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# Irrigation and the Environment

## A Review of Environmental Issues

### Part I

### Influence of Irrigation on the Environment and Vice-Versa

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# IRRIGATION AND THE ENVIRONMENT

A review of environmental issues

## Part I Influence of Irrigation on the Environment and Vice-Versa



## Part II Environmental Considerations in Planning and Operation

# Part I
# Influence of Irrigation on the Environment and Vice-Versa

# IRRIGATION AND THE ENVIRONMENT

A Review on Environmental Issues

## Preface

This working document is intended as a sourcebook which reviews and discusses relevant publications on various issues governing the interrelationships between irrigation and the natural environment. Intensive use was made of recent publications, either textbooks, or symposium proceedings and journals which often have limited circulation amongst interested scientists, planners, and those involved in implementation and operation of irrigation systems.

Due to the large variety of disciplines involved in such a review, the selection and depth in which some issues are reviewed may appear to some readers as imbalanced; some sections may even give the impression being inadequate to the specialist. Therefore, it is intended to up-date this sourcebook as soon as possible with the assistance of anyone who feels prepared to submit additional information or who wants to address amendments or eliminate errors.

The working document draws heavily on various sources most of which are cited at the end of each section. Short excerpts are sometimes not explicitely quoted. Therefore, the sourcebook published as an internal working document.

An important part of this study is the compilation of **references**. The interested reader is referred to these publications to obtain in-depth technical or scientific details. In addition, a large number of tables and figures are used to illustrate the information and to serve as a 'manual'. These tables and figures were extracted from the references quoted.

This sourcebook complements existing **textbooks** and **symposium papers** which deal with environmental impacts either by giving a generalized overview (eg Zonn) or emphazising specific issues. The reader is thus refered to the following sources:

FAO/UNESCO 1973. Irrigation, Drainage and Salinity. An International Source Book. (Kovda/van den Berg/ Hagan ed.)

ICID 1975. Environmental Control for Irrigation, Drainage and Flood Control Projects. General Report by Holy, M.; in addition, 19 articles on environmental issues, eg. Hagan/Roberts 1975.

COWAR 1976. Arid Lands Irrigation in Developing Countries. Environmental Problems and Effects. COWAR-UNESCO-UNEP-ISSU. Cairo (see also: Worthington 1977)

White 1978. Environmental Effects of Arid Land Irrigation in Developing Countries. UNESCO-UNEP-SCOPE. MAB Technical Notes 8

Zonn 1979: Ecological Aspects of Irrigated Agriculture

Kharchenko/Maddock 1982. Investigation of the Water Regime of River Basins Affected by Irrigation. UNESCO. See also other UNESCO/UNEP documents.

ICID 1990. 14th Congress on Irrigation and Drainage in Brazil. Question 42: The Influence of Irrigation and Drainage on the Environment with particular Emphasis on Impact on the Quality of Surface and Ground Waters. General Report: Holy 1990. Question 43: The Role of Irrigation in Mitigating the Effects of Drought. General Report: Pereira (1990). Socio-economic and technological impacts of mechanized irrigation systems. Gernal Report: Kruse (1990).

Case studies with environmental issues are for example published by ODI, Irrigation Management Network. Overseas Development Institute. UK.

German references are rarely used because special references on irrigation are few, although many are dealing with **agricultural impacts** and **water resources development** related to fertilizers and pesticides pollution. Important german textbooks are for example

Busch/Fahning 1992, Domsch 1992, Blume et al. 1992, Krumm/Stumm 1992, UVP-Förderverein 1993, Zauke et al. 1992, Hötzel 1986, Sauerbeck 1985, Diercks 1985, RSU 1985, Welte/Timmermann 1985, Domsch 1985, Baumann et al. 1984.

Fig. 1-1

## Key Environmental Issues in Irrigation Schemes

**Problems related to natural conservation and quality of life values**

N 1 Use of agro-chemicals and ecotoxicological impairments

N 2 Direct intervention into protected conservation areas

N 3 Interventions into wetlands & other ecologically sensitive areas

N 4 Hazards to public health

N 5 Impacts on socio-cultural values

N 6 Resettlement and migration

**Problems related to the use of natural resources**

R 1 Impacts on sensitive water resources

R 2 Water use conflicts: volume changes and quality impairments

R 3 Land use conflicts

R 4 Soil productivity problems: salinization, alkalinization, water-logging, fertility, biological imbalances, soil contaminations

R 5 Degraded watersheds

R 6 Use of non-renewable resources (energy, water)

**Positive effects of agricultural development by irrigation**

Increased yields & diversified agricultural production
Increase in income and living standard
Improvement of health conditions
Improvement in water sanitation standards
Social and cultural development in rural areas





# 1 Introduction

Few environmental concerns now occupying public attention are as fraught with emotions as are the **large dam** and **irrigation** issues (Fig. 1-1 and Tables 1-1, 1-2). However, dogmatic assertion is an inadequate substitute for truth, and it is hoped that judicious use of the information in the following sections will help reduce emotional debate over irrigation and its associated water development and agronomic practices, leading to rational analysis and reasoned debate. Through such an approach the environmental and socio-economic problems of the majority of people in developing countries may again be focused on the major issue - that of ensuring adequate food supply and sustainability of agricultural production, improving public health conditions, and the conservation of land, water and biological resources.

Sources: Gardner in: Cheng ed. 1990; Biswas/Quipeng ed. 1987; Goldsmith/Hildyard 1984; Goldsmith/Hildyard ed. 1984

It would be misleading to speak of the environmental impacts or problems caused by irrigation systems (or individual irrigators). There are, in fact, **multiple effects** and **various types of impacts:**

- some impacts are applicable to the majority of irrigation schemes, some only to specific agro-climatic regions, and others only to specific locations, scheme types, irrigation methods or agronomic practices,
- some impacts are adverse to other human users, land uses or to fauna and flora, but others are benficial to agricultural production, other land uses or fauna and flora,
- some impacts are unavoidable, but many impacts which contribute to the degradation of water and land resources are induced by certain human-made management practices which are usually changeable and which can be influenced with regrad to their magnitude,
- some impacts are significant, others are insignificant or neutral to human users or ecosystems,
- similar irrigation management activities may result in different environmental responses with changing environmental and/or socio-economic contexts.

It is important to recognize significant physical differences between various qualities and quantities of impacts, their causes and their effects on other human users and ecosystems. This review attempts to distinguish between those important differences where appropriate and avoid inappropriate generalizations.

It should also be worthwhile to mention that the **perception** of impacts on human-made or natural ecosystems has changed over the decades. Historically, some degree of, for example, increased salt concentrations in soils or waters as a result of irrigation was usually accepted as the 'price' for irrigation. In some areas, however, there was so little attention to environmentally sound management that degradation has become a serious matter. As pressure on land and water resources, resulting from increased population and increased necessity to produce food becomes greater, there are increasing demands for effective control of river systems, water quality and soil degradation, including salinisation. The perception that environmental control is required for irrigation, drainage and flood control projects is not a recent development but has been of topical interest since the late 1960s, and various national and international symposiums and workshops were convened in the mid 1970s to discuss relevant environmental issues (eg ICID 1975; COWAR 1976).

A prerequisite for the understanding of irrigation problems is the knowledge of **processes** which may lead to the deterioration of natural resources required for successful irrigation development. For example, successful soil management requires a knowledge of the pro-

Fig. 1-2

## Subjects and Qualities of Environmental Appraisals

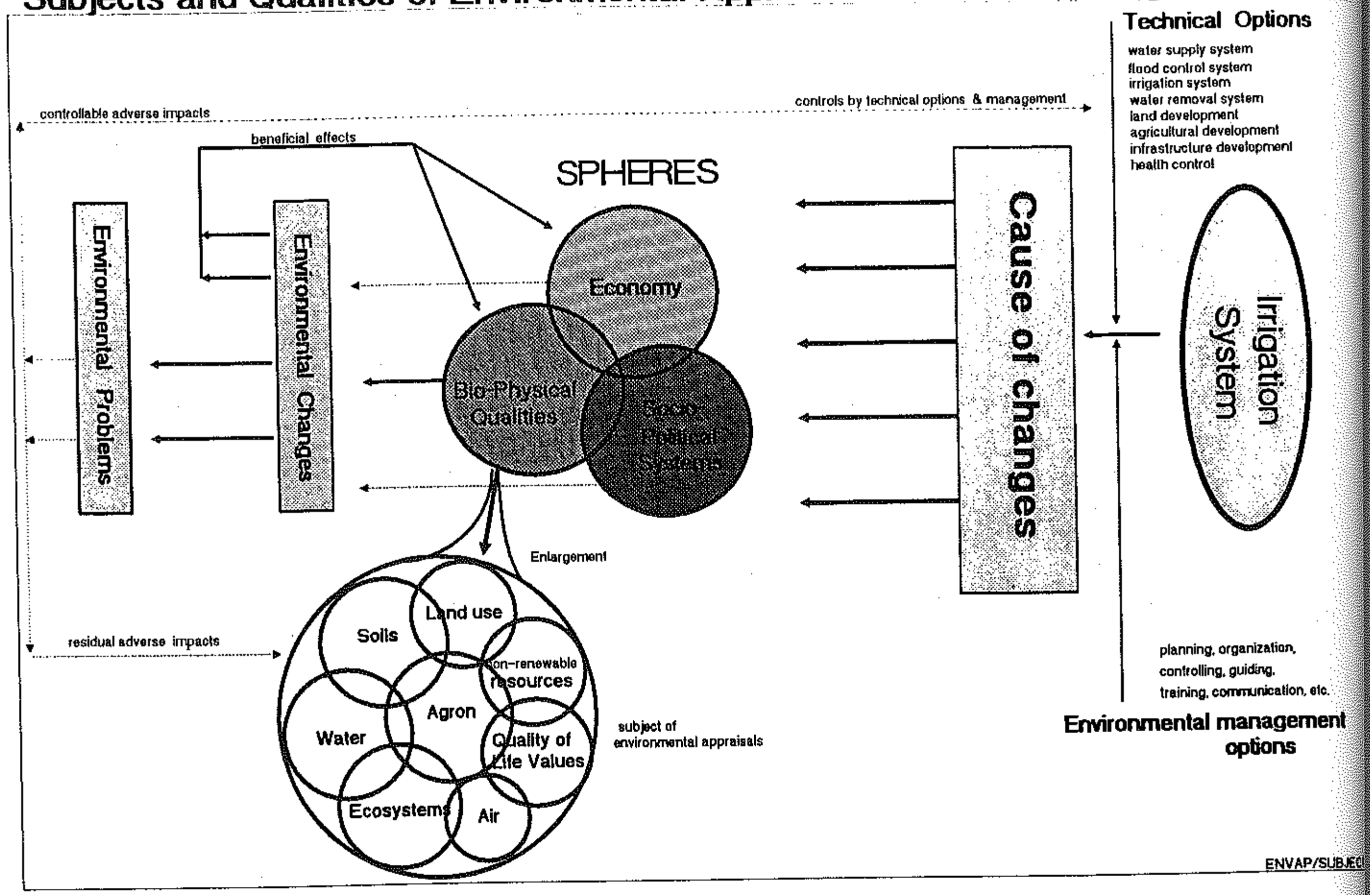
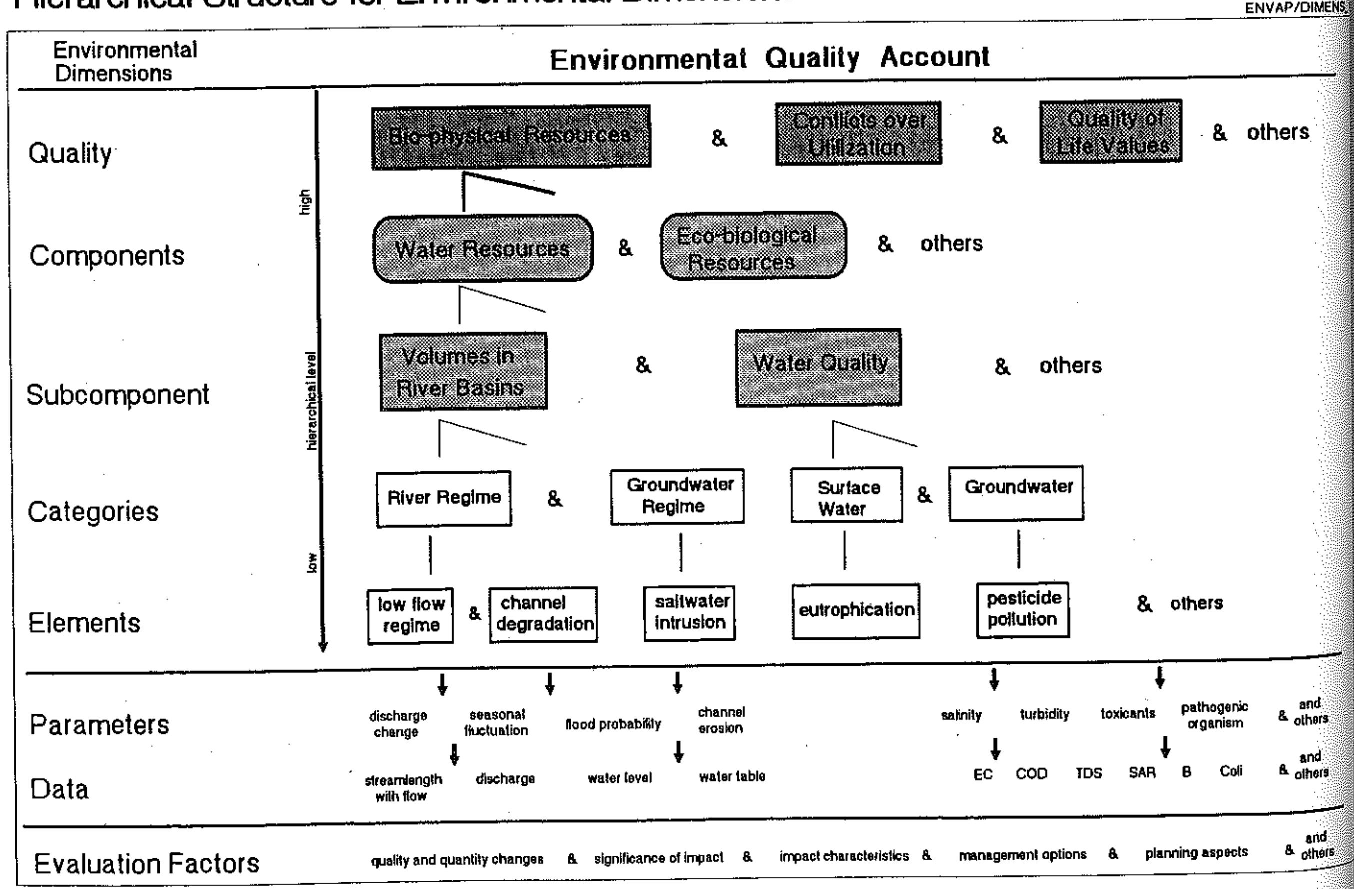



Fig. 1-3

## Hierarchical Structure for Environmental Dimensions








cesses of salt accumulation and leaching in soils under irrigation and plant response to inceased salinity and moisture deficits under different agro-climatic conditions.

## 1.1 Characteristics of Environmental Impacts

Land and water resources development is associated with environmental changes within and outside the developed areas. However, these changes can be either positive or negative unless one takes the attitude that any environmental change is bad. In order to assess the many types of changes which are associated with irrigation projects it is necessary to define the environmental problem and the characteristics of potential impacts.

Environmental impacts of irrigation activities (see Fig. 1-2) can be divided to

(i) ecological, agricultural, hydrological and engineering aspects, ie. mainly physical and biological parameters are altered,

(ii) economic aspects,

(iii) social aspects.

Economic impact analyses are generally included in feasibility studies, although economic appraisal may become important in assessing economic impacts of environmental degradation and the formulation of alternative developments which reduce environmental impacts. On the other hand, social impact analysis (SIA) is a component of other planning appraisals and, therefore, may not necessarily be a main focus in environmental impact assessments (EIA). Nevertheless, some socio-cultural issues are clearly related to environmental problems in irrigation schemes or associated water development projects (see section 10). Vice-versa, environmental management must be seen in the socio-economic context of sustainable development. Hence, the social and environmental development issues are to be treated complementary, especially in the development of environmental management objectives and measures (see section 3.1).

In ecological literature, environment is often defined as the biophysical system in which human intervention takes place (eg Duinker 1989). In this sourcebook, environment is used synonymously as **'natural human habitat resources'** (natürliche Existenzgrundlagen, see Weimert/Kresse/Karpe. BMZ. 1981). The environment may also be understand in a broader sense as the biological, physical and socio-economic systems that surround a development activity (following the Stockholm Conference 1972; Horberry in: DSE 1984).

## 1.2 Taxonomy of Environmental Dimensions

The taxonomy of environmental dimensions comprise four **levels** (Fig. 1-3):

Level 1 Environmental Quality (aggregated natural goods and services; human uses)

Level 2 Environmental Components/Subcomponetns (eg water, soil, human health)

Level 3 Environmental Categories (specification of the component: river regime)

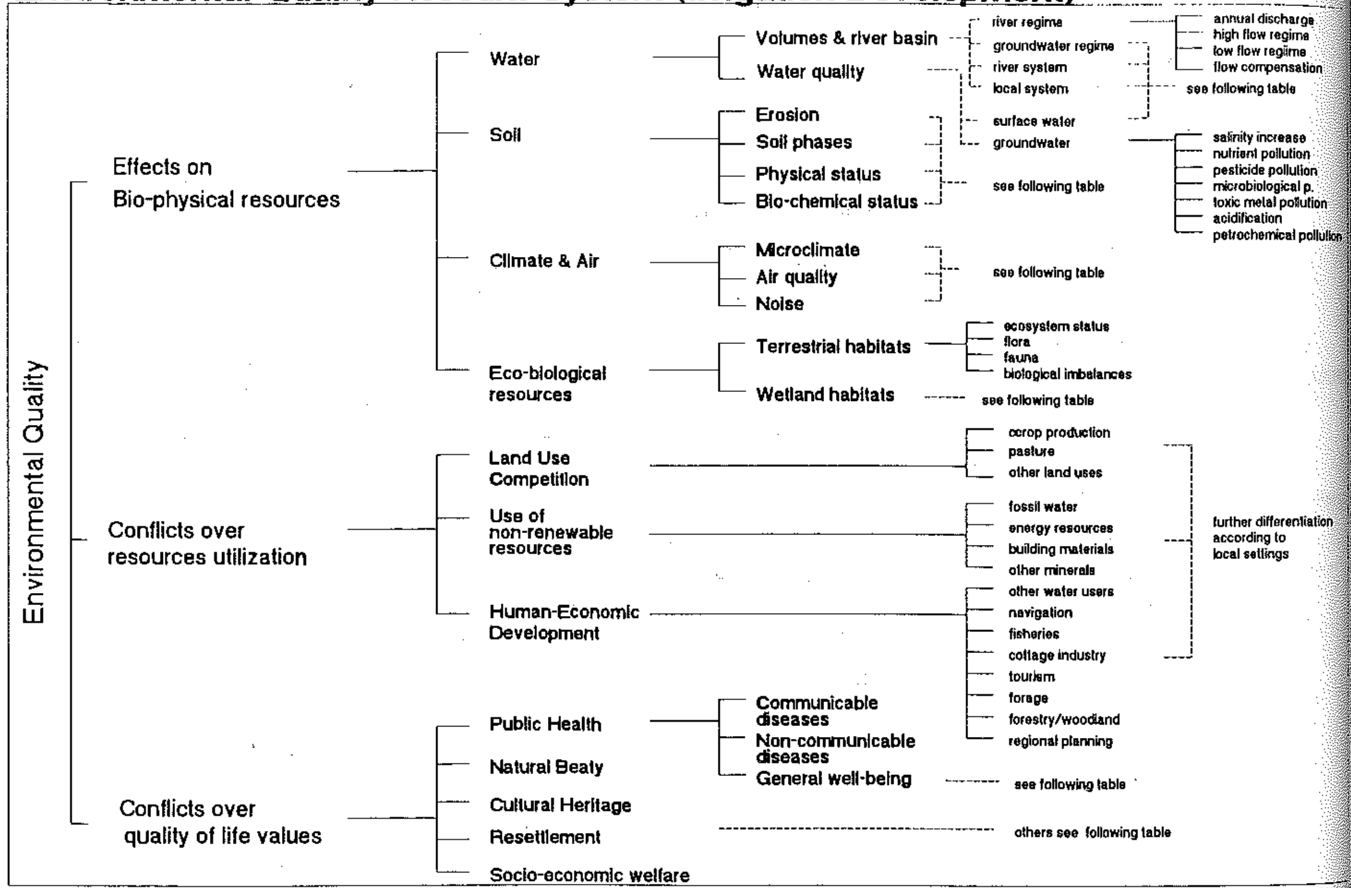
Level 4 Environmental Elements (eg low flow regime)

Environmental analysis requires an inventory and evaluation of the state of the environmental categories, ie the particular type of natural resource (eg river, soil, ecosystem) in the concerned area. Each category in that inventory would then be evaluated in terms of five **evaluation** factors:

Quantity
Quality
Human influences in both directions: human upon resources and visa versa
Uniqueness of affected resource
Irreversibility of changes.

Fig. 1-4

## Environmental Quality Account System (Irrigation Development)








Under each factor, a number of measures may be taken for quantitative (eg river discharge in $m^3/s$, ppm salts) or qualitative assessments (eg visual landscape beauty on an ordinal scale). A complete list of environmental elements to be compiled for water resources development is in OECD 1985 and for irrigation projects in Petermann 1992.

Environmental qualities, components and categories

Environmental qualities (see also Fig. 1-4) may be distinguished under:

- **physico-chemical**: soil (land), surface- and groundwater, atmosphere, noise,
- **biological**: flora and fauna,
- **human**: health and safety, aesthetic and cultural, socio-economic.

Soruce: Biswas/Geping ed. 1987

A similar classification gives emphasis to quality criteria in the context of natural goods and services (see Part II 1.1) and their values for human qualities of life:

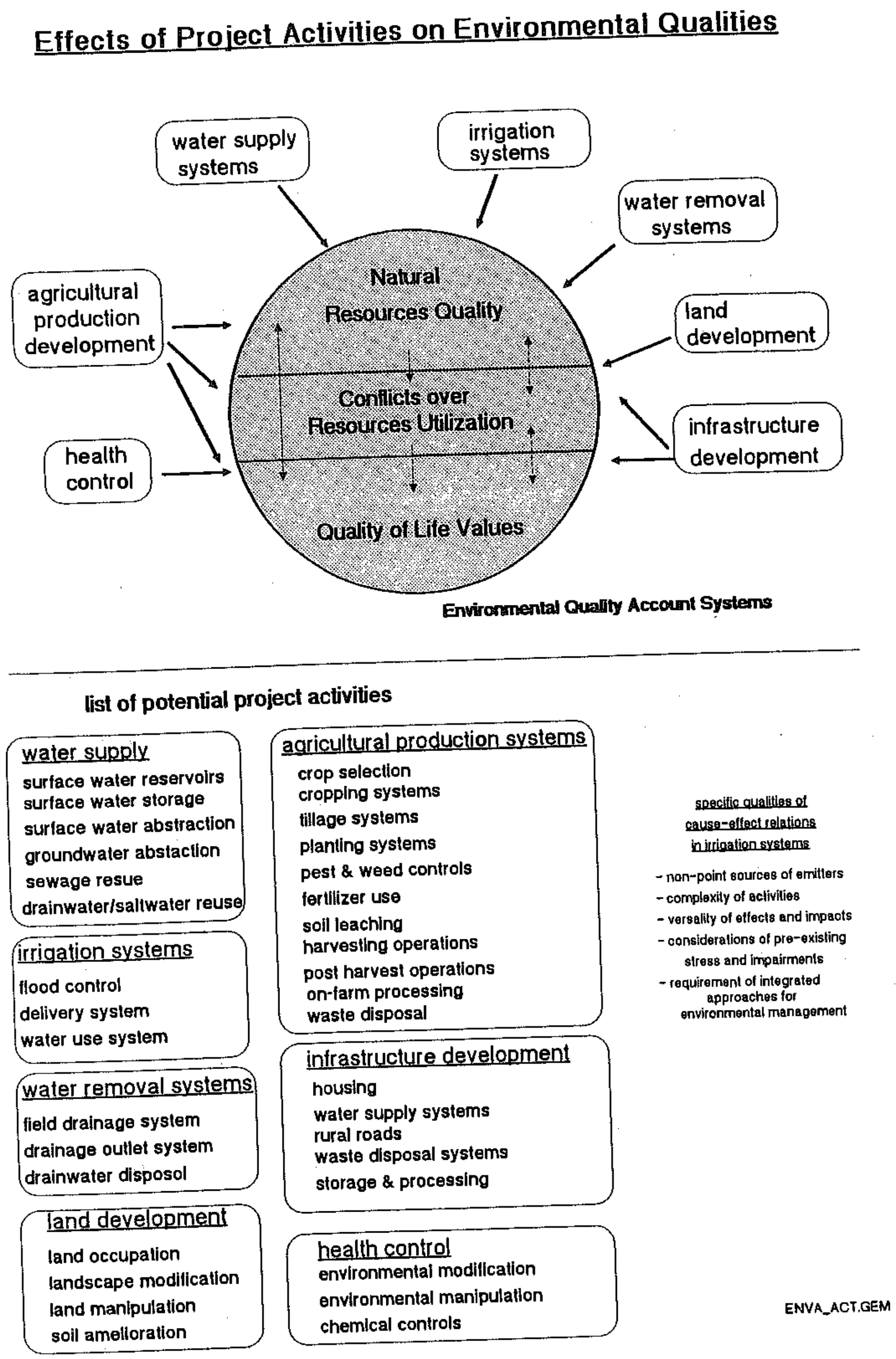
| | Component | Category |
|---|---|---|
| I | **quality for human use** | land, groundwater, surface water, soil, air quality/ climate for productive use of resources; visual, geological resource |
| II | **quality for human health** | air, water and food qualities; noise; soil/water pathogens, and well being vector habitat; exposure to natural hazards (floods/earthquakes); crop production, housing, infrastrucutre |
| III | biological, ecological | biological resources (flora, fauna), ecological systems |
| IV | areas of natural beauty and human enjoyment | forests, open space, watercourses, rivers, lakes, reservoirs, wetlands, wilderness, estuarine areas |
| V | socio-cultural | cultural, historical resources, settlement area, visual, recreational use, traditional land use |

Source: modified after: OECD 1985, Part IV

The following detailed environmental **components** and their **parameters** may be used for irrigation appraisals:

| | environmental component | environmental parameters (examples) |
|---|---|---|
| 1 | water quality | Salinity, pH, temp, organic/anorganic toxins, N, P, BOD, organic C, TDS, bacteria, viruses, parasites, SAR |
| 2 | water quantity | flow rates, total volumes, daily or annual fluctuations, flooding hazards, flood level |
| 3 | land/soil quality | physical and chemical soil characteristics: EC, SAR, pH, nutrients N, P, K, total CEC, ESP, infiltration, water retention, permeability, land drainage; erodibility, soil moisture status, runoff, sedimentation, bank erosion, leaching facilities, presence of toxins, pathogens |

Fig. 1-5








| | | |
|---|---|---|
| 4 | air quality | toxic volatiles, N-volatiles, particulates, greenhouse gases, pathogenic aerosols (from wastewaters) |
| 5 | microclimate | changes in temperature, humidity, windspeed |
| 6 | noise | traffic, machinery, power plants, construction |
| 7 | amenity/recreation | clean water, turbidity, colour/odour, visibility, surface appearances (oil, bacteria films), weeds |
| 8 | aquatic ecosystems | breeding and migration of fish; maintenance of natural and genetic heritage, including endangered species; habitat of aquatic plant systems |
| 9 | terrestrial ecosystems | breeding and migration of fauna species; maintenance of natural and genetic heritage including endangered species and vegetation communities |
| 10 | aesthetics | loss of rare and valued scenery |
| 11 | socio-cultural | loss of rare and valued historical or cultural sites, loss of traditional settlement area, |

Sources: modified after: OECD 1985; a modified system was developed by Petermann 1992 (Fig. 1-3)

## 1.3 Environmental Impact Identification

Adverse impacts may vary in **time**, **space** and **intensity**, and they may act **directly** or **indirectly** through another environmental category (water, soil, air). Some impacts may be simple, of minor importance and, therefore, require only local and timely limited action to mitigate, but others occur on a large-scale and may be associated with complex developments and potential impacts on national or even international natural resources (eg rivers).

Cause of impact. Environmental impacts from irrigation are caused by either

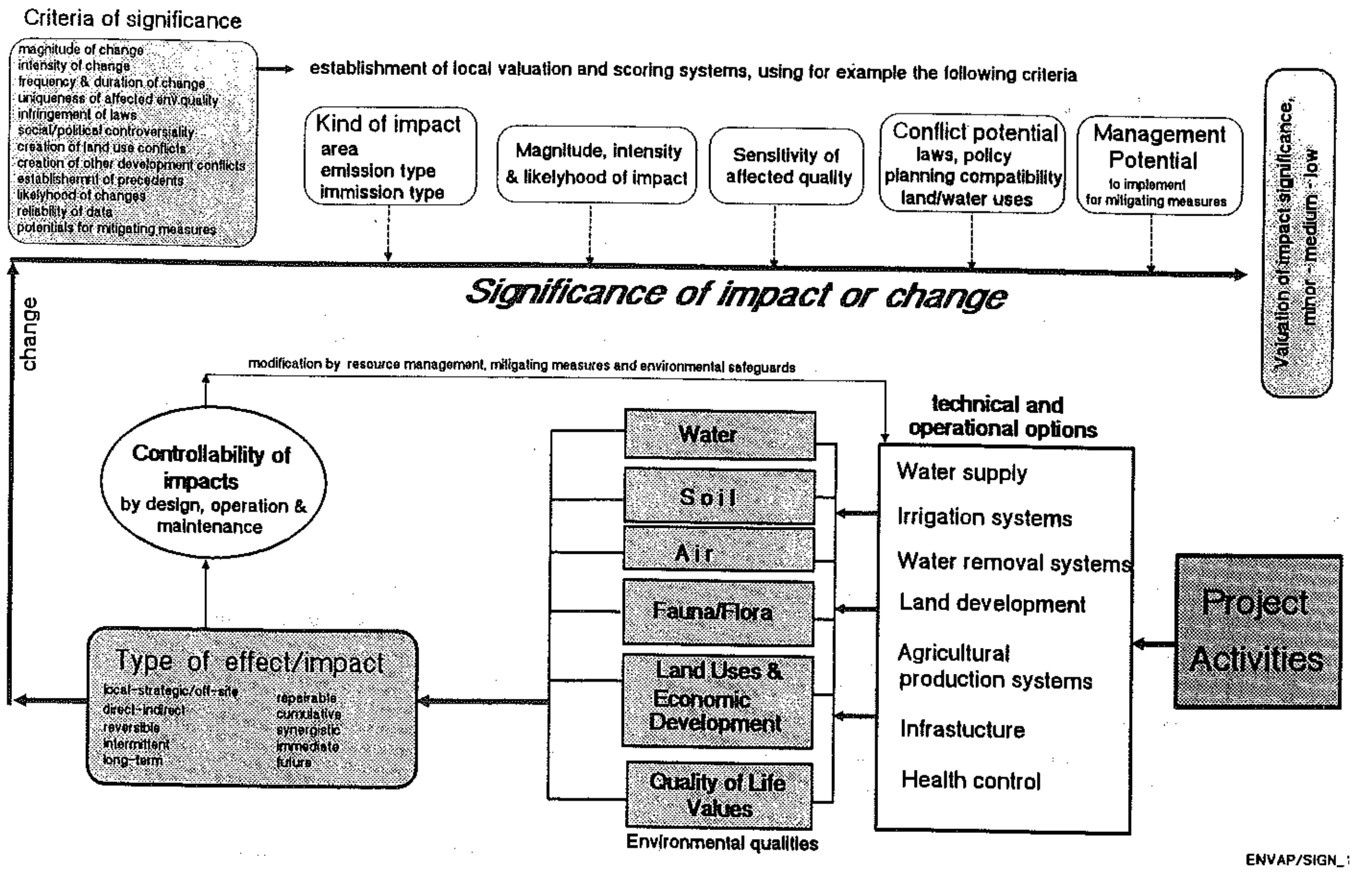
- minor, medium or large scale irrigation projects: typically centrally organized and with substantial public financial support. Farm operations may be centrally or individually organized; water supply and irrigation scheduling are typically centrally organized, either by public authorities or by cooperative institutions
- individual irrigation by farmers without direct public support. Farm operations, water supply facilities and irrigation scheduling are generally individually organized, but parts of the services may be organized by cooperatives or by other institutions.

Causal **factors** of impacts can be identified at various levels and they may be caused by different activities (Fig. 1-5). Impacts may be attributed to

(i) irrigated agriculture as a part of the complex farming system (eg livestock farming)
(ii) activities related to irrigated agriculture, such as crop protection, tillage practices, other crop production activities
(iii) irrigation system components such as:
  * multi-purpose reservoirs, tanks
  * water supply systems (including wastewater & drainage reuse)
  * water distribution systems
  * water application systems (field water management)
  * water disposal systems (drainage systems).

Fig. 1-6

## Environmental Impact Analysis: Significance Assessment








Nature of impact. The nature of the impact determines which environmental **component** and **category** is beneficially or adversely affected, eg groundwater quality or human health.

Levels of impact. Irrigation developments may pose direct or indirect impacts on resources or neighbouring ecosystems;

* **direct impact**: eg pollution of surface water with solid particles, nutrients or salts resulting in a degradation of fish habitat(s)
* **indirect impact**: eg. reduction in the number of fish species or population caused by habitat degradation.

These levels can also be grouped as 'first order' (direct) and 'higher order' (second order, third or indirect) impacts. Indirect impacts are much harder to identify and to assess in quantitative terms. For example, the fish habitat may also be affected by other human activities such as pollution from dryland/rainfed farming or from untreated domestic sewage, or by natural processes, such as low rainfall which reduces discharge and flow velocity which affects chemical water qualities.

It is certainly possible to make some estimates of their importance and magnitude, and even to assess tertiary effects, eg on fisheries (number of catches per fisherman per day) or even higher order impacts on trade and local markets, for example. But such examinations of higher order impacts are only required in the case of such an environmental effect being critical to the success or failure of the irrigation development planning application.

Impact analysis. The following specifications apply to all kinds of development activities and impact analysis (Fig. 1-6).

There are various **characteristics** of impacts:

1) spatial dimension: area or spatial extent of impact, eg on-site versus off-site
2) probability: likelyhood of occurence
3) time dimension: immediate effects to medium- or long-term effects
4) reversibility or irreversibility; potential for recovery
5) importance and magnitude, intensity
6) type of disturbance of ecosystems: cumulative, synergistic, antagonistic effects: cumulative effects of many small actions; chain reactions; or secondary effects of interrelated activities

There are several **criteria** of impacts and effects:

- people adversely affected: identification of groups, individuals, communities
- natural resources affected: land, soil, water, air, fauna/flora
- duration/length of impact
- controllability; the know-how and technology that can be used in mitigation and reversing impacts.

The **magnitude** of impact or the degree of ecosystem disturbance can be assessed by:

- measurement of quantifiable parameters, eg salinity, erosion rate, pollution rate, population affected
- ordinal scales of non-quantifiable impacts (visual beauty) or estimates of quantifiable parameters in case of lack of precise data, eg high-medium-low erosion rates.

The **signficance** criteria may include:

- degree of irreversibility
- spatial extent of effects (see also below: local versus strategic impacts)
- degree and rate of changes
- uniqueness of threatened organisms/goods; rareness of a natural resource
- dependance of various important organisms on affected component/category
- degree of disturbance of ecosystems' function and structure
- anticipated public interest (local, national, international; government or non-government)
- local as opposed to national or even international impacts (strategic impacts)
- salience of environemental problems in their social, economic and cultural context.

The **severity** of impacts can be assessed by

- social costs
- direct costs (in economic terms: loss in value, costs for mitigating measures)
- human health hazards (costs for health control programmes)
- indirect socio-economic costs (eg ecosystems degradation with a long-term perspective: future development potential).

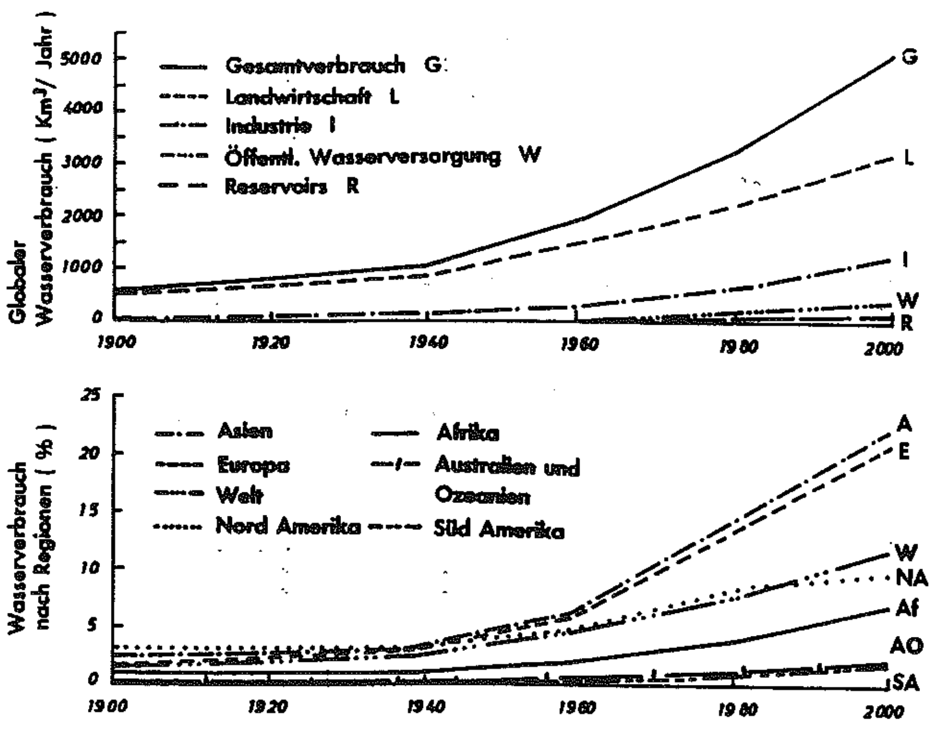
Although there are studies emphasizing the environmental costs of human development (or economic activites), there is still some debate about appropriate methodologies and techniques to be used in **environmental economics**. It is recognized that any deterioration of natural resources will eventually result in the scarcity of these resources and, hence, the deterioration of the environment is also an economic problem. A major problem in such analyses remains the non-tangible nature of some resources (aethetics, biological diversity, socio-cultural values) and the time dependency, eg which time frame will be used for evaluation of effects on non-renewable resources? For further details the reader is referred to OECD 1991b, IIED, Barbier/Markandya 1989, Barbier 1989, Barbier 1990, Michel/Pearce 1990, Pearce/Barbier/Makandya 1988. German readers are referred to Hampicke 1991, Hampicke et al. 1991.

Sources: Biswas/Geping ed. 1987; Roque in: ADB 1986; OECD 1985; Horberry in: DSE 1984

Further readings: DSE 1984; Gassneer/Siederer 1987

Fig. 2-1

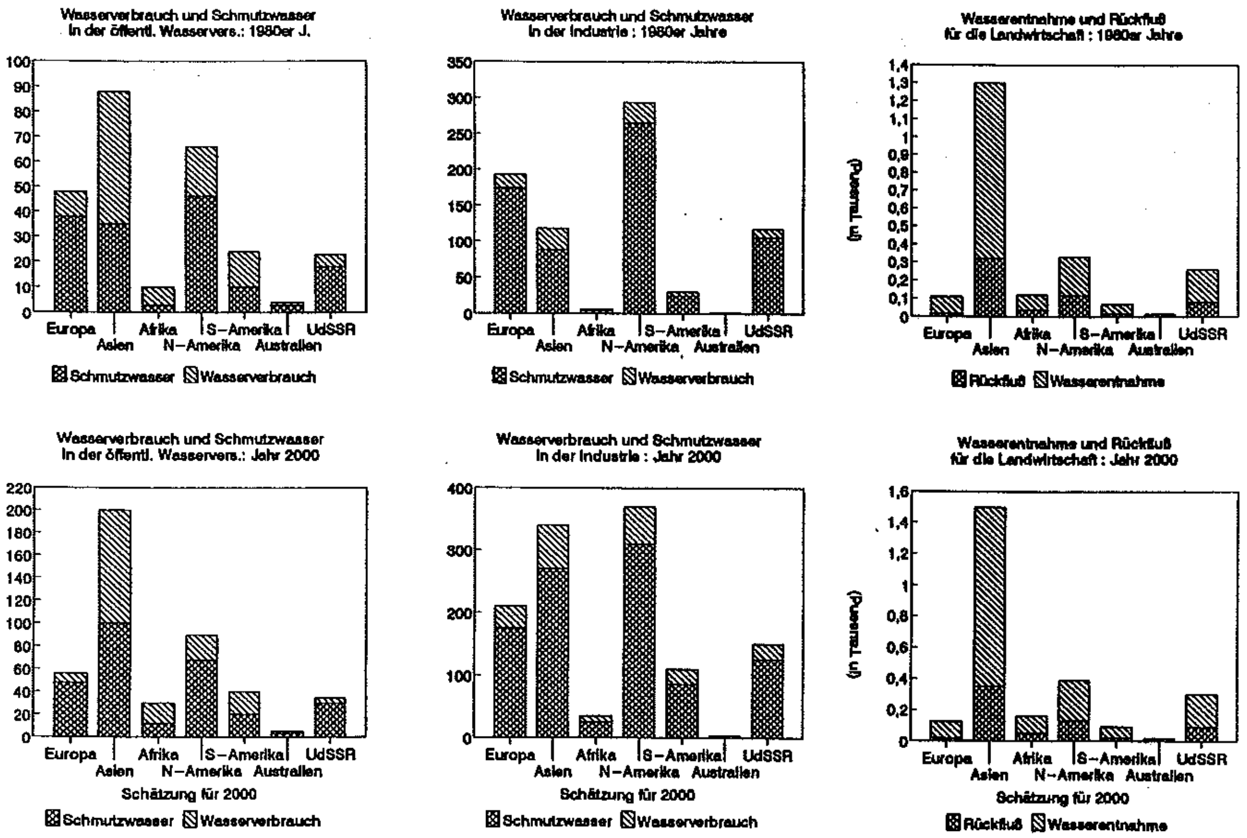
Abb.4-4: Entwicklung des Welt Wasserverbrauchs




Quelle : World Resources Institute, World Resources 1990 - 1991. New York, Oxford

Fig. 2- 2

Abb. 4–5: Wasserentnahme und Schmutzwasser/Rückfluß nach Sektoren, 1980er Jahre und 2000




Quelle: World Resources Institute, World Resources 1990–91, New York, Oxford, 1990

Source: GITEC 1992





# 2 Impacts on Water Resources

There are three major impacts on water resources, (1) the extraction of water for irrigation from rivers, lakes or groundwater aquifers, (2) the subsurface or surface return flow into ground- or surface waters and (3) changes in water quality of the return flow. These impacts are assessed in the following sections.

General reference with numerous case studies in: Kharchenko/Maddock (UNESCO) 1982

## 2.1 Irrigation as a Major Water User

### 2.1.1 Introduction

Irrigated agriculture is typically the **largest** single consumptive water user in both industrialized countries and developing countries (Fig. 2-1). Global figures estimate that irrigation uses is some 2,200 km³ out of total 3,500 km³ of total water abstraction (WRI 1990). OECD figures for the late 1980s show that irrigation withdrawals (out of total human use) ammunt to 41% in the USA, 57% in Italy, 66% in Spain and Japan, and 79% in Turkey. In Pakistan, almost 98% of the annual withdrawal is for agricultural use. This high quota may be representative for most arid countries with developed irrigated agriculture, eg countries in the Near East. In subhimud to humid South and East Asia the percentage of agricultural use is also high, ie ranging between 50 % to over 95% of total consumption. The actual annual withdrawal in terms of annual renewable freshwater resources is rather low, accounting for just some 1-18 % (ADB 1991).

A more intense **competition** for good quality water will in future result from increased non-agricultural demands (Fig. 2-2, Tables 2-1 and 2-2) and from increased groundwater extraction by tapping deeper aquifers. It is estimated that irrigation demand will increase by 10% over the next decad (WRI 1990).

References: WRI 1990; German reader: GITEC 1991 (summary on water issues)

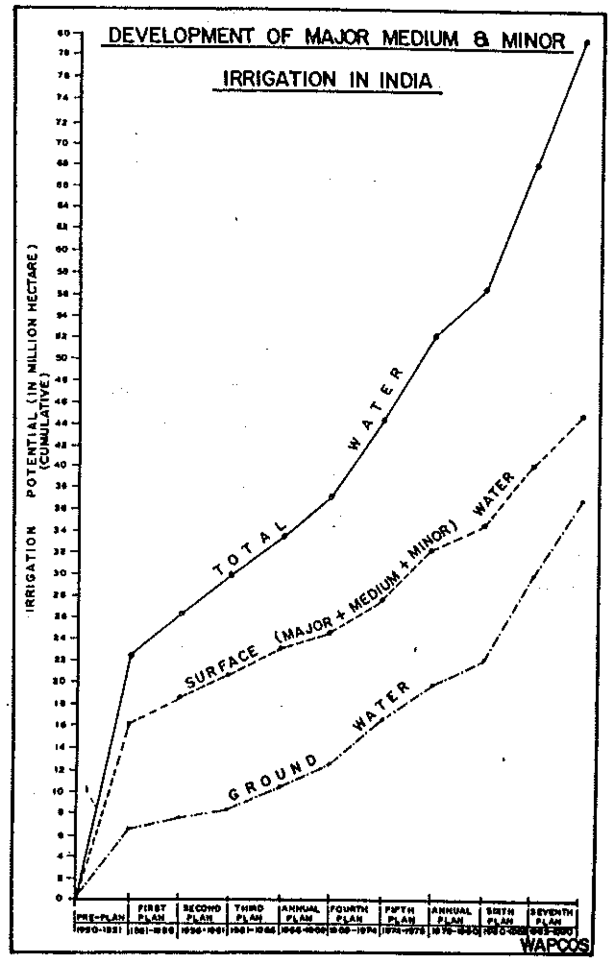
### 2.1.2 Surface Water Withdrawals

Agriculture uses water from rivers or lakes or human-made canals and reservoirs. It is estimated that agriculture uses some 2,200 km³ on 227 Million ha anually (Table 2-3). A part of the extracted water returns groundwater or through surface runoff to rivers (see section 2.2) but a larger proportion is lost to the atmosphere through evaporation from the soil surface, water bodies (inundated fields) and evapotranspiration from crops, other plants or aquatic weeds. Return flow is estimated to some 1/4 of total supply, assuming that evaporative uses amount to some 7,200 mm per season (Fig. 2-1; WRI 1990).

Typically, the total farm irrigation supply amounts to some 1 l/s per ha (= 10,000 m³/ha per crop; double cropping about 15-20,000 m³/ha) under average management and arid agro-climatic conditions. This amount may be substantially reduced by good water management (high system efficiency, low transmission, conveyance and application losses; on-demand supply) to some 5-7,000 m³/ha per crop. Overall figures for various continents are shown in Table 2-3a (figures added in the 2nd column).

Surface water withdrawal may also have some beneficial effects when a larger proportion of seasonal flood water is used in irrigated floodplains (eg paddy), retarded and returned to the downstream river section and probably subsequently repeatedly used in irrigation. Under conditions of a good quality of drainage return flow, such a system, which covers for example in Japan some 54% of agricultural lands located in watersheds, counteracts floods in lowlands and prevents soil losses, ie reduces sediment loads in rivers (OECD 1991).

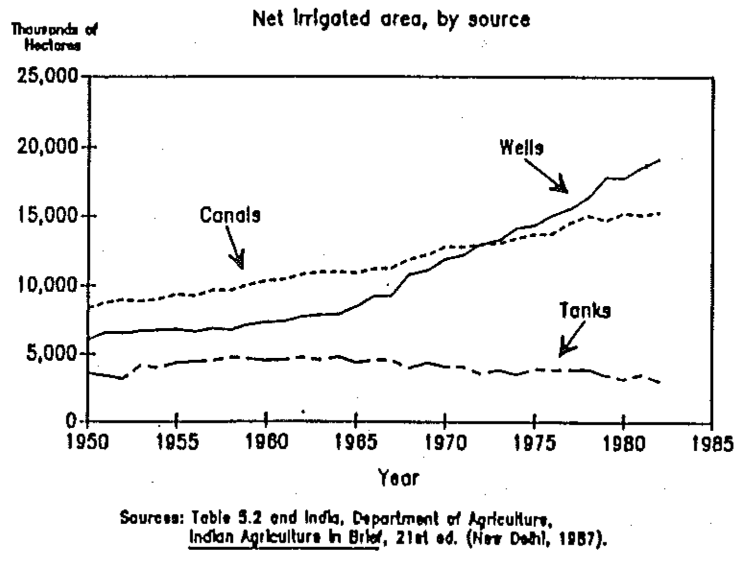
Fig. 2-3a




65

Source: INCID 1991

Fig. 2-3b




Source: Meinzen-Dick/Svendsen 1991





## 2.1.3 Groundwater Withdrawals

Groundwater plays an increasing role in water supply for irrigation. Over the past two decades many surface water sources are already fully developed and groundwater aquifers are increasingly used for supply, although groundwater irrigation has a long tradition, eg in the Indus valley since some 2,500 years ago (APO 1991). For example, the groundwater utilisation in Asian countries is shown in Table 2-3b. Hroundwater use has a long tradition in Asia, and Detailed figures for selected countries are illustrated in Table 2-3c.

*Case Studies*

In India, the area irrigated by groundwater increased from 12 M ha in 1969 to 28 M ha in 1986. Thus, almost 50% of the total irrigated area of 62 M ha in 1986 was irrigated by groundwater (INCID 1991) (Fig. 2-3a). Detailed figures for uses by different sources are shown in Table 2-3 d.

In North China some 168 M mu (1 mu = 1/15 ha) are irrigated by shallow wells and 12.5 M mu by tubewells (some 401 M mu are irrigated by surface water). In North China the annually pumped groundwater amounts to 45-50,000 MCM and about 35-40 000 MCM are used for irrigation, which was 90% of shallow groundwater. It is estimated that the groundwater is exploited by 55 to 70% in most northern provinces (CNCID 1991). Some 2.2 M tubewells were installed (APO 1991).

In Iran, the present distribution of irrigation water is as followsgroundwater 30 MCM, surface water by traditional methods 18 MCM and surface water supplied by modern dams and irrigation structures is 13 MCM (IIMI 1987)

In many arid and semi-arid regions, groundwater is the only reliable source of irrigation water supply. However, in these dry regions, one major concern is the withdrawal in excess of the long-term rate of recharge, called **mining** or **overdraft**. Groundwater mining for irrigation is common in arid and semi-arid areas in the USA, the| Near East, North Africa, India, Pakistan, and Australia, but it may also be practiced locally in other countries. Increasing shortages are reported in many locations in the southwestern USA (Canter 1986). Since the efficiency of water use is rather low in irrigation there is a growing perception in many countries that fossil groundwater reserves or overdrafting should be restricted to more important industrial activities or be reserved for irrigation of high value crops.

Mining of **fossil groundwater** is common in most arid areas in the Near East and North Africa. The large scale abstraction commenced in the 70s with development of new pump technologies and the availability of huge financial resources in some oil-exporting countries such as Libya, Algeria and Saudi Arabia. In most locations the groundwater is either used for the development for settlement schemes of traditional farmers or for production schemes which typically produce staple foods to substitute for grain imports. Ocassionally other crops, fruit trees and ornamenals may be grown. Some large scale groundwater transfer projects convey fossil groundwater to the main population and agricultural centres, eg in Libya. In general, large scale development schemes using non-renewable groundwater resources are under debate, but conservation objections are usually from outside (eg. Allan 1991). Responsible agricultural and economic planners of these countries regard groundwater as a resource similar to oil.

Groundwater abstraction is also practiced in subhumid climates under seasonal irrigation. Here, groundwater is considered as a **renewable** natural resource, eg in Bangladesh:

*Case Study*

Bangladesh: it is estimated that in Bangladesh the net groundwater abstractions for irrigation amount to 5,227 MCM/a, whereas domestic and industrial uses are of about 908 MCM/a (Khan 1988). The annual groundwater recharge is about 24,400 MCM with a total usable groundwater quantity of about 47,700 MCM (1987).

In 1979, some 24% of the total net irrigated area was supplied with groundwater, ie some 0.35 M ha out of 1.1 M ha (Khan 1988).

In 1985, the irrigated area supplied by groundwater increased to 1.2 M ha, ie 50% of the total irrigated land of 2.5 M ha. There are about 20,000 deep tubewells, 156,000 shallow tubewells and 285,000 manually operated shallow tubewells in operation.

Fig. 2-4 a, b

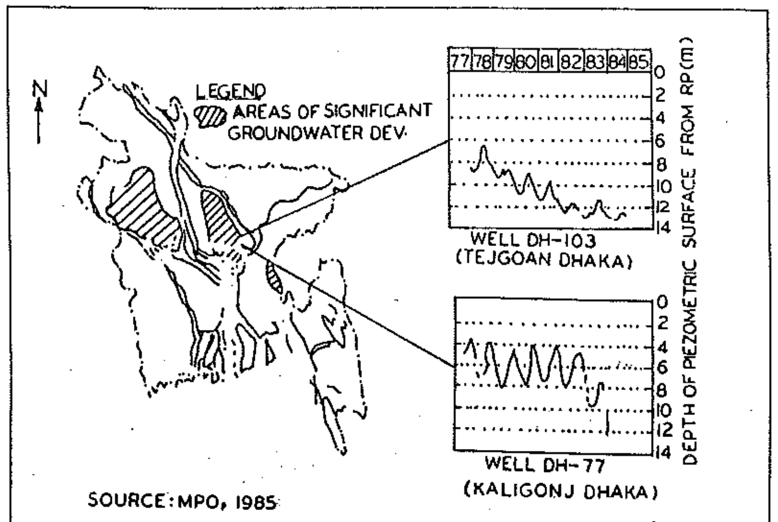



FIG. 4 THE EFFECTS OF GROUNOWATER ABSTRACTION ON GROUNOWATER LEVELS.

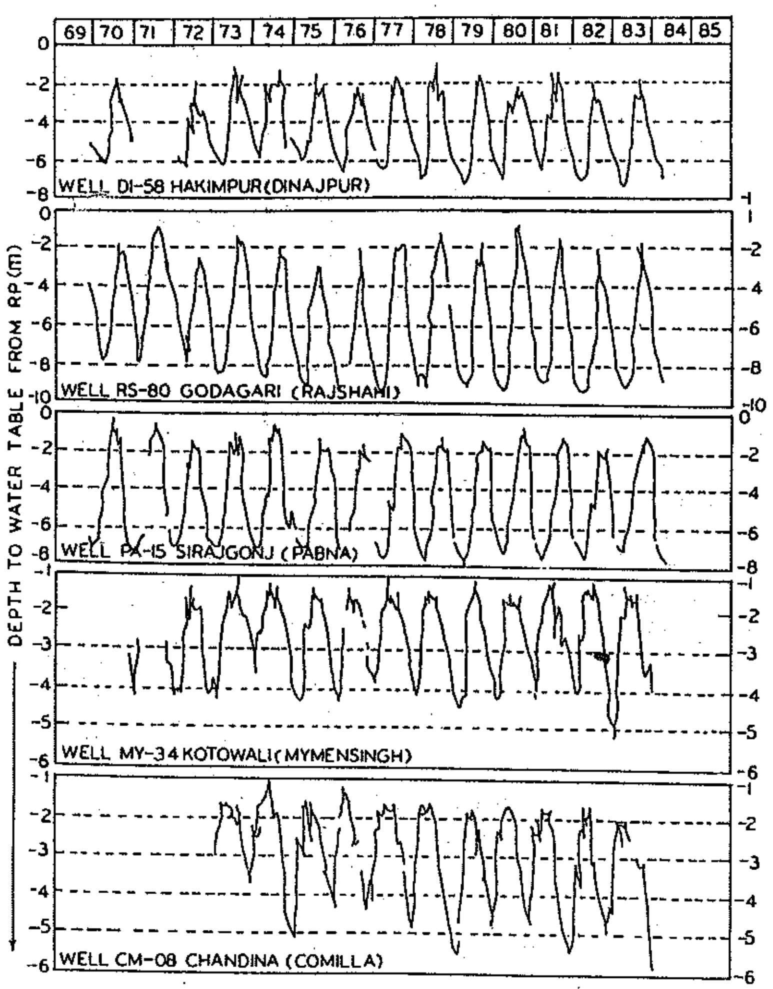



FIG. 2 WELL HYDROGRAPHS SHOWING GROUNDWATER LEVEL FLUCTUATIONS (SOURCE MPO, 1985)

Source: Khan 1988





By 1990 some 3.1 M ha were under irrigation, ie about 70% of the irrigable land. Most newlands are developed by groundwater exploition.

In 1987, some 21% of the available groundwater was used for irrigation on a national scale. However, in some areas the groundwater abstraction resulted in serious decline of water tables. Groundwater levels typically decline during the dry season due to irrigation demands (intra-annual decline), as a temporary overdaft. In many areas, however, replenishment during the wet season does not restore the previous watertable level and a continuous inter-annual decline occurs (Fig.2-4a,b). In some northern parts of the country many shallow tubewells, including drinking water wells, have failed because the pumping head has increased beyond the maximum suction lift limit of centrifugal pumps. Furthermore, some 40,000 ponds have almost dried up (1987) resulting in acute shortages of surface water for irrigation and aquaculture. In addition many traditional fruit tree areas and non-irrigated croplands suffered from the groundwater decline.

Groundwater overdraft is a typical feature of **commercialized farming** areas or of large scale government operated development schemes because it often requires increasing financial investments and operational costs with increased abstraction volumes and pumping depths. However, in areas with easy and cheap access to groundwater, overdrafting may also occur in minor irrigation projects, for example in India and Pakistan (Shah 1990; Toulimin/Tiffen 1987), especially under supportive government policies which make subsidies and credit available for private groundwater development. With new technologies available for groundwater development to more farmers, incentives for private farmers are favourable to promote crop intensification. Consequently, more irrigation areas are developed, up to three crops a year are possible and new crops with higher water demands replace traditional crops (or varieties). Typically, little attention is given to groundwater overdraft until the often limited aquifers are fully exploited or negative impacts are recognized:

- decline in **water levels** with negative impacts on ecosystems and/or increasing development and operational costs for future domestic, agricultural or industrial uses
- reduction in **river flows** caused by reduced throughflow, ie discharge from hydraulically connected shallow unconfined groundwater aquifers, with detrimental impacts on navigation, fishery and other downstream users. In larger watersheds the increasing abstraction of water from upstream locations may make the river baseflow more dependant on the aquifer strorage in the floodplains (eg in India-Bangladesh); hence, excessive groundwater abstractions near the river are usually directly at the expense of river flow
- interference in traditional downstream **water rights** (to some limited extent also upstream affects); groundwater decline may alo have adverse socio-economic aspects because well deepening is typically practices by the 'well-off farmers'
- land **subsidence** problems caused by water level decline: damages to buildings, hydraulic infrastructure, eg flood protection works, irrigation and drainage canals. Severe damages are known for example from Japan, Mexico, Taipeh and USA, eg the Southern Great Valley of California. where maximum land settlement has exceeded 4.5 m. Bangkok City area has also experienced a subsidence of about 1 m. Todd reported an average subsidence ratio of 1/13 indicating that 1 m land subsided for every 13 m lowering in water table (Khan 1988)
- water **quality** problems caused by extraction of fresh water lenses, eg depending on geological stratification
- in coastal areas and deltas **intrusions** of saline **seawater** may be experienced, eg in Egypt, India, Pakistan and Bangladesh (Shah 1990; Birch/vanWonderen 1990, Khan 1988; ODU). In Bangladesh, saline seawater intrusions are reported from various coastal districts and several production wells had to be abandoned (Khan 1988).

Sources: INCID 1991; CNCID 1991; Shah 1990; Toulimin/Tiffen 1987; Khan 1988

Fig. 2-5

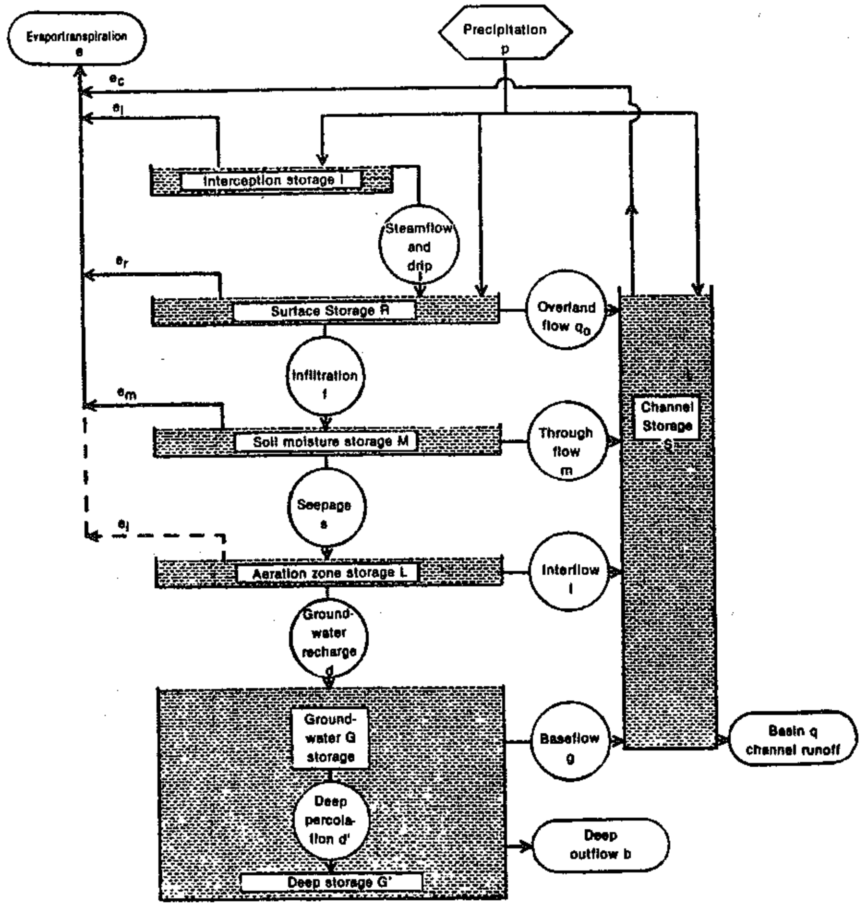



Fig. 35-1. Conceptual view of the basin hydrologic cycle depicting inputs, outputs, storage units, and transfer processes (More, 1969).
Source: Tanji/Hanson, in: Stewart et al. 1990 p.1058

Source: Stewart et al ed. 1990





## 2.2 Irrigation Surplus and Drainage Return Flow

### 2.2.1 Introduction

This section focuses on the type, quantity and quality of irrigation surplus and drainage return flows as affected by irrigation. Details on agricultural and water management measures for control or reuse of these flows are given in Part II section 2. Further cross-references should be made to relevant sections dealing with water quality (2.3), soil salinity (3.1), soil erosion (3.3), and wastewater applications (3.6).

The practice of irrigation is to provide water to supplement effective rainfall in order to meet the evapotranspiration needs of crops. The actual relation between rainfall and irrigation depends on the climate and the soil water balance. Irrigation is practiced in desert, arid, semiarid and subhumid climates (Table 2-4 a,b). Thus, drainage return flows may occur in various agro-climates and may become mixed to varying degrees with runoffs from rainfall. The basin hydrological cycle is defined by rainfall plus change in storage which equals outflow plus evapotranspiration (Fig. 2-5).

Surface and subsurface return flows, either wanted or unwanted, are considered as significant impacts of irrigation activities and as significant components of water resources. In the past, irrigated agriculture discharged its return flows to the hydrologic system with little or no restrictions and constraints. Increasing interest is now being placed on these return flows because of

- decreasing return flow **quality** which includes salinity, sediment load, nutrients (mainly N and P), pesticide residues, and organic or inorganic toxic or harmful trace elements,
- increasing perception that irrigation may not **efficiently** use water resources,
- extension of irrigated areas in the past decades which resulted in a sharp rise in the total water **volume** used by irrigation.

All this will force irrigatators to use water more conservatively in future. This trend is more acute in industrialized countries (eg in the USA, Australia) with higher competition for water by various sectors of the society, but with rapidly increasing growth of irrigation this will also be evident in developing countries in the near future (eg Egypt).

### 2.2.2 Diversion and Return Flow

Whenever water is diverted from a river or extracted from groundwater aquifers for irrigation use, the quality of the return flow declines. The degraded return flow then mixes with the natural flows in the river system, except in arid areas, where the drainage water may be conveyed straight to an evaporation lake. This mixture is then available to other downstream users (agricultural, industrial, domestic, ecological systems) to satisfy their water needs. This process of diversion and return flow may be repeated several times along the course of a river.

The degree of **degradation** depends on:

i) quantity of total river flow (dilution or concentration effects),
ii) quantity of extraction (in % of total flow),
iii) quantitiy of return flow (in % of total flow),
iv) quantity of pollutants in river flow upstream,
v) quantity of pollutants in return flow (eg total salts, sediments, specific ions).

If water is diverted several times from the major rivers, the water typically shows a continual degradation of quality in the downstream direction. If water resources in the lower reaches are utilized without effective controls, the quality in the lower reaches of the ri-

Fig. 2-6

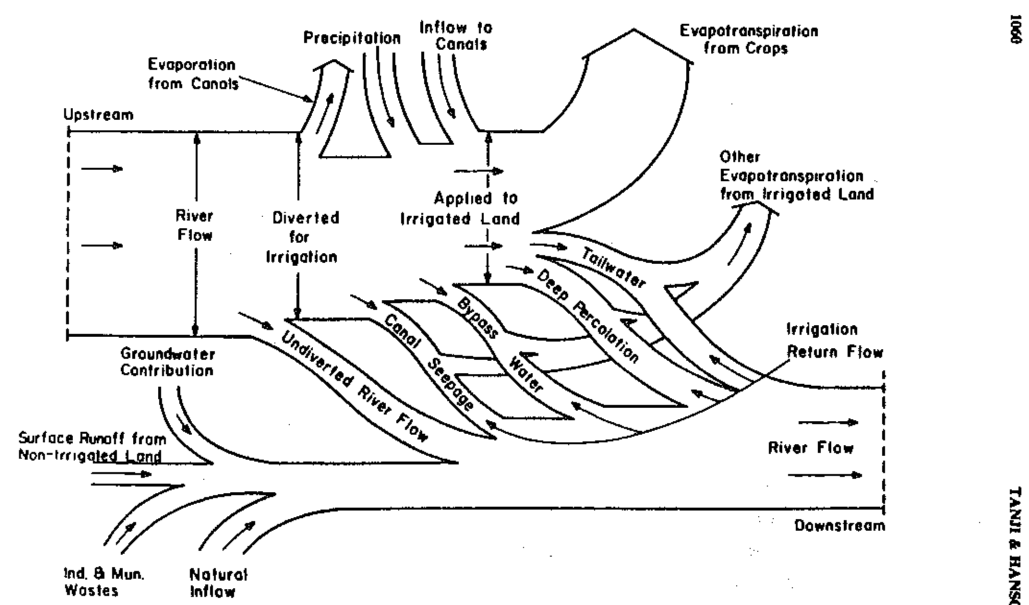



Fig. 35-2. Conceptual diagram of the irrigation return flow system for a given reach of a river system (Utah State Univ. Foundation, 1969).

Fig. 2-7

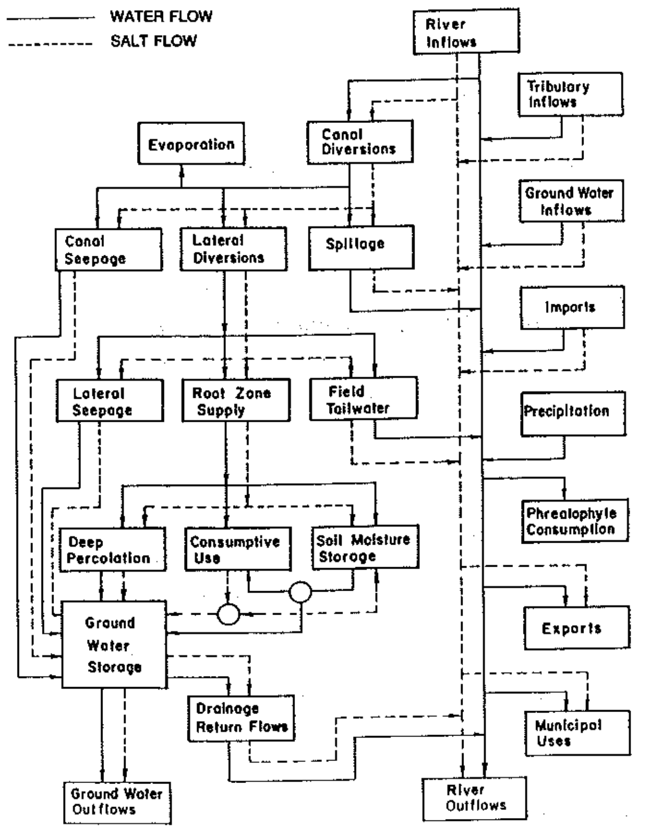



Fig. 35-3. Conceptual diagram of water and salt flows for a generalized hydrosalinity model (Hornsby, 1973).

Sources: all in Stewart et al ed. 1990





ver are likely to become degradated to such a point that the remaining flows are unsuited for many users, and previous uses may no longer be possible.

The irrigated agricultural system can be conceptualized in a similar manner (Fig. 2-6), depicting a reach of a river from which water is diverted for irrigation, and evapotranspiration (ET) losses and a number of return flow paths to the river are identified. Another irrigation system model visualized water and salt flows based on on-farm components (Fig. 2-6). In following these models, the irrigation system consists of the following **hydrological subsystems**:

- water delivery system (reservoirs, diversions, wells),
- water conveyance (irrigation main canals),
- irrigation distribution system (secondary and/or field canals),
- soil-water system (storage),
- drainage system (surface and subsurface),
- groundwater system (aquifer characteristics).

The components typically assessed in irrigation projects are:

rainfall; water supply (from intake); operational spill: distrubution losses, operational wastage; surface and subsurface return flows (marked in the flow diagram).

Generally, there are methodological problems in measuring components such as surface runoff from fields unless the tailwaters or other losses are collected immediately behind the fields (eg Tanji/Hansson 1990). Sometimes, tailwaters are reused for irrigation within the same command area. Another bias in analysis may derive from the differentiation between storm and irrigation return flows; a separation is often impossible for areas where significant rainfall occurs during the irrigation season. Time lags and long distances between measurement stations can also complicate assessments.

## 2.2.3 Type and Quantity of Return Flow

The quantity and type of irrigation return flow from fields mainly depends on the irrigation application method and its operational management. Irrigation return flow into river systems may be via the following **routes**:

(i) disposal of drainage water from subsurface drainage systems via collector drains,
(ii) disposal of drainage water from open field drains and collector drains,
(iii) surface run-off from irrigated fields either (1) directly into the river or (2) via natural channels or drainage canals,
(iv) deep percolation, finally intercepted and collected by the river or its tributaries.

Return flows can be **beneficial** or **detrimental** to the different water users:

- poor quality water may have negative impacts to downstream users, either human-made or natural ecosystems; it contains suspended sediments, soluble salts or agro-chemicals,
- good quality return flow - either planned or incidentally - has typically beneficial off-site or downstream effects because a part of water extracted for irrigation is returned back to the surface (or groundwater) hydrological subsystem with insignificant quality changes. The term good quality is defined in relation to needs of various users (see Part II section 2.1),
- stagnant water caused by surface runoff from fields is detrimental due to increased health risks, and the development of waterlogged and saline soils in downslope areas; similar effects are often caused by stagnant rainwater pools.

Aspects of beneficial drainage water reuse are treated in depth in Part II section 2. Water reuses may occur at two spatial dimensions or levels:

- on-site, ie within the farm area itself,
- off-site, differentiated by various downstream users, or by hydrological subsystem levels: regional, river basin, or interbasin levels.

Typically, beneficiaries use slightly or mildly affected return waters for pasture land, for pasture lands, livestock water supply, wetlands/ wildlife habitats, for domestic and industrial applications, fisheries, navigation, recreation, etc. This is actually the case in most large river basins in Asia, Near East, and the USA.

Further beneficial effects may be attributed to

- repulsion of saline water in tidal habitats and coastal groundwater bodies,
- groundwater recharge,
- maintenance of flow in rivers during low flow season.

Irrigation return flows consists of two **components**:

(i) **surface** irrigation return flows, either from conveyance, distribution canals or tailwaters from surface applications: irrigation water that does not infiltrate but runs off the lowest portion of the fields and which is drained off by open ditches or which flows directly into a watercourse or reservoir, or remains as stagnant pools in depressions. In some irrigation systems tailwater losses are planned, eg in cascade rice terraces or specially designed basin irrigation systems,

(ii) **subsurface** irrigation return flow: water that has drained through the rootzone and which is intercepted and removed by drains or which moves laterally along the hydraulic gradient. A certain quantity of subsurface flow is intentional in many irrigation systems where salts are present in the irrigation water. These must be removed from the rootzone to maintain productivity for crop growth (see section 3.1, Part II sections 2.4 and 3.3).

Surface return flow occurs when the application rate exceeds the infiltration rate of the soil on an inclined area (see also sections 3.3 and Part II section 2.4). Factors which determine runoff under sprinkler irrigation include application rate, uniformity of application, total amount applied, tillage system, crop type, soil infiltration rate (compaction and aggregation), and field topography. Under surface irrigation systems the length of run, slope of field, and infiltration rates are more important. Subsurface return flow is caused by overirrigation and by non-uniform applications when water is leached through the root zone into the groundwater at some depth.

Excessive seepage losses from canals and laterals (ditches) can be attributed to poor operations and/or the use of unsuitable construction materials or earth canals. In some large schemes these losses may account for 30-50% of the total water supplied (Bos/ Nugteren 1974), whereas minimum losses in the range of 10 to 15% are attainable. Despite the fact that these losses are uneconomic, they do not usually present a pollution hazard to surface or groundwater unless a large proportion evaporates and thus increase the salt concentration of the return flow. These losses, however, often contribute to rising water tables in the command area and waterlogging and salinity build up within the rootzone (see section 3.1).

The attainable **application efficiency** at the field level, which is a direct measure of water losses, would theoretically be almost identical for properly designed and managed irrigation systems, but in practice there are immense variations due to soil properties, conditions of irrigation, drainage and water management (see following list).

Potential Attainable Uniformities and Application Efficiencies of Irrigation Systems

| System | Uniformity | Application Efficiency | Typical Efficiency |
|---|---|---|---|
| | ---------- % | ------------ | -- % -- |
| Drip/Trickle | 80-90 | 75-90 | 80-90 |
| Sprinklers | | | |
| periodic move | 70-80 | 65-80 | 60-70* |
| continuous m. | 70-90 | 75-85 | |
| solid set | 90-95 | 85-90 | |
| Surface | | | |
| furrow | 80-90^ | 60-90# | 50-60* |
| border | 70-85^ | 65-80# | |
| basin | 90-95^ | 75-90# | 55-60* |

^ soil variability may increase the uniformity by 5 to 10 %

# higher values for tailwater recovery systems or cutback flow

these efficiencies represent USA-experience; the application efficiency is defined by the ratio of the average amount of water stored in the root zone to the amount of water applied

* values of field application efficiency determined by Bos/Nugteren 1974 in developing countries

In surface irrigation systems a high deep percolation rate is often unavoidable, because the minimum application is typically 70-1000 mm which exceeds the water holding capacity of many sandy soils.

Source: Tanji/Hanson 1990 in: Stewart et al 1990; further figures are given in Kharchenko/Maddock 1982:33

In general, both types of return flow are prominent characteristics of surface (gravity) flow systems as compared to pressureized systems (sprinkler, spray, drip) with typically higher uniformity and lower application rates. Tanji/Hansen (1990) provide the following figures for surface return flow:

* furrow irrigated rice fields in California: 19% of total surface inflow,
* furrow irrigated tomato in California: 29% runoff.

Further quantification of return flows are given in the next section in the context of water quality changes.

Sources: Tanji/Hanson in: Stewart ed. 1990

## 2.3 Surface and Groundwater Pollution

### 2.3.1 Introduction

This section addresses the type and severity of pollution problems induced by irrigation, whereas Part II sections 2.2, 2.3, 3.4 and 5.2 provide an overview of present techniques and methods to minimize potential water pollution impacts.

Irrigation may lead to water quality degradation, eg through an increase in salinity levels. All water contains dissolved salts and the consumptive use of irrigation water by crops always results in an increased concentration of total dissolved solids (TDS) in the subsoil drainage water. Fertilisers and pesticides likewise are not totally removed by crops,

Fig. 2-8 a

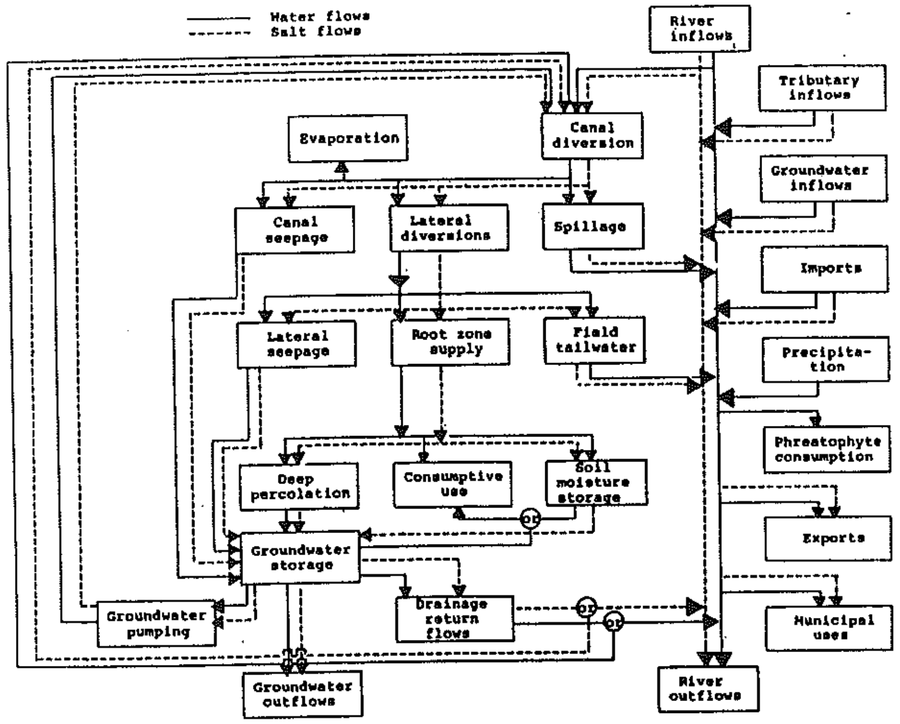
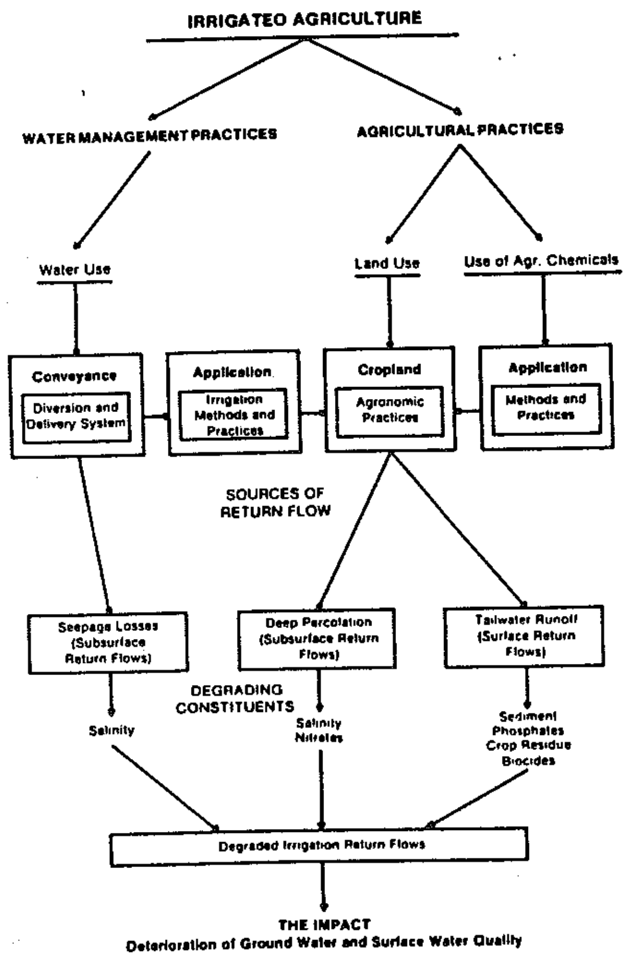



Fig. 2 Water and salinity flow diagram for an irrigated area

Source: FAO (IDP 31) 1979

Fig. 2-8 b




Source: Canter 1986

Figure 13: Water Quality Problems from Irrigated Agriculture (U.S. Environmental Protection Agency, 1978)





transformed to harmless constituents, or degradaded before reaching the rivers and groundwaters and eventually the consumers of these waters. Agro-chemical but also organic fertiliser residues are an unavoidable consequence of agricultural production. At the same time, the public demands increased quantities of water and high quality foodstuff, safe drinking water, and maintenance of wealthy natural ecosystems.

Polluted irrigation return flows will usually have detrimental impacts on the **downstream** water resources. The significant intensification of agriculture in both developing and industrialized countries in some cases caused an increase in erosion, pollution of water, and the contamination of soils. Some generalization is possible about the extent and significance of these processes which ultimately lead to the degradation of soil and water resources (eg OECD 1991. Environmental Data). GITEC (1992) prepared a world-wide list of water quality assessment (Table 2-5a). However, the actual extent of pollution in a specific situation may well differ from these generalised values and conditions are rapidly changing. Unfortunately, reliable and detailed investigations are very limited for developing countries in general and for irrigation projects in particular. Only recently, in some intensively utilised areas such as the Nile Delta have programmes of water quality monitoring been enforced (eg El Quosy in: ICID 1990). International hydrological monitoring programmes are now focusing on establishing reliable data bases, for example the International Hydrological Programm (IHP), Operational Hydrology Progamme (OHP), Global Environmental Monitoring System (GEMS/WATER), World Climate Programme (CP/WATER).

Pollution occurs from the following **sources**:

- runoff into streamflow and groundwater recharge from **non-irrigated farmland** (rainfed crops, pastures): 47% of land in USA from which streamflow is generated
- runoff into streamflow and groundwater recharge from **irrigated fields**: 2% of land in USA: 4.4% of streamflow (may be higher)
- streamflow recycling from **industry** wastewaters: 12% of river streamflow
- streamflow recycling of **domestic** wastewaters: 3% of streamflow.

These figures are estimates and in individual watersheds the values for comparent catchments may **deviate** considerably from these nationwide figures for the USA:

- in upper watersheds, the human extraction of water for irrigation is typically lower than in lowland watersheds where more favourable conditions for irrigation on the floodplains exist
- the relative importance of irrigation as a water user is much higher in developing countries than in most industrialized countries because industrial and electrical cooling, which amounts to some 85% of total industrial uses, is not widely used.

Sources: WRI 1990; ADB 1991; OECD 1991; Chanlett 1973

Irrigation (or agricultural) induced pollution is regarded as a **nonpoint source** of pollution. Agricultural water pollution sources are

(i) **fertilisers** and dissolved salts which are derived from fertilisers

(ii) soluble **salts** in the irrigation water itself or soluble soil constituents (see Fig. 2-8a)

(iii) **pesticide** residues

(iv) degradadable **organic wastes**, mainly from livestock production (eg feedlot runoff).

Typical **pathways** which result in deterioration of water quality are shown in Fig. 2-8b. Typical concentrations of agricultural pollution sources in comparison with other pollution sources are shown in Table 2-5b-d.

Hydrological system **models** are used to assess and to simulate impacts from agricultural sources and to evaluate their significance as compared with natural sources, point sources and non-point sources. These models are based on monitoring data and may also be

Fig. 2-9

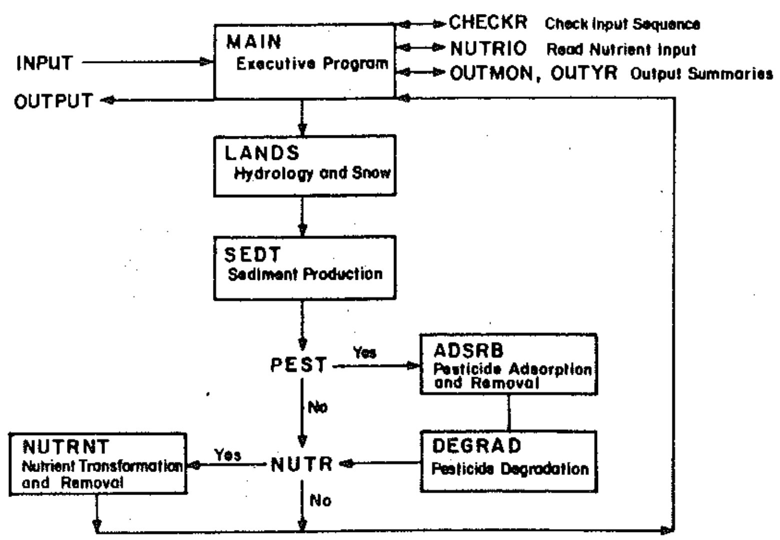



Fig. 14.18. ARM model structure and operation.

Fig. 2-10

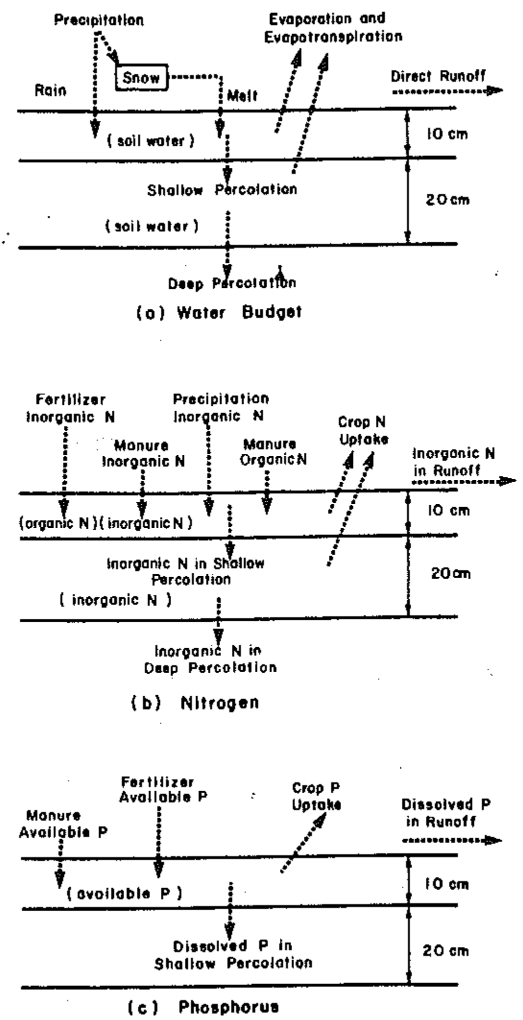



Fig. 14.20. Cornell Nutrient Simulation Model.

Fig. 2-11

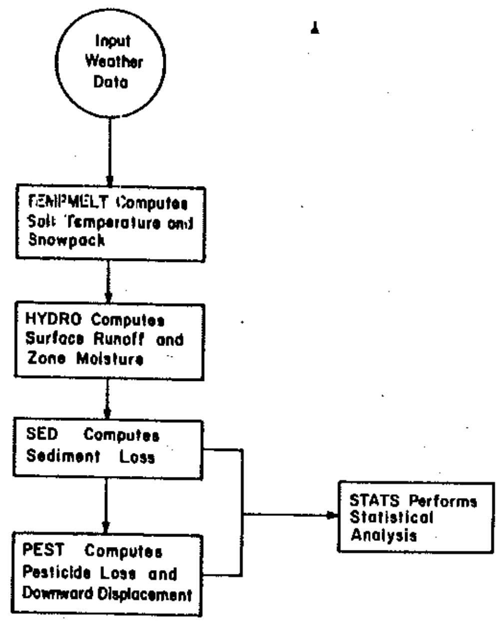



Fig. 14.21. Flow chart for Cornell Pesticide Model.

Sources: all in Joergensen ed. 1983





well suited for development of 'best management practices'. Some of these models are described and reviewed in Biswas et al (1991), Canter (1986) and Skogerboe/Walker/ Evans (in: Joergensen ed. 1983). Many models are applicable to both irrigated and non-irrigated agriculture. For example,

* Agricultural runoff management model (ARM) simulates nutrient, salt or pesticide movements in the watershed by water or sediment; it consists of five submodels (Fig. 2-9)
* Cornell nutrient simulation model (CNS) is deterministic and based on daily water balances, daily erosion calculations and monthly N and P inventories; Fig. 2-10
* Cornell pesticide model (CPM) consists of five sub-models (Fig. 2-11)

Sources: Skogerboe/Walker in: Joergensen 1983; Canter 1986; Biswas/Khoshoo/Khosla 1991

## 2.3.2 Salts in Irrigation Return Flow

It is estimated that agriculture including irrigation is responsible for virtually all non-point pollution in surface waters in the USA (USA, Canter 1986).

Whilst the salinity removal from the command area may be a beneficial on-site effect (except in sodic soils), it has detrimental off-site impacts. Agricultural, domestic or industrial downstream users have the burden of increased salinity derived from irrigation. The impacts of water salinity on crop yields are discussed in sections 2.6 and Part II section 3.3. Important processes which lead to saline irrigation return flows are

(i) over-irrigation and nonuniform field application which leads to excessive leaching, from at least part of the field
(ii) major reclamation activity of naturally saline soils, for example desert soils, and soils deteriorated by irrigation,
(iii) residual salt enrichment in soil solutions resulting from evaporation (through the soil surface and plants) of irrigation water. Under good irrigation management some 60% of the irrigation water is used by crops for growth. Salts are removed to a lesser extent thus leaving higher concentrations in the remaining solution (see section 3.1)
(iv) natural saline deposits which are dissolved as drainage or groundwater water percolates through them.

Analysis of impacts

An assessment of the hydrological impacts induced by irrigation must be based on inflow-outflow analyses. For example, regional watershed modelling as presented by Skogerboe/Walker/Evans (in: Joergensen ed. 1983) can be used. Basic data are river and tributary inflows, subsurface inflows, irrigation inputs, surface and subsurface outflows, reservoir operations, and the associated water quality parameters (eg salinity, N-contents) of each of the above.

These modelling methods also allow 'best management practices' and their effects on the hydrological cycle to be identified. The planning framework for developing the best management practices for one specific irrigation area is shown in Fig. 2-12 (opposite next page). Unfortunately, in many irrigation projects most of these data are not available as direct measurements. Estimates are the most common practice in evaluating the impacts of irrigation projects on the hydrological cycle.

*Case Studies*

Iraq, Tigris: Irrigated agriculture has long been a major user of water in the Tigris river system which has an average annual flow of 38 MCM. Agricultural activites, in turn, are a significant source of increased salinity along the river course. Salts and other chemical constituents are derived from dissolved mineral salts from soil materials or dissolved evaporation residuals which are transported in irrigation return flow, and in modern times from pesticides and fertilisers. In addition, some 1.9

Fig. 2-12

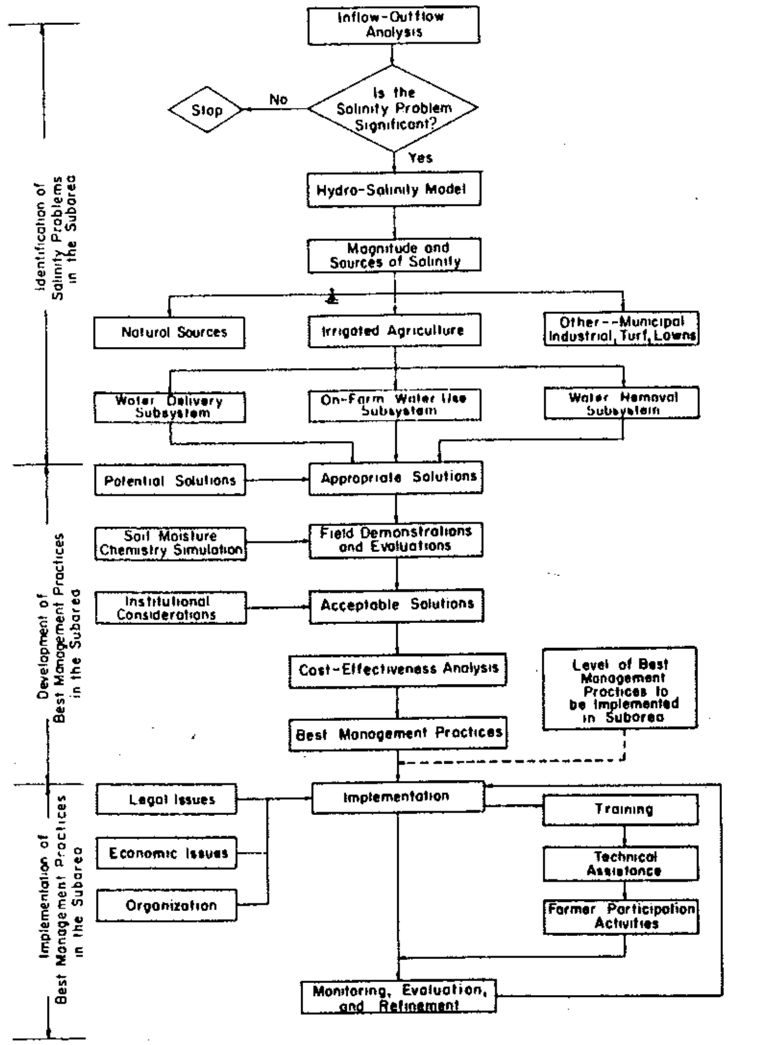
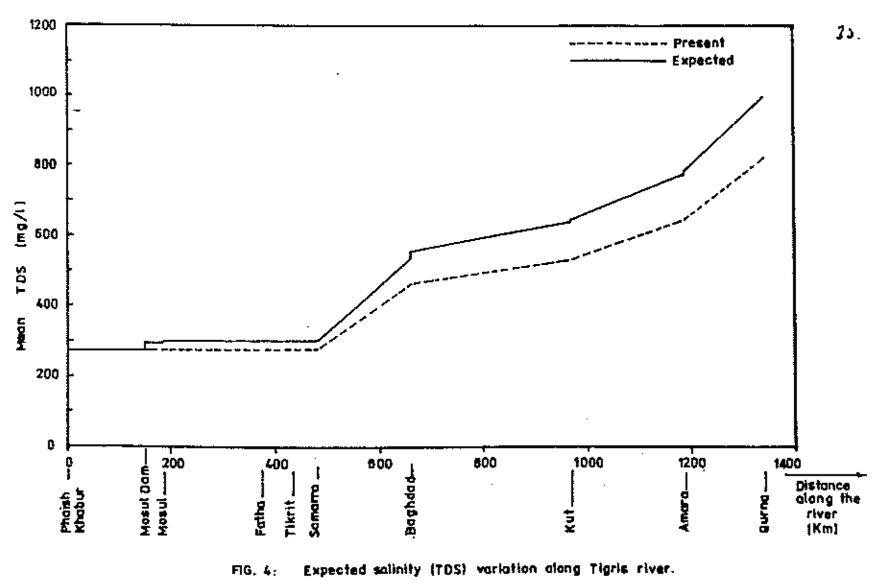
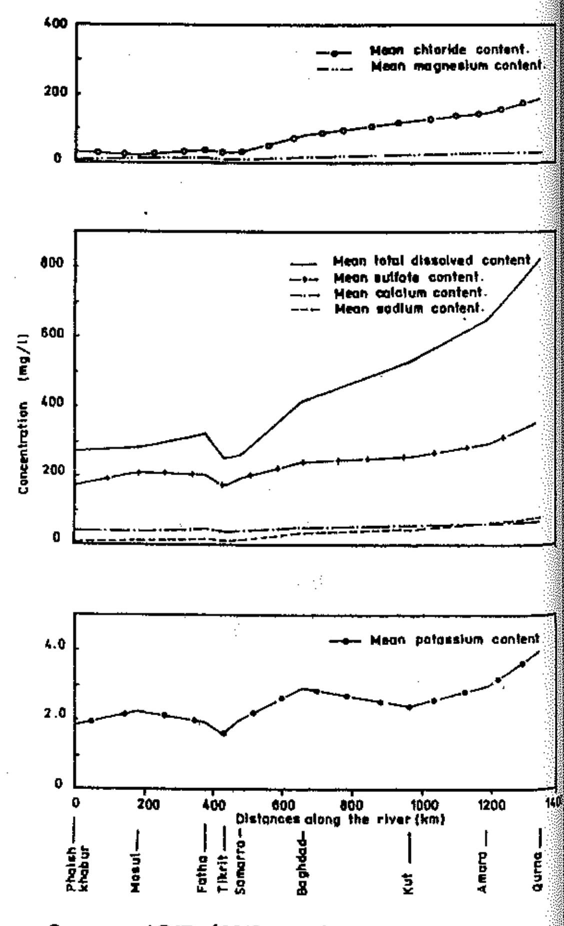



Fig. 14.5. Planning framework for developing best management practices for only one irrigated area.

Source: Joergensen ed. 1983

Fig. 2-13 a, b




Source: ICID (STS-C14) 1991







MCM of industrial and municipal wastewaters are annually discharged into the river system without treatment (excluding Baghdad since 1990). By 1995 it is predicted that the total water requirement will amount to 63 MCM, and the total water disposal will be 22 MCM. About 50% will be derived from irrigated lands.

The electrical conductivity (EC) of drainage water from these irrigated fields ranges from 9 to 19 dS/m. During reclamation, the EC of the leaching water may reach 30 dS/m. Return flows from flooded fields (mainly rice) have EC values ranging from 1.1 to 2.5 dS/m. (Dimensions dS/m = mS/cm = mmhos/cm)

River water analyses show an increase of total salts and individual ions: Fig. 2-13 a, b.

Source: Abdel-Dayem et al. in: ICID (STS-C14) 1991 Beijing

Egypt, Nile Delta: Here, irrigated agriculture is the main user of Nile waters with about 90% of the irrigation water is supplied from the river. In 1988, total irrigation deliveries to the Delta amounted to some 34,000 MCM/a, of which some 2,600 MCM/a were derived from drainage backflow. In some new Eastern Delta projects drainage water may amount for 50% of the total water applied. Reuse of drainage water should increase to 7,000 MCM/a by the year 2000. The present average salinity of re-used water was 1.4 dS/m in 1988; drainage water with less than 1 dS/m is used directly for irrigation, others being blended with Nile water. The average Nile water salinity is 0.35 dS/m (Delta inflow) (see also section 11)

Source: Al-Layala/Fathalla in: ICID 1984. Brazil; see also: El Quosy in: ICID 1990

Others: Data for Murray-Darling River Basin (Australia) and Colorado River (USA) are shown in Fig. 2-14 a and b, respectively (see opposite next page).

Further readings: Westcot in: Hoorn 1988; French ed. 1984

## 2.3.3 Nitrogen

Nitrogen losses from agricultural land may occur directly from surface **runoff** into surface water bodies or as **leaching** losses to groundwater. Losses are typically associated with high or inefficient N-applications and inadequate measurs to prevent soil erosion. N-fertilisers may even be removed before they can be taken up by plants.

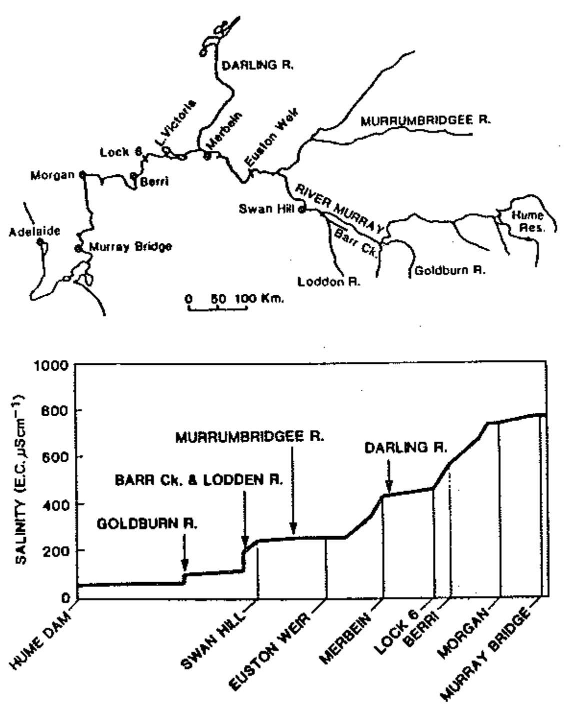
While most industrialized countries are experiencing rising trends in nitrigen levels in ground- and surface waters, with concentrations sometimes exceeding the critical value (drinking water standard) of 45 mg nitrate/l, there are still very few reports of serious N-pollution in developing countries, though this may reflect a lack of investigation. With regard to irrigation, high nitrogen concentrations in waters represent a (usually wanted) supplementary supply of nutrients, eg in domestic wastewaters.

It is estimated that agriculture including irrigation, contributes about 40-45% of the total nitrogen and phosphorus non-point pollution of ground- and surface waters in the USA (Canter 1986).

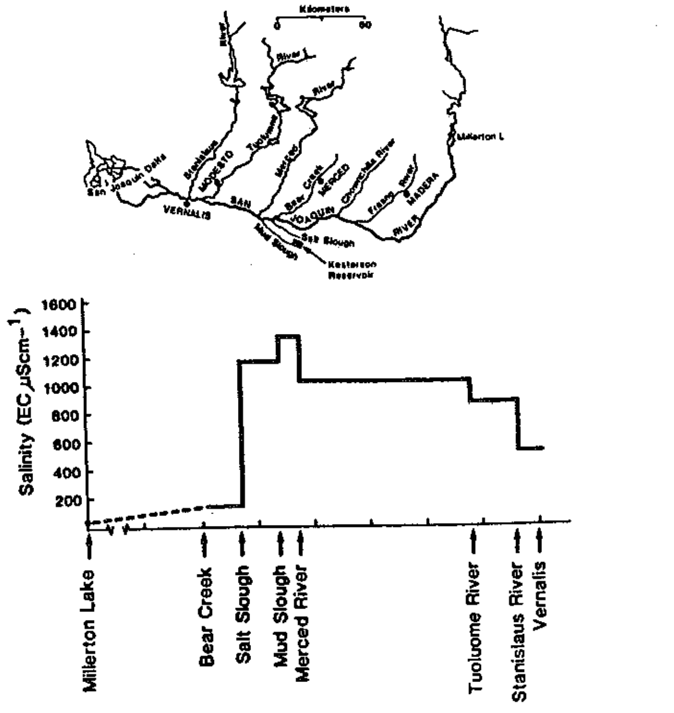
Sources of **non-point** N pollution in developing countries may be open defaecation, latrines or untreated sewage from small settlements. In some areas, livestock wastes may contribute to non-point pollution (Loehr 1976). Usually, high concentrations of nitrates are combined with faecal coliform bacteria which clearly indicates human and animal wastes as the pollution source. Factories may become important point pollution sources in many developing countries due to either poor sewage treatment standards or the complete lack of treatment (Conway/Pretty 1988).

Excess nutrients may lead to accelerated **eutrophication** of surface water bodies. At high nurtient concentrations, algae populations flourish (blooms) and subsequent concentrations of $O_2$ in rivers and especially in reservoirs results in fish habitat deterioration. The aest-

Fig. 2-14 a, b




Average salinity for August - April for the period 1977-1983 at various points along the River Murray in Australia (adapted from O'Brien, 1984 with permission from Butterworth Publishers, Stoneham, MA)




Median salinity for June - September 1985 at various points along the San Joaquin River in the U.S.A. (adapted from Gilliom, 1986)

Source: Westcot in van Hoorn 1988

Fig. 2-15

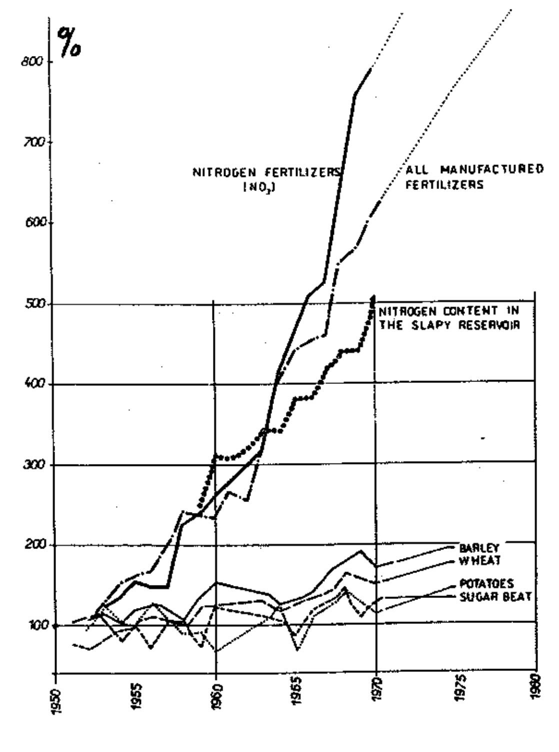



Fig. 85. Water pollution due to fertilizers.

Source: Holy 1980

Fig. 2-16

94 IMPACTS OF AGRICULTURAL ACTIVITIES

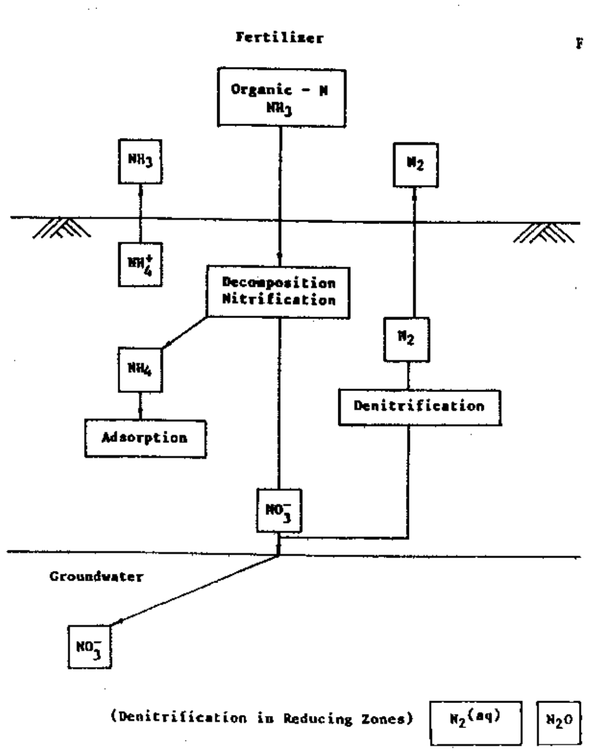



Figure 16: Form and Fate of Nitrogen in the Subsurface Environment

Source: Canter 1996





hetic and recreational value will be diminished and navigation or fishery may be restricted.

Human **health** problems are related to high concentration of nitrates in water. They are especially hazardeous to infants because $NO_3$ is converted to toxic $NO_2$ in the digestive system. $NO_2$ reacts with blood hemoglobin to form methemoglobin which reduces oxygen transport in the blood. By the age of about 12, enough acid (HCL) is produced by the body to kill the bacteria which convert $NO_3$ to $NO_2$.

*Case studies:*

Average N and P contents of different water sources in industrialized countries are shown in Table 2-6 and the increase over the past decades is shown in Fig. 2-15.

The form and **fate** of nitrogen in the subsurface environment is shown in Fig. 2-16.

The nitrogen balance of an average field in Sweden is shown in Fig. 2-17.

The results show that the **efficiency** of N-flux is very low, ie typically only 20% of the applied nirtogen is used by the plant. The yields increased considerably at even low input levels. Perennial plants use nitrogen most efficiently. Actual N-losses in irrigated fields also depends on the soil moisture status. On-demand irrigation systems, ie sprinkler or drip systems, may minimize deep percolation. Thus they minimize nutirent leaching losses. In irrigated agriculture, the level of N-flux efficiency can be increased by good management practices when compared with non-irrigated crops because of the increased biomass production under irrigation..

Nitrates which are not removed by plants or lost by volatilization usually reach the groundwater because of their high solubility and anionic form. They migrate with minimum transformation and over long distances with groundwater movement. A decline in the redox potential of the groundwater can effect this migration. The quantity of nitrogen lost may be higher in the **tropical regions** than in temperate climates.

Some important factors which enhance losses are high runoff (caused by high rainfall intensity), surface irrigation, low level of soil conservation tillage practices, and higher rates of mineralization through repeated wetting and drying at high temperatures. Some crops with a low canopy cover during development stages (eg maize, cotton) may enhance runoff from natural rainfall or sprinkler irrigation at high intensities. Typical losses to ground- or surface waters from tropical **dryland** fields are up to 40-50% of the applied nitrogen. Even under controlled conditions and improved application methods losses are rarely below a level of some 30-35% (Conway/Pretty 1988). Total nitrogen losses (including volatilization) in **paddy** rice irrigation may reach 60% (DeDatta/Buresh 1989), especially when a continuous flow is maintained from one field to the next and surface drainage systems collect and convey the excess flow into surface water bodies.

*Case Study*

Thailand. Losses of nitrogen from runoff in **paddy** fields (40,000 ha; double cropping) were estimated for a lake catchment in terms of total nitrogen load

wet season (60 kg N/ha applied to all fields)

| | | |
|---|---|---|
| fertiliser broadcast | total N outflow | 5.6 kg N/ha |
| fertiliser incorporated into soil | total N outflow | 3.7 kg N/ha |

dry season

| | | |
|---|---|---|
| fertiliser broadast | total N outflow | 6.8 kg N/ha |
| fertiliser incorporated into soil | total N outflow | 3.8 kg N/ha |

total annual N load to Laguna de Bay: human 1400 t/y
paddy 400 t/y (average loss of 5 kg N/ha)

Source: Singh et al., cit. in: Conway/Pretty 1988. Further case studies in section 2.3.4

Fig. 2-17

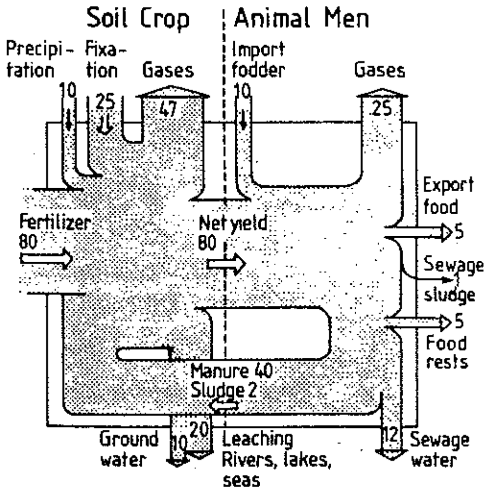



**Figure 1 - Nitrogen balance sheet of an averfage hectare of arable land in Sweden. Values in kg.ha$^{-1}$.yr$^{-1}$**

Source: Brink in Lessafre ed. 1990





Greatest losses occur when fertiliser is broadcast and irrigation flow continues over fields also in the dry season. Hence, water and fertiliser management practices offer the possibility of reducing losses by almost 50%. Eutrophication and explosive algae blooms may also occur within flooded paddies with detrimental consequences on the N-availability to crops - up to 30% is fixed by algae - and increasing pH due to carbonate releases from algae with subsequent increased volatilization of nitrogen as ammonia.

For further details refer to references on N-pollution, eg Blume ed. 1990; Canter 1986; De Datta/Buresh 1989; Summer (USCID) ed. 1986, 1988, 1989; Anderson in: USDA 1988; Conway/Pretty 1988; Nieder et al. 1985; Obermann in: Nieder et al. 1985; IRRI 1978.

## 2.3.4 Phosphates

Phosphates are easily fixed in the soil by **chemisorption** (eg on Fe- and Al-minerals as relatively insoluble P-compounds) and chemical **precipitation** (eg Ca-phosphates). The actual movement through the soil depends on fertiliser application rates, percolation rates, pH-values and presence of free sorptive agents such as clays, carbonates, and oxides of iron and aluminum. In sandy and peaty soils, however, phosphorus may move rapidly through the soil profile. In most soils, however, phosphate losses are closely related to soil erosion when particels are washed off, containing adsorbed phosphates.

Large cow stables, dungyards and silage bunkers are frequently the most important polluters of rivers in industrialized countries (Brink 1990; Loehr 1976). They are usually associated with intensive cultivation methods and **livestock** farming. Phosphate pollution problems may be less critical in developing countries due to lower application rates and less intensive organic manure applications on fields. However, in areas with high P applications and high soil erosion (because P is fixed to washed soil particles), surface waters may be polluted, too.

Sources: Brink in: Lesaffre ed. 1990; Conway/Pretty 1988; Canter 1986; Holy 1980; Loehr 1976

*Case Studies:* (Nitrogen and Phosphates)

USA. Drainage studies showed no evidence of significant P-transport to groundwater (Evans/Gilliam/Skaggs in: ICID 1990).

Bangladesh: nitrate problems in groundwaters are not yet encountered in rice fields (Khan 1988).

India: a survey on 350 rivers did not result in concentrations > 10 mg nitrate/l (Handa in: Conway/Pretty 1988). However, groundwaters may contain higher levels: about 20% of 3000 analysed well waters contained nitrate in excess of 50 mg/l, though deep aquifers showed less than 10 mg/l. In all surveys, pollution was greater in wells near villages than those in open fields, suggesting that domestic excreta was leaching to the groundwater.

In Sri Lanka, drinking water contains up to 0.1 mg nitrate/l; the Mahaweli River contains 1.1 to 2.4 mg nitrate/l in upstream and downstream sections respectively. Kandy Lake contains up to 45 mg nitrate/l, and the drainage canal into the Lake may contain concentrations as high as 310 mg nitrate/l. Contamination may be caused by latrines or villagers using the canal for open defaecation as well as algae pollutants (Weerasooriya in: Conway/Pretty 1988).

In Central Nigeria, some 50% of village well waters had concentrations in excess of 45 mg nitrate/l, the maximum value of 400 mg/l contrasting strongly with a maximum of only 6 mg/l from wells in fields.

In Southeastern Namibia, concentrations exceeding 90 mg nitrate/l were found in 75% of wells polluted by livestock wastes. Similar results exist from other southern African countries (Conway/Pretty 1988).

Fig. 2-18

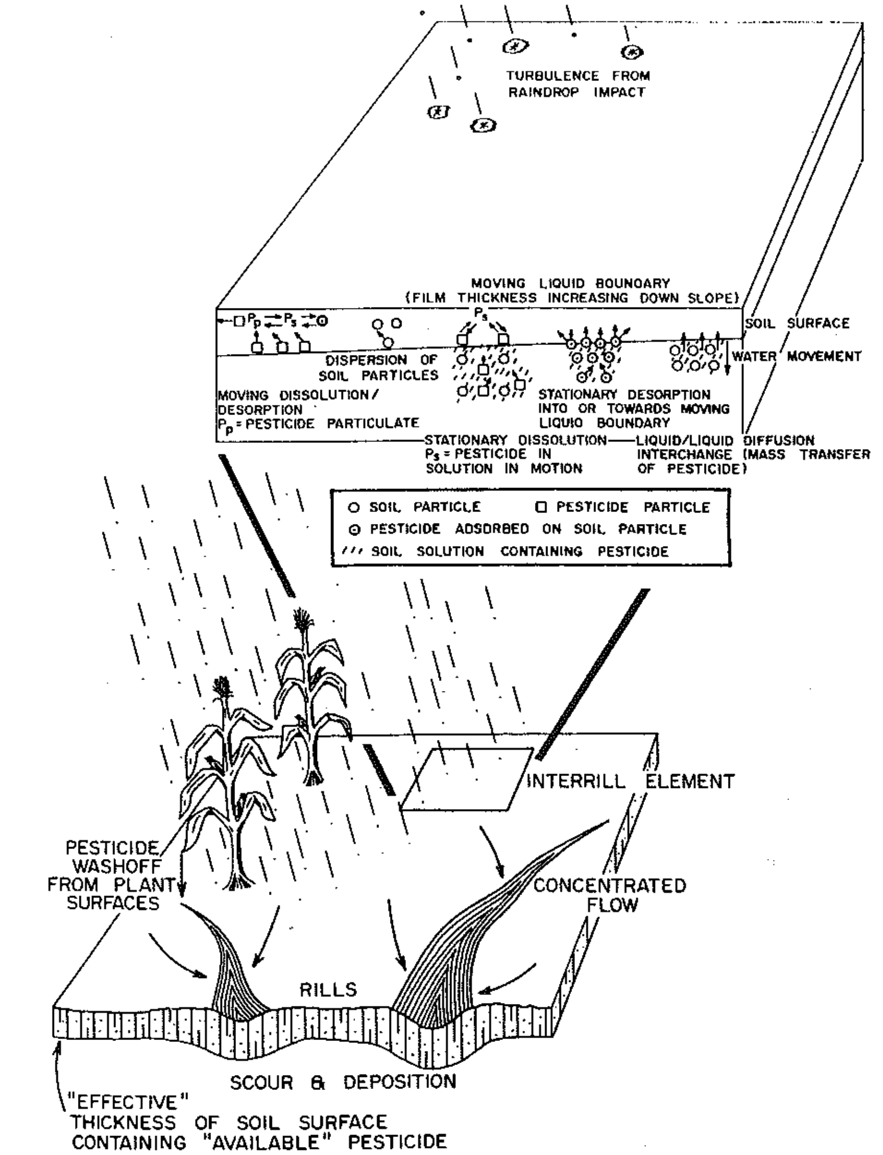



Fig. 9-1. Processes of entrainment and transport of pesticides in surface runoff. (Modified from Bailey et al., 1974 and Leonard & Wauchope, 1980.)

Source: Leonard in Cheng ed. 1990

Fig. 2-19

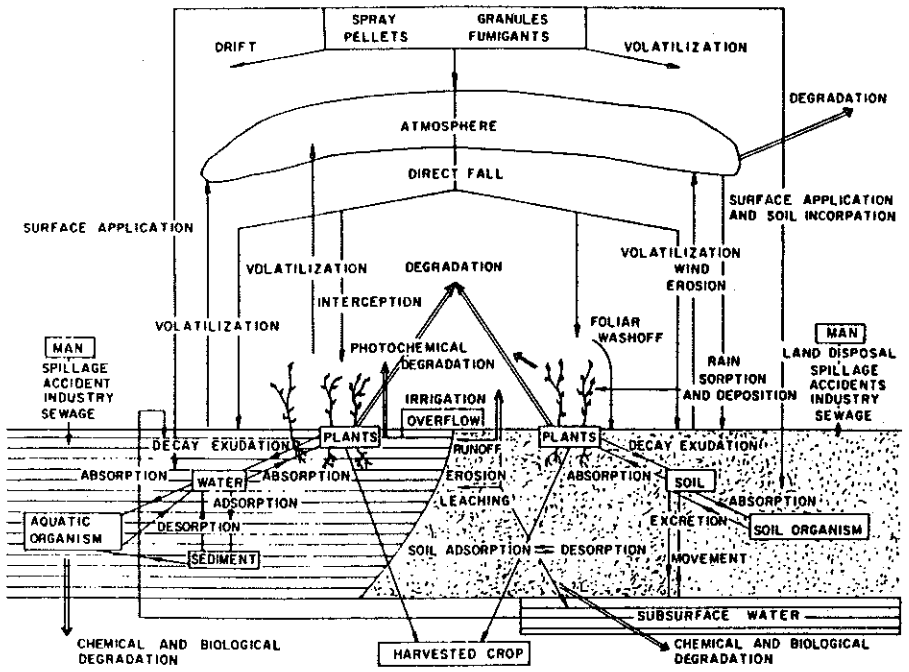



Figure 15: The Pesticide Cycle in the Environment (Bailey and Waddell, 1979)

Source: Canter 1986





Other (natural) sources of excessive nitrogen may be the mineralization of organic material derived from waterside vegetation and aquatic plants and animals. Large increases in nutrients may occur in human-made lakes and reservoirs especially during the initial stages of filling (Zauke et al. 1992). Blooms of algae and aquatic weeds (eg water hyacinth) may cause problems unless the vegetation is removed.

## 2.3.5 Pesticides in Runoff and Drainage Effluent

The agricultural application of pesticides is a main source of water pollution with potentially toxic chemicals in rural areas (see also section 3.4). In North America, it is estimated that some 40% of the agricultrual land is treated with pesticides (Freedmann 1989). Despite the previously widespread opinion that pesticides usually do not leach in substantial amounts through soils to surface and groundwater (eg Halberg 1987) there are numerous examples of serious contamination of rivers in industrialized countries (eg Leonard 1990; Brink 1990; Cohen et al. 1987). Typically, this may be attributed to **incorrect handling** of application equipment, **over-dosages** and **spray drift**, but other transport processes exist, namely transport during **runoff** (Fig. 2-18). Transport from soils with a high percentage of large pores (sandy soils, structured clayey soils) is mainly responsible for **leaching** losses into the groundwater.

Many pesticides render an undesirable and unpleasant odour and taste to the water and they are a health hazard for humans and domestic and wild animals not only by direct contact but also through the food chain. Some pesticides are extremely toxic to fish and other aquatic fauna. The main concern with the application of pesticides lies in the fact that they are often very **mobile** and relatively **persistent** in the environment. This is illustrated in Fig. 2-19 which shows the possible pesticide cycle and numerous transport mechanisms and pathways that can lead to soil contamination (see sections 3.4 and Part II section 3.2), water and air pollution (see section 5).

Sources: Leonard 1990 in: Lesaffre ed. 1990; Brink 1990 in: Lesaffre ed. 1990; Cohen et al. 1987

*Case Study DDT*

The environmental impacts of the persistent pesticide DDT, banned in many industrialized countries since the early 1970s, are clearly demonstrated by numerous investigations. DDT was used in human health programmes, forestry and crop production. The bioconcentration and food-web accumulation effects of DDT are illustrated in Fig. 2-20 which shows the typical concentrations of DDT in a variety of atmospheric, terrestrial, aquatic, and biotic compartments of the environment. Concentrations in soils are relatively small, compared with the concentrations in organisms. Residues increase in the following order: plants-herbivores-predatory mammals-fish-birds-humans-predatory birds (Freedman 1989: chapter 8).

On the other hand, many agrochemicals are not acutely toxic, do not persist for prolonged periods, and do not accumulate in food chains. The **relative environmental hazard** posed by a pesticide depends upon

- characteristics of the pesticide (dosage, solubility, mode of transport, toxicity, persistence)
- chemical and physical conditions (see section 3.4 and Part II section 3.2)
- soil-water-conditions, microbiological activity
- soil and air temperatures and humidity gradients.

Generalized quantifications of the transport and fate of agro-chemicals are almost impossible, because site specific conditions must be assessed. In evaluating the effects of pesticides it is also important to remember that the use and mix keeps altering: because of changes in cropping pattern, pest resistence, appearance of new chemicals, use of more

Fig. 2-20

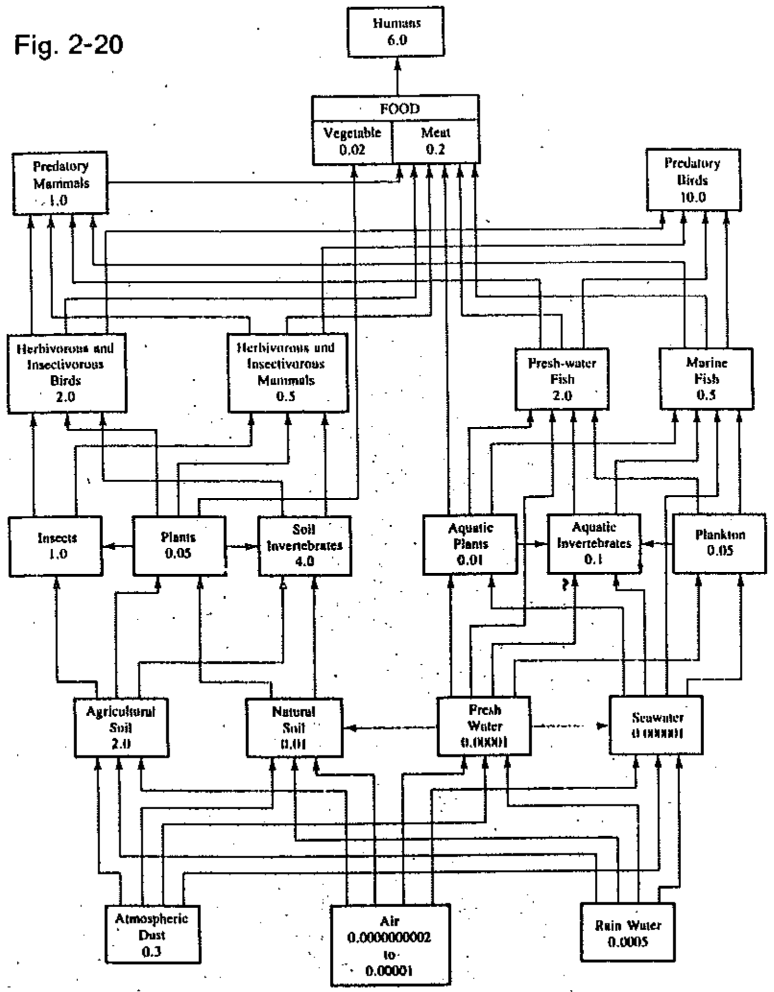



Fig. 8.1. Typical concentrations of DDT in the environment (ppm). Data were derived from a literature review of DDT residues. From Edwards (1975).

Source: Freedman 1989

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Fig. 2-21 a, b

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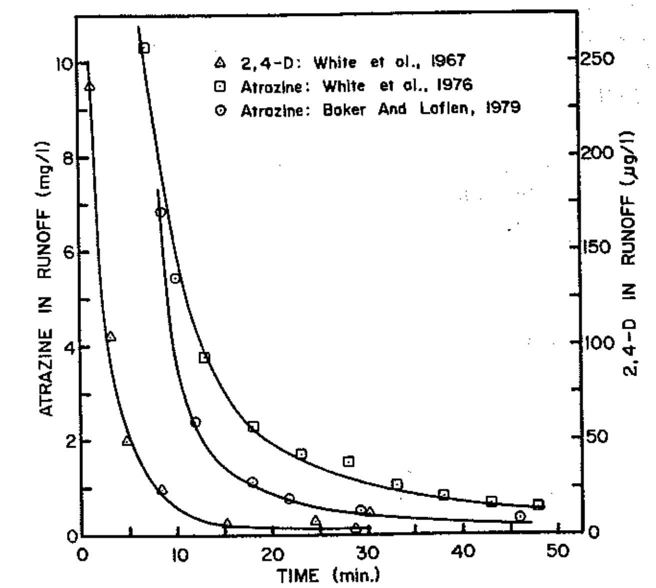



Fig. 9-4. Runoff concentration of pesticides from small plots as related to time after start of runoff. From Leonard (1988).

LEONA

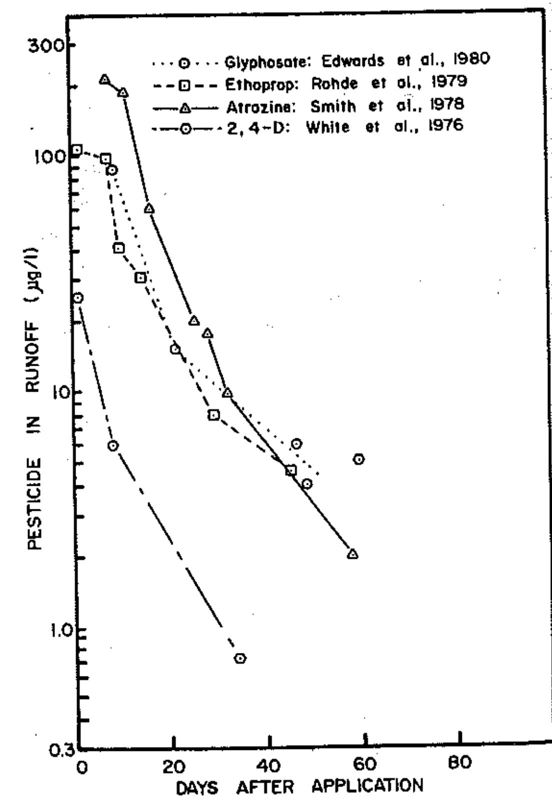



Fig. 9-6. Concentration of pesticides in runoff in relation to time after application. From Le (1988).

Sources: Leonard in Cheng ed. 1990





selective and less resistent insecticides, changing agronomic ... of other means of integrated pest management (see section 3 ... proved application methods and timing, and changes in far... cals. Usually, there is lack of adequate information and ... risks.

Source: Leonard in: Cheng ed. 1990

The pesticides that cause most serious hazards to aquatic systems are ... **insecticides** and certain **herbicides** (eg triazines). The more soluble pesticide... washed out from aquatic systems relatively quickly, but the less soluble and mo... stent chemicals are usually bound to suspended organic particulate matter which gra... ly falls into the bottom sediment, where it remains until brought back into suspension by turbulence. Once pesticides reach river systems, they become transferred gradually downstream. In aquatic systems, pesticides are either degradated to simplier compounds, or they move into the atmosphere by volatilisation (see also section 3.4).

Source: Edwards 1987

*Case studies and key findings*

For the majority of pesticides, total losses in runoff waters from rainfed fields are 0.3 to 0.5% or less of the amount applied. This applies mainly to water-soluble and soil-incorporated pesticides. Losses of organochlorine insecticides and insoluble pesticides (emulsions) may amount to 1% because of their long persistence. Losses of wettable powder formulations of herbicides may be 2-5%. Pesticides are mainly washed off as solutions from soil surfaces whereas organochlorine pesticides, paraquat and arsenic pesticides are strongly adsorbed by sediments, and their transport depends on soil erosion (Wauchope 1978). Most losses occur immediately after runoff starts (Fig. 2-21a). Traces of pesticides in runoff can be detected during more than 60 consecutive days after application (Fig. 2-21b, Leonhard in: Cheng ed. (SSSA) 1990).

Improved agricultural practices with the introduction of soil conservation tillage often requires an increase in herbicide use for weed control. Herbicides account for more than 80% of all pesticide use in USA. Field experiments showed atrazine losses in subsurface and surface drainage systems in the range of 1.4% to 3.2%. Metochlor losses were 1.2 and 2.4%, respectively (Bengtson et al. cit. in: Hoffman 1990, in: Lessafre ed. 1990).

Generally, much higher herbicide losses occur as runoff compared to leaching losses (Schwab et al. 1973, cit. in: Hoffman 1990).

Some herbicides are transported by runoff in solution and others only on adsorbed sediments. For example, DCPA 5% in water, 95% in sediment; Prometryn 100% in water; Trifluralin 35% in water, 65% in sediment; Paraquat mainly on sediment (Yaron/Gerstl/Spencer 1985.).

There exists a relationship between herbicide concentration in topsoil layers and concentrations in runoff from non-irrigated and irrigated soils (Fig. 2-22, opposite next page). The relationship between pesticide runoff and pesticide distribution and persistence in the runoff-active zone is shown in Fig. 2-23. Table 2-8 lists climatic, soil, pesticide, and management factors that are known to affect pesticide runoff. (Leomard in: Cheng ed. (SSSA) 1990).

Comprehensive data on **pesticides in surface runoff** from small plots, single cover fields and watersheds are compiled in Table 2-9.

Source: Leonard in: Cheng ed. 1990

Nonpoint source prediction models for estimations of losses of dissolved and solid-phase pesticides in cropland runoff are numerous and are used in pesticide leaching assessment.

Fig. 2-22

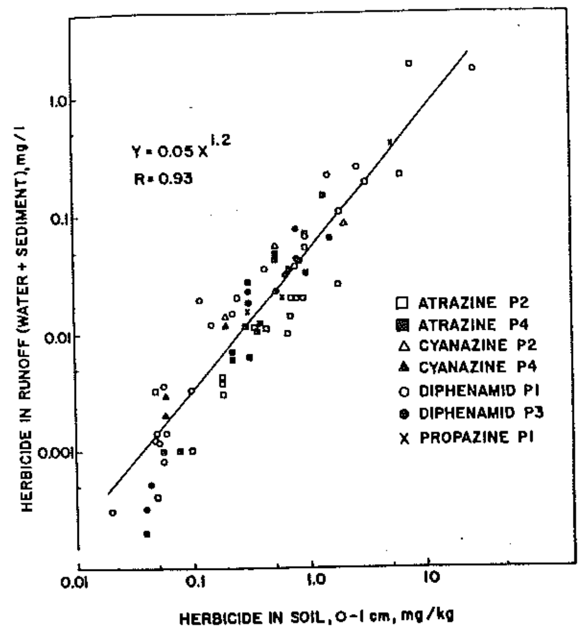



Fig. 9-2. Relationship between pesticide concentrations in 0 to 1 cm surface soil layer and concentrations in surface runoff (Leonard et al., 1979).

310 LEONARD

Fig. 2-23

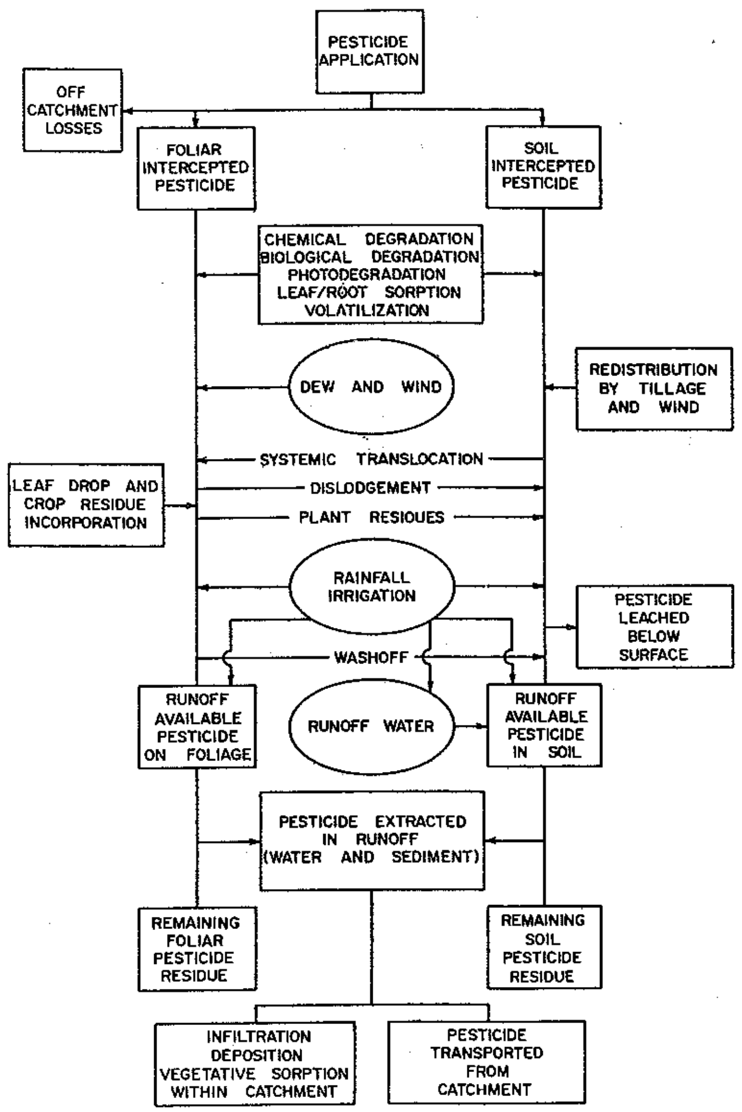



Fig. 9-3. Relationship between pesticide runoff and pesticide distribution and persistence in the runoff active zone.

Sources: Leonard in Cheng ed.





Review in: Green/Loague/Yost in: USDA 1988; Canter 1986; recent models for example: SWAG-groundwater model in: Enfield/Yates in: Cheng ed. (SSSA) 1990; CREAMS-surface water model in: Leonard in: Cheng ed. (SSSA) 1990; PRZM-model in: Green/Loague/Yost in: USDA 1988.

Semi-empirical predictions on pesticides (and toxic elements) are available for rapid assessments of potential soil contamination and water pollution risks. Soil models are described in section Part II 3.2. Pesticides are classified into four groups in the likelyhood of runoff losses in Table 2-10.

The maximum concentrations in runoff events can be predicted within one order of magnitude if pesticide formulation, use, and application rate are known, together with the time elapsed between application of the pesticide and subsequent runoff.

Sources: Cheng in: Cheng (SSSA) ed. 1990; Madhum/Freed in: Cheng (SSSA) ed. 1990; Severn/Ballard in: Cheng (SSSA) ed. 1990; Leonard in: Cheng (SSSA) ed. 1990; Hoffman in: Lesaffre ed. 1990; Blume ed. 1990; Freedman 1989; Nielsen/Lee (USDA) 1987; Cohen/Eiden/Lorber in: Garner et al. eds. 1987; Edwards 1987; Canter 1986; Spencer et al 1985 (cit. by Leonard in: Cheng)

Further readings: Cheng (SSSA) ed. 1990; Blume ed. 1990; Summers (USCID) 1986, 1988, 1989; Garner et al. ed. 1986

## 2.3.6 Metals and Toxic Substances

Chemical pollution is typically a feature of industrial wastewaters (OECD 1991). Toxic trace elements are only occasionally found in agricultural drainage effluents. They may be derived from soil weathering (case studies section 2.3.9) or originate as concentrations from irrigation waters. Typically, toxic trace elements are not a severe problem in drainage waters because most metals are fixed and transformed in soils if they occur at normal concentrations (Canter 1986). During reclamation leaching, however, some toxic elements may be leached from the soils, eg boron. Other elements such as selenium, cadmium, lead, chromium, mercury, and molybdenum are also occassionally found in drainage water in the USA (Deason 1989).

*Case Studies*

USA. Extensive surveys are under way to identify potential sites with irrigation-induced contamination problems. To date a comperehensive survey of about 600 irrigation projects and major wildlife areas is nearing completion, and 14 sites have been identified as having evidence of contamination from agricultural drain water (Hoffman 1990).

Sources: Hoffman in: Lesaffre ed. 1990; Blume ed. 1990; Deason 1989; OECD 1991; Canter 1986

## 2.3.7 Pathogenic Microorganism

Pathogenic microorganisms may be found in drainage effluents of wastewater irrigation projects (see sections 3.6, 8.1 and Part II sections 2.5, 4). On the other hand, pathogens are typically introduced into irrigation water by non-agricultural upstream sources, municipal or rural wastes, where water may be either treated or untreated. Agricultural wastes from farmsteads may also contribute to pathogen enrichments, eg from septic tanks or nightsoils (excreta resuse). On the other hand, irrigation may have overall beneficial off-farm impacts by reducing the number of pathogens released to downstream users through the intensification of soil biological processes of adsorption, fixation and transformation (see section 3.5 and Part II section 3.2).

Source: Loehr 1976

## 2.3.8 Sediment Pollution

It is estimated that agriculture (including irrigated agriculture) contributes about 40% of total sediment loads from non-point sources in the USA (Canter 1986). The off-site impacts of sediment pollution include:

- clogging of structures, including downstream irrigation facilities
- deterioration of aquatic habitat by influences on light penetration and temperature
- impaired quality of recreational waters or lakes
- increased water treatment costs
- transport of chemicals and fertilisers which are adsorbed by suspended load
- transport of organic material and pathogenic or harmless micro-organism which are adsorbed by fine materials
- changes in soil properties at deposition sites which is often associated with a reduction in soil fertility.

More details are discussed in section 3.3 (soil erosion), including other such impacts as reduction in water storage capacity of reservoirs and lakes and changes in stream bed hydrology.

## 2.3.9 Consequences of Water Pollution by Agriculture

The gravest problems accrue to domestic users which extract surface water or groundwater for consumption. Some substances may cause health risks, eg pesticides or high concentrations of phosphates, nitrates and chlorides.

Apart from the food industry, most wastewaters from agricultural lands in general are <u>not</u> a hazard to industrial uses (Loehr 1976). More seriously, however, are the detrimental impacts on the biological balance of rivers and lakes posed by ample supply of nutrients. This causes the rapid growth of algae, which gives an unfavourable taste and odour to water, reduces the efficiency of filters and structures by clogging and reduces available oxygen to such an extent that fish populations and other aquatic life suffers.

*Case Studies*

<u>USA</u>: San Joaquin Valley California. High salinity of drainage flows (10-15 dS/m) with selenium toxicity. Selenium is derived from rock weathering and transport in drainage effluents. This process is intensified under irrigation. A drainage programme with various management options was enforced in 1984 to reduce the toxicity problems. (Tanji/Hanson in: Stewart 1990).

<u>Taiwan</u>: Fertiliser pollution is generally not serious due to their rather restricted use caused by high costs. Average use per ha is 276 kg N, 65 kg P2O5 and 105 kg K2O and there has been no significant increase in use since 1971. Occasionally high nitrate and ammonium was detected in shallow wells under double cropped rice. Rice pest losses range from 9 to 45% (average for 1st crop 15%); hence, pesticides are widely used. However, most organochlorine pesticides are banned. Three programmes analysing for residues of commonly used pesticides detected traces of diazinon and parathion in one case. Generally the pollution by pesticides is not a serious problem in Taiwan. Nevertheless, control programmes have been introduced (Wen 1986).

## 2.4 Changes in Groundwater Regime under Irrigation

Under irrigation the groundwater regime will usually change as a result of increased deep percolating water compared with conditions under natural rainfall. The excess water input will cause the waterlevel to rise until a new equilibrium is established between deep percolation and the natural land drainage capacity of the substratum. The latter is controlled by the groundwater flow which, in turn, depends on the hydraulic potential of the local groundwater drainage system.

Under good soil and water management conditions it is unlikely that wetness problems will occur in permeable soils with a high hydraulic gradient towards the local drainage outlet and a low groundwater table. However, a number of serious problems may occur under long-term irrigation especially with **poor operation**:

- rising watertables will cause **waterlogging** within the rootzone and eventually the build-up of a shallow watertable,
- in semiarid to arid regions groundwaters are often saline and they will eventually cause a build-up of soil salinity within the capillary fringe zone. Occasionally, this process may also occur in subhumid or humid areas in the presence of marine brakkish water intrusions,

**Agronomic** problems related to waterlogging are:

- impaired crop growth due to temporary oxygen deficiency (except paddy soils); growth of some better adapted weeds may be accelerated; anaerobic conditions may have adverse effects on microorganisms and eventually on soil structure,
- excess water applications will impede farm operations as optimum workability of soils is limited; traditional farming systems are typically less affected than mechanised farming systems,
- ponding water may cause the destabilisation of soil aggregates which will result in impeded infiltration.

Although potential waterlogging and salinity build-up are typically the two major problems in many irrigated areas (section 3), an increasing water table is not an inevitable process. They result from by poor water management, inadequate site selection during planning, and lack of commitment to install an adequate drainage system.

Groundwater tables may rise under surface irrigation systems as a result of one or a combination of the following factors:

(i) **deep percolation:**

- application of irrigation water which percolates to the groundwater table: poor water management due to over-irrigation and excessive application depth may enhance deep percolation unnecessarily,
- restricted natural land drainage due to low permeability of soils or geologic conditions, eg stratification of substratum or inadequate discharge capacity of natural waterways and channels,

(ii) **seepage**, ie groundwater flow into the irrigated area from adjacent areas within the command area or elsewhere:

- as an indirect effect of river regulation by dams when the low flow regime is replaced by a continuous medium or high flow regime: the seasonal low flow regime is no longer effective in providing efficient land drainage,
- inadequate open ditches for disposal of water from the command area resulting from poor drainage design,
- insufficient capacity of surface or subsurface drains resulting from either poor design or lack of maintenance,

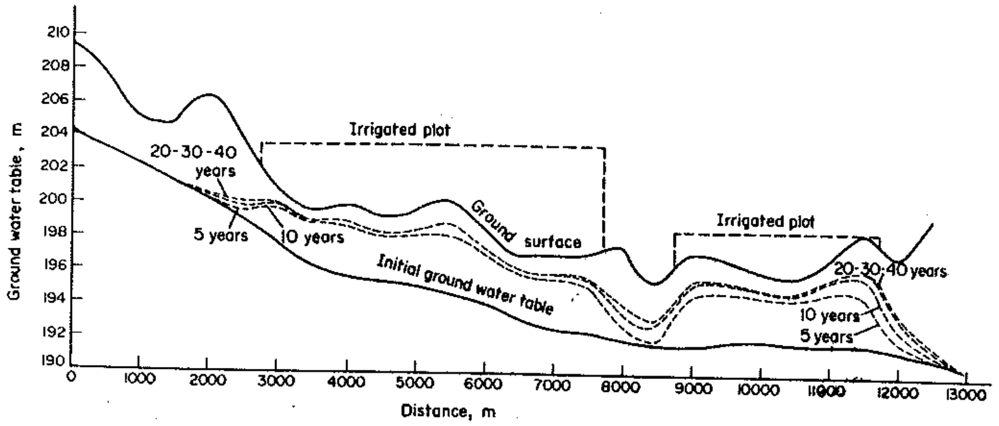



Fig. 4.16.

Source: ICID 1980

Fig. 2-24 a, b

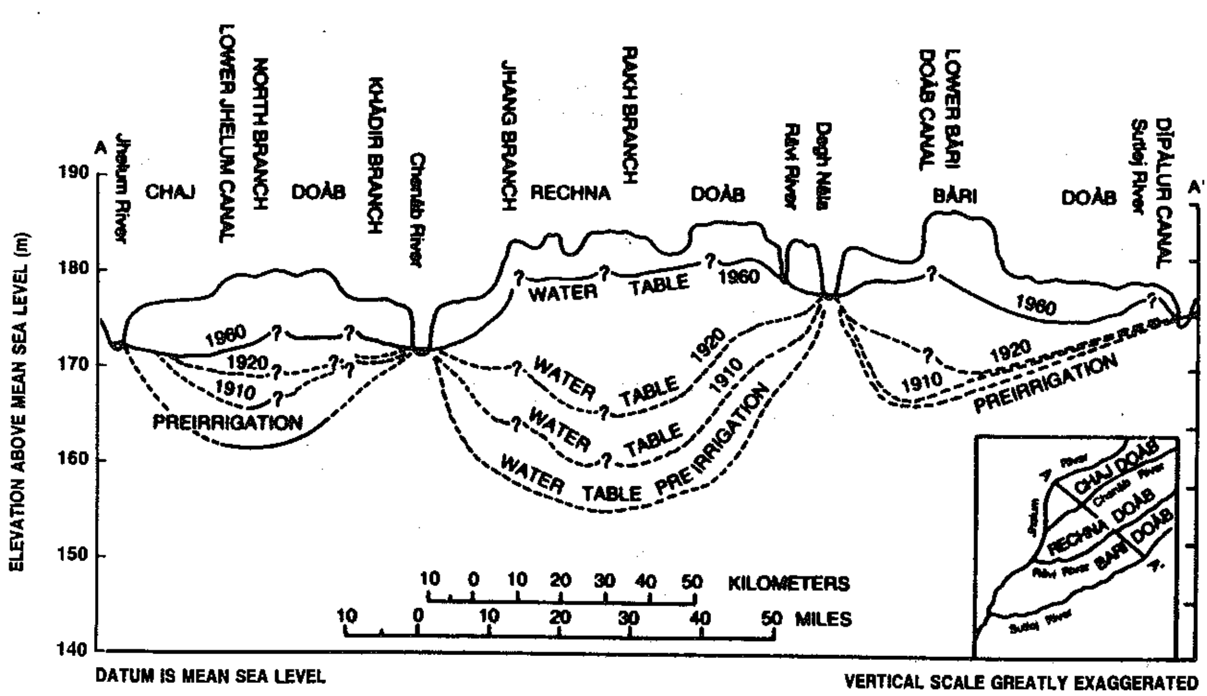



Fig. 3-1. Water table profiles, Chaj, Rechna, and Bari doabs (Greenman et al., 1967).





- inadequate design, maintenance or operation of conveyance system canals,
- blockage of natural drains by human activities, eg drifts, roads,
- blockage of human-made drainage canals by sedimentation. This sedimenation or siltation may be caused by off-site (ie upstream induced) or on-site erosion; if resulting from poor maintenance it may aggravate other problems,
- lateral inflow from adjacent reservoirs: poor design and incorrect siting of reservoirs,
- lateral inflow from adjacent irrigation schemes.

The most effective provisions to avoid rising water tables which should be undertaken during the **planning** stage are:

- selection of soils which are relatively permeable and choice of soil and water management practices which retain this permeability (the permeability depends on the hydraulic conductivity of single layers and the stratification of profiles)
- selection of sites which show adequate natural land drainage properties, ie sufficient hydraulic gradient and a natural 'outlet'.

If these conditions are not met the installation of an adequate **drainage system** is required. This may be a surface or subsurface system, or a combination of both.

References: Smedema/Rycroft 1983; vanSchilfgaarde ed. 1974; Eggelsmann 1973; ILRI 1972-74

*Case studies and examples*

Four typical situations of groundwater regime changes under irrigation are described.

1) Decrease in water table depth in areas where large quantities of irrigation water are **pumped** from underlying groundwater aquifers. For example in the upper Gonaives Plain (Haiti) a decrease of the water table occured between 1965 and 1986 in the range of 0.5 to 1.5 m (Petermann 1986). Short-term seasonal fluctuations may be superimposed on these long-term trends.

2) In **paddy** rice culture, it is a water management goal to maintain a perched water table at shallow depths or to restrict infiltration by puddling. For example, a shallow perched temporary watertable at some 25-50 cm depth is favourable for rice cultivation in valley soils (Northern Ivory Coast. Petermann 1985).

3) The temporary or **cyclic build up** of a perched water table depends on irrigation practices and variations in percolation (or seepage) rates. These cycles may occur on a seasonal or short-term basis and they may cause damage to some sensitive crops at certain development stages. The cycles typically occur also under non-irrigated conditions and under irrigation they are to some extent manageable by field application methods. In the New Valley soils (Southern Egypt) a shallow perched water table developed within 0.9 to 1.4 m depth below the surface after few weeks of continuous irrigation. One month after irrigation stopped, the water table dropped rapidly to the original depth of some 3 to 5 m below the surface (Petermann 1984).

4) **Long-term rise** in water tables induced by seepage or/and deep percolation and impeded land drainage. The prediction of groundwater table rises may be derived from modelling: Fig. 2-24.

Ther are numerous examples of irrigation projects which have resulted in rising water tables. A few examples are given:

| project | original depth (m) | depth under | rise (m/y) | Source |
|---|---|---|---|---|
| Bhatinda, India | 15 | | 0.6 | Smedema 1990 |
| Khaipur, Pakistan | 4-10 | | 0.1-0.3 | Smedema 1990 |
| SCARP IV, Pak. | 10-15 | | 0.4 | Smedema, 1990 |
| Nubariya, Egypt | 15-20 | | 2-3 | Smedema 1990 |
| Ben Amir, Marocco | 15-30 | | 1.5-3.0 | Smedema 1990 |
| Amibara, Ethiopia | 10-15 | | 1.0 | Smedema 1990 |
| Salt Valley, USA | 15-30 | | 0.3-0.5 | Smedema 1990 |
| Gonaives, Haiti | 2-4 | 0.6-1.5 (after 21y) | | Petermann 1986 |
| Eshkedia, Libya | 3-10 | 1-5 | | Petermann 1983 |
| Hamera, Libya | 4-15 | 2-10 (after 10y) | | Petermann 1982 |
| Hamam, Libya | >10 | 1.5-4 (after 8y) | | Petermann 1982 |
| Sanghar, India | >3.6 | 1-2 (50y) | | Birch/vanWonderen1990 |

Sources: Birch/van Wonderen in: ICID 1990; Mistry/Purohit 1989; Smedema 1990; Lesaffre 1990; Smedema/Rycroft 1983; Petermann unpublished project reports

**Off-site effects**

In many locations detrimental effects of rising groundwater tables do not only affect the command areas but also neighbouring lowlying areas where groundwater throughflow collects. In cases where these low lying areas are traditionally used for irrigation, pastureland or fruit tree gardens (eg date palms), detrimental impacts are expected. For example, in the Fezzan region of Southern Libya there have been several instances where the development of new large scale irrigation projects on sloping land caused water tables to rise in traditionally irrigated downslope locations: Murzuq, Braq, Wadi Adjal, Um-el-Araneb, Esch-Schergia, Goddwa. Economic losses to farmers' families were limited because the owners of traditional arable areas benefited from the new smallholder irrigation developments. However, some farmers, especially elderly people, were not allocated new farms.

## 2.5 Hydrological Impact of Land Drainage

The installation of drainage systems on irrigated or non-irrigated lands results in changes in hydrology brought about by the lowering of the watertable and the collection and disposal of excess water. The magnitude of changes vary with location and depend on the type of drainage, soil properties (and stratification), and the climatic and topographical setting. The potential effects of drainage are summarized as follows:

- Effects of subsurface drainage are lowered watertable levels and increased soil moisture storage especially for rainfall; this may temporarily lead to increased soil moistore storage of excess irrigation and rainfall, thus reducing the runoff hazard. Flow (erosion) is also diverted to deeper, less permeable horizons within the soil profile. the combined effects tend to smooth out and prolong hydrographs of flow from fields.
- Hydrological impacts of field drainage are generally small on a catchment scale, mainly on account of the trade-off between reduced runoff and increased subsurface drainflow.

Fig. 2-25

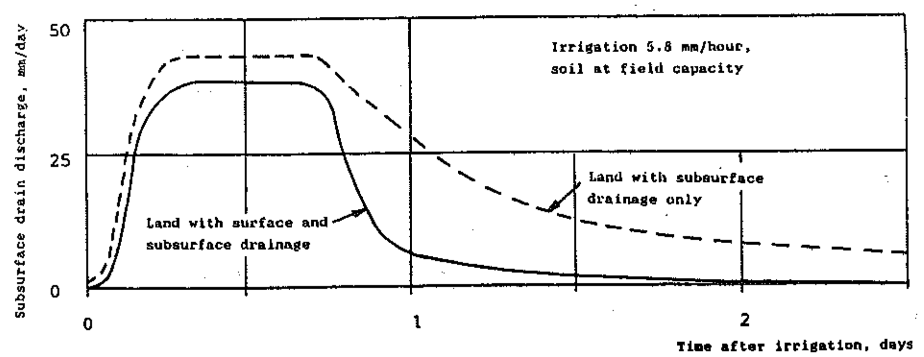



Figure 4 - Effect of surface drainage on subsurface drain discharge, after Schwab et al (1963)

193

Fig. 2-26

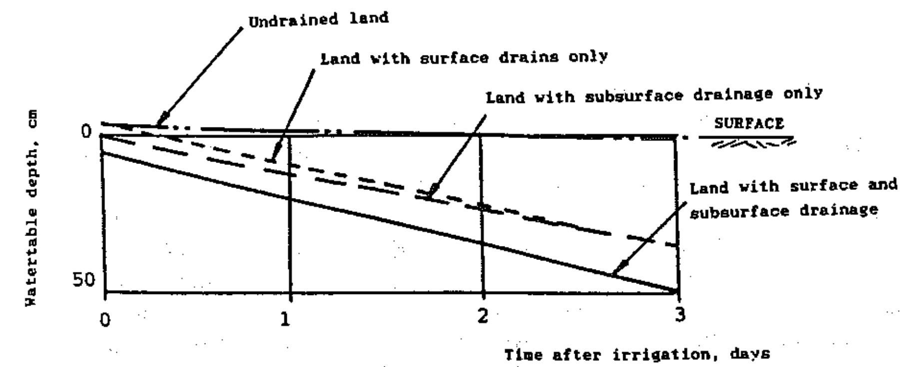



Figure 5 - Watertable recession following irrigation of grassland during growing season, after Schwab et al (1963)

Source: Rycroff in Lessafre ed. 1990





- Improvements to **main drainage channels** (outlet) which evacuate water from the area can significantly reduce the catchment response time and thus increase peak discharges.
- Improvements to main drainage channels in previously undrained areas such as lakes, swamps or depressions can significantly increase total flow as well as peak flow rates and reduce response times.

Source: Rycroft in: Lesaffre ed. 1990

Typical effects of subsurface drainage on surface runoff, drain discharge and watertable levels are illustrated in Fig. 2-25 ab b.

In general, field drainage systems in irrigation systems have relatively small off-site impacts, ie on the downstream watershed. However, drainage channel (outlet) maintenance and improvements (cleaning, dredging, deepening, lining) generally have large impacts on downstream watersheds, resulting in watertable fall within the channel influence area, and increasing total flow and discharges at downstream sections. The magnitude of impacts may increase linearly with increased areal extension of the drained area. The hydrological response may be investigated using models such as DRAINMOD (Skaggs 1982).

Large scale irrigation projects and associated drainage systems may have detrimental impacts on entire river systems. There are several example, where irrigation caused increased salinisation of river water and serious off-site disturbance of wetlands with detrimental impacts on wildlife within the riparian plain (Lakey in: Lesaffre ed. 1990; see also section 4). Long-term and off-site effects have often not been considered in many large scale irrigation and drainage schemes elsewhere in the world (eg Hoffman in: Lesaffre ed. 1990), although potential impacts are well known (eg Kienitz 1979).

In arid areas the development of natural drainage lakes outside the project area may create brackish water habitats in previously arid terrestrial habitats which can be seen as a gain in habitat diversification.

Drainage systems are designed to modify the soil-water status of irrigated fields, namely the watertable depth and its fluctuation. Consequently, drainage related impacts on cultivated lands are planned interventions to create favourable conditions for optimum plant growth. Environmentally sound planning and operation of such systems should be focused mainly on minimising or avoiding detrimental off-site effects (Part II section 2.4). Such effects relate to downstream water pollution, changes in discharge of rivers and in lowering of watertable levels next to drained fields.

A case study for Pakistan is provided in: Mohtadullah in: Lessafre ed. 1990

Further readings: Gardiner ed. 1991 ; Hoffman in: Lesaffre ed. 1990; Newson/Robinson 1983; Skaggs 1982; Hornsby in: Stewart et al. 1990; Carter in: Stewart et al. 1990; Tanji/Hanson in: Stewart et al. 1990; Skogerboe/Walker in: Yaron 1981; Hotes/Pearson in: COWAR 1976

Fig. 3-1 a

Sources: ILRI 1980





# 3 Impacts on Soil Resources

## 3.1 Salinity Problems in Irrigated Agriculture

### 3.1.1 Introduction

It is common knowledge that soil salinity is the most prevalent and widespread problem limiting irrigated crop production under arid and semiarid conditions. However, the process of salinisation not only has direct impacts on irrigated soils. Detrimental impacts may also occur to water and soil resources in river basins. Impacts vary in time and space, and they may affect biological resources and human activities further downstream.

Saline soils are defined by a high content of soluble constituents in the soil solution which adversely affect plant growth and yields. The degree of salinity is usually measured as the electrical conductivity of water extracted from the soil paste or other soil-water ratios. Salinity usually fluctuates seasonally, depending on evaporation, rainfall and water management practices. Salinity often occurs together with sodicity (or alkalinisation), ie when sodium is present at high percentage (usually >15%) at the soil's exchange surfaces. Alkaline soils may become non-saline, especially after sucessful leaching. For simplification, the term 'salinity', as used hereunder, refers to all kind of saline soils regardless of the predominat type of salts present.

General references: Ghassami et al. 1993 (forthcoming); Kandiah (FAO) 1990; Rhoades/Loveday in: Stewart ed. (1990), Bresler et al. (1982), Shainberg/Shalhevt ed. (1984),, FAO/UNESCO 1973.

### 3.1.2 Salinity: A Worldwide Problem

Previous estimates suggested that salinity and waterlogging affects about 50% of all irrigated land (FAO, Kovda 1982; FAO 1976; Framji 1976; Kovda et al. (FAO/UNESCO) 1973). The areas concerned include regions where the climate is humid, subhumid, semiarid and arid. The problems are more widespread and acute in arid and semiarid than in subhumid or humid regions. High salinity in soils may adversely affect yields on irrigated lands to such an extent that the land is abandoned.

Salinity problems under irrigation have existed ever since irrigation enhanced crop productivity, namely along the Nile, Euphrates, Tigris and Indus Rivers and the Gangetic- and Chinese plains. Well before 2,000 B.C. irrigated land was abandoned in the Mesopotamian Plain because of extreme salinity. Increases in cropping intensities and the use of water resources for irrigation of more and more - even marginally suitable - land over the last 40 years have resulted in widespread salinity and waterlogging problems.

On all continents there are vast areas of salt-affected soils, either natural or human-made.

- In the USA, about 28% of irrigated land suffers from depressed yields due to salinity (Yaron 1981).
- A rough estimate of the distribution of salt and alkali-affected soils has been compiled for affected regions, based on the FAO/UNESCO soil map. The global area of salt-affected soils was estiomated to some 950 M ha (Table 3-1 a-b and Fig. 3-1 a-c; collected and compiled in: Szabolcs 1979; Beek in: ILRI 1980).
- Framji (1978) estimated that some 27 M ha of saline soils were irrigated (Ghassemi et al. using correced figures from Framji 1976) which was about 30% of the irrigated area.
- Kovda (1983) estimated that some 1 to 1-.5 M ha are salinised per year and that the total land affected by salinisation from both natural and human factors to be about 20-30 M ha.

Fig. 3-1 b



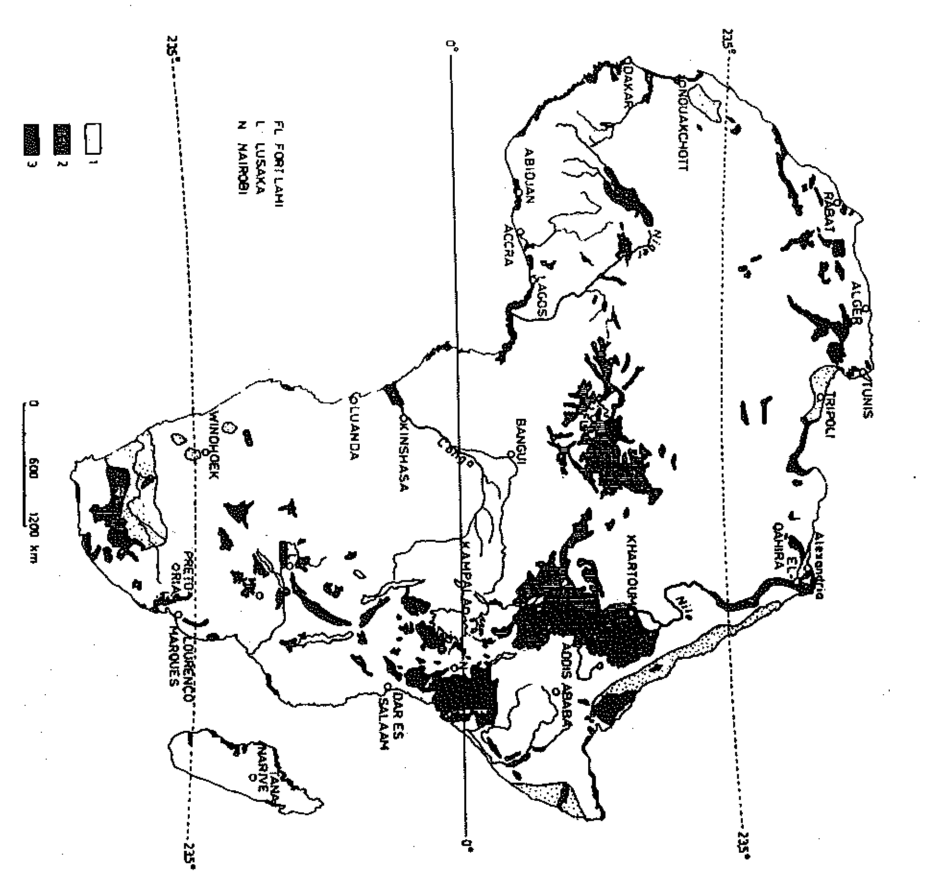



Fig. 15. Distribution of salt-affected soils in Africa (after G. Aubert, 1970).
1. Potentially salt-affected soils
2. Alkali soils
3. Saline soils

Fig. 3-1 c



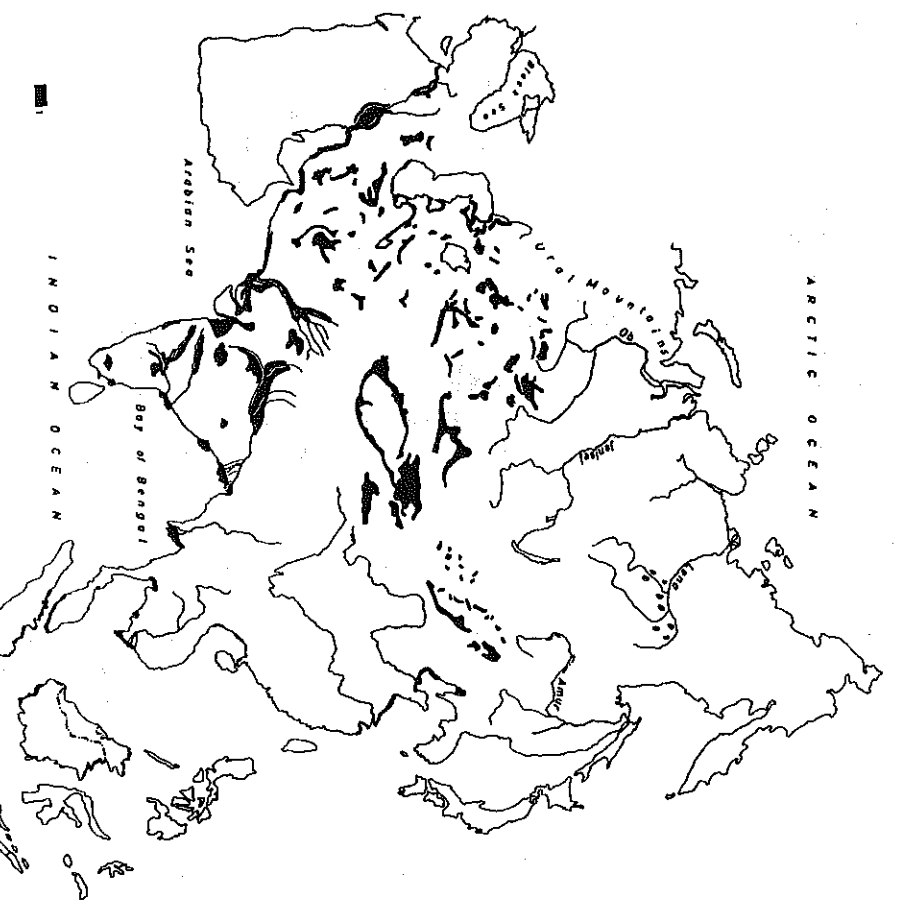



Fig. 7. Distribution of salt-affected soils in Asia (after V. A. Kovda et al., 1964).
1. Areas of salt-affected soils





- Postel (1990) estimated that 38 M ha or 24% of irrigated soils are affeced by salinity in the five most important countries (see Table 3-1 c). On a global scale, he conclude that some 60 M ha (of the 250 M ha irrigated soils) are affected by salinity.
- Oldeman et al. (1991) estimated worldwide that some 77 M ha are affected by salinity (Table 3-2 a-b) but no differentiation was made for irrigated and non-irrigated lands (revised FAO/UNESCO maps).
- Dregne et al. (1991) estimated that about 43 M ha of irrigated land in arid and semi-arid areas is affected by various degress of degradation, mainly salinity, waterlogging and alkalinisation. Annually, some 1.5 M ha of irrigated lands are lost due to land degradation, mostly salinisation.
- Ghassemi et al (draft 1993) concluded from detailed figures from 11 countries that some **45 M ha or 20% out of a total 227 M ha irrigated land are salt affected** (Table 3-3). A total global of 31 M ha can be attributed to secondary salinisation of non-irrigated lands if it is accepted that 77 M ha of land is affected by human-induced salinisation (Oldeman et al. 1991).

The spread of degradation affects not only older, traditional irrigation but also modern schemes. Although such global figures are not very precise, it is obvious that salinity is a major problem under irrigation, except in humid rice irrigated agriculture. On the other hand, continuous efforts are made to reclaim these soils and soil reclamation programmes attain high priority in both soil research and development plans.

The process of irrigation-induced salinisation and the progress in reclamation is illustrated from examples from China and Egypt. In a project in North China, salinisation increased shortly after irrigation was introduced (Fig. 3-1/d). Salinity declineed after the installation of drainage systems in the late 1960s, but poor functioning of the systems remained a problem and the area of moderately salinie soils inceased. Reclamation programmes in the mid 1980s were successful to control salinity. In Egypt, proper water managment and drainage systems controlled salinity in irrigated land (Fig. 3-1/e).

Extremely saline soils under irrigation occur widespread in parts in India and the Near East (eg Pakistan, Iraq, Iran), USA (COL, CAL), Mexico, former USSR (Central Asia, eg Caspian Sea) and N-Africa. Some examples are given in Table 3-3 b for various countries. Table 3-3 c summarises the available data on area, hydrology, water uses, cultivated land and irrigation-induced salinisation from 11 countries wich cover 70% of the world's irrigated area (Ghassemi et al. draft 1993).

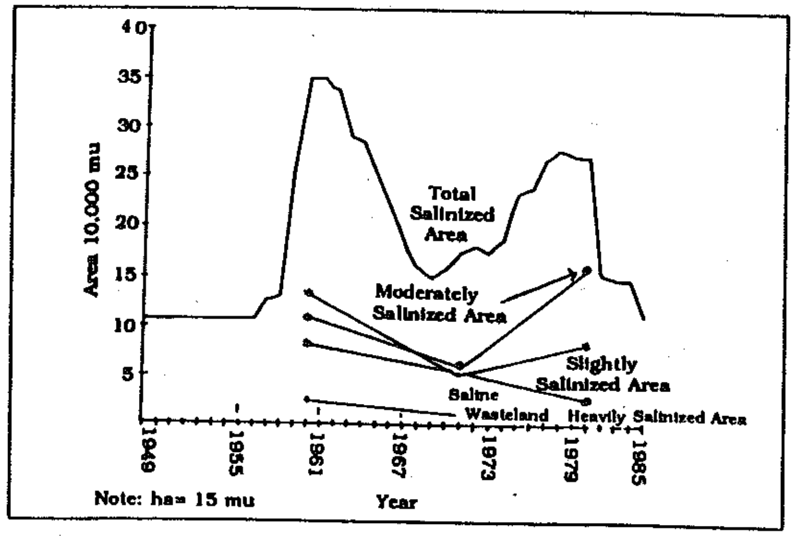
Alkali soils (pH > 8.0) occur over considerable areas in the Western USA, India, Pakistan, Egypt, Mesopotamia, Russia, Hungary (see also Table 3-1b).

### 3.1.3 Development Trends

In arid areas almost all land suitable for irrigation is salt-affected to some degree and it is the main objective of soil surveys to identify those locations which offer the best reclamation options and that minimize future risks of salinisation. In many subhumid or semiarid areas saline soils occur in floodplains, ie areas with reliable and easily available water resources, with ideal topographic conditions for cultivation, and with high population densities. Therefore, in many countries agricultural development is focused on these susceptable and fragile salt-affected areas.

In the Near East (including Pakistan) the increase in irrigated lands - from 36% of arable land to some 51% during the period 1962 until 1985 - took place mainly in locations adjacent to major river systems and within low-lying alluvial plains. These extensions further exacerbated problems in salinisation since most of them have high risks of salinisation due to adverse hydrological and soil conditions (waterlogging, use of saline water). The same correlation recently developed irrigated agriculture and increased problems in salinity was observed in the USA, for example in the Colorado River Basin and the Imperial Valley (Yaron ed. 1981). Important lessons can be learnt from Iraqi conditions, where local salinity problems have existed since ancient times, but salinity problems have only recently become wiespread due to increased utilisation of limited water and soil resources and

Fig. 3-1 d *Figure 1. Salinized area in Yucheng County.*




Source: Maurya in Yoder ed. (IIMI) 1990

Fig. 3-1 e1

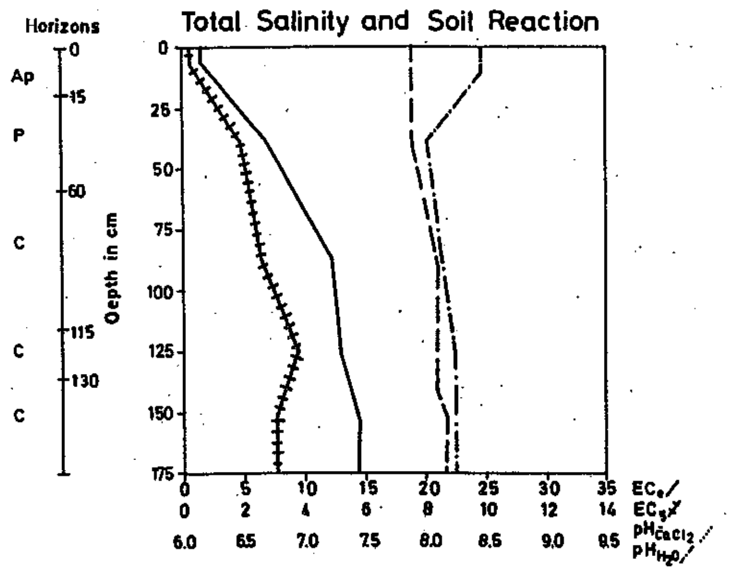
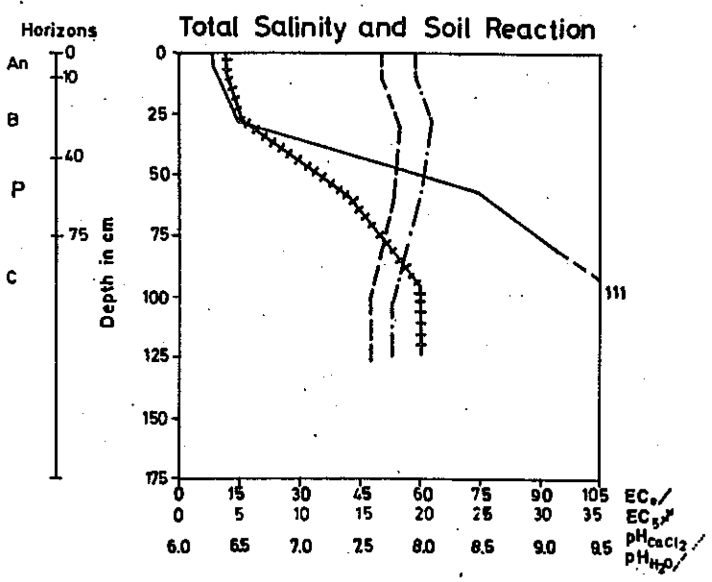



Fig. 3-1 e2




Source: Petermann 1986, New Valley Egypt



cumulative effects over centuries (Dieleman et al. 1977). In most of these areas, although potential salinity problems caused by shallow water tables were recognised, drainage systems were not established, often due to financial contraints.

### 3.1.4 Causes of Salinity in Irrigated Agriculture

Soil salinity originates from **evaporation residues** of soluble constituents of the soil solution. Consequently, the actual salt content of a soil depends on the dynamics of its soil-water system. All soils contain some native salts which are derived from either weathering, rainfall or lateral transportation. In addition, some soils are saline due to having been farmed under saline conditions (utilising marine/lacustrine sediments) or from saline surface deposits, either aeolian (eg dust) or fluvial. In coastal regions, salt water intrusions and/or submergence of low-lying areas sea water accumulate saline deposits. All these are refered to as native salts.

In irrigation, any salinity problem stems from the fact that practically all water contains some dissolved salts. During irrigation, these salts tend to concentrate in the root zone as the water, but little of the salt is extracted by the crop. The salt **accumulation** takes place progessively unless salts are **removed** towards the groundwater by either rainfall or irrigation water in excess of potential evapotranspiration. The addition of salts from irrigation may vary from 0.1 t/ha to 7 t/ha per year or more.

Factors which contribute to salinity problems under irrigation are (i) inherent soil and water properties and (ii) **soil and water management** practices or cultivation patterns:

> Enhancing factors are: low soil permeability, inadequate natural drainage, use of saline water, use of sewage for irrigation, hydromorphic conditions, high potential evapotranspiration, high water table, presence of natural salts, crop selection (which determines irrigations scheduling), fertilisers and soil amendments.
>
> Poor water and crop management may intensify or modify salinisation: inadequate leaching practices and water scheduling, cultivation/cropping pattern.

Under **natural condictions**, three major factors cause salinity, namely climate and rainfall, shallow groundwater, and soil-forming processes (mineral weathering, mobilisation).

Climate is an important factor because salts within the rootzone are redistributed towards the soil surface through the upward flux of water driven by evaporation. Salts may move up the soil profile from groundwater by capillary rise. The rate and extent of capillary rise depends mainly on physical soil characteristics, namely texture and porosity. Potential evaporation is controlled by climate, namely air and soil temperature, windspeed and air humidity. Evaporation usually shows pronounced seasonal and high inter-annual variations in subtropical regions.

Salts accumulate on irrigated surfaces when they are left behind as the soil water is used by plants or lost by evaporation. The root zone and the soil surface can become salinised by these processes, especially where shallow saline water tables occur. These typically develop in irrigated lands, usually in downslope positions, when the portion of water (including irrigation channel seepage and excessive rainfall) is not dissipated through crop use or drainage beyond the root zone.

Soil formation, the release of soluble constituents from the mineral phase, depends on abiotic and biotic factors. High temperatures and abundant water create favourable environments for all kinds of biological activities in soils which contributes to the transformation of minerals and also promote chemical and physical weathering. Therefore, irrigation usually creates favourable conditions for weathering and transformation (decomposition) of organic and inorganic soil materials; thus, in the long-term salinity may eventually increase or toxic substances may be released (eg Selenium in San Joaquin Valley, California).

**Factors** which contribute to salinisation problems in irrigation are summarized as follows:

(1) Use of saline soils for irrigation development without adequate prior soil reclamation.

(2) Use of saline irrigation water without adequate counteractive reclamation measures such as efficient leaching practices or drainage systems.

(3) Inadequate irrigation application practices, namely over-irrigation, which may cause water tables to rise, waterlogging or ponding water, resulting in subsequent evaporation deposits in the upper soil profile.

(4) Secondary salinisation caused by capillary uprise of saline water from a shallow water table. The extent of such capillarity depends on climate and soil properties.

(5) Use of low permeable soils without adapted water management and tillage practices to avoid waterlogging and ponding water.

(6) Use of land without adequate natural land drainage without the provision of an artificial drainage system.

(7) Seepage losses from reservoirs and conveyance canals which cause water tables rise. In unlined canals, about 50-60% of the water nmay be lost by seepage.

(8) Lack of efficient control of field canals (tertiary systems) which may cause temporary stagnant pools and subsequent saline evaporation deposits at the surface.

(9) Inadequate soil tillage practices which, for example, may facilitate the rise of saline soil water from deeper layers into the upper rootzone or which may lead to uneven distribution of saline layers in the deeper rootzone.

(10) Inadequate land preparation methods during the preparation of virgin land for irrigation by ineffective deep loosening, chiseling, land levelling.

(11) Inadequate control of intrusion or inundation by saline (brackish) water, either from the sea (daily, tidal, seasonal) or inland sources (rivers, lakes).

(12) Inefficient soil reclamation methods in problem soils, eg peat, sandy or clayey soils.

(13) Inadequate lay-out of irrigation systems in relation to water and soil quality, topographic conditions, and managerial skills of farmers.

(14) Application of fertilisers, manure or chemical amendments which add salts to soils.

It is obvious that many salinity problems in irrigation are related to changing the preexisting natural balance of the soil-water-climate system. Soil deterioration by salinity will occur under irrigation when the response is inadequate either to maintain the existing salt balance or to introduce efficient reclamation and control measures to manage the salt balance in both soils and water. Since many causes of salinisation under irrigation are interrelated consequently also the management of salinity problems requires a holistic view, and the understanding of the soil-water-climate system is a prerequisite for the solution of water management problems in irrigation. Concepts of water and crop mangement practices to control salinity under irrigation are given in Part II sections 2.3 and 3.3.

### 3.1.5 Salinity and Crop Growth

Salinity problems cause the decrease of crop yields which adversely affect the economics of irrigation, and they cause agricultural development to be non-sustainable. Eventually salinity contributes to the deterioration of soils and surface- or groundwater resources, accelerate wind erosion risks and hence contribute to the degradation of regional resources which may hamper future development options (desertification).

Fig. 3-2

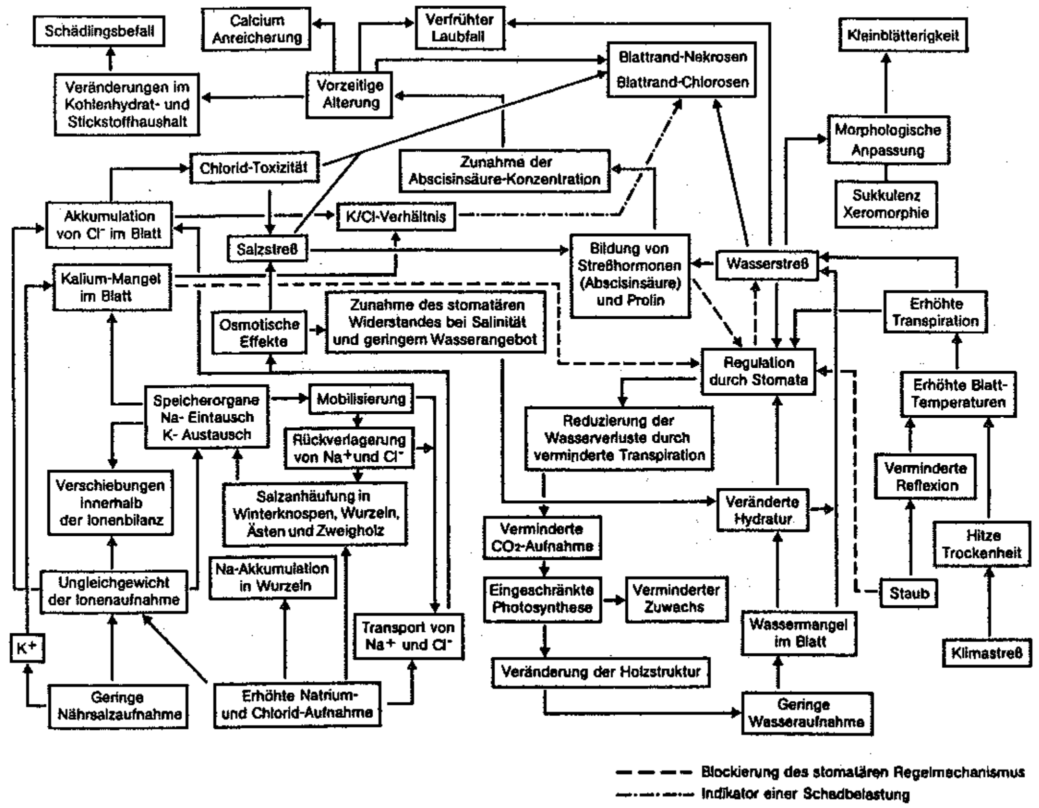



Abb. 2.7.4/2: Interaktionen zwischen Salz-, Wasser- und Nährstoffhaushalt – Betrachtungsebene Pflanze (aus HABERMANN 1989)

Source: Blume ed. 1992 307





The effects of salts on crops production are manifold: emerç … f areas be hampered, rates of plant growth and yields are reducec' failure occurs. Decreases in yields are crop specific and h sensitive crops and crop rotations adverse effects can be … s- re are two principal factors which affect crop growth:

- Firstly, excessive salt concentrations in the soil s growth directly through the osmotic effect which re absorb water from the soil solution. Specific-ion or the toxicity of specific ions (physiological processes, factors.
- Secondly, salts have effects on physical and chemical **soil properties** an… ming processes. Most important is the secondary specific-ion effect of sodiu… which may lead, if present in excess, to adverse physical soil properties such as soil swelling and dispersion, causing water infiltration, aeration and root penetration problems.

The detrimental effects of salts, on plants and soils, differ greatly with the composition and concentration of salts present. Furthermore, crop salt tolerance varies significantly between different types of crops, growth stage and cropping patterns. Hence, simple statements regarding risk, actual degree of degradation, natural causes and contributions of mismanagement are not possible and each scheme must be assessed individually. The complex nature of soil-plant-water relationships and their interactions with salinity are illustrated in Fig. 3-2.

## 3.1.6 Assessment of Degradation by Salinity

The process of soil degradation by salinity refers to a human-made increase of salinity in soil. The process may take place in saline or non-saline soils and may be the result of the use of saline or non-saline irrigation water, in the case of non-saline soils the use of saline water may initiate the degradation process.

Soil degradation by salinisation may form part of the process of desertification (impoverishment of terrestrial ecosystems by human) and it is measurable in different soil strata, ie topsoils (main rootzone), subsoils; deeper substratum; soils adjacent to reservoirs and conveyance canals, drainage outlets. Biological resources may be affected and examination of habitats downstream and adjacent to watercourses and irrigated fields may assist in quantifying the extent of degradation.

The spatial distrubution of the impact can be classified by soil salinisation

- within the command area (on farm, adjacent to canals, reservoirs)
- in downstream areas (saline ground- or surface water resulting in secondary effects on soils).

The impacts of overall degradation be <u>identified</u> as:

- reduced productivity of irrigated lands
- limited selection of suitable, less sensitive crops
- increased skilled management requirements (eg tillage, irrigation scheduling) to maintain productivity
- increased needs for capital and/or labour intensive reclamation measures to maintain productivity,
- temporary or permanent ababdoning of irrigated lands
- need for increased quantities of water for leaching

- undesirable changes in the diversity of micro- and macrofauna and flora of areas adjacent to irrigated lands and downstream areas
- loss of potential for future agricultural or non-agricultural uses.

Thus, soil degradation by salinity may be described in its final stage as desertification especially when irrigated lands have been abandoned. It is obvious that in dryland areas (semiarid or arid ecosystems) the prevailing climatic conditions are already a limiting factor in the resilience of an ecosystem, ie the ability of land (soil) to recover from the transformation to saline conditions. Therefore, in these environments salinisation may ultimatively become an irreversible process when viewed on the time scale of human lifespans and normal restoration capabilities. Resilience potential may be higher in subhumid or humid environments.

### 3.1.7 Risk Assessment

The risk of salinisation under irrigation depends on a variety of environmental factors, which can only be modified to a limited extent by land development and soil reclamation measures, or the irrigation and cropping system itself. The levels of natural salinity of parent materials and groundwaters and climatic conditions differ substantially, and require a precise study and specific analysis for each area concerned. Methodologies which identify potential salinity hazards and aid in planning are given in Part II sections 3.2 and 3.3.

Generally, the following natural factors may contribute to a substantial risk in soil salinisation under irrigation:

- low total rainfall (less than about 200 mm), very low rainfall intensity (about < 5 mm/hr)
- low soil permeability (about 10 cm/d) down to the watertable
- flat topography, low hydraulic gradient of watertable
- presence of salts in subsoil strata, relevant for areas where lateral flow takes place and dissolved constituents can be translocated and enter the surface flow system.

Salinity problems in irrigated soils are likely to occur, if,

- irrigation water contains high amounts of salts
- shallow groundwater tables exist; the critical depth is between 1.5 to 6 m, depending on soil and climatic properties such as pore size distribution and evaporation
- the shallow groundwater is already of medium or high salinity
- a rise in groundwater takes place resulting from irrigation
- naturally saline soils are irrigated without prior reclamation
- internal drainage conditions (soil permeability) are poor, ie they do not allow for adequate downward flux of soil water
- soil tilth conditions cause reduced infiltration rates; conditions may be poor due to cultivation methods (tillage etc) or due to soil dispersion (sodium induced)
- land drainage conditions are poor, ie flat topography, shallow slope towards the local dainage basin (eg river, valley), low hydraulic gradient to the watertable
- saline soil layers are exposed or lifted upwards by deep ploughing or subsoiling (mechanical melioration)
- high evaporation rates occur without a continuous downward flux of soil water
- over-irrigation when water is stagnant (ponding) for prolonged periods and evaporation rates are high

- rainfall conditions in a particular year are insufficient to remove salts from the root-zone (natural leaching); this applies to supplementary (seasonal) irrigation systems or in semi-arid regions where rainfall is used for leaching
- insufficient leaching water is applied; the appropriate quantity depends on the salt concentration in the irrigation water, the method, frequency and intensity of irrigation, the initial salt content in the soil, groundwater level and the permeability of the soil.

Thus, a reliable method to predict the **risk of salinisation** must include the source of salts, the salt balance (depending on the climatic factors and groundwater tables), characteristics of the water regime influenced by irrigation practices, and influences of water quantity and cultivation methods on infiltration and permeability.

There are three methods to determine the actual degree of salinisation:

- field samples and laboratory tests (total salinity, specific ion analyses)
- visual appearance, areal affected
- air photo interpretations and satellite imagery can be suitable for a reconnaisance of the areal extent
- indirectly by field observations of crops/trees and yield data (often of limited value because ther are many factors governing yields).

Existing data on actual soil salinity may be obtained from soil survey departments, soil survey reports (soil maps, land suitability maps), agricultural extension services, and research stations. Information may occasionally be obtained from private farmers, governmental and non-governmental schemes and agricultural agents (ie suppliers of farm inputs). However, in any analysis, changes of salinity under cultivaton, seasonal fluctuations, depending on evaporation and rainfall, groundwater fluctuations, cropping season (consumptive use of crops), and on-farm irrigation practices should be considered as factors contributing to a high variability of salinity data in time and space.

Method of Degradation Assessment. FAO/UNESCO (1979) gives the following indices of soil degradation by salinity:

for **status**, consider max. ECe (dS/m) in upper 75cm of soil; max ESP in upper 75cm; plant yields (%of yields in similar non-saline soils); new formations; morphological observations; salts in t/ha/1.5m soil depth; t/ha/0.75m soil depth.

for **rate**, consider: ECe increases in dS/m/yr in upper 75cm; ESP increases in upper 75cm in % per year; yields in % decrease per year; surface affected by soluble salts in %.

for **risk**, consider: climatic index for salinisation; number of dry months (in absence of data on critical depth to groundwater table); average depth of groundwater table (cm); salt concentration of irrigation water.

EC = electrical conductivity, a measure of total salinity in the soil solution

ESP = exchangeable sodium percentage, a measure of sodicity in soils.

The present state of salinity and sodicity (ECe > 15dS/m; ESP >15%) and the degradation rate (increase of ECe and ESP per year), and risks are shown for Africa and the near East region in: FAO/UNEP/UNESCO (1979) on a scale of 1: 5 M.

### 3.1.8 Future Scarcity of Freshwater

There is every reason to suppose that irrigation water resources will become increasingly saline and that an increasing demand in irrigation water will arise which will lead to its increased scarcity. This can be learned from experiences in both industrialized countries, namely the USA and Israel, but also from developing countries, eg Egypt, Iraq, and India.

Fig. 3-3

SALINITY IN IRRIGATED AGRICULTURE 1107

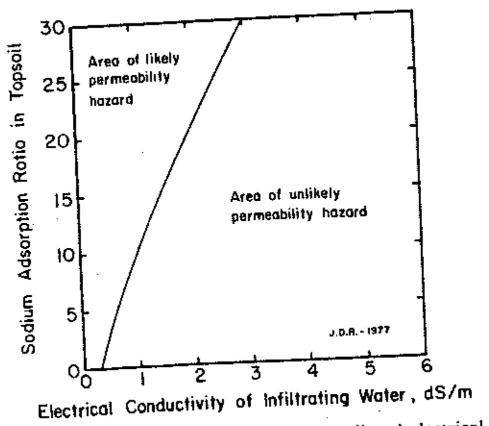



Fig. 36-4. Threshold values of Na adsorption ratio of topsoil and electrical conductivity of infiltrating water associated with the likelihood of substantial losses in permeability. After Rhoades (1982b).

Source: Loveday in Stewart ed. 1990





The manifest pressure of scarcity of food supply plus the availability of capital in some arid countries (eg Near East) resulted in incentives to increase irrigation and in consequence to permit less and less fresh water to drain further downstream and eventually into the sea. This tendency has been exacerbated by the introduction of new crop varieties ('green revolution') that both need and respond effectively to irrigation. Less salts will tend to be flushed from land through surface and subsurface channels, and the salinity of waters, especially in arid areas, will tend to further increase.

Some technical measures are available to reduce these detrimental impacts, eg diversion of natural or human-made saline inflows, diversion canals, cultivation of high yielding crops, less sensitive crops, modern irrigation techniques. Such measures, however, rather require heavy investments and excellent management and they adapt to salinity rather than control it which still reduces the flexibility with which the affected water be used downstream. In addition, most of these measures are unlikely to be introduced on a world scale, especially in the least developed countries, due to economic constraints, lack of management, and more recently, due to environmental concerns.

Examples of rapid large scale deterioration of water and land resources can be seen from:

| | |
|---|---|
| USA: | Colorado River, Imperial Valley |
| UdSSR: | Aral Sea, Caspian Sea |
| Israel: | all rivers on the coastal plain. |

Source: Kovda 1983

## 3.2 Sodic and Alkaline Soils

Sodification problems, casued by the increase of exchangeable sodium ions in proportion to other cations (ESP), are associated with a loss of favourable **soil structure**. Eventually tilth problems will occur in agricultural soils. Sodification as a result of irrigation is a common process when water of a poor quality is applied, for example water with a high sodium adsorption ration (SAR-value). The final ESP reached in a soil in equilibrium with a given irrigation water, depends on the SAR-value, ionic composition, total salt concentration as well as various soil properties, eg its buffer capacity and the actual concentration and composition of the soil solution.

However, irrigation practices are important, too: sodification processes will be favoured if water with a high salt concentration is followed by water with low salt concentration. In practice this may occur if poor quality irrigation water is followed by good quality water, eg during the rainy season or when blended water is applied. A similar situation arises in coastal regions if soils which are inundated with seawater (typically SAR > 100, EC >40 dS/m) are leached with good quality water, either with rainwater or river water. Sodification is a common process in saline-alkaline soils which are reclaimed by leaching. The desalinisation process will cause severe sodification unless further ameliorative measures are undertaken.

The assessment of **sodicity** hazard (sodium concentation in the soil solution) is complicated by the fact that there exist a variety of factors contributing to the deleterious effects of high sodium percentages in soils, which ultimately may lead to alkalinity (pH-values above 8.5). Under irrigation, the processes which occur during infiltration and percolation are to be considered. These may vary considerably according to the status of the soil structure which is time dependent, too. In medium to fine textured soils, sodicity is most important because of their high buffer capacity, ie they are less susceptible to changes in the soil solution and hence, less easy to reclaim by leaching. Furthermore, soil structure is the prominent feature in these soils, governing infiltration and permeability.

The sodicity hazard is related to potential permeability and tilth problems. Fig. 3-3 serves as an approximate guideline for assessing sodicity hazard in relation to total salinity of

Fig. 3-4

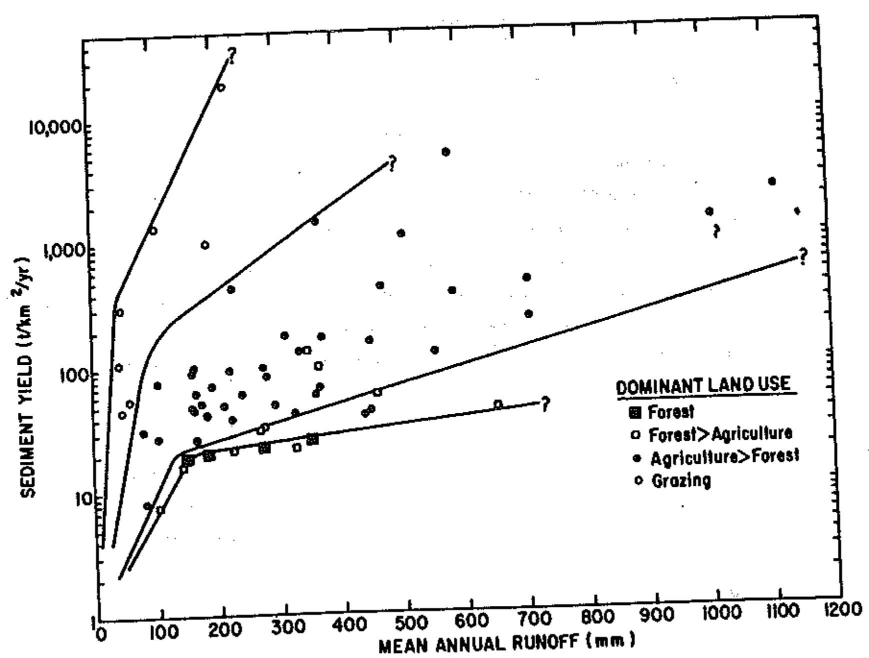



Fig. 1. Mean annual sediment yield and mean annual runoff for catchments with indicated dominant land uses. (After Dunne, 1979.)

Source: ASA 1986





the irrigation water and the known SAR in the topsoil solution. Other inherent soil factors such as mineral composition (eg cementing materials such as $CaCO_3$, oxic or siliceous compounds) and the presence of organic materials may contribute to the stability of soil aggregates. It is advisable to establish site specific relations for irrigation projects to test the susceptibility of soils to sodicity-induced disaggregation, clay dispersion and reductions of permeability whenever possible (Rhoades/Loveday 1990).

The term **alkalinity** refers to the pH-value, depending on the hydrogen ion concentration in the soil solution. Alkaline soils tend to be sodic, although the reverse is not always the case: eg Solonetz soils or sodic Solonchaks have high ESP-values but may be almost neutral or even acid in reaction, eg Solods or solodized Solonchaks. Strong alkaline reactions depend on high concentrations of carbonate and bicarbonates in the soil solution. Alakali sodic soils will eventually be formed if irrigation water contains an excess of carbonates and bicabonates over calcium and magnesium ions (RSC value). In the long run, carbonates and bicarbonates added in the water will precipitate with calcium and magnesium exchanged from the soil, until the adsorption complex is saturated with sodium. Continued addition of water will cause accumulation of dissolved sodium-carbonate, leading to pH-values in excess of 10, even in well-aerated soils (Bolt/Bruggenwert 1978).

Sources: Rhoades/Loveday in: Stewart et al. ed. 1990; Szabolcs 1979; FAO/UMEP/UNESCO 1979

## 3.3 Soil Erosion

### 3.3.1 Introduction

Erosion is an important soil degradation process which may become a major hazard to agricultural production. Cultivated land produces 10 to 100 times more erosion than other land use types and it is estimated that 16 t/ha of soil (equaivalent to 1-2 mm) are annually lost on croplands. In modern agriculture, the detrimental effects of erosion on crop yields are hidden by agronomic measures, eg by fertilising or the use of new varieties. However, the problem is obvious in many subsistance agricultural systems in developing countries (Brown/Wolf 1984).

Erosion impacts are twofold: erosion implies the loss of soil material, usually fertile topsoils from erosion sites, and **sedimentation** at deposition sites. This sedimentation may occur on-farm or off-farm and it may contribute to increased suspended loads in rivers before the sediments eventually deposit on flooded areas or along river banks or is transported further into lakes or the sea.

Soil erosion may be **beneficial** or **detrimental**, depending on the point of view. Erosion on agricultural lands is usually regarded as detrimental: it lowers soil productivity through a loss of storage capacity for water, loss of plant nutrients, degradation of soil structure, and decreased uniformity of soil conditions within a field. The characteristics of each individual soil profile, however, can strongly affect the actual quantitative impact of erosion upon productivity. Sedimentation on agricultural lands can be beneficial by improving soil characteristics (eg the fetility of floodplains is largely due to the deposition of eroded material furtehr up the catchment), increasing land height (polders) or increasing the depth to groundwater but it can also be detrimental by burying seeds and plants. Therefore, scale and time factors as well as magnitude and the users' view must be considered when evaluating the effects and impacts of erosion.

Soil erosion is induced by either water or wind forces which can be far more important than in the 'normal' (geological) erosion process because of human interference in natural ecosystems. Most human ecosystems are significantly more prone to erosion than natural ecosystems (except extreme deserts) mainly due to changes in the vegetative cover and interference in hydrological cycles (Fig. 3-4 and Table 3-3). The natural-induced rate of

Fig. 3-5

2 *Soil Erosion and Conservation*

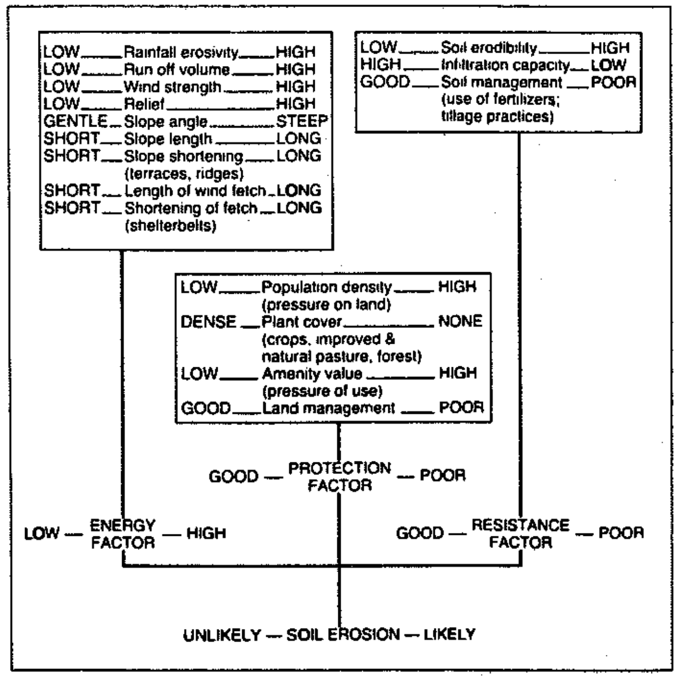



**Fig. 1.1** Factors affecting soil erosion.

Fig. 3-6

4 *Soil Erosion and Conservation*

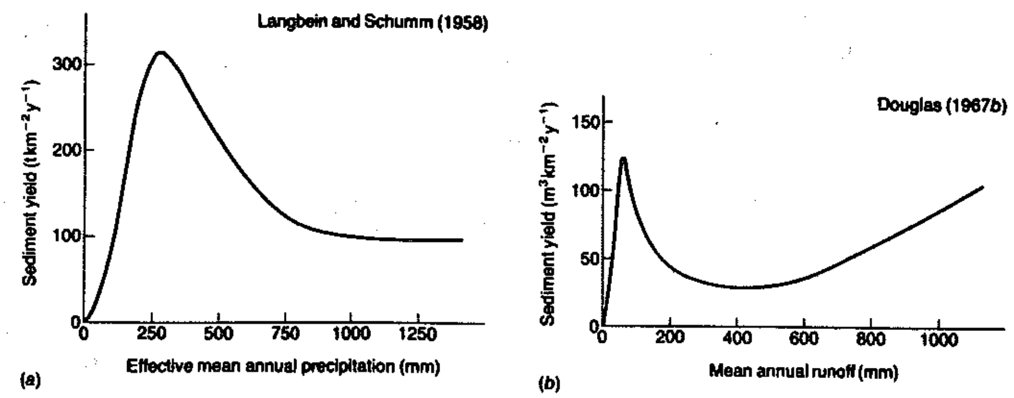



**Fig. 1.2** Proposed relationships between sediment yield and (*a*) effective mean annual precipitation; (*b*) mean annual runoff (after Gregory and Walling, 1973).

Source: Morgan 1981





erosion varies with climatic, geological, topographic conditions and soil. In common soil conservation practice an acceptable rate of soil erosion is 5 to 25 tons/ha per year or 0.2 to 1 mm/y. However, this rate may be too high to keep pace with the rate of soil weathering, and recent approaches set values closer to 0.02 to 0.2 mm/y.

Table 3-4 shows recommended maximum **permissible** rates of soil loss on various scales. Controlling factors for erosion rates are: rainfall energy, and vegetation cover at the field level and runoff at the drainage basin level (macro-scale). Rainfall energy is used as an indicator of rainfall intensity and total amount.

Source: Morgan in: Kirkby/Morgan ed. 1980

Irrigated agriculture may contribute to accelerated erosion in similar ways as in non-irrigated systems. In the following section, a brief review of irrigation-induced erosion is provided. Control measures are outlined in Part II section 3.4.

## 3.3.2 Water Erosion

The difference in erosion on irrigated and non-irrigated croplands is that on the latter water erosion is caused solely by natural rainfall and flooding. Under irrigation, additional water is added by man, which increases the potential for water erosion.

The erosion of soils by water consists of the **detachment** and the subsequent **transport** of soil particles. These may be detached by the kinetic energy of impacting water droplets or by the energy of flowing water. The transport for water to flow over the surface of detached particles occurs when the land slope is sufficient to transport them as suspended sediment or bedload. This process occurs wherever infiltration into the soil profile is lower than the rate of water application or rainfall intensity.

The most important factors determining the degree of water erosion on irrigated fields are: soil stability, exposure of soil particles (or reverse: the vegetation cover), slope and length of slope, infiltration rate, application rate, and the energy of water droplets (relevant for sprinkler irrigation). These factors are described as the **erosivity** (runoff, droplet impact) and **erodibility** (related to soil, vegetative cover- and topographic conditions). Most of these factors may be manipulated for agricultural systems (see Fig. 3-5).

Semiarid to subhumid tropical regions (definition in Table 2-4) are characterized by a high 'erosivity', resulting from rainfall pattern and intensity, which is a major hazard on most non-irrigated croplands (Fig.3-6 and Table 3-5). Erosion was controlled by **terraces** in traditional irrigation systems in the Andean and Asian regions, even in mountainous areas. Such areas would otherwise be considered unsuitable and prone to severe erosion risks. Consequently, erosion on irrigated areas occurs where **soil and water conservation measures are inadequate.** Erodibility can be reduced under surface irrigation systems by improving water retention properties by changing the length and grade of slopes and by partitioning the field, eg by farming basins or bunds. Irrigation may therefore have indirect beneficial effects by intercepting rainfall, improving soil moisture in situ and reducing river sedimentation because runoff is limited within the field boundaries.

Water harvesting is another type of water management which immediately intercepts rainfall for its on-site use and, hence, indirectly controls erosion on arable land (eg Boers/Ben-Asher 1982; Hudson (FAO) 1987). Level dam terraces in mountain areas (eg rice terraces in Southeast-Asia) are a special combination of water harvesting and irrigation farming (see also: Klemm 1990; Pacey/Cullis 1986, Kutsch 1983).

Irrigation usually increases cropping intensity, ie the arable land is less frequently under fallow than non-irrigated areas are and consesquently, rainfall erosion is further reduced by a protective vegetative cover during one or two additional cropping seasons compared with rainfed systems. This may apply to semiarid to subhumid areas.

In arid regions irrigation-induced water erosion becomes important because these areas have low potential and actual erosion rates by virtue of limited rainfall (extreme rainfall events are not considered here). On the other hand, vegetative cover in arid areas is limited by moisture deficits and irrigation compensates for those deficits. Consequently, irrigation may contribute to reducing (water and wind induced) erosion hazards by providing favourable environments for vegetative growth, allowing the build-up of organic matter which stabilizes soils and increasing soil cohesion by keeping soil surfaces wet.

Generalized impacts of water erosion

The primary impacts of water erosion is a reduction of agricultural productivity. Yield reduction on eroded fields may occur as a result of decreasing topsoil depth and eventually the exposure of less fertile subsoil layers, the loss of organic matter and other nutrient rich layers from topsoils, the loss of seed or damage of yound plants, and loss of arable land due to gully erosion.

These factors contribute to a reduction in available soil moisture and reduced water-use efficiencies in non-irrigated cropping systems. Additional economic losses may occur due to losses of fertilisers and pesticides. Actual productivity losses on specific sites are extremely variable because of the interrelation of numerous factors. General conclusions from loss estimates drawn from experiments should be treated with caution, especially if decreasing soil depth is used as an indicator. Some generalised yield loss estimates on eroded non-irrigated fields which occur after a few decades are

> about 40% on some soils in the CIS, 30% on eroded soils in Haiti, 50% decline in some Nigerian soils, 17 to 50% yield loss in some US states (Carter in: Stewart et al. 1990). Carter estimated yield reductions of some 25% after 80 seasons of irrigated furrow erosion on approximately 1 M ha of furrow-irrigated land in the USA.

Other impacts are increased downstream sedimentation with impacts on downstream agriculture through siltation of irrigation canals or blocked structures, reduced reservoir lifetimes, stream aggregation, damage to fishery, increased maintenance costs in waterways, and increased costs in harbour maintenance.

Downstream water quality may be impaired by overland flow which contains solid or soluble constituents of fertilisers or pesticides. There may be increased downstream flooding, probably in connection with sedimentation, and on a large scale level, ie for large watersheds there may be a decrease in dry season stream run-off, due to reduced interception by soil and vegetation.

Erosion on Irrigated Fields

Erosion may occur whenever water flows over agricultural land. Where irrigation is practiced on almost level land and low flow velocities occur during flooding of close growing crops, erosion is usually slight. Likewise, no surface flow should occur with properly designed sprinkler irrigation systems. Drip irrigation is regarded as best suited to control erosion. Irrigation-induced erosion can be divided into the following types

(i) Furrow erosion. Furrow irrigation was identified in the USA as a serious source of surface water pollution (sediment load) and regulations were established to control erosion. Parameters which influence the intensity of furrow erosion are: furrow shape and grade, furrow roughness, soil particle size, soil stability, previous water contents, infiltration rates, duration of irrigation, and flow rate. Sediment loss on a specific site can be about a 2 to 3-power function of furrow slope and about a 1.5-power function of flow rate. Furrow irrigated fields on slopes steeper than about 2% are usually prone to erosion due to uncontrolled concentration of runoff water and excessive flow velocity. Erosion will always occur when flowing water comes into contact with friable, unstructured soils, and even flow at the design rate will produce some unavoidable erosion on the upper 25 to 40% of each furrow and sedimentation on the lower half. The furrow stream must be large enough to carry enough water to irrigate the entire furrow length, and infiltration time should be ideally the same over the entire length to provide uniform applications. Hence, erosion along furrows is difficult to control. Irrigation field practices are usually focused on assuring complete flooding at the lower ends of furrows with greater runoff than necessary along upper furrow sections; as a result, furrow erosion may be severe with up to 40 to 50% of the applied water running off the field into the surface drainage system (Carter in: Stewart et al.1990).

(ii) Erosion under sprinkler irrigation is similar to that under rainfall: soil particles are detached by falling drops, and transported by drop splash and sometimes flowing water. The actual rate of erosion depends on the design of sprinklers and the operating pressure.

Erosion risks may be assessed on the basis of the applied kinetic energy in the following ascending order of magnitude: center pivot systems, mobile hand moved sprinklers, wheel line systems and finally rain-guns (high kinetic energy). Low-pressure sprinklers and spray heads are in practice often less favourable because the application rate per unit area on the wetting areas must be greater to achieve the same total application. Typically, erosion under sprinkler irrigation occurs when water application rates exceed infiltration, water ponds in small depressions and eventually moves downslope and concentrates in tillage tracks or previous erosion channels. The flow rate in these rills increases downslope as a result of increasing collecting areas. Eventually larger channels may develop further downslope or in adjacent irrigated areas and drainage channels or off-farm areas may be partially flooded, causing on- and off-farm damage.

Actual rates of on-farm erosion under various sprinkler systems vary considerably and they are easily controllable by the operator. The amount of erosion under center pivot irrigation is relatively small when only 30-50 mm of water is applied at low rates (10-20 mm/hr). The threshold value of rainfall intensity (ie when significant overland flow and erosion occurs) has been given as 25 mm/h for Zimbabwe, 6 mm/h for Germany and 10 mm/h for Britain (Morgan in: Kirkby/Morgan ed. 1980).

(iii) Sheet erosion by uncontrolled flooding on border dyke or border strip systems is essentially the same as under furrow irrigation. Topsoil redistribution often occurs when slopes exceed 2%. The actual rate of erosion largely depends on land preparation (eg levelling) and tillage practices. Uncontrolled flooding requires strict control during the application of water in order to avoid topsoil redistribution.

(iv) Erosion caused by overtopping of dykes and levees may occur under consitions of uncontrolled flooding of basin or border strip systems. Under controlled conditions checks and level basins offer an effective control of rainfall- and irrigation-induced erosion and the avoidance of any off-field losses. However, in practice flooding is often uncontrolled. Large ponded areas may result and rills and gullies may develop finally from overland flow as under sprinkler irrigation. Highly regimented time schedule operations and poor on-farm water supply control may contribute to this type of erosion.

Reference: Carter in: Stewart et al.1990; Mech/Smith in: Hagan et al. 1967

Further reading: Morgan 1986; Morgan ed.1981; ASA 1982; Greenland/Lal 1977

### 3.3.3 Wind Erosion

Wind erosion is a natural hazard in dry climates and in areas with clustered or diffuse natural vegetation or where vegetation is destroyed by human. Severe erosion by wind occurs whenever a loose and dry soil surface is unprotected by vegetative cover and winds are sufficiently strong. Critical wind speed velocities were established as some 4 m/s at 1 m height (although the lower limit of erosion is at some 0.5 m/s). This is the threshold value when severe erosion commences under average conditions. These conditions are usually met in areas which are prone to natural drought. Yet, wind erosion occurs in many irrigated regions and irrigation is affected by wind erosion although it does not

Fig. 3-7

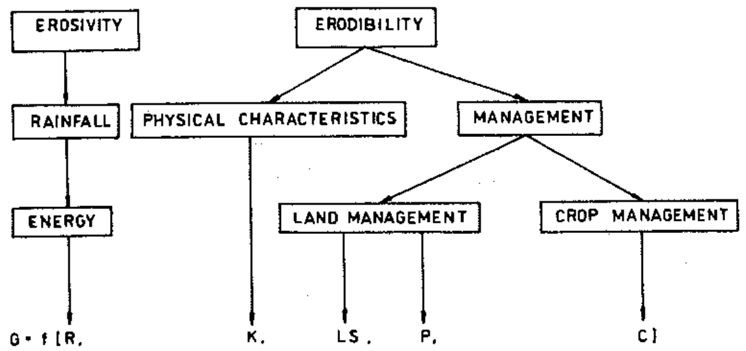



Fig. 65. Diagram expressing erosion intensity in dependence on the erosivity of rainfall and soil erodibility after N. Hudson.

Source: Holy 1980





contribute to it. In other words, wind erosion is an inherent hazard on many irrigated lands because of high potential erosivity and erodibility.

Factors related to **erosivity** are: wind velocity, duration and prevailance of a particular wind direction; surface roughness affected by vegetation, tillage practices, windbreaks and shelterbelts and by local changes in topography. Surface roughness is significantly increased by vegetation cover; the effectiveness depends upon the height and continuity/uniformity of the canopy, the density of the ground cover and the root system.

Factors affecting the **erodibility** of individual grains or soil aggregates are: moisture content, soil cohesiveness, texture and organic constituents.

Source: Morgan 1986; Wilson/Cooke in: Kirkby/Morgan ed. 1980; FAO 1960

The effect of irrigation on wind erosion hazard is related to increased water contents in soils, tillage practices and changes in vegetative cover. Most of those effects are beneficial, ie vegetation growth is enhanced by irrigation, the soil surface is kept moist, and the surface roughness of bare soils is increased with adequate tillage practices.

The physical effects of wind erosion can be summarised as:

- **soil damage**: fine material, including organic matter, may be removed; soil structure may be damaged by disaggregation; coarse layers of stones or pebbles may remain as residues; fertilisers and herbicides may be redistributed or lost,
- **crop damage**: seedlings may be covered by sediments; sandblasting may cause foliage abrasion; seeds and seedlings may be blown away; fertiliser redistribution may cause uneven growth conditions or even locally toxic concentrations; soil borne disease may be spread (as particles, aerosols); rabbits and other pests may inhabit dunes trapped in hedges and feed on the crops,
- other **on-farm damage**: soil is deposited in ditches, canals, roads, windbreaks, hedges; fine material may clog irrigation structures; farm machinery and irrigation equipment may be abraded,
- **irrigation**: strong winds may hamper timely sprinkler applications; other work may be delayed by unpleasant conditions; drip systems may become blocked by sediments.

Reference: Wilson/Cooke in: Kirkby/Morgan ed.1980; Mech/Woodruff in: Hagan et al.1967; FAO 1960, 1965, 1979

## 3.3.4 Erosion Risk Assessment

There are numerous methods for risk assessments on croplands, considering the potential and actual hazards. These comprise theoretical **numerical** solutions (eg Kirkby in: Kirkby/Morgan ed. 1980), **empirical** quantifiable predictions (eg USLE-formula, Wischmeyer/Smith 1978), rule of thumb **field observations** (eg Hurni 1988) and generalised **assessments** on a world-wide scale (FAO/UNEP 1983, FAO/UNESCO/UNEP 1979; FAO (SB 13) 1971).

Despite these efforts to develop practical guidelines a basic constraint to quantitative approaches remains that soil erosion is a **complex process** involving the interaction of environmental, physiochemical (soil) and agronomic factors as seen in Fig. 3-7.

**Empirical** models have the disadvantage of comprising complex interactions of many factors whose simplification (from site specific experience) may result in an unacceptable reduction in the accuracy of predictions on other sites. **Conceptual** models are often too complex for simple application and a large number of coefficients may need to be be experimentally determined.

Reliable empirical predictions of erosion hazards must consider all individual factors of erosivity and erodibility, and their interrelations. Site specific assessments still require educated guesses of some of the factors and parameters involved. Furthermore, economic considerations must be introduced so as to evaluate the feasibility and viability of site specific erosion control measures. For further details the reader is referred to specialist literature on soil erosion, eg proceedings of national or international soil science societies and scientific journals). No generalised models have been developed for predicting erosion hazards in irrigated agriculture, but many models can be used for both, irrigated and non-irrigated farming.

Comprehensive reviews in: Blume ed. 1990; Landon ed. 1984; Holy 1980

### 3.3.5 Costs of Soil Erosion

Costs due to erosion occur on-site and off-site. On-site costs are related to

- long term loss of soil fertility (bio-chemical and physical properties)
- short and medium term lower yields per unit area
- replacement costs of fertilisers and pesticides
- crop damage
- implementation and maintenance of technical control measures for sheet runoff: strips, terraces, interception ditches, ridges, storm drainage canals
- implementation and maintenance of technical measures to control concentrated runoff: runoff (retention) reservoirs, gully and ravine control; torrent control
- application of agricultural and forestry measures for control: special tillage methods, vegetation methods, afforestation (windbreaks, shelterbelts)
- siltation of reservoirs (on site)
- repair and maintenance costs for cleaning drainage structures
- repair and maintenance costs for cleaning water intake structures and canals
- replacement of material and infrastructure; additional working hours.

Off-site costs are difficult to assess because they are often indirect and quantification would require considerable research:

- siltation of larger downstream reservoirs at accelerated rates; reduction of effective storage capacity
- increased water treatment costs for downstream domestic water users if water is contaminated, carries high sediment loads or pathogens
- indirect losses to fishery if water contamination causes reduced fish growth, increased mortality (total population) or changes in fish species
- aeolian deposits which contain salts might cause salinisation
- damage to processing equipment in industrial plants if polluted or contaminated water is used without prior treatment
- eutrophication of rivers, lakes and reservoirs due to increases in phosphate and nitrogen; subsequent loss in recreational value etc.

*Case Studies*

Java. High sediment loads in the irrigation water, caused by upper watershed erosion, may cause damage to irrigation systems. An estimate for Java assumes that irrigation system siltation causes annual costs in the range of US $ 9-13 M (Table 3-6). Sedimentation imposes high costs in terms of shortened beneficial investment time, high maintenance requirements, and reduced services. Siltation of reservoirs, some of them also used for irrigation water supply, causes cost in the range of US $ 16 to 75 million annually (Doolette/Magrath 1990).

Fig. 3-8

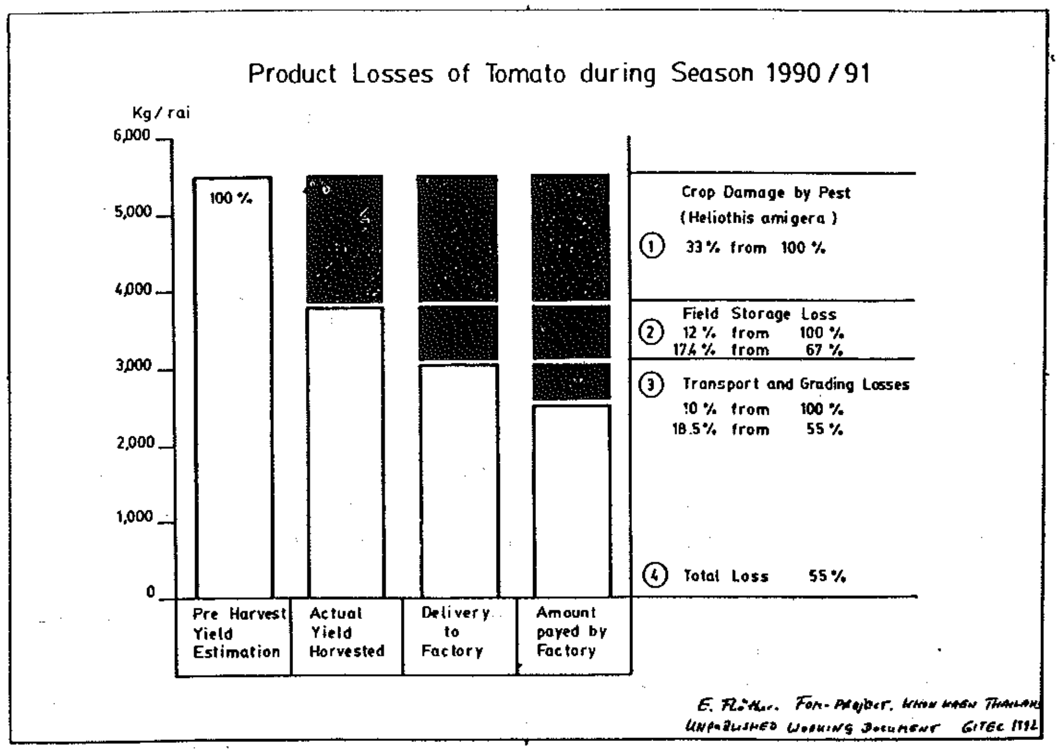
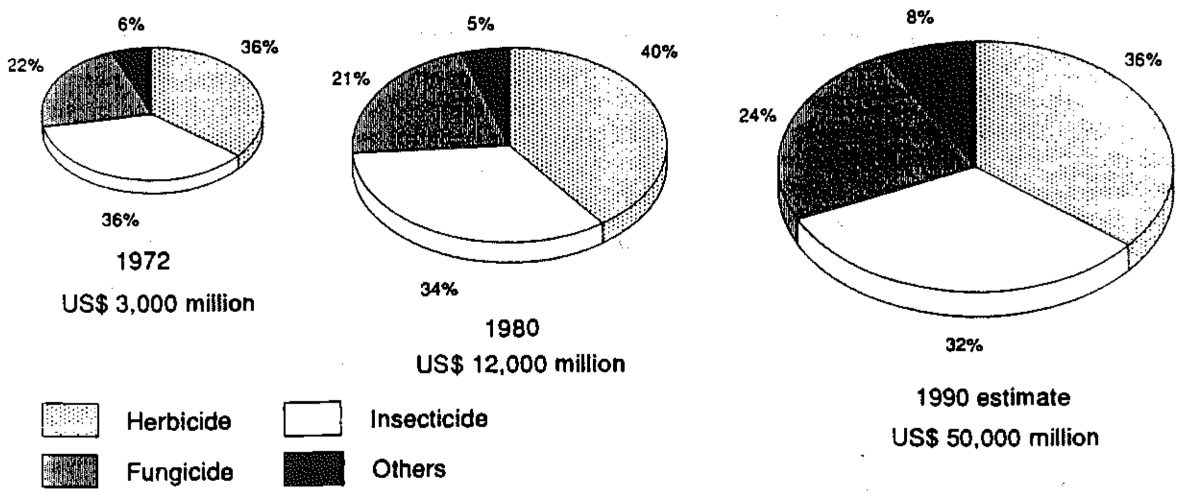



Fig. 3-9

App. 4-7(i): Entwicklung der Verkäufe bei wichtigen Pestiziden




Quelle: Meybeck, M. et at., Global Freshwater Quality, Oxford, 1989

Source: GITEC 1992





Luzon. Without watershed management control actions, high sedimentation rates in the upper watershed of San Roque Multipurpose Project (Luzon) will cause losses about $ 200 M over a period of 50 years. The watershed control costs will be some $ 27 M (Briones in: Easter et al. ed. 1986)

Sources: Easter et al. ed. 1986; Morgan 1986; ASA43. 1986; Morgan ed. 1981; Kirkby/Morgan ed. 1980; Holy 1980; FAO/UNEP/UNESCO 1979

Further readings: Barbier 1990; Kratz 1989; Hurni 1988; Lal 1989; FAO/UNEP 1983; Schwab et al. 1981; Hudson 1971; FAO 1965; FAO 1960

## 3.4 Contamination of Soils with Pesticide Residues

### 3.4.1 Introduction

Pests destroy up to one third of the world's food crops during growth, harvest and storage (example in Fig. 3-7). Therefore, synthetic organic pesticides have become a major element in modern agricultural production practices (Fig. 3-8). The advent of pesticide use has coincided with the tremendous increase in agricultural productivity together with expansion of agriculture over the past century. Together with the adoption of improved varieties, use of synthetic fertilisers, improved irrigation practices, and more efficient farm machinery, pesticides have been credited as one of the major contributors to modernized agricultural production which led to dramatic improvements in crop yields and nutritional quality of most products (quality may also have been declined in some products, see Pacey/Payne 1985). Synthetic chemicals have essentially replaced inorganic chemicals and many tillage and cultural practices. The recent trend towards minimal tillage (projected to be practiced by the year 2010 on some 60% of US farms) has also meant an increased reliance on pesticides, although recent integrated pest management approaches combine non-chemical means with chemical use

Further figures on pesticide uses are given in Part II section 5.2, especially 5.2.2

Remark: In the USA, about 70% of pesticides in 1983 were for agricultural purposes (Leonard in: Cheng ed. (SSSA) 1990). Other important users are health programmes and agroforestry.

The **advantage** of chemical pesticides include their effectiveness in controlling pests and their rapid and (relatively) easy application. The **disadvantage** is that few pesticides possess a high degree of specificity and most of them are also toxic to non-target organisms. Their use also constitutes a potential health hazard to the person who handles them as well as to consumers of treated crops as well as posing serious entvironmental threats.

Conventionally, it is believed that the careful handling and application of pesticides under appropriate soil and environmental conditions is proven to be effective in pest control with little adverse effects on the surrounding environment. Growing evidence, however, indicates that **trace** amounts of pesticides are present in **soils**, **groundwater** and the **atmosphere**. Since pesticides are toxic by design, there is a natural concern on the impact of their presence in the environment on human health and envrionmental quality (soil/water/air resources/biotic life). In addition to concern for the acute and chronic toxicity of chemical pesticides, their potentials as carcinogens, teratogens, and mutagens have led to questions about the acceptability of continued use.

The purpose of this section is to review the presence and fate of pesticides in soil environments based on recent publications on pesticide issues, mainly from studies conducted in industrialized countries.

Remarks: Most analyses and assessments are made in **industrialized** countries, namely USA, Canada and Europe. Analytical data from developing countries are rare but the **increased use** of pesticides and fertilisers in developing countries make it more likely that contamination and pollution problems will increase in the near future. Problems in developing countries are often exacerbated by lack of infrastructure and resources to deal with them (see also: Bull 1982; Davies et al. 1982, both cit. in: Madhun/Freed, in: Cheng ed. 1990).

Drastic changes in pesticide characteristics and uses over the past 10-15 years require that data in earlier publications and generalisations should be treated with caution.

Sources: Cheng; Severn/Ballard; Leonard all in: Cheng ed. 1990; FAO 1985a;

### 3.4.2 Nature and Scope of Contamination Impact

Impacts are a function of the **nature** of the chemical (eg toxicity and properties) and the **exposures** received (eg amount/concentration, frequency and duration). Generally, pesticides create several problems including widespread accumulation of residues, resulting in impairments to wildlife, fisheries, beneficial insects, and even humans. Impacts on wildlife may result in

- increased mortality due to **acute** toxicity,
- **subtle** effects on reproduction and behaviour due to chronic toxicity or habitat deterioration,
- **long-term** impacts through accumulation of residue.

Impacts may occur on-site and off-site, during storage and handling, and during or after application on target plants. They include (1) pollution of soil and water resources, (2) contamination of humans which are in contact with the the chemical or the products treated with pesticides, and of biotic life which is in contact of affected air, soil and water. The impact on the natural environment is often not obvious, but insidious and it has more serious effects than is apparent. The nature and magnitude of the impact are influenced by many factors with respect to pesticide formulation, organism and biological interaction. For example, regarding impacts on fish species for a given pesticide, levels of toxicity vary with temperature, water chemistry, and biological factors such as age, sex, size, and health conditions as well as species (Madhun/Freed in: Cheng ed. 1990).

Table 3-7 indicates the physico-chemical characteristics of pesticides and their relationship to such fundamental environmental behaviour as adsorption, leaching, vaporisation, breakdown, and in terms of biological effects, bioaccumulation (Madhun/Freed 1990). On the basis of persistency and toxicity, pesticides can be classified as:

<u>Persistent</u> chemicals which can exert pressure on ecosystems for considerable periods and what constitute one of the greatest potential hazards to the environment are organochlorine insecticides (eg DDT, dieldrin, endosulfan). Organophosphate insecticides (OP) are less persistent but many have higher toxicity to mammals and some are systemic in plants. Carbamates include insecticides, fungicides and nematicides; they are more persistent than OP and differ considerably in mammalian toxicity. A few fungicides (eg mercury compounds) and herbicides (eg triazines) are also moderately persistent.

<u>Transient</u> chemicals, including certain insecticides of high toxicity, occasionally account for spectacular incidents and kills of wildlife, but populations usually recover quite rapidly and the contamination disappears quickly. Most nematicides (eg D.D., chloropicrin, methyl bromide, aldicarb) are of very high mammalian toxicity and have a broad spectrum of toxicity. They can cause drastic localised impacts. Molluscicides cause few environmental problems if used as baits. Systemic herbicides (eg 2,4,5T, 2,4-D, MCPA, CMPP) are selective and of low mammalian and fish toxicity. Although soluble and mobile they have been thought not to pose serious environmental hazard, atlhough recent research challanges these assumptions. Contact

Fig. 3-10

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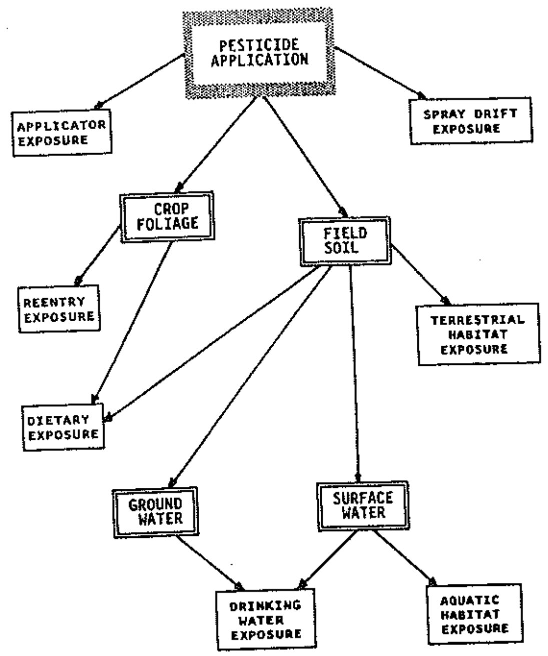


Fig. 13-3. Pathways of pesticide exposure.

Fig. 3-11

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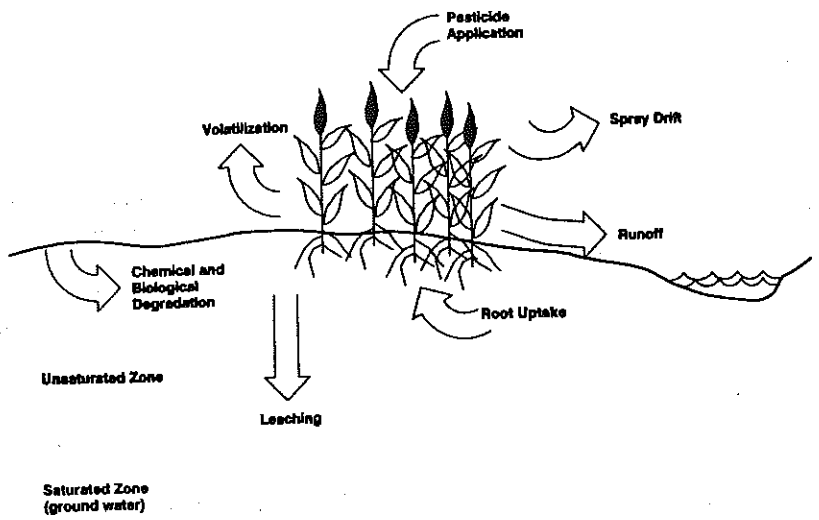



Fig. 13-2. Pathways of pesticide degradation and transport.

Source: Sever/Ballard in Cheng ed. 1990

Fig. 3-12

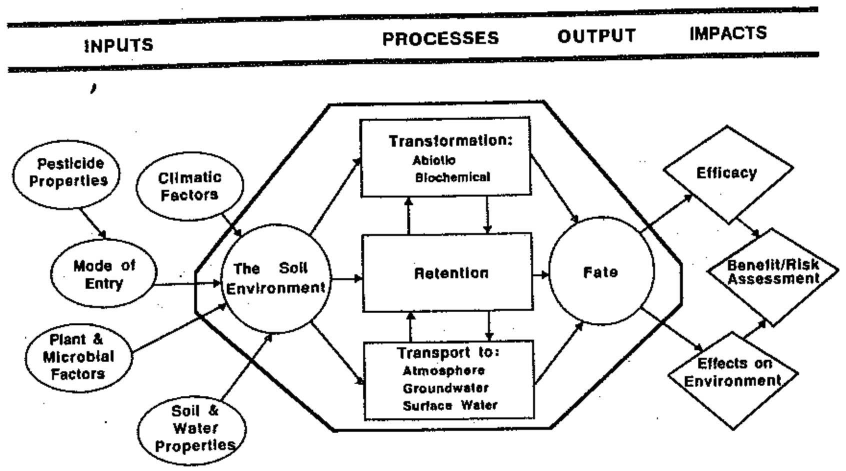



Fig. 1-1. A conceptual framework depicting the factors and processes that govern the fate of pesticides in the soil environment and how pesticide fate affects their efficacy and their impact on the environment.

Source: Cheng in Cheng ed. 1990





herbicides (eg paraquat) are of low mammalian toxicity and cause few problems, although some of them have a medium toxicity and they may accumulate. Fungicides differ widely; most have low mammalian toxicities and have a low range of toxicity to soil and aquatic organisms.

Sources: Edwards 1987; Madhun/Freed in: Cheng ed. (SSSA) 1990

On-site impacts, due to pesticide use may occur to

- target or non-target plants
- soil microorganism and invertebrates: mortality, subtle and long-term impacts may occur to target or non-target organisms. Insecticides, nematicides and molluscicides have the greatest direct impacts on vertebrates but herbicides may affect them through effects on vegetation. Negative effects may occur to predators that help to control pests (eg mites, centipides and carabid beetles)
- insects, birds, mammals: mortality, subtle and long-term impact may occur
- exposed humans through respiration, dermal (skin) exposure or ingestion; direct toxic or subtle reactions from acute or chronic impacts may occur if proper precautions and protective clothing during storage, handling and application are not employed. The major route of exposure for farmers is dermal due to spillage, splashes, or contamination of clothing. The respiratory exposure during mixing and application varies largely with type of chemical application method and individual handling. The potential pathways of pesticide exposure to humans are shown in Fig. 3-10.

Off-site impacts due to pesticides may occur on:

- all users or consumers of polluted ground- and surface waters further downstream of the application area, especially to fish, birds and mammals,
- all consumers of contaminated plants. There is no consensus amongst scientists about the actual human health threat posed by pesticides at legal concentrations in consumed food.

Sources: Madhun/Freed in: Cheng ed. (SSSA) 1990; Edwards 1987

Further reading with references and examples of impacts in: Madhun/Freed in: Cheng ed. (SSSA) 1990

### 3.4.3 Pesticide Entry into the Environment

Pesticides may be introduced directly into the environment in a liquid phase, as a dispersion or solution, or in the solid phase, eg as a powder, dust, microcapsule, or granule. Environmental entry can occur during application as spray drift and during rainfall/irrigation due to foliar wash-off. Pesticide sources and environmental exposure pathways are shown in Table 3-8 and Fig. 3-11.

The fate of pesticide in soils is governed by retention, transformation, and transportation processes, and the interaction between them (see conceptual framework in Fig. 3-12.)

**Retention** (or sortion) is the consequence of interaction between the pesticide chemical and the soil particle surface or soil components. It may be reversible or irreversible, retard or prevent pesticide movement, and affect its availability for plant or microbial uptake or for biotic and abiotic transformation.

**Transformation** is a change in the chemical nature of the molecule. Changes may be purely chemical in nature (eg catalysed by soil constituents or induced photochemically) or by biochemical means, such as soil microorganism.

**Degradation** tends to decrease the toxicity although occasionally the metabolic products may be even more toxic than the original compound.

Fig. 3-13

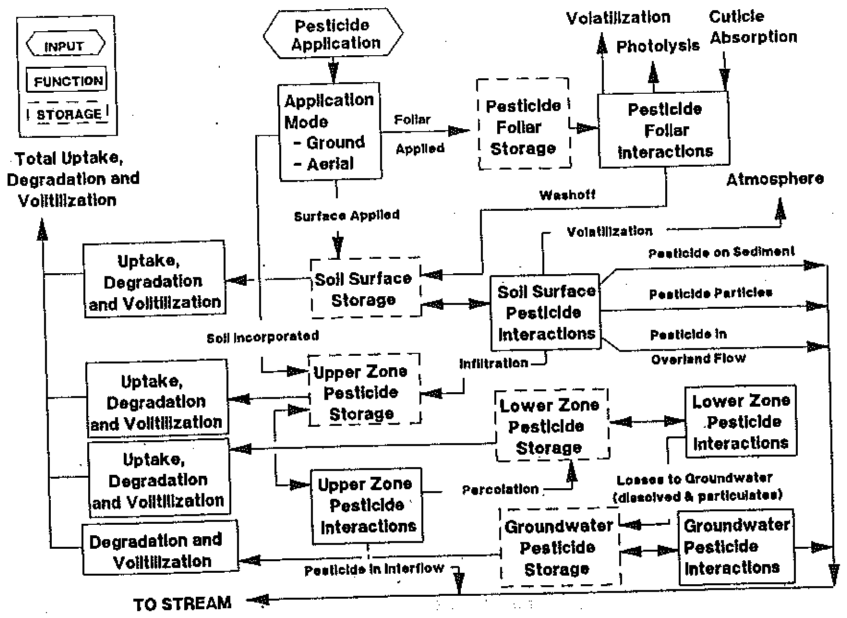



Fig. 2-1. Pesticide transport and transformation in the soil-plant environment and vadose zone. After Donigian and Crawford (1976).

Fig. 3-14

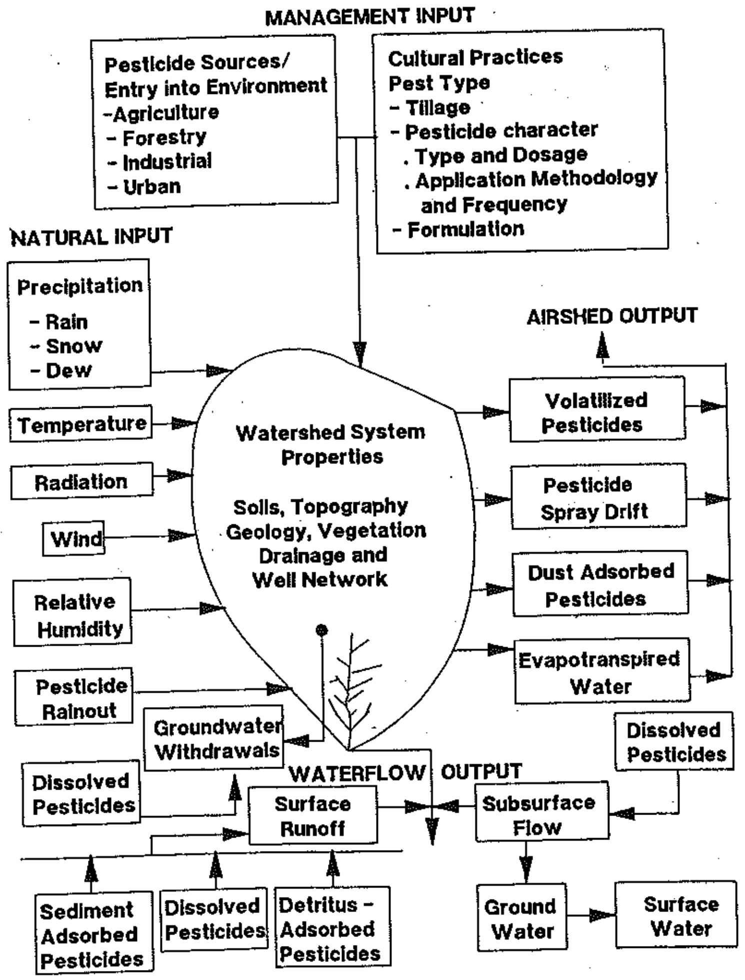



Fig. 2-2. Factors influencing the behavior and export of pesticides from a watershed. After Bailey et al. (1985).

Source: Himel et al in Cheng ed. 1990





Transformation and degradation processes dictate whether and how long pesticides may be present and **transportation** processes dictate where the pesticides are present. Volatilisation and direct evaporation from plant tissues lead to the distribution of pesticides from the soil/plant to the atmosphere, leaching results in movement towards groundwaters and overland flow moves pesticides into surface waters. Soil properties determine the flow characteristics (of both water and pesticide), sorption determines the availability for transport (vapour vs. aqueous vs. particulate vs. dissolved), and the kinetics of transformation/bioaccumulation determines the concentration present to be transported. The hydrological cycle interacts with chemical properties and soil characteristics to transform and transport pesticides in runoff and leachate to water sources.

Source: Cheng in: Cheng ed. 1990; Himel et al. in: Cheng ed. 1990; Bailey in: Cheng ed. 1990
Further reading: Leistra/Green in: Cheng (SSSA) 1990; Blume ed. 1990; Edwards 1987

Pesticide transport and transformation processes in the soil-plant-groundwater environment are shown in Figs. 3-13 and 3-14. The current state-of-understanding of the pesticide-soil porous media-plant **system** and the nature of these interactions can be seen in Fig. 3-15 and Table 3-9. Land use, cultural and irrigation practices determine the crop type, the pesticide type and formulation, and the application technology used. Exogenous environmental factors are typically uncontrolled and determine the stochastic nature of pesticide fate in, through, and from the soil to connected groundwater and surface water systems.

Source: Bailey in: Cheng ed. (SSSA) 1990

## 3.4.4 Herbicide Behaviour in Irrigated Soils

Five main factors affect the behaviour of herbicides in irrigated soils:

i) **Chemical** characteristics of the pesticides: solubility, vapour pressure, chemical and biological stability to surface or biologically induced reactions determine the behaviour in the soil-water system; this in turn is governed by irrigation practices. Biodegradation of herbicides, ie the structural transformation by oxidative, reductive, hydrolytic, or conjugative reactions, are governed directly or indirectly (via microbial metabolic activities) by soil properties, temperature and moisture contents. Enhanced herbicide biodegradation occurs with increased temperatures and at moist (not wet) soil conditions. Hydrolysis is the most important means of chemical degradation. Wet (irrigated) soils may bring about additional reactions. The volatilization from soil surfaces is also controlled by soil moisture, ie the concentration of the desorbed pesticide and the rate of movement in the soil solution. Volatilization from moist soils (or wet plant tissues) can approach 90% within 3 days for volatile pesticides but much less (three orders of magnitude) for dry surfaces.

ii) Properties of the **soil** and their spatial variability: the composition of the liquid-solid phase in soils determines adsorption-desorption from and into the liquid phase. The most significant properties are the clay and organic matter contents and pH-values of the soil. The presence of salts in the soil solution can cause a decrease in the adsoprtion of cationic herbicides due to competition for exchange sites; neutral soils are less effective but may show increased adsorption (Table 3-10).

iii) Herbicide **application techniques**: Surface broadcasting may favour volatilisation or transport by runoff. Application with irrigation water (herbigation) results in distribution within the soil profile and there may be subsequent leaching. Mechanical incorporation may reduce volatilisation but increases the heterogeneity of distribution.

iv) **Irrigation** technology: Significantly affects distribution patterns which may or may not lead to an increase or decrease in application efficiency accompanied by leaching processes. For example, using surface irrigation methods to apply highly volatile herbicides is an extremely inefficient method considering the high volatilisation los-

Fig. 3-15

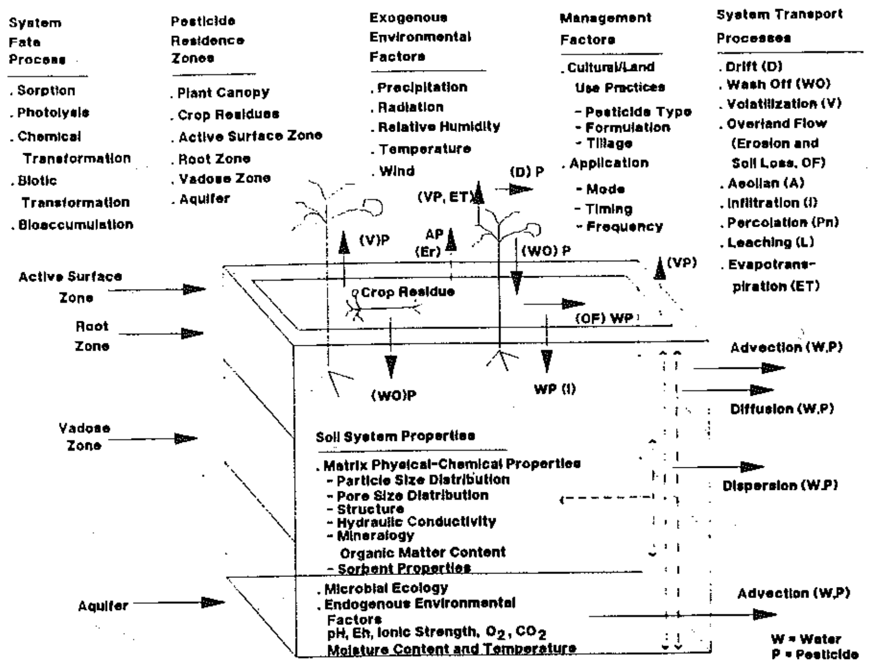



Fig. 14-1. System description of pesticide-soil/porous media-plant interactions.

Source: Bailey in Cheng ed. 1990





ses. On the other hand, deliberate volatilisation can be induced by irrigation scheduling in order to minimise leaching losses (agronomic option). Low rates of irrigation application may restrict downward leaching of deeply injected pesticides.

Basin and border strip irrigation induce one-dimensional flow and uniform, vertical transport. Furrow and drip irrigation induce two-dimensional flow while subsurface irrigation favours three-dimensional flow. Here, the dynamics of flow are more complex and matric potentials govern flow and redistribution once the water enters the soil. Unsaturated conditions are predominant under sprinkler, drip and furrow irrigation methods, whereas saturated conditions in surface horizons are predominant in other surface methods. Anaerobic conditions (ie <10-20% of pore space is gas-filled) during saturated flow inhibit the microbial activity, which affects the fate of herbicides.

v) Fluctuations in the **environmental conditions** during the season: irrigation modifies fluctuations in water content and temperature of the soil which in turn directly affects the herbicide behaviour (see Table 3-11).

It may be concluded that **irrigation technology** and **scheduling** can be used to increase the application <u>efficiency</u> of herbicides and to <u>minimise losses</u> to the environment (ground- or surface water or volatilisation losses). This can be achieved by careful applications of herbicides through modifications of processes like adsorption-release, volatilisation, decomposition and leaching losses. Irrigation can also be used to increase the <u>efficacy</u> of herbicides and to hasten their <u>losses</u> to prevent residual carry-over to the next crop or to groundwaters. If herbicides are applied to moist soils following irrigation, excessive volatilisation may occur before they can be incorporated. Irrigation can also be used to prevent volatilisation by the timely redistribution of the chemical into the soil and by preventing capillary rise to the surface. Howevr, the <u>type</u> of herbicide must also be considered:

For example, non-polar herbicides may be more effective when applied to prewetted soils due to the competition between water and chemicals. Likewise, the application of herbicides with a high vapour pressure to wet soils may increase volatilisation.

Source: Yaron/Gerstl/Spencer 1985

<u>Fate of herbicides in irrigated soils</u>. Herbicides may be directly applied to the soil surface and then wetted by irrigation, applied to the soil in irrigation water, or sprayed onto flooding water:

- Herbicides applied prior to irrigation: the behaviour of herbicides is defined by the irrigation regime (method, rate, total amount, and frequency) because its spatial distribution, the extent of dispersion and the fluctuation of anaerobic-aerobic conditions is affected. Consequently, the degradation rate is also affected. Herbicide losses induced by runoff under furrow irrigation can be in the range of 1 to 2% (Yaron/Gerstl/Spencer 1985)
- Herbigation: this requires strict control of the amount of water applied per unit of land. Pressure systems (sprinkler, trickle) are most convenient for herbicide incorporation into soils via irrigation water. Exessive application may cause harmful biocidal effects on the irrigated crop, eg injury to foliage. Potential evaporation losses of water and the herbicide may be in the range of 10% (atrazin) to 85% (trifluralin). The application of chemicals with a high vapour pressure or unstable photochemical properties is by this method questionable.
- Herbicides applied to flooded soils is common practice in rice culture and in open channels conveying water to fields. Rice fields contain reactive nucleophiles such as hydroxydes characterized by a pH between 8 and 10, ammonia, amines, sulfides, dissolved oxygen and other oxidants, organic and inorganic reducing agents, and

Fig. 3-16

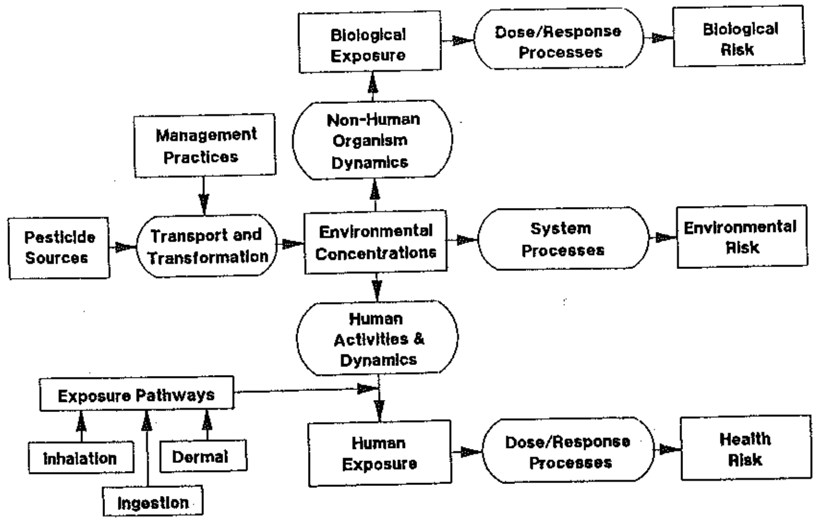
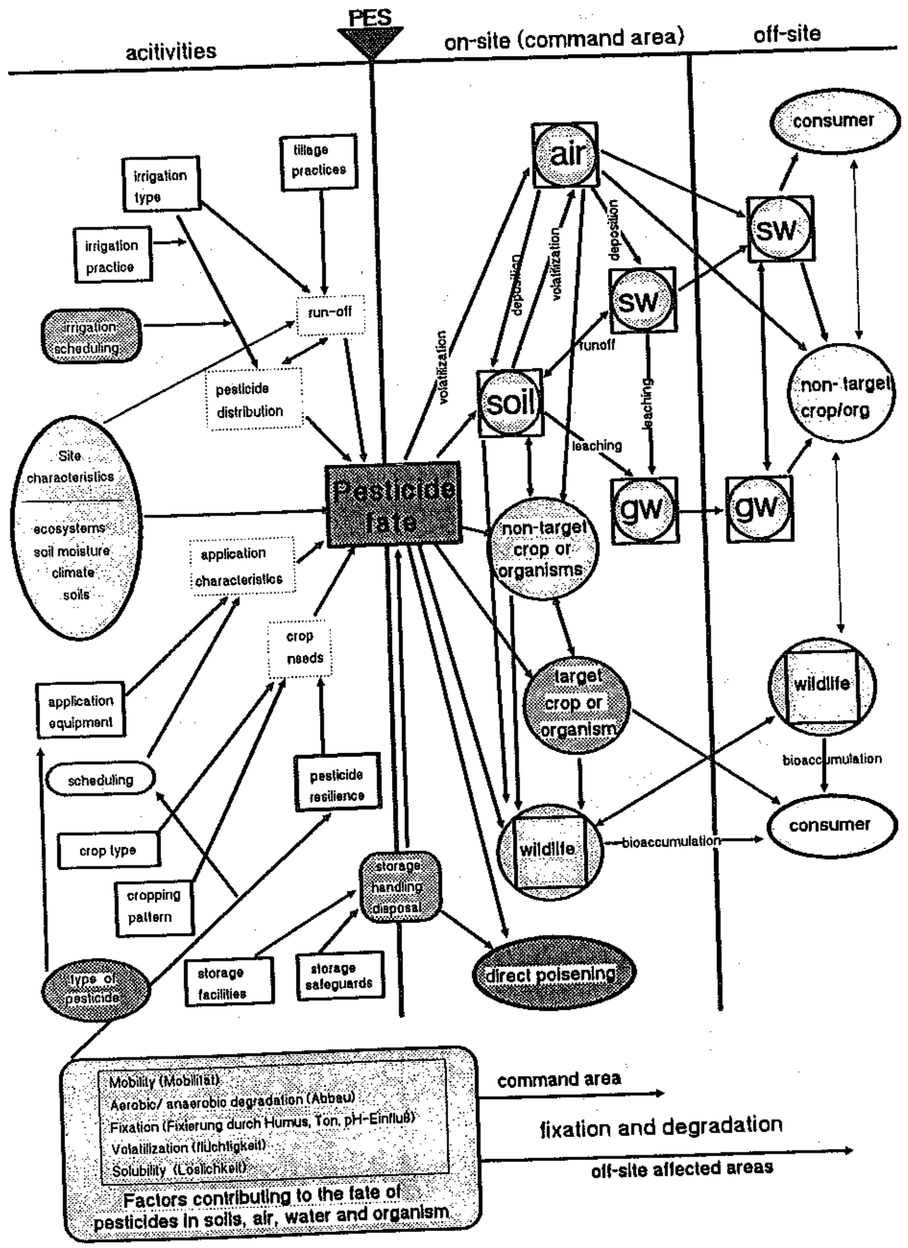



Fig. 2-3. Concept of pesticide exposure and risk assessment. After Bailey et al. (1985).

Source: Himel et al in Cheng ed. 1990

Fig. 3-17

Environmental Impacts of Pesticides Use in Irrigation




Network showing characteristics (left hand) and fate of the pesticide (right hand)





biochemical compounds resulting from intensive microbiological activity. Herbicides released into this environment are subjected to dissolution, adsorption, leaching, runoff, volatilisation, and biological, chemical, and photochemical conversion. Volatilisation is often one of the main dissipating pathway in a flooded soil. Leaching of herbicides will be greater than on upland fields because in submerged fields there is continuous leaching. In fact, runoff can be a major pathway of dissipation in a flooded ecosystem. Photochemical and biochemical degradation govern the fate of herbicides in flooded environmentes. The high pH induces intensive hydrolysis. Microbial degradation is less important due to anaerobic soil conditions. A summary of the residual periods of herbicides in flooded ecosystems is presented in Table 3-12. The fate of (non-persistent) molinate, when applied in paddy, is shown in Table 3-13.

Source: Yaron/Gerstl/Spencer 1985

### 3.4.5 Pesticide Source Characterisation and Risk Assessment

Risk assessment is a tool used to evaluate the probability of an adverse impact that a pesticide may have on human health, or the environment. To assess the risk which may be encountered under any given set of circumstances, the route and rate (dose/amount) of the chemical reaching the organism must be known. The key role of detailed knowledge of soil physical conditions and their spatial distribution can be seen from Fig. 3-16. The role of management practices on pesticide transport and transformation are shown in Fig. 3-17.

### 3.4.6 Irrigation and Pesticide Use

Irrigation has specific influences on the use, behaviour and export of pesticides from fields. **Transportation** processes of pesticides are accelerated during sprinkler irrigation applications through foliar wash-off. Also increased surface runoff from surface irrigation applications (eg furrow) may contribute to rapid on-farm and, under poor water management, to off-farm dislocation of pesticide residues. Improved drainage systems increase subsurface flow and contribute to increased leaching losses from soils.

Furthermore, it can be expected that transformation and probably also **degradation** processes are accelerated by irrigation due to the higher soil moisture status in irrigated soils and the presence of ample moisture for enhanced chemical and biotic processes.

In addition, irrigation contributes indirectly to the increased use of pesticides in agriculture by

- the tendency towards **monoculture** in large schemes; pest control can then only be achieved by pesticides
- providing a favourable soil (moisture) and plant (increased growth and prolonged seasons) **habitat** for many pests to survive and reproduce abnormally
- indirect changes related to the intensification of the production system, eg stimulating the **mechanisation** of agricultural production which may enhance the use of pesticides
- sprinkler and trickle/drip irrigation systems allow easy, rapid/flexible and labour-saving **application** of pesticides.

### 3.4.7 Pesticide Impacts on Birds and Mammals

Many pesticides, particularly insecticides, are toxic to birds when their food becomes contaminated. The greatest hazards appear to be from persistent organochlorine insecticides. These are taken up in the birds' food, and although they may not kill them immediately, they are stored in fatty tissues and may have drastic effects when fat tissues are mobilised. Moreover, several insecticides have been found to cause thinning of the egg shells of birds of prey.

Organophosphates and carbamates which have replaced the organochlorines are not stored in the birds' tissue in large quantities, although they have a higher acute toxicity to birds. Consequently, since the 1970's, reports of large-scale adverse effects on birds are relatively rare, although there have been many localised bird kills.

There is much less evidence of pesticides having effects on mammals than on birds. Although organochlorines are stored in the tissues of mammals, there is little evidence that these residues are toxic or have major effects. However, there is more evidence of mammal kills resulting from organophosphate insecticides which have a high mammalian toxicity.

Source: Edwards 1986)

## 3.5 Contamination of Soils with Heavy Metals

Soil contamination with trace elements (or 'heavy' or 'toxic' metals) may be due to inherent soil properties, atmospheric additions or deliberate (farm-initiated) additions:

i) **air pollution** (see section 5)
ii) **wastewater** effluent applications, often containing Cd, Pb, Zn, Ni, (see sections 2.3 and 8.1)
iii) **animal waste** or sewage sludge applications, often rich in Cu, Zn, and Cd derived from weathering of parent material
iv) polluted ground- or surface **water** which is used for irrigation (see Part II 2.2)
v) additions by metal-containing substances such as **fertilisers**, soil amendments.

The following metal ions are of environmental concern in soil: Al, As, Be, Cr, Cd, Hg, Ni, Sb, and Sn. In addition, the following ions are of ecotoxicological importances, but are plant nutrients: B, Co, Cu, Fe, Mn, Mo, and Zn.

Cadmium is often regarded as the most important heavy metal because of its relatively frequent occurence, mobility and toxicity.

Sources: Schimming in Blume ed. 1990; Blume in: Blume ed. 1990; Finck 1992; Tiller 1989

Some agricultural **chemicals** and **fertilisers** may contain heavy metals as incidential impurities derived from raw material. The highest concentrations usually occur in phosphate fertilisers, eg raw phosphate or treated phosphatic fertilisers which contain Cd in the range of 2 to 100 (156) mg/kg. Zinc salts, copper and lead arsenates and metallo-organic compounds are frequently used for pest control. Applications are common in horticulture soils (Finck 1992; Tiller 1989).

Soil weathering may be an important source of heavy metals in irrigated soils, because irrigation is usually carried out on fine-textured soils, which have potentially high contents in trace elements and it typically enhances physical and chemical weathering processes by providing additional water to the soil profile. Enrichments of heavy metals may occur in clay, humus and iron enriched layers. The type and intensity of transformation processes vary with climatic regimes (eg temperature, moisture), cultivation, water management practices, soil chemical properties (eg pH, sorption properties; synergistic influences), and soil parent material. Average contents of trace elements with potential toxicity are shown in Table 3-14 for typical locations in Germany. Such high concentrations are often caused by air pollution from industrial point sources (Table 3-15). They are are usually less important in most rural areas in developing countries.

Irrigation may have a distinct influence on reducing the concentration of heavy metals in the soil solution. Typically, under proper irrigation the soil is moist during most parts of the growing season, compared with dryland farming, and thus, due to dilution, the concentration of heavy metals is reduced.

Irrigation also influences the transportation of heavy metals within or below the root zone. Typically, irrigation enhances the translocation of trace elements by runoff and leaching. However, high concentration of metals in drainage effluents are rarely encountered in rural areas in industrialized countries (eg Germany. Schimming in: Blume ed. 1990). The use of polluted river water for irrigation may become an increasingly important factor in soil contamination in the future. The occurence of the Itai-Itai desease in Japan is a well documented example of the problem (Tiller 1989).

Only recently have large scale investigations on soils contaminated by heavy metals commenced in industrialized countries. Most studies have revealed that there may be a potential long-term effect. Current hazards appear minimal, although monitoring is recommended.

> Germany. An investigation on Cd-contamination on 12 M ha of cropland found that some 1% of agricultural soils have slightly increased Cd values, 0.6% have increased values (<3 mg Cd/kg soil) and 0.4% are contaminated (>3 mg Cd/kg soil). Generally, in Germany some 1% of agricultural soils are slightly to moderately contaminated with one or more heavy metals. Atmospheric, then geogenic, then anthropogenic factors (eg wastewater applications) are the most important means of contamination (Schimming in: Blume ed. 1990).

Data on soil contamination in developing countries are scarce and, therefore, all statements should be considered as **preliminary** only. Data analysis is hampered by the fact that trace element analyses are usually very costly, require sophisticated laboratory equipment and trained staff, and high sampling densities are needed for reliable evaluations. It may be concluded from general observations on present levels of air pollution and the limited use of waste slurries, sewage sludge and wastewaters for agricultural use that contamination of soils is generally less a hazard than in industrialized countries. Typically, contaminations in irrigated soils are often restricted to wastewater treatment areas, to horticultural areas with heavy chemical treatments or to locations close to industrial sites.

> *Case Study*
>
> Egypt, Irrigation is practiced in the Helwan district with polluted wasterwater and on soils prone to airborne pollution (dust). Wastewater originates from urban-industrial areas. Water supply is from main canals. Analysis were made of Fe, Mn, Zn, Cu, Ni, Cd, and Cr.
>
> Soil contents of Fe (35000 ppm), Mn (600 ppm), Zn (80 ppm), and Cu (40 ppm) were almost normal for alluvial soils in Egypt. Ni and Cr contents of some 40 ppm were well below critical limits (100 ppm). Cd was below 1 ppm. Pb in soils was significantly increased up to 20 ppm in the vicinity of the industrial sites up to some 6 km distance from the plants. Plant (corn) contents showed significantly increased levels of Fe, Mn, Zn and Cu which may be beneficial as they are micronutrients (see Sillanpää 1982) unless toxicity levels are reached. Actually, contents are about 2-10 times higher than normal. Increased Pb (5-20 ppm) and Cr (5 ppm) values in crops, however, may be potentially hazardous, though they are currently below critical levels (El-Falaky/Hussein in: ICID 1989).

The impact of heavy metals may be beneficial (growth stimulation) or detrimental (toxic) to certain plants, microorganism and soil fauna. Many metals (and other trace elements) are necessary for growth but at high concentrations they may be toxic (Table 3-16). Typical **contents** in soils, **transfer coefficients** between soil and plants and critical **limits** for plants and fodder are indicated in Table 3-17a. Average contents of heavy metals in various soils in Germany are shown in Table 3-17b.

Ecological consequences of heavy metal contamination are related to metal mobility and solubility. These chemical factors determine transmission through the soil to the water table, availability to microorganism, soil animals, agricultural crops and animals, and ultimately to humans.

- high heavy metal contents may inhibit microbial **enzyme activity** and reduce the diversity of microorganisms and soil fauna. Reductions in populations of soil animals are documented in orchard soils at very high concentrations. Contaminated soil animals may introduce heavy metals into the food chain of higher animals and thus humans. Soil biological processes considered especially sensitive to heavy metals are mineralisation of N and P, cellulose degradation, and possible nitrogen fixation. Although the potential of hazards is recognized, there is little evidence to date that soil biological processes are being affected significantly in most (mildly) contaminated soils (Tiller 1989).
- at moderate heavy metal concentrations (ie above the deficiency range), most soils act as a **sink** or repository without any obvious effects on soil biological behaviour.
- the extent of transfer from soil to plant depends on the kind of plants. The relative accumulation of heavy metals by several crops and vegetables is shown in Table 3-18. The actual uptake reflects the concentration in the soil solution. Here, additive, synergistic, or antagonistic effects may be important. It must also be observed that potentially dangerous levels may be reached in the plant food diet of animals or humans without any evidence of deleterious effects on plants because of different toxicity tolerances.

Further details on the behaviour of soils to heavy metals are given in section Part II 3.2.

Sources: Cheng in: Cheng ed. (SSSA) 1990; Himel/Loats/Bailey in: Cheng ed. (SSSA) 1990; Madhun/Free in: Cheng ed. (SSSA) 1990; Severn/Ballard in: Cheng ed. (SSSA) 1990; Blume in: Blume ed. 1990; Schimming in: Blume ed. 1990; Litz/Sattelmacher in: Blume ed. 1990; El-Falaky/Hussein in: ICID 1989; Tiller 1989; Edwards 1987

Further readings: Cheng ed. (SSSA) 1990; Blume ed. 1990; Tiller 1989; Sillanpää (FAO) 1982

## 3.6 Impacts from Wastewater and Application of Excreta

### 3.6.1 General

Contamination of soils can occur during the application of excreta and wastewater. In this context, wastewater refers to domestic sewage and municipal wastewaters that do not contain substantial industrial effluent. Excreta refers to 'nightsoil' and excreta-derived products such as sludge. Details and examples of human waste reuse are given in section 2.5; further details on impacts to human health are covered in section 8. The use of industrial wastewaters or sludges is not considered here, because it is not recommended for agricultural use under conditions in developing countries (Biswas/Arar ed. 1988).

Human wastes are regarded as a resource in many parts of the world, and they have been widely used since ancient times for various purposes in agriculture, aquaculture and water resources planning. In agriculture human wastes are regarded as:

- a **water resource** (under limited supply conditions)
- **soil fertilisers** (nightsoil, sludge, dissolved and solid constituents in wastewaters) to improve soil nutrient status and physical properties.

Fig. 3-18 a

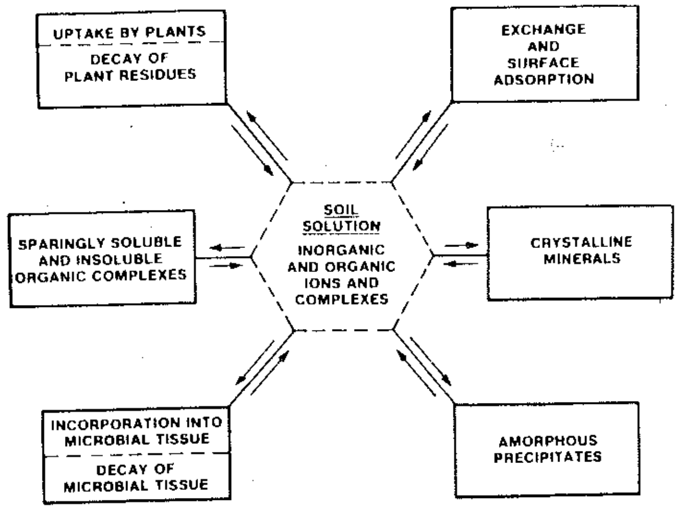



Fig. 3.21 Possible pathways of trace elements in soils (Page et al. 1981)

Source: Feigin et al. 1991

Fig. 3-18 b

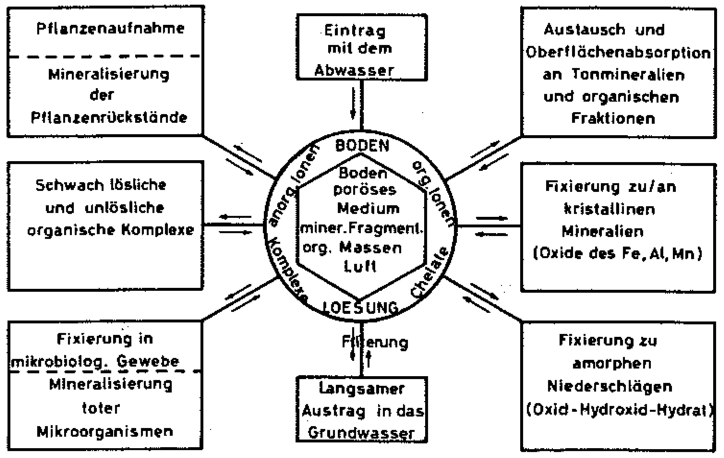



Abb. 2.5.4/1: Mögliche Reaktionswege der Stoffe im offenen, dynamischen System der Böden (aus ISKANDAR, 1981, erweitert.

Source: Blue et al. 1992





## 3.6.2 Wastewater and Irrigation

An indirect use of wastewaters is always practiced - in the form of water extraction from rivers or groundwater aquifers receiving upstream wastewater effluents. Salinity problems from saline waters are related to this indirect usage.

The type and magnitude of impacts on soils varies with sewage effluent and soil characteristics. Important reactions and transformations in the soil phase are shown in Figure 3-18a/b. Wastewater changes its constitution for example by filtration of solids, precipitation (eg phosphates, heavy metals), ion-exchange reactions, adsorption at colloidal surfaces, biological oxidation and reduction, and organic decomposition. Hence, as water quality changes (usually improves) in the soil-water phase during percolation, soil properties also change. Some changes are beneficial for agricultural soils and some are detrimental. The processes are complex and interrelated which makes impossible the practical use of any model for simple prediction of soil behaviour under wastewater applications.

Typical wastewaters are composed of 99.5 to 99.9% of water. The remaining percentage is composed of inorganic and organic solids, colloids, and dissolved solids. These contain major plant nutrients (N,P,K) and some trace elements (Table 3-19). Treated wastewater contains less N and P, depending on the processes used. Average annual applications may correspond to about 300 and 60 kg/ha of N and P respectively (Table 3-20a-b), although higher rates can be achieved especially for N:

| | | |
|---|---|---|
| assuming 800 mm/ha/a | $= 8\ 000\ m^3/ha/a$ | |
| N = 70 $\mu$g/l | $= 70\ g/m^3 * 8\ 000$ | = 560 kg N/ha/a |
| P = 6 $\mu$g/l | $= 6\ g/m^3 * 8\ 000$ | = 40 kg P/ha/a |

Supplementary fertiliser requirements can thus be reduced by wastewater applications.

Sources: Shuval et al. 1986; Biswas/Arar 1988; Blume et al. 1990

## 3.6.3 Impact of Wastewater on Soils

The maintenance of favourable physical soil properties can be promoted by organic manure applications or green manuring. Similar effects can be attributed to most wastewaters which contain suspended microorganisms (excluding pathogens) and to the use of sludge (solid waste). Aggregation can be enhanced and the formation of macropores improves rather infiltration and soil aeration (Burn/Rawitz 1981). The net results are site-specific and can be modified by crop- and water management practices. High concentrations or application rates as well as anaerobic processes (stagnant water, often associated with odour impacts) may result in surface pore clogging and surface crust formation and, hence, reduced intiltration which is beneficial in earth canals and paddy fields due to seepage losses. Surface clogging by accumulating sludge is also undesireable in rapid-infiltration installations, eg in ponding (land treatment) of wastewater for groundwater recharge.

Tillage and intermittent drying promote aerobic decomposition and, hence control unwanted clogging and odour impacts. Suspended solid particles may add appreciable amounts of fine material to soils which can be especially important with regard to improving fertility of sandy soils. Significant increases of silt and clay fractions have been observed (Noy/Feinmesser 1977).

Applications for over 100 years in Berlin/Germany with a mixture of treated domestic and industrial wastewater resulted in the following soil modifications (conditions: humid, cool climate; appliation rate 1 600 mm/a; applied on sandy soils and using basin irrigation).

i) slight <u>morphological changes</u>:

- increase in morphological evidence (Mn-concretions; mottling) of hydromorphic properties resulting from reduction processes (temporary waterlogging and anaerobic conditions)
- thin organic layers in the upper subsoil horizons (caused by filtration)
- increased mobilisation of clay minerals; evidence of illuvial layer-lattice clays in the subsoil, especially around subsurface drains
- lack of Ca-accumulations (mycelia) in the subsoil due to leaching

ii) moderate changes in <u>soil composition</u> and <u>chemical properties</u>:

- increased soil humus content
- nitrogen and phophorus status is higher than in traditionally fertilised soils
- soil reaction is less acid (pH 5-6) than under natural conditions (< 5); development of high $CO_2$, $HNO_3$, $H_2SO_4$ concentrations under temporarily anaerobic conditions hampered the development of strongly alkakine reactions (wastewater: 8 - 8.5 pH)
- strong accumulation of Na, Zn, Pb, Cu, Cd, and Cr within the rootzone
- no accumulation of Fe and Mn despite high inputs from wastewaters

iii) <u>growth conditions</u> changed and hence altered the composition of grasses:

- improved nutritional and soil-moisture status
- high application rates (200-400 mm) produced temporary poor aeration
- plant societies (eg grasses) adapted to temporary poor aeration in the main root zone and tolerant to high N-status become predominant, however there is no significant loss of species (Sukopp et al. 1980)
- anaerobic soil microorganisms prevail over aerobic ones (with high water applications (ie in wastewater systems meant primarily for safe disposal of excessive water)
- ammonium-fixing bacteria increased and nitrification intensified
- bulk of soil fauna is concentrated in the continuously wet topsoil; worm activitiy increases with smaller applications
- buffer capacity decreases at time, eg as a result of temporarily low redox potential which increases mobility of heavy metals, eg Fe, Mn
- $NH_4$ ions compete with remove K, Mg and Ca on the exchange complex
- Na, $NO_3$, Fe, Mn, Cl are present in soil solution

iv) <u>microbiological activity</u> increases due to ample supply of material for decomposition and favourable moisture conditions:

- formation of various highly mobile organic complexes with possible positive symbiotic side-effects in the rhizosphere of crops
- enzymatic activities are considerably increased
- formation of $CO_2$ during decomposition of organic constituents may enhance photosysnthesis,
- the mineralisation of organic compounds continuously delivers nutrients
- negative impacts are associated only with long-lasting anaerobic conditions (reduction phase) and the possibility of formation of sulfidic complexes
- soil fauna may change considerably due to changed conditions as described above. There is no significant change in the number of individuals but there is a change in species. New species are characterised by higher tolerances to higher salinity, hydromorphic and decaying conditions.

Source: Blume/Horn 1982; Aurand 1981; Kretzschmar in: Blume et al. 1990

Fig. 3-19

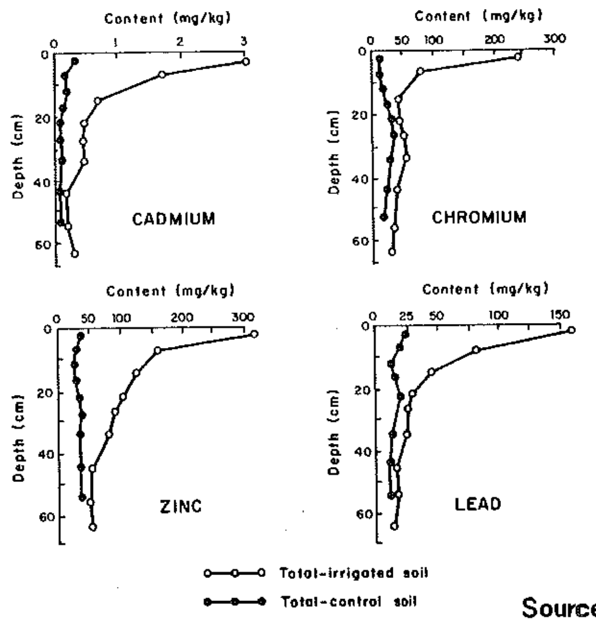
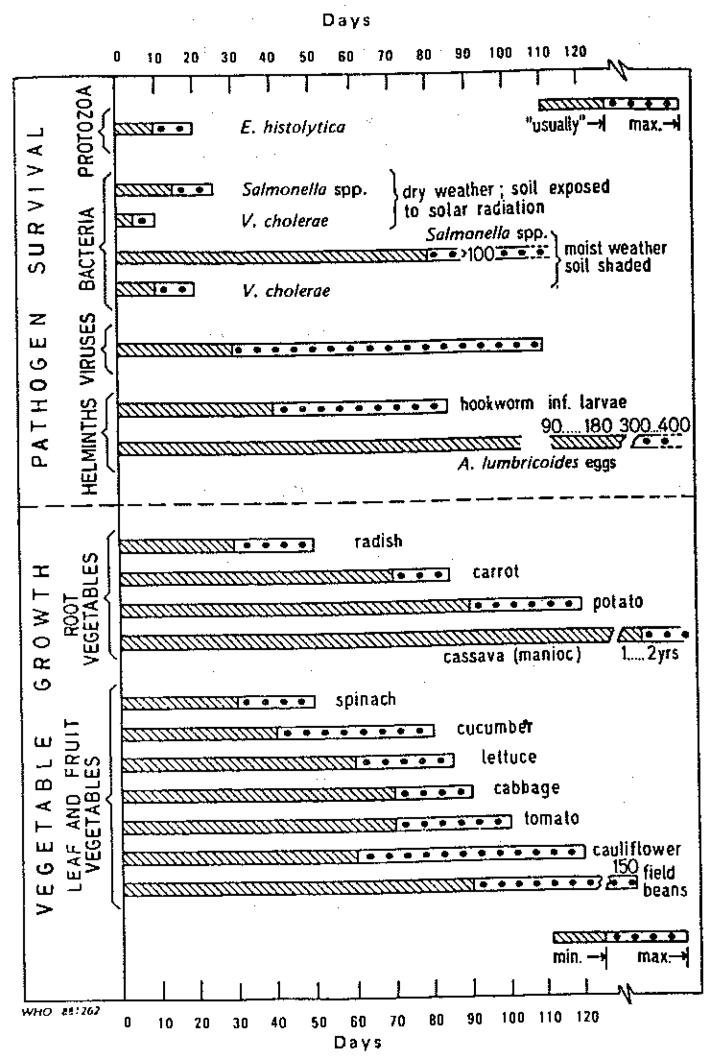



Fig. 23

Heavy metal content of the soil profile after 80 years of irrigation with wastewater
(Evans, Mitchell and Salau 1979)

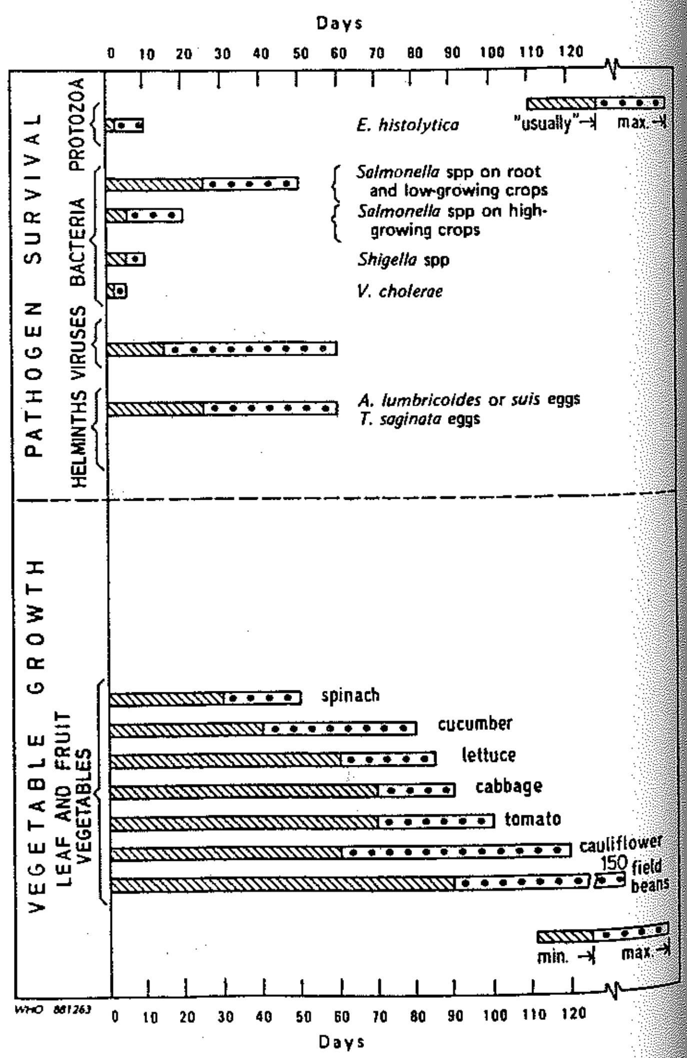
Source: Ayers/Westcot (FAO) 1985

Fig. 3-20
(Figure 4.2) Pathogen survival in soil compared with vegetable growth periods in warm climates




Reproduced by permission from Strauss (1985).

Fig. 3-21
(Figure 4.3) Pathogen survival on crops compared with vegetable growth periods in warm climates




Reproduced by permission from Strauss (1985).

Source: Mara/Cairngross (WHO) 1989





Soil fertility related problems may occur if secondary treatment of sewage occurs (eg chlorination), or if water has been previously treated chemically to lower the hardness of Ca and Mg-rich waters for domestic purposes. The addition of amendments or ion exchange processes usually replaces calcium with sodium ions. Such water may require additional treatment giving exactly the reverse effect to be suitable for alkaline soils or to reduce the sodicity risk in soils (see section 3.2).

In addition to beneficial nutrients wastewaters also may contain

- **toxins**, ie trace heavy metals which include Ag, Al, As, Ba, Cd, Cr, Cu, Co, Fe, Fl, Hg, Li, Mn, Mo, Ni, Se, Pb, and Zn,
- **contaminants**, ie disease causing organisms (pathogenic microorganisms): viruses, bacteria, protozoa and helminths,
- high contents of soluble **salts**, excessive concentrations of nutrients; unfavourable ionic composition,
- persistent organic synthetic **organic compounds**.

High concentrations of heavy metals are ususually not present in treated domestic wastewaters (they precipitate as hydroxides or oxides during treatment) but may be present in untreated wastewaters, excreta and especially in industrial wastewaters (Tables 3-21a and b). Under average conditions in developing countries, such chemicals are not present at dangerous concentrations (Shuval et al. 1986, Biswas/Arar 1988). However, precise data and systematic surveys in developing countries are rare.

Trace metals sources can pose significant health hazards, especially Cd, Co, Mo, Ni,, Zn, and Se. They tend to accumulate in soils and plants and in animals consuming the contaminated plants (Fig. 3-19). Immediate phytotoxicity is relatively rare because of low concentrations in wastewaters, except for boron which may be present in concentrations well above 1 ppm. Provided that the quality of the wastewater conforms to that recommended by FAO (Ayers/Westcot 1984) or others (see Part II section 2.1), it may be used safely in agriculture.

For a qualified risk assessment of wastewater uses the typical uptake rates or transfer coefficients between plant and soil water should be known and subsequently, the actual wastewater quality can be evaluated for its agricultural use. Tables 3-22a and b may be used, although they have been developed for hunid European conditions.

Enteric pathogens are of special interest because they are always present in wastewater sewage effluents and they can survive in soils at considerable concentrations for some time, and some, especially bacteria, may multiply in suitable environments. Furthermore, they can be mobile in soil-water solutions (Tables 3-23 and 3-24). Migration of bacteria, ova of intestinal worms or protozoa cysts occurs as transport through soils and depends on straining, sedimentation and adsorption rates. The mobility of viruses depends onthe degree of adsorption to soil components. Generally, low flow rates in soils (ie most medium to fine textured, unstructured soils) favour retention and most faecal organism (>90%) are usually concentrated in the surface layers (Pescod/Arar 1988).

Mobility and persistence of pathogens at ambient temperatures in various environments and factors affecting survival time are shown in Tables 3-25 to 3-28 and Figs. 3-20 and 3-21. In hot and arid climates survival of pathogens is limited to 2-3 months at most, whereas in cool and moist soils and those rich in organic matter survival is longer (Table 3-29). Adsorption onto solids can protect viruses from envrionmental factors and thus extend average survival also in warm climates up to 3 months.

Heat, sunshine (UV-radiation) and low humidity promote pathogen death. Average survival times are significantly shorter than in water or soils (Tables 3-25 and 3-26). Whereas bacteria and viruses cannot penetrate undamaged vegetable skins they may survive on crop surfaces that have been irrigated (mainly relevant to sprinkler irrigation). Pathogens may survive harvesting and marketing and eventually they may reach the consumer. Pathogen removal by wastewater treatment is covered in Part II sections 2.5 and 4.

Soluble salts concentrations are always higher in wastewaters compared with original water quality. Therefore, all criteria for the use of saline waters and the control of soil salinity are applicable to wastewaters, too. This applies also for wastewater with an unbalanced ionic composition which have potential detrimental effects on soil fertility status and physical conditions (section 3.1).

Complex synthetic organic compounds are not common in domestic wastewaters produced in developing countries. Some of them are highly toxic and are discussed in section 2.7 as they are commonly derived from pesticides.

Organic compounds (colloids) in wastewaters are usually not harmful to crop production, since there is only insignificant - if any - direct uptake from the soil. Most organic compounds contribute to improvement soil physical conditions.

In arid climates there may exist a potential danger of over-fertilisation and/or imbalanced supply of nutrients if all water requirements are met by wastewater over long periods. An application of 800 mm wastewater would result in 640 kg N/ha/season if the wastewater contained 80 g $N/m^3$. It should be realized, however, that nutrient concentrations of wastewaters are usually lower in developing countries than in industrialized countries, eg in India the average N-concentration is in the range of 30 to 60 mg/l.

Summarising, wastewater and excreta reuse may have beneficial or detrimental impacts on soils, depending on the quality and quantity of effluents, use of remedial measures to optimise beneficial and minimise detrimental effects and adequate soil and water management practices (see Part II sections 2.5 and 4).

Wastewater and excreta use schemes can have several direct or indirect positive environmental impacts:

- using effluents to substitute for other fertiliser sources
- use of wastewater in areas with limited water resources
- avoidance of groundwater pollution which would occur if wastewater drained untreated into rivers or lakes. Major problems associated with surface water pollution can be minimised: eutrophication, depletion of dissolved oxygen, foaming
- contribution to soil conservation through the enhancement of soil aggregation to prevent soil erosion and the additional supply of water for shelterbelts/ windbreaks in arid regions
- enhancement of biological diversity (species, number of individuals) especially in arid areas by the supply of water, nutrients and microorganisms.

Potential hazards - except health-related hazards (see section 8) - are associated with:

- increased salinity from saline effluents
- effluents with high ESP-values with associated damage to soil structure
- over-irrigation causing waterlogging and prolonged anaerobic conditions
- overloading with nutrients and microorganisms beyond the capacity of the soil as filter, adsorbant and transformer, thus, contaminating the soil which serves as a natural filter to prevent groundwater pollution.

In practice, however, contamination of soils by wastewater reuse under irrigation not widespread and in most cases soil fertility is maintained or improved over decades of irrigation (eg Mexico City). Most treated wastewaters usually have low concentrations of industrial or other chemicals (toxants, organic compounds, heavy metals). Nevertheless, careful control is required during project planning and operation. Safety standards can on-

Fig. 3-22

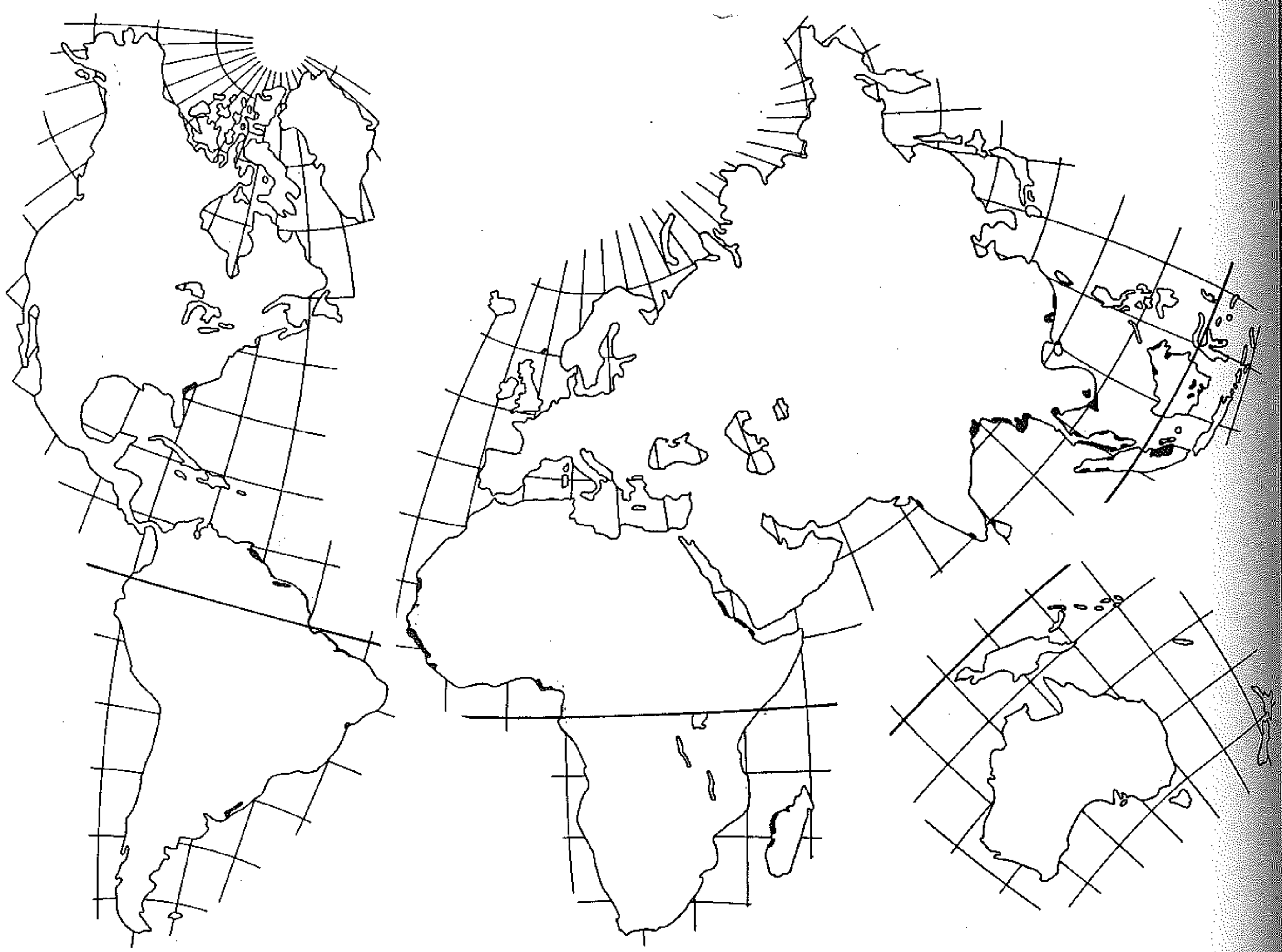


Table 3.
Regional distribution of acid sulphate soils (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome).

| Region | Area($10^6$ ha) | Area (million ha) per length of growing period | | | |
|---|---|---|---|---|---|
| | | <90 days | 90–180 days | 180–300 days | > 300 days |
| Africa | 3.7 | 0.4 | 0.7 | 1.5 | 1.1 |
| Near and Middle East | – | – | – | – | – |
| Asia and Far East | 6.7 | – | 0.2 | 5.1 | 1.4 |
| Latin America | 2.1 | – | 0.1 | 0.8 | 1.2 |
| Australia | – | – | – | – | – |
| N. America | 0.1 | – | – | – | – |
| Europe | – | – | – | – | – |
| World total | 12.6 | | | | |

Source: ILRI 1980





ly be met with continuous monitoring of effluents and soils by qualified personnel (see Part II sections 2.5 and 4).

Souces: Feigin et al. 1990; Biswas/Arar ed. 1988; Cairncross/Mara 1988; Shuval et al.1986; Pescod/Arar ed. 1988

## 3.7 Other Chemical Soil Degradation Processes

### 3.7.1 Acid Sulphate Soils

Acid sulphate soils are formed from both river and estuarine alluvial soils that become exceptionally acid on drainage and oxidation, either as a result of natural processes (land upheaval, regression of the sea) or of human-made drainage or empoldering. They develop from sulfidic materials (>0.75% S), are waterlogged (gleyic) and rich in organic matter (>1%). They are found in brackish coastal environments, usually formerly under mangrove. The total area of actual and potential acid sulphate soils (Thionic Fluvisols) comprises some 10 M ha in the tropics (Fig. 3-22) and another 20 M ha of coastal peat are underlain by potential acid sulphatic soils (Histosols, mainly in Indonesia and Thailand).

The use of acid sulphate soils for irrigation has a long tradition in some Asian regions. Acid sulphate soils developed where apparently promising coastal plains were reclaimed for rice cultivation. However, the rapid expansion during the last century occured on areas, unsuitable for permanent use with traditional methods. Meanwhile, thousands of hectares of injudiciously reclamed land in coastal swamps have been degradated or abandoned and mangrove areas destroyed. Time consuming and costly technical solutions for large scale reclamations exist but their economic feasibility is questionable and the destruction of mangrove areas may be hardly justifiable. Costly engineering works such as dikes and weirs/sluices, designed for preventing salt water intrusion, have been abandoned.

*Background Information:*

The most important properties of acid sulphate soils are pH-values of below 3.5, frequently in the range of 2 to 3, associated with Al- and Fe(III)-, Mn(II)-toxicity and limited nutrient availability, eg P. On submerged soils with pH 6 to 8 in the topsoil Fe(II)-toxicity may occur. The profile is usually a clay (cat-clays), but sandy loamy soils may also become acid sulphatic. When submerged, colours are grey to blueish black with pH values of above 5 and a smell of hydrogen sulphide. If such soils are reclaimed by drainage, yellow jarosite mottles develop and the pH decreases within 1.25 m from the surface. Vertical cracking results in coarse prismatic structures to the mottled horizons, whilst the subsoil remains structureless and relatively impermeable. Apart from actual or potential acidity most soils are also affected by salinity because they are located in active tidal areas.

The cause of acidification is the oxidation of pyrites, FeS2, with the formation of sulphuric acid. Sulphates from the seawater are deposited during mud sedimentation and later reduced by bacteria under anaerobic conditions to form hydrogen sulphide (H2S). The presence of organic matter is required for bacterial growth. H2S reacts with iron compounds in the soil to form ferrous iron sulphide (FeS2). Oxidation on contact with air causes the formation of ferric sulphate, which produces the mottles and staining, and sulphuric acid. Further reaction with clay minerals forms aluminium sulphate at toxic concentrations (further details in Mohr et al. 1972).

Most potential acid sulphate soils are under natural vegetation, while some are used for fishponds or salt extraction. Extensive delta areas, for example the Bangkok plain, Mekong delta, Ganges delta and estuaries in West Africa (Sierra Leone, Gambia), are under irrigation with paddy rice, sometimes with vegetables, fruit trees or oil palms. Preference is given to areas with low tidal movements, passive sectors of old channels, or deltas where saline intrusions are blocked off by flood embankments, port schemes or estuary barrages.

Best possibilities for sustainable cultivation exist on older and deeply developed Thionic Fluvisols with low pyrite contents in the topsoil. They may be traditionally used under rice cultivation. Yields are generally low to moderate which can be attributed to a relatively low fertility, to deficiency levels of micronutrients (Zn, Cu, Mn, Mb) or to toxic concentrations of B, Mn, Al and Fe (Pagel 1974), and reduced activity of microorganisms responsible for decomposition.

There are several approaches for sustainable use of acid-sulphate soils under cultivation; the key lies in controlling acidity.

- Keeping soil subsurface horizons saturated to prevent oxidation of pyrites. This condition is often met in some plains where deep water rice is grown on older, well developed Thionic Fluvisols (in Thailand) which are subject to seasonal flooding; in Malaysia oil palms are grown with carefully maintained groundwaters at shallow depths (60 to 90 cm); the crucial factor with this method is the availability of freshwater (rain or irrigation) for seasonal leaching.
- Submerging with freshwater when under paddy cultivation and seawater during the dry season. Acidity during the growing season will be reduced and pH-values will increase in the topsoil layers; soils are almost permanently submerged (Sierra Leone Research Station).
- Neutralise the soil with lime. Theoretically, large quantities of lime in the range of 30 to 300 (average 100) t/ha or more are usually required for 1 to 5% of pyrite, which usually make reclamation uneconomic. Recent research, however, has indicated that beneficial effects may be achieved by smaller applications (3 to 6 t/ha) applied over a period of some years.
- Drain, aerate and leach the soil with freshwater. This approach is applicable only if the pyritic substratum occurs at greater depths. Leaching efficiency in Thionic Fluvisols is usually limited due to the relative immobility of sulfidic material and low permeability. A special method has been successfully used in Vietnam where deep ditches are excavated to make 3 to 5m wide ridges; after some years of pyrite oxidation and leaching the soils are suitable for crops, eg pineapple; negative impacts are associated with strong drainage water acidity (pH 2 to 3).
- Leaching may be sucessful if carried out with saline seawater which provides bases to substitute the exchange acidity; subsequently fresh water is needed for desalinisation; this method requires permeable soils.

The leaching method may have detrimental impacts at other places receiving the leachate which may contain toxic concentrations of Al (eg reports from Kalimantan, Vietnam).

Large engineering schemes for the reclamation of potentially acid sulphate soils are rarely economically feasible, and in most cases young, strongly acid sulphate soils should not be reclaimed for irrigation. Possibilities for reclamation and sustainable crop production exist on older, deeper developed acid sulphate soils and sucessful development is usually attributed to the availability of sufficient fresh water, a combination of fertilization and liming, good water management, and skilled farmers (eg Muda project, Malaysia). Hydrological research and numerical modelling for large river regulation schemes which aim to control seasonal saline intrusions in deltas in order to permit irrigation, have been conducted by Hydraulic Research (Overseas Development Unit) on the Gambia estuary, Guayas estuary (Ecuador), Abary river (Guayana) and the Irrawaddy delta (Burma). (Overview in ODA Bulletin 1987).

Preconditions for future development activities should be: adequate soil surveys with selection of suitable sites; detailed hydrological surveys including models for long-term prediction of saline intrusion; seasonal availability of sufficient freshwater (rain or irrigation);

adequately trained farmers who will use good soil and water management practices; establishment of research trials and trained extension service; adequate supply of and access to lime amendments and fertilisers (especially phosphorus).

Sources: Seiler 1989; Beek et al. in ILRI 1980; Spaargaren et al. (ISM) 1981; Mohr et al. 1972

Further readings: Dost ed. (ILRI) 1986; Dent 1986. Dost/van Breemen ed. (ILRI) 1973; Bloomfield/Coulter 1973; van Beers (ILRI) 1962

### 3.7.2 Others

Occasionally, high concentrations of trace elements and metals are found in irrigation waters which may lead to unfavourable enrichment in soils (or plants) or to subsequent groundwater contamination. Groundwaters may contain high concentrations of boron and iron.

High **boron** concentration are found in some Southern Libyan groundwaters which restrict the continuous use for irrigation (see water quality Part II section 2.1).

High **iron** concentrations occur in groundwater of some districts in Bangladesh (Khan 1988). The precipitation of iron in the subsoils resulted in the formation of hardpans which are relatively impermeable and restrict root penetration. Growth is restricted due to waterlogging and poor soil aeration.

## 3.8 Physical Changes in Soils under Irrigation

Changes in soil physical properties induced by irrigation and drainage are manifold and many of them already have been treated in separate sections dealing with salinity, erosion and sodicity. Soil compaction which is mainly caused by tillage practices under prevailing conditions in developing countries is treated in section 9.

Irrigation and subsequent drainage modify the natural soil-moisture regime in qualitative and quantitative terms. These changes may be either temporary or permanent and most impacts are due to changes induced by soil tillage practices and cropping pattern. The most important irrigation-induced changes are modifications of the soil-air-water system with subsequent impacts on soil structure, soil temperature and biotic activities. The response of soils influenced by continuous and intensive farming, however, may vary with the soil type including their biotic activities, and generalisations from isolated observations should be carefully examined.

For sustainable irrigated farming, the most important factors are the **creation or maintenance** of favourable soil structure and aeration status for the specific crops to be grown. These conditions may vary with type of crops and cropping pattern, but also with types of irrigation (see Part II sections 2.3 and 3.2).

The prominent changes and features of irrigated soils are

i) in arid and semi-arid regions the introduction and intensification of wetting-drying cycles respectively
ii) in semiarid or subhumid regions the extension of wet cycles by water applications in addition to the natural humid phases of the rainy season.

Hence, soil structure forming processes can be either intensified or a loss of favourable structure can occur under situations of prolonged wetting. Indirect effects of irrigation on soil structure occur with modifications of soil temperature and enhancement of microbiological life, especially in arid and semiarid areas. This, in combination with wetting-drying cycles, typically improves the formations of micro-aggregation and macropores which provides favourable conditions for crop growth. Extreme drying (a typical feature of arid and semiarid regions under natural moisture conditions) is usually avoided under irrigation and favourable conditions for microorganism and soil fauna is provided throughout most parts of the year.

Indicators of physical soil conditions and typical influences of agricultural and irrigation practices are briefly summarised below.

- **bulk density** and total porosity: there is a tendency for both to increase under cultivation but tillage practices may exert a large influence; observed changes range from large decreases to moderate increases; irrigation typically enhances intensification of cultivation and mechanisation and may result in increased negative impacts (see also section 9 under soil compaction)
- **hydraulic conductivity** and infiltration rate: there is a tendency for these to decrease under cultivation, but tillage practices, reclamation measures and drainage may exert large effects; observed changes range from decreases to increases; irrigation with non-sodic water may be neutral or a positive modifier,
- **pore size distribution** and moisture retention characteristics: there is a tendency to decrease available water holding capacity under cultivation but tillage and drainage practices may exert a moderately large influence; observed changes range from moderate increases to large decreases; irrigation and drainage may be positive modifiers or neutral,
- **aggregate stability** and water stable aggregates: there is a tendency for these to decrease under cultivation, but tillage practices, agronomic measures and cropping pattern exert large influences: observed changes range from large decreases to moderate increases; irrigation with sodic water may enhance deterioration; irrigation with non-sodic water may be a positive modifier,
- **organic matter content** and organic matter composition: there is a tendency for these to decrease under cultivation (except in arid regions) but tillage practices and agronomic measures exert a large influence; observed changes range from large decreases to large increases. Irrigation may contribute to increased crop growth and, hence, increases in organic matter; on the other hand, additional soil moisture and lower temperatures in arid areas may enhance decomposition,
- **soil texture**: there is a tendency for fine particles and organic matter to be lost from topsoils due to accelerated soil erosion under cultivation; tillage practices and other agronomic measures exert a large influence; observed changes range from slight to heavy losses of fine particle. Irrigation may be a neutral, a positive or a negative modifier. For example, irrigation in arid and semiarid regions may enhance soil weathering and the formation of fine clay and silt particle sizes. Irrigation can reduce both wind erosion losses and - under good management - water erosion losses from irrigated lands compared with non-irrigated croplands; however, poor water management can increase runoff and enhance fine partile losses in topsoils,
- **shrinking-swelling processes** can be intensified under intermittent irrigation practices; this may result in heavy textured soils in the development of unfavourable macro-aggregation.

Sources: Lal 1987; Sanchez 1976

Further readings: Lal/Greenland ed. 1979; Hillel ed. 1972; Taylor/Ashcroft 1972

## 3.9 Special Problems in Rice Soils

Rice (paddy) soils are continuously or intermittently flooded. This flooding sets a series of physical, chemical and microbiological processes in operation. These include retardation of gaseous exchange between soil and air, anaerobic soil conditions, and the chemical and electrochemical processes accompanied with reduction. There is a decrease in redox potential, increase in pH under acid conditions, and decrease under alkaline conditions, and an increase of conductivity. Flooding causes denitrification, accumulation of ammonia, release of methane, reduction of magnesia, iron (ferric iron), and sulphates, accumulation of the products of anaerobic organisms and other secondary effects of reduction. Aluminium hydroxides are precipitated and ferrous iron is absorbed by clay minerals.

Impacts of paddy cultivation

Paddy soils undergo chemical and physical changes that differ from other irrigated soils and are caused by permanent or intermittent submergence. The flooded soil-rice ecosystem consists of five major subsystems: floodwater, surface oxidised layer, reduced puddled layer, subsoil alternatively oxidised and reduced, and the rice plant, its phyllosphere and rhizosphere. Most important for soil processes are sequential changes of several soil redox systems.

Common problems in paddy soils are related to iron toxicity in acid and extremely alkaline soils, phosphorus deficiencies in ultisols, oxisols, vertisols and andepts, zinc deficiencies in sodic, calcareous, and peat soils (see also acid sulphate soils).

Important chemical changes that have implications for soil degradation, agricultural productivity and soil fauna are:

- Change in **pH**: a few weeks' submergence causes the pH of acid and alkaline soils to converge between 6 and 7. The rate and degree of changes depends on soil properties (eg organic matter, active iron) and temperature. The effect may be positive by eliminating extreme pH-values.
- Changes in **salinity**: EC of the soil solution increases with time after submergence, reaches a peak and eventually decreases. Most submerged soils, regardless of their initial salinity level, have values of EC > 2dS/m during most of the growing season. Changes are correlated with iron and manganese concentrations in acid soils and with calcium and magnesium bicarbonate in alkaline soils.
- **Reduction** of Fe(III) to Fe(II): Fe(III)-oxide hydrates are reduced to Fe(II) -compounds and Fe-concentration in the soil solution may increase to toxic levels; manganese and aluminium toxicity may subsequently occur for dryland crops. These resultin negative effects on crop production and soil fauna.
- Increase in supply and availability of **nitrogen**; the turnover of available N is faster in tropical paddy soils than in temperate zones. The effect is positive.
- Increase in availability of **phosphorus, silicon, molybdenum**. This may benefit nitrogen-fixing algae at the surface, anaerobic bacteria in reduced soils, and aerobic bacteria on the roots.
- Decrease in concentrations of water-soluble **zinc** and copper, especially on continuously wet and peat soils. Deficiencies are not acute for subsequent dryland crops. The effect is negative for rice production, but almost neutral to soil fauna and dryland crops.
- Production of **toxins**, organic acids, ethylene and hydrogen sulphide by reduction and anaerobic decomposition. These hamper productivity in sulphate soils and soils with high organic matter. The effect on crop productivity and soil fauna is negative.
- Total **algae biomass** production increases sharply during the crop cycle.

In addition, rice soils are exposed to changes in physical properties through **puddling**. This is the process of breaking down soil aggregates into a uniform mud, accomplished by applying mechanical force to the saturated soil. Whereas puddling in other cropping systems is the unintentional outcome of tilling at too high moisture contents, it is an important practice in lowland rice cultivation aimed at minimising the percolation of water.

Puddling decreases pore volume, increases bulk density, eliminates aggregates and macropores, reduces hydraulic conductivity and infiltration, creates anaerobic conditions, and effects pH and Eh (redox potential). Rice shoot and root growth, nutrient uptake and water use are typically favourably affected by moderate compaction unless soil strength remains low. The effects of traditional puddling on medium textured soils are often less significant for increasing rice yields and water use efficiency but require more energy and time (Ghildyal in: IRRI 1978).

The anaerobic conditions typically hasten the anaerobic microbial degradation and detoxication of most pesticides in paddy soils. This is in contrast to the increase in stability of natural organic compounds, but chemical compounds with reductive and hydrolytic pathways seem to undergo rapid decomposition:

> Important pesticide transformations stimulated by flooding are reductive dechlorination (PCP, DDT), dehydrochlorination (HC), hydrolysis (organophosphates), and reduction (fensulfothion, parathion). Epodixation (aldrin, heptachlor) and ring cleavage are inhibited. Anaerobic microorganism are particular implicated in these transformations, but chemical degradation catalysed by redox reactions such as the iron redox system may also be common.
>
> Anaerobic metabolism of pesticides leads to the formation of easily soil-bound residues. The alternate oxidation and reduction processes may assist in more extensive degradation of pesticides than will either system alone.
>
> The persistence of insecticides in non-flooded soils usually follow the order chlorinated HC > organophosphates = carbamates. In flooded soils, certain chlorinated HC (DDT, BHC, endrin, heptachlor) are readily destroyed; in contrast, cyclodienes (aldrin, dieldrin) persist in both flooded and non-flooded fields (see Table 3-30)
>
> Source: Sethunathan/Siddaramappa in: IRRI 1978

Sources: Watanabe/Roger in: IRRI 1985; Mohrmann/van Breemen (IRRI) 1978; Ghildyal in: IRRI 1978; Patrick/Reddy in: IRRI 1978; Yoschida in: IRRI 1978; Sanchez 1976; Russel 1973

Further reading: IRRI 1978

# 4 Impacts on Land Use and Biological Resources

## 4.1 Introduction

Biological resources include ecosystems and their biotic components fauna and flora. The term resources implies their value for human use and their contribution to ecosystem functioning and utilisation values but also non-tangible values such as aethetic, leisure and scientific value.

Human impacts on land use and biological resources derived from irrigation are manifold:

- **utilising land** for irrigation, thus destroying habitats of current natural fauna and flora and genetic resources in these ecosystems which are often precious wetland ecotones (ie transitional ecosystems at the boundary of aquatic-terrestrial habitats). New habitats for terrestrial species, adapted to cropland ecosystems, are developed. Irrigation in arid areas may lead to the creation of new ecosystems along drainage canals and evaporation lakes, thus contributing to an increase in the diversity and population of soil microfauna,

- abstraction of **water** from rivers, lakes or groundwater aquifers modifies, and sometimes degrades (but seldom destroys unless total abstraction takes place) the habitat of aquatic and terrestrial ecosystems and species in downstream river sections or in adjacent areas with a groundwater drawdown,

- chemical **residues** from intensified agricultural production accumulate in soils and groundwater, eventually polluting downstream river sections and aquifers at a further distance, thus, modifying or degrading terrestrial and aquatic species along downstream river sections,

- **erosion** may occur, which affects river water quality (turbidity), thus modifying and degrading auatic habitat in downstream sections

- **reservoirs** have manifold impacts on land occupancy and the hydrological regime of rivers with potential impacts on marine (deltaic) ecosystems. Habitats in the reservoir zone are destroyed while habitats of aquatic and terrestrial species along downstream sections are modified, degraded or destroyed, depending on reservoir size and operation.

When land is developed for agricultural use, almost all types of natural flora and wildlife resources are changed. Often a degradation of aquatic and terrestrial ecosystems results from these changes, affecting breeding and migration, but also basic habitat functions such as shelter and food supply. Impacts related to land occupancy result from all agricultural systems and they cannot be attributed to irrigation alone unless development takes place in environments which are otherwise not suitable for arable farming. Such areas which are especially affected by irrigated agriculture are wetlands. In other areas, only impacts related to the abstraction or storage of water can be attributed to irrigation, whereas other impacts, related to soil and water resources degradation and pollution may occur under other agricultural uses, too.

Note: The boundaries of an ecosystem can be identified by changes in vegetation, soils , topography, water status, and animal habitat. The scale of an ecosystem depends on the purpose of the analysis: an irrigation canal with its adjacent impoundments may constitute a small ecosystem, whereas the entire irrigation scheme is a medium scale ecosystem with its distinct functions and structures, while a lower watershed of a large river system may constitute a third scale of ecosystem. All ecosystems are connected with others of various scales through exchanges of energy and biotic or abiotic material.

## 4.2 Human Impact on Ecosystems

The continuing progress of evolutionary change and adaption have led to the development of the enormously diverse community of aquatic and terrestrial organisms on earth. The collective impact of humans on this process was on a global scale for long time hardly perceptible. But as humans increased in number and particularly after the development of urbanisation, industrialisation, and intensive agriculture and forestry, the impacts on selection and evolution have became progressively more important. Over the last century, increasing pressure has been put on the natural ecosystems which are used as a resource for human goods and services (see section 3.1). This pressure has resulted in widespread changes or destruction of habitat for many species and biotic communities. Such changes result from various classes of stress factors that affect the health, productivity, species composition, genetic diversity, geographic distribution, and survival of ecosystems and their components. Natural stresses or growth limitations include competition, climatic, biological and chemical classes. Agriculture and irrigation may exert the following stresses on ecosystems and organisms (taxa) living in them:

- **human competitional stresses** occur when humans compete with other sepcies in the same ecological niche for a limited supply of growing space, food, solar radiation, water, and essential nutrients. These also include interactions among organisms which result from injurious chemicals produced by man which adversely affect the survival and development of fauna and flora in the same environment,

- **human disturbances stresses**: these are imposed by various deliberate or inadvertent human activities including waterlogging, drainage, burning, physical disturbance of soils, erosion, leaching of nutrients, accumulation of toxic substance; eg the disturbance of mosquito breeding sites is a human stress factor on disease vectors as is the drainage of wetlands which may be used by wildlife or plant communities,

- **air pollution stresses** may occur whenever ecosystems are exposed to injurious concentratons of toxic gases, toxic aerosol particles or coarse particles in air or precipitation, eg from erosion, sprinkler application of toxins, fertilisers, etc.,

- **water pollution stresses** may occur whenever aquatic communities are exposed to injurous concentrations of toxic chemicals, temperature changes or turbidity changes which affect the thermal stratification and light penetration of aquatic systems,

- **global climate stresses** may occur as a result of increased accumulation of radiatively active gases (greenhouse gases) in the atmosphere, such as methane from rice fields.

Sources: Cowling in: Mathy ed. (CEC) 1986; see also: Freedman 1989; Westman 1984

As a result of stress, the following consequences, apart from sheer physical destruction, may occur to ecosystems and their fauna and flora when they are transformed from natural ecosystems or rainfed croplands to irrigated lands.

- **energetics**: for example, primary production increases under irrigation (compared with rainfed); respiration increases (eg from increased water supply under irrigation); the ratio between production-respiration (P/R) becomes unbalanced.

- **nutrient cycling**: nutrient turnover increases under irrigation; horizontal-vertical transport ratio changes under irrigation to any direction, depending on water management; nutrient input increases with fertilisation; nutrient export increases without fertilisation and green manuring

- **community structure**: proportion of "R-Strategists" may increase (in non-equilibrium, early successional habitats, species with short generation times and large reproductive efforts are selected); size of organisms may increase or decrease under irrigation; life spans of organisms may decrease; food chains may be shorter because of reduced energy flow at higher trophic levels and greater sensitivity of predators to stress; species diversity decreases and dominance increases; if original diversity is low (eg in most arid soil habitats) the reverse may occur; redundancy of parallel processes declines

- general **system-level trends**: system becomes more open, ie inputs and outputs become more important as internal cycling is reduced; efficiency of resource use may decrease; parasitism and other negative interactions increase, and mutualism and other positive interactions decrease; functional properties (community metabolism) may be more robust than are species composition and other structural properties.

Source: Freedman 1989, modified from Odum

The intensity of human stress varies in time and space. After some time, the affected ecosystems and its taxa will either recover after **alleviation** of the stress (eg reduced pollution in affected downstream river sections) or, more likely under irrigation, **succession** occurs associated with changes in ecosystems structure and function. This is with changed composition of the biota and the predominance of particular taxa which are better adapted to the emerging irrigated field habitats. This may ultimately lead to an increase in biodiversity and species number in arid and in semiarid regions due to higher moisture levels in irrigated soils and increased nutrient supply, since water usually provides a medium of transfer and storage of energy and materials used by living organisms within the ecosystem.

Essentially, there are two issues which are to be addressed: (i) identification of current predominant species and ecosystems which are to be preserved or protected, and (ii) definition of the maximum allowable stress (directly or indirectly induced by human activities) for such species, taxa or ecosystems without affecting the integrity of the biotic communities. Such aspects are treated in Part II section 1 where environmental performance standards are defined. In the following sections stresses induced by land occupancy, ie the direct competition for space are treated. Further aspects of disturbances (air, soil and water pollution) are treated under separate sections, eg 2, 4 and 5.

## 4.3 Structured Evaluation for Ecosystem Impact Analysis

Ecosystems are complex and varied, multiscaled and multitiered, and subject to continual change and adaption. Hence, the practical characterisation of ecosystem disturbances induced by anthropogenic stress is a rather complex process and many concepts exist. Recovery and succession of ecosystems are dependent in part upon the characteristics of the impact/stress and in part upon the characterisation and history of the ecosystem. The difficulties of characterisations of ecosystems, responses and recovery (or succession) require adoption of points of view, operational definitions, and choices on how to simplify and what scales to emphasise. All of these have influences on what and how to measure, and simple models and extrapolations are simply inadequate because ecosystems are 'individualistic'. Ultimately, site specific concerns need consideration in every case. However, the qualitites of measurements may be considered more generally.

The most useful single criterion to apply in order to reduce the measures of ecosystem health down to a manageable level is the relevance to issues of concern to humans (see section 3.1). That means, a change in an ecosystem is only considered of importance if it relates to something of concern to humans. By focusing on such generic ecological endpoints, a structured way of evaluating ecological effects can be developed. Such a framework of **ecological endpoints** can be divided into a hierarchy of levels:

i) Human Health: vectors for exposure to humans
ii) Species-level endpoints:
    direct interest: economic, aesthetic, recreational, nuisance, species
    indirect interest: biospecies effect (predation, competition, pollination), habitat role

ecological role: trophic role, functional relationship, critical species

iii) Community-level endpoints: food-web structure, species and biotic diversity

iv) Ecosystem-level endpoints: ecologically or economically important processes, water quality, soil quality, air quality (habitat quality).

Source: Kelly/Harwell 1989

These endpoints provide an initial base for deciding what indicators should be significant for a given or predicted disturbance. Indicators are not mutually exclusive and, indeed, they may strongly complement each other, and multiple indicators of several qualities may be required. Categories of **indicators** include:

i) intrinsic indicator: economic species, endangered species, other species of importance; key: indicator is the endpoint

ii) early warning indicators: use when the endpoint is slow in response; key: rapid indication of effect

iii) sensitive indicator: use when endpoint is relatively insensitive; key: reliability in predicting

iv) process indicator: monitoring other than biota: decomposition rate; complement structure; key: endpoint is the process

v) indicator of ecosystem sensitivity/vulnerability: abiotic indicators (soil/water/air); key: system attributes

Source: Kelly/Harwell 1989

**Critieria** for such indicators include:

i) reliability of response: specific to a given stress

ii) rapid response: early exposure, quick dynamics

iii) signal-to-noise ratio: sensitivity to stress

iv) ease/economy of monitoring: field sampling, lab expertise, data base

v) relevance to endpoint: intrinsic, string of ecological connections

vi) feedback to regulations or management: adaptive management potential

vii) relevance to recovery process

Source: Kelly/Harwell 1989

A multitude of criteria can be used to identify and evaluate the significance of natural areas (further details in: Smith/Theberge 1986); they include:

| | |
|---|---|
| rarity, uniqueness | biotic, abiotic type |
| diversity | biotic, abiotic |
| size | biotic, abiotic, planning and management |
| naturalness | biotic, abiotic |
| productivity | biotic |
| fragility | biotic, abiotic |
| representativeness | biotic, abiotic |
| importance to wildlife | abundance of biotic, abiotic types |
| threat | planning and management |
| educational value | cultural |
| cultural resource | cultural |
| research investment | cultural, economic |
| recreational value | cultural |
| level of significance | planning and management |

| | |
|---|---|
| consideration as buffer | planning and management |
| geographic location | planning and management |
| shape | planning and management, biotic. |

Source: Smith/Theberge 1986

General references: Kaule 1992; Freedman 1989; Kelly/Harwell 1989; Cowling in: Mathy ed. (ECE) 1986; FAO (EEP 6, EEP 7, EEP 8) 1986; Westman 1986

**Review of literature relevant to ecological assessments:**

Duinker 1989: Ecological effects monitoring. Monitoring can be used as a check on changes over time. For prediction, implicit, process-based, quantitative forecasting models are favoured.

Wakeley 1988: Simplified versions of existing Habitat Suitability Index (HSI) for Habitat Evaluation Procedures (HEP) which determine the impact on fish and wildlife habitat (US-models)

Herricks/Schaeffer 1985: Optimisation of Biomonitoring as an element of environmental management

Gassner/Siederer: Definitions of terms Gestaltsänderung, Nutzungsänderung, Beeinträchtigung des Naturhaushaltes und Landschaftsbildes; Erheblichkeit und Nachhaltigkeit der Beeinträchtigungen (German)

see also under: wetlands section 4.7.

## 4.4 Socio-Economic Background: Human Land Occupation

Increases in human population have meant an increase in the demand for food, which, in turn, has resulted in conversion of bushland/forests into cropland. Whereas population growth remained rather low in most developing countries (except Latin America) until the 19th century, there has been an accelerated rate of cropland expansion in the 20th century and especially over the past 30 years. Between 1850 and 1950, cropland in Asia increased at an annual rate of 1.2 M ha, resulting in an increase of cropland from 70 to 200 M ha in South Asia, and from 10 to 60 million ha in Southeast Asia. Currently, in Asia are some 374 M ha under cultivation.

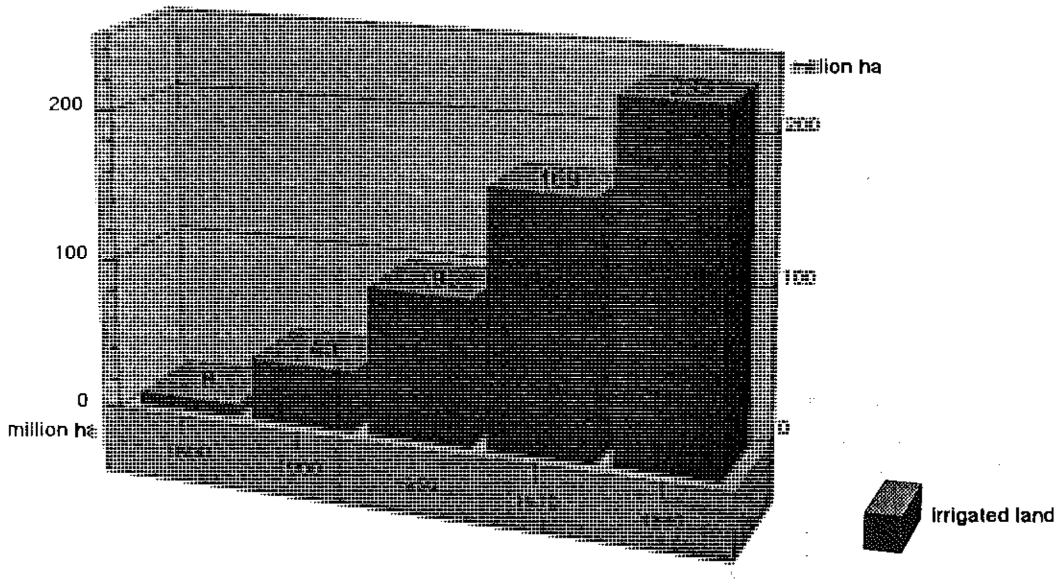
The situation differs from country to country, for example, in China, cropland area has almost tripled in this century, whereas in Bangladesh increases were small because most arable lands were already under cultivation at the beginning of this century. However, cropland expansion slowed down in recent years and expansion in some countries is expected to come to a halt as the land frontier is exhausted and structural changes of economies reduces the absolute size of agricultural populations. In some Asian countries the total cropland area decreased over the decade 1976 to 1986 (eg in China -2.9%), and only in Southeast Asia and Pakistan are growth rates in the range of 3 to 8% over that decade. It is projected that these expansions will level off in the early 1990s.

Over the past two decades agricultural growth without arable land extension was made possible by the application of land-use saving technologies such as **irrigation** and **modern farm technologies** (agricultural imputs such as fertilisers, pesticides, improved seeds, high yielding varieties, mechanisation, improved tillage) in most Asian and OECD countries (ADB 1991).

However, the situation is different in **Africa**, where only 2% of the world's irrigated areas are located and food production per capita has declined by some 17% although conversion of land to cropland had been increased over the last 20 years. By 1985, only 15% of the irrigation potential is developed in Sub-Saharan Africa (FAO 1987). The irrigation needs for crop production in Africa are high, because many areas suitable for rainfed production outside the rainforests require, irrigation for secured and increased yields, due to temporary or permanent water deficits.

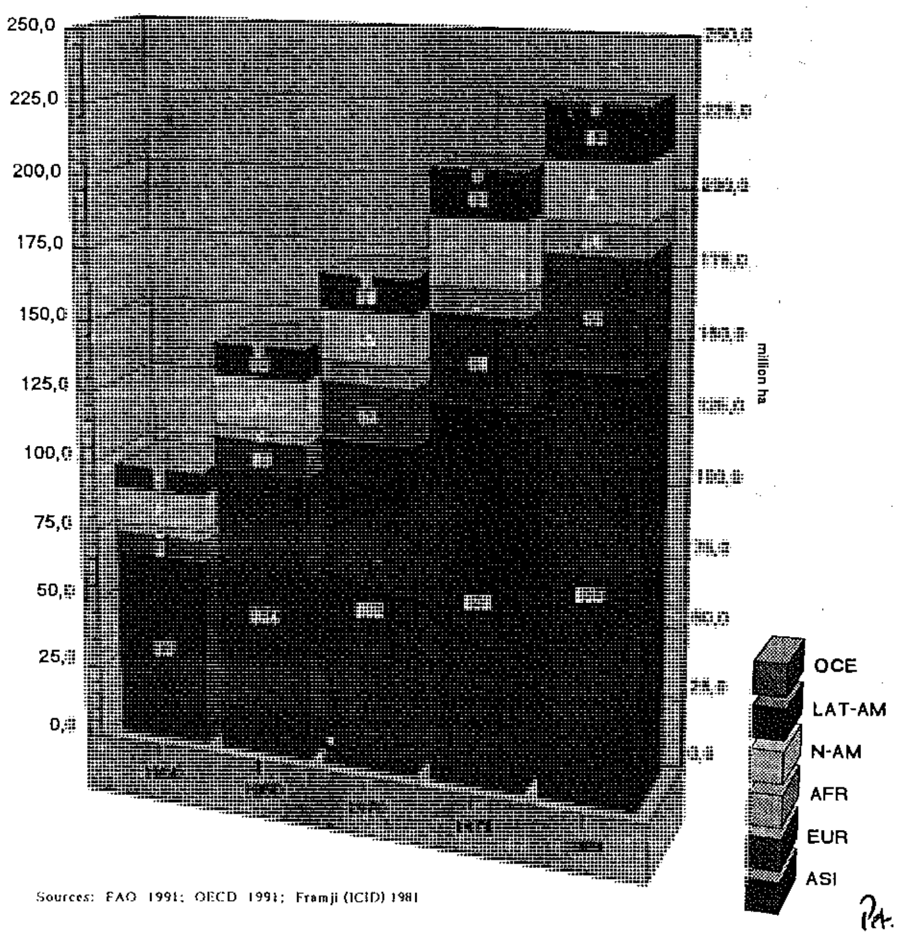
Fig. 4-1 a, b

Total Irrigated Areas in the World 1800 to 1990




Sources: Framji (ICID) 1981; FAO 1991

Irrigated Areas in the World by Continents




Sources: FAO 1991; OECD 1991; Framji (ICID) 1981





The land resources for arable farming in Africa are assessed by FAO as follows:

| | | | |
|---|---|---|---|
| good rainfall areas | 244 | M ha | 38% of arable land (120-270 growing days) |
| low rainfall areas | 62 | M ha | 10% of arable land (<120 growing days) |
| problem areas | 288 | M ha | 45% of arable land (>270 growing days) |
| flooded areas | 44 | M ha | 7% of arable land (naturally flooded) |
| desert | 1 | M ha | currently under irrigation |
| total arable areas | | 639 M ha | 100% |

It is estimated that in Africa about 115 M ha are suitable for irrigation (18% of the arable land). The water resources are sufficient for irrigating some 40 M ha of which probably 20-25 M ha match with land suitable for irrigation (without consideration of large scale water transfer schemes). Water reuse increase the water resources in some areas.

Source: Seckler in: Barghouti/Le Moigne (WB) 1990; FAO (EEP 6) 1986

There is no reason to assume that the rapidly growing **demand** for food can be met in Africa without future **expansion** and **intensification** of agriculture. It cannot be that Africa needs less irrigation or fertilisers or other agronomic inputs than Asia does, nor that Africa has a surplus of agricultural land and therefore requires a low-input, low-yield form of agricultural production. There are still vast savanna and forest areas which could be converted to cropland, but land use saving technologies are also applicable, such as irrigation and other means to improve rainfed productivity or a combination of irrigation and new agricultural technologies.

Sources: Seckler in: Barghouti/Le Moigne ed (WB) 1990; FAO 1987; FAO (EEP 6) 1986

Further readings: Barghouti/Le Moigne ed. (WB) 1990; FAO (EEP 6, EEP 7, EEP 8) 1986

## 4.5 Irrigation and Competition in Land Use

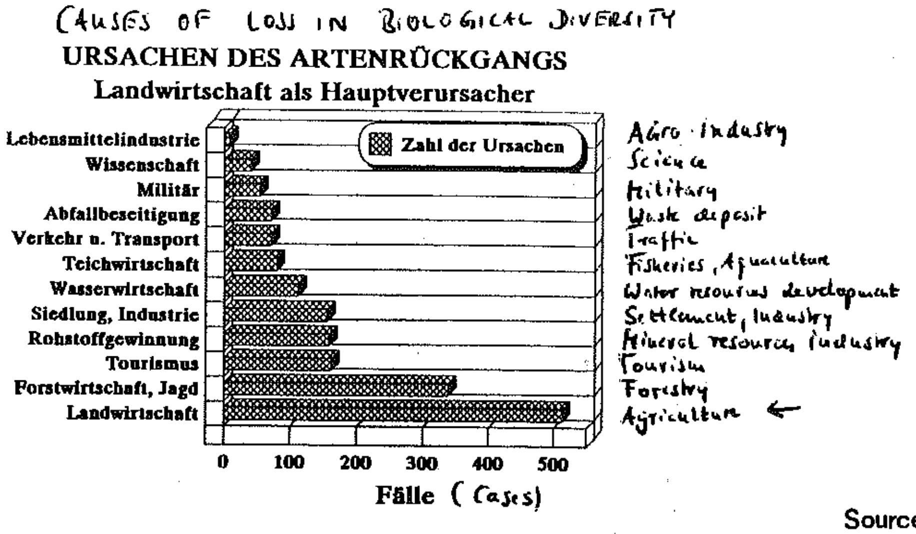
A major 'environmental cost' of agriculture is related to land occupancy in relation to natural ecosystems. Irrigation competes, like any other human land use system, with natural ecosystems. Figure 4-1 shows the increase in irrigated area. Per unit area, irrigated agriculture produces considerably more food than any other agricultural cropland system, and, thus, irrigation may also be understand as a land-saving cropland technology (Further details related to the productivity of agricultural systems are compiled in Table 4-1; but: see also: section 4.7). For example, in a semiarid region, irrigated farming produces about 3.5 times more grains than rainfed farming (Sub-Saharan Africa, FAO 1987) and irrigation improvements in Asia (namely India and China) contributed to the decrease in the per capita agricultural land area.

On the other hand, irrigation tends to use the most fertile agricultural lands, areas which are ecologically sensitive, or areas of a high natural biotic potential or diversity. Irrigation is, independent of agro-climatic zones, mainly practiced in riverine areas, floodplains and along seasonal or perennial wetlands and lakes. These, in turn, belong to natural ecosystems with the highest productivity and degree of diversity: riverine or riparian woodlands, wetlands, alluvial savanna (scrub or grassland) plains.

Losses of natural ecosystems or disturbances may occur within and outside the irrigation command area:

- the irrigated area itself (command area) is converted to agricultural land,
- upstream areas: if dams are built then the reservoir zone may submerge vast areas of land (land losses to large reservoirs are shown in Table 4.2.),

Fig. 4-2




Source: Boesel 1990

Fig. 4-3

**Table 2: Wetland Values**

| | Estuaries (without mangroves) | Mangroves | Open coasts | Floodplains | Freshwater marshes | Lakes | Peatlands | Swamp forest |
|---|---|---|---|---|---|---|---|---|
| **Functions** | | | | | | | | |
| 1. Groundwater recharge | ○ | ○ | ○ | ■ | ■ | ■ | ● | ● |
| 2. Groundwater discharge | ● | ● | ● | ● | ■ | ● | ● | ■ |
| 3. Flood control | ● | ■ | ○ | ■ | ■ | ■ | ● | ■ |
| 4. Shoreline stabilisation/Erosion control | ● | ■ | ● | ● | ■ | ○ | ○ | ○ |
| 5. Sediment/toxicant retention | ● | ■ | ● | ■ | ■ | ■ | ■ | ■ |
| 6. Nutrient retention | ● | ■ | ● | ■ | ■ | ● | ■ | ■ |
| 7. Biomass export | ● | ■ | ● | ■ | ● | ● | ○ | ● |
| 8. Storm protection/windbreak | ● | ■ | ● | ○ | ○ | ○ | ○ | ● |
| 9. Micro-climate stabilisation | ○ | ● | ○ | ● | ● | ● | ○ | ● |
| 10. Water Transport | ● | ● | ○ | ● | ○ | ● | ○ | ○ |
| 11. Recreation/Tourism | ● | ● | ■ | ● | ● | ● | ● | ● |
| **Products** | | | | | | | | |
| 1. Forest resources | ○ | ■ | ○ | ● | ○ | ○ | ○ | ■ |
| 2. Wildlife resources | ■ | ● | ● | ■ | ■ | ● | ● | ● |
| 3. Fisheries | ■ | ■ | ● | ■ | ■ | ■ | ○ | ● |
| 4. Forage resources | ● | ● | ○ | ■ | ■ | ○ | ○ | ○ |
| 5. Agricultural resources | ○ | ○ | ○ | ■ | ● | ● | ● | ○ |
| 6. Water supply | ○ | ○ | ○ | ● | ● | ■ | ● | ● |
| **Attributes** | | | | | | | | |
| 1. Biological diversity | ■ | ● | ● | ■ | ● | ■ | ● | ● |
| 2. Uniqueness to culture/heritage | ● | ● | ● | ● | ● | ● | ● | ● |

Key: ○ = Absent or exceptional; ● = present; ■ = common and important value of that wetland type.

Source: Dugan (IUNC) 1990





- downstream areas: loss or deterioration of seasonal or perennial wetlands due to shifts or substantial changes in hydrological regimes, eg reservoir operations for flood control will reduce the downstream flooded areas.

## 4.6 Impacts on Biological Diversity

Biodiversity is an important feature of an ecosystem's function and structure. The extinction of a species represents an irrevocable and regretable loss of a portion of the biological richness (Fig. 4-2; Tables 4-3, 4-4). Anthropogenic habitat destruction, eg by large-scale conversion of wetlands in irrigated agriculture, is an increasingly dominant cause of extinction, although other conversions may contribute to extinction at much higher levels, for example tropical forest conversions with the extinction of endemic taxa with local distributions.

Biodiversity can be interpreted from agricultural, floral or faunal perspectives, or from environmental or economic views. **Perceptions** may vary with different socio-cultural backgrounds. For example, in African societies maintaining biodiversity is currently often seen as an alternative, rather than a complement to economic development. In contrast, biodiversity in modern 'environmental economics' is, amongst others, an important feature (or indicator) of the natural capital stock. This stock is an indicator of sustainability, with the presupposition that maintaining environmental quality is a condition for sustainability.

Important criteria for such analysis includes 'intergenerational equity' and 'risk minimising'. In this respect, biodiversity may be related to risks and irreversibilities of human interference in ecosystems. A major problem arises with the fact that the environmental consequences of development projects are often unknown and hence impacts emerge from natural resource degradation over time. The problems stem from the lack of comprehensive understanding of (1.) ecosystem functions, structures and interactions and (2.) how ecological systems assist certain economic activities. Irreversible losses of environmental functions and structures are difficult to identify and to evaluate in economic terms.

Thus, sustainability includes avoiding, as far as possible, irreversable changes due to human interference and, hence, moves towards the preservation of integrity of biological communities (see also section 3.1). Any change in biodiversity, however, must be interpreted in the context of human basic needs (eg for food production) and the need for the development of human ecosystems such as irrigated agriculture.

Further readings: McNeely et al. (IUCN) 1990; Risser in: Naiman/Dechamps ed. (UNESCO) 1990; Pearce et al. 1989; Freedman 1989; Barbier 1989

## 4.7 Wetland Degradation

In the past, **wetlands** were often seen as **wastelands** or as places which should be avoided or at least be reclaimed because they carry diseases or were of little human use unless drained. Only recently has their value been re-assessed in industrialized countries (Figure 4-3); natural wetlands help to control floods, they produce various types of food, serve as a resource for materials, help to stabilise wildlife population, remove bacteria, viruses, organic and inorganic toxicants/pollutants and suspended solids, and serve as a genetic resource for precious fauna and flora (Hemond/Benoit 1988).

Since 1900, over half of the world's wetlands disappeared (Figure 4-4, Tables 4-5, 4-6). Originally, some 6% of the land was classified as wetlands (Dugan IUCN 1990). In the USA alone, some 87 M ha were lost, of which 87% are accounted for by agricultural development, 8% by urban development, and 5% by other conversions (Maltby 1986).

Fig. 4-4a

## The Causes of Wetland Loss

| Human Actions | Estuaries | Open coasts | Floodplains | Freshwater marshes | Lakes | Peatlands | Swamp forest |
|---|---|---|---|---|---|---|---|
| ***Direct*** | | | | | | | |
| Drainage for agriculture, forestry, and mosquito control. | ■ | ■ | ■ | ■ | ● | ■ | ■ |
| Dredging and stream channelization for navigation and flood protection. | ■ | ○ | ○ | ● | ○ | ○ | ○ |
| Filling for solid waste disposal, roads, and commercial, residential and industrial development. | ■ | ■ | ■ | ■ | ● | ○ | ○ |
| Conversion for aquaculture/mariculture | ■ | ● | ● | ● | ● | ○ | ○ |
| Construction of dykes, dams, levees, and seawalls for flood control, water supply, irrigation and storm protection. | ■ | ■ | ■ | ■ | ● | ○ | ○ |
| Discharges of pesticides, herbicides, nutrients from domestic sewage and agricultural runoff, and sediment. | ■ | ■ | ■ | ■ | ■ | ○ | ○ |
| Mining of wetland soils for peat, coal, gravel, phosphate and other materials. | ● | ● | ● | ○ | ■ | ■ | ■ |
| Groundwater abstraction | ○ | ○ | ● | ■ | ○ | ○ | ○ |
| ***Indirect*** | | | | | | | |
| Sediment diversion by dams, deep channels and other structures. | ■ | ■ | ■ | ■ | ○ | ○ | ○ |
| Hydrological alterations by canals, roads and other structures. | ■ | ■ | ■ | ■ | ■ | ○ | ○ |
| Subsidence due to extraction of ground-water, oil, gas and other minerals. | ■ | ● | ■ | ■ | ○ | ○ | ○ |
| ***Natural Causes*** | | | | | | | |
| Subsidence | ● | ● | ○ | ○ | ● | ● | ● |
| Sea-level rise | ■ | ■ | ○ | ○ | ○ | ○ | ■ |
| Drought | ■ | ■ | ■ | ■ | ● | ● | ● |
| Hurricanes and other storms | ■ | ■ | ○ | ○ | ○ | ● | ● |
| Erosion | ■ | ■ | ● | ○ | ○ | ● | ○ |
| Biotic effects | ○ | ○ | ■ | ■ | ■ | ○ | ○ |

Key: ○ = Absent or exceptional; ● = present, but not a major cause of loss; ■ = common and important cause of wetland degradation and loss.

Source: Dugan (IUNC) 1990





*Case studies*

Many river basins in Africa contain large floodplains that are of outstanding ecological importance. Among those are the Sudd and White Nile region, Lake Chad (Logone-Chari system), Inner Delta of Niger, and the Okavango Delta in Botswana. Major riverine plains exist along the rivers Senegal, Gambia, Nile, and Zambesi. These areas help to control floods, stabilise river flow, trap sediment, and are highly productive for natural ecosystems, ie for plants and migratory wildlife, such as mammals and birds.

But, considering the productivity per unit of water in the Inner Delta of the Niger and the Office du Niger irrigated rice schemes, the former produces some 10 000 t meat, 120,000 t milk, 100,000 t fish, and 80,000 t rice (traditional) whereas the latter produces 100 000 t of rice. When computed per unit of water, irrigated rice produces almost 10 times as many calories and almost twice as many grams of protein as the swamp, although the swamp's produce is much more varied in type and nutritional value (Le Moigne/Barghouti in: Barghouti/Le Moigne (WB) 1990). This is illustrated in Table 4-7a (from: Hollis et al. 1988). Whilst both systems (traditional and modern rice schemes) produce about the same gross profit margin, the high interest charges arising from the modern irrigation scheme turns the net profit of irrigated rice into a loss of \$0.65 per 100 $m^3$ of water.

In West Africa there are 114 dam projects, which are likely to have an impact on wetlands, with 51 percent operational at present (Ketel et al. 1987, cit. in: Hollis et al. 1988). Modern medium and large scale irrigation projects in West Africa are shown in Fig. 4-4b.

In northern Nigeria, the Bokolori dam was built in the mid-1970s to supply a 30,000-ha irrigation scheme. The dam reduced the magnitude of the wet-season floods which supported an extensive agriculturral system and a fishery upon which some 50,000 people depended. Reducing flooding caused a shift from rice to lower-value millet and sorghum crops in the wet season and a significant reduction in the extent of dry season cultivation. Fish population declined, and fishing decreased (Adams 1985, cit. in Hollis et al. 1988). Other case studies in: Goldsmith/Hildyard 1984.

Inland wetlands, ie marshes and swamps, in the world equal about 2 M $km^2$, of which 75% are located in the tropics (Crutzen cit. in: Lal 1987). In South and Southeast Asia most of these swamps have been utilised intensively. In fact the Asian lowland rice culture is a sustainable system that has supported the high population density in these regions without causing far reaching ecological imbalances and soil degradation problems that have limited the intensive utilisation of tropical uplands.

Also tidal marsh vegetation is under serious threat and vegetation changes result from tidal restriction. Restrictions are imposed by tide gates and associated structures to protect agricultural (including irrigated) land from flooding by seawater and from discharge regulation devices imposed by dams across larger rivers, eg. Senegal River, River Volta, etc.

The characteristics of wetlands are influenced primarily by hydrological regimes which affect many abiotic factors, including salinity, nutrient availability and soil anaerobiosis (Holland et al.). Many wetland-uplands support relatively high biological diversity, but species diversity for a particular wetland system may be affected by a variety of factors. Some upland ecosystems have few species due to sharp boundaries. Often the primary production is high in wetland-open water systems but conditions can be stressful for less adapted plants, especially in wetland-upland ecosystems which are only occasionally flooded. On the other hand, such periodically or seasonally flooded plains provide sufficient moisture for prolonged plant growth periods in semiarid and arid areas, and distinct community structures exist, adapted to both flooded and upland conditions. Human interference in such plant communities often reduces productivity and homeostasis and stability of the wetland as well as adjacent systems can be disrupted.

Fig. 4-4b

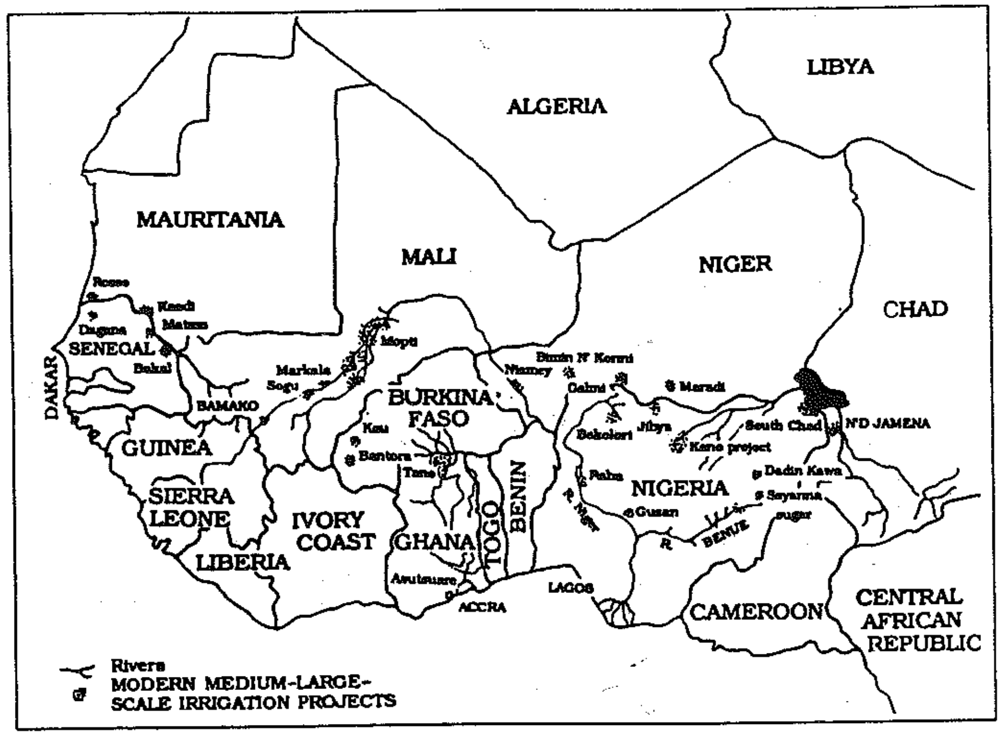
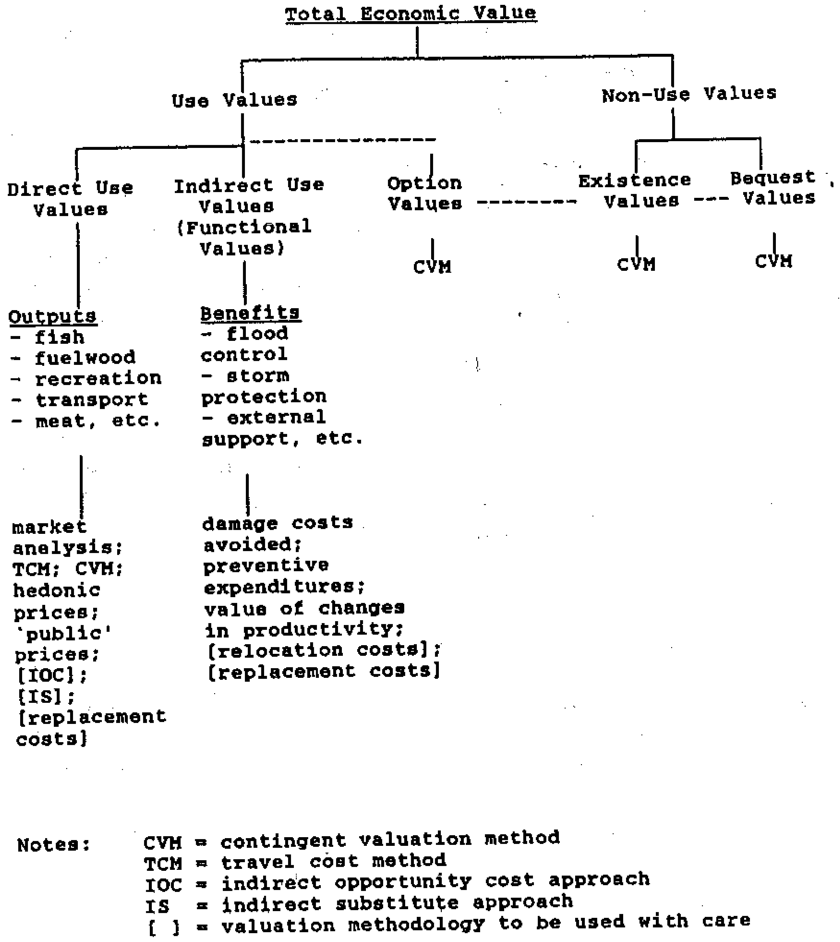



*Figure 1. Map of West Africa showing modern medium- and large-scale irrigation projects.*

Source: Maurya in IIMI 1990

Fig. 4-5

Figure 1. Valuing Wetland Benefits




Source: Barbier o.J.





Source: Holland/Whigham/Gopal in: Naiman/Dechamps ed. (UNESCO) 1990; Roman/Niering/Warren 1984; Dugan (IUCN) 1990

Further reading regarding cumulative impacts on wetlands and their assessment: Hemond/Benoit 1988

The characteristics of wetlands with value to humans include (details see Table 4-8)

**Components** (direct harvest or use of structural ecosystem components; resource stocks)

1. Water Resources
2. Fisheries Resources
3. Forest Resources
4. Wildlife Resources
5. Agricultural Resources (germplasm collection)
6. Forage Resources
7. Medicinal Plants Resource, Herbs
8. Ornamentals Resource

**Attributes**

1. Biological diversity
2. Uniqueness to culture, heritage
3. Aesthetic views

**Functions** (ecosystems flows and services which may assist or support human activities)

1. Groundwater discharge and recharge
2. Flood and flow control
3. Shoreline stabilisation
4. Sediment retention
5. Nutrient retention and decomposition
6. Retention and decomposition of toxins
7. Water quality maintenance (general)
8. Storm protection (shelterbelt)
9. External support
10 Micro-climatic stabilization
11. Recreation/Tourism
12. Water Transport

Sources: modfied after Barbier 1989, see also OECD 1985; ADB 1988, Westman 1985]

The **economic** values of these components, attributes and values may be **direct** (value derived from economic uses), **indirect** (through services) or related to preservation or non-human **uses** (typically the attributes). The magnitude of importance is subject to the specific valuation. An approach to the valuation of wetland benefits is shown in Fig. 4-5.

Further details on economic evaluation are given in Barbier o.J. ; Pearce/Barbier/Markandya 1988

The impacts of irrigation on wetlands may include:

- direct conversion to agricultural land under irrigation,
- hydrological interference by up- or downstream water abstractions,
- pumping of groundwater with subsequent lowering of watertables,
- land filling and drainage for new land uses or for eliminating vector habitats,
- alteration or complete removal of vegetation,
- pollutant inputs: fertilisers, xenobiotic organic chemicals

- peat harvesting,
- wildlife management (through 'pest' control, or by neighbouring population)
- drainage effluents (these may have negative or beneficial overall effects).

Further readings on general wetland degradation: Hemon/Benoit 1988; Winter 1988; Preston/Bedford 1988; Bedford/Preston 1988; Hirsch 1988; Stakhiv 1988; Harris 1988; Cable/Brack/Holmes 1988

In addition, the conversion or alteration of wetlands may have impacts on downstream water resources, eg water quality, which, in turn, may affect other downstream users.

Further reading: Brinson 1988; Dugan 1990

The development of irrigation and drainage projects has typically had detrimental impacts on wetland ecosystems. In semiarid to subhumid regions irrigation areas, especially for paddy cultivation are those areas around lakes or low lying depressions. In other places, wetland zones are dispersed within riverine floodplains which generally offer the best potential for irrigation because of fertile alluvial soils and ample availability of water for irrigation. To meet the increasing demand for food production, additional wetlands will have to be brought under irrigation, especially under paddy production. In fact, the area sown to rice is expected to increase from 98 to 126 M ha by the year 2000 (Dudal cit. in: Lal 1987).

Wetlands in tropical Africa constitute a huge potential useful land resource for intensive cropping. Wetlands and hydromorphic soils can often be utilized for double or triple cropping provided that environmentally sound agricultural and soil/water resource management practices are applied. In humid to subhumid areas of West Africa the total wetland area ranges from 13 to 28% of the total land area of various countries. One third of this is in streamflow valleys which are the likely targets for development to meet future land use demands in tropical Africa. Most of these areas also offer great potential for irrigation. However, their use in large-scale irrigation would jeopardise or destroy wildlife and plant diversity and would be detrimental to indigenous populations and/or traditional land use systems which rely on fish, collection of plants or fruits and rainfed crops.

Indirect impacts of irrigation on surface water resources are of similar importance. Changes in quality and quantity of stream flow typically result in a deterioration of habitat quality for wildlife and aquatic life.

It is obvious that more precise information needs to be obtained on the environmental and economic costs and benefits associated with large scale irrigation development to determine whether water diverted from swamps (or further upstream) will indeed find more worthwhile use elsewhere. This however, also implies that development or conservation priorities must be set in the social, cultural and economic context of the area under concern. Technical and ecological information may contribute towards formulating alternative solutions if conflicts between various actual or potential future users arise.

*Case Studies:*

USA. San Joaquin Valley in California: An increased concentration of selenium from drainage effluents has caused reproduction failures and death in some species of aquatic organisms and waterfowl in the Kesterton National Wildlife Refuge. (Tanji/Hanson in: Stewart ed. 1990).

USA. Central Valley in California: This area once contained some of the finest bird and fish habitats in the world. As the valley was developed and land was converted to agricultural (irrigation) use, fish and wildlife habitats declined. Today only 120,000 to 170,000 ha of natural wetlands remain out of an estimated 1.6 M. In addition, 10,000 km of productive stream and river habitat habe been reduced to about 1,500 km, as a result of construction of dams and other major water developments. Reduction of habitat area has resulted in corresponding reductions in fish and wildlife populations. (Hoffman in: Lesaffre ed. 1990).

USA. Arid Western States: Many wildlife refuges are, in essence, terminal points for irrigation schemes. These areas are often closed basins with no outlet to the sea, and so water quality problems can become severe. In all cases, the reduction of stream flow and the deterioration of water quality have been stressful for fish and wildlife. (Hoffman in: Lesaffre 1990)

Australia. Central Murray River Catchment: Large scale flood irrigation of pasture lands and associated infrastructure works without adequate drainage has lead to a rise in watertables and the build-up of soil, groundwater and streamflow salinity. Most of the stream systems have been degraded by works intended to upgrade their water carrying capacity, including dredging, channelisation and levee banking. Dredging of low-lying natural streams has led to the interception of saline groundwater and consequently more saline streamflow. All wetlands have undergone major changes affecting the water regime, water quality and the vegetation. None of the wetlands can be classified as pristine. 21 out of 40 wetlands in the area have declined in rating in the past 15 years. Increasing salinity has reduced the value of many wetlands for waterbird breeding to the extent that some wetlands no longer meet the Ramsar Convention criteria. Salinity can reach high levels during the non-irrigation season and dramatic changes can occur in some areas as saline slugs are flushed through the system during the early part of the following irrigation season. These slugs are particularly detrimental to the aquatic environment and to high value horticulture enterprises. Stratification in lakes and streams due to salinity and the associated deoxygenation of the lower, more saline layer, can result in significant loss of habitat and the development of potentially toxic conditions for instream fauna (Lakey in: Lefeffre ed. 1990)

Sources: Lakey in: Lesaffre ed. 1990; Hoffman in: Lesaffre ed. 1990; Tanji/Hanson in: Stewart 1990; Holland/Whigham/Gopal in: Naiman/Dechamps ed. (UNESCO) 1990

Further readings: UNESCO/UNEP/FAO 1979; Dugan IUCN 1990

Further reading: Assessments and Regulatory Alternatives for Management: Lee/Gosselink 1988

## 4.8 Riparian Habitat Degradation

Riparian habitats support some of the richest terrestrial vertebrate faunas of semiarid and arid areas. These composite terrestrial-aquatic ecosystems are ecotones (ecosystem transitional zones) which have not only the highest densities of bird populations but also contribute significantly to the distribution of birds in adjacent areas. They also contain numerous habitats for large and small mammals in dryland regions. Changes in ecotones thus affect the diversity of adjacent ecological communities. For example, 95% fewer birds and 32% fewer species were recorded on agricultural lands along the Sacramento River, USA), from which the adjacent riparian vegetation had been removed. Such removals may also reduce invertebrate and fish production due to a loss of energy inputs into adjacent streams. Generally, riparian forest can affect the flow of water, nutrients and other materials from uplands into streams. They may capture (filter) significant portions of N, Ca, P, and Mg which otherwise would have been washed into the river. Each riparian ecotone has unique features which reflect different hydrological regimes and positions.

Source: Risser in: Naiman/Dechamps ed. (UNESCO) 1990

Irrigation development typically contributes to the clearing of riverine forests, especially in semiarid regions. Often, they consist of fertile strips of land which are brought under cultivation. But the construction and operation of intake structures may also result in portions of riparian rivers being destroyed. Riparian habitat degradation may occur due to human health or other pest control activities because riparian forests may be sources of agricultural pests or provide habitats for water-related vectors.

## 4.9 Impacts on Aquatic Fauna

Aquatic fauna is affected twofold by impacts resulting from irrigation and irrigated agricultural activities:

- Changes in **hydrological regimes** of rivers by water abstractions: typically seasonal variations and total flow volume may be changed by irrigation projects. The magnitude of impacts on aquatic life varies from negligible to significant. Changes and impacts induced by large dams are treated in section 11.
- Changes in **water quality**, namely increased salinisation and other water pollution from agro-chemicals from washed or leached from agricultural areas into the river systems (especially persistent pesticides and toxic metals, see sections 3, 4 and 9).

Any significant impact on the hydrological regime of a river has effects on fish populations and indirectly on fishery. Irrigation projects may have direct and indirect impacts:

- **Direct** impacts are related to (i) the total reduction of downstream water flow, (ii) changes in seasonal flow regimes, and (iii) changes in downstream water quality, namely increasing salinity and introduction of toxic chemicals.
- **Indirect** influences include changes in river regime caused by large-scale water development schemes such as reservoirs. These impacts can become a serious threat to migratory fishes and may result in a reduction of breeding habitats.

*Case Studies*

In Thailand dams have impacts on marine and fresh-water fisheries; the daming of main inflows caused a serious decline of fishery productivity, since dams trapped nutritious sediment loads; in several cases the dams interupted the life cycle of fish or crustaceans (Tuntawiroon in: Goldsmith/Hildyard ed. 1986).

In Egypt, after the construction of the Aswan High Dam, both downstream fishery and marine declined.

On the other hand, favourable fish habitats may be developed in reservoirs, with new fish populations adapted to lacustrine conditions and typically higher fish catches compared with the average fish catches in such rivers:

In Egypt, the Aswan High Dam reservoir exhibits high rates of biological production in the range of 8-15 g $O^2/m^2/d$ in some favourable habitats (khores).

The actual impacts from changes in water quality differ greatly and may vary from insignificant to acutely toxic. Fish kills as a direct impact from irrigation projects are rarely observed because toxic concentrations from drainage effluents may only occur incidentally. In large resevoirs the development of aquatic weeds may become a threat to fish populations. For example, blue-green algae (Cyanophyta) in reservoirs or swamps are impoundment organisms which deplete the oxygen in water, fix nitrogen, cause taste and odour problems, are toxic to certain fish and represent the dead end in the food chain.

More important are indirect effects from changes in fish breeding habitats in downstream reaches which may be affected by siltation or changes in seasonal water level fluctuations. However, the most serious impacts are where reservoirs across larger streams hamper the migration of fish populations. In addition, some fish species may not adapt to lake or reservoir conditions and fish numbers may fall unless new species are introduced. Indirect impacts also occur from an increase in sediment loads in rivers caused by increased farming and soil erosion on farmland. Irrigation practices may increase or decrease runoff but poor farming practices will increase runoff and hence increase turbidity in downstream reaches of rivers.

The concentration of a pesticide is rarely distributed evenly through the aquatic phase. Soon after introduction (or application) there is a high concentration close to the surface or the emitter (eg drainage pipes) where it may kill fish, and thereafter, it tends to become absorbed on to particulates or dead organisms and become depostied on the bottom.

Most planktonic organisms tend to be extremely susceptible to pesticides in solution. However, there is much less difference in susceptibility between different groups of aquatic invertebrates belonging to different taxa than there is between organsim of different taxa that inhibit the soil. Invertebrates used in laboratory bioassay tests provide evidence of this comparatively uniform susceptibility to pesticides, eg water fleas, ostracods and stoneflies.

Most **insecticides**, including the organochlorines, organophosphates and pyrethroids are very toxic to aquatic arthropods with relatively little difference in relative toxicity between them. The greatest kill occurs within a few hours of a pesticide reaching the system. Usually, the effects of several successive incidential exposures are catastrophic.

Although aquatic systems are often polluted with herbicides, most of these chemicals have little direct toxicity to aquatic invertebrates, although they have drastic effects on the availability of food. The use of herbicides can decrease the amount of floating phytoplankton but, when they are killed and sink to the bottom, detritus-feeding invertebrates in the bottom sediment may be favoured. The greatest reduction in aquatic invertebrate populations resulting from herbicide use reported to date is 50% (Edwards 1987).

After the aquatic invertebrate fauna population has been affected by pesticides, the time taken for repopulation depends mainly on how long it takes for the residues to disappear. Populations tend to take longer to recover in isolated ponds or streams than in faster flowing systems where contamination is soon removed (dilution effect). Usually, repopulation is relatively rapid and direct effects on fish populations feeding on invertebrates are relatively small. Many invertebrates, however, accumulate pesticides in their tissues without being killed, so that fish that feed on them are exposed to the residues. Fish may contain concentrations of residues many thousand times greater than the water. However, although it is common for animals at higher trophic levels to contain greater concentrations of residues, such bioconcentrations, induced by typical pesticide pollutions from agricultural lands, have not been demonstrated in food chains at significant levels. Thus, pesticides certainly have the potential to affect all the functions of aquatic systems and fish productivity. Care should therefore always be taken to minimise or eliminate such pollution even if direct killings are not encountered.

Source: Edwards 1987

Further readings regarding changes in reservoirs: Baumann et al. (BMZ) 1984, Zauke/Niemeyer/Gilles 1992

# 5 Impacts on Air Quality

## 5.1 Introduction

Impacts may occur on-site and off-site: on-site effects are especially related to particulate emission (dust) and potential health hazards from pesticide usage. Off-site effects can be related to air deposits (particulate, vapor) on areas neighbouring irrigated lands (settlements, natural vegetation) and contributions to the 'greenhouse effect' by emissions of the greenhouse gases $CO_2$, $CH_4$ and $N_2O$. The relative contribution (ratio) to global warming is 15, 5 and 1, respectively. If only biotic sources (natural, agricultural areas, cattle) are considered, their relative contributions are 5, 4 and 1. Especially $CH_4$ and $N_2O$ have important impacts on atmospheric photochemical reactions in addition to their effect on the atmosopheric radiation balance.

Irrigated agriculture impacts on air quality are usually of minor concern because of their marginal significance and - often - limited spatial impact, when compared to air pollution from non-agricultural sources. Nevertheless, some negative and postive impacts do exist and it should be noted that air quality itself has some stress effects on agricultural production, too.

Significant direct air pollutant **emissions**, related to soil cultivation, irrigation, crop production and waste disposal, are usually fugitive and include:

| | |
|---|---|
| - during field operations | particulate, $NO_x$, HC, $CO_x$, odour, visibility effects |
| - during growth | particulate, HC (Hydro-Carbonates), |
| - during decay | particulate, HC, $CO_x$, odour (anaerobic) |
| - field fires | particulate, $NO_x$, $CO_x$, HC, odour, sulphur, visibility |
| - transportation related | particulate, $NO_x$, $CO_x$, HC |
| - during irrigation | aerosolized enteric pathogens during wastewater irrigation. |

Source: Canter 1986 (air pollution by other farm activities is treated in depth in Loehr 1976)

The proportion of various emissions produced by **agriculture** is estimated to:

| | | |
|---|---|---|
| methane | 40-60 % | paddy, livestock, biomass burning |
| nitrous gases | 10-25 % | fertilisers, biomass burning |
| ammonia | 80-90 % | livestock, wastes, paddy |
| other combustion gases | 60-65 % | biomass burning |
| particulates, smoke | 60-65 % | biomass burning. |

Source: Pretty/Conway 1989, using other sources

During tillage operations dust particles are injected into the atmosphere from the loosening and pulverisation of soils. Emissions can be significantly reduced when the soils are slighly moist. Under irrigation good water management soils are moist during field operations such that dust emissions under irrigation are lower compared with non-irrigated cropping practices.

## 5.2 Biomass Burning

Globally, biomass burning contributes approximately 10 to 20% of total annual $CH_4$ emission, 20 to 40% of CO, 5 to 15% of $N_2O$, and 10 to 35% of $NO_x$ emissions, in addition to contribution to atmospheric $CO_2$ emissions. Agricultural burning due to **shifting cultivation** and **pastureland** burning contribute more than 50% of all biomass burned annually. Agricultural field burning (including farm wastes, crop debris) can be a major source of carbon, sulphur and nitrogen pollution. However, this cannot be directly attrributed to irrigation

Fig. 5-1

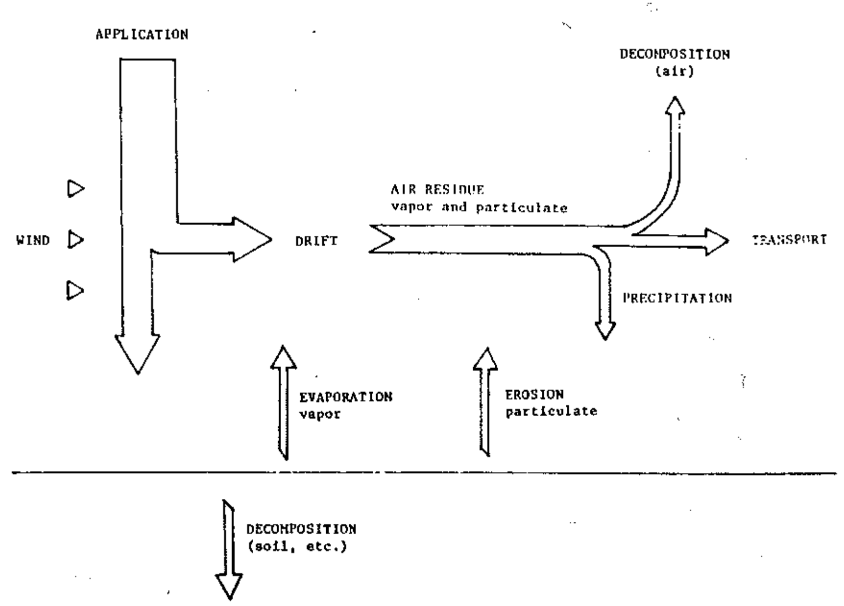



Figure 29: Sources and Fate of Airborne Residues Related to Pesticide Applications (Seiber, et al., 1980)

Source: Canter 1986





practices. Usually carbon monoxide and dioxide, nitrogen oxides, nitrous oxide, ammonia, methane and other hydrocarbons and various sulphur products are emitted during burning. In places, emissions can be of about the same quantity as those from wood refuse or open burning of municipal refuse, or - in the case of carbon monoxide - considerably higher, by a factor of 1 to 2.

Open burning of harvest residues is rarely practiced under irrigation and is more common in traditional non-irrigated farming and pasture or wildlife management. On the other hand, crop production usually increases under irrigation, and so do crop residues. These are often used in irrigated agriculture either for cattle feeding or as organic manure.

During land clearing large areas of natural shrub and woodland are converted to unvegetated land subsequently used for agriculture. Land clearing is practiced for rangelands, dryland and irrigated agriculture and often includes burning, either on-site or later as firewood. In some cases, the degree of land clearing and the amount of debris can be higher in irrigated areas compared with dryland (rainfed) agriculture, eg due to riparian woodland clearing, canal cleaning and higher crop residues. As yet, no estimate of the contribution of irrigation to the total budget are available.

Source: Canter 1986; Burke/Lashof in: Kimball et al. 1990

## 5.3 Other Pollutants

### 5.2.1 Introduction

Air pollution from agricultural vehicles may increase under irrigation because of increased farm mechanization. Pollution includes sulphur oxides and particles from the exhaust system, carbon monoxide, hydrocarbons, nitrogen oxides, and particulates from tyre wear. In developing coubntries, the emission control standards, where present, are less rigid than in industrialized countries and most vehicles are older aged. This usually implies considerably higher emission rates per unit in developing countries, although the number of vehicles is much lower than in industrialized countries.

Harvesting and grain handling can produce large quantities of particulate and hydrocarbon emissions. The magnitude depends on handling practices. In developing countries traditional practices often favour the emission of particulates (eg during drying and threshing of small grains) (Canter 1986).

Air pollution from pesticide/herbicide applications are significant during spraying operations. Appreciable quantities may drift under windy conditions and later on volatilisation occurs during evaporation (Fig. 5-1). The relative amounts of constituents of a given pesticide entering the atmosphere depend on the type of application method, weather conditions during application, its physical properties, chemical reactions and volatilization during evaporation. Drift losses, besides having implications on economics and efficiency, may pose a health threat to exposed on-farm and off-farm personnel and phytotoxic damages to non-target foliage may occur.

In developing countries, technical standards for safe pesticide operations are usually not adeqately followed by farm workers (and probably neither the personnel from extension services). Therefore, risks of pollution in developing countries are considerably higher than in industrialized countries where farmers are generally well trained.

In irrigated agriculture there is a trend to cultivate high yielding varieties or other crops which often require pesticide applications. Therefore, the risk of air pollution from pesticide applications is generally increased under irrigation.

Health. Dispersion of enteric pathogens in aerosols occurs during wastewater treatment and sprinkler irrigation. Under average conditions with sprinkler irrigation, between 0.1 and 1% of the liquid is aerosolised. Variable factors which affect pathogen survival and concentration are wind speed, sprinkler nozzle (orifice) diameter, water pressure, humidity, and radiation.

The initial density of microorganisms in the aerosols is a function of their concentration in wastewaters. This initial concentration is usually rapidly reduced by dilution, initial aerosol shock, biological decay, or die-away with time and distance downwind. Enteroviruses are least affected whereas survival rates of most bacteria are low, ie they die at a rate of 1.0 $log_{10}$ reduction per 100m distance. Enteric bacterial indicators are usually found within 400 m distance from the source with maximum distances being 1.0 to 1.2 km. Typical concentrations of microorganisms range from 1-100/$m^3$. Thus a person may respire 10 to 1000 airborne microorganisms daily. Therefore, sprinkler irrigation with wastewaters pose a potential risk of disease transmission to farmworkers and to people living within the vicinity, since some bacteria and viruses cause infections by the respiratory route (see also sections 3.6, 8.1 and Part II 4 and 5.2).

Sources: Shuval et al. 1986; see also: Hillman in: Biswas/Arar 1988; WHO 1979

## 5.2.2 Nitrous Oxide

Other air pollutants may include pollens, odours and several nitrogen forms. Odours in irrigation projects may be caused by organic decay in stagnant water in drainage canals and by processing industries. **Nitrogen** losses are more important. It is estimated that approximately 90% of all $N_2O$ is of biogenic origin. Further research is needed to define the proportion of $N_2O$ originating in different ecosystems (eg irrigation). Recent estimates assume that from a global emission of 8 to 22 M t/y, nitrogenous fertilisers and biomass burning contribute 0.14 to 2.4 M t/a and 1 to 2 M t/a, respectively (Burke/Lashof). The most important single source is given by natural soils which account for >40% of total global $N_2O$ emissions.

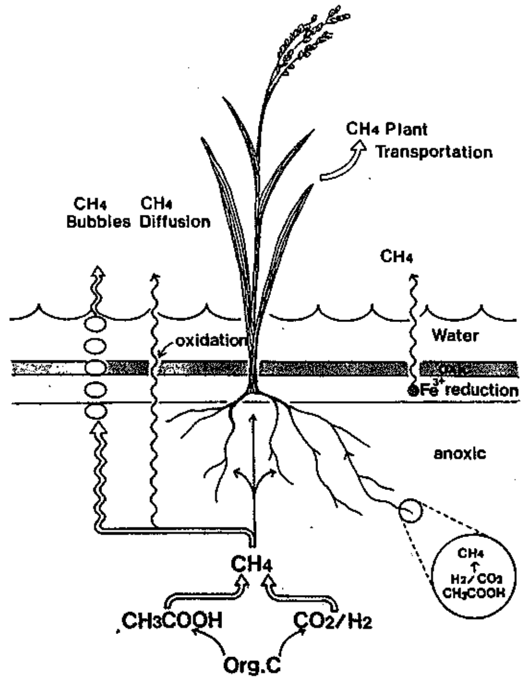
Special attention must be paid to areas with high rates of organic matter and N-turnover such as (tropical) rainforests, areas with marked dry-wet seasons (semiarid regions) as well as heavily N-fertilised areas. It is estimated that some 10-20% of the applied nitrogen fertiliser is released into the atmosphere, ie converted by bacterial action to $N_x$ and nitrogen oxides, and volatilised (Canter 1986). Other estimate suggest that 30-40% of nitrogen is volatilised (see section 2.3).

**Fertilized** soils often emit about 2 to 10 times as much NOx as non-fertilised soils. Practices affecting fertiliser-derived $NO_2$ emissions include fertiliser type, amount of fertiliser application, tillage practices, use of other chemicals, irrigation practices, type of vegetation, and residual N in the soil.

Natural factors such as temperature, rainfall, organic matter content, and soil pH also affect emissions. Ammonia losses can occur during application, but proper application can minimise losses. Ammonia losses from animal wastes and biomass burning are most important. Estimates suggest that the fertiliser-derived emissions of $NO_2$ are 0.5% N (of N-applied) for anhydrous ammonia and 0.1% N for ammonium types. Nitrous emissions are likely to be higher with increased fertiliser applications, broadcasting rather than deep-placement, and when the soil is flooded intermittently. It can be deducted from general observations that **irrigation** may contribute to **increased** N-losses as a result of intensification of agricultural production: fertilisation rates are higher, organic decomposition is increased, organic matter is applied at higher rates, and soils are more often prone to drying-wetting cycles.

Sources: Burke/Lashof in: Kimball ed. (ASA) 1990; Conway/Pretty 1988; Canter 1986; Bolle et al. in: Bolin et al. (UNESCO) ed. 1986

Fig. 5-2




*Methane production in wetland rice fields (after Wada & Takai, in Scharpenseel et al., 1990)*

Source: Scharpenseel ed. 1990

Fig. 5-3

GREENHOUSE GAS EMISSIONS 35

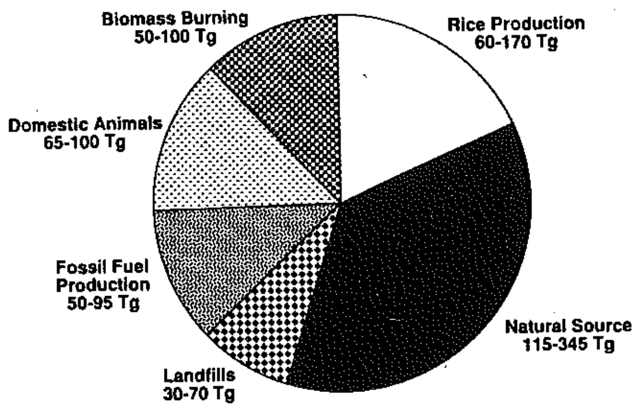



Fig. 3-4. Current global annual emissions of $CH_4$ by source. (teragrams $CH_4$ $yr^{-1}$). Human activities in the agricultural sector (domestic animals, rice production, and biomass burning) are major sources of atmospheric $CH_4$. Natural sources from wetlands, oceans, and lakes probably contribute less than 25% to the global $CH_4$ budget (sources: Cicerone & Oremland, 1988; Crutzen et al., 1986; Lerner et al., 1988; IRRI, 1986).

Source: Burke in Kimball ed. (ASA) 1990

Fig. 5-4

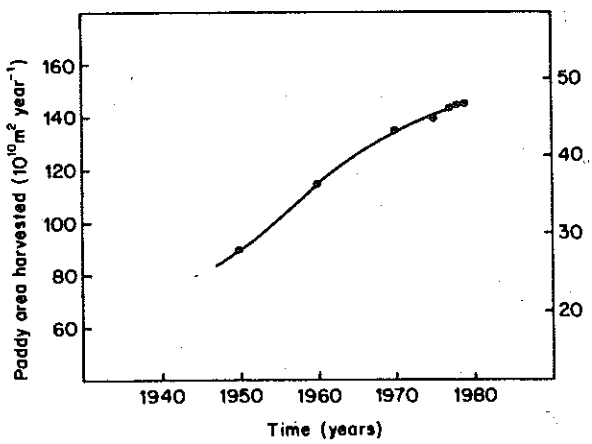



Figure 15.30 Temporal increase of the harvested area of rice paddies and the corresponding global $CH_4$ emission. The calculated $Ch_4$ emission rates do not take into account the possible influence of mineral nitrogen fertilizer on the $CH_4$ production rates in paddy soils (Seiler *et al.*, 1984)

Source: Lal 1987





## 5.2.3 Methane

Methane ($CH_4$) is produced by bacteria during **anaerobic decomposition** of organic matter. Main **sources** include natural swamps and wetlands, oceans and paddy rice fields (Fig. 5.2). The total budget (on world scale) for methane is relatively well defined, but individual sources are poorly documented. About 70% of atmospheric methane is of **biotic** origin, the rest is fossil (ISRIC1990). Human activities contribute about 350 out of the 550 M t total annual emissions (Graedel/Crutzen 1986). Tentative estimates of global production rates of individual sources are presented in Fig. 5-3 and Tables 5-1 to 3.

Average emissions of methane from anaerobic decomposition in rice paddies during the growing season are estimated to range from 12 to 25 or 54 g/m$^2$ according to various measurements (cit. in: Lal 1987). Emission rates are affected by the particular growth phase of the rice plant, temperature, irrigation and water management practices (eg duration of inundation), fertiliser usage, presence of organic matter, rice species, and number of rice harvests (continuous growing). Manuring techniques enhance methane production. High yielding varieties (HYV), which have a higher grain-to-straw ratio than traditional varieties, produce less methane per unit of rice, due to a relative reduction in the amount of crop residue available for decomposition and the reduction of the maturation period which reduces the time period during which the paddy is flooded (Tables 5-4 to 6). These experiences are mainly from Europe and the USA; precise data from the major rice producing areas of Asia are still lacking and available data do not characterise the full range of water management regimes used under paddy rice production. However, research to decrease methane emissions into the atmosphere is now under way in the IRRI, Philippines.

> Example "rice species": Bacterial soil decompositions of organic matter in flooded rice produces methane. But most of this methane is broken down by oxidation. 80% of gas that escapes enters the atmosphere by pasisng from the roots up through the plant, which acts as a chimney. Smaller amounts bubble up or diffuse slowly from the soil through the water. Increased methane oxidation in flooded rice soils would mean less escape. Some rice varieties bring in more oxygen than others (Neue, project leader at the IRRI).

Other methane sources (see Fig. 5-3) are enteric fermentation (eg in the guts of cattle, other ruminants and wood-eating insects), burning of fossil fuels and biomass, decomposition of biomass and landfills, mining of coal and mining of natural gases.

The recent growth of areas under paddy rice cultivation has resulted in an increase in methane emissions (Fig. 5-4). Other sources estimate that rice production nearly tripled between 1950 and 1984, whereas the area under cultivation increased by only 40%. On the other hand, in most subhumid and humid regions rice is cultivated on former wetlands (swamps, marshes) and, hence, only the relative increase compared with natural emissions can be directly attributed to irrigation. Nevertheless, in the light of global implications of increased methane concentrations it may be desirable to increase mean on-farm rice yield rather than areas under production (Fig. 5-5).

Other strategies for limiting emissions are the removal and alternative uses of crop residues (eg for building materials or animal fodder), although this will reduce soil fertility. Also, improved fertilisation practices such as direct placement during (trans)planting, could increase crop yields with no concomitant increase in $CH_4$. Improved understanding of the factors controlling methane emissions is important and quantifications of processes are required. Appropriate soil and water management practices, breeding of new varieties, and a shift to upland varieties may contribute towards reducing emissions.

Sources: Burke/Lashof in: Kimball ed. (ASA) 1990; ISRIC 1990; Lal 1987; Graedel/Crutzen 1986; Wada/Takai in: Scharpenseel et al. 1990;

Fig. 5-5

GREENHOUSE GAS EMISSIONS 29

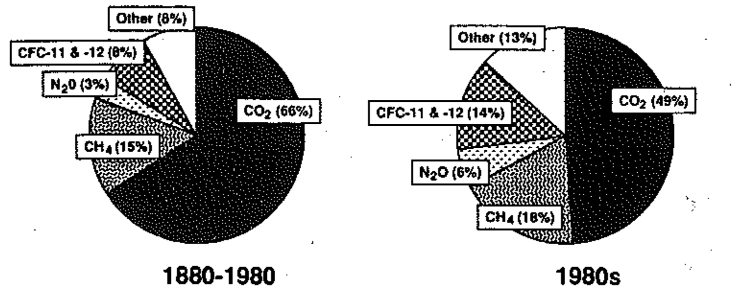



Fig. 3-1. Relative contributions to the increase in the greenhouse effect. Greenhouse gases other than $CO_2$ account for about half of the increases in the greenhouse effect in the 1980s. The "other" category includes halons, tropospheric $O_3$, and stratospheric water vapor (sources—1880-1980: Ramanathan et al., 1985; 1980s: Hansen et al., 1988).

Source: Burke in Kimball ed. (ASA) 1990





## 5.2.4 Particulate Emissions

Impacts mainly include dust (particulate pollution) and reduced visibility resulting from wind erosion. Dust is produced by high wind speeds in considerable amounts when the protective vegetation is diminished, either naturally in deserts or due to human interferences in semi-arid and humid regions (see Chapter 3.4). Wind erosion is a natural process in all climates. However, semiarid and arid areas are highly prone to wind erosion due to limited vegetative cover of soils resulting from soil moisture deficits and high wind velocities.

Regarding particulate pollution, **positive** and **negative trends** can be attributed to irrigation:

- in arid regions the vegetated area under irrigation usually increases during all seasons. In addition, the establishment of shelterbelts and windbreaks contributes to the reduction of wind speed and hence wind erosion and dust derived from irrigated lands is reduced. There is usually only a limited off-site impact,

- in semiarid areas, under natural conditions, a sparse vegetative cover exists. In areas with high population densities, extented livestock keeping and dryland agriculture, many areas become degraded and wind erosion may be as important as in arid areas. Under irrigation the length of the cropping season is extended and soils are moist for longer periods compared with dryland farming. Therefore, under irrigation, detrimental effects of wind erosion are generally reduced and dust production decreases,

- irrigated fields in subhumid areas may be temporarily or seasonally bare, whereas the surrounding natural areas are densely vegetated. However, wind erosion is usually not significant in subhumid and humid areas. Furthermore, non-irrigated agricultural areas are usually more exposed to wind erosion because they are fallow in the dry season, whereas irrigation is usually practiced in the dry season. Therefore, irrigation in subhumid areas has usually a minimal impact on dust pollution when compared to other arable land use systems.

Occasionally, detrimental impacts may occur from abandoned irrigated lands once saline accumulations have developed on soil surfaces. These lands usually have a very scattered vegetation cover and they are prone to severe wind erosion. Consequently, saline particles may be distributed with the dust over vast areas. Saline dust depositions occur in many arid areas under natural conditions, being derived from the surroundings of saline lakes. In this respect, irrigation may contribute to off-site saline dust pollution in addition of the natural cycles. Large scale impacts are known from irrigated lands in the southern CIS-states (eg Lake Aral).

Occasionally, health impacts may occur in areas where (human) excreta or other forms of organic manure are used for soil fertilisation and these excreta are partially transported as solid particles over considerable distances during dust storms. The persistance of many pathogenic microorganisms is a potential risk for airborne disease transmission, not only for farmworkers but also for populations working or living in the vicinity (see section 8.1).

## 5.3.5 Summary

Air pollutants from various agricultural activities have the potential to cause damage to other plants and animals and contribute to global air pollution. Compared to the effects of air pollutants from industrial or other human sources, agriculture has relatvely little impact on large scale air-borne emissions of toxic substances. Potential problems related to soil contamination or health impacts exist on-farm and in the vicinity by the inappropriate use of **pesticides** and by sprinkler applications of **wastewaters**. A number of effective remedial measures exist for control (see Part II sections 2.5 and 4).

More important are emissions of radiatively active **gases**, especially N-emissions and methane. A tendency of **increased** emissions under irrigation is observed because of intensified agricultural production, however, the balance of ecological trade-off must consider the increased yields from irrigated fields. These emissions may be only partly controlled or avoided by technical innovations or new operational practices.

Irrigation may have beneficial overall impacts with regard to a considerable reduction of dust pollution. Irrigation, in this respect, can be regarded as a mitigating measure to fight seasonal or annual soil moisture deficits, ie drought, which contributes to air pollution in agricultural production systems.

Sources: Kimball ed. 1990; ISRIC 1990; Canter 1986, Pretty/Conway 1989

Further readings in: Mathy ed. 1986; Scharpenseel et al. (ed) 1990; Scharpenseel/Hamadi (ed) 1990, Bolin et al. ed (UNESCO) 986

# 6 Impacts on the Microclimate

Impacts on climatic elements may occur on the meso- and microclimate levels. Impacts from irrigation schemes may be caused by irrigated fields and open water surfaces, associated larger water reservoirs, and occasionally fish ponds (eg in rice cultivation). Typically, off-site impacts of irrigation are only marginal.

## 6.1 Large Reservoirs

There are no confirmed reports of significant changes in the vicinity of small reservoirs serving for irrigation supply. Mesoclimatic influences are usually attributed only to large reservoirs with areas exceeding about 10 $km^2$. Large reservoirs of some thousand $km^2$ may have influences on climatic elements at a distance of some 15 to 25 km from the water body, although significant changes are usually confined to the lakeshores.

Changes of temperature, air humidity, windspeed and direction, cloudiness and precipitation are reported from the USA and the CIS. Investigations on **rainfall** and cloudiness at Lake Nasr/Aswan High Dam, Lake Volta, Lake Kariba and in India showed that changes are insignificant. **Temperature** changes in the vicinity of large reservoirs are more likely, and generally a lower temperature up to about 3 °C can occur. During nighttime and in the cool season higher lake water temperatures may result in slight increases in temperature in neighbouring areas. Air humidity changes can become significant if hot, dry air masses pass over large reservoirs and moist air advects into adjacent areas. **Wind speed** and turbulence may increase due to pronounced land-sea differences in surface temperatures and convection. The magnitude of changes depends on specific orographic features and macroclimatic conditions; thus generalizations should be avoided.

Sources: Baumann et al. 1984; Panella (ICOLD) 1973

## 6.2 Irrigated Areas

Irrigated soils have a distinct influence on the microclimate caused by changes in soil water status and by wind erosion control measures. The magnitude of effects depends on the climatic characteristics of the areas under irrigation. Changes are significant in arid areas, seasonally significant in semiarid regions and less significant in semihumid or subhumid regions. Impacts are usually beneficial for crop growth because they minimise or reduce harsh climatic factors. In this respect, wind erosion control measures which reduce windspeed, namely windbreaks and shelterbelts are most important. Their efficiency depends mainly on the barriers composition, shape, width, and porosity.

The following effects on microclimate caused by irrigated cropland can be derived from generalised observations:

- Slightly reduced <u>short-wave radiation</u> in the shading areas (eg windbreaks),
- Slight interception of <u>long-wave outgoing</u> radiation through the whole day (effect on evaporation, temperature),
- Slight effect on <u>temperature</u>: modifications depend on changes in soil moisture status and turbulence of the air masses. At low windspeeds in sheltered areas (low turbulence and advection) temperatures of dry soils are usually slightly higher during daytime and lower during the afternoon and night. During the morning hours when the heat balance is positive, the windbreaks produce a warming effect and the vertical temperature gradient is higher than in unprotected areas (unless the area is shaded). In the afternoon, when the balance is negative, windbreaks produce cooling effects; the heating and cooling of air results from contact with the surface of the soil and the vegetation which receive and impart energy by radiation. Thus the lower air layers are warmer than the higher ones when they receive energy by ra-

Fig. 6-1

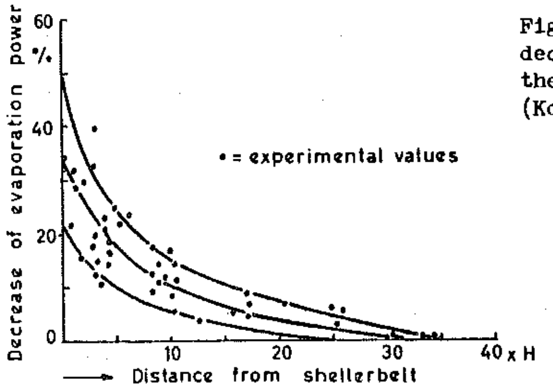



Figure 56 - The dependence of the decrease of evaporation power upon the distance from shelterbelt (Konstantinov and Struser, 1953)

Source: van Eimern 1964





diation and cooler when they impart it. With decreased windspeed (advection forces) the vertical and horizontal exchange is lower.

Reduced radiation (eg cloud cover; seasonal changes) lowers the effect of windbreaks. High windspeeds reduce the effects of shelterbelts on temperature. The areas close to the shelterbelts or windbreaks show different changes in temperatures, caused by interception of outgoing radiation and reflection. Temperatures are usually higher in the morning and during nights, except in shaded areas.

Without considering the cooling effects of evaporation, it seems that windbreaks increase daily average temperatures in sheltered areas. In Europe the effect is in the range of 0.5 to 2.0 °C, but in areas with higher incoming radiation the effects may be more pronounced. It may be expected that in dry, hot summers the effects on crops can be slightly detrimental, but in dry, cool winter time the effects are beneficial. Experiences from the (former) USSR have shown that increases may be harmful to some summer cereal crops, but beneficial to sunflowers, maize and soyabeans. Frost hazard may be increased by shelterbelts due to low advection, especially in sloping areas; although this may be compensated for by slightly reduced outgoing long-wave radiation during night hours.

In arid areas, however, the assessment of temperature changes is complicated due to the fact that high actual evaporation of irrigated soils has a cooling effect. This cooling effect may completely compensate the other effects which contribute to a temperature increase, especially during light winds.

The cooling effect is greater under sprinkler irrigation than surface or drip irrigation. With the latter method only soil and plant surfaces contribute to cooling, whereas under sprinklers significant portions of the water evaporates before reaching the ground (up to 50% may be lost). The magnitude of temperature changes depends on actual water management practices and soil-plant-atmosphere characteristics and may range from almost zero to several degrees.

- The influence on air humidity is not uniform. Generally, relative and absolute air humidity increases and the amount of dew fall increases. The magnitude of changes again depends on water management, irrigation type and soil-water-plant characteristics. Under sprinkler irrigation, the air humidity increases significantly. Higher relative air humidity usually occurs during the early morning and late afternoon in protected areas.
- Changes in temperature, windspeed and air humidity will result in changes of evaporation from soil surfaces and crops. Generally, potential evaporation will be significantly reduced in sheltered areas. The main effect is attributed to reduced advection, but higher air humidity over irrigated areas also contributes to reductions. Tentatively, the overall reduction is in the range of 10 to 30% over a distance of 20 times the height of the belt (Fig. 6-1). The actual evaporation increases with supply of sufficient moisture, and in wet soils the actual evaporation may be close to the potential evaporation. The effect of reduced evaporation is higher during calm days with low to moderate advection. The reduction is partly compensated by increased convection, which is caused by higher temperatures under calm conditions.
- Theoretically soil moisture depletion will be reduced in accordance with lower potential evaporation. As most water saved by reduced potential evaporation will be used for actual consumptive evaporation by plants, the use of field moisture data without consideration of actual increase in dry matter production is meaningless. This effect was shown by investigations in the CIS (USSR): in sheltered areas total evaporation increased from 173 to 217 mm but soil evaporation amounted to only 52% in open areas and 37% in sheltered areas.

The following data illustrate the effects, although they are only indicators of the significance and absolute values will depend on local conditions

| | |
|---|---|
| reduced windspeed behind windbreaks | 30 to 47% reduction (USSR; Blüthgen 1966) |
| reduced potential evaporation | 34 to 47% reduction (USSR; Blüthgen 1966) |
| reduced windspeed (average) | 39% reduction (FRG. Kreutzer in: Blüthgen) |
| reduced potential evaporation | 19% reduction (FRG. Kreutzer in: Blüthgen) |
| increased air humidity above ground | 19% reduction (FRG. Kreutzer in: Blüthgen) |

Agro-climatological data from semi-arid Botswana (Petermann unpublished 1990) showed microclimatological differences between areas under flood recession farming, sheltered by an irregular mesorelief and riparian treelines, and adjacent dryland areas without shelter:

- mean annual temperatures are lower (1 °C) in sheltered areas,
- temperature differences are greater for Tmin than for Tmax, ie 2 to 3 °C and 0.5°C
- differences are higher during the dry cool season than during the hot rainy season
- gound frost (ie air temperature below 3 °C) occurs more often in sheltered areas
- average relative air humidity is about 10% higher in sheltered areas in the dry season
- reduction in daily windspeed amounts to some 50% in sheltered areas
- potential evaporation is reduced by 10 to 20% in sheltered areas.

The impact of irrigation on absolute air humidity is obvious because irrigation is used for mitigating drought. The impacts increase with increased aridity of the region. Any water applications to soils will always result in increased moisture releases to the air through evaporation from both plants and soil. The effect of increased air humidity, however, is confined to the air strata immediately above the irrigated areas and with advection (slight wind) the effect is lost within about 10 to 20 times the horizontal extension of the areas (estimate derived from effect of shelterbelts on air flow). It is assumed that an increase in air humidity does not have any significant effect on adjacent ecosystems or human settlements.

Reference: van Eimern ed. (WMO) 1964; FAO 1962, Berenyi 1967; Blüthgen 1966

Fig. 7-1

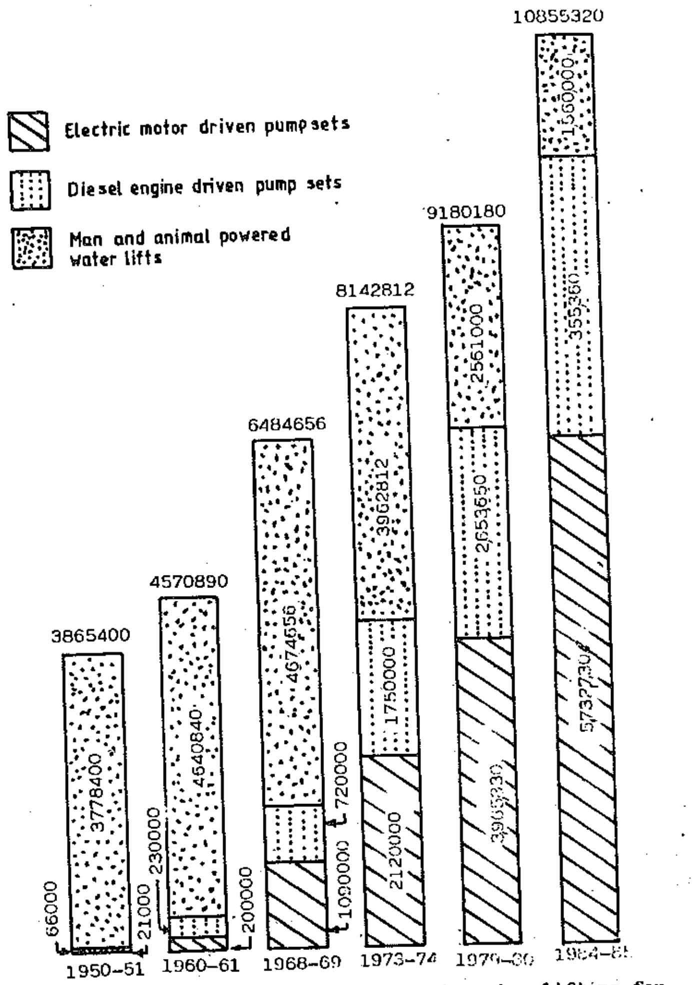



**Figure 2.** Progressive mechanization in water lifting for irrigation. The figures at tne top of the bars show the total number of pumps and water lifts

Source: Michael in ICID 1990

12

SPECIAL SESSION - R.1

Fig. 7-2

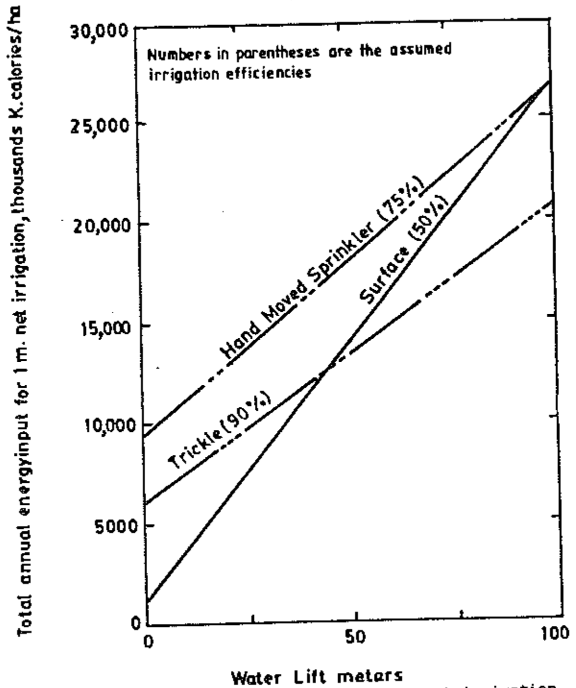



**Figure 3.** Energy requirement for different irrigation application methods (Exigence d'energie pour des méthodes d'application différentes de l'irrigation.

Source: Keller in ICID 1990





# 7 Impacts on Energy Resources and Related Problems

Energy requirements for various farming systems differ substantially. Irrigation systems are typically more mechanised than non-irrigated systems, as a result of substitution of labour. Thus, they require more energy for water lifting, farm operations, off-farm activities (processing) and the provision of farm supplies (fertilisers, pesticides, machines, etc.).

## 7.1 Traditional Irrigation Systems

Generally, energy has always played a critical role in many irrigation systems, either through its limited availability at the time of demand or high costs involved. Before the widespread use of fossil fuels for pumping, the availability of human or animal muscle power was a major constraint to irrigation development. In other words, in traditional systems, the amount of water available for irrigation was limited by the availability of human and animal **labour**. They, in turn, consumed a considerable proportion of the crops and fodder produced on irrigated fields. Apart from watering crops, human and animal power was needed to build and maintain irrigation schemes, as well as dams, reservoirs, levees and canal systems, and for land development and farming operations, such as land levelling and the construction of ditches and furrows.

> Ancient studies in Egypt in 1800 showed that the energy input (in terms of the average labour requirement) in traditional irrigation systems for the five main crops was 115 work day per ha per crop and that nearly one quarter of power expended in agriculture was used to apply irrigation water. Some 255 KJ of human energy was metabolized to lift 1 $m^3$ of Nile water three meters from the irrigation canal to the field, some 9 times the theoretical minimum energy requirement for lifting the water. In the modern USA systems, the labour needed to irrigate 1 ha varies from a maximum of 40 work-hours (hand-moved sprinkler) to a minimum of about 1 work-hour for drip or center pivot systems. In Egypt, 100 work-days of labour were needed in 1800 to irrigate the same hectare of maize.
>
> Source: Stanhill 1984

## 7.2 Modern Irrigation Systems

In modern irrigation systems the annual variable costs of energy may be in the range of some 25 to 40% of total fixed and variable on-farm costs (in Brazil. Rodriguez et al. in: ICID 1990). In US farming, irrigation requires about 17% of the total farm energy requirements, including costs for fertilisers and other farm inputs (Hughes 1980). The progressive mechanisation in water lifting for irrigation in India (45 M ha) is shown in Fig. 7-1. From 1950 to 1985, mechanized pumping units increased from fewer than 70,000 to more than 9,000,000, whereas the number of man- and animal powered units decreased by more than 50%.

The energy required for different types of irrigation is indicated in Fig. 7-2. In total, the average annual consumption of energy in India over the period 1980-1987 is 83 M t of oil equivalent (1 t OE = 10.2 M KJ). Agriculture is accounting for 2.4 % and irrigation uses 60 % of the agriculture total, ie 1.5% of total energy. The energy is obtained from burning of fossil fuel (coal, diesel, gasoline) and from hydropower. The use of renewable sources is almost non-existent (Michael et al. in: ICID 1990). In Brasil, about 1% of the total annual energy consumption is used by irrigation (Rodrigues et al. in: ICID 1990).

A complete analysis of the energy requirement of an irrigation system will consider the energy required to **manufacture** the different components of the system and transport from the manufacturer to the site, and energy related to the water **supply** and **distribution system**. In the case of groundwater supply, additional energy requirements occur during dril-

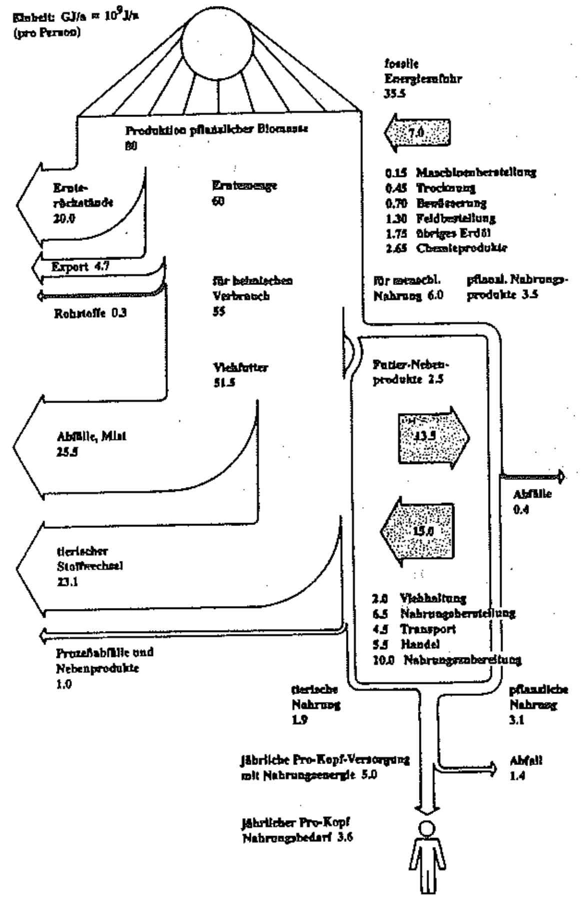
Fig. 7-3

**(R3.8) Eine moderne Nahrungsmittelversorgung arbeitet mit einem Gesamtwirkungsgrad von etwa 3.1% : Um die erforderlichen 3.6 GigaJoule Nahrungsenergie für die Jahresversorgung eines Menschen zu erzeugen, müssen 80 GJ an Biomasse unter Einsatz von 35.5 GJ fossiler Energie erzeugt und verarbeitet werden. Der Aufwand an fossiler Energie ist zehnmal so hoch wie die Energie in der Nahrung!**

**Beispiel USA (GJ/a):** Der Energieinhalt der erzeugten Biomasse = 80 GJ, davon gelangen nur 3.1 als pflanzliche Nahrung direkt in die menschliche Ernährung. Etwa 90% der Erntemenge dient der Erzeugung tierischer Produkte in Höhe von 1.9 GJ.

```
Energieinput      = 80 + 7 + 15 + 13.5 = 115.5
Energieoutput     = 1.9 + 3.1 = 5
Ernährungsenergie: 10 MJ * 365 = 3.6
Wirkungsgrad der Umwandlung = 3.6/115.5 = 3.1%.

Aufgewendete fossile Energie: 7 + 15 + 13.5 = 35.5
Verhältnis fossiler Energieaufwand zu Nahrungsenergie =
35.5/3.6 = 10
```



Die intensive Landwirtschaft und industrielle Verarbeitung erfordern etwa zehnmal mehr fossile Energie, als (als Nahrungsenergie) in der gelieferten Nahrung steckt (ähnliche Verhältnisse für Westeuropa).

Fig. 7-4

**(R3.9) Traditionelle landwirtschaftliche Verfahren sind wesentlich energieeffizienter, allerdings bei geringeren Hektarerträgen.**

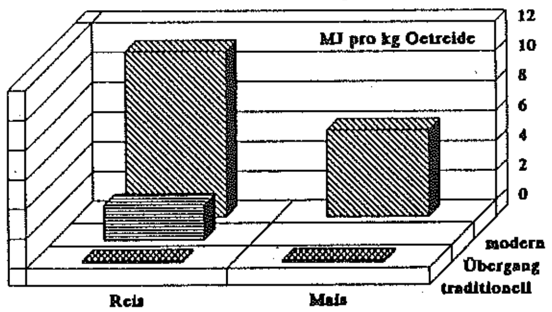
Traditionelle landwirtschaftliche Methoden erfordern einen wesentlich geringeren Einsatz an kommerziellen (vor allem fossilen) Energien. Ähnliches gilt auch für extensive Viehhaltung. Die unrationelle Energienutzung in der modernen Landwirtschaft läßt sich nur durch höhere Hektarerträge rechtfertigen.

**Beispiel:** Beim Reisanbau nach traditionellen Methoden werden für einen kommerziellen Energieeinsatz von 1 Einheit 107 Einheiten gewonnen; bei modernen Reisanbaumethoden ist das Verhältnis nur noch 1.34.

Energieinhalt von Reis: 15 MJ/kg

**Traditioneller Reisanbau (Philippinen):**
Energieaufwand für Maschinen und Geräte): 0.173 GJ/ha
Ernteertrag: 1250 kg/ha
Energieinhalt des Ertrags: 1250 * 15 = 18.75 GJ/ha
Verhältnis Nahrungsenergie/Energieaufwand: 108
**Moderner Reisanbau (USA):**
Energieaufwand für Maschinen, Geräte, Treibstoff, Dünger, Bewässerung, Biozide, Trocknung, Transport u.a.: 64.9 GJ/ha
Ernteertrag: 5800 kg/ha
Energieinhalt des Ernteertrags: 5800 * 15 = 87 GJ/ha
Verhältnis Nahrungsenergie/Energieaufwand: 1.34

**ENERGIEAUFWAND**
**hoher fossiler Energiebedarf**




Sources: Boesel 1990





ling, pump tests and well construction, and reservoir construction also involves a variety of energy consuming activites.

A complete energy balance for a modern US-farm is shown in Fig. 7-3. Figure 7-4 comapares the engergy balance of a traditional rice scheme in the Phillippines and the modern scheme in the USA.

Furthermore, on-farm energy requirements arise during land preparation and construction and may include:

- levelling, vegetation clearing, grading, subsoiling
- irrigation infrastructure construction, eg intakes, canals, distribution structures,
- construction of drainage systems, eg subsurface systems, ditches, collector drains, etc.

Also the construction of farm houses, farmsteads and farmroads consumes energy. In modern irrigation systems, this so-called 'embodied energy' is of minor significance, ie some 5 to 10% of that used to transport the water. In ancient Egypt, the embodied energy for canals amounted to some 25 KJ per $m^3$ (Stanhill 1984).

In addition, there will be an annual energy requirement for most systems, generally for pumping water from wells, rivers or reservoirs to the fields and for pressurising the water if so required by the system.

The energy required in manufacturing is high for sprinkler and drip irrigation systems. On the other hand, surface systems requires considerable site preparation which is labour intensive or uses heavy machinery. Water supply costs are typically higher with groundwater supply systems (except if groundwater is lifted by renewable resources, eg wind and solar pumping systems) than by systems with supply from rivers or reservoirs which often use gravity for conveyance.

The actual manufacturing, construction and operation energy requirements differ substantially, depending on site conditions and farming systems.

In wastewater irrigation systems, energy is used to treat water of inferior quality so that it can be used for irrigation (see Part II sections 2.5 and 4). The amounts of energy involved vary with the type of treatment, the concentration of pollutants and the water quality standards. To convert municipal effluent into water suitable for irrigation, approximately 10 MJ of energy per $m^3$ are required (Stanhill 1984).

## 7.3 Energy Requirement Versus Water Use Efficiency

Systems with a low water application effiicency will use more water per unit of crop production and operation cost per unit may be higher than in automatized systems with higher manufacturing and construction costs.

To illustrate the trade-offs between energy and water the total energy requirements of various systems are compared (Stanhill 1984):

| | | gravity-supply | 100 m lift |
|---|---|---|---|
| surface system | 50 % efficiency | 3.7 GJ | 110 GJ |
| hand-moved sprinkler system | 75 % efficiency | 38.3 GJ | 109 GJ |
| drip system | 90 % efficiency | 24.9 GJ | 103 GJ |

1 barrel of oil is equivalent to 5.5 GJ; the figures indicate only the variation in energy requirements; absolute figures are only valid for the special case under investigation.

Hence, substituting a sprinkler system for flood irrigation in a situation with a gravity supply results in a 90% energy save. Converting a sprinkler to a drip system saves a similar volume of oil equivalent for each $m^3$ of water saved, due to the lower operating pressure.

When water must be pumped to a significant height (eg 100 m, above), the energy cost for lifting the water increases enormously, so taht the costs of applying water by alternative irrigation systems hardly vary, despite different system efficiencies giving different water requirements (Stanhill 1984).

It is evident that there are no simple and general answers to the energy problems in irrigation and each location requires an assessment individual so that the energy costs of different irrigation systems can be balanced against their water-, labour-, and capital costs. Further issues relating to energy saving measures are dealt with in Part II section 5.4.

Sources: Kruse et al. in: Stewart et al. ed. (ASA) 1990; Michael et al. in: ICID 1990; Keller in: ICID 1990; Stanhill 1984

Further readings in: ICID 1990 Volume E; Batty and Keller in: Pimental ed. 1980

# 8 Impacts on Human Health

In many irrigation projects located in tropical or subtropical regions there has been serious impacts on human health. This stems from the fact that irrigation water enhances the spread of infectious human diseases. Examples of the spread of schistosomiasis can be cited from irrigation schemes in Gezira (Sudan), Tanzania, Swaziland, and Egypt. There have also been malaria outbreaks reported in Tunisia and river blindness (Onchocerciasis) in Central America and Africa (Zonn 1979). On the other hand, drainage facilities in irrigation projects or drainage projects for wetland development are explicitly, amongst other benefits, aimed at controlling human diseases (Holy in: ICID 1975).

The range of human diseases associated with water is summarized in Table 8-1. In the context of this review water-washed faecal-oral and wastewater induced public health impacts are outlined in section 8.1. Other vector-borne diseases are treated separately in section 8.2. Health control measures are introduces in Part II sections 2.5 and 4.

Sources: Zonn 1979; UNESCO (MAB 8) 1978; Coumbaras in: COWAR 1976; Holy in: ICID 1975

Further readings: Oomen et al. 1990, Tiffen 1991, Birley 1991, WHO 1980, COWAR 1976; ICID 1975

## 8.1 Health Risks from Reuse of Sewage Effluent for Irrigation

Domestic wastewaters and excreta can carry the full spectrum of fecally excreted human pathogens endemic in the community. This includes viruses, bacteria, protozoans, and helminths (Table 8-2). Their concentrations and their persistence are often great enough to create the potential for human infections. The mere detection of a pathogenic microorganisms in water, soils, food crops or the air, is not in itself proof that human beings are in fact becoming infected or sick as a result of contact or exposure to that pathogen.

In some regions, irrigation is considered an efficient method of waste disposal, in addition to other land treatment approaches. However, in arid regions, the scarcity of water makes its conservation a matter of survival. The reuse of wastewater in agriculture is therefore expected to rise in future. It is estimated that by 1987 some 540, 000 ha worldwide (excluding China with some 1.3 M ha) were irrigated with treated or pre-treated wastewater; most of these areas are located in India and Mexico, but also Peru, Chile and Tunisia, others in Germany, USA, Australia, Israel and the Near East (Bartone/Arlosoroff, cit. in: Mara/Cairncross WHO 1989).

Growing interest in issues dealing with the reuse of wastewater effluent in irrigation has resulted in a steadily growing number of publications dealing with engineering, health and environmental aspects. The following sections draw heavily on these sources, namely Oomen et al. 1990, WHO 1989, Mara/Caimcross 1989; Birley 1989, Shuval et al. (WB) 1986.

### 8.1.1 Pathogens

The infections in question are communicable diseases whose agents (pathogenic microorganisms) pass via the excreta of infected persons, eventually reaching other people, whom they enter via the mouth (eg consumption of contaminated food) or the skin (eg hookworm, schistosomiasis). There are about 30 excreta-related infections of major public health importance. They can be grouped into five categories according to environmental transmission characteristics (Table 8-3). Epidemiological features are shown in Table 8-4. Major helminthic, viral, bacterial and protozoal pathogens are listed in Tables 8-5a-b. Water-borne pathogens and their effects on health are shown in Table 8-6.

### 8.1.2 Health Risks and Epidemiological Factors

Any wastewater or excreta used in agriculture is a potential hazard which becomes an actual risk to health if all of the following criteria are met:

- either an infective dose reaches the field or the pathogen multiplies in the field
- the infective dose reaches a human host, either on farm or off-farm
- the host becomes infected
- the infection causes disease or further transmission.

If the sequence is broken at any point, the potential hazard cannot come to constitute an actual risk. Pathogen-host properties influencing the sequence of events are shown in Table 8-7.

Excreta and wastewaters always contain certain concentrations of pathogens and many of these arrive at irrigated fields where they may multiply. However, even if sufficient pathogens do reach fields, infections only occur if the infective dose is received by a susceptible host. This depends on (i) survival times of pathogens, (ii) presence of the intermediate host where relevant, (iii) mode and frequency of wastewater applications, (iv) type of crop to which wastewater is applied and (v) nature of exposure of the human host. Strategies to minimise these effects are discussed in Part II sections 2.5 and 4.

The persistency of pathogens in various environments has already been treated in section 3.6 (soil contamination). The most important concern is with pathogen survival rather than pathogen removal because health hazards are posed by pathogens that survive the treatment process. A removal figure of 99% may appear impressive, but the degree of survival may still be highly significant and a survival of 1% can be inadequate.

Another important intervening factor is host immunity with viral and several bacteriological diseases. Some endemic pathogens, such as enteroviruses, are obviously so infectious and so common in the household environment of the developing countries that most infants acquire lifelong immunity at an early age. Consequently, additional external environmental exposures do not lead to a quantifiable increase in disease levels, even under the most unsanitary conditions such as paddy cultivation when human or animal excreta are used.

In many countries multiple concurrent infections from contaminated water, food, and poor personal and domestic hygiene may be at such intensive levels that additional exposure by wastewater will not cause excess disease. However, when such routes are restricted or blocked (eg by improved domestic water supply and standard of living) exposure to the same level of pathogens may lead to detectable levels of disease. For example, this occured with the case of typoid fever and sewage irrigation in Santiago, Chile.

On a generalised level health burdens associated with common wastewater-related diseases can be ranked in the following descending order:

- hookworm serious debilitation, widespread infections of all age groups
- tapeworm moderate to serious
- ascaris, trichuris light for adults, serious for infants
- typhoid fever & cholera during times of epidemics very severe , and with serious economic implications, less serious under low-endemic level
- *shigellosis* seldom severe implications; serious for children
- enteric viruses mild or benign to quite severe; infants or children infected.

Sources: Oomen et al. 1990, Shuval et al. 1986.

### 8.1.3 Evidence of Quantifiable Health Impacts

An examination of credible evidence of quantifiable health effects from well-designed and validated epidemiological studies did not support the widespread view that wastewater irrigation contributes significantly to health hazards (Shuval et al. 1986). The conclusions of the World Bank/UNDP review are:

- crop irrigation with untreated wastewater causes significant excess infection by intestinal **nematodes** in consumers and farm workers (under poor health safeguards). Long-term repeated exposure results in severe debilitating effects,
- salad crops and other vegetables that are normally eaten **uncooked** and that are irrigated with raw wastewater can effectively transmit **helminth** diseases caused by Ascaris and Trichuris, as well as typhoid fever and cholera,
- crop irrigation with treated wastewater does not lead to excess **intestinal nematode** infection,
- cattle grazing on pasture irrigated with raw wastewater may become infected with beef **tapeworm** with little evidence of actual risk of human infection,
- limited circumstantial evidence that aerosolizd **enteric viruses** in poorly treated wastewater from sprinkler irrigation may be transmitted to infants and children,
- sewage farm workers with low levels of personal hygiene can become infected with **bacterial** diseases (eg cholera) and **parasitic** diseases (eg Ascaris, Trichuris),
- well-settled wastewater which has been retained over a sufficiently long period entails an efficient reduction in the concentration of helminths and protozoans; no evidence that exposed populations or consumers showed excess levels of ascaris or other parasitic diseases.

Agricultural use of <u>excreta</u> offers higher health risks caused by

i) considerably **higher concentrations** of pathogens in human or animal excreta than in either treated or raw wastewater
ii) less **rigid control** of excreta from domestic sources than from controlled treatment plants.

Experiences from Asia show that

- crop fertilisation with raw excreta causes excess infection with **intestinal nematodes** in both consumers and field workers
- excreta **treatment** reduces transmission of nematode infection
- fertilisation of paddy fields leads to excess schistosomiasis infection among rice farmers (see also section 8.2).

### 8.1.4 Assessment of Risk for Developing Countries

The following main variables contribute to effective transmission of pathogens by wastewater irrigation as compared with other routes of transmission (Shuval et al. 1986):

- long persistence in the environment
- low minimal infective dose
- short or no immunity
- minimal concurrent transmission through other routes (eg domestic hygiene)
- long latent period for development in soil required.

The epidemiological characteristics of enteric pathogens as related to these variables are listed in Table 8-8. Derived from field evidence, the pathogenic agents can be ranked in the descending order of risk for developing countriess under poorly treated wastewater irrigation and excreta applications:

1) high risks for **helminths** (intestinal nematodes, ascaris, trichuris, hookworm, taeniasis),
2) lower risks for enteric **bacterial** infections (cholera, tiphoid, shigellosis) protozoan infections (ambiasis, giardiases),
3) low risks for enteric **viral** infections (gastroenteritis, hepatitis),
4) **trematode** and **cestode** infections, eg schistosomiasis, taeniasis, chlonorchiases varying with circumstances, from high to no risks.

In countries where helminth diseases are not endemic risks may be limited mainly to bacterial and virus diseases, in that order. Wastewater treatment processes that effectively remove all or most of these pathogens could reduce or even eliminate the health effects known to be caused by untreated wastewater reuse (Shuval et al. 1986).

Sources: Feigin et al. 1990; WHO 1989, Mara/Cairngross (WHO/UNEP) 1989; Biswas/Arar 1988; Pescod/Arar 1988; Shuval et al. (WB) 1986

Further readings: Hillman in: Rydzewski ed. 1987; Cairngross/Feachem 1983; Feachem et al. ed. 1977

## 8.2 Other Vector-Borne Water-Related Diseases

### 8.2.1 Introduction

Irrigation brings with it profound ecological changes and in tropical regions these changes may have more severe impacts on health than in temperate climates. One reason is that vector-borne diseases are already a major public health problem in most developing countries, and ecological changes associated with irrigaton often lead to the explosive propagation of these vectors. Another reason is that the public health infrastructure in most developing countries is unable to cope with the increased burden of diseases (see Tiffen 1991). Unrealistic assumptions or projections by planners and politicians have contributed to the aggravation of existing health problems.

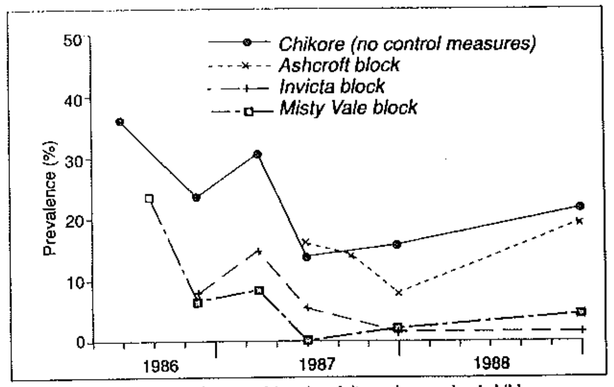
*Case Studies*

In India, malaria in rural areas increased with the area under irrigation:

| | | |
|---|---|---|
| year 1965 | 0.1 M incidents | 33 M ha irrigated land |
| year 1973 | 1.9 M incidents | 37 M ha irrigated land |
| year 1977 | 4.7 M incidents | 51 M ha irrigated land |
| year 1978 | 4.1 M incidents | 54 M ha irrigated lands. |

Source: Michael in: Biswas/Queping 1987. There is, however, still some debate as to whether the increase in malaria can be attributed solely to the development of irrigation; however, it is gene-

Fig. 8-1

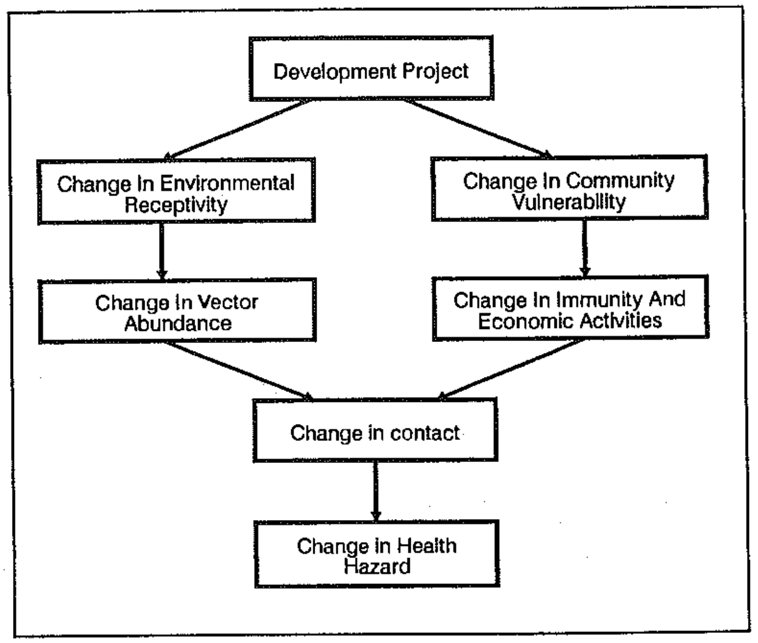



*Prevalence of schistosome haematobium in adults and non-school children. Control of aquatic snails is contributing towards a reduction in schistosomiasis transmission in two pilot areas, but other factors are counteracting this in the third.*

Source: Chimbari et al. in: Wooldridge ed. 199

Fig. 8-2

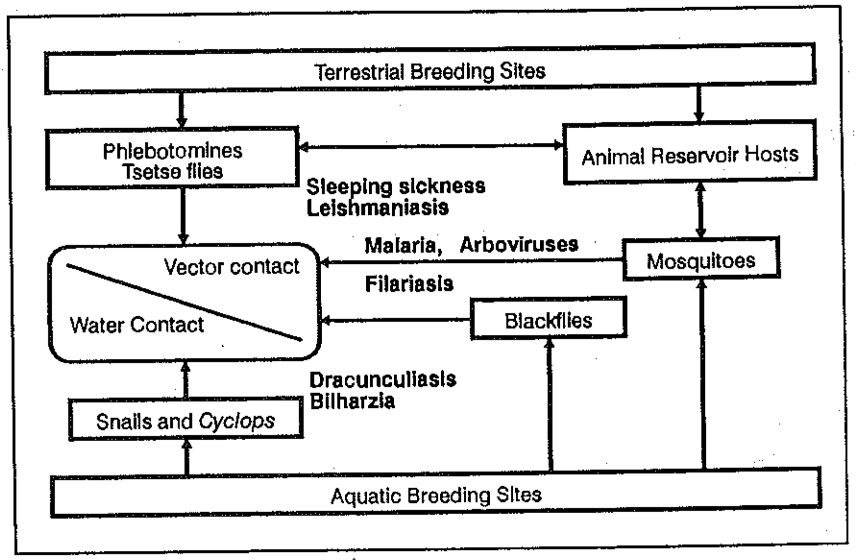
Figure 2-1 How development can affect health.




Sources: Birley 1992

Fig. 8-3

Figure 2-2
The pathways by which water resource development projects affect vector-borne disease transmission.








rally recognised that irrigation contributes to this increase (Biswas 1991). Case studies are cited later in this section. Further case studies are provided in: Goldsmith/Hildyard 1984.

In the Nile Delta, Egypt, prevalence of bilharzia is highest amongst farmers and fisherman:

| | |
|---|---|
| farmers and farm laboureres: | male 53%, female 43% |
| fisherman | 60% |
| all other occupations : | male 25%, female 25% (eg clerical: 21%) |

Source: Oomen et al. 1991:144. However, there are alos many examples which show that health controls can improve existing situations, eg in Zimbabwe (Fig. 8-1).

The close relationship between water use and public health is well established and it is not surprising that the development of irrigation has distinct impacts on the health of those who apply irrigation water or live within the vicinity of irrigated farms or reservoirs. Irrigation changes the environment (eg breeding habitats) and the community vulnerability which influence the contact with potential carriers of diseases (Figs. 8.1, 8-2). Consequently, health impacts should be regarded as an equally critical design parameter as the estimation of yield, water demand or land reclamation measures (Tiffen 1991).

Unfortunately there is ample evidence that the importance of health impacts have not been fully recognized by decision makers, economists, technical planners, extension workers or farmers. The example of bilharzia (Table 8-9) demonstrates this.

The spread of water-related diseases not only contributes to the ill-being of people but also to economic losses which should be considered in economic analyses:

*Case Studies*

In Egypt, it is estimated that bilharzia, one of the major water-related diseases, was in 1969 responsible for a direct loss of some 5% of the gross national product, on the basis that about 2% of the people had heavy clinical involvement or total disability, and that 31% had moderate disease with a working capacity rduction of 11%. In 1972, there was a 3 % loss in manpower in irrigation and agricultural sectors because of the disease, with a consequent loss of 0.25% in other sectors. (Agamieh, cit. in: Pike 1987).

In Tanzania, a study amongst sugar cane workers indicates that uninfected field workers were 5% more productive than infected ones (Fenwick/Jorgenson cit in: Pike 1987).

On the other hand, health is also related to development and irrigation is one means of agricultural development. There is historical evidence that the decrease in mortality and the increase in life expectancy in industrialized countries were associated with (1) decreased incidence of infectious diseases and (2) with improved nutritional standards (sufficient and balanced food supply), nutritional hygiene, drinking water supplies, and excreta disposal systems. Therefore, irrigation contributes to increased incomes, albeit with a considerable time lag in most developing countries, which in turn has an overall positive impact on health.

Sources: Oomen et al. ed. (ILRI) 1990; Hillman in: Rydzewski ed. 1987

Remark: This section draws heavily on recent publications by PEEM (Panel of Experts on Environmental Management for Vector Control), WHO/FAO/UNEP, namely Birley 1989 and WHO 1989 and on the ILRI publication: Omen et al. 1990

## 8.2.2 Types of Diseases

Vector-borne infections are characterised by one (or more) intermediate host(s) which are necessary for the transmission to occur. They are not distributed uniformly through a region but occur in relatively discrete patches where the habitat and climate are favourable. The hosts may be insects or aquatic animals. Vector-borne transmission can be mechani-

Fig. 8-4

Table 2-3
The principal diseases associated with water in relation to the principal habitats of the vectors.

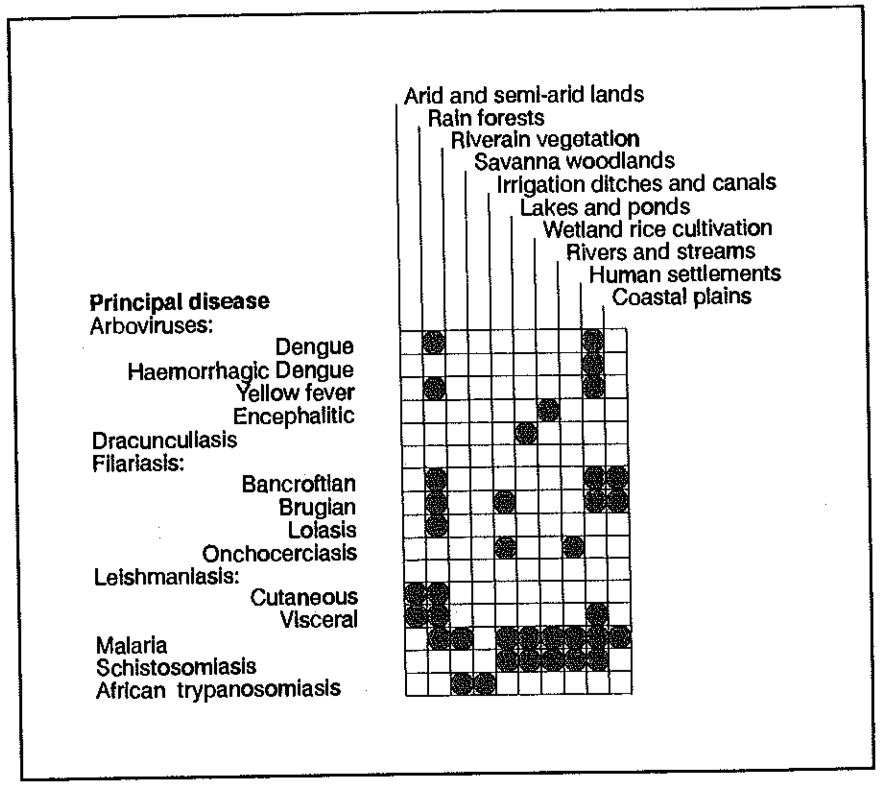
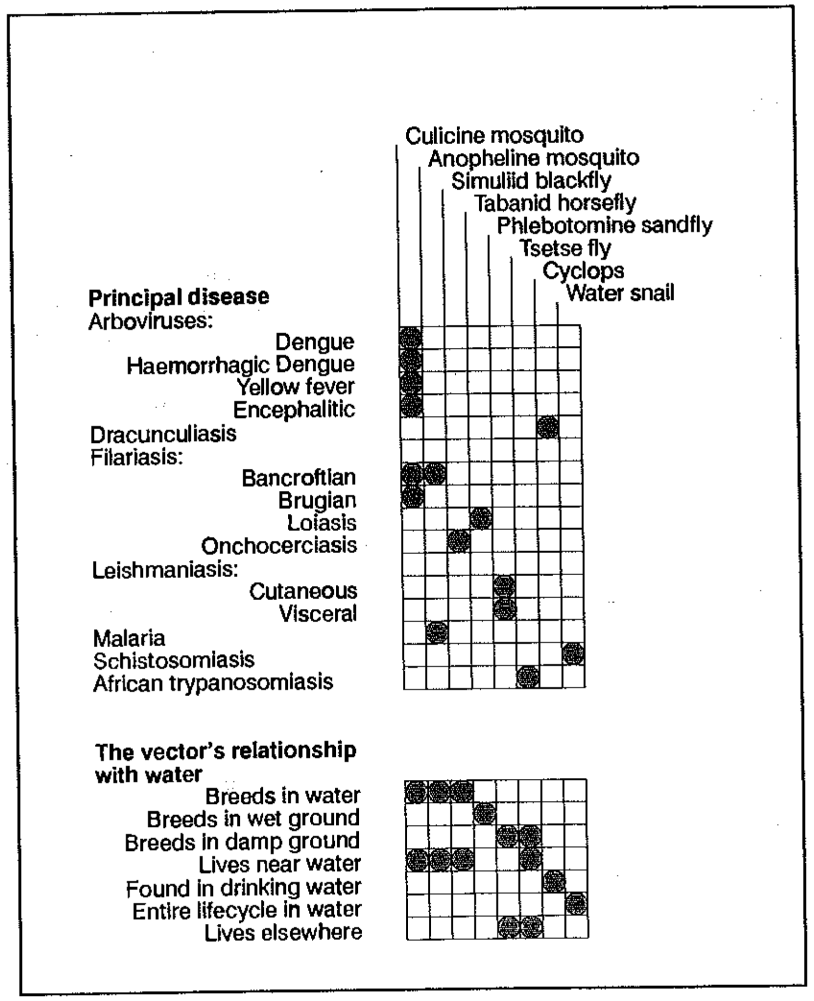



Fig. 8-5

Table 2-4
Association between vector, disease and water.




Sources: Birley 1992





cal (ie the vector carries the parasite from one host to another, eg viruses, bacteria) or biological (eg most helminths and protozoa, with parasite multiplication within the host). Some types of vector infections, diseases, and disease organisms are listed in Table 1.10, although not all of them are directly related to irrigation.

The most important diseases, relevant to water resource developments (Fig. 8-3) are:

(1) Schistosomiasis (bilharzia), (2) malaria, (3) yellow fever, (4) lymphatic filariasis, (5) river blindness (onchocerciasis), (6) dengue and dengue haemorrhagic fever, (7) visceral leishmaniasis, (8) cutaneous leishmaniasis, (9) Japanese encephalitis, and (10) African trypanosomiasis.

Fact sheets on these diseases are given, copied from Birley (PEEM) 1989 (Tables 8-11a-e). Further details on definitions, distributions, symptoms, diagnosis, life cycle, epidemiology, and control are provided in Oomen et al. ed. 1990: 36-69.

## 8.2.3 Diseases, Vectors and their Regional Distribution

The distribution of vectors and reservoir hosts are strictly limited, usually to zoogeographical boundaries. The main regions are indicated in Table 8-12 together with infections which are naturally transmitted in the region. The association between disease and region is shown in Table 8-13.

Mosquitos are by far the most important insect vectors and they are well adapted to capitalise on environmental changes produced by water resources developments. Such changes in vector habitats due to project activities can be enhancing or decreasing the area of favourable habitat (see Part II section 4.2). The distribution of mosquito-borne diseases is shown in Table 8-14. In 1980, about 3,100 M people were living in malarious regions; of these, 2,200 million were in areas with high to moderate malaria hazards.

The geographical distribution of schistosomiasis is shown in Table 8-15. WHO estimates that by 1980 some 200 million people were suffering from the infection and some 600 million people were constantly exposed to the risk of infection. About 900 million people are under the threat of contracting lymphatic filariasis, while river blindness (onchocerciasis) infects more than 20 M people.

Sources: Birley (PEEM) 1989; Pike 1987; Mather/Ton That (FAO) 1984

## 8.2.4 Habitat of Vectors and Transmission Factors

The principal habitats of vectors or intermediate hosts associated with important diseases are indicated in Figure 8-4. Typical mosquitos habitats are

- **impoundments**: bodies of fresh water in full or partial sunlight; larvae occur in floating or emergent vegetation or floatage near the edges; lakes, pools, bays, large borrow pits, slow rivers and pools in drying beds of seasonal rivers are all mosquito habitats
- **marshes**: wetlands, swamps and bogs associated with impoundments
- **rainpools**: small temporary collections of runoff; stagnant and often muddy, but not polluted; full to partial sunlight; includes roadside ditches, clogged drainage ditches, small borrow pits, natural depressions
- **paddy fields**: rice fields become seasonal breeding sites which are especially important between transplanting and closure of the crop canopy
- **shaded water**: partially or heavily shaded water in forests, including pools, ponds, and swamps
- **streams**: running water courses in direct sunlight; includes lowland grassy or weedy streams and irrigation canals

Fig. 8-6

Table 2-5
The main animal hosts of vector-borne diseases.

| Principal disease | Pigs | Birds | Rodents | Monkeys | Large herbivores | Carnivores | Human is principal host |
|---|---|---|---|---|---|---|---|
| **Arboviruses:** | | | | | | | |
| Dengue | | | | ● | | | ● |
| Haemorrhagic Dengue | | | | ● | | | ● |
| Yellow fever | | | | ● | | | |
| Encephalitic | ● | ● | | | | | |
| Dracunculiasis | | | | ● | | ● | ● |
| Filariasis: | | | | | | | |
| Bancroftian | | | | | | | ● |
| Brugian | | | | ● | | | ● |
| Loiasis | | | | ● | | | ● |
| Onchocerciasis | | | | | | | ● |
| Leishmaniasis: | | | | | | | |
| Cutaneous | | | ● | | | ● | |
| Visceral | | | ● | | | ● | |
| Malaria | | | | | | | ● |
| Schistosomiasis: | | | | | | | |
| *mansoni* | | | ● | ● | | | ● |
| *haematobium* | | | | | | | ● |
| *japonicum* | ● | | ● | | ● | ● | |
| African trypanosomiasis: | | | | | | | |
| Rhodesian | ● | | | | ● | ● | |
| Gambian | ● | | | | | | ● |

Source: Birley 1992





- **seepage**: springs, seepage from streams, irrigation canals or tanks (reservoirs) with clear in direct sunlight
- **natural containers**: such as wells, cisterns, water storage tanks (eg night storage reservoirs/tanks), basins, tins/barrels
- **polluted water**: water contaminated by faecal or other organic waste; foul water; However, highly saline waters are unfavourable sites for anopheline mosquitos
- other breeding sites: according to local circumstances

Sources: Birley (PEEM) 1989; WHO 1982, WHO 1980

The breeding site preference of a particular species may depend on factors such as the exact degree of shading, flow rate, temperature and amount of organic material. Favourable habitats for aquatic snails (eg *Bulinus, Biomphalaria, Ocomelania* ) are:

> moderate light penetration, partial shade; gradual change in water level; water velocity < 0.3 m/s; gradient < 20 m/km; little turbidity, temperature 0-37°C (optimum: 18-28°C); slight pollution with excreta; firm mud substrate (Birley (PEEM) 1989).

Vector-borne diseases may be categorised as water-based or water-related. In all cases the parasite or pathogen leaves an avian (bird) or a mammalian host and must undergo development in an insect, crustacean or snail before entering a new mamalian or avian host.

The vector's <u>relationship to water</u> is explained in Fig. 8-5. Parasites which have <u>non-human hosts</u> are indicated in Fig. 8-6. The method of transmission together with the life cycle of the parasite determines whether a low or high <u>frequency of contact</u> (see Fig. 8-2) is required between humans and the vector or infected water to cause clinical illness.

- low frequency: malaria - arboviruses - african trypanosomiasis - leishmaniasis
- high frequency: filariasis - dracunculiasis - schistosomiasis.

Direct injection of a parasite is most efficient in measn of infection. The frequency of contact will depend on the abundance of the vector or infested water source and the degree of contact between vector and host.

> For example, in resettlement schemes diseases requiring only low frequency contact are likely to affect the communities at an early phase whereas diseases requiring high frequency contact will increase in prevalence more slowly.

The diseases themselves are classified as chronic or acute and the importance of each disease will vary according to cultural and political boundaries and settings.

Source: Birley (PEEM) 1989

## 8.2.5 Classification of Health Risks

Possible risks to human health and welfare due to under circumstances related to water development are

- **occupational** risks: increased exposure to various vectors; accidents; handling of toxic chemicals,
- **infections in adults**: respiratory diseases, parasitic or other communicable diseases (see above),
- **infections in children**: respiratory and virus infections, diarrhoea, intestinal parasites (see above),
- **non-infectious diseases**: eg malnutrition,

- social risks: both uncontrolled and controlled migration of people are stimulated by reservoirs and irrigation projects. They often result in poor sanitary conditions in new settlements, inadequate relocation and resettlement procedures, high population density in new settlements what favour respiratory infection, loss of traditional economic activities, loss of social security, economic insecurity, poor hygiene and nutritional conditions.

The existence of adequate health services and of an infrastructure for the control of endemic diseases can reduce or eliminate specific risks and improve general health.

Source: Hunter/Rey/Scott (WHO) 1980

### 8.2.6 Specific Impacts of Irrigation

There are numerous human activities which have impacts on the environment in relation to breeding sites of water-related vectors. Many of them are directly related to irrigation as it contributes to an increase in the surface of water bodies through the construction of impoundments, canals and wetted or flooded areas. These environmental changes may create favourable mosquito habitats which were not previously present or which increase in size and number. If a disease already exists in an area and a habitat is created for the vector then the new habitat will be invaded and transmission may occur.

Impacts on health hazards are typically related to on-site effects within the command area and where new mosquito breeding sites may be created such as

- small pools during construction of buildings, along farmroads, buildings, borrow-areas during land preparation works, bunds, etc
- digging of shallow wells,
- conveyance and distribution canals especially if poorly designed, implemented or maintained, eg sediment loads or vegetation which create blockages, irregular gradient, shallow side slopes which favour vegetative growth, etc.
- inlet structures (or other structures in canals) which restrict flow and create floating vegetation blockages,
- temporarily submerged fields (especially paddy fields) and ponding of water in small pools caused by over-irrigation or reduced infiltration after heavy rains from compacted soils (caused by tillage),
- stagnant pools resulting from excessive canal seepage or overflow from canals,
- drainage systems: ditches, runoff-collectors. Under poor maintenance they are easily invaded by weeds and aquatic vegetation which provides a habitat for mosquitos,
- reservoirs or tanks associated with water supply for irrigation
- indirectly the intensification of agricultural production leads to the creation of new and rapid pathways for vectors: increased mobility through roads, fords, paths, agricultural equipment which moves over large areas; increased number of migrating people,
- inorganic pollution of ground- and surface waters may be detrimental to natural enemies of vectors (but may also be detrimental to the vectors),
- increased intensity of weed growth and increased length of growing season(s) on irrigated fields may extend the breeding outside the normal season under natural conditions. In addition, creation of terrestrial succession by planting treelines, bushes or perennial crops may provide habitats for birds and animals which are potential reservoirs of disease. These activites may contribute to longer transmission seasons and more frequent contacts between potential hosts and vectors.

Generally speaking, the least risks are presented by the following irrigation systems:

- low head closed pipe irrigation systems (eg subsurface systems)
- pressure pipe irrigation systems, eg sprinkler, drip
- closed pipe subsurface drainage systems.

On the other hand, the highest risks are imposed by irrigation and drainage systems which leave stagnant water in earth canals during vector breeding season.

Off-site impacts are typically related to changes in the hydrological regime of streams and to new buildings and settlements associated with village development. The type and magnitude of impact differs and depends on site specific water resources development measures, such as:

- reduced occurence of flash floods in streams due to reservoirs which regulate flow. Reduced flows may flush larvae out of stagnant pools or rainpools, although flood-pools are not any longer recharged,
- water abstraction and reservoir management may lead to reduced total seasonal or/and annual flow in lower reaches of streams which may create more temporary stagnant pools,
- prolonged periods where breeding sites are available due to increased flow volume during dry seasons (changes in seasonal discharge pattern),
- borrow pits for dam sonstruction, buildings and structures,
- creation of drainage outlets which carry water enriched with fertiliser leachates which are easily invaded by weeds and aquatic vegetation.

Typical habitat changes induced by water resource developments can be outlined with regard to other important vectors and diseases:

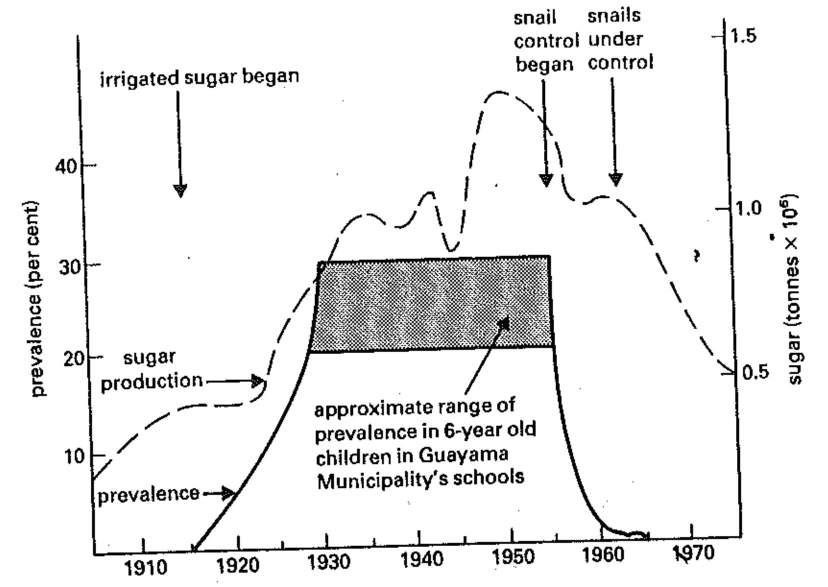
**Blackfly** (onchocerciasis): all spillway structures provide potential breeding sites; down-stream scouring of river beds, caused by changes in flow regime (example: River Nile), may expose rock which forms a suitable breeding habitat.

**Sandfly** (leishmaniasis): in arid and semi-arid areas they typically feed on the blood of rodents. In irrigation projects they may feed on humans. Desert rodents often inhabit low lying areas with fertile alluvial or loess (aeolian) soils which have a very high production potential under irrigation. Ploughing eliminates some species of rodents (eg Rhombomys) but encourage others to increase in numbers, eg Meriones. Rising watertables favour a sandfly species which is the most important vector of rural cutaneous leishmaniasis. Serious outbreaks have been recorded in Libya, Saudi Arabia, USSR, Pakistan and India.

Sources: Birley (PEEM) 1989; WHO 1982

Diseases and crops. There are many examples where disease outbreaks have been recorded in association with irrigated crops. For example cotton, or rice and malaria, and sugarcane to bilharzia; asian tea and malaria or hookworm; coffee and hookworm; bananas and bilharzia; sugar cane and yellow fever (Oomen et al. ed. 1990). In most of these associations, water is the major causing disease factor. In paddy rice cultivation, water requirements are high and areas of shallow water is provided for several consecutive months. The large work force required for rice cultivation provokes frequent contact between vectors and humans. Sometimes, requirements for certain crops coincide with the micro-climate and soil conditions favoured by certain species of snails or mosquitos. Design criteria originally intented to be applied for certain crops may, in fact, have adverse impacts on human health through providing excellent conditions for the transmission of water-related diseases.

Fig. 8-7




The pattern of the relationship between irrigated sugar, schistosomiasis and snail control in Puerto Rico (7).

Source: Pike 1989

Fig. 8-8

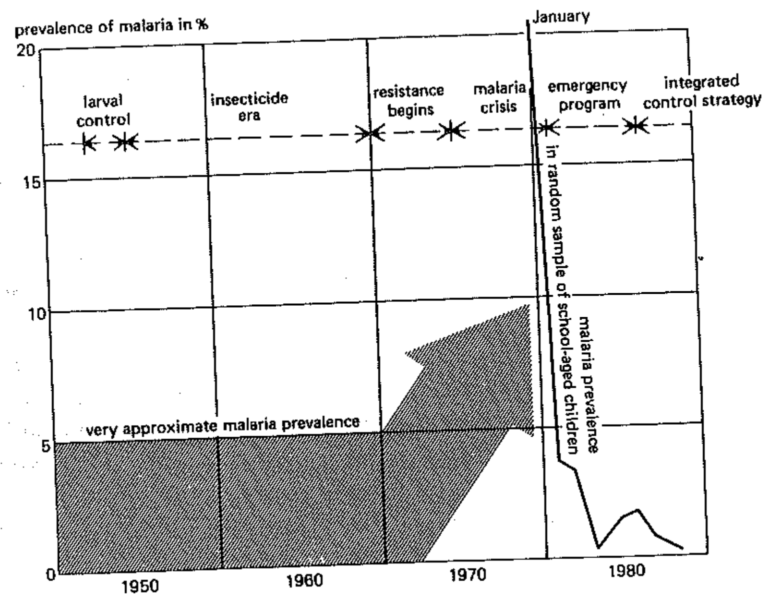



Figure 4.3 Pesticide resistance and prevalence of malaria

Sources: Oomen et al. 1988 Vol. 2

Fig. 8-9

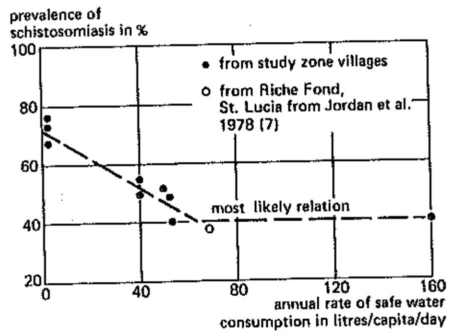



Figure 4.5 Prevalence of *Schistosoma mansoni* in villages in the 'Study Zone' versus their annual mean experience of safe water consumption, 1981 – 1982





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The risk of spread of parasitic infections has been stressed on many occasions. Evidence of helath impacts would be most valuable when a direct comparison can be made between pre-project and post-project development data. There are, however, few instances where such comparison is possible due to (i) the absence of reliable pre- or post development data, or data which are adequate for interpretation of cause-impact relationships, and (ii) reluctance on the part of governments to publish reports. Generally, the development of health hazards in irrigation projects must be seen in the context and the background of general health developments in surrounding areas. Typically, few reliable studies deal with the development of health hazards in areas without projects. Nevertheless, there is evidence that under uncontrolled management the intensified water use may result in increased prevalences of specific parasitic infections. Most data are available for Africa, probably because here irrigation development has lagged behind that in Asia, where most water-borne diseases were already endemic, but also because traditional or new control measures in Asia have been more effective due to advanced social and economic conditions.

Puerto Rico: The large scale introduction of irrigated sugar in the 1910's caused an increase in bilharzia infection in humans (Fig. 8-7) (Jobin cit. in: Pike 1987; detailed information in: Oomen et al. 1988).

Sudan. Gezira-Managil Irrigation Scheme: Perennial irrigation coupled with increased waterlogged conditions resulted in a sharp increase in the incidence of malaria in the early 1970's. The rise in the annual parasite index (number of positive cases detected per 1000 of population) is shown in Fig. 8-8. Malaria has been closely linked to agricultural developments ever since the Gezira Scheme began in 1924.

During the first 25 years control was possible through good water management and larviciding. After 1950 chlorinated hydrocarbons were used for household spraying. During the further expansion of the project there was a gradual trend towards pesticide resistance because of large scale applications.

The occurence of resistance to drugs produced a serious health crisis in the 1970's which coincided with agricultural expansion and intensification programmes. Introducing winter wheat was the critical element in increased transmission in addition to the creation of new habitats (horizontal and vertical expansion of irrigation). The irrigation of wheat added water to the larvae-producing fields at a time when temperatures favoured long life in the adult insect. This allowed the parasite an increased chance of completing its development cycle and being passed on to a second human carrier before the mosquito died. The main breeding grounds were irrigation ditches, drains, swamps, and those lands flooded due to excess water applications, in addition to small pools around taps for drinking water and leaking canals. High numbers of migrant workers also contributed to infections.

The reorganization of the health service and new organophosphorus chemicals caused a rapid decline in prevalence. In the late 1970's a comprehensive approach with reduced chemical treatment, new biological measures, improved village water supply and educational measures were introduced.

Bilharzia was also prevalent in the area from the very beginning of the project. Urinary and intestinal bilharzia were equal in prevalence. However, this changed due to the dynamics of transmission, and the intestinal form had become predominant in the 1970's. Field studies showed that the prevalence of schistosomiasis was inversely related to the rate of safe water consumed (Fig. 8-9). The residual prevalence of some 40% is due to non-domestic activities such as irrigation, daily bathing, and swimming (children). In addition, a close relationship was found between the prevalence and the distance to the nearest minor (feeder) canal in small villages (Fig 8-10). Similar relations between the safe domestic water supply and prevalence of diarrhoeal diseases were established as indicated in Fig. 8-11. (Oomen et al. 1988).

Fig. 8-10

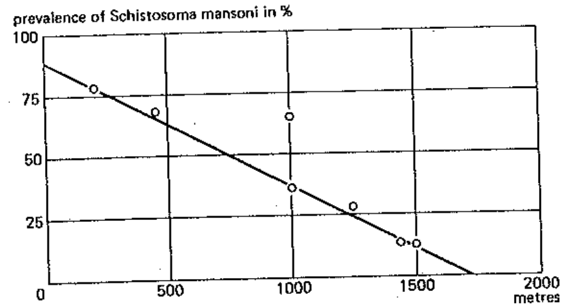



Figure 4.6 Prevalence of *Schistosoma mansoni* versus distance to nearest minor canal in small villages, without safe water supply, in 'Study Zone', 1981-1982, prior to intervention with comprehensive strategy

Fig. 8-11

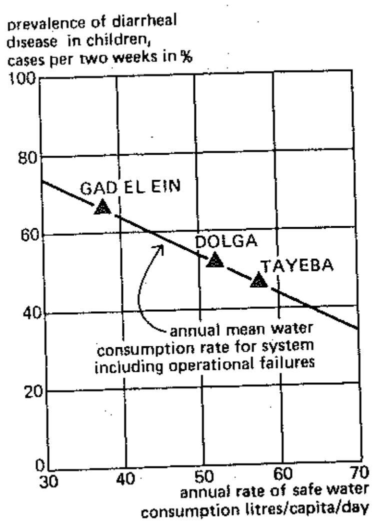



Figure 4.8 Relation of prevalence of diarrhoeal diseases and safe water consumption for intensive study villages, 1981

Fig. 8-12

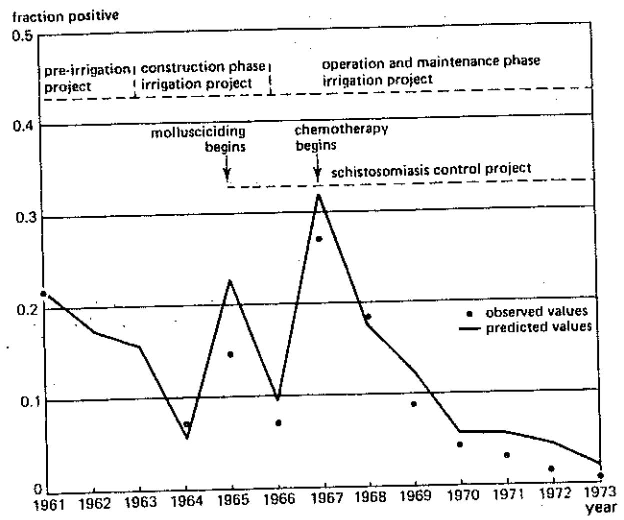



Figure 4.22 Bilharzia prevalence in the Dez Irrigation Scheme. 1961-1973

Sources: Oomen et al. 1988 Vol 2





Sudan. Rahad Scheme: Pre-project bilharzia prevalence in 1978 was intestinal S. mansoni 14% (29%), and urinary S. haematobium 1% (figure of S. mansoni for uncontrolled Gezira in brackets). A comprehensive programme for control was initiated including chemotherapy, sanitation, mollusciciding, and village water supply. By 1982, the prevalence of S. mansoni had declined to 10% (increase in uncontrolled Gezira to 61%). (Pike 1987).

Egypt. River Nile: An increase in intestinal bilharzia infections occured as a result of intensified irrigation and shifts in water regime (associated with impacts on aquatic ecology) by the construction of dams along the Blue Nile, Atbara River and the Nile (Aswan High Dam). Before 1940, the urinary form of S. haematobium, was predominant in the Nile Valley. Now, the intestinal form, S. mansoni, is dominant in most large scale irrigation systems, namely the Nile Delta, Gezira and El Girba schemes in Sudan. This marks a shift from light, inconsequential infections to heavy, debilitating, and even lethal intestinal infections.

The change is based on the difference between transmission of both forms of bilharzia, in terms of the excretion of bilharzia eggs: in dry areas or in simple irrigation systems with short periods of favourable habitats for snail populations, the urinary form predominates. Where irrigation is intensified and the number of snails increases, the intestinal form overcomes its disadvantage in the snail phase of the transmission cycle. Then, in the human host, the intestinal worm dominates over the urinary form, and has the extra advantage of a longer life span (Oomen et al. 1990).

Brazil. North-East Coast Reservoirs: Small reservoirs built by individual farmers or small village communities have been a serious source of bilharzia infection. Snail control with the chemical bayluscide has been successful in these reservoirs but long-term applications are uneconomic due to high costs of chemical control and the need for continuous treatments. An analysis of snail populations and snail habitats showed that main chemical applications are most effective when applied at the start of the dry season, when reservoir levels are low (immediately before the reservoirs fall dry) and when temperatures are too high for oviposition. This forces the survivors to aestivate (Oomen et al. 1988).

Iran. Dez Scheme: The expansion of irrigation to 20 000 ha (final stage 125 000 ha) resulted in an increase in bilharzia infections. Irrigation canals and drains were more important transmission sites than village ponds. A bilharzia control program (drugs, habitat modifications, chemical control of vectors) reduced the prevalence of urinary bilharzia to a level lower than pre-project (Fig. 8-12). The early decline in prevalence, since 1965, is attributed to land improvements during early irrigation development. (Oomen et al. 1988).

Swaziland. Lowfeld: Irrigation started in the late 1950s and within four years the prevalence of S. mansoni rose in three areas from 23% to 60%. The concurrent pre-project prevalence of S. haematobium was 68%. The reason for the increase in S. mansoni was attributed to the complete lack of any anti-schistosome precautions, and in particular because: (1) thick faeces were found along the banks of channels; (2) all housing was close to canals; (3) night storage dams and fields above channals were used for sanitary purposes; (4) water for domestic purposes was drawn from channels, dams and seepage areas. (Pike 1987).

Ethiopia. Awash Valley: Prevalence of schistosomiasis increased from almost nil to 5-11% and malaria incidents increased slightly as a result of estate irrigation development in the area. On the other hand, schistosomiasis declined by 50% in the Lower Valley due to the drying up of swamps resulting for upstream water abstractions from irrigation schemes and the provision of drainage (Kloos cit. in: Tsegaye in: Wooldridge ed. 1991).

Tanzania. Arusha Chini: In an irrigated sugar cane estate schistosomiasis prevalence among field workers rose from almost nil to 85%, and the annual incidence of new infections was more than 80% (in the late 1930s). After several control programmes (chemotherapy and mollusciciding) the prevalence declined from 59 to 31% in field workers, from 36 to 15% in other workers, and from 28 to 14% in wives of employees (Fenwick/Jorgenson cit. in: Pike 1987).

Large Dam Projects without health control:

Lake Volta in Ghana: (hydro-energy project). Over 80 000 people were resettled around the lake shores in villages without sanitation or piped water. Fishermen migrated from outside and introduced bilharzia. In three villages the prevalence of schistosomiasis rose from some 5% to 30% after 3 years and 91% after 4 years.

Lake Kariba in Zambia: 70% and 15% increase in schistosomiasis was found in children and adults, respectively, within 10 years after implementation in Zambia.

Lake Nasser in Egypt: After implementation of the Aswan High Dam, a 60% increase in schistosomiasis after both fishermen and irrigators.

Kainjii in Nigeria: Schistosomiasis increase by 30% after 1 year and 45% after 2 years amonst irrigators (Sam/Ayibotele in: Wooldridge 1991; Pike 1987; Hunter/Rey/Scott (WHO) 1980).

Lake Kariba: Resettled Tonga tribesmen were exposed to trypanosomiasis infections due to relocation into tsetse fly infested woodland areas (Bolton in: Goldsmith/Hildyard ed. Vol.2 1985).

Small Dams in Mali: In the circle de Bandiagara urinary schistosomiasis increased from about 80% to 93% during reservoir implementation (1977). The local transmission of instestinal schistosimiasis (S. mansoni) was recorded for the first time in the same year (Hunter/Rey/Scott (WHO) 1980).

Parana-Paraguay Basin: Endemic malaria has found to be aggrevated by water impoundments and irrigation projects (Hunter/Rey/Scott (WHO) 1980).

In Indonesia, the prevalence of intestinal helminths range from 70 to 80% and malaria and filiriasis are a continuous threat to traditional irrigators (Hunter/Rey/Scott (WHO) 1980)

further examples are in: Goldsmith/Hildyard 1984 and Goldsmith/Hildyard ed. 1986

To summarize, there is firm evidence that irrigation contributes directly and indirectly to the potential spread of water-related diseases caused by either the intensification of endemic or the introduction of new diseases. This is mainly the result of

- the increase of water surfaces in and around agricultural areas,
- poor maintenance of canal systems,
- the poor sanitation and domestic water supply conditions of the steadily increasing population in irrigation schemes,
- careless waste disposal.

Access to water during all seasons also contributes towards changing people's habit, especially those of children, who use the irrigation canals for other activities. This is clearly demonstrated by the fact that for example the impact of schistosomiasis is closely related to people's living circumstances: use of home latrines, use of potable water for drinking, avoiding canals for bathing and swimming, and avoiding canals for laundry and housework all contribute to significant reductions in prevalence in the range of 10 to 20% (experience from Egypt, cited in Pike 1987). Further precautions can significantly reduce the prevalence of diseases. However, the literature also indicates that

- there are considerable differences between the impact of irrigation and different diseases. Malaria or river blindness prevalence may rise or may decline, whereas schistosomiasis typically increases unless controlled,
- the impact of irrigation on diseases varies substantially from project to project. There are locations with a decline and locations with a sharp increase of prevalence or incidence.

Sources: Birley in: Wooldridge ed. 1991; Bolton/Imevbore/Fraval in: Wooldridge ed. 1991; Chimbary/Chitsoko/Bolton in: Wooldridge ed. 19991; Tayeh/Cairngross in: Wooldridge ed. 1991; Oomen et al (ILRI) Vol. 1, 1990, Vol 2, 1988; Birley (PEEM) 1989; Hillman in: Rydzewsli ed. 1987; Pike 1987; Mather/Ton That (FAO) 1984; WHO 1980; Hunter/Rey/Scott (WHO) 1980; Amin in: Worthington ed. 1977; Farid in: Worthington ed. 1977

Articles: Mistry in: ICID 1990; Grubinger/Pozzi (ICID) 1985

Further readings: Wooldridge ed. 1991; Listori (WB) 1990; Oomen et al. ed. Vol1 1990, Vol 2 1988; Chanlett 1973

Critical review in: Goldsmith/Hildyard 1984; 1986

## 8.3 Occupational Health Risks in Agriculture

The handling and use of agro-chemicals may pose potential health risks to farmers or persons coming into contact with agro-chemicals stored on the farm. Agro-chemicals comprise soil amendments, fertilisers and pesticides. Each aspect of storage, handling and its application in the field has its own type and degree of potential hazard. Poor practices and failure to follow the manufacturer's instructions may lead to effects varying from acute to chronic toxicity or insignificant or nil, in adults and children, pets, livestock and working animals or wildlife (especially aquatic life). The result of exposure to pesticides will depend upon the organism exposed, the situation in which exposure occurs, the duration of exposure, and upon variables relating to the pesticide itself, especially concentration and mode of exposure.

The detrimental effects of specific pollutants and risks of nutrient, pesticide and metal toxicity are treated in sections 2.3 and 3.4. Special pathogenic problems related to the use of wastewaters under irrigation are treated in sections 2.5 and 8.1. Specific pollutants in irrigated farming or induced by irrigated farming are

- sediments which may have adsorbed pollutants. They occur as runoff from the farm but may also be received with irrigation water,
- nutrients, especially excessive N and P concentrations in effluent or supply waters,
- salinity, namely the concentration of Cl and SO4 in ground and surface water effluents from irrigated fields,
- pesticides in soils, plants and ground and surface water effluents. Advisory health standards for pesticides in drinking and irrigation waters are given in Table 8-17.
- toxic concentrations of trace elements cause toxicosis and damage to vital organs.

Source: Hornsby in: Stewart ed. 1990

Fig. 9-1



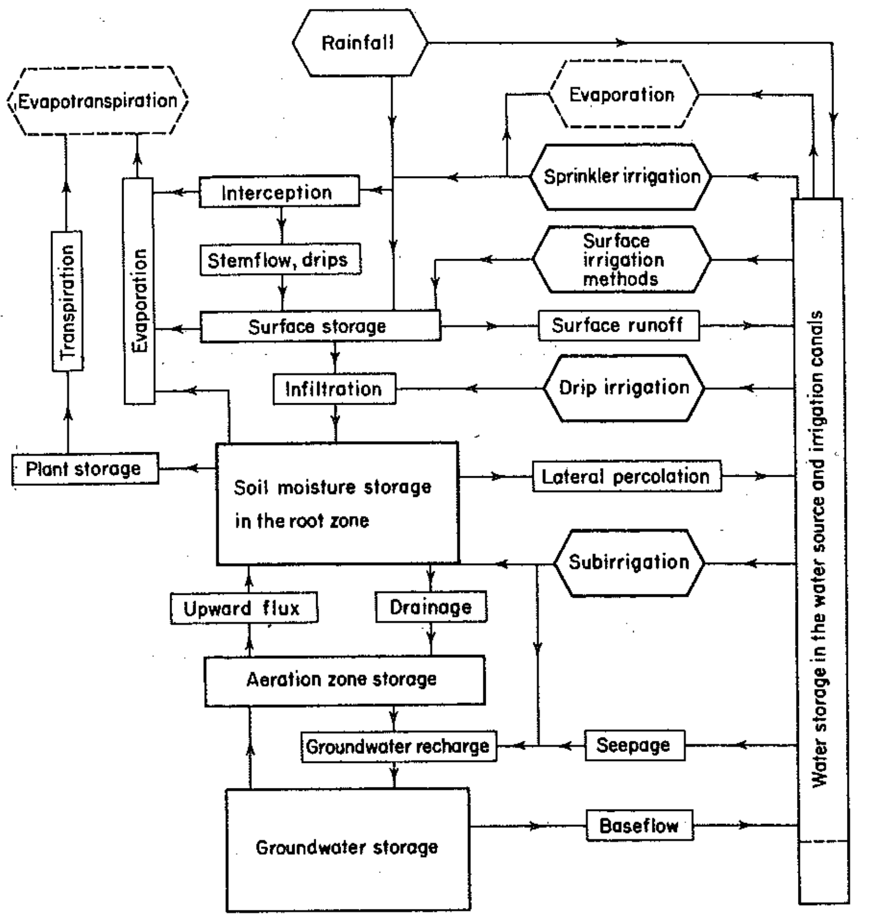



Figure 5.1 The field hydrological cycle as influenced by irrigation

Source: Rydzewski ed. 1987

Fig 9-2

**Table 1. Selected environmental effects of agriculture**

| Agricultural practices | Soil | Groundwater | Surface water | Flora | Fauna | Others air, noise, landscape, agricultural products |
|---|---|---|---|---|---|---|
| Land development, land consolidation programmes | Poor management leading to soil degradation | Other water management influencing groundwater table | | Loss of species | | Loss of ecosystem, loss of ecological diversity. Land degradation if activity not suited to site |
| Irrigation, drainage | Excess salts, water logging | Loss of quality (more salts), drinking water supply affected | Soil degradation, situation, water pollution with soil particles | Drying out of natural elements affecting river ecosystem | | |
| Tillage | Wind erosion, water erosion | | | | | |
| Mechanization, large or heavy equipment | Soil compaction, soil erosion | | | | | Combustion gases noise |
| Fertilizer use - Nitrogen | | Nitrate leaching affecting water | | | | |
| - Phosphate | Accumulation of heavy metals (Cd) | | Run-off, leaching or direct discharge leading to eutrophication | Effect on soil microflora<br>Eutrophication leads: i) to excess algae and water-plants | ii) to oxygen depletion affecting fish | |
| - Manure, slurry | Excess: accumulation of phosphates, copper (pig slurry) | Nitrate, phosphate (by use of excess slurry) | | | | Stench, ammonia |
| - Sewage sludge, compost | Accumulation of heavy metals, contaminants | | | | | Residues |
| Applying pesticides | Accumulation of pesticides and degradation products | Leaching of mobile pesticide residues and degradation products | | Affects soil microflora: resistance of some weeds | Poisoning resistance | Evaporation: spray drift, residues |
| Input of feed additives, medicines | Posible effects | | | | | Residues |
| Modern buildings: e.g. silos and intensive livestock farming | See: slurry | See: slurry | See: slurry | | | Ammonia, offensive odours, noise, residues. Infrastructure: aesthetic impacts |

Reproduced from: OECD 1984: *Workshop on Critical Issues in Natural Resource Management*, Paris, 11-12 October 1984.

Source: ESCAP 1991





# 9 Environmental Impacts of Agricultural Practices

## 9.1 Introduction

Irrigation usually implies the intensification of crop production and increased yields. In semiarid sub-saharian Africa, the productive value of an irrigated area is about 3.5 times that of rainfed area. This intensification is associated with the (i) exploitation of soil and water resources, (ii) increased application of agronomic off-farm inputs which are designed to stimulate growth or protect crops and (iii) farm mechanization with negative impacts from farm machines on soils and greater energy inputs. Hence, irrigated crops are managed and fertilised differently, and grow more luxuriantly than non-irrigated crops.

Such major adjustments in crop management have important effects on plant diseases and insect problems. Modification of the natural water supply changes the biological equilibria between crops and their pests in numerous and complicated ways. Even changes in farm operations that may be required under irrigation may, in turn, make it necessary to develop new pest control methods. Parasitic diseases (eg fungal and bacterial foliage diseases) need, in order to develop to damaging proportions in a crop, a favourable microclimate for spore germination and infection, and for sufficient sporulation for secondary infections. In general, free water must be present on the plant surface during morning hours to permit infection, and a much longer time is necessary for secondary sporulation. In addition, many disease organisms depend on the splashing of water to spread them to other plants. Usually, optimum temperatures for spores production, germination and infection are lower than normally prevailing during hot periods. The normal process of fungus disease development in plants is thus uniquely adapted to the natural humid microclimate.

It is obvious that irrigation, especially sprinkler irrigation of low-growing vegetables, often provides more favourable conditions for disease development than natural rainfall, which does not provide prolonged periods of high humidity and lowered temperatures conducive to disease development. Increases in diseases may not only occur in arid or semiarid regions but also in subhumid regions where irrigation is practiced to supplement natural rainfall. Under such supplementary irrigation the magnitude of disease outbreaks is closely related to weather conditions and even a slight prolonging of time in which favourable conditions for the spread of diseases occur may be important. The root diseases of irrigated crops differ in some respect from those of dryland crops, but it is difficult to show direct relations to changed soil water regimes. Generally, increasing water supply to an optimum level favours crop growth, but excessive supply (waterlogging) may increase root rots without compensating benefits from higher yields.

Other physiological disorders of crops may also be aggravated or caused directly by irrigation, for example lime-induced chlorosis, and effects caused by the use of saline and/or alkaline waters. Irrigation can also disseminate disease producing agents not only within the field, but over much longer distances, for example with the drainage water. There is ample evidence that the rapid distribution of many pathogens/pests are caused or facilitated by the interconnected water distribution systems and poor control of tailwaters during irrigation applications. The reuse of drainage water - either directly from surface water or from reservoirs - often facilitates the spread of such diseases which are caused by pathogenic organisms.

Furthermore, the introduction of irrigated farming in arid regions provides a unique new environment; islands of lush vegetation occur, surrounded with bush or barren land which supports only limited fauna and flora. Under irrigation, a dramatic change in the existing insect (and other fauna) species and total population number may take place. Many sukking or chewing insects feed readily on certain irrigated crops and may become serious pests. In the soil, affected by changed water regime, some indigenous species cannot survive but many other species find improved conditions to develop high populations and new species are able to become established. There are numerous examples of new pests introduced under irrigation:

Hessian fly and fruit-fly on wheat in Russia; clover root borers; rice stem borer in India; two-spotted spider mites on alfalfa; mirid bug on cotton (Klostermeyer 1967).

Continuous development of irrigated lands in arid regions may result in the development of 'bridges' over deserts across which pests can travel.

On the other hand, experience has demonstrated that the careful use of irrigation will rarely lead to significant increased risks of crop diseases. Healthy crops which do not suffer from water shortages are typically less susceptible to diseases. In some circumstances, irrigation techniques may even be used to control potential pest, eg (i) irrigation ditches and canals may serve as barriers for certain species, for example for migrating Mormon crickets and (ii) flooding may be used to control certain soil pests, eg the lesser corn stalk borer attacking maize and sorghum; on the other hand, weeds may be transmitted and more evenly distributed across fields under flood irrigation.

Sources and further readings: Menzies in: Hagan et al. (ASA) ed. 1967; Klostermeyer in: Hagan et al. (ASA) ed. 1967; Viets et al. in: Hagan et al. (ASA) ed. 1967

## 9.2 Irrigation and the Use of Fertilisers

With regard to land productivity, fertilisation can be regarded as an agronomic 'land saving input' because the productivity per unit area increases considerably with increased fertiliser use. It is estimated that higher fertiliser inputs have been responsible for a quarter of the growth in output since the mid-1960s, the remainder being due to new varieties, irrigation, and other agronomic improvements (Conway/Pretty 1988). The result has been a rise in global food production per capita by 7% since 1964, in Asia by 27%, in Latin America by 9% and only in Africa, with a low adaption rate has it fallen by 17%. (FAO Production Yearbook 1987).

In many respects, fertilisation and irrigation are complementary means to increase productivity, because irrigation reduces water stress and allows increased extraction of nutrients from soils, thus increasing yields. In order to replace them and to sustain the fertility levels, chemical fertilisers are applied. The use of high yielding varieties and other improved seeds requires - for their full production potential to be met - the use of fertilisers or other amendments to provide adequate nutrients.

It is estimated that, on a global scale, less than 20% of the cropped area is irrigated. It produces 40% of total crop production, and receives more than 60% of all fertiliser that is applied (Hotes 1982; cit. in: Oomen et al. (ILRI) 1990). In 1988, the consumption of fertilisers in developing countries reached almost the level of average applications in industrialized countries, which is 54 kg N/ha and 57 kg N/ha, respectively (OECD 1991a,b; ADB 1991; Conway/Pretty 1988). Most Asian countries doubled or tripled their consumption during the period 1970 to 1987, reaching levels of between 26 and 395 kg N/ha, compared with some 200 kg N/ha in Germany and Britain. In contrast, in Africa the consumption was only 4 kg N/ha (1985).

Impacts of excessive fertiliser applications and their subsequent leaching into surface or groundwater caused by poor soil conservation and water management practices are treated in detail in section 2.

Sources: OECD 1991; ADB 1991; Conway/Pretty 1988; Canter 1986

## 9.3 Irrigation and the Use of Pesticides

The effects of irrigation on potential pests are usually brought about by irrigation's influence on crop growth and soil moisture conditions. Under conventional pest management, many irrigated agricultural crops are increasingly dependent on the increased use of pesticides to control crop losses. Consequently, the use of pesticides in modern irrigated farming is typically much higher than on traditional or ecofarming systems with integrated plant protection (eg Kotschi et al. (GTZ) 1989). Large scale monoculture, high-value crops and fruit trees contribute especially to increased pesticide applications.

Environmental problems associated with the widespread use of pesticides are not only caused by soil and water pollution (see sections 2 and 3). The disturbances of biological balances in natural ecosystems are significant, too. Here, the development of new plant pests and diseases and the development of resistant strains of pests must be mentioned. It is essential to bear in mind that

- The population growth potential of organisms tends to be stabilised by **abiotic** factors, such as climate, air, soil, water, space, and light, as well as **biotic** ones through the direct or indirect activities of other living organisms. The resulting complex interactions determine a population level for each organism, which fluctuates about an equilibrium level characteristic for any given ecosystem.

- When such organisms are harmful, the role of their natural enemies in keeping them under control can be considerable. Of the total number of insect species of 1.5 M, some 5000 are considered as potentially important because they damage crops and injure domestic animals or humans, either directly or by transmission of disease. If these pests had no natural enemies, the figure would be much larger. Unfortunately, these parasites and **predators of pests** are often **more** susceptible to pesticides than their prey, and there are few types of insecticides selective enough to kill any particular pest, without affecting their predators (systemic insecticides do to a certain extent achieve this).

- Furthermore, pesticides sometimes kill not only the enemies of pests but also those of relatively innocuous plant-feeding species, which, released from predator/parasite pressure, may multiply rapidly in numbers and become new pests. For example: fruit tree red spider mite becomes a pest after applications of DDT; cotton pest species increased from two to as many as 15 with the advent of pesticides into new regions; new pests have emerged in tea and cocoa plantations. These effects are of particular importance in developing countries, where pesticides are just beginning to be used on a large scale.

Source: Edwards 1987

Most major technological innovatons in modern agriculture, such as monoculture, fertilisers, cultivation equipment, precision drilling, minimum tillage, new crops and varieties, were introduced without adequate assessment of their influence on crop protection issues. Many of these have led to increased crop losses to pests, although the increasingly efficient control of weeds may have also promoted the incidence of pests, because they provide not only alternate sources of food for pests, but also encourage the buildup of populations of pest predators.

When some pesticides are used continually repeatedly against the same pest it often becomes necessary to gradually increase the dose applied. Eventually the pest may become almost immune to the insecticide and resistant strains are developing. Although only about 5% of the 5000 known arthropod pests have developed resistance, this 5% unfortunately includes some of the most important pests.

Source: Edwards 1987

Fig. 9-3

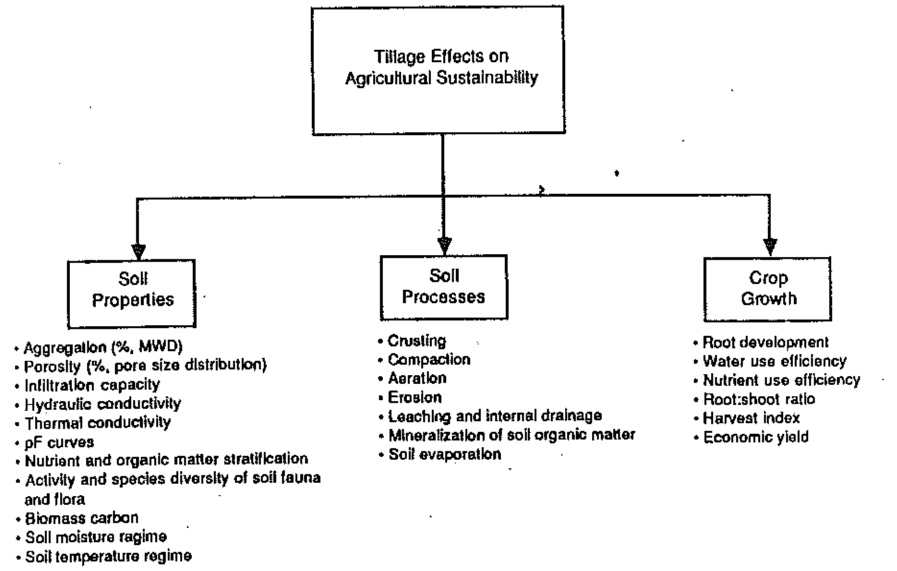



Fig. 2. Tillage effects on agricultural sustainability.

Fig. 9-4

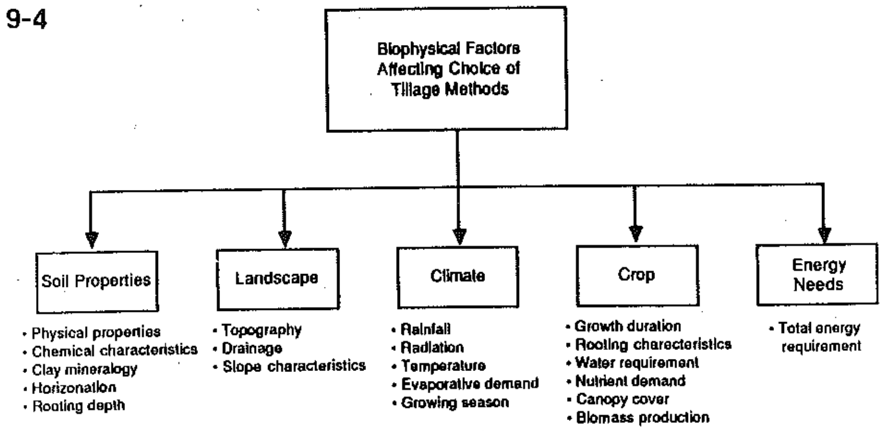



Fig. 1. Factors affecting choice of tillage methods.

Sources: Lal in Lal ed. 1991





## 9.4 Irrigation and Tillage Practices

Tillage operations are aimed at creating an optimum environment for seeds to germinate and emerge, and for roots to develop. Weeds should be controlled and if possible eradicated and organic material should be incorporated into the topsoil horizons. Hence, tillage practices have distinct impacts on **physical soil properties**, especially pore size distribution, bulk density and soil strength, which, in turn, determine soil moisture and aeration status and ultimately crop growth conditions. Various tillage effects on agricultural sustainability are shown in Fig. 9-3. Tillage may enhance or curtail soil fertility properties, soil forming processes and crop yields, depending on antecedent soil conditions, the type of tillage tools and practices used, and crops grown.

An important effect of tillage is its impact on **soil degradation** and **pollution** of ground and surface waters. While conservation tillage can reduce soil erosion, it may increase the risk of water pollution through increased use of pesticides and surface application of fertilisers and other agricultural chemicals. In contrast, plough-based tillage methods may enhance the risk of soil erosion, increase rates of mineralisation of soil organic matter, and accentuate emission of greenhouse gases from soils.

Tillage practices are governed by various biophysical and agronomic factors including crop selection, irrigation management and the farming system, for example the degree of mechanisation. Biophysical factors are shown in Fig. 9-4. Soil factors play an important role in determining the intensity, frequency, and type of tillage required.

In developing countries four types of mechanised farm operations are often practiced in irrigated agriculture:

- soil reclamation and land preparation for irrigation by, for example, deep subsoiling and levelling or tied ridging
- tillage for seedbed preparation and planting
- tillage to control weeds
- harvesting.

Typically, irrigation requires **additional mechanised tillage** operations in comparison with non-irrigated cropping systems. Such practices include land levelling, re-shapening of furrows or ridges for water distribution, maintenance of drainage ditches, soil loosening to eliminate crusting of surface layers which may result from droplet impact or overland flow, and increased weeding requirements caused by enhanced weed growth. Some of these activities can be performed by hand labour but speed, timeliness and precision of operations are a unique advantages of mechanised farming. In many irrigation farming systems in developing countries there are constraints in labour available, and mechanisation is the only means to overcome these. On the other hand, limitations exist in efficient large scale use and the use of heavy equipment in most smallholder farms in developing countriess. Often the optimum field layout for most surface irrigation systems curtails the efficient use of modern farm machinery (Wolff in: DLG 1982). Nevertheless, there is room for small farm machines which are often more appropriate in farming systems in many developing countries (Wienecke/Friedrich 1982).

Socio-economic aspects and impacts of farm mechanisation are beyond the scope of this review. the reader is referred to the relevant literature, eg. Doppler in: DLG 1982

Despite tillage operations are aimed at loosening the soil to promote aeration, create favourable soil moisture status, and enhance infiltration and permeability, there is some evidence that tillage implements and other wheeled traffic on agricultural lands lead to the compaction of topsoils and subsoil horizons. Typically, bulk density and soil strength may be adversely affected during land clearing and with continuous ploughing and farm machinery traffic. For example, subsoil 'plough pans' may develop when heavy machines are used for tillage operations and/or tillage operations are conducted under wet conditions which cause the destruction of soil aggregates and a loss in macroporosity. A loss in macroporisity usually results in reduced permeability, frequent waterlogging, and may have detrimental impacts on soil fauna, too. Habitat conditions for invertebrates (worms) may be adversely affected but microorganism habitat can also be damaged by heavy traffic. This, in turn, has impacts on the microbiotic activity in the topsoil layers; the decomposition of organic matter may be hampered. A loss in micropores may result in frequent waterlogging and anaerobic conditions in some horizons. This, in turn, has effects on nutrient availability and denitrification (N-loss to the atmosphere) is enhanced. Root growth may be hampered by high penetration resistance.

Sources and further reading: Lal ed. 1991 with country reports from Latin America, West Africa, semi-arid West Africa, India, North America, and Australia; ISTRO 1991; Hanus in: Blume ed. 1990

However, it is impossible to generalise from empirical data on tillage impacts due to the immense variety of tillage equipment and practices, the heterogeneity of soil physical conditions under which tillage and cropping takes place, variability in climatic conditions, variable irrigation management, and crops grown.

- In arid regions, ploughing and deep subsoiling has been shown to create a favourable soil structure by increasing porosity, root growth, permeability and increasing crop yields in structurally inactive (eg sandy) soils. However, ploughing brings about only a transient improvement in soil structure, and follow-up restorative measures are necessary for long-lasting effects (Lal in: Lal 1991 with further references; Laryea et al. in: Lal ed. 1991).
- Conservation tillage practices ("no- or minimum till") may result in a higher bulk density in topsoils, and lower macroporosity, infiltration rates and crop yields as compared with conventional tillage (disk ploughing) (Alegre et al. in: Lal ed. 1991).
- No-tillage in comparison with conventional tillage on loamy soils may result in increasing microflora activity, soil porosity, infiltration rates, soil water retention capacity, and organic carbon. The reverse occured in a sandy soil with conventional tillage outyielding no tillage. (Hulugalle/Maurya in: Lal ed. 1991).
- Appropriate tillage in irrigated soils with high organic matter and fine sandy or silt particles can create a favourable structure which cannot be achieved under no- or minimum tillage (Hulugalle/Maurya in: Lal ed. 1991; Laryea et al. in: Lal ed. 1991).

Tillage is practiced in various regions at different levels. In <u>Africa</u>, irrigation is traditionally manual with animal traction being more frequent used in recent times (Starkey/Faye ed. 1990). Minimum or no-tillage are common practices in traditional irrigated lowland agriculture. In large-scale irrigation projects intensive use of tractor-drawn implements is more common (Hulungalle/Maurya in: Lal ed. 1991).

Estimates of economic losses or gains are difficult to make owing to the compounding effects of several interacting variables (Lal in: Lal 1991). Hence, only site specific predictions and recommendations on improved tillage practices are available (see Part II 5.1). There is ample empirical evidence of both beneficial and detrimental impacts of tillage operations on soil properties and of both <u>increased and decreased yields</u> under various tillage systems (see articles in: ISTRO 1991, Sections 1, 3, and 4; and Lal ed. (ISTRO 1991). In some circumstances, slight soil compaction is desired, namely when light textured soils are under surface irrigation and the infiltration rate should decrease to allow a more uniform water distribution within a field or along furrows (eg Agrarwal et al. 1987).

Sources: Lal in: Lal ed. (ISTRO) 1991; Lal ed. 1979

Further reading: Lal ed. (ISTRO) 1991; ISTRO 1991; Wolff in: DLG 1982; Doppler in: DLG 1982; Koopman/Hoodgmoed in: DLG 1982; DLG 1982; Wienecke/Friedrich 1982

# 10 Socio-Economic and Socio-Cultural Impacts

## 10.1 Introduction

Irrigation development is ultimately aimed at the **benefit of the people**, but experience in large scale projects and especially in projects associated with large scale water development schemes or reservoirs has shown negative impacts at least on parts of the affected communities. **Any development** has impacts on social values and attitudes and is accompanied by socio-cultural and socio-economic changes in the communities. Irrigation, for example, implies the intensification of **agricultural production**, integration into the **national economy**, extension of **area** under cultivation, intensification of **land use,** and intensification of the use of **soil and water resources**.

The rural community (or parts of it) has explicit influences on the type and intensity of development and, in turn, the irrigation development exerts distinct impacts on the rural community in which development takes place, but also on neighbouring communities. Impacts may be adverse to all or to groups of community members if an imbalanced, unsustainable economic and social development takes place, although irrigation is primarily aimed at mitigating drought for increased and secured food production.

Environmental effects related to socio-economic and social changes are the subject of environmental protection policies. It is not intended to cover the full range of issues and impacts which irrigation development may exert on rural communities. This would be subject to socio-economic and agronomic appraisals in the context of formulating strategies for the development of rural communities.

The role of modern (not necessarily mechanised) irrigation for development is under **debate**:

> Some argue that "to build water-development schemes, .... , is a lost cause', especially if they are associated with the construction of large dams. Cut-off funds from all large-scale water development schemes would mean: Nor it will condemn those inhibiting the irrigated areas to see their children ravaged by malaria and schistosomiasis to which many of them must inevitably succumb. Nor will it systematically transform their remaining agricultural land [ie rainfed] into a waterlogged and salt-encrusted desert [ie irrigated land]..." (from Goldsmith/Hildyard 1984, p.346).
>
> Others argue that the importance of irrigation cannot be overemphasised in efforts to develop agriculture. In Asia the irrigated areas, although covering less than half the cultivated land, provide almost two-third of the food production. In Brasil 3% of land is irrigated but produces 16% of the grain harvest. About one-thirds of the world population depends directly on irrigation for food. (Barghouti/Le Moigne (WB) 1990; Kruse in: ICID 1990; FAO (industrialized countriesTP) 1986; Taba in: COWAR 1976)

There are four critical issues which must be addressed in the socio-economic and socio-cultural context: **resettlements** in association with large-scale water development projects, social **imbalance** of development induced by irrigation, the loss of **land of** cultural or heritage value, and aspects of **mechanisation** in irrigated agriculture.

Further reading: Cernea 1985; Carruthers/Clark 1981

## 10.2 Settlement Schemes and Large-Scale Water Developments

Generally, there are four groups associated with resettlement or irrigation settlement schemes:

- relocatees or evacuees: communities displaced by large-scale irrigation projects and especially by associated reservoirs (large dams) (see also section 11)
- scheduled migrants: settlers selected by government
- unscheduled settlers: self-selected settlers, squatters and encroachers
- temporary residents: construction workers and seasonal farm workers.

Evacuees are typically associated with the development of large multi-functional reservoirs. For example, the network of reservoirs that will accompany the Narmada Valley Project (India) will displace possibly some 80 000 people living in the inundated area (Dixon et al. (WB) 1989). Similar resettlement schemes have been implemented in Egypt, Syria and Ghana. The social, organisational, economic and health impacts accruing from such resettlement programmes are generally either neglected or underestimated by the institutions involved. Further problems may arise if the evacuees are tribal people of diversified ethnic and linguistic groups and especially minority groups.

Several examples of such settlement schemes and their negative impacts have been compiled by Goldsmith/Hildyard 1985 and specific project details are given in Hildyard/Goldsmith ed. 1986 by for example, Graham/Volta; Vriksh/Narmada.

Often, the arrival of unscheduled migrants is completely unanticipated or underestimated during the initial planning phase. For example, many unscheduled fishermen settled at Lake Volta, ghana, attracted by the abundance if fish during the early years of the project. these migrants were almost as numerous as the evacuees, for whom settlement provision had at least been made by planners.

It is a common feature of large-scale water development projects that affected rural people are neither consulted nor involved in decision making. Inevitably, the upheaval of resettlement will cause social breakdown of traditional social and economic structures. The authority of the elders will be weakened and young people will no longer accept the rules of family life which provides some social security in traditional rural societies (eg Mounier in: Goldsmith/Hildyard ed. 1985). Such large-scale resettlements are typically justified by decision makers in order to overcome cultural impoverishment and to initiate or enhance economic development. Obviously, such developments did not occur to the high levels anticipated in many projects in the past (see Goldsmith/Hildyard 1984; example: Lake Kariba/Zambia).

Typical project killers which limit any positive benefits of large-scale resettlements projects include:

- lack of appropriate communication between the agency and settlers,
- selection of unsuitable sites for the anticipated level of irrigated agriculture,
- project located in close proximity to critical ecosystems or other communities with potential for conflict over land, water, and soil resources,
- failure to take into account the different needs and perceptions of various heterogeneous groups, especially between indigenous people and migrants,
- disregard of level of technology, capital investment, and skilled manpower required to manage the systems,
- degradation of the resource characteristics of neighbouring sites,
- lack of sufficient on-site management safeguards to promote sustainable development,

- settlers lack technical skills, managerial capacity and social (organisational) background to successfully utilise the irrigation system,
- rigid implementation of irrigation production system that limits modification and local adaption based upon farmers experience or desires,
- lack of regional planning and watershed controls to protect the new schemes from adverse off-site impacts which increases the vulnerability of new schemes,
- hazards to human health resulting from the build-up of disease vectors following changes in vector habitats (see section 8).

Source: modified after Burbridge et al. (FAO) 1988

Irrigation settlement schemes must be based on an objective investigation of the physical land use capability, irrigation methods and farming systems, and the level of technology to be employed (see Part II section 1.3 and 3.1). Of special interest are the following issues:

- agricultural skills of the potential farmers,
- training and technical support to assist farmers to adapt to the new location and irrigated production system,
- cost of necessary agricultural inputs for anticipated production level,
- market prices for goods produced,
- access to credit and technical support,
- land tenure and farming systems of proposed irrigation schemes,
- indigenous land/water rights,
- measures to ensure equity and sustainability

Source: modified after Burbridge et al. (FAO) 1988

## 10.3 Principles for Environmentally Sound Settlement Schemes

Generally, principles and procedures for environmental management are similar for both settlement/resettlement schemes or rehabilitation/extension schemes. However, to ensure sustainable development for farmers who have been transferred to new areas or must adopt new farming systems or new technologies, some socio-economic considerations require closer attention. The following questions typically arise:

- have alternatives to resettlements been considered, for example are all means to improve socio-economic conditions under current production and irrigation systems fully exploited?
- have these alternatives been fully explored?
- have the social, economic and environmental background of the people who will be resettled been fully assessed?
- has the proposed resettlement project been selected on the basis of the background and perceived needs of the farmers being relocated? Are incentives for sound land husbandry and irrigation absent, for example by lack of secure land titles? Do settlers participate in or control the decision making processes?
- what alternative locations and possible economic activities have been explored?
- has the proposed irrigation system been selected on the basis of the abilitities of the settlers to manage the activities and the ability of the natural resource systems to sustain these activities?
- have provisions been made in the project design and management plan to assist settlers to adapt to their new environment and to manage the new techniques and the new agricultural production system?
- will the project be sustainable once external financial and technical assistance is removed?

- have potential adverse environmental impacts been identified within the project documents and what mitigating measures are proposed to reduce or eliminate these impacts?
- does the project make provision for environmental monitoring, periodic assessment and the adaption of policies, management strategies and techniques?
- further questions for irrigation projects deal with: land and soil suitability for anticipated crops and cropping pattern, reliability of water resources; assessment of water resources versus anticipated crops or cropping pattern and total area to be developed; safeguards and mitigating actions to control water-related diseases; flexibility of the management plan to respond to monitoring findings.

Source: modified after Burbridge et al. (FAO) 1988

Socio-economic principles for environmentally sound (re-)settlement schemes are outlined by FAO as:

- **sustainability**: development must be capable of being sustained by the natural resources, abilities of people to manage both their new environment and the proposed irrigated agricultural system, and the ability of local, regional and national institutions to provide the technical support and other facilitites (credit, marketing, etc) to service the scheme once external development assistance is withdrawn,

- **equity**: all people being settled and the local population should have equal access to the physical and economic resources available within the project, including housing, land, water, machines, equipment. agronomic inputs, marketing facilitites, other materials, financial assistance, credit and public services such as education, training, and health care,

- **conservation** of natural resources and development options: the location should be compatible with the conservation (or long-term use) of the ecosystem functions which generate the resources required to sustain the proposed irrigated farming activities; attention must be given to current or future alternative forms or mixes of development offered by the resource system (see Part II section 1),

- **matching people** and **potential settlement locations**: the new development area should have environmental features similar to the areas from which settlers are moving, otherwise intensive technical training programmes and health safeguard programmes must be incorporated,

- **integration** of activities: other activities than irrigated farming may be introduced or integrated, eg part-time fishery, depending on local potentials and farmers' preferences,

- **monitoring** and **adaptive management**: a follow-up of environmental impacts must be ensured because not all changes and environmental impacts can be precisely predicted; furthermore, key indicators of environmental impacts should be established for an efficient and management-oriented monitoring and evaluation system.

Source: slightly modified after Burbridge et al. (FAO) 1988

Socio-economic aspects which influence the environmental regulation system are:

- existence of well defined and accepted limits of different types of environmental degradation: eg erosion, salinity, wetness, drainage pools, etc
- provision for restrictions on the use of common property resources (eg water) through direct regulation or cooperative management by users
- inclusion of standards with respect to sound environmental management in terms which farmers must meet to obtain land (and water) titles, credit and governmental subsidies.

Source: modified after Burbridge et al. (FAO) 1988

Checklists for basic information, essential for sustainable development of resettlement schemes, are listed in Birbridge et al. (FAO) 1988 Chapter 5. The relevant factors are divided into bio-physical, socio-economic and productive factors. Forestry, fishery and agricultural projects are considered. Checklists for agriculture (including irrigation) are given in Table 10-1. Further checklists are available for the selection of settlers, property rights, the economic system, assessment of equity of access to project benefits, knowledge and learning systems, and adaption systems and emergency response systems.

During the final environmental assessment the following issues are to be addressed:

- scope of potential adverse impacts
- specific potential impacts which may reduce the sustainabilty of the settlement project or have an adverse impact upon ecosystem functions, environmental quality, natural resources, economic activities, and human populations outside the command area
- measures proposed within the command area to avoid, ameliorate, or compensate for potential adverse impacts
- assessment of the adequacy of initial assessment and planned mitigating measures
- formulation of amendments to previous measures to reduce potential adverse impacts

Source: modified after Burbridge et al. (FAO) 1988

Source: Dixon et al. (WB) 1989; Cernea (WB) 1988; Burbridge et al. (FAO) 1988; Goldsmith/Hildyard 1984

## 10.4 Social and Economic Imbalances

The real economic benefits from irrigation and especially aspects of equity are often a matter of arguments:

> India: Irrigation has lead to changes in cropping pattern and has encouraged the transfer of 'green Revolution' techniques. These developments have led to economic polarisation and social conflicts - a pattern which is well documented in the literature. Moreover, few irrigation projects can be counted economic successes. In many cases, the revenues from water-taxes are not enough to cover the annual maintenance and operational expenses. In effect, many irrigation projects were subsidised by ordinary people (Bandyopadhyay in: Goldsmith/Hildyard ed. 1986). In 1981, the Auditor General of India pointed out that the Rs 1 billion Tawa irrigation project in Madhya Pradesh had reduced farm production instead of increasing it (Mishra in: Goldsmith/Hildyard ed. 1986; also: Vriksh et al. in: Goldsmith/Hildyard ed. 1986)..
>
> Often, expected (or measured) increases in agricultural production are exclusively attributed to be a result of irrigation; in reality, the increase is due to various other agronomic inputs such as improved tillage, fertilisers, pesticides, high yielding varieties, etc (after: Vriksh et al. in: Goldsmith/Hildyard ed. 1986).

But, findings of World Bank evaluations in Mexico (two large-scale partly mechanised surface irrigation projects for smallholders with 12 ha average farm size) and Morocco (two medium scale sprinkler systems for smallholders with 2.1 ha average farm size) were:

- regarding **agricultural** and **economic** impacts: a tendency at project completion to over-estimate yields and cropping intensitites at full development when uptake of irrigation is successful and agricultural development is rapid. In Mexico, private farmers have performed well (high value crops) but most ejidos (government scheme farmers) went bunkrupt and lost credit, resulting in reduced use of agricultural inputs and low yields. There is a need to pay close attention to minimising risks in the transfer of technology in climates which permit rainfed farming or livestock production with higher profitability and lower risk (eg Mexican-case studies). The most rapid transfer has come in the projects with low annual rainfall (rainfall <500 mm/a) with satisfactory results (economic rate of returns in the range of 9-12%).

- regarding **land tenure**: in Mexico, there is a tendency to revert back to the situation which prevailed before agrarian reform or land consolidation; in irrigation, with increased value and higher productivity of land, the land tenure system is continually evolving; in both countries, experience has shown the danger of introducing collective farming where there is little tradition of communal cultivation. Systems tend to develop back to small group or individual farming. The smallholder approach with high employment and high productivity per unit area is questionable in Mexico but sucessful in Morocco.
- regarding **social** impacts: large income disparities developed in Mexico with yearly incomes of US $ 40,000 and US $ 1,320 for private (average farm size >30ha) and ejidos in Panuco project; in Sinaloa project average incomes have increased by about three times to US $ 15,300 and US $ 5,480 for private farmers and ejidos, respectively. Hence, the expected narrowing of income distribution among beneficiaries is not attainable or sustainable in the absence of a smallholder development approach. Nevertheless, all projects contributed towards stabilising the rural population, limiting migration to cities and alleviating underemployment. In Morocco, successful agricultural development entails an increasing workload, particularly for women and children, and in traditional societies is often at the expense of school attendance. New villages may complete lack success and traditional styles should be maintained wherever possible.

Source: WB 1989

Further reading on economic aspects: Dixon et al. (WB) 1989, Chapter 4

## 10.5 Loss of Cultural Heritage and Historical Sites

Some land which is lost to agricultural and irrigation development, including impoundment areas of associated reservoirs or lakes, may be sites of cultural heritage importance for the local population, related to their religious beliefs and traditional customs. Often such sites are sacred riverine forests, traditional sites for community conventions or cemeteries. There are numerous examples where these cultural heritage sites have been neglected during planning for both large and small scale projects. Appropriate participation of all members of the 'target' group during early planning phases (site selection) is an easy and efficient way of avoiding such impacts.

Archeological monuments and sites of general public interest (eg ancient village site remains) are sometimes also submerged by the development of reservoirs. There are numerous examples of such sites of local or general public interest being completely submerged by large reservoirs, for example

Lake Nasser in Egypt: impoundment of numerous ancient temples and other historical sites; some, like Abu Simbel and Philae, were replaced

Rajghat Dam Project in Uttar Pradesh, India: 23 temples were submerged; 2 palaces were submerged. (Source: Sudershan in: Goldsmith/Hildyard ed. Vol. 2.1986)

Remains of prehistoric settlements may exist in remote or sparsely settled areas. Such remains include stone terracing, stonewalling, granaries, middens containing pottery, bones, ironware and glassware, mining for minerals, metal working and foreign-trade goods, etc. These may be destroyed by large scale irrigation development or by associated reservoirs. Examples of serious losses of unique sites are:

In the Fezzan in Libya and the New Valley in Egypt, various new smallholder settlements or productions schemes were constructed on unique prehistoric sites without attention having been given to archeological surveys or sampling. Similar settlements and prehistoric sites may exist in Southern Africa (South-Africa-Zimbabwe-Botswana) in areas which are now under agricultural or large-scale water development.

In contrast, in Botswana, for example, such developments have included, since the late 1980s, archeological surveys and mitigating actions to survey and collect important artefacts from prehistoric sites to preserve the cultural heritage (eg developments associated with the Lower Shashe Dam; Feasibility Study - Environmental Impact Study, unpublished. Department of water Affairs. Gaborone).

It is essential that, prior to large scale inundations or new land developments, the archeological importance of a given area and the impacts on any archeological features be assessed. Mitigating actions must be identified and important and unique areas must be investigated by an archeological survey, archeological recording and excavations. The potential for damage to sites outside the projected development area must also be considered, eg damage from access roads, campsites, borrow and broad-acre stockpiling areas directly associated with the development.

Further reading: Goodland/Webb (WB) 1987

## 10.6 Socio-Demographic Changes

The population in many parts of the world has doubled or will do so in a few decades. The world's population reached five billion in 1987 and is increasing by some 80 M each year. In many places in the Middle East, Africa, and Latin America, the population is growing at a rate of 3% or more. As nearly all of the additional inhabitants of developing countries earn their living directly from their physical surroundings, thus putting stress on the immediate environment, population growth will constitute one of the principle obstacles to protecting resources on a global scale and to integrating it with socio-economic development in a sustainable way.

Sources: OECD 1991a

Rural development and associated socio-economic and cultural changes must also be seen against this changing demographic context. The creation of social imbalances, inequity and loss of cultural identity, which are often due to the negative influences of large scale development projects, must be seen in the framework of increased consumption of environmental resources by the rapidly increasing population in most rural areas in developing countries.

## 10.7 Socio-Economic Impacts of Mechanised Irrigation Systems

The development of mechanised irrigation has not always proceeded as rapidly as mechanisation of other agricultural operations. Among the reasons are the varied and dispersed nature of irrigation enterprises in developing countries, and site characteristics (eg paddy terraces in SE-Asia), traditions or personal preference, or simply the lack of financial resources and technical know-how all of what resulted in the development of many different types of traditional, manually operated irrigation facilities.

Mechanisation is seldom technically unsuitable in developing countries, but frequently the social and economic conditions necessary for their sucessful application pose serious constraints and have not been given adequate attention in many large-scale irrigation developments financed with public funds. Of greatest concern is the additional energy required for mechanised pumping and pressurised systems and the need for special support systems to provide repairs, spare parts and mechanical services. The more mechanised and automated the technology, the more complex the required support structure and off-farm inputs. This requires involvement in the cash economy and that increased productivity be economically feasible.

Farmers who use modern technologies (either surface or pressurised methods) may not need much special training to operate them. However, they still must understand and adopt the new principles involved and be aware of and meet the maintenance requirements. Most often **failure** is due to use of untested, unreliable or inadeqate equipment, insufficient service and spare parts, lack of maintenance and knowledge by farmers of how best to use the equipment, and limited knowledge amongst technicians as to where and how best to apply, design and service the system. In contrast, traditional systems can be constructed and maintained using indigenous capacity available within communities in developing countries.

For the average farmer, the main reason for mechanisation is to save labour. Labour is often either scarce or expensive in industrialized countries. Benefits other than labour savings include more precise control of water delivery, higher accuracy of on-farm water applications, increased reliability of operations, greater flexibility for the farmer because his presence is not required during the whole irrigation application period, greater flexibility of irrigation scheduling around the clock and greater flexibility regarding changing discharge rates (for example low application rates may be possible for longer periods). Typically, irrigation efficiency is higher in mechanized systems than in non-mechanised systems; with traditional methods, only farmers with small areas, small water supplies, and high value crops can afford to take the time to attain high application uniformities. Strategies for development through mechanisation may contribute towards reducing the impact on water resources (see Part II sections 1.3, 2.3 and 5).

Sources: Keller in: ICID 1990; Kruse in: ICID 1990

The high capital costs of mechanisation relative to traditional systems, is the major factor inhibiting their adoption. Despite the fact that savings in labour, increased crop production or reduced water demand will, over a period of years, repay the inital and operation costs of well designed, operated and maintained mechanised systems, most smallholders in developing countries face many constraints and risks. In those cases where mechanisation would result in more reliable, uniform and efficient irrigation, investment may be required for improved seeds, fertilisers and pest control to get maximum benefit from the irrigation investment.

The **cost component** of mechanised irrigation varies from one region to another, mainly on account of national market prices, site-specific land and water development characteristics and the irrigation method used.

In Brazil (Rodriguez et al. in: ICID 1990), for example, costs of surface irrigation development (in 1988) were in the range of US $ 900 to 1,300 per ha, drainage accounting for US $ 200 to 350, irrigation for US $ 530 to 1,100, operation and maintenance for some US $ 30 to 50 per year.

Total fixed costs for sprinkler systems range between some US $ 200 and 350 per ha, total variable costs between some US $ 220 and 330 per hectare per year. Energy costs may account for some 25 to 40% of the total costs.

In Chile, the investment costs of sprinkler and micro-irrigation may vary from some US $ 2,500 to 9,000 per ha, the lowest unit costs being for fodder crops (Avendano in: ICID 1990).

In France, annual costs (fixed and variable, as of 1989) of surface irrigation systems were in the range of US $ 150 to 200 per ha, and for modern types of gated pipe and buried pipe with surface cablegation costs were between US $ 430 to 800 (Frey et al. in: ICID).

Table 10.2 lists initial costs and annual maintenance as a percentage of initial costs in mid-1980 prices for various modern irrigation methods and techniques for installations on large fields (65 ha). Typically, costs for modern systems range between US $ 1-3,000 without large scale water supply facilities, which may account for some US $ 5,000.

In most developing countries there is an additional increase in costs in the range of 25 to 100% due to freight, taxes, small units, etc. In **India** costs for government-financed projects designed to deliver water to smallholder farms vary from US $ 2-4,000. In other countries where many resources must be imported the costs may average US $ 5,000. In Sub-Saharian **Africa** government-financed irrigation development costs are often US $ 10,000 per ha and more. Drainage costs generally vary between US $ 1-2,000 per ha (Keller in: ICID 1990).

Thus, a **global average** cost for government-financed irrigation systems complete with drainage works range from US $ 5-6,000 per ha. To recover such high costs high productivity is required (Keller in: ICID 1990).

Typically, irrigation mechanisation results in improvements in farm **practices**, farmers **income**, and in both regional and national economies. Commonly, a single farmer's response to mechanisation may be affected by farm size, labour availability, site-specific land and water characteristics and suitability for a variety of crops, market conditions, need to support livestock and other factors.

In India, as a result of pumped irrigation development, the farmer's crop selection options have become greater, productivity (per unit area) is higher, farm income increased, and risk of crop failure reduced. Multiple cropping has increased, resulting in a 40% increase in cropping intensity and a single farmer can irrigate more land with his family labour (Michael in: ICID 1990).

Impacts on the community vary with the type of irrigation. Large-scale sprinkler systems (eg center pivots) which irrigate a number of small farms may constitute the type of mechanised irrigation with the most impacts. In such situations, it is imperative that the land holders organise so as to make cooperative decisions on crops, cropping pattern, and irrigation scheduling. Under certain favourable socio-economic conditions such systems may operate fairly well, eg in Morocco and Guatemala (Abderrazak/Mohamed in: ICID 1990; Keller in: ICID 1990).

In several countries the mechanisation of irrigation has had beneficial impacts with regard to the creation of new jobs in the manufacturing industry, eg in India, China and Brazil. However, in other, less industrialised countries, only marginal effects may occur and a large porportion of foreign currency earnings must be used for purchasing equipment and spare parts from outside. If additional income from irrigation must be spent on foreign trade, then farmers may be forced by government policy to grow export crops and the beneficial effects of irrigation may be counteracted. On the other hand, new opportunities for foreign trade may be offered through the development of high-value crop or fruit production in more productive mechanised irrigation systems. For example, in Chile some 12% of current national exports are earned from fruit exports.

Sources: Kruse in: ICID 1990; See also: critical discussion in: Goldsmith/Hildyard 1984

Energy consumption in mechanised irrigation systems is obviously higher than for traditional systems (see section 7). Pressurised systems use more energy than (modern) surface irrigation systems. In traditional systems, most energy is used for water supply facilities, especially for pumping groundwater. If farmers must do their own pumping, they must be involved in the cash economy to be able to pay for fuel/power.

Labour savings and convenience may be the principle factors that induce farmers to adopt mechanisation. Often the **type** of labour required is different for mechanised than for manual systems. Manual labour may be required during installation, but such requirements are typically reduced when the systems are operational. Then, operators with ability to understand the system, diagnose problems and repair mechanical, electrical and hydraulic systems. Hence, mechanical (hand) labour may decrease, but 'cultural' labour requirements increase, with an increased demand for operational skills, demand for more fertiliser and pest control, greater volume of harvest, selling of produce to market, etc. Farm labour is more highly-qualified and family labour may become less important whereas qualified off-farm (seasonal) labour is available. Labour skills must also be considered with regard to water distribution if water supply is provided by centralised systems.

Mechanization may thus result in the displacement of unskilled manpower. In the fruit producing sector in Chile, increased mechanisation is expected to eliminate the need for 3000 workers in the irrigation sector. However, the added irrigation potential (increased productivity, increased efficiency of water use, side effects on trade and manufacturing) will create the need for 45 000 additional farmers or farm workers (Avendano in: ICID 1990).

Sources: Kruse in: ICID 1990; Keller in: ICID 1990; Michel et al. in: ICID 1990; Rodrigues et al. in: ICID 1990; Marr in: Hagan et al. ed. (ASA) 1967

Further reading: most recommended: Keller in: ICID 1990; other in: ICID 1990

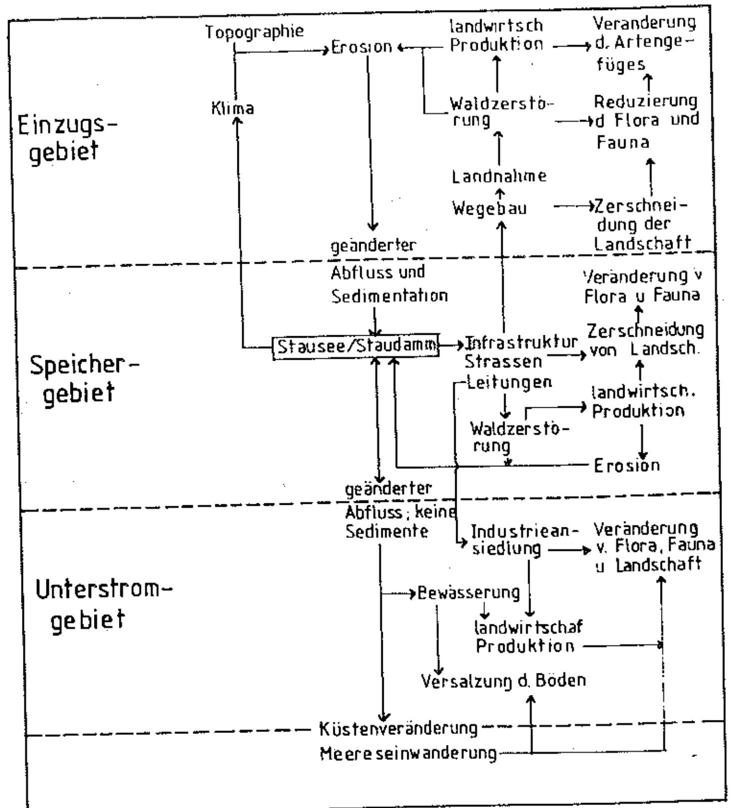
Critical review in: Goldsmith/Hildyard 1984; Various case studies in: Goldsmith/Hildyard ed. 1985

## 10.8 Solutions: Conflict Minimising Strategies

Sustainable irrigation development in its economic, social and cultural dimensions requires environmental management of natural resources in terms of natural goods and services. The objective is to improve the quality of human life by the mobilization of land/water and biotic resources and the administration of both natural and economic goods and services. Important criteria include **acceptance, equity** and improved **efficiency**.

Practical consequences and possible strategies and procedures for sustainable development in irrigation projects are outlined in section Part II sections 1.1 and 1.4.

Fig. 11-1 a




Ausschnitt aus dem ökologischen Wirkungsgefüge eines Flußstaus

Source: Dilger in Stübeb ed. 1987

Fig. 11-1 b

Matrix I (Grobmatrix)

| UMWELTBEREICHE (ENVIRONMENT) / MASSNAHMEN (ACTIVITIES) | NATÜRLICHE UMWELT (NATURAL RESOURCES): Physisch-Geograph. Bereich | | | | | | | | Biologischer Bereich | | | NUTZUNGSBEREICH (HUMAN USE) | | | | | | HUMANBEREICH (SOCIO-ECONOMIC ASPECTS) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Klima (CLIMATE) | Erosion | Sedimentation | Versalzung (SALINIS.) | Wasserqualität (QUAL.) | Grundwasser (GROUNDW.) | Abflußverhalten (FLOW) | Seismik | Eutrophierung | Versumpfung (WATERLOGGING) | Flora/Fauna | Fischerei (FISHERIES) | Landnutzung (LAND USE) | Industrie | Schiffahrt (NAVIGATION) | Tourismus/Erholung | Infrastruktur | Soziale Auswirkungen | Umsiedlung (RESETTLEMENT) | Gesundheit (HEALTH) | Schutzzonen (PROTECTION) | Gesetze/Administration/Landesplanung (LAWS) |
| Stausee (LAKE) | o | o | ◯ | | ◯ | ○ | ◯ | ○ | ◯ | ○ | ○ | ◯ | | | o | ○ | ○ | | ◯ | ◯ | ○ | |
| Speicherräumung (RESERVOIR FILL) | | | | | ◯ | | | | ◯ | | ○ | ◯ | | | | | | | | o | | |
| Umsiedlung/Besiedlung (RESETTLEMENT) | | | | | ○ | | | | ○ | | | | | | | | ◯ | ◯ | | o | | ◯ |
| Trinkwasserversorgung (POTABLE WATER) | | | | | ◯ | | | | ◯ | | | | | | | | | | | ◯ | | ◯ |
| Bewässerungsprojekt (IRRIGATION) | o | ○ | | ◯ | ○ | ◯ | | | ○ | ◯ | ◯ | | ◯ | | | | | ◯ | | ◯ | ○ | ◯ |
| Wasserkraftnutzung (HYDROPOWER) | | ○ | | | | | ◯ | | | | | ○ | | ◯ | o | | ○ | ○ | | | | ◯ |
| Hochwasserschutz (FLOOD CONTROL) | | o | | | | | ◯ | | | | | | ○ | | o | | | ◯ | | | | |

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Übergeordnete Maßnahme, unabhängig von der Nutzung (shaded rows: Stausee, Speicherräumung, Umsiedlung/Besiedlung) ◯ großer Einfluß ○ mittlerer Einfluß o geringer Einfluß

Source: Baumann et al. 1984





# 11 Impacts Related to Large Dams

Development projects involving dams represent large investments, extensive construction works and, hence, large impacts on natural and human-made ecosystems. Dams for irrigation, hydropower, flood regulation, fisheries and to secure domestic and industrial water supply are large infrastructural investments that can produce major economic benefits. However, some of the intended developments associated with dams have provedto be elusive and the large-sclae destruction of natural ecosystems and disruption of traditional land use systems and settlements is now under discussion. Some public observers even take the extreme view that all large dams are bad and that new construction should be stopped (Goldsmith/Hildyard 1985; Stüben ed. 1987). As a result of these discussions, the potential and actual environmental impacts of larg reservoirs are now well documented, firm assessments are now available, and environmental factors have recently attained a high priority in project planning. Detailed discussions are found in many sources (see references). This section provides a brief outline of impacts.

Sources: Dixon et al. 1989, Canter 1983, Hagan/Roberts 1975, and various ICOLD Transactions

## 11.1 Dams and International Funds

The construction of large reservoirs and their funding by donor agencies and international banks leads to widespread criticism of these projects. However, only a small number of dams are in fact funded by the industrialized countries. The World Bank for example, is funding about 5-10 dams per year, ie less than 5% of the average annual construction of dams worldwide, excluding China. Explicit formal environmental attention (ie reports) was given to about half the dams which have been appraised since 1972, of which 55% are primarily irrigation, water supply or flood control dams. Since 1983 all dam projects, funded by the World Bank have had to produce environmental reports and the number of irrigation and water supply dams increased to 70% of all dams constructed. On the other hadn, most of the very large dams (outside China) were, in fact, designed and constructed with international assistance and these reservoirs resulted in widespread detrimental impacts on natural and human-made ecosystems and are responsible for large scale resettlement schemes. Examples are, Lake Kariba in Zambia-Zimbabwe, Lake Volta in Ghana, Lake Manantali in Mali-Senegal, Cabora Bassa in Mocambique; Lake Nasser in Egypt-Sudan, Itaipu in Brazil-Paraguay.

## 11.2 Dams and the Environment

Examples of publications reviewing the impacts of dams on the environment include the following reports:

Baumann et al. (1984) conducted a comprehensive review of the possible impacts of large reservoirs, including associated construction works and infrastructure, on climate, hydrology, seismicity, aquatic and terrestric ecosystems (see also: Zauke et al. 1992), health conditions, production systems (agriculture, industry, fishery), resettlement and administrative and legal aspects. They concluded that the risks of negative direct and indirect impacts can be significant, especially when feasibility appraisals are based solely on economic considerations which do not consider welfare economics. The risks include the destruction of extensive natural ecosystems, destruction of settlements with long traditions, destruction of traditional land use systems in the reservoir zone, increase in erosion, salinisation of irrigated areas, increase of water-related health risks, increased sedimentation of reservoir, changes in water quality, and increased risk of floods. They identified two critical issues: resettlement and the destruction of natural ecosystems. They called for environmental impact assessments and submitted three schematic evaluation matrices

Fig. 11-2

Figure 1.1

STORAGE DAMS AND THE ENVIRONMENT
CHAIN OF MAIN EVENTS

EFFECT OF ENVIRONMENT ON THE RESERVOIR

| EFFECTS | CONSEQUENCES |
|---|---|
| - Precipitation<br>- Soil erosion<br>- Pollutants & natural chemicals<br>- Aquatic life & waterfowl<br>- Evaporation<br>- Climate<br>- Debris | - Run-off (for storage) with extreme events of floods & low flows<br>- Siltation of reservoir and outlet<br>- blockage.<br>- Deterioration of water quality<br>- Settlement on reservoir<br>- Water loss<br>- Low temperature water inflows<br>- Outlet blockage. |

RESERVOIR

EFFECT OF THE RESERVOIR AND ITS STORAGE FUNCTION ON THE ENVIRONMENT

| EFFECTS | CONSEQUENCES |
|---|---|
| - Smaller variations in downstream streamflows<br>- Lower silt content of water<br>- Inundation of land<br>- Creation of lake/pond<br>- Creation of gravity head<br>- Lower flows downstream<br>- Temperature<br>- Interception of river<br>- Inundation of forests<br>- Induced seismicity<br>- Reservoir drawdown<br>- Subterranean leakage<br>- Construction activity | - More plentiful and reliable supplies of water; less flood damage; lower after-flood crop production; less flood plain fisheries; more/less estuarial salinity depending on topography. less bank erosion.<br>- Lower cost of water management; downstream erosion.<br>- Displacement of settlers; damage to fauna & flora, archaeology, and infrastructure; loss of land.<br>- Recreation; new fisheries; better animal watering but disruption of migration routes; eutrophication.<br>- Command of irrigable land; potential power production.<br>- More estuarial salinity (in extreme cases).<br>- Better conditions for users (warmer water, less frazzle ice).<br>- Interference with fish migration.<br>- Poor water quality for potable purposes.<br>- Induced landslides.<br>- Dry season cropping/grazing.<br>- Rise in groundwater.<br>- Economic development; environmental change. |

SECONDARY EFFECTS ON "SERVICE AREAS" AND SYSTEMS DOWNSTREAM

IRRIGATION

| EFFECTS | CONSEQUENCES |
|---|---|
| - Lower silt content in water<br>- More regular supply of water<br>- Additional water supply<br>- Gravity supply to irrigation system (where feasible)<br>- Regulated river flows | - Lower O&M cost; better water management leading to less water logging.<br>- Changes in fauna and flora.<br>- Adoption of perennial in place of non-perennial irrigation with better crop production.<br>- Expansion of irrigated area.<br>- Better control of some pests and diseases; less control over others.<br>- More waterlogging but, with good management, better salinity control.<br>- Lower energy consumption.<br>- Lower pumping costs. |

Note: Almost all storage dams supplement water supplies to existing run-of-river systems.

DOMESTIC & INDUSTRIAL WATER SUPPLY

| EFFECTS | CONSEQUENCES |
|---|---|
| - More reliable supplies ** <br>- Lower biological quality *<br>- Higher chemical quality *<br>- Wider spatial availability of water **<br>- Poorer taste * **<br>- Lower silt contents ** | - Less failures and less rationing hence better public health control.<br>- Better repulsion of salt intrusion in estuaries giving more sustainable rural water supplies.<br>- Higher treatment cost.<br>- Lower treatment cost.<br>- Less concentration of urban areas and industries.<br>- Higher treatment cost.<br>- Lower treatment cost. |

Notes: * compared with groundwater
** compared with run-of-river

POWER

| EFFECTS | CONSEQUENCES |
|---|---|
| - Non-thermal energy production<br>- Renewable energy source<br>- Lower cost of production<br>- Simplicity of operation<br>- Lumpy investment | - Displaces fossil fuel and nuclear power and their associated environmental effect.<br>- Sustainable production.<br>- Permits special industries such as smelting<br>- Provides low cost domestic amenities.<br>- Less failure in regions with few skilled human resources.<br>- Debt burden. |

Note: Treats fossil fuel and nuclear power as the alternative sources to hydroelectric (excludes tidal wave, and other sources.

Source: Dixon et al. 1989





on all important potential impacts and interrelations: a generalized impact matrix, an activity-impact matrix and an assessment matrix (Fig. 11-1a).

Goldsmith/Hildyard (1984 and 1985) submitted a most critical review of the impacts and effects of large dams, including modem irrigation. They conclude that most large dams and irrigation projects had not met their objectives, and that they were destructive to the environment and social life. Their recommendation is: "... to persuade Third World governments to abandon plans to build water-development schemes ... " (Vol. 1, p. 345).

Bolton (in: Goldsmith/Hildyard ed. Vol.2. 1986) notes, referring to the Cabora Bassa Dam in Mozambique, "the tendency throughout the history of the Cabora Bassa Dam for the authorities to underestimate the constraints governing the regulation of a river of this size and the extent of changes which the dam must introduce. As a result, unrealistic claims about supposed multiple-purpose benefits have been made which, on close examination, are technically unjustified, since they fail to take into account possible long-term environmental problems or depend on the availability of skills and resources that are not, in fact, available" (p.165).

Dilger (in Stüben ed. 1987, in german), provides a critical overview (Fig. 11-1b) and concentrates on biological issues (Table 11-1 b).

Dixon/Talbot/Le Moigne (World Bank 1989) submitted a **review** of potential environmental hazards based on spatial relationships: upstream - on-site - downstream (Fig.11-2). Environmental aspects of reservoir projects are outlined in Tables 11-2a-b in terms of natural goods affected. Environmental effects and their likely economic impacts are shown in Table 11-3. Impacts can be negative or destructive but also generating benefits. Sometimes one physical component will produce both environmental costs and benefits. For example, the creation of a dam may block a fish migration route, thereby reducing fish stock and catch. At the same time, the reservoir can create a potential lake fishery. Environmental processes and effects are usually interconnected: people relocated from the inundated area may move upstream into the watershed. Their land use practices may contribute to erosion and thus an increased siltation rate of the reservoir. This, in turn. may reduce capacity for hydropower or water supply to other lake water users, whilst sediment trapped in the reservoir may improve downstream water quality for irrigation and domestic supply. A detailed summary of findings is presented in detail in Table 11-4.

A comprehensive overview of environmental issues was compiled already in 1975 by Hagan/Roberts. A checklist on dam impacts was prepared by Canter (Table 11-5).

## 11.3 Dams and Irrigation

About 50% of all dams funded by the World Bank are primarly aimed at flow regulation for irrigation. The number of small dams which are built primarily for irrigation purposes are not known, but they by far outweigh the number of large and medium sized dams. A list of all dams higher than 100 m is given in Goldsmith/Hildyard Goldsmith/Hildyard Vol 1, 1984, Appendix).

The influences of dams/reservoirs on irrigation are manifold:

(i) effects on (timely) **water availability**

- in arid regions: mitigating drought through the supply of water for crop growth which would otherwise not be possible,

- in semi-arid and subhumid regions: extension of the growing season into the dry season when the natural discharge of most streams in semiarid zones is declining; allowing two or more crops per season (increasing seasonal and inter-seasonal availability); allowing an early start to the season by water supply prior to the rainy season (depending on storage capacity),

- elsewhere higher security of irrigation: mitigating the seasonal variations and annual variabilities of long-term water supply through the scheduled delivery of water.

(ii) effects on **water volume**:

- typically more water is available for irrigation through the provision of reservoirs; however, the exact water volume depends on reservoir management options depending on the type of reservoir and other users such as hydro-electricity, multi-purpose dams, navigation reservoirs (canals), irrigation reservoirs or tanks, etc.,
- the percentage evaporation losses from reservoirs depends on several factors, especially the ratio of surface area extent to storage volume. Generally speaking, there is an increase in proportional evaporation losses especially in shallow reservoirs which are filled during the hot-dry season. However, some evaporation losses are compensated for because of reduced flows to the downstream floodplains which would occur under natural flood regimes. Under natural regimes these are typically flooded during peak flow(s) and losses to evaporation (and infiltration) from these shallow inundated areas can be higher than lake evaporation losses; on the other hand, these natural floods may be favourable to wetland ecosystems, flood-rice cultivation or other human-made ecosystems, such that depriving such areas of flows constitutes a net cost.
- further losses to downstream users are posed by seepage losses which usually account for 10 to 30% of the losses in reservoirs; losses usually decline after several years because of fine deposits at the bottom of the reservoir.

(iii) effects on **water quality**

- usually there is slight increase in salinity in the downstream flow of large reservoirs because some of the stored water evaporates, thus increasing concentrations in the remaining water. The rate of annual increase is directly proportional to the volume of water evaporating, which depends on climatic factors, water temperature, dynamics of thermal stratification, surface areas, and occurence of aquatic weeds. The actual increase is modified by the annual reservoir exchange ratio. If saline layers occur within the river bed additional salts may be dissolved and thus increase the reservoir salinity. Increases in the water salinity are given for two examples for large reservoirs:

Egypt. Aswan High Dam: Average reservoir evaporation 11%. An increase of EC 5 to 20% (from 0.26 to 0.37 dS/m) was predicted before construction. 10 years after construction (1984) an average increase of only about 4% was measured: 0.27 dS/m [Source: Wolff 1986]

Iraq. Mosul Dam River Tigris: predicted increase from 0.42 to 0.46 dS/m or 3%. Tharthar Reservoir: increase from 0.46 to 0.50 dS/m. [Source: A. Al-Layala/L.N. Fathalla in: ICID. Transactions. Brazil 1984)

*Case Study*

Impacts of the Aswan High Dam in Egypt

The dam was designed to serve three functions:

(i) to store water from the annual flood to allow for secured regulated releases for irrigation and other purposes throughout the year and carry over storage

(ii) to generate hydroelectric power

(iii) to control disastrous high floods.

Some 20 years after completion (1968) it can be stated that the reservoir achieved its major goals: floods have been controlled, irrigated areas enlarged, and power generation increased. In fact, the reservoir allowed continued irrigation of the Nile soils, even during the drought years for the 1980s. The displacement of some 110,000 people in Egypt and the Sudan was unavoidable. Egyptians were resettled

Fig. 11-3

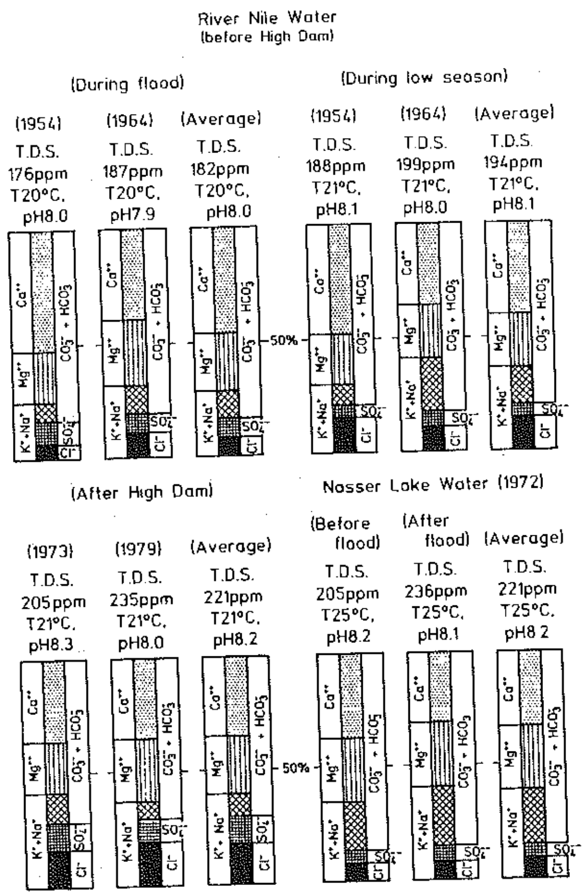



**Fig. 1.** Graphical representation of water chemical analyses

$Ca(HCO_3)_2$

$Mg(HCO_3)_2$

$(Na+K)_2$ $HCO_3$

$(Na+K)_2$ $SO_4$

$(Na+K)$ Cl

Source: Khalil/Hanna 1984





north of Kom Ombo and some in the New Valley. They were provided with new irrigated lands. Health conditions improved through a reduction in infectious diseases. Fishing in the reservoir provides employment for some 7,000 fishermen; the catch amounts to 20,000 to 34,000 t. About 85 M $m^3$ of sediment load is sedimented in the reservoir, ie 88% of the total load. It will require some 350 years to fill the dead storage reservoir, assuming the current rate of sedimentation. The retention of silt has had some effects on downstream users:

- stream channel degradation: releases of water low in silt resulted in stream bed degradation, bank erosion and meandering of the main stream. Scouring resulted in changes in the river cross section; the water surface elevation dropped 0.6 m downstream of Aswan High Dam, 1.0 m downstream of Naga-Hamadi barrage and 0.7 m downstream of Assiut Barrage. Meandering and shallow water depth in the winter season created navigation problems at some locations, especially when new banks developed within the bed. Some downstream structures needed to be strengthened and additional scour depth was created by local scouring downstream from the barrage apron floor (at smaller downstream barrages). Dredging is required to allow for continued navigation through these blockages.

- navigation: benefit from regulation: maximum fluctuation in water level decreased from 9 to 3 m; navigation also developed behind the dam

- water quality: turbidity dropped by 94% but the amount of dissolved solids increased by 30% along the river section between Aswan High Dam and the Delta, caused by drainage return flow from irrigated lands. The High Dam water releases showed no significant trend of increased salt contents (Fig. 11-3). No significant changes in pH, oxygen content and Cl-contents were observed in dam releases. Loss of nitrogen added to fields during flooding is estimated to be equivalent to 1,800 t annually. Before construction, the average annual sedimentation rate was about 1.0 and 0.3 mm in the Upper and Lower Nile Valley and 0.06 mm in the Nile Delta, equivalent to 18, 12 and 1.5 t/ha.

Due to the rather low nutrient content of the Nile water, the actual high nutrient demand of crops, and the relatively favourable soil conditions (6-12 m thickness of flood sediments) the importance of annual nutrient deposition may have been largely over-estimated in the past. In any case, high yielding varieties would require fertiliser applications.

Increases in water salinity after construction are due to increased leaching of soils and wastewater from settlements. The water quality is still sufficiently good for irrigation and domestic purposes.

- irrigation: irrigated areas have increased; the supply to individual fields has increased and is now reliable; many areas have been converted from irregular flooding to perennial irrigation; some irrigated areas have been degraded or lost due to waterlogging, salinisation and alkalinisation.

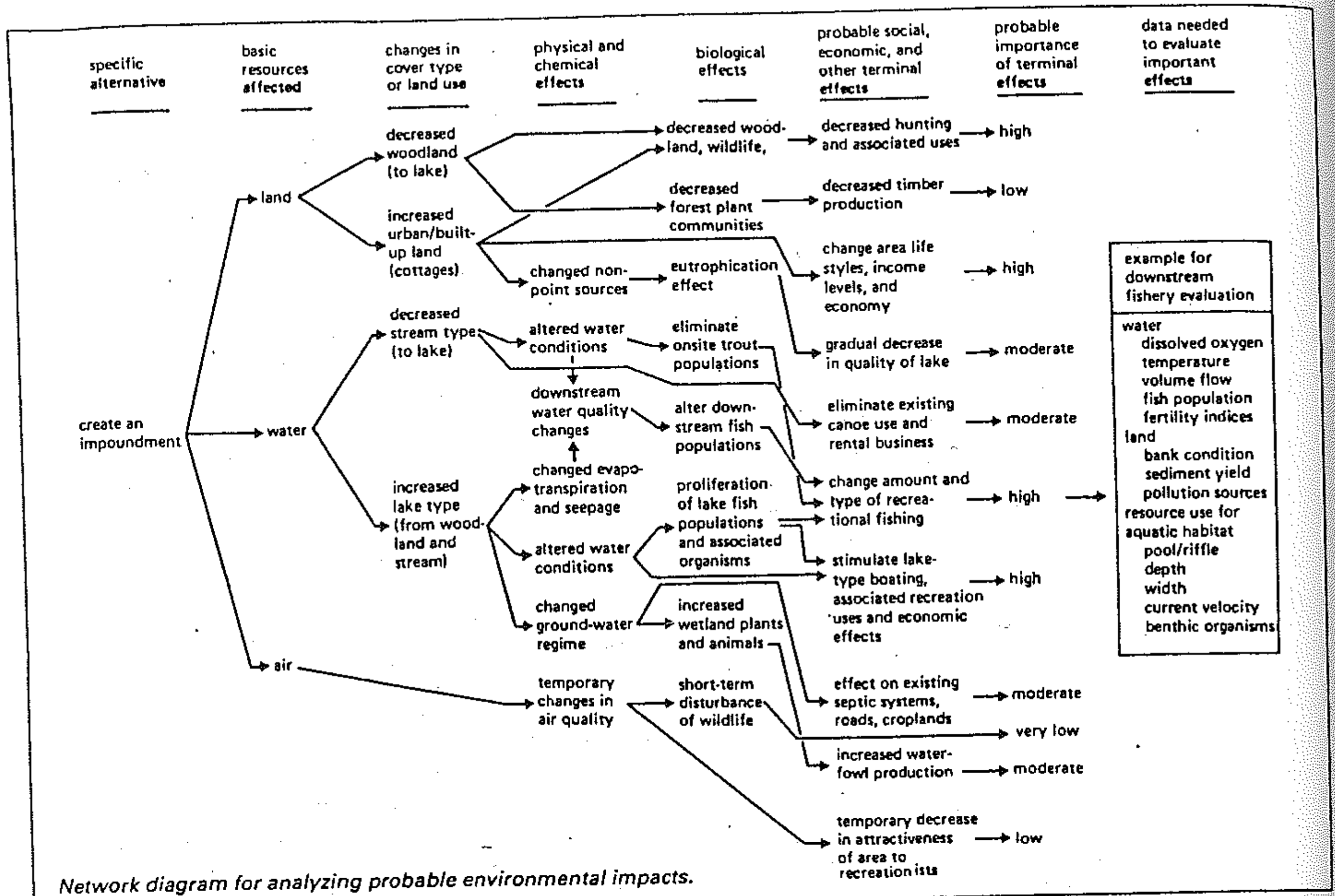
- drainage: is the major problem: due to the rapid areal extension of irrigation, introduction of perennial irrigation, over-irrigation and poor land levelling, groundwater levels have risen in many areas. Drainage problems are addressed by large scale drainage schemes and improved water management practices

- fishery: this has declined, both in the downstream part of the Nile and in the Mediterranean. The species diversity has also declined.

- agriculture: productivity has increased due to an expansion of the irrigated area and intensification of irrigation.

- endemic water-related deseases: urinary schistosomiasis has declined (due to village water supply schemes) but intestinal schistosomiasis has spread especially in the Delta.

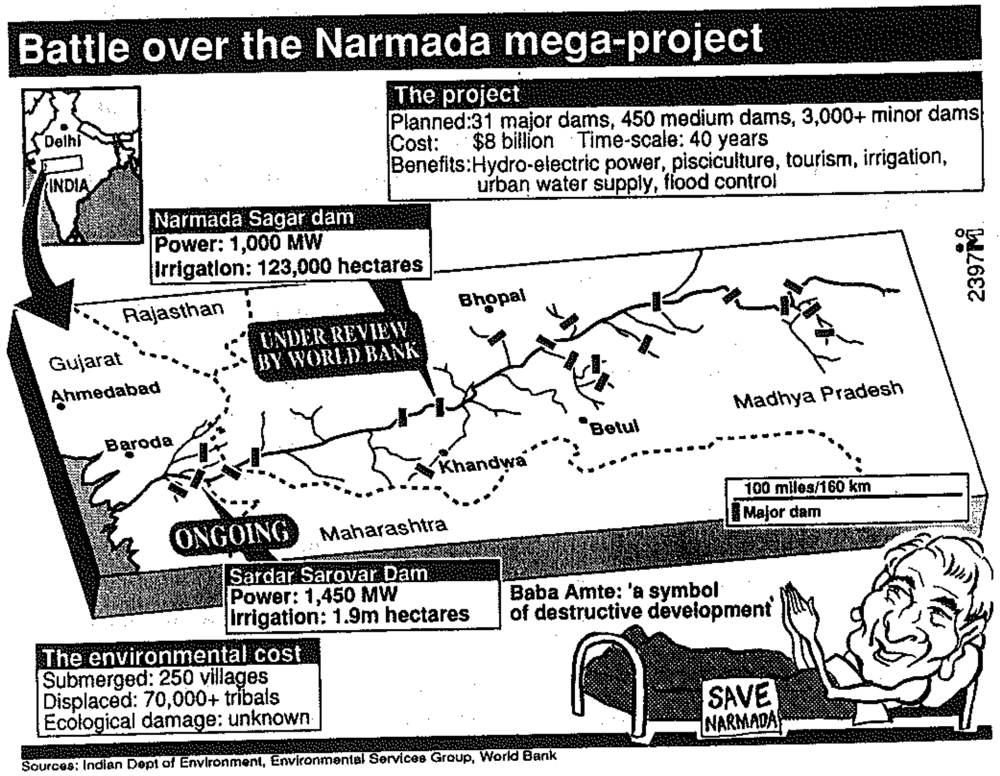
Fig. 11-4




Network diagram for analyzing probable environmental impacts.

Source: Canter 1983

Fig. 11-5

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Source: from Development & Cooperation, DSE 1/93





It seems evident that the beneficial overall effects outweigh the social and environmental costs. Most negative impacts were anticipated in advance, eg drainage problems. However, funds were not available in time and corrective measures commenced too late. Only recently have water quality aspects received more attention because water quantity aspects had always been the major issue in regulating the Nile.

Sources: Gasser/Saad 1991; in: ICID (STS-B13) Bejing; White 1988; Shalaby in: ICOLD 1988; Abu-Zeid in: Biswas/Qu Geping 1987; Wolff 1986; Khalil/Hanna 1984

## 11.4 Conclusions

1. Generalisations on the impacts of large dams should be avoided: not all dams have significant negative or disastrous impacts on the environment. The type and magnitude of impacts on each environmental factor should be separately investigated for each individual reservoir project. The network Fig. 11-4 shows that complex analysis is required for qualified statements. The following spatial dimensions must be observed: upstream - on site - downstream.

Not all factors pertain to all dams, for example not all dams impound villages, important agricultural land, wetlands of ecological importanc or marketable timber.

2. Some major critical environmental issues are now being given a higher priority than in the past: for example, involuntary resettlements, tribal people's interests, cultural property and wildlands (see section 10).

3. It is important to use a holistic environmental approach in the planning stage, where all relevant factors are considered. Environmental appraisals should be performed as early as possible to allow for adjustments in the location or design of the project.

4. Despite the fact that environmental issues are now treated more carefully even during early planning stages, the dam-issue will also in future remain controversial. The holistic balance between negative and positive effects of dams will remain merely a political question which is beyond the scope of scientific arguments. One may argue that even relocation of a few people will outbalance otehr positive aspects, and hence most water resources development (eg irrigation) with large dams is not justified.

Recent examples of such controversial debates over dams are for example:

* the Narmada project in India (Fig. 11-5), see: Dixon et al. 1990 (Annex) and various other World Bank papers.

* the Southern Okavango Integrated Water Development Scheme (SOIWD) in Botswana. After a planning period from 1986 to 1991 the SOIWD was terminated just before construction started in 1992 due to environmental and socio-economic aspects (IUCN review report 1992, Botswana unpublished report). However, debates are still ongoing.

Main Sources: Dixon/Talbot/Le Moigne (WB) 1989; LeMoigne/Barghouti/Plusquelles (WB) 1989, Baumann et al. 1984; Wolff 1986

Further readings: Talbot 1987; ICOLD 1987

Main criticism: Goldsmith/Hildyard Vol.1 1984, Goldsmith/Hildyard ed. Vol.2 1985

Ecological studies on human-made lakes in the tropics: Zauke et al. 1992.

# 12 Environmental Factors Affecting Irrigation

Most of the important ecological (environmental) conditions which are required for sustainable development of irrigated agriculture are well understand and known. There are many textbooks which deal with these conditions in detail, eg Stewart (ed.) ASA 1990, FAO (Irrigation & Drainage Papers, Soil Bulletins, Conservation Papers), van Schilfegaarde (ed) ASA 1974, and Kreeb 1964. Hence only a few issues will be outlined in the following chapter. Section 2.5 includes a summarising list of potential environmental factors affecting irrigation.

## 12.1 Water Quality Effects

Poor quality of irrigation water affects the following qualities of irrigation environenments:

- soil salinity build-up (through adding salts to the soil which are only partly removed by leaching and plants),
- soil sodicity build-up (through altering the soil's exchangeable sodium content towards an equilibrium with the content of the irrigation water),
- soil alkalinity build-up (through modification of the chemical composition of the soil solution and the exchange complex),
- drainage effluent quality: the quality of groundwater or surface run-off may be impaired
- soils may be contaminated by toxic substances or pathogens from wastewater or, to a lesser degree, from surface water resources. If the project is located in the lower watershed this may be due to industrial and domestic wastewaters.

Increased soil salinity/alkalinity/sodicity influences the type of plants suitable for irrigation and the cropping pattern may need to be adapted to saline/alkaline/sodic conditions. Furthermore, reclamation needs will be higher or more sophisticated with poorer water quality: the leaching demand will increase, permeable soils are required and land drainage must be secured either through natural drainage or the provision of a drainage system.

### Seawater Intrusions

The intrusions of saline seawater is of importance in some estuarine deltas, eg in Asia and West Africa. The salt water intrusions may be a danger to delta agriculture (or other users) by direct flooding or through lateral saline groundwater movements. During the wet season the upland flows are usually so large that the entire delta is fresh. At the end of the wet season (or flood season) a sudden change occurs especially in the passive sectors of large deltas, ie the old channels that in the dry season take little flow. Their freshwater inflow is cut off and saline intrusion advances again.

Seawater intrusions are able to contaminate increasingly larger areas of deltas. This is due to both the increase in water abstraction by domestic and industrial uses along the upper river, and the establishment of irrigation schemes in the upper catchments both of which reduce freshwater inflows to deltas particularly during the dry season.

This change in upstream abstraction patterns causes a gradual recession of freshwater upland flows. The pattern of saline intrusion in tidal deltas is determined by the balance between saltwater flow causing upstream motion, and the freshwater flow causing downstream motion.

Source: ODU Bulletin 1987

## 12.2 Water Availablity Effects

Upper watershed (hinterland) mismanagement may lead to disastrous floods further downstream, causing damage to human live, livestock and wild animals, riverine ecosystems, and settlements. It is commonly agreed that conversion of woodland to agricultural lands, either cropland or rangeland, in humid mountain and hilly areas leads to a significant increase in total downstream flow volume and a change in distribution and timing of floods in downstream reaches.

Recent research, however, has not supported the hypothesis that deforestation in the upper catchments is the major contributor to disastrous floods in the great river plains in Asia. The following factors are more likely determinants of the extent of floods in Asia: changes in lower catchment basin characteristics, river constrictions, large areas of human-made compacted and sealed surfaces, and increased river- and floodplain occupancy by man and his modified environments. In general there is growing uncertainty amongst scientists as to the effect of environmental conditions in upper watersheds on the frequency and severety of flooding, because the effects usually diminish with distance down the watershed, ie. as the catchment area increases. On the other hand, in small catchments the direct impact can be clearly measured. The disentangling of impacts of upland uses from other factors in determining the frequency and severety of floods is an elusive task. Sound statistical analysis is often impossible due to poor and limited data and theoretical analysis is often speculative and hazardous. A consensus has emerged that agriculture and forestry in upper watersheds are less important than was previously thought in exacerbating the effects of major flood events in Asia:

> *Case Study*
>
> Brahmaputra River. Actual data on annual runoff, sediment load, and high and low flows for the Brahmaputra river system show no definite trend towards a deterioration of environmental quality. Data are often not consistent with expectation that upland degradation leads to higher peak flows; data on incidence and severety of floods do not show a trend towards worsening floods; it is likely that concern over floods is growing as a function of greater economic activity in floodplains.

Sources: Rogers et al. 1989; Hamilton/King 1983; Hamilton 1988; Ives/Meserli 1989, all cit. in: Magrath/Doolette 1990

## 12.3 Land Quality Effects

Physical land qualitites are important determinants of land development options, especially in irrigated agriculture because of high development costs involved. Important land factors are:

- topography: slope, microrelief, slope length
- hydro-pedological and soil physical conditions and constraints: infiltration, permeability, aeration, watertable level and fluctuations, land drainage, available soil moisture capacity, texture clas, bulk density, structure (aggregate) stability, consistency
- soil chemical properties: cation exchange characteristics, salinity, alkalinity/sodicity, available macro- and micronutrients, soil reaction, mineral compositon
- erodibility
- climatic conditions: daylength, temperature characteristics, potential evaporation, effective rainfall and rainfall pattern (the climate is considered a land quality in land evaluation systems). For further details see Part II section 3.1 and 3.2.

Fig. 12-1

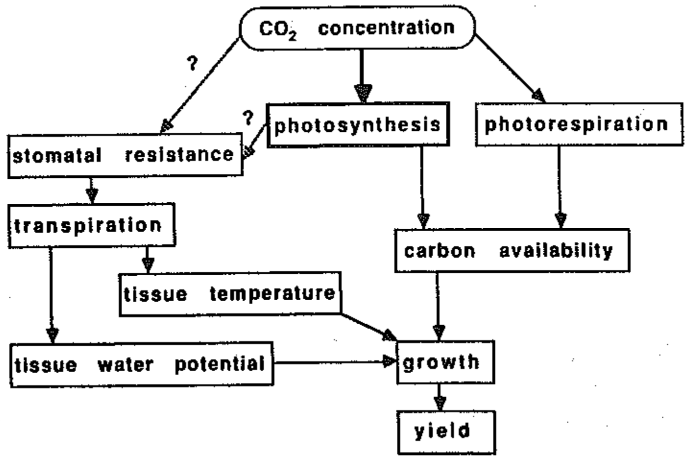


Fig. 4-1. A hierarchy of plant responses to $[CO_2]$.

Fig. 12-2

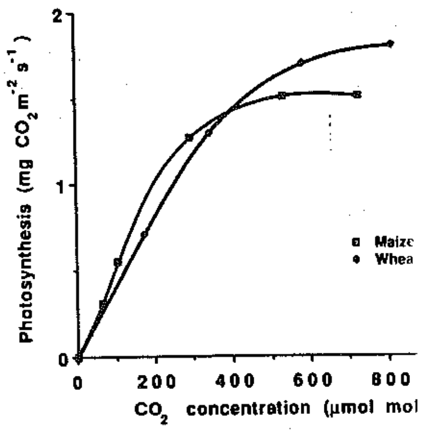


Fig. 4-2. Leaf net photosynthetic rate as a function of $[CO_2]$ for m... ta & Moss, 1973).

Source: Acock in: Kimball ed. (ASA) 1990

Many irrigation projects have failed because of poor planning (eg site selection, groundwater resource evaluation, hydropedological surveys) and the lack of understanding of conditions which are suitable for irrigated agriculture. On the other hand, many natural conditions can be changed to some degree by water management (eg mitigating drought), agricultural measures (eg fertilising), and land improvement measures (eg levelling, drainage, terracing, subsoiling). The type of conditions which can be changed may vary under different technical, economic and socio-cultural conditions and settings. For example, leaching and drainage may be technically suitable under a given set of conditions but economically unfeasible due to low anticipated production levels. The feasibilty of a given land development option depends on the unique setting of each individual location or project with regard to natural resources, socio-cultural perceptions (and needs) and economic constraints. These factors are interrelated and solutions must be found individually for each location depending on the perceived needs of the local populations and regional land development planning targets.

Criteria and standards for land evaluation regarding land and soil resources are given in Part II sections 3.1 and 3.2, whilst water resources are treated in Part II section 2.

Further reading: Maletic/Hutchings in: Hagan et al. ed. (ASA) 1967; Kreeb 1964

## 12.4 Effects of Air Pollution on Agricultural Crops

The current state of knowledge regarding known and projected responses of ecosystems to airborne chemicals is as follows:

(i) essential nutrient substances which are regarded for growth are dispersed in the atmosphere. These substances include 13 essential mineral elements (eg C, S, P, B, Mo, Cl, K, Ca, Mg, Fe, Cu, Zn, Mg) and some other beneficial elements which are required for normal growth (Cowling 1986) (see Figs. 12-1 and 12-2).

(ii) injurious airborne chemicals may inhibit growth or cause direct injury: examples are toxic gases ($O_3$, $SO_2$, NO, $NO_2$, F, $H_2O_2$, PAN, PPN), toxic metals (Al, Pb, Hg, Cd, Zn), excess nutrient substances (especially NOx and $SO_2$), and growth-altering organic chemicals (Cowling 1986).

(iii) radiatively active gases contribute to climate-altering (global warming), by absorbing energy and thus altering the radiative energy balance of the atmosphere (eg $CO_2$, $N_2O$, $NO_2$, $CH_4$, $S_2$). (Cowling 1986).

(iv) increased carbon dioxide stimulates the photosynthetic process and promotes crop growth; about 5 to 10% of the actual rate of increase of agricultural productivity worldwide can be ascribed to the fertilising effect of rising atmospheric CO2 (Goudriaan/Unswoth in: Kimbell ed. (ASA) 1990).

All of these airborne substances are derived from a wide variety of natural sources and human processes. Natural sources include volatile emissions from decomposing plant and animal remains, volcanoes and weathering, fires, sea spray, wind blown dust from arid/semiarid areas, and biogenetic materials. Human processes include the release of volatile waste products from combustion of fossil fuels (eg for power generating, heat, transport), volatile emissions from decomposition or incineration of domestic, industrial and agricultural wastes, burning of residues, evaporation of solvents, liquid fuels, pesticides and other chemicals. The relative contribution of airborne chemicals from natural and human sources of airborne chemicals vary greatly with the particular chemical and in time and space.

## Damages to Agricultural Systems

Airborne pollution is thought to cause damage not only to buildings and forest ecosystems but also to agricultural crops. The economic damage caused by pollution-induced reductions in the yield of major crops in the USA in 1980 is estimated to be 1.2 to 3 * 109 $ (Bonte 1986). Most susceptible areas are in industrialized areas where a generally high level of industrial and urban air pollution occurs, but also in developing countries high concentrations of toxic airborne chemicals may cause damage to agricultural lands adjacent to industrialized or urban centres. For example, injury to vegetation caused by airborne fluorides from an Al-factory has been reported from Greece. Fluoride is phytotoxic and accumulates in plant tissues even when air concentrations ar low. Visible toxicity symptoms were found in orchards within some 10 km distance, whereas accumulation in leaves were found at even larger distances from the source (Holevas 1986).

Plant growth occurs in a dynamic biological system. Hence, envrionmental factors (eg water, temperature, humidity, nutrient availability, soil reaction, soil aeration status) can substantially modify the response of crops to air pollutants. The reverse also applies and air pollutants may exert unexpected impacts on agricultural crops via such secondary pathways, but the nature and magnitude of these have rarely been investigated. Extensive studies have been undertaken recently in the USA (NCLAN and NAPAP programmes, Irving 1986) and in Europe (acid rain, 'Neuartige Waldschäden', eg Krause 1986). The most important pollutions are those with high concentrations of $NO_2$, $SO_2$ and $O_3$ (Bell/Posthumus 1986). However, the results should probably not be extrapolated to tropical climates and the different types and magnitudes of air pollution which are predominant in developing countries.

## Quantifying Air Pollution Stresses

Despite the fact that research into the effects of air pollution on agricultural crops commenced only recently and that cause-effect relationship under field conditions is extremely complex, some current research results may be given here:

Based on fumigation experiments, it is expected that growth reduction can occur at $SO_2$ concentrations in excess of 40-50 mg/m$^3$, Exposure to $SO_2$, $O_3$, $SO_2$ plus $NO_2$ can increase the susceptibility of woody plants and herbs to frost. The morphology of plants (shoot to root ratio) can be changed by exposure to pollutions. Reduced capacity for stomata to close under serious water stress after slight exposures to $SO_2$ and $NO_2$ (concentration of each 10 ppb) has been reported. Attacks of both fungal and insect pathogens may be increased by exposures to $SO_2$ (0-100 ppb)

The nutrient status of the soil can exert a strong influence on the response of the whole plant to aerial pollution (Mansfield/Lucas/Wright 1986). Photosynthesis is affected directly by elevated ozone concentrations. Wheat grain yield was more affected than straw yield (Fuhrer et al. 1986). Experiments in the USA have shown that there is no measurable and consistent yield response from current levels of rain acidity (S-induced). The reduction in crop yield from high ozone concentrations varies widely with species and cultivars, ranging from negligible (sorghum, maize) to -30% (alfalfa) (Irving 1986).

The effects of an increase in carbon dioxide concentrations on phytosynthesis, plant growth and other processes can be summarized:

- the primary effect is to increase photosynthesis and decrease the transpiration rate; the former response is more pronounced in C-3 plants (eg wheat) than in C-4 plants (maise) at concentrations below 400 mmol $CO_2$ per mol (or cm3 $CO_2$/m$^3$). At higher concentrations, the C-4 plants will gain that advantage.
- the extra carbohydrate increases the dry weight of all organs, with proportionately more going to roots and stems in many plants

- the size of most vegetative organs increases unless limited by other environmental factors such as nutrients, water, temperature, and light.

Source: Acock in: Kimball ed. (ASA) 1990; further readings in: Kimball ed. (ASA 1990

**Summary**. Excessive concentrations of airborne chemicals or toxic substances have direct physiological effects by reducing growth and indirect effects by increased damage by a range of important crop pests. Pollutant stress may also occur as a result of the accumulation or mobilization of toxic substances in soils after deposition from the atmosphere. The magnitude of importance may be negligible for most developing countries because the level of pollution is generally considerably lower than in industrialized countries, especially in rural areas. Locations close to industrial sites (probably within 10 to 20 km) may be exposed to toxic airborne pollutants which should be considered, when designing irrigation projects. Occasionally, the addition of airborne nutrients during dust storms in arid areas may contribute marginally to an increased supply of nurtients to plants.

References: Acock in: Kimball ed. (ASA) 1990; Bonte 1986; Cowling 1986, Bell/Posthumus 1986, Irving 1986; Mansfield et al. 1986, Holevas 1986, Krause 1986; Fuhrer et al. 1986 all in: Mathy ed. (CEC) 1981.

## 12.5 Natural Hazards which may affect Irrigation Schemes

Natural hazards which may have detrimental impacts on irrigation schemes are

Water
* saisonal variability in water availability
* groundwater fluctuations
* high groundwater table
* floods
* high sediment loads in irrigation water
+ saline or sodium-rich irrigation water
* seawater intrusion
* polluted water (metals, organic compounds, pathogens, pesticide residues)
* extremely low saltload and nutrient level in irrigation water
* seasonal and annual shortage of floodwater for flood recession farming (not all areas are flooded to optimum stages)

Soils
* low fertility and moisture storage capicity
* high salt contents or alkalinity
* irregular soil pattern which may restrict large scale operations
* high susceptibility to wind or water erosion
* unfavourable soil tilth conditions
* unfavourable infiltration/permeability rates

Air/Climate
* high windspeed and high rainfall erosivity
* hurricans, sand storms
* erratic seasonal rainfall with frequent dry spells
* low annual total rainfall

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* heavy rainfall which may cause local wetness
* favourable conditions for vector diseases
* extreme temperatur and humidity ranges

Biotic risks
* vector-borne diseases including malaria and schistosomiasis
* water-borne diseases including gastroenteric diseases and hepatitis A
* other health diseases including hookworm, amoebiasis, trachoma
* pests including quelea birds and locust
* favourable conditions for other crop pests
* wildlife damages to crops, fences, and flood control structures
* wildlife harm to livestock and humans
* weeds as competition for crops

other
* earthquakes

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# References

At compiling data the conventions and styles set for the American Society of Agronomy (ASA Publications Handbook and Style Manual 1988) were followed as far as possible, although, in some cases, due to the indifferent use of conventions and styles in various sources, deviations from the SI system or other standards are still incorporated. References are cited mainly following the ASA guidelines, by one exeption: papers in conference/ symposium/ workshop proceeedings are cited only with the name-year system, and reference is made solely to the editor(s), ie only the editor and the textbook or proceedings title are mentioned in the List of References': For example:

citation in the main text is: Smedema in: van Hoorn ed. 1988.

further citation in the List of References: van Hoorn, J.W. ed. 1988. Agrohydrology - Recent Developments. Proceedings of the Symposium 'Agrohydrology' at the IAC 1987, Wageningen. Elsevier. Amsterdam.

## Abbreviations of Organizations

| | |
|---|---|
| ADB | Asian Development Bank |
| ASA | American Society of Agronomy |
| ASCE | American Society of Civil Engineers |
| BMZ | Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung |
| DSE | Deutsche Stiftung für Internationale Entwicklung |
| DVWK | Deutscher Verband für Wasserwirtschaft und Kulturtechnik |
| ESCAP | Economic and Social Commission for Asia and the Pacific |
| FAO | Food and Agricultural Organization of the United Nations |
| (FAO CP) | FAO Conservation Paper |
| (FAO-EEP) | FAO Environment and Energy Paper |
| (FAO IDP) | FAO Irrigation and Drainage Paper |
| (FAO ICTP) | FAO Investment Centre Technical Paper |
| (FAO PY) | FAO Production Yearbook |
| (FAO SB) | FAO Soils Bulletin |
| GTZ | Deutsche Gesellschaft für Technische Zusammenarbeit |
| ICID | Internation Commission on Irrigation and Drainage |
| ICOLD | International Commission on Large Dams |
| IIED | International Institute for Environment and Development |
| ILACO | International Land Devlopment Consultants Arnhem |
| ILRI | International Institute for Land Reclamation and Improvement |
| INCID | Indian Commission on Irrigation and Drainage |
| IRRI | International Rice Research Institute |
| ISM | International Soil Museum Wageningen |
| ISTRO | International Soil Tillage Research Organization |
| IUCN | The World Conservaton Union |
| OAS | Organization of American States |
| ODI | Overseas Development Institute |
| ODU | Overseas Development Unit of Hydraulics Ressearch |

| | |
|---|---|
| OECD | Organization for Economic Co-Operation and Development |
| PEEM | Panel of Experts on Environmental Management (WHO) |
| RSU | Rat der Sachverständigen für Umweltfragen (FRG) |
| SSSA | Soil Science Society of America |
| UNEP | United Nations Environmental Programme |
| UNDP | United Nations Development Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| USAID | United States Agency for International Devlopment |
| USDA | United States Department of Agriculture |
| USCID | US Committee on Irrigation and Drainage |
| WB | The World Bank |
| WHO | World Health Organization |
| WMO | World Meteorological Organization |
| WRI | World Resources Institute |

## Common units and measures

| | |
|---|---|
| a | year (annum) |
| dS | deci-Siemens (equivalent to mmhos) |
| EC | electrical conductivity (salinity measure) |
| ECe | EC from a saturated soil extract |
| EO | open water evaporation |
| ESP | exchangeable sodium percentage |
| ET | evapotranspiration |
| g | gram |
| ha | hectare |
| hr | hour |
| l | litre |
| M | million |
| MCM | million cubic meter |
| m | meter |
| N | north |
| TDS | total dissolved solids |
| W | Watt; kW kilowatt, MW megawatt, GW gigawatt |
| y | year |

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Table 1-1

## Key Environmental Issues in Irrigation Schemes

### 1. Use of agro-chemicals and ecotoxicological impairments

(1) pesticides: choice; transport; storage; handling; use-maintenance-repair of application equipment; safe & effective use; complience with local laws and regulations; disposal

(2) fertilizers including soil amendments/conditioners: choice, storage, handling, safe & effcient use, disposal

(3) post-harvest control measures

---

### 2 Direct intervention into protected areas (IUCN-categories I to X)

strict nature reserves, national parks, natural monument, managed nature reserves, biosphere reserves, natural world heritage sites; protected landscape, resource reserve, multiple use management areas

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### 3. Direct or indirect interventions into wetlands and other ecologically sensitive areas (ESAs)

(1) wetlands which have important functions, products or attributes: estuarines, mangroves, floodplains, freshwater marshes, lakes, peatlands, swamp forests

(2) areas susceptible to wind or water erosion

(3) habitats that support important natural vegetation on soils of low inherent fertility and

(4) yields of little value if transformed

(5) habitats that provide important biogenetic and medicinal potentials

(6) critical habitats of threatened plant & fauna species for breeding, feeding or staging

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### 4. Interventions in sensitive water resources

(i) international rivers or groundwater reservoirs

(ii) important national water reserves

(iii) water supplies of regional importance

---

### 5. Implications to public health

(1) extra risks in faecal-oral (water-washed or water-borne), water-washed, water-based or water-related vector-borne diseases: increase in community vulnerability, environmental receptivity and vigilance of health services

(2) extra risks from excreata use

(3) extra risks from water pollution (pathogenic microorgansim, nitrogens, toxicants)

(4) risks from toxic aerosols (pesticide applications)

(5) risks from chemical health control measures: molluscicides, residual house sprayings

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### 6. Impairments of socio-cultural values

(1) critical habitats which provide livelyhood for specific and minority population groups

(2) areas of unique historical, archeological, or other cultural heritage, or important to cultural or religious beliefs

(3) unique areas of diversified rural patterns: settlements, diversified croplands

(4) areas which provide important habitat for natural industry: cottage industry, handicraft materials, indigenous food

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### 7. Resettlement and migrants

relocations or evacuations; scheduled or unscheduled migrants, temporary residents

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### 8. Degradaded watersheds

typically impairments on irrigation schemes: floods, unreliable water supply, sedimentation, etc.

## Important Potential Impacts Caused by Irrigated Agriculture

**Water regime impacts**
* river flow changes, flooding pattern changes, groundwater fall/ -rise, saltwater intrusion

**Stream morphology and water body changes**
* stream degradation (bank erosion, river bed changes)
* creation or alteration of impoundments, drainage lakes
* estuary degradation (coastal erosion, delta formation)

**Pollution**
* particle pollution of surface waters (erosion, sediment transportation, siltation)
* organic pollution of surface waters (nutrients, organic compounds, pathogens)
* eutrophication of surface waters (nutrients, organic compounds)
* organic pollution of groundwaters (nutrients, organic compounds, pathogens)
* toxic concentrations of substances in surface waters (metals, salts, pesticides)
* toxic concentrations of substances in groundwaters (salts, metals, pesticides)
* toxic concentration of substances in soils (salts, acids, pathogens, metals, pesticides)
* gas emissions (air pollution, radiatively active gases)
* aerosol emissions (pathogens, toxic concentrations of pesticides)

**Soil degradation**
* soil loss or accumulation (wind & water erosion)
* waterlogging
* salinization (also: acidification, alkalinization)
* soil compaction and structural degradation
* loss in fertility (biotic activity, agricultural productivity)
* biological imbalances increase (pests, weeds)

**Eco-biological imbalances**
* impairment or loss of valuable wetlands
* plant community changes (terrestrial flora)
* plant diversity loss (terrestrial flora)
* threatened or/and endemic species loss or impairments
* wildlife habitat loss, wildlife migration restrictions

**Land use and ecomomic development conflicts**
* conflicts with competing agricultural uses
* conflicts with other land uses
* use of non-renewable resources (fuel, materials, etc.)
* conflicts with other water users (industrial, domestic, agricultural)
* conflicts with navigation (through water regime & stream morphology changes)
* conflicts with fishery
* conflicts with natural resources industry
* conflicts with forestry/woodland uses
* conflicts with planning (policies, programmes, projects)

**Public health risks**
* communicable disease risks (communal vulnerability, environmental receptivity, vigilance of health services)
* non-communicable disease risks (occupational, water and air pollution, phytotoxic crop contamination, accidents)
* risks associated with general well-being (water supply, nutrition, habitation, sanitation)

**Natural beauty impairments** (landscape diversity, aesthetics)

**Cultural heritage site loss or impairments** (buildings, monuments etc.)

**Socio-economic impacts** (higher order impacts)
* regional disparity
* population change
* community facilities
* group development (and participation)
* ethnic minority group development
* employment/labour
* women's situation
* income

**Resettlement effects** (migrants, evacuees)

## Important Potential Environmental Impacts on Irrigation

* river regime changes (hinterland degradation, upstream uses)
* groundwater regime changes (regional urban uses, hinterland degradation)
* surface water pollution (upstream urban pollutions, hinterland degradation)
* groundwater pollution (urban pollutions, agricultural pollutions)
* soil erosion (regional degradation)
* soil contamination (wastewater reuse)
* air pollution (urban pollution, traffic pollution)
* land use competition (livestock grazing, urban uses)
* health hazards (vector diseases, aninal diseases etc.).

## Table 10.3 River Runoff and Its Use

Table 2-1

*(cubic kilometers per year)*

| Elements | World Regions | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Europe | Asia | Africa | North America | South America | Australia Oceania | U.S.S.R. | World Total |
| Total River Runoff | 2,321 | 10,485 | 3,808 | 6,945 | 10,377 | 2,011 | 4,350 | 40,67 |
| Groundwater Discharge to Rivers | 845 | 2,879 | 1,464 | 2,222 | 3,736 | 483 | 1,020 | 12,69 |
| Surface Runoff | 1,476 | 7,606 | 2,720 | 4,723 | 6,641 | 1,528 | 3,330 | 27,98 |
| 1980s | | | | | | | | |
| Water Withdrawal | 364 | 1,591 | 176 | 767 | 161 | 26 | 443 | 3,53 |
| Consumptive Use | 134 | 1,145 | 146 | 339 | 110 | 19 | 239 | 2,12 |
| Waste and Returning Waters | 230 | 446 | 42 | 428 | 51 | 7 | 204 | 1,41 |
| Use of Resources (percentage of total river runoff) | 16 | 15 | 4 | 11 | 2 | 1 | 10 | 9 |
| Year 2000 Projection | | | | | | | | |
| Water Withdrawal | 404 | 2,160 | 289 | 946 | 293 | 35 | 533 | 4,66 |
| Consumptive Use | 158 | 1,433 | 201 | 434 | 165 | 22.5 | 286 | 2,70 |
| Waste and Returning Waters | 246 | 727 | 88 | 512 | 128 | 12.5 | 247 | 1,96 |
| Use of Resources (percentage of total river runoff) | 17 | 21 | 7 | 14 | 3 | 2 | 12 | 11 |

<u>Tab. 4-4</u>: Wassernutzung nach Sektoren und Entwicklung der Entnahme (%)

Table 2-2

| Region | Agriculture Landwirtschaft | | | Domestic uses Haushalte und öffentliche Nutzung | | | Industry Industrie | | |
|---|---|---|---|---|---|---|---|---|---|
| | utilisation Nutzung (%) | | increase Anstieg (%) | Nutzung (%) | | Anstieg (%) | utilisation Nutzung (%) | | increase Anstieg (%) |
| | 80er Jahre | 2000 | 80er Jahre bis 2000 | 80er Jahre | 2000 | 80er Jahre bis 2000 | 80er Jahre | 2000 | 80er Jahre bis 2000 |
| Europa | 31 | 26 – 33 | 14 | 14 | 12 – 15 | 17 | 55 | 52 – 62 | 4 – 55 |
| Asien | 86 | 74 | 15 | 6 | 10 | 127 | 8 | 16 – 17 | 171 – 186 |
| Afrika | 88 | 71 – 73 | 33 | 7 | 13 – 14 | 200 | 5 | 14 – 16 | 382 – 438 |
| Nordamerika | 48 | 46 | 18 | 10 | 11 | 36 | 43 | 43 – 44 | 22 – 26 |
| Südamerika | 56 | 38 – 39 | 29 | 19 | 17 | 67 | 24 | 43 – 48 | 233 – 267 |
| Australien und Ozeanien | 74 | 69 – 70 | 25 | 19 | 19 | 34 | 7 | 11 – 12 | 114 – 150 |
| UdSSR | 65 | 62 – 63 | 15 | 6 | 7 | 52 | 29 | 29 – 31 | 20 – 28 |
| GESAMT | 68 | 59 – 62 | 17 | 8 | 10 – 11 | 74 | 24 | 27 – 30 | 52 – 72 |

<u>Quelle</u>: World Resources Institute, World Resources 1990–91, New York, Oxford 1990

## Table 10.4 Water Withdrawals for Irrigation

Table 2-3a

| Region | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|
| Europe | 17 | 110 | 95 | 15 | 19 | 125 | 105 | 20 |
| Asia | 140 | 1,300 | 980 | 320 | 165 | 1,500 | 1,150 | 350 |
| Africa | 11 | 120 | 85 | 35 | 15 | 160 | 110 | 50 |
| North America | 29 | 330 | 215 | 115 | 35 | 390 | 260 | 130 |
| South America | 8.5 | 70 | 55 | 15 | 11 | 90 | 70 | 20 |
| Australia and Oceania | 2.0 | 16 | 13 | 3 | 2.5 | 20 | 15 | 5 |
| U.S.S.R. | 20 | 260 | 180 | 80 | 23.5 | 300 | 210 | 90 |
| World Total | 227.5 | 2,206 | 1,623 | 583 | 271 | 2,585 | 1,920 | 665 |

**Source:** A.V. Belyaev, U.S.S.R. Academy of Sciences, Institute of Geography, Moscow in consultation with other international sources.
**Note:** Oceania is defined as Australia, Fiji, New Zealand, Papua New Guinea, and Solomon Islands.

Sources: World Resources Institute

Table 2-3b

**Table 1. Sources of Water Supply in 16 Asian Countries**

| Type | Arable Area (million ha) | Actual cultivated area (million ha) | Cropping intensity (%) |
|---|---|---|---|
| Surface irrigation | 100.0 | 144.5 | 145 |
| Groundwater irrigation | 35.0 | 46.3 | 132 |
| Rainfed and others | 223.0 | 227.0 | 102 |
| Total | 358.0 | 417.8 | 117 |

*Note:* Summarization of 16 Asian countries i.e. Bangladesh, Bhutan, China, Korea (DPR), Korea (Republic of), India, Indonesia, Laos, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam and Japan.

Table 2-3c



**Table 2. Groundwater Utilization in Asian Countries**

| Country | Groundwater potential (Billion cubic metre/year) | Groundwater Utilization (Billion cubic metre/year) | | | Land irrigated by groundwater (Net) (million ha) |
|---|---|---|---|---|---|
| | | Irri | Others | Total | |
| Bangladesh | – | 6.0 | 1.7 | 7.7 | 0.8 |
| China | 700 | 39.6 | – | – | 9.0 |
| India | 423 | 43.5 | 6.5 | 50.0 | 19.0 |
| Indonesia | 456 | 0.01 | 3.7 | 3.7 | 0.02 |
| Pakistan | – | 40.0 | – | 40.0 | 5.6 |
| Philippines | 33 | 0.5 | 2.1 | 2.6 | 0.2 |
| Thailand | – | 0.2 | 2.7 | 2.9 | 0.01 |

*Source:* Water Resources Journal (ESCAP) Dec. 1986 and other information gathered by FAO/RAPA.



**Table 2. Area Irrigated by Different Sources in India During 1950-51 to 1984-84 (Area: '000 ha)**

| Source | 1950-51 | 1960-61 | 1970-71 | 1980-81 | 1984-85 |
|---|---|---|---|---|---|
| Canals | 8295 (39.8) | 10370 (42.1) | 12838 (41.3) | 15292 (39.5) | 15861 (37.9) |
| Tanks | 3613 (17.3) | 4561 (18.5) | 4112 (13.2) | 3198 (08.2) | 3330 (07.9) |
| Tube wells | N.A. | 135 (0.6) | 4461 (14.3) | 9527 (24.6) | 11265 (27.2) |
| Other wells | 5978 (28.7) | 7155 (29.0) | 7426 (23.9) | 8207 (21.1) | 8723 (20.9) |
| Other sources | 2967 (14.2) | 2440 (09.8) | 2266 (07.3) | 2585 (06.6) | 2600 (06.2) |
| Total (Net Irrigated Area) | 20853 (100.0) | 24661 (100.0) | 31103 (100.0) | 38806 (100.0) | 41779 (100.0) |

(Figures in parenthesis indicate percentage of total irrigated area)

*Source:* Indian Agriculture in Brief 21st Edition, Directorate of Economics and Statistics, Dept. of Agric. & Coop., Ministry of Agriculture, Government of India, New Delhi.

**Source: APO 1991**

# Table 22.1 Freshwater Resources and Withdrawal

| | Annual Internal Renewable Water Resources: Total (cubic km) | Annual Internal Renewable Water Resources: 1990 Per Capita (000 cubic meters) | Annual River Flows: From Other Countries (cubic km) | Annual River Flows: To Other Countries (cubic km) | Annual Withdrawal: Year of Data | Annual Withdrawal: Total (cubic km) | Annual Withdrawal: Percentage of Water Resources (a) | Annual Withdrawal: Per Capita (cubic meters) | Sectoral Withdrawal (percent): Domestic | Sectoral Withdrawal (percent): Industry | Sectoral Withdrawal (percent): Agriculture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **WORLD** | **40,673.00 b** | **7.69** | | | **1987 b** | **3296** | **8** | **660** | **8** | **23** | **69** |
| **AFRICA** | **4,184.00 b** | **6.46** | | | **1987 b** | **144** | **3** | **244** | **7** | **5** | **88** |
| Algeria | 18.90 | 0.75 | 0.20 | 0.70 | 1980 | 3.00 | 16 | 161 | 22 | 4 | 74 |
| Angola | 158.00 b | 15.77 | X | X | 1987 b | 0.48 | 0 | 43 | 14 | 10 | 76 |
| Benin | 26.00 | 5.48 | X | X | 1987 b | 0.11 | 0 | 26 | 28 | 14 | 58 |
| Botswana | 1.00 | 0.78 | 17.00 | X | 1980 | 0.09 | 1 | 98 | 5 | 10 | 85 |
| Burkina Faso | 28.00 b | 3.11 | X | X | 1987 b | 0.15 | 1 | 20 | 28 | 5 | 67 |
| Burundi | 3.60 b | 0.66 | X | X | 1987 b | 0.10 | 3 | 20 | 36 | 0 | 64 |
| Cameroon | 208.00 | 18.50 | X | X | 1987 b | 0.40 | 0 | 30 | 46 | 19 | 35 |
| Cape Verde | 0.20 | 0.53 | 0.00 | 0.00 | 1972 | 0.04 | 20 | 148 | 9 | 2 | 89 |
| Central African Rep | 141.00 b | 48.40 | X | X | 1987 b | 0.07 | 0 | 27 | 21 | 5 | 74 |
| Chad | 38.40 b | 6.76 | X | X | 1987 b | 0.18 | 0 | 35 | 16 | 2 | 82 |
| Comoros | 1.02 b | 1.97 | 0.00 | 0.00 | 1987 b | 0.01 | 1 | 15 | 48 | 5 | 47 |
| Congo | 181.00 b | 90.77 | 621.00 | X | 1987 b | 0.04 | 0 | 20 | 62 | 27 | 11 |
| Cote d'Ivoire | 74.00 | 5.87 | X | X | 1987 b | 0.71 | 1 | 68 | 22 | 11 | 67 |
| Djibouti | 0.30 | 0.74 | 0.00 | X | 1973 b | 0.01 | 2 | 28 | 28 | 21 | 51 |
| Egypt | 1.80 | 0.03 | 56.50 | 0.00 | 1985 | 56.40 | 97 | 1,202 | 7 c | 5 c | 88 c |
| Equatorial Guinea | 30.00 b | 68.18 | X | X | 1987 b | 0.01 | 0 | 11 | 81 | 13 | 6 |
| Ethiopia | 110.00 | 2.35 | X | X | 1987 b | 2.21 | 2 | 48 | 11 | 3 | 86 |
| Gabon | 164.00 b | 140.05 | X | X | 1987 b | 0.06 | 0 | 51 | 72 | 22 | 6 |
| Gambia, The | 3.00 | 3.50 | 19.00 | X | 1982 | 0.02 | 0 | 33 | 7 | 2 | 91 |
| Ghana | 53.00 | 3.53 | X | X | 1970 | 0.30 | 1 | 35 | 35 | 13 | 52 |
| Guinea | 226.00 b | 32.87 | X | X | 1987 b | 0.74 | 0 | 115 | 10 | 3 | 87 |
| Guinea-Bissau | 31.00 b | 31.41 | X | X | 1987 b | 0.01 | 0 | 18 | 31 | 6 | 63 |
| Kenya | 14.80 | 0.59 | X | X | 1987 b | 1.09 | 7 | 46 | 27 | 11 | 62 |
| Lesotho | 4.00 b | 2.25 | X | X | 1987 b | 0.05 | 1 | 34 | 22 | 22 | 56 |
| Liberia | 232.00 b | 90.84 | X | X | 1987 b | 0.13 | 0 | 54 | 27 | 13 | 60 |
| Libya | 0.70 | 0.15 | 0.00 | 0.00 | 1985 | 2.62 | 374 | 262 | 15 | 10 | 75 |
| Madagascar | 40.00 | 3.34 | 0.00 | 0.00 | 1984 | 16.30 | 41 | 1,675 | 1 | 0 | 99 |
| Malawi | 9.00 b | 1.07 | X | X | 1987 b | 0.16 | 2 | 22 | 34 | 17 | 49 |
| Mali | 62.00 b | 6.62 | X | X | 1987 b | 1.36 | 2 | 159 | 2 | 1 | 97 |
| Mauritania | 0.40 | 0.20 | 7.00 | X | 1978 | 0.73 | 10 | 473 | 12 | 4 | 84 |
| Mauritius | 2.20 | 1.99 | 0.00 | 0.00 | 1974 | 0.36 | 16 | 415 | 16 | 7 | 77 |
| Morocco | 30.00 | 1.19 | 0.00 | 0.30 | 1985 | 11.00 | 37 | 501 | 6 c | 3 c | 91 c |
| Mozambique, People's Rep | 58.00 b | 3.70 | X | X | 1987 b | 0.76 | 1 | 53 | 24 | 10 | 66 |
| Niger | 14.00 b | 1.97 | 30.00 | X | 1987 b | 0.29 | 1 | 44 | 21 | 5 | 74 |
| Nigeria | 261.00 b | 2.31 | 47.00 | X | 1987 b | 3.63 | 1 | 44 | 31 | 15 | 54 |
| Rwanda | 6.30 b | 0.87 | X | X | 1987 b | 0.15 | 2 | 23 | 24 | 8 | 68 |
| Senegal | 23.20 b | 3.15 | 12.00 | X | 1987 b | 1.36 | 4 | 201 | 5 | 3 | 92 |
| Sierra Leone | 160.00 b | 38.54 | X | X | 1987 b | 0.37 | 0 | 99 | 7 | 4 | 89 |
| Somalia | 11.50 | 1.52 | 0.00 | X | 1987 b | 0.81 | 7 | 167 | 3 | 0 | 97 |
| South Africa | 50.00 | 1.42 | X | X | 1970 | 9.20 | 18 | 404 | 16 | 17 | 67 |
| Sudan | 30.00 | 1.19 | 100.00 | 56.50 | 1977 | 16.60 | 14 | 1,089 | 1 | 0 | 99 |
| Swaziland | 6.96 b | 8.82 | X | X | 1987 b | 0.29 | 4 | 414 | 5 | 2 | 93 |
| Tanzania | 76.00 b | 2.78 | X | X | 1970 | 0.48 | 1 | 36 | 21 | 5 | 74 |
| Togo | 11.50 | 3.33 | X | X | 1987 b | 0.09 | 1 | 40 | 62 | 13 | 25 |
| Tunisia | 3.75 | 0.46 | 0.60 | 0.00 | 1985 | 2.30 | 53 | 325 | 13 | 7 | 80 |
| Uganda | 66.00 b | 3.58 | X | X | 1970 | 0.20 | 0 | 20 | 32 | 8 | 60 |
| Zaire | 1,019.00 b | 28.31 | X | X | 1987 b | 0.70 | 0 | 22 | 58 | 25 | 17 |
| Zambia | 96.00 b | 11.35 | X | X | 1970 | 0.36 | 0 | 86 | 63 | 11 | 26 |
| Zimbabwe | 23.00 b | 2.37 | X | X | 1987 b | 1.22 | 5 | 129 | 14 | 7 | 79 |
| **NORTH & CENTRAL AMERICA** | **6,945.00 b** | **16.26** | | | **1987 b** | **697** | **10** | **1,692** | **9** | **42** | **49** |
| Barbados | 0.05 | 0.20 | 0.00 | 0.00 | 1962 | 0.03 | 51 | 117 | 52 | 41 | 7 |
| Canada | 2,901.00 | 109.37 | X | X | 1980 | 36.15 | 1 | 1,501 | 18 | 70 | 12 |
| Costa Rica | 95.00 | 31.51 | X | X | 1970 | 1.35 | 1 | 779 | 4 | 7 | 89 |
| Cuba | 34.50 | 3.34 | 0.00 | 0.00 | 1975 | 8.10 | 23 | 868 | 9 | 2 | 89 |
| Dominican Rep | 20.00 | 2.79 | X | X | 1987 b | 2.97 | 15 | 453 | 5 | 6 | 89 |
| El Salvador | 18.95 | 3.61 | X | X | 1975 | 1.00 | 5 | 241 | 7 | 4 | 69 |
| Guatemala | 116.00 | 12.61 | X | X | 1970 | 0.73 | 1 | 139 | 9 | 17 | 74 |
| Haiti | 11.00 | 1.69 | X | X | 1987 b | 0.04 | 0 | 46 | 24 | 8 | 68 |
| Honduras | 102.00 | 19.85 | X | X | 1970 | 1.34 | 1 | 508 | 4 | 5 | 91 |
| Jamaica | 8.30 | 3.29 | 0.00 | 0.00 | 1975 | 0.32 | 4 | 157 | 7 | 7 | 86 |
| Mexico | 357.40 | 4.03 | X | X | 1975 | 54.20 | 15 | 901 | 6 | 8 | 86 |
| Nicaragua | 175.00 | 45.21 | X | X | 1975 | 0.89 | 1 | 370 | 25 | 21 | 54 |
| Panama | 144.00 | 59.55 | X | X | 1975 | 1.30 | 1 | 744 | 12 | 11 | 77 |
| Trinidad and Tobago | 5.10 b | 3.98 | 0.00 | 0.00 | 1975 | 0.15 | 3 | 149 | 27 | 38 | 35 |
| United States | 2,478.00 | 9.94 | X | X | 1985 | 467.00 | 19 | 2.162 | 12 c | 46 c | 42 c |
| **SOUTH AMERICA** | **10,377.00 b** | **34.96** | | | **1987 b** | **133** | **1** | **476** | **18** | **23** | **59** |
| Argentina | 694.00 | 21.47 | 300.00 | X | 1976 | 27.60 | 3 | 1,059 | 9 | 18 | 73 |
| Bolivia | 300.00 b | 41.02 | X | X | 1987 b | 1.24 | 0 | 184 | 10 | 5 | 85 |
| Brazil | 5,190.00 | 34.52 | 1760.00 | X | 1987 b | 35.04 | 1 | 212 | 43 | 17 | 40 |
| Chile | 468.00 b | 35.53 | X | X | 1975 | 16.80 | 4 | 1,625 | 6 | 5 | 89 |
| Colombia | 1,070.00 | 33.63 | X | X | 1987 b | 5.34 | 0 | 179 | 41 | 16 | 43 |
| Ecuador | 314.00 | 29.12 | X | X | 1987 b | 5.56 | 2 | 561 | 7 | 3 | 90 |
| Guyana | 241.00 b | 231.73 | X | X | 1971 | 5.40 | 2 | 7,616 | 1 | 0 | 99 |
| Paraguay | 94.00 b | 21.98 | 220.00 | X | 1987 b | 0.43 | 0 | 111 | 15 | 7 | 78 |
| Peru | 40.00 | 1.79 | X | X | 1987 b | 6.10 | 15 | 294 | 19 | 9 | 72 |
| Suriname | 200.00 b | 496.28 | X | X | 1987 b | 0.46 | 0 | 1,181 | 6 | 5 | 89 |
| Uruguay | 59.00 b | 18.86 | 65.00 | X | 1965 | 0.65 | 1 | 241 | 6 | 3 | 91 |
| Venezuela | 856.00 | 43.37 | 461.00 | X | 1970 | 4.10 | 0 | 387 | 43 | 11 | 46 |

| | Annual Internal Renewable Water Resources: Total (cubic km) | Annual Internal Renewable Water Resources: 1990 Per Capita (000 cubic meters) | Annual River Flows: From Other Countries (cubic km) | Annual River Flows: To Other Countries (cubic km) | Annual Withdrawal: Year of Data | Annual Withdrawal: Total (cubic km) | Annual Withdrawal: Percentage of Water Resources (a) | Annual Withdrawal: Per Capita (cubic meters) | Sectoral Withdrawal (percent): Domestic | Sectoral Withdrawal (percent): Industry | Sectoral Withdrawal (percent): Agriculture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ASIA** | **10,485.00** | **3.37** | | | **1987 b** | **1,531.00** | **15** | **526** | **6** | **8** | **86** |
| Afghanistan | 50.00 | 3.02 | X | X | 1987 b | 26.11 | 52 | 1,436 | 1 | 0 | 99 |
| Bahrain | 0.00 | 0.00 | X | X | 1975 | 0.20 | X | 735 | 60 | 36 | 4 |
| Bangladesh | 1,357.00 | 11.74 | 1000.00 | X | 1987 b | 22.50 | 1 | 211 | 3 | 1 | 96 |
| Bhutan | 95.00 b | 62.66 | X | X | 1987 b | 0.02 | 0 | 15 | 36 | 10 | 54 |
| China | 2,800.00 | 2.47 | 0.00 | X | 1980 | 460.00 | 16 | 462 | 6 | 7 | 87 |
| Cyprus | 0.90 | 1.28 | 0.00 | 0.00 | 1985 | 0.54 | 60 | 807 | 7 c | 2 c | 91 c |
| India | 1,850.00 | 2.17 | 235.00 | X | 1975 | 380.00 | 18 | 612 | 3 | 4 | 93 |
| Indonesia | 2,530.00 | 14.02 | X | X | 1987 b | 16.59 | 1 | 96 | 13 | 11 | 76 |
| Iran, Islamic Rep | 117.50 | 2.08 | X | X | 1975 | 45.40 | 39 | 1,362 | 4 | 9 | 87 |
| Iraq | 34.00 | 1.80 | 66.00 | X | 1970 | 42.80 | 43 | 4,575 | 3 | 5 | 92 |
| Israel | 1.70 | 0.37 | 0.45 | 0.00 | 1986 | 1.90 | 88 | 447 | 16 c | 5 c | 79 c |
| Japan | 547.00 | 4.43 | 0.00 | 0.00 | 1980 | 107.80 | 20 | 923 | 17 | 33 | 50 |
| Jordan | 0.70 | 0.16 | 0.40 | X | 1975 | 0.45 | 41 | 173 | 29 | 6 | 65 |
| Kampuchea, Dem | 88.10 | 10.68 | 410.00 | X | 1987 b | 0.52 | 0 | 69 | 5 | 1 | 94 |
| Korea, Dem People's Rep | 67.00 b | 2.92 | X | X | 1987 b | 14.16 | 21 | 1,649 | 11 | 16 | 73 |
| Korea, Rep | 63.00 | 1.45 | X | X | 1976 | 10.70 | 17 | 298 | 11 | 14 | 75 |
| Kuwait | 0.00 | 0.00 | 0.00 | X | 1974 | 0.01 | X | 10 | 64 | 32 | 4 |
| Lao People's Dem Rep | 270.00 | 66.32 | X | X | 1987 b | 0.99 | 0 | 228 | 8 | 10 | 82 |
| Lebanon | 4.80 | 1.62 | 0.00 | 0.86 | 1975 | 0.75 | 16 | 271 | 11 | 4 | 85 |
| Malaysia | 456.00 | 26.30 | X | X | 1975 | 9.42 | 2 | 765 | 23 | 30 | 47 |
| Mongolia | 24.60 | 11.05 | X | X | 1987 b | 0.55 | 2 | 272 | 11 | 27 | 62 |
| Myanmar | 1,082.00 | 25.96 | X | X | 1987 b | 3.96 | 0 | 103 | 7 | 3 | 90 |
| Nepal | 170.00 | 8.88 | X | X | 1987 b | 2.68 | 2 | 155 | 4 | 1 | 95 |
| Oman | 2.00 | 1.36 | 0.00 | X | 1975 | 0.43 | 22 | 561 | 3 | 3 | 94 |
| Pakistan | 298.00 | 2.43 | 170.00 | X | 1975 | 153.40 | 33 | 2,053 | 1 | 1 | 98 |
| Philippines | 323.00 | 5.18 | 0.00 | 0.00 | 1975 | 29.50 | 9 | 693 | 18 | 21 | 61 |
| Qatar | 0.02 | 0.06 | 0.00 | X | 1975 | 0.04 | 174 | 234 | 36 | 26 | 38 |
| Saudi Arabia | 2.20 | 0.16 | 0.00 | X | 1975 | 2.33 | 106 | 321 | 45 | 8 | 47 |
| Singapore | 0.60 | 0.22 | 0.00 | 0.00 | 1975 | 0.19 | 32 | 84 | 45 | 51 | 4 |
| Sri Lanka | 43.20 | 2.51 | 0.00 | 0.00 | 1970 | 6.30 | 15 | 503 | 2 | 2 | 96 |
| Syrian Arab Rep | 7.60 | 0.61 | 27.90 | 30.00 | 1976 | 3.34 | 9 | 449 | 7 | 10 | 83 |
| Thailand | 110.00 | 1.97 | 69.00 | X | 1987 b | 31.90 | 18 | 599 | 4 | 6 | 90 |
| Turkey | 196.00 | 3.52 | 7.00 | 69.00 | 1985 | 15.60 | 8 | 317 | 24 c | 19 c | 57 c |
| United Arab Emirates | 0.30 | 0.19 | 0.00 | X | 1980 | 0.42 | 140 | 429 | 11 | 9 | 80 |
| Viet Nam | 376.00 b | 5.60 | X | X | 1987 b | 5.07 | 1 | 81 | 13 | 9 | 78 |
| Yemen Arab Rep | 1.00 | 0.12 | 0.00 | X | 1987 b | 1.47 | 147 | X | 4 | 2 | 94 |
| Yemen, People's Dem Rep | 1.50 | 0.60 | 0.00 | X | 1975 | 1.93 | 129 | 1,167 | 5 | 2 | 93 |
| **EUROPE** | **2,321.00 b** | **4.66** | | | **1987 b** | **359** | **15** | **726** | **13** | **54** | **33** |
| Albania | 10.00 | 3.08 | 11.30 | X | 1970 | 0.20 | 1 | 94 | 6 | 18 | 76 |
| Austria | 56.30 | 7.51 | 34.00 | X | 1980 | 3.13 | 3 | 417 | 19 | 73 | 8 |
| Belgium | 8.40 | 0.85 | 4.10 | X | 1980 | 9.03 | 72 | 917 | 11 | 85 | 4 |
| Bulgaria | 18.00 | 2.00 | 187.00 | X | 1980 | 14.18 | 7 | 1,600 | 7 | 38 | 55 |
| Czechoslovakia | 28.00 | 1.79 | 62.60 | X | 1980 | 5.80 | 6 | 379 | 23 | 68 | 9 |
| Denmark | 11.00 | 2.15 | 2.00 | X | 1977 | 1.40 | 11 | 277 | 30 | 27 | 43 |
| Finland | 110.00 | 22.11 | 3.00 | X | 1980 | 3.70 | 3 | 774 | 12 | 85 | 3 |
| France | 170.00 | 3.03 | 15.00 | 20.50 | 1984 | 33.30 | 18 | 606 | 16 | 69 | 15 |
| German Dem Rep | 17.00 | 1.02 | 17.00 | X | 1980 | 9.13 | 27 | 545 | 14 | 68 | 18 |
| Germany, Fed Rep | 79.00 | 1.30 | 82.00 | X | 1981 | 41.40 | 26 | 671 | 10 | 70 | 20 |
| Greece | 45.15 | 4.49 | 13.50 | 3.00 | 1980 | 7.00 | 12 | 726 | 8 | 29 | 63 |
| Hungary | 6.00 | 0.57 | 109.00 | X | 1980 | 5.38 | 5 | 502 | 9 | 55 | 36 |
| Iceland | 170.00 | 671.94 | 0.00 | 0.00 | 1987 b | 0.09 | 0 | 349 | 31 | 63 | 6 |
| Ireland | 50.00 | 13.44 | 0.00 | X | 1972 | 0.40 | 1 | 135 | 16 | 74 | 10 |
| Italy | 179.40 | 3.13 | 7.60 | 0.00 | 1981 | 46.35 | 25 | 811 | 14 | 27 | 59 |
| Luxembourg | 1.00 | 2.72 | 4.00 | X | 1976 | 0.06 | 1 | 166 | 42 | 45 | 13 |
| Malta | 0.03 | 0.07 | 0.00 | 0.00 | 1978 | 0.02 | 92 | 68 | 76 | 8 | 16 |
| Netherlands | 10.00 | 0.68 | 80.00 | X | 1980 | 14.20 | 16 | 1,004 | 5 | 61 | 34 |
| Norway | 405.00 | 96.15 | 8.00 | X | 1980 | 2.00 | 0 | 489 | 20 | 72 | 8 |
| Poland | 49.40 | 1.29 | 6.80 | X | 1980 | 16.80 | 30 | 472 | 16 | 60 | 24 |
| Portugal | 34.00 | 3.31 | 31.60 | X | 1980 | 10.50 | 16 | 1,062 | 15 | 37 | 48 |
| Romania | 37.00 | 1.59 | 171.00 | X | 1980 | 25.40 | 12 | 1,144 | 8 | 33 | 59 |
| Spain | 110.30 | 2.80 | 1.00 | 17.00 | 1985 | 26.30 | 24 | 682 | 12 | 26 | 62 |
| Sweden | 176.00 | 21.11 | 4.00 | X | 1980 | 3.98 | 2 | 479 | 36 | 55 | 9 |
| Switzerland | 42.50 | 6.52 | 7.50 | X | 1985 | 3.20 | 6 | 502 | 23 | 73 | 4 |
| United Kingdom | 120.00 | 2.11 | 0.00 | X | 1980 | 28.35 | 24 | 507 | 20 | 77 | 3 |
| Yugoslavia | 150.00 | 6.29 | 115.00 | 200.00 | 1980 | 8.77 | 3 | 393 | 16 | 72 | 12 |
| **U.S.S.R.** | **4,384.00** | **15.22** | **300.00** | **X** | **1980** | **353.00** | **8** | **1,330** | **6** | **29** | **65** |
| **OCEANIA** | **2,011.00 b** | **75.96** | | | **1987 b** | **23** | **1** | **907** | **18** | **16** | **76** |
| Australia | 343.00 | 20.48 | 0.00 | 0.00 | 1975 | 17.80 | 5 | 1,306 | 65 | 2 | 33 |
| Fiji | 28.55 b | 38.12 | 0.00 | 0.00 | 1987 b | 0.03 | 0 | 37 | 20 | 20 | 60 |
| New Zealand | 397.00 | 117.49 | 0.00 | 0.00 | 1980 | 1.20 | 0 | 379 | 46 | 10 | 44 |
| Papua New Guinea | 801.00 b | 199.70 | X | X | 1987 b | 0.10 | 0 | 25 | 29 | 22 | 49 |
| Solomon Islands | 44.70 b | 149.00 | 0.00 | 0.00 | 1987 b | 0.00 | 0 | 18 | 40 | 20 | 40 |

Sources: Bureau of Geological and Mining Research, National Geological Survey, France; U.S. Geological Survey; and Institute of Geography, National Academy of Sciences, U.S.S.R.

Notes: a. Water resources include both internal renewable resources and river flows from other countries.
b. Estimated by the Institute of Geography, U.S.S.R.
c. Sectoral percentages date from the year of other withdrawal data.
0 = zero or less than half the unit of measure; X = not available.
For additional information, see Sources and Technical Notes.

Sources: World Resources Institute

Table 2-4 a

Table 1. Definitions of arid regions.

| Type of Climate | $\frac{P}{Etp}$ | Vegetation | Interannual Variability of P | P (in mm) | Utilization |
|---|---|---|---|---|---|
| Hyper-arid | 0.03 | No permanent vegetation or a very few very scattered shrubs; ephemeral when rain or dew, with short cycle. Oasis permanent water. | up to 100% | Nil or very low, extremely irregular with sometimes no rain during long periods of several years. | Oasis culture. True nomadism by transport caravans |
| Arid | 0.03-0.20 | Constructed along with water channels, spiny or succulent plants. Steppes, pseudo-steppes, para-steppes. | 50-100% | From 80-150 to 200-350. Low atmospheric humidity. High rainfall variability. | Pastoralism No farming except with irrigation |
| Semi-arid | 0.20-0.50 | Steppes, pseudo-steppes, para-steppe, low savannas low savannas with bush, thorny low savannas exceptionally savannas where high rainfall in summer. | 25-50% | From 300-400 to 700-800 with summer rains. From 200-250 to 450-500 with winter rains. | Rain-fed cultivation with more or less regular production. Combined with sedentary livestock production. |
| Sub-humid | 0.50-0.75 | Savannas and wooded savannas. Riparian forests along rivers. Maquis and Chaparrals under Mediterranean climate: Steppes on tchernozems | Less than 25% | Abundant with usually more than six humid months (more than 30 mm) | Rain-fed cultivation and industrial crops with a regular production. |

Table 2-4b

Table 2. Distribution of arid lands

| Continents | Total Area ($km^2$) | Semi-Arid ($km^2$) (A) | % | Arid ($km^2$) (B) | % | Hyperarid ($km^2$) (C) | % | Total ($km^2$) (A+B+C) | % |
|---|---|---|---|---|---|---|---|---|---|
| America | 39,917,000 | 3,943,160 | 10 | 2,910,000 | 7.5 | 780,700 | 2 | 7,633,860 | 19.5 |
| Africa | 29,797,000 | 5,546,490 | 18.5 | 7,325,560 | 24.5 | 4,527,240 | 15 | 17,309,280 | 58 |
| Asia | 42,365,000 | 6,354,750 | 15 | 8,049,350 | 19 | 1,270,950 | 3 | 15,675,050 | 37 |
| Australia | 7,703,850 | 2,234,120 | 29 | 3,928,960 | 51 | 0 | 0 | 6,163,080 | 80 |
| Europe | 10,032,100 | 752,500 | 7.5 | 200,500 | 2 | 0 | 0 | 953,000 | 9.5 |
| Total | 129,814,950 | 18,741,020 | 14.5 | 22,414,370 | 17 | 6,578,890 | 5 | 47,734,270 | 36.5 |
| Other lands (Greenland) (New Zealand) | 23,418,050 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Land Area | 153,233,000 | 18,831,020 | 12.2 | 22,414,370 | 14.6 | 6,578,890 | 4.2 | 47,734,270 | 31 |

Sources: FAO 1985 (CG)

| Verschmutzungs-art | Vereinigte Staaten | Karibik | Mexiko, Zentral und Südamerika: Amazonas Orinoko | Mexiko, Zentral und Südamerika: Andere Gebiete | Indischer Subkontinent | Südost-asien | Pazifische Inseln | China | Japan, Australien und Neuseeland |
|---|---|---|---|---|---|---|---|---|---|
| Pathogene Keime | 0–1 | 1–2 | 0 | 1–3 | 1–3 | 1–2 | 2–3 | 1–3 | 0–1 |
| Organische Stoffe | 0 | 1–2 | 0 | 1–3 | 1–3 | 0–2 | 0–1 | 1–3 | 0–1 |
| Versalzung | 0 | 1–2 | 0 | 0 | 0–1 | 0–1 | 0–3 | 0–2 | 0–2 |
| Nitrate | 0–1 | 1 | 0 | 0–1 | 0–1 | 0–1 | 1–2 | 0–2 | 0–1 |
| Fluoride | 0 | 0 | 0 | 0 | 0–1 | 0 | 0 | 0–2 | 0 |
| Eutrophierung | 1–2 | 1–2 | 0 | 1–3 | 0–1 | 0–3 | 0 | 0–2 | 0–1 |
| Schwermetalle | 0–1 | 0–1 | 0–1 [a] | 1–3 | 0–1 | 0–2 | 0–1 | 0–2 | 0–2 |
| Pestizide | 0–1 | n/a | 0 | 1–3 | 0–1 | 0–1 | 0–1 | 0–1 | 0–1 |
| Ind. organische Stoffe | 0–1 | 0–1 | 0 | 1–3 | n/a | n/a | n/a | n/a | n/a |
| Sedimente | 0–1 | 0–1 | 0–1 [a] | 1–3 | 0–2 | 0–2 | 0–1 | 0–3 | 0–1 |
| Versauerung | 0–2 [b] | 0 | 0 | 0–1 | 0 | 0–1 | 0 | 0–1 | 0–1 |
| Abwärme | 0 | 0 | 0 | 0 | n/a | n/a | n/a | n/a | n/a |
| Radioaktivität | 0 | 0 | 0 | 0 | n/a | n/a | n/a | n/a | n/a |

(a) Quecksilber und Verschmutzung durch Sedimente aus der Goldexploration an einigen Flüssen

(b) Ost–Kanada und nordöstliche USA

App. 4–7 (a): Wasserqualität in Afrika

| Verschmutzungs-art | Maghreb | Sahel | Golf von Guinea | Kongo-Becken | Nil- [e] Becken | Östl. und südl. Seen | Große Seen | Arabische Halbinsel [a] | Östl. Mittelmeergebiet |
|---|---|---|---|---|---|---|---|---|---|
| Pathogene Keime | 1–2 | 1–3 | 1–3 | 1–2 | 1–2 | 1–3 | 1 | 0 | 1 |
| Organische Stoffe | 1–2 | 1–2 | 1–2 | 0–1 | 1–2 | 1–2 | 0 | 0 | 1 |
| Versalzung | 0–2 | 0–2 | 0–1 | 0 | 0–1 | 1–2 | 0 | 3 | 1 |
| Nitrate | 0–2 | 1–2 | 1–2 | 0–1 | 0–1 | 1 | 0 | 0 | 1 |
| Fluoride | 0–3 | 0–2 | 0 | 0 | 0 | 1–3 | 0 | 0 | 0 |
| Eutrophierung | 0–2 | 0–1 | 1 | 0 | 0–2 | 0 | 1 [c] | 0 | 1–2 |
| Schwermetalle | 0–1 | 0–1 | 0–1 | 0–2 [b] | 0–1 | 0–1 | 0 | 0 | 0 |
| Pestizide | 0–1 | 1 | 1–2 | 1 | 0–1 | 0–1 | 1 [c] | 0 | 1–2 [c] |
| Ind. organische Stoffe | 0–1 | 0 | 0–1 | 0–1 | 0–1 | 0 | 0 | 1 [b] | 1 [c] |
| Sedimente | 1–3 | 0–2 | 0 | 0 | 0–2 | 0–2 | 0 | 0 | 1 |
| Versauerung | 0 | 0–1 [d] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Abwärme | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 [b] | 0 |
| Radioaktivität | 0 | 0–1 [a] | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

0 keine Verschmutzung oder irrelevant

1 geringe Verschmutzung, Wasser kann verwendet werden, wenn geeignete Maßnahmen ergriffen werden

2 stärkere Verschmutzung

3 schwere Beeinträchtigung für Wassernutzung

(a) Uranminen im Niger

(b) Oberes Zaire Basin

(c) Lokale Probleme

(d) Übersäuerung des Bodens

(e) Die schlechteste Qualität wird generell im Nildelta vorgefunden

(a) kein Oberflächenwasser, überwiegend Grundwasser und Meerwasserentsalzung

(b) möglicherweise in Küstengebieten

(c) möglicherweise in Flüssen

Quelle: Water Quality, Progress in Implementing the Mar del Plata Action Plan, New York, 1990

Source: GITEC 1992

## Table 2-5 b

Table 20: Comparison of Typical Magnitudes of Concentrations from Nonpoint Sources and Sewage (Novotny and Chester, 1981)

| | Suspended Solids[a] | $BOD_5$ | COD | Total N | Total P | Lead | Total Coliform |
|---|---|---|---|---|---|---|---|
| Precipitation | 11-13 | 12-13 | 9-16 | 1.2-1.3 | 0.02-0.04 | | |
| Background levels | 5-1000 | 0.5-3 | | 0.05-0.5 | 0.01-0.2 | 0.1 | |
| Agricultural cropland | | 7 | 80 | 9 | 0.02-1.7 | | |
| Animal feedlots | 30 | 1000-11,000 | 31,000-41,000 | 920-2100 | 290-380 | | |
| Urban storm water | 100-10,000 (630)[b] | 10-250 (30) | 20-600 | 3-10 | 0.6 | 0.35 | $10^3$-$10^8$ |
| Combined sewers | 100-2000 (410) | 20-600 (115) | 20-1000 | 9-10 | 1.9 | 0.37 | $10^5$-$10^8$ |
| Municipal sewage, untreated | 100-330 (200) | 100-300 (200) | 250-750 | 40 | 10 | | $10^7$-$10^9$ |
| Municipal sewage, treated | 10-30 | 15-30 | 25-80 | 30 | 5 | | $10^2$-$10^4$ |

[a]all units are in mg/l except for total coliform expressed in no./100 ml.
[b]( ) flow weighted averages

Source: Canter 1986

## Table 2-5 c

TABLE 3.9
Summary of Nonpoint Source Characteristics[a]

| Source | Concentration (mg/liter) COD | BOD | $NO_3$-N | Total N | Total P | Area yield rate (kg/ha/year) COD | BOD | $NO_3$-N | Total N | Total P | Surface area of interest |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation | 9–16 | 12–13 | 0.14–1.1 | 1.2–1.3 | 0.02–0.04 | 124 | – | 1.5–4.1 | 5.6–10 | 0.05–0.06 | Total land area |
| Forested land | – | – | 0.1–1.3 | 0.3–1.8 | 0.01–0.11 | – | – | 0.7–8.8 | 3–13 | 0.03–0.9 | Forest area |
| Range land | – | – | – | – | – | – | – | 0.7 | – | 0.08 | Range land |
| Agricultural crop land | 80 | 7 | 0.4 | 9 | 0.02–1.7 | – | – | – | 0.1–13 | 0.06–2.9 | Active-crop land |
| Land receiving manure | – | – | – | – | – | – | – | – | 4–13 | 0.8–2.9 | Crop or unused land used for manure disposal |
| Irrigation tile drainage, western United States | | | | | | | | | | | |
| Surface flow | – | – | 0.4–1.5 | 0.6–2.2 | 0.2–0.4 | – | – | – | 3–27 | 1.0–4.4 | Irrigated western soils |
| Subsurface drainage | – | – | 1.8–19 | 2.1–19 | 0.1–0.3 | – | – | 83 | 42–186 | 3–10 | Irrigated western soils |
| Crop land tile drainage | – | – | – | 10–25 | 0.02–0.7 | – | – | – | 0.3–13 | 0.01–0.3 | Active crop land requiring drainage |
| Urban land drainage | 85–110 | 12–160 | – | 3 | 0.2–1.1 | 220–310 | 30–50 | – | 7–9 | 1.1–5.6 | Urban land areas |
| Seepage from stacked manure | 25,900–31,500 | 10,300–13,800 | – | 1,800–2,350 | 190–280 | – | – | – | – | – | Manure holding area |
| Feedlot runoff | 3,100–41,000 | 1,000–11,000 | 10–23 | 920–2,100 | 290–360 | 7,200 | 1,360 | – | 100–1,600 | 10–620 | Confined, unenclosed animal holding areas |

[a]Data do not reflect the extreme ranges caused by improper waste management or extreme storm conditions; the data represent the range of average values reported.

Source: Loehr 1976

## Table 2-5 d

**Herkunft der Gewässerbelastungen**

| Herkunft | leicht abbaubar: Schmutzfracht $BSB_5$ | Nährstoffe N,P | schwer abbaubar: Rest-CSB | krit. Schadstoffe | Salze | Metalle |
|---|---|---|---|---|---|---|
| Haushalte | +++ | +++ | ++ | 0 | ++ | I |
| Industrie | +++ | ++ | +++ | +++ | +++ | +++ |
| Landwirtschaft | ++ | ++ | + | + | + | 0 |

+++ : über 25% der Gesamtmenge
++ : 5 - 25% " "
+ : 1 - 5% " "
I : 0.2 - 1% " "

Source: Boesel 1990

## Table 2-6

TABLE 8.1 N a P content in different sources (after McCarty).

| Source | Nitrogen (mil. kg/year) | Phosphorus (mil. kg/year) |
|---|---|---|
| Domestic wastes | 500 to 720 | 90 to 225 |
| Industrial wastes | > 450 | x |
| Runoff from agricultural land | 680 to 6800 | 54 to 545 |
| Runoff from non-agricultural land | 180 to 860 | 68 to 340 |
| Wastes from live-stock production | > 450 | x |
| Runoff from urban areas | 50 to 500 | 5 to 77 |
| Atmospheric precipitation | 13 to 265 | 1.5 to 4 |

x - no data

Source: Holy 1980

Table 2-8



Table 9-1. Factors affecting pesticide entrainment and transport in runoff. After Leonard (1988).

| Factors | Comment | Selected references |
|---|---|---|
| | **1. Climatic** | |
| A. Rainfall/runoff timing with respect to pesticide appliction | Highest concentration of pesticide in runoff occurs in first significant runoff event after application. Pesticide concentration and availability at the soil and foliar surfaces dissipate with time thereafter. | White et al., 1967; Bovey et al., 1975; Bradley et al., 1972; Wauchope & Leonard, 1980a, b; Baker & Johnson, 1979; Edwards et al., 1980; Smith et al., 1983; Triplett et al., 1978 |
| B. Rainfall intensity | Surface runoff occurs when rainfall rate exceeds infiltration rate. Increasing intensity increases runoff rate and energy available for pesticide extraction and transport. May also affect depth of surface interaction. Increasing intensity reduces time to runoff within storm. | Skaggs & Khaleel, 1982; Sharpley et al., 1981; Sharpley, 1985a |
| C. Rainfall duration/ amount | Affects total runoff volumes; pesticide washoff from foliage related to total rainfall amount; leaching below soil surface also affected. | White et al., 1967; Bovey et al., 1975; Baker et al., 1981; Willis et al., 1980 |
| D. Time to runoff after inception of rainfall | Runoff concentrations increased as time to runoff decreased. Pesticide concentrations and availability are greater in first part of the event before significant reduction occurs as a result of leaching and incorporation by raindrop impact. | Baker & Laflen, 1979; Gaynor & Volk, 1981; Baker et al., 1982; Barnett et al., 1967 |
| E. Water temperature | Little data available, but increasing temperature normally increases pesticide solubility and decreases physical adsorption. | Barnett et al., 1967; Bailey et al., 1974 |
| | **2. Soil** | |
| A. Soil texture and organic matter contents | Affects infiltration rates; runoff is usually higher on finer-textured soils. Time to runoff is greater on sandy soils reducing initial runoff concentrations of soluble pesticides. Organic matter content affects pesticide adsorption and mobility. Soil texture also affects soil erodibility, particle transport potential, and chemical enrichment factors. | Rawls & Brakenaiek, 1982; Rao & Davidson, 1980; Wischmeier & Smith, 1978; Foster et al., 1980 |
| B. Surface crusting and compaction | Crusting and compaction decreases infiltration rates, reduces time to runoff, and increases initial concentrations of soluble pesticides | Baker & Laflen, 1979 |
| C. Water content | Initial soil water content at beginning of a rainstorm may increase runoff potential, reduce time to runoff, and reduce leaching of soluble chemicals below soil surface before runoff inception. | Knisel & Baird, 1969; Davidson et al., 1975; Barnett et al., 1967 |
| D. Slope | Increasing slope may increase runoff rate, soil detachment and transport, and increase effective surface depth for chemical extraction. | Wauchope, 1978; Sharpley et al., 1981; Foster et al., 1980 |
| E. Degree of aggregation and stability | Soil particle aggregation and stability affects infiltration rates, crusting potential, effective depth for chemical entrainment, sediment transport potential, and adsorbed chemical enrichment in sediment. | Sharpley et al., 1981; Foster et al., 1980; Ahuja et al., 1981 |
| | **3. Pesticide** | |
| A. Solubility | Soluble pesticides may be more readily removed from crop residue and foliage during the initial rainfall or be leached into the soil. However, when time to runoff is short, runoff concentration may be enhanced by increasing solubility. | Barnett et al., 1967; Trichill et al., 1968; Baker et al., 1978; Baker & Johnson, 1979; Willis et al., 1980; Baker et al., 1982 |
| B. Sorption properties | Pesticides strongly adsorbed in soil will be retained near application site, i.e., possibly at soil surface and be more susceptible to runoff. Amounts of runoff when dependent on amount of soil erosion and sediment transport. | McDowell et al., 1981; Willis et al., 1983 |
| C. Polarity/ionic nature | Adsorption of nonpolar compounds determined by soil organic matter; ionized compounds, and weak acids/bases affected more by mineral surface and soil pH. Lyophillic compounds retained on foliage by leaf surface and waxes, whereas polar compounds more easily removed from foliage by rainfall. | Rao & Davidson, 1980; Willis et al., 1980; Wauchope & Leonard, 1980a, b |
| D. Persistance | Pesticides that remain at the soil surface for longer periods of time because of their resistance to volatilization, chemical, photochemical, and biological degradation have higher probability of runoff. | Wauchope, 1978; Mills & Leonard, 1984; Leonard & Knisel, 1986 |
| E. Formulation | Wettable powders are particularly susceptible to entrainment and transport. Liquid forms may be more readily transported than granular. Esters less soluble than salts produced higher runoff concentrations under conditions where initial leaching into soil surface is important. | Wauchope, 1978; Rohde et al., 1979; Wauchope & Leonard, 1980a, b; Wauchope, 1987b |
| F. Application rate | Runoff concentrations are proportional to amounts of pesticide present in runoff zone. At usual rates of application for pest control, pathways and processes (e.g., sorption and degradation rates) are not affected by initial amounts present, therefore, runoff potential is in proportion to amounts applied. | Barnett et al., 1967; Hall, 1974; Leonard et al., 1976 |
| G. Placement | Pesticide incorporation or any placement below the soil surface reduces concentrations exposed to runoff process. | Leonard et al., 1979; Wauchope, 1978; Rohde et al., 1979; Wauchope & Leonard, 1980a, b |
| | **4. Management** | |
| A. Erosion control practices | Reduces transport of adsorbed/insoluble compounds. Also reduces transport of soluble compounds if runoff volumes are also reduced during critical times after pesticide application. | Caro, 1976; McDowell & Grissinger, 1976; Pionke, 1977; McDowell et al., 1981; Willis et al., 1983 |
| B. Residue management | Crop residues can reduce pesticide runoff by increasing time to runoff, decreasing runoff volumes, and decreasing erosion and sediment transport. However, pesticide runoff may be increased under conditions where pesticides are washed from the crop residue directly into runoff water (high initial soil water, clay soil, intense rainfall immediately after pesticide application). | Triplett et al., 1978; Baker et al., 1978; Baker & Johnson, 1979; Edwards et al., 1980; Baker et al., 1982; Hall et al., 1984 |
| C. Vegetative buffer strips | Buffer strips around treated fields may reduce transport of some pesticides by secondary infiltration, sediment deposition and sorption on plant surfaces and debris. | Asmussen et al., 1977; Rohde et al., 1980 |
| D. Irrigation | Chemical application by sprinkler irrigation may move soluble pesticides into soil surface and reduce runoff potential. Aerial application of pesticides during periods of flood irrigation greatly increases pesticide runoff in surface drainage. | Dowler et al., 1982; Spencer et al., 1985 |

Source: Leonard in: Cheng ed. 1990

Table 9-2. Runoff losses of pesticides from small plots and single cover watersheds (1978–1985).

| Compound | Rate, kg/ha | Location | Crop/Cover | Conc. in runoff, µg/kg† | Total seasonal losses, % of application | Comments | Reference |
|---|---|---|---|---|---|---|---|
| | | | | Runoff from natural rainfall or snowmelt | | | |
| Atrazine | Various | Ohio | No-till and conventionally tilled corn | 480 | 0–5.7 | No-till reduced herbicide runoff primarily by reducing runoff volume. Time of runoff event relative to application most important factor | Triplett et al., 1978 |
| Simazine | Various | Ohio | No-till and conventionally tilled corn | 1200 | 0–5.4 | | |
| Simazine | Various | Various | Irrigation canals | 250 | -- | Applied to canals with and without flowing water | Anderson et al., 1978 |
| 2,4-D | 3.7 | Florida | Citrus | 75 | -- | Concentrations in tile outflow generally in range of 20–25 µg/L | Wheeler et al., 1978 |
| Atrazine | 1.45–4.03 | Georgia | Corn | 1 900 (water) | 0.2–1.9 | Results from comprehensive studies to provide data for model development and testing | Leonard et al., 1979 |
| Paraquat | 1.53–16.3 | Georgia | Corn | 980 000 (sed.) | 3.4–10.9 | | |
| Trifluralin | 1.12 | Georgia | Soybean | 21 (water) | 0.1–0.3 | | |
| Propazine | 1.66 | Georgia | Grain sorghum | 400 (water) | 6.7 | | |
| Cyanazine | 1.35–1.61 | Georgia | Corn | 180 (water) | 0.07–1.0 | | |
| Diphenamid | 2.31–3.52 | Georgia | Soybean | 2 070 (water) | 0.1–7.2 | | |
| Alachlor | 2.24 | Iowa | Corn | | 0.96 (avg.) | Losses depend on time between application and runoff; decreased runoff and erosion decreased pesticide losses, but not in proportion because conc. in water and sediment were higher for conservation systems | Baker & Johnson, 1979 |
| Atrazine | 2.24 | Iowa | Corn | | 2.1 (avg.) | | |
| Cyanazine | 2.24 | Iowa | Corn | | 2.1 (avg.) | | |
| Fonofos | 1.12 | Iowa | Corn | | 0.36 (avg.) | | |
| Ethoprop (liquid) | | Georgia | Soybean | 283 | 0.1 | Major differences in runoff and dissipation of ethoprop observed between liquid and granular formulations | Rohde et al., 1979 |
| Ethoprop (granular) | | Georgia | Soybean | 45 | 0.01 | | |
| Atrazine | | Maryland | Corn | 16.9 (avg.) | 1 | Field soil sampling indicated both vertical and lateral movement of atrazine, but not of alachlor | Wu, 1980 |
| Alachlor | | Maryland | Corn | 0.6 (avg.) | 0.16 | | |
| Picloram | 2.8 | Arizona | Pinyon-Juniper | 320 | 1.1 | Highest runoff conc. in initial runoff event after application | Johnsen, 980 |
| Glyphosate | 1.10–8.96 | Ohio | No-till corn | 5200 one event others ≤100 | 1.85 (extreme yr, <1 other yr and watersheds | Abnormally high conc. because of high application rate and runoff occurring 1 d after application | Edwards et al., 1980 |
| Trifluralin | 1.12 | Georgia | Soybean | 38 | 0.17 | Trifluralin detected in surface runoff for 16 wk after application; none in tile outflow except trace 16 wk after application | Rohde et al., 1980 |
| Permethrin | 0.112 (10 applications) | Louisiana | Cotton | <1 | <1 | Runoff losses low even under extreme runoff conditions | Carrol et al., 1981 |
| Toxaphene | | Mississippi | Cotton | -- | 1–0.5 | Linear relationships observed between sediment yields and toxaphene yields in runoff. 93% of toxaphene in runoff attached to sediment; 7% in solution | McDowell et al., 1981 |
| 2,4-D | | Oregon | Rangeland | -- | 0.014 | Nearly all herbicide runoff observed resulted from direct deposits in stream channels and streambanks | Norris et al., 1982 |
| Picloram | | Oregon | Rangeland | -- | 0.35 | | |
| 2,4-D | | Saskatchewan, Canada | Wheat stubble, fallow | 31 (avg.) | 4.1 (6-yr avg.) | Snowmelt runoff | Nicholaichuk & Grover, 1983 |
| | | | Fallow | 3 (avg.) | 0.3 | | |
| Toxaphene | | Mississippi | Cotton | | | Pesticide conc. in sediment were directly proportional to sediment clay and organic matter conc. Storm and yield of pesticides were linear functions of storm sediment yields in years where no new applications made. In those years, correlations required separation into similar tillage-application regimes | Willis et al., 1983 |
| DDT | | Mississippi | Cotton | | | | |
| DDE | | Mississippi | Cotton | | | | |
| Trifluralin | | Mississippi | Cotton | | | | |
| Azinophos-Methyl | | Louisiana | Sugarcane | 250 | 0.55 | 1981 losses shown were twice that in 1980, mainly because of rainfall timing relative to application. Fenvalerate might cause problems for aquatic habitats immediately surrounding application sites | Smith et al., 1983 |
| Fenvalerate | | Louisiana | Sugarcane | | 0.56 | | |
| Cyanazine | 1.1–1.7 | Pennsylvania | No-till and conventionally tilled corn | | 0.73–5.7 conventional <0.01–0.75 no-till | Herbicide runoff reduction accomplished primarily by reduction in volume of runoff | Hall et al., 1984 |
| Picloram | | Texas | Bermudagrass | 250 | 6.3 | Conditions during study strongly conducive to herbicide transport from treated source area. Studies additionally traced transport through larger watershed system~ | Mayeaux et al., 1984 |

Sources: Leonard in Cheng ed. 1990

| Compound | Rate, kg/ha | Location | Crop/Cover | Conc. in runoff, µg/kg† | Total seasonal losses, % of application | Comments | Reference |
|---|---|---|---|---|---|---|---|
| | | | | Runoff from simulated rainfall | | | |
| Cyanazine | 2.24 | Iowa | Corn with various treatments | 1 330 (water)<br>5 140–420 (sed.) | 11.0 avg. all treatments | Herbicide losses under conservation tillage greater than under conventional tillage; effects of reduced runoff volumes offset by higher conc. Total losses of Fonophos related to sediment transport | Baker et al., 1978 |
| Alachlor | 2.24 | Iowa | Same as above | 610–60 (water)<br>3 590–510 (sed.) | 7.9 avg. all treatments | | |
| Fonofos | 1.2 | Iowa | Same as above | 19–41 (water) | 1.8 avg. all treatments | | |
| Propachlor | 2.5 | Iowa | Fallow with wheel-track and pesticide incorporation variables | 3 800 (weter)<br>7 000 (sed.) | 0.8–12.7 | Runoff losses from surface applications compared to incorporated applications; runoff losses enhanced by wheel tracks because of increased runoff volumes and shorter times to start of runoff | Baker & Laflen, 1979 |
| Atrazine | 2.5 | Iowa | | 6 800 (water)<br>28 000 (sed.) | | | |
| Alachlor | 2.5 | Iowa | | 5 000 (water)<br>22 000 (sed.) | 1.7–22.1 | | |
| Fluometuron | 4.4 | Various | – | 0.87<br>0.30 (avg.) | <1 avg. | Major emphasis placed on first event | Wiese et al., 1980 |
| Atrazine | | | Limed and unlimed soil | | 3.7 | Greater sediment transport of terbutryne. Liming significantly reduced runoff volumes. | Gaynor & Volk, 1981 |
| Terbutryne | | | Same as above | | 0.3 | | |
| Propachlor | 2.09 | Iowa | Fallow and plots with corn residue | 59–173 (water; avg.)<br>370–840 (sed.; avg.) | 0.76–6.1 | Values given are for range of averages across treatments. Herbicide conc. not affected by placement above or below residue, but were negatively correlated with time to runoff which was increased by presence of residue | Baker et al., 1982 |
| Atrazine | 2.09 | Iowa | | 83–141 (water; avg.)<br>600–1110 (sed.; avg.) | 0.97–5.7 | | |
| Alachlor | 2.09 | Iowa | | 78–220 (water; avg.)<br>880–2240 (sed.; avg.) | 1.0–8.6 | | |

Table 9-2. Continued.

| Compound | Rate, kg/ha | Location | Crop/Cover | Conc. in runoff, µg/kg† | Total seasonal losses, % of application | Comments | Reference |
|---|---|---|---|---|---|---|---|
| | | | | Runoff from irrigated fields | | | |
| Cycloate | 2.9 | California | Sugarbeets | 6.2 | 0.03 | Irrigation runoff | Spencer et al., 1985 |
| DCPA | 3.4–7.6 | California | Cotton | 189 | 1.22–1.40 | Irrigation runoff | |
| Dinitramine | 1.3 | California | Cotton | 34 | 1.32 | Irrigation runoff | |
| EPTC | 2.8–13.8 | California | Sugarbeet and alfalfa | 1630 | 6.4–7.2 | EPTC applied in irrigation water at 2 mg/L | |
| Prometryn | 1.3–3.1 | California | Cotton | 1408 | 0.95–5.0 | Irrigation runoff | |
| Trifluralin | 0.96–1.1 | California | Cotton | 19 | 0.14–0.29 | Irrigation runoff | |
| Azinphosmethyl | 0.52 | California | Cotton | <0.5 | – | Irrigation runoff | |
| Chlorpyrifos | 0.98–2.88 | California | Cotton | 480 | 0.02–0.24 | Significant proportion of losses because of aerial application during irrigation | |
| Diazinon | 0.48–2.69 | California | Sugarbeet, mellon | 22 | 0.04–0.07 | Irrigation runoff | |
| Malathion | 1.17–4.46 | California | Cotton, sugarbeet, alfalfa, lettuce | 21 | 0.0003–0.09 | Irrigation runoff | |
| Methidathion | 1.02–1.12 | California | Cotton | 473 | 0.16–2.0 | Significant proportion of losses because of aerial application during irrigation | |
| Mevinphos | 0.14 | California | Alfalfa | 26 | 0.27 | Irrigation runoff | |
| Ethyl Parathion | 0.28–4.20 | California | Lettuce, sugarbeet, alfalfa | 77 | 0.02–0.51 | Irrigation runoff | |
| Methyl Parathion | 0.14–2.1 | California | Lettuce, sugarbeet | 27 | 0.003–0.32 | Irrigation runoff | |
| Sulprophos | 4.55–6.00 | California | Cotton | 0.32 | 0.001–0.007 | Irrigation runoff | |
| Methomyl | 0.4–5.82 | California | Cotton, lettuce, sugarbeet, alfalfa | 223 | 0.13–1.73 | Irrigetion runoff | |
| Endosulfan | 1.66–5.96 | California | Lettuce, melon | 104 | 0.19–0.62 | Irrigaiton runoff | |
| Ethylan | 3.2 | California | Lettuce | 8.0 | 0.008 | Irrigetion runoff | |
| Fenvalerate | 0.27–1.23 | California | Cotton | 133 | 0.05–0.21 | Significant proportion of losses because of aerial application during irrigation | |
| Permethrin | 0.10–0.71 | California | Cotton | 71 | 0–0.16 | Significant proportion of losses because of aerial application during application | |

† Maximum reported concentrations unless specified otherwise.

Source: Leonard in: Cheng ed. 1990

Table 9-3. Pesticides in streams and water bodies resulting from agricultural applications. Selected examples (1978–1985).

| Watershed stream systems | Location | Pesticide residues found | Conc. ranges (µg/kg) | Loads | Comments | Reference |
|---|---|---|---|---|---|---|
| Grassed watershed (53 ha); with partial treatment by herbicide. Stream system draining 1772 ha of perennial pasture watershed | Riesel, TX | Picloram | 250 maximum from treated 8-ha area | Most of herbicide leaving treated area was transported through the 53-ha watershed-system, but at reduced concentrations | Experiments conducted to study patterns of dilution, transport, and dissipation of herbicides in complex watersheds | Mayeux et al., 1984 |
| | | | 13 720 injected directly into stream | Only a small fraction of injection detected to pass 5400-m point. Apparent loss because of concentration decreasing to below limit of detection | | |
| Rivers and agricultural drainage | Japan | CNP | 0.01–16.67 | | Highest levels found above 4 wk after rice planting and when flood waters released from paddies. | Suzuki et al., 1978 |
| 2025 ha of agricultural watershed; corn and soybean major crop | Lincoln, NE | Atrazine<br>Alachlor<br>Propachlor | 14–24<br>0–1.4<br>0.58–3.0 | | Results based on limited sampling during drought years | Schepera et al., 1980 |
| Black Creek Watershed | Allen Co., IN | 2,4,5-T | 0.2–7.7 | | Atrazine, alachlor, carbofuran, and malathion not detected | Dudley & Karr, 1980 |
| Honey Creek Watershed and rivers of Northwest Ohio | Northwestern Ohio | Atrazine<br>Simazine<br>Metribuzin<br>Alachlor<br>Metolachlor<br>Butylate<br>Phorate<br>Terbufos<br>Fonofos<br>Carbofuran | 87†<br>7.4†<br>2.3†<br>105†<br>140†<br>0.49†<br>0.24†<br>0.54†<br>1.0†<br>45† | 7.5% of applied atrazine exported from Honey Creek Watershed in 1981 | Study reports higher concentration values than expected from other published sources; however, rainfall during study was two to three times above long-term average. Author concludes that concentrations observed not acutely toxic to fish and invertebrates, but may produce inhibitory growth effects on plants and algae | Baker et al., 1981 |
| Parana River, 600 km upstream from mouth | Argentina | Lindane<br>Parathion<br>Alpha-BHC | 0.009‡<br>0.022‡<br>0.009‡ | | Sediment transported pesticides were positively correlated with discharge as was sediment concentrations | Lenardon et al., 1984 |
| Well water, surface water (lakes, ponds, and rivers), and municipal water | 205 sites in South Carolina | DBCP | 0–0.4 | | In area of high use, 37% of surface water samples exceeded background (0.05 µg/L) levels, but none above 0.4 | Carter & Riley, 1981 |
| Forested watersheds | Central Tennessee | None | – | – | 1.68 kg/ha a.i. hexazinone applied as pellets. No detectable residue in streamflow for 28-wk after application | Neary, 1983 |
| Forested watershed; 104 ha containing four 1-ha watersheds | Upper Piedmont, GA | Hexazinone | 442 ± 53 first event maximum for treated area. 0–40 hexazinone + metabolite in streamflow for 104-ha watershed | 0.53% of application (avg. from watersheds) | Authors conclude that residue not high enough for aquatic damage | Neary et al., 1983 |
| Wye River Estuary | Eastern Chesapeake Bay region | Atrazine | 0–300 edge of field; 15 maximum in estuary; <3 avg. in estuary at peak loading | >3% moved in estuary | Herbicide level rarely approached levels that would reduce aquatic photosynthetic rate | Glotfelty et al., 1984 |
| | | Simazine | Simazine concentration in estuary significantly lower than for atrazine | | | |
| Various drainage basins surrounding Chesapeake Bay | Chesapeake Bay area | Linuron | <10 (sed.)<br><0.2 water | | No apparent accumulation of linuron in estuary | Zahnow & Riggleman, 1980 |
| Rhode River Watershed | Chesapeake Bay, MD | Atrazine<br>Alachlor | 0–40<br>0–6 | | Little correlation between use and hericide loading rates in water; herbicides in runoff from nontreated areas suggested aerial or subsurface transport in addition to surface runoff | Wu et al., 1983 |
| 11 agricultural watersheds ranging in size from 20–79 km$^2$ | Canadian Great Lakes Basin, Co. Ontario | 18 parent compounds plus isomers and metabolites found in drainage waters. Organochlorines not in current use also detected. Only atrazine, endosulfan, and simazine appeared year round | Atrazine 1.1, 1.6§<br>Endosulfan 0.0037, 0.002§<br>Simazine 0.02, 0.06§ | 2.02 g ha$^{-1}$ yr | Report summarizes extensive studies on pesticides in streamflow; concentrations of four pesticides (organochlorines consistently greater than established water quality criteria. No herbicide concentrations exceeded criteria | Frank et al., 1982 |

† Maximum values observed. ‡ Mean values. § Overall mean for 11 watersheds 1976 and 1977, respectively.

Source: Leonard in: Cheng ed. 1990

Table 2-10

Table 26: Classification of Pesticides by Availability Index A[a] (Wauchope and Leonard, 1980)

| Class | Assigned Value of A, ppb ha $kg^{-1}$ | Properties of Pesticide or Application Situation | Pesticide Data Used in A Calculation Common Name |
|---|---|---|---|
| I | 10,000 | Wettable powders applied to soil surface | Cyanazine, prometryne, fluometuron, simazine, atrazine, terbuthylazine, diphenamid, propazine, propachlor, metribuzine, linuron |
| | | Soluble salts which strongly bind to clay particles | MSMA, paraquat |
| | | Soluble salts applied to foliage | Arsenic acid[b], 2,4,5-T,2,4-D, picloram, dicamba |
| | | Nonionic pesticides applied in diesel oil | 2,4,5-T ester[c] |
| II | 3,000 | Soluble salts applied to soil | 2,4-D, picloram, 2,4,5-T, dicamba, fenac |
| | | Granular and pelleted pesticides, regardless of solubility--even if incorporated | Picloram, endrin, fonofas, dieldrin, carbaryl, carbofuran, diazinon |
| III | 1,000 | EC (insoluble), persistent pesticides applied to foliage | Endosulfan, endrin, DDT, toxaphene, diuron, methoxychlor |
| | | Incorporated but persistent | Dieldrin |
| IV | 300 | Insoluble pesticides applied to soil surface | Alachlor, 2,4-D ester, methoxychlor |
| | | All incorporated but not persistent pesticides except granular/pelleted soluble salts | Atrazine, dichlobenil, trifluralin |
| | | EC (insoluble) and nonpersistent pesticides applied to foliage | Parathion |

[a]the ratio between application rate (kg/ha) and runoff concentration (ppb) if runoff occurs immediately after application.

[b]Arsenic acid was not used as a "pesticide", but as a defoliant, in this experiment.

[c]Limited data available

Source: Canter 1986

## Regional Distribution of Salinity/ Alkalinity and Irrigated Soils (in 1,000 ha)

Table 3-1 a

| region | salt-affected soils | irrigated soils |
|---|---|---|
| North America | 15755 ha | 32000 ha |
| Central America | 1965 ha | included in N-America |
| South America | 129163 ha | 10000 ha |
| Africa | 80538 ha | 12000 ha |
| Southern Asia | 84838 ha | included in N-Asia |
| North./Cent.-Asia | 211686 ha | 220000 ha |
| SE-Asia | 19983 ha | see N-Asia. |
| Australia | 357330 ha | 2200 ha |
| Europa | 50804 ha | 30000 ha |
| total | 952062 ha | 306200 ha |

salt affected soils include: Solonchaks and soils with saline phases, Solonetz, and soils with alkaline phases; figures from Szabolcs 1979

irrigated soils in 1985: figures from Framji ICID 198

Table 3-1 b

TABLE 2. Distribution of salinity and alkalinity in countries most extensively affected (expressed in 1,000 ha)

| Area | Solonchaks | Saline phase | Solonetz | Alkaline phase | Total |
|---|---|---|---|---|---|
| *North America* | | | | | |
| Canada | — | 264 | 6,974 | — | 7,238 |
| United States of America | — | 5,927 | 2,590 | — | 8,517 |
| *Mexico and Central America* | | | | | |
| Cuba | — | 316 | — | — | 316 |
| Mexico | 242 | 1,407 | — | — | 1,649 |
| *South America* | | | | | |
| Argentina | 1,905 | 30,568 | 11,818 | 41,321 | 85,612 |
| Bolivia | — | 5,233 | 716 | — | 5,949 |
| Brazil | 4,141 | — | 362 | — | 4,503 |
| Chile | 1,860 | 3,140 | — | 3,642 | 8,642 |
| Colombia | 907 | — | — | — | 907 |
| Ecuador | 387 | — | — | — | 387 |
| Paraguay | — | 20,008 | 1,894 | — | 21,902 |
| Peru | 21 | — | — | — | 21 |
| Venezuela | 1,240 | — | — | — | 1,240 |
| *Africa* | | | | | |
| Afars and Issas | 59 | 1,682 | — | — | 1,741 |
| Algeria | 1,132 | 1,889 | — | 129 | 3,150 |
| Angola | 126 | 314 | 86 | — | 526 |
| Botswana | 1,131 | 