails on moist soil (g/m²)	0.2	–	0.4-10	5	Ineffective	?

* (mg/l·h) indicates that the figures given are the product of the concentration and the number of hours of exposure
LC Lethal concentration
LD Lethal dose
W.P. Wettable powder
E.C. Emulsifiable concentrate

Source: Oomen et al 1990

Table 4-9

Table 8.3 Comparison of molluscicide program costs for ten schistosomiasis control projects

Country	PUERTO RICO		ST LUCIA			BRAZIL		EGYPT	IRAN	TANZANIA
Locality	Vieques	Patillas	Guayama Arroyo	Cul de Sac	Sao Lourenco	Belo Horizonte	Taquarendi	Kom El Birka	Dez Scheme	Misungwi
Hydrology	i*	i and ii	i and ii	i	i	i and ii	ii	ii	ii	i
Annual rainfall (cm)	115	179	140	250	150	160	50	30	30	100
Controlled area (km²)	130	122	207	18	80	200	2.5	52	220	100
Population	8,400	17,100	47,000	6,000	4,280	20,000	1,500	17,000	18,000	4,300
Annual volume of snail habitat treated (m³)	65,000	89,000	106,400	182,000	80,000	39,000	15,000	1,354,000	500,000	200,000
Habitat volume per surface area (m³/km²)	500	739	514	10,000	1,000	195	6,000	16,000	2,300	2,000
Population density (persons/km²)	64	140	227	333	54	100	600	330	82	43
Habitat volume per person (m³)	7.8	5.2	2.3	30	18.5	2.0	10	80	28	46
Molluscicide	NaPCP	NaPCP	NaPCP	Niclo-samide	Niclo-samide	Niclo-samide	Niclo-samide	NaPCP + Niclo-samide	Niclo-samide	Niclo-samide
Cost period (years)	10	7	1	1.1	10	4	5	1	1	1
Currency	US$	US$	US$	US$	US$	US$	US$	Egypt pound	US$	Sh.T
Total cost of program	63,600	60,380	8,298	32,500	316,800	34,000	6,800	20,700	17,000	30,000
Base year for costs	1960	1960	1955	1972	1972	1968	1968	1963	1972	1972
Annual cost in 1972 US$	13,000	17,000	20,000	25,000	32,000	10,000	1,500	58,600	17,000	4,178
Annual cost per 100 m³ treated	20	19	19	17	40	26	10	1.40	3.40	2.10
Annual cost per km²	100	139	97	1,700	400	50	600	1,130	77	42
Annual cost per person	1.50	1.00	0.43	4.00	7.40	0.50	0.70	3.45	0.94	0.75
Program cost breakdown										
Labour	65%	61%		50%	80%	50%	36%	5%	6%	
Molloscicide	3%	6%	11%	12%	10%	11%	40%	85%	19%	25%
Transport and equipment	7%			16%	5%	15%	24%		21%	
Supervision	22%			16%		24%			54%	
Others	3%	33%	89%	6%	5%			10%		75%

*; Natural drainage systems, comprising small streams, pools, or small water collections (either natural or man-made), seepages and marshy areas
ii Irrigation systems

Source: Oomen et al. 1990

Table 4-10

Table 4.1 Epidemiological variables for monitoring and evaluating the integrated control of vector-borne diseases

CONTROL METHODS	EPIDEMIOLOGICAL VARIABLES									
	Breeding habitat	Larvae/ pupae	Adult vectors density	Vector survival	Man-biting rate	Water contact	Popu-lation coverage	% infected	% diseased	Mortality
Environmental modification	x	x	x					x	x	x
Environmental manipulation	x	x	x		(x)			x	x	x
Residual insecticides control			x	x	x		x	x	x	x
Non-residual biochemical control		x	x		x			x	x	x
Biological control		x	x	x				x	x	x
Reduction man-vector contact					x	x	x	x	x	x
Prophylaxis/immunization							x	x	x	x
Treatment							x	x	x	x
Corresponding type of EVALUATION					I (and II)				III	

Source: Oomen et al. 1990

Table 4-11

Table 5.2 Classification of the most common potential breeding places in Zone 2, System C

Category	Description	Index
A	Large bodies of fresh water in full or partial sunlight Floating or emergent vegetation, especially near edges	1 Ulhitiya Reservoir, buffer reservoirs, large borrow pits, waterlogged pools behind bunds of distributary channels constructed in fill, large natural surface depressions. 2 Marshes
B	Small watercollections, stagnant and often muddy, but not polluted, full to partial sunlight 1 Vegetation present: scattered or at fringes 2 Vegetation absent	Marginal pockets along irrigation canals semi-permanent rain pools in natural or man-made surface depressions (e.g. in between road and canal bund), seepage pools behind buffer reservoir or canal bund, old borrow pits, clogged drainage ditches 2 Recent borrow pits, rock pools on excavation sites, new road ditches, wheel ruts, foot or hoof prints, rainwater pools
C	Marshy patches, often polluted with organic matter; mostly abundant vegetation (oily monolayers, iron-coloured water, smell of decomposition)	1 Seepage ponds/depressions along irrigation canals constructed in fill, poorly drained shallow but extensive surface depressions 2 Roads saturated with water from overtopped field channels bunds 3 Muddy broad sections of natural drains where the waterflow stagnates (mainly in upper parts of intermediate drains).
D	Paddy fields	1 Swampy and poorly drained fallow lowland paddy fields, prior to land preparation. 2 Recently tilled fields 3 Fields during seeding (levelled fields, no water layer, but small shallow pools) 4 Fields during transplanting (levelled fields, shallow water layer) 5 Fields during crop growth 6 Washing pits
E	Partially or heavily shaded water under abundant vegetation	1 Sluggish irrigation drainage streams (slow waterflow from one pool to another), pools at the interception of drains in distributary channels, ponds. 2 Stagnant pools in spillway drainage beds
F	Running water courses, clear fresh water, direct sunlight	1 Pools in drying stream beds (natural streams or irrigation canals), seepage pools from irrigation structures in canal beds, pools in stream-eroded canal depressions directly behind dropstructures, turnout structures and cross-regulators 2 Irrigation ditches and lowland grassy/weedy field-drainage ditches 3 Small side-pockets along embankments or irrigation canals (erosion gullies, bund breaches, etc.)
G	Man-made containers	1 Stilling basins of irrigation structures (turnouts, cross-regulators), silt catcher of reservoir spill 2 Wells, cisterns, discarded receptacles, old tyres, gutters

Source: Oomen et al. 1988

Table 4-12

	Pre-irrigation	Land-preparation	Crop Establishment	Vegetative growth	Harvest	Post-irrigation
Reservoir	A1; G1	A1; G1	A1; G1	A1; G1	A1; G1	A1; G1
Main/Branch Canal	F1	F3	F3	F3	F3	F1
Level Crossing/Tanks	A2	A1; B1; C1	A1; B1; C1	A1; B1; C1	A1; B1; C1	A2
Distributory Channel	A1; C1 G1; F1	A1; B1; B2 F3; E1	A1; B1; B2 F3; E1	A1; B1; B2 F3; E1	A1; G1; C1; F1	A1; G1; C1; F1
Field Channel	C1; F1	B1; C1; C2	B1; C1; C2	B1; C1; C2	C1; F1	C1; F1
Field Ditch		F2	F2	F2		
Field	D1	D2; D6	D4;D6;D3;D6	D5; D6	D6	D1
Field Drainage		F2	B1; F2	B1; F2	B1; F2	
Natural Stream/Major Drainage	E1; F1	C3; E2	C3; E2	C3; E2	C2; E2	E1
Domestic Environment	G2	G2	G2	G2	G2	G2
Natural Environment	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1	A1; B1; B2; C1

Figure 5.5 Matrix II, Phases of the irrigation and crop husbandry cycle and locations in the irrigation area proper and in the remaining area in relation to potential breeding places

Source: Oomen et al. 1988

Table 4-13

	Irrigation feature					
	Hydrology	Farm water Management	Design	Construction	Operation	Maintenance
Reservoir	A1		G1		A1	A1
Main/Branch Canal				F3		F1; F3
Level Crossing/Tanks	A2; C1			B1	A1	A1
Distributory Channel			A1; E1; G1	A1;B1;B2;C1 E1;F1;F3	C1	B1;C1;F1 F3
Field Channel			F1	B1; C1; C2; F1	B1; C1; C2; F1	B1; C1; C2; F1
Field Ditch		F2		F2		F2
Field		D1; D6				
Field Drainage		F2				F2; B1
Natural Stream/ Major Drainage	A1; C3; E1 E2; F1			C3; E1; E2		C3; E1; E1
Domestic Environment				G2		G2
Natural Environment	A1; B1; C1		B1	B2		B2

Figure 5.6 Matrix III, Relationship between irrigation feature and breeding place

Source: Oomen et al. 1988

Table 38-1. Lifetime Health Advisory Levels (HAL) for pesticides in drinking water (USEPA, 1989a, b).

Common and chemical name	Concentration, μg/L
Acifluorfen	1
Sodium 5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoate	
Alachlor†	0.4
2-Chloro-2'-6'-diethyl-*N*-(methoxy methyl) acetanilide	
Aldicarb	10
2-Methyl-2(methylthio) propionaldehyde *O*(methylcarbamoyl) oxime	
Ametryn	60
2-(Ethylamino)-4-(isopropylamino)-6-(methylthio)-1,3,5-triazine	
Ammonium Sulfamate	1500
Ammonium sulfamate	
Atrazine	3
2-Chloro-4-ethylamino-6-isopropylamino-1,3,5 triazine	
Baygon (Propoxur)	3
2-(1-Methylethoxy)phenyl methylcarbamate	
Bentazon	20
3(1-Methylethyl)-1*H*-2,1,3-benzothiodiazin-4(3*H*)-one-2,2-dioxide	
Bromacil	90
5-Bromo-3-*sec*-butyl-6-methyluracil	
Butylate	700
S-Ethyl diisobutylthiocarbamate	
Carbaryl	700
1-Napthyl methylcarbamate	
Carbofuran	40
2,3-Dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate	
Carboxin	700
5,6-Dihydro-2-methyl-*N*-phenyl-1,4-oxathiin-3-carboxamide	
Chloramben	100
3-Amino-2,5 dichlorobenzoic acid	
Chlordane†	0.03
1,2,3,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methanoindene	
Chlorothalanil†	2
Tetrachloroisophthalonitrile	
Cyanazine	10
2-{[4-Chloro-6-(ethylamino)-*S*-triazin-2-yl]amino}-2-methylproprionitrile	
Dacthal (DCPA)	3500
Dimethyl tetrachloroterephthalate	
Dalapon	200
2,2-Dichloropropionic acid	
2,4-D	70
(2,4-Dichlorophenoxy) acetic acid	
DBCP†	0.03
1,2-Dibromo-3-chloropropane	
Diazinon	0.6
O,O-Diethyl *O*-2-isopropyl-6-methylpyrimidin-4-yl phosphorothioate	
Dicamba	200
3,6-Dichloro-*o*-anisic acid	
1,2-Dichloropropane	0.6
1,2-Dichloropropane	
1,3-Dichloropropene (Telone)	0.2
1,3-Dichloropropene	
Dieldrin†	0.002
1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-*endo*-1,4,-*exo*-5,8-dimethanonaphthalene	

Table 4-14

Common and chemical name	Concentration, μg/L
Dimethrin	2100
2,4-Dimethylbenzyl-2,2-dimethyl-3(2-methyl propenyl) cyclopropanecarboxylate	
Dinoseb	7
2-(*sec*-Butyl)-4,6-dinitrophenol (alkanolamino salts)	
Diphenamid	200
N,N-Dimethyl-2,2-diphenylacetamide	
Disulfoton	0.3
O,O-Diethyl *S*-[2-(ethylthio)ethyl] phosphorodithioate	
Diuron	10
3-(3,4-Dichlorophenyl)-1,1-dimethylurea	
Endothall	140
7-Oxabicyclo-(2,2,1)heptane-2,3-dicarboxylic acid	
Endrin	0.3
1,2,3,4,10,10-Hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-*exo*-1,4,-*exo*-5,8-dimethanonaphthalene	
Ethylene Dibromide (EDB)†	0.0004
1,2-Dibromoethane	
Ethylene Thiourea†	0.2
2-Imidazolidinethione	
Fenamiphos	2
Ethyl 3-methyl-4-(methylthio) phenyl (1-methylethyl) phosphoramidate	
Fluometuron	90
1,1-Dimethyl-3-(α,α,α-trifluoro-*m*-tolyl) urea	
Fonofos	14
O-Ethyl-*S*-phenylethylphosphonodithioate	
Glyphosate	700
N-(Phosphono-methyl) glycine	
Heptachlor†	0.008
1,4,5,6,7,8,8-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methanoindene	
Hexachlorobenzene	0.02
Hexachlorobenzene	
Hexazinone	200
3-Cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*, 3*H*)-dione	
Maleic Hydrazide	3500
1,2-Dihydropyridazine-3,6-dione	
Methomyl	200
S-Methyl-*N*-[(methylcarbamoyl)oxy] thioacetimidate	
Methoxychlor	400
1,1,1-Trichloro-2,2-*bis*(4-methoxyphenyl)ethane	
Methyl Parathion	2
O,O-Dimethyl-*O*-4-nitrophenyl phosphorothioate	
Metolachlor	100
2-Chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-metboxy-1-methylethyl) acetamida	
Metribuzin	200
4-Amino-6-(1,1-dimathylethyl)-3-methylthio-1,2,4-triazin-5(4*H*)-one	
Oxamyl	200
S-Methyl *N',N'*-dimethyl-*N*-(methylcarbamoyloxyl)-1-thiooxamimdate	
Paraquat	30
1,1'-Dimethyl-4,4'-bipyridinium-dichloride	
Pentachlorophenol	200
Pentachlorophenol	
Picloram	500
4-Amino-3,5,6-trichloropicolinic acid	
Prometon	100
2,4-Bis(isopropylamino)-6-methoxy-*s*-triazine	
Pronamide	50
3,5-Dichloro-*N*(1,1-dimethyl-2-propynyl) benzamide	
Propachlor	90
2-Chloro-*N*-isopropylacetanilide	
Propazine	10
2-Chloro-4,6-*bis*(isopropylamino)-*S*-triazine	
Propham	100
Isopropyl carbanilate	
Simazine	4
2-Chloro-4,6-bis(ethylamino)-*s*-triazine	
2,4,5-T	70
2,4,5-Trichlorophenoxy-acetic acid	
Tebuthiuron	500
N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea	
Terbacil	90
3-tert-Butyl-5-chloro-6-methyluracil	
Terbufos	1
S-tert-butylthiomethyl *o,o*-diethyl phosphorodithioate	
2,4,5-TP (Silvex)	50
2-(2,4,5-Trichlorophenoxy) propionic acid	
Trifluralin	2
α,α,α-Trifluoro-2,6-dinitro-*N,N*-dipropyl-*p*-toluidine	

† No HAL established: Lifetime exposure at this level represents an excess cancer risk of one in one million.

Source: in Stewart ed. 1990

Table 4-15

Annex 1

MATRIX FOR THE STUDY AND ASSESSMENT OF IMPACTS RESULTING FROM ENVIRONMENTAL MANAGEMENT FOR VECTOR CONTROL

Main elements and sectors of the environment likely to be affected		Main proposed actions																	
		Environmental modification							Environmental manipulation										
		In man-made reservoirs and other still waters				In man-made courses and other flowing waters			In man-made reservoirs and other still waters					In man-made courses and other flowing waters			In all types of water bodies		
		Cutting, deepening and filling	Dyking and dewatering	Drainage in catchment area	Consolidation of shores	Rectification of courses and cross-sections	Consolidation and lining	Conversion of open to closed conduits	Basin preparation and maintenance	Cutting of trees and shrubs	Vegetation clearance	Shore maintenance	Water level fluctuation	Dredging and desilting	Vegetation clearance	Intermittent flow and flushing-drying	Manipulation of biological pollution	Manipulation of salinity in coastal areas	Manipulation of vegetation to provide shade or sunlight
Topsoil structure	Erosion/silting																		
Topsoil structure	Disintegration/dust																		
Topsoil structure	Acidity/alkalinity																		
Topsoil structure	Ion exchange/salinity																		
Topsoil structure	Aeration																		
Topsoil structure	Microbial content																		
Topsoil structure	Helminths and insects																		
Water	Surface flow and seepage																		
Water	Groundwater flow and recharge																		
Water	Water quality/pollution																		
Vegetation cover	Trees and shrubs																		
Vegetation cover	Grass and weeds																		
Vegetation cover	Aquatic plants																		
Vegetation cover	Cultivated crops																		
Wildlife	Fish																		
Wildlife	Birds																		
Wildlife	Other animals																		
Human activities and interests	Irrigation																		
Human activities and interests	Agriculture																		
Human activities and interests	Fisheries																		
Human activities and interests	Flood control																		
Human activities and interests	Land reclamation																		
Human activities and interests	Recreation																		
Human activities and interests	Communications																		
Human activities and interests	Cultural assets																		
Human activities and interests	Aesthetic assets																		

Notes on the use of the matrix

The effects on the environment resulting fron environmental management measures for vector control can be assessed subjectively and shown quantitatively in this matrix, by using a rating for "magnitude" (the extent of the effect in space, time, population affected, etc.) and another for "importance" (the intensity or the relative seriousness of the effect).

1. Rate magnitude and importance between 1 and 10, 1 for the least and 10 for the greatest impact. Use a plus sign to indicate a beneficial effect and a minus sign for a detrimental effect.
2. Show the ratings in the relevant blocks of the matrix by recording two numbers, separated by a diagonal line, one for the magnitude and one for the importance of the impact; each pair of numbers should have its own plus or minus sign.
3. Actions that offer the most beneficial effects and the least adverse effects should be preferred in the choice and design of a control strategy.

Source: WHO 1980

Table 5-1

Table 27: Crop Management Methods (Bailey and Waddell, 1979)

A. Crop Management
   1. Tillage
      - Conventional - moldboard plow, disc, harrow
      - Timing - fall, spring
      - Chisel plowing
      - Conservation - minimum, no-till
   2. Crop Sequencing
      - Mono-crop
      - No-meadow crop
      - Relay cropping
      - Double cropping
   3. Seed/Plant Improvement
      - Weather resistance
      - Salt tolerance
      - Production efficiency
      - Early or late maturation

B. Soil/Water Management
   1. Runoff and Erosion Controls
      - Contouring
      - Terraces
      - Cover crops
      - Grassed waterways
      - Tile drains
      - Diversions
      - Land forming
      - Row spacing
      - Harvesting and planting times
   2. Moisture Conservation Practices (e.g., fallow cropping)
   3. Wind Erosion Controls
      - Strip cropping
      - Barrier rows
      - Windbreaks

C. Nutrient Management
   1. Formulation, Granular, Liquid
   2. Species (e.g., NH_4 vs. NO_3 form of N, animal vs municipal)
   3. Amount Applied
   4. Application Methodology
   5. Timing of Application

D. Pest Management
   1. Scouting
   2. Pesticides
      - Application methodology
      - Amount applied
      - Timing of application
   3. Pest-Resistant Crops
   4. Integrated Controls
   5. Cultural/Mechanical Methods
   6. Biological Controls

Source: Canter 1986

Table 5-2

Table 1 . Physiological processes interesting the crop manipulation for droughts and water stress resistance: A summary

Processes	References
Cell growth, dynamics of cell water (relative water content, water potential, wall dehydration)	Boyer, 1983; Hsiao & Bradford, 1983; Rascio et al, 1987
Cell and tissue turgor; osmotic regulation	Radin, 1983; Turner & Burch, 1983.
Stomatal opening	Hsiao & Bradford, 1983; Kirkham, 1984; Planchon, 1987.
Water and Co_2 exchanges	Krieg, 1983a; Rosenberg et al, 1983; Shalevet & Hsiao, 1986.
Photosynthesis, protein synthesis	Boyer, 1983; Kramer, 1983; Krieg, 1983b; Pearcy, 1983.
Changes in concentration of growth regulators	Austin et al, 1982; Hsiao & Bradford, 1983; Davies et al, 1987.
Leaf development and leaf senscence patterns	Boyer, 1983; Kramer, 1983; Shalevet & Hsiao, 1986.
Root development patterns	Passioura, 1982, 1983; Kramer, 1983; Jones & Zur, 1984.
Shoot - root relations	Turner, 1986.
Water fluxes : xylem conductancy	Wenkert, 1983; Jones & Zur, 1984.
Water fluxes : leaf water potential kinetics	Turner & Burch, 1983; Kirkham, 1984; Jones, 1985; Lorens et al, 1987.
Water fluxes : capacitance behaviour	Wenkert, 1983; Katerji & Hallaire, 1985.
Stand establishment : germination and emergence	Kramer, 1983; Jordan 1983.
Yield process : flowering, yield potential, fruit/grain yield	Jordan, 1983; Krieg, 1983a.

Source: Pereira 1990

Table 5-3

Table 2 . Drought resistance mechanisms and traits for plant breeding

Mechanisms	Characteristics/Traits	Benefits	Yield affected	Reversible
Drought escape				
Rapid phenological development	Short biological cycle	Lower total water demand	yes (?)	no
Developmental plasticity	Branching/tillering and variation in flower, floret and panicle	Lower reduction in seed numbers	no	yes
Drought avoidance (at high water potential)				
Reduction of water losses				
. stomatal resistance (+)	Size, number and opening of stomata	Less transpiration	yes	yes
. evaporative surface (-)	Leaf rolling, smaller and fewer leaves, senescence	Smaller loss surface end less radiation absorved	yes	limited
. radiation interception (-)	Leaf pubescence and leaf orientation	Higher reflectivity and less radiation	yes	limited
. cuticular resistance (+)	Thicker and tighter cuticules	Lower transpiration, higher resistance to dissecation	no	no
. epicuticular wax (+)	Waxiness	Lower transpiration, higher resistance to dissecation	no	no
Maintenance of water extraction.				
. root depth and density (+)	More extensive and intensive rooting	Lower root and soil resistances	no (?)	no (?)
. liquid phase conductance (+)	More or larger xilems in roots and stems	Lower resistances to water fluxes	no	no
Drought tolerance (at low water potential)				
Maintenance of turgor				
. osmotic adjustment	Water potential kinetics	Decrease osmotic potential in response to stress	no (?)	yes
. cellular elasticity (-)	Cell membranes	Large chenges in volume	no	?
. cell size (-)	Cell size	Increased bound water fraction (in cell wall)	yes	limited
Tissue water capacitance	Favourable water potential Kinetics	Ability to maintain the daily water balance	no	no
Dissecation tolerance	Protoplasmic and choroplast conditions	Maintaining photosynthetic activity	no (?)	?
Accumulation of solutes	Proline, abscissic acid, ethylene, betaine	Regulation of senescence and absicissión	no	yes

Adapted from Hsiao (1982), Turner (1982; 1986), Jordan et al. (1983), Clarke (1987), Marshall (1987) and Monti (1987).

Source: Pereira 1990

Table 5-4

Table 4 . Soil management techniques, benefits and effectiveness for limiting drought and water stress impacts

Soil management techniques	Benefits	Effectiveness	References
Water retention on the soil surface/runoff control			
. Tillage/soil cultivation with surface roughness	Storage of rainfall excess in micro depressions; increased time for infiltration	Variable	Unger & Stewart, 1983.
. Loosening tillage	Increased porosity, higher infiltration and soil water retention	Variable	Unger & Stewart, 1983.
. Contour and graded furrows	Runoff and erosion control, increased infiltration	High	Unger & Stewart, 1983.
. Conservation tillage, mulching	Increased infiltration, lower soil and water losses	High	Sojka et al, 1984; Griffith et al, 1986
. Furrow dikes	Runoff control and increased infiltration	High	
. Bed surface profile	Idem	Limited/high	Spoor et al, 1987.
Water yield and water spreading and infiltration (arid lands)			
Microwatersheds combined with vertical mulches	Runoff from one area to be infiltrated in the cropped one	Limited	Unger & Stewart, 1983.
Water harvesting, runoff farming and water spreading	Maximize runoff to be utilized in the cropped area	Limited	Boers et al, 1986; Sharma, 1986.
Water infiltration and soil storage volume			
Organic matter for improving aggregation	Stability of aggregates and increased infiltration	Limited	Unger et al, 1981.
Chemicals for aggregates	Idem	Economic limits	Unger & Stewart, 1983.
Soil loosening or subsoiling for fragipans, hardpans and plowpans	Increased water penetration and soil depth explorable by roots	Variable	Unger et al, 1981; Reicosky, 1983; Spoor et al, 1987.
Deep tillage/profile modification in presence of clay horizons	Idem	Variable	Unger et al, 1981; Reicosky, 1983; Spoor et al, 1987.
Chemical and physical treatments of salt-affected soils	Increased infiltration and available soil water	High	Hoffman, 1981; 1986.
Crop rotations including grasses and legumes	Higher organic matter, better aggregation, increased infiltration	Variable	Loomis, 1983
Mulches, crop residues	Soil protection, higher infiltration reduced erosion	Very high	Larson et al, 1983; Sojka et al 1984; Griffith et al, 1986.
Traffic control	Decrease compaction, improve water penetration	High	Reicosky, 1983; Spoor et al, 1987.
Water retention in the soil profile			
Deep soil treatments	Deeper roots and water storage volume	High	Unger et al, 1981; Reicosky, 1983.
Adding fine materials to sandy/coarse soils	Increase water retention	Economic limits	Unger et al, 1981.
Mixing fine and coarse horizons	Increase water retention	Variable	Unger & Stewart, 1983.
Asphalt barriers in sandy soils	Decrease deep percolation	Economic limits	Unger et al, 1981.
Compacting sandy soils	Slowing water penetration	Interesting	Agrawal et al, 1987.
Mulches	Decrease of soil evaporation	Variable	De et al, 1983; Rosenberg et al, 1983.
Chemical hydrophilics in sandy soils	Increase water absorption	Economic limits	Azzam, 1987.
Chemical surfactants	Decrease capillary rise	Limited	Unger et al, 1983.
Control of toxicity and acidity, liming	More intensive and deep rooting	Limited/high	Reicosky, 1983.

Source: Pereira 1990

Table 5-5

Table 5 . Techniques for crop management for coping with droughts and water stress conditions

Crop management techniques	Benefits	Effectiveness	References
Drought risk management			
Change of crop patterns replacing sensitive by tolerant crops (eventually decreasing the irrigation surface)	Limit effects of droughts	High	Section 4, Table 3.
Choice of drought tolerant instead of high productive crop varieties	Limit drought impacts	High	Section 4, Table 3.
Use of short cycle varieties	Low water requirements	High	Section 4, Table 3.
Early seeding	Avoidance of terminal stress	High	French, 1983.
Early cutting of forage crops	Avoid degradation of the stressed crop	High	Dawdy et al, 1983.
Grazing drought damaged fields	Alternative use; livestock support	High	Dawdy et al, 1983.
Supplemental irrigation of rainfed crops	Avoid stress at critical stages	High	
Management for controlling the effects of water stress			
Use of appropriate soil management techniques	Increase available soil water	High	Section 5, Table 4.
Adaptation of crop patterns to the environmental constraints and resource conservation	Coping with water stressed environments	High	Loomis, 1983.
Use of fallow cropping in rainfed systems	Increase in soil moisture	Controversial	Larson et al, 1983; Loomis, 1983.
Use of mixed cropping and intercropping, nemely for forages	Better use of resources	Low	Loomis, 1983.
Increase plant spacing of perennials and for some row crops	High individual explorable soil volume	Limited/high	Gardner & Gardner, 1983; Loomis, 1983.
Cultivation techniques			
Minimizing tillage	Avoidance of evaporation from the soil	High	Larson et al, 1983.
Adequate seed placement	Prevention of rapid drying of soil layers around the seed	High	Larson et al, 1983.

Crop management techniques	Benefits	Effectiveness	References
Pre-emergence weed control	Alleviating competition for water; avoiding herbicide effects on stressed crop plants	High	Dawdy et al, 1983.
Reduced and delayed fertilization	Favorizing deep rooting; adaptation to crop responses under water stress	Variable	Loomis, 1983.
Dry soil land preparation and seeding of paddy rice	Water savings	High	Pereira et al, 1986.
Early defoliation (maize)	Decrease evaporative surfaces, so the water use by the crop	Limited	Crookston & Ouattar, 1987.
Antitranspirants	Reduction of plant transpiration	Controversial	De et al, 1983; Rosenberg et al, 1983.
Reflectants (increasing albedo)	Decrease energy available for transpiration	Limited/high	De et al, 1983; Rosenberg et al, 1983.
CO_2 enrichment (controlled environments)	Increased water use efficiency, higher yield per unit of water	Limited	Rosenberg et al, 1983; Allen et al, 1985.
Windbreaks	Decrease energy available for evaporation	Limited	Rosenberg et al, 1983.
Growth regulators	Improved responses of physiological processes to water stress	Promising	Reviewed by Davies et al, 1987.

Source: Pereira 1990

Table 5-6

TABLE 3

Specific technologies for sustainable management of soil and resources for different ecological regions

Humid	Sub-humid	Semi-arid	Arid
Soil management systems for improving water-use efficiency			
Mulch farming	No-till	Rough plowing	Water harvesting
No-till	Mulch farming	Tied ridges	Fallowing
Manual clearing	Contour ridges	Mulch	Early planting
Drainage and water management	Agroforestry	Micro-catchments	Grass hedges (Vetiver)
Erosion control	Drainage and water management	Diggets	Salinity
Water harvesting		Contour bunds	Irrigation
		Grass hedges (Vetiver)	Water conservation
		Fallowing	
		Early planting	
		Salinity control	
		Irrigation	
		Water harvesting	
Soil/crop management systems for increasing nutrient-use efficiency			
Perennial crops	Cover crops	Manure/kralling	Manure/kralling
Root crops	Mulch farming	Mulch farming	Irrigation
Agroforestry	Agroforestry	Cover crops	Water harvesting
Mulch farming	Mixed cropping	Relay-mixed cropping	N and P fertilizers
Fertilizers	Crop rotations	N and P fertilizers	Salinity and alkalinity control
In-situ burning	In-situ burning	Irrigation	
N and P fertilizers	N and P fertilizers	Leaching and salinity control	
Drainage and water management	Drainage and water management		

Source: Lal 1991

Table 5-7a

TABLE 4

Some examples of tillage-based technological packages for sustainable management of soil and water resources on small-scale farms (less than 5 ha) in the tropics

	Structurally active soils	Structurally inert soils
(a)	Grain crop–cover crop rotation Conservation tillage–mulch farming Strip cropping Chemical fertilizers (supplementary) Water management Irrigation	Conservation tillage and water management options will differ as follows: Contour ridges Tied ridges Periodic sub-soiling or chiseling Supplementary irrigation
(b)	Grain crop–alley cropping systems Conservation tillage Chemical fertilizers (supplementary) Water management Irrigation	
(c)	Ley/mixed farming Conservation tillage Grain crop–pasture rotation Growing woody perennials to supplement food Reservoirs for runoff storage Organic manures Chemical fertilizers (supplementary) Drainage and irrigation Water harvesting	
(d)	Agro-forestry systems Same as (c) but pasture replaced by shrubs and woody perennials	
(e)	Smallholder plantations Cover crops (Kudzu, Centro, etc.) Tangya system Chemical fertilizers Supplemental irrigation	

Table 5-7b

TABLE 5

Some examples of tillage-based technological packages for sustainable management of soil and water resources on medium sized farms (5–25 ha) in the tropics

	Structurally active soils		Structurally inert soils
(a)	Grain crop–cover crop rotation Conservation tillage with herbicides and periodic loosening to alleviate compaction Chemical fertilizers Planting trees or woody perennials at 1 m intervals Water management	(a)	Contour ridges Terraces and waterways Engineering structure Water management Supplemental irrigation
(b)	Grain crop–pasture rotation Water harvesting and reservoirs Conservation tillage with herbicides Tree hedges at 1 m intervals Chemical fertilizers Drainage and irrigation	(b)	Water reservoirs and engineering structures Supplementary irrigation Tied-ridge or basin tillage Water management
(c)	Plantation and cover crops Erosion control Fertilizer management Drainage and irrigation	(c)	Erosion control access on roads Fertilizer management Water harvesting Supplemental irrigation

Source: Lal 1991

Table 5-8

TABLE 9

Soil eco-regional guide to tillage methods for upland crops in West Africa

Moisture regime	Texture of soil surface	Constraints	Tillage methods
Per-humid and humid	Sandy, sandy loam, loam, sand	Soil erosion by water, low soil fertility low AWC[1], high soil temperature	No tillage, reduced tillage, mulch farming with cover crops, agroforestry with plantation/tree crops
Per-humid and humid	Silt loam, silty clay loam	Soil erosion, crusting compaction, high soil temperature	Reduced tillage or minimum tillage, cover crops, mulch farming, agroforestry
Per humid and humid	Clay loam, clay	Water logging, poor trafficability, erosion	Ridge/furrow system, surface drainage, raised beds or mounds, agroforestry
Sub-humid	Sandy loam, loamy sand, sandy clay	Soil erosion by water, crusting, compaction, drought, low soil fertility, low AWC	No tillage with periodic chisel plowing, mulch farming with cover crops and alley cropping
Semi-arid and arid regions	Sandy loam, loamy sand	Soil erosion by wind and water, drought, low AWC, high soil temperature, sand blasting	Chisel plowing, tied ridges, plowing at the end of rains, rough seed bed
Semi-arid regions	Clayey, sandy clay, swelling soils	Soil erosion, poor trafficability, water logging, drought	Ridge/furrow system broad beds, water harvesting
Arid regions	Sandy loam, loamy sand	Wind erosion, drought, sand blasting, low AWC	Wind breaks, reduced tillage, water harvesting techniques

[1]AWC is available water capacity.

Source: in Lal 1991

Table 5-9

Table 1. The rate of fertilizer use in regions of the world

Region	Kilo nutrients applied/ha (N + P_2O_5 + K_2O)	
	1964	1984
World	[illegible]	[illegible]
North America	[illegible]	[illegible]
Western Europe	[illegible]	[illegible]
Eastern Europe & USSR	[illegible]	[illegible]
Africa	[illegible]	[illegible]
Far East	[illegible]	[illegible]
Centrally planned economies in Asia	[illegible]	[illegible]

Source: [illegible]

Source: ESCAP 1991

Table 5-10

Table 3.5 Agricultural Inputs in Selected DMCs

	Irrigated Land (per cent of cropland)		Average Annual Pesticide Use (1000 metric tons)		Average Annual Fertilizer Use (kg/ha)	
	1975-77	1985-87	1975-77	1982-84	1975-77	1985-87
Korea	48	58	4.7	12.3	334	395
Indonesia	26	34	18.7	16.3	27	100
Lao PDR	6	13	...	...	0	2
Malaysia	7	8	...	9.7	68	154
Philippines	14	18	3.5	4.4	34	50
Thailand	15	20	13.1	22.3	14	26
Viet Nam	18	28	1.7	0.9	58	61
Bangladesh	15	23	...	0.2	29	68
India	20	25	52.5	53.1	22	52
Myanmar	10	11	3.7	15.3	5	18
Nepal	12	28	...	...	6	20
Pakistan	70	77	2.1	1.9	32	81
Sri Lanka	25	30	...	0.7	49	106
China	43	46	150.5	159.3	74	195

Source: World Resources Institute, *World Resources 1990-91* (New York, 1990).

Source: ADB 1991

Table 5-11

[illegible]

Source	Cadmium content			
	Published values range	Industry survey range	Approximately ... mean	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Source: ESCAP 1991

Table 5-13

Table 1

CHANGES IN THE USE OF PESTICIDES FOR FOOD CROPS IN INDONESIA, 1980-89

Year	Pesticide use (tons)	Rice fields (000 ha)	Production (000 tons milled rice)
1980	6 366	9 105	20 161
1981	9 006	9 382	22 286
1982	11 256	8 988	22 837
1983	13 887	9 162	24 006
1984	13 816	9 764	25 933
1985	14 980	9 902	26 547
1986	17 216	9 988	27 014
1987	17 342	9 923	27 253
1988	10 840	10 090	28 340
1989	8 660	10 531	29 072

Source: Ministry of Agriculture, Indonesia.

Source: Kasrunyo in OECD 1991d

Table 5-12 →

Table 5-12

Table 31: Practices for the Control of Nutrient Loss from Agricultural Applications and Their Highlights (Stewart, et al., 1975)

No.	Nutrient Control Practice	Practice Highlights
N 1	Eliminating excessive fertilization	May cut nitrate leaching appreciably, reduces fertilizer costs; has no effect on yield.
	Leaching Control	
N 2	Timing nitrogen application	Reduces nitrate leaching; increases nitrogen use efficiency; ideal timing may be less convenient.
N 3	Using crop rotations	Substantially reduces nutrient inputs; not compatible with many farm enterprises; reduces erosion and pesticide use.
N 4	Using animal wastes for fertilizer	Economic gain for some farm enterprises; slow release of nutrients; spreading problems.
N 5	Plowing-under green legume crops	Reduces use of nitrogen fertilizer; not always feasible.
N 6	Using winter cover crop	Uses nitrate and reduces percolation; not applicable in some regions; reduces winter erosion.
N 7	Controlling fertilizer release or transformation	May decrease nitrate leaching; usually not economically feasible; needs additional research and development.
	Control of Nutrients in Runoff	
N 8	Incorporating surface applications	Decreases nutrients in runoff; no yield effects; not always possible; adds costs in some cases.
N 9	Controlling surface applications	Useful when incorporation is not feasible.
N 10	Using legumes in haylands and pastures	Replaces nitrogen fertilizer; limited applicability; difficult to manage.
	Control of Nutrient Loss by Erosion	
N 11	Timing fertilizer plow-down	Reduces erosion and nutrient loss; may be less convenient.

Source: Canter 1986

Table 5-14

Table 39: Practices for the Control of Pesticide Loss from Agricultural Applications and Their Highlights (Stewart, et al., 1975)

No.	Pesticide Control Practice	Practice Highlights
	Broadly Applicable Practices	
P 1	Using alternative pesticides	Applicable to all field crops; can lower aquatic residue levels; can hinder development of target species resistance.
P 2	Optimizing pesticide placement with respect to loss	Applicable where effectiveness is maintained; may involve moderate cost.
P 3	Using crop rotation	Universally applicable; can reduce pesticide loss significantly; some indirect cost if less profitable crop is planted.
P 4	Using resistant crop varieties	Applicable to a number of crops; can sometimes eliminate need for insecticide and fungicide use; only slight usefulness for weed control.
P 5	Optimizing crop planting time	Applicable to many crops; can reduce need for pesticides; moderate cost possibly involved.
P 6	Optimizing pesticide formulation	Some commercially available alternatives; can reduce necessary rates of pesticide application.
P 7	Using mechanical control methods	Applicable to weed control; will reduce need for chemicals substantially; not economically favorable.
P 8	Reducing excessive treatment	Applicable to insect control; refined predictive techniques required.
P 9	Optimizing time of day for pesticide application	Universally applicable; can reduce necessary rates of pesticide application.
	Practices Having Limited Applicability	
P 10	Optimizing date of pesticide application	Applicable only when pest control is not adversely affected; little or no cost involved.
P 11	Using integrated control programs	Effective pest control with reduction in amount of pesticide used; program development difficult.
P 12	Using biological control methods	Very successful in a few cases; can reduce insecticide and herbicide use appreciably.
P 13	Using lower pesticide application rates	Can be used only where authorized; some monetary savings.
P 14	Managing aerial applications	Can reduce contamination of non-target areas.
P 15	Planting between rows in minimum tillage	Applicable only to row crops in non-plow based tillage; may reduce amounts of pesticides necessary.

Table 39: (Continued)

Source: Canter 1986

Table 5-15

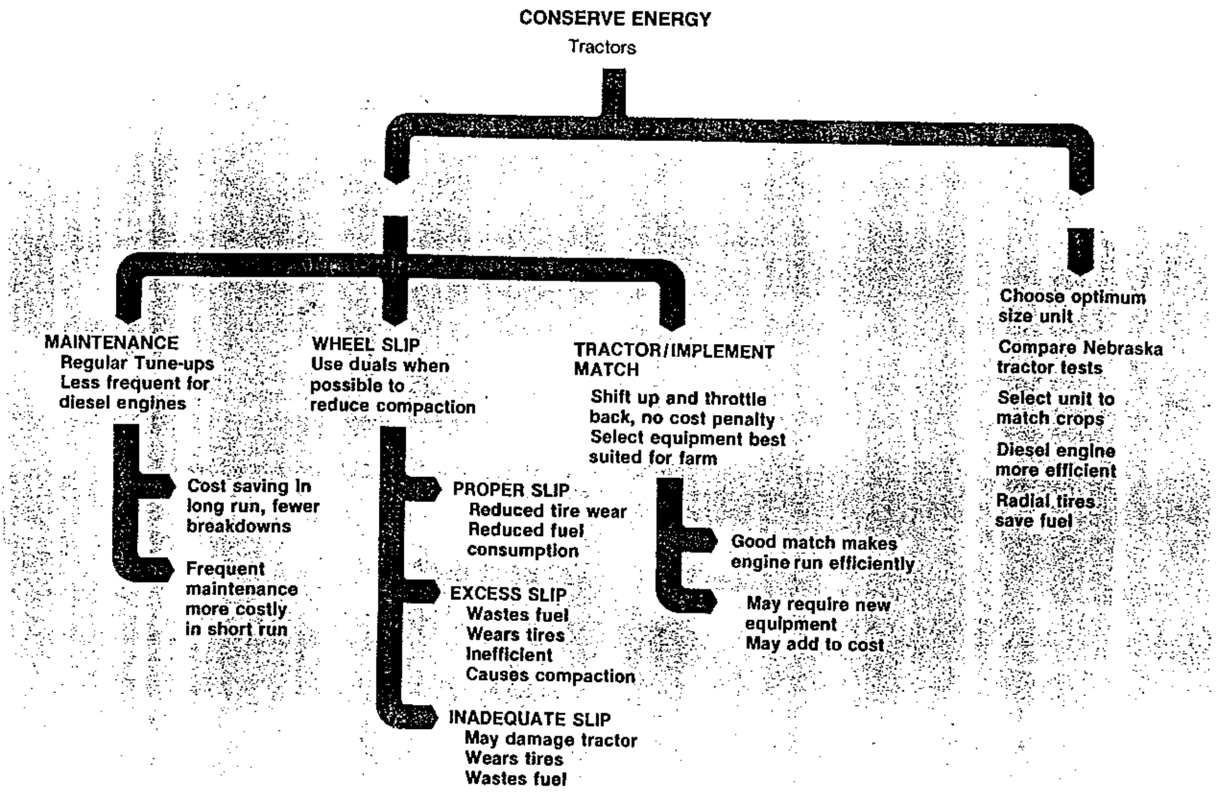


Chart 3-Tillage Systems

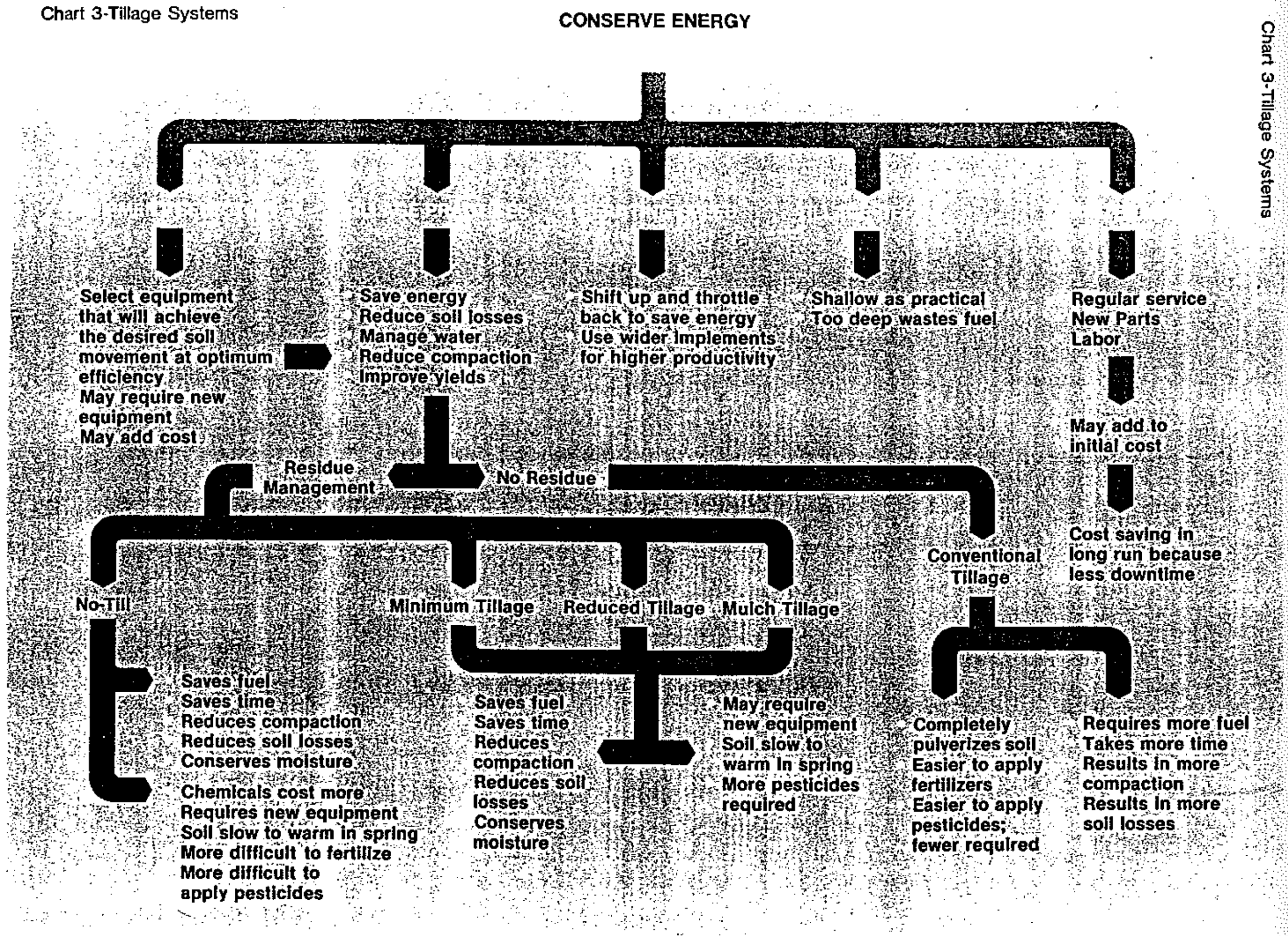


Chart 3-Tillage Systems

Source: Hughes 1980

Chart 5-Crop Drying

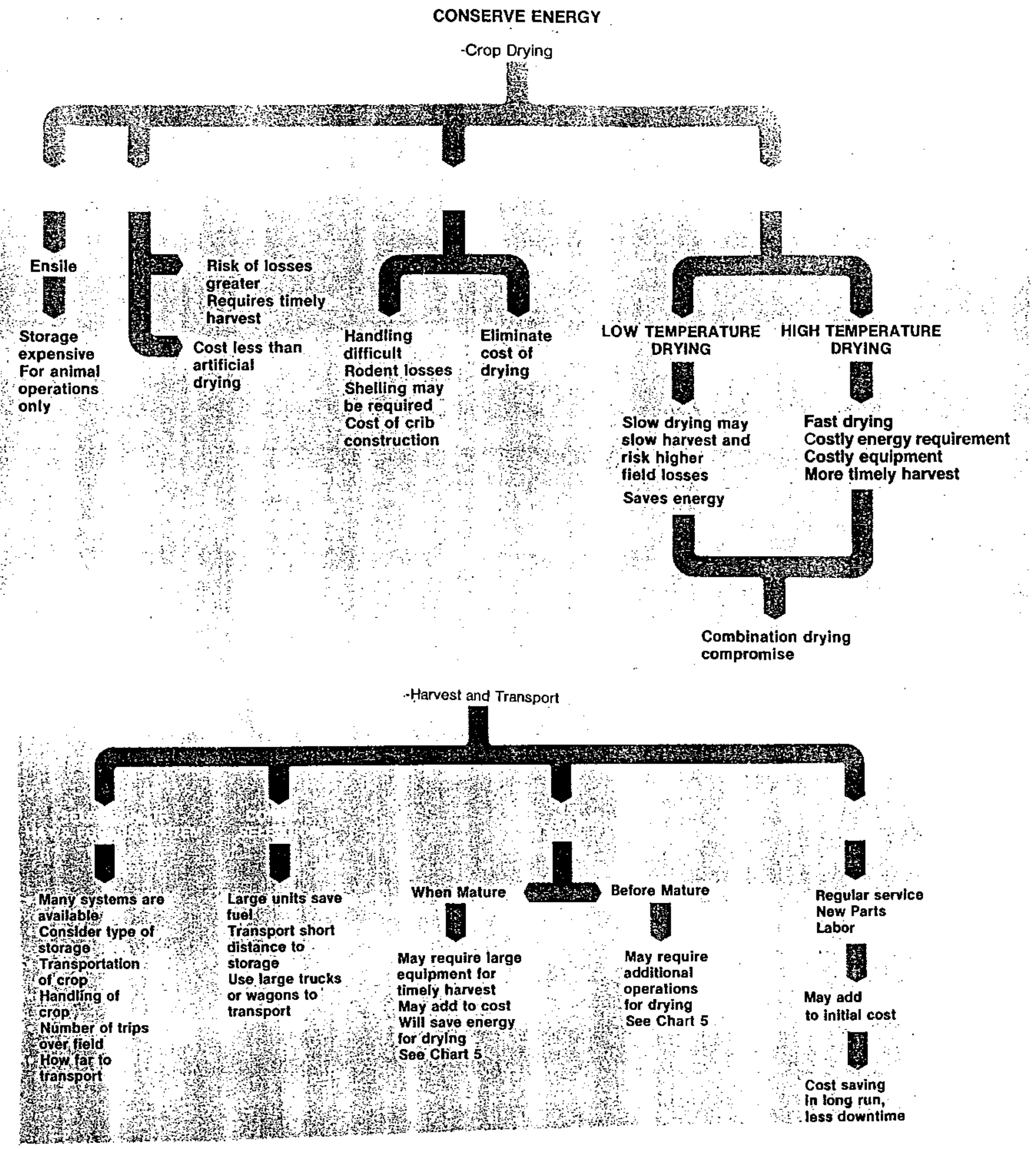


Chart 6-Alternate Energy Sources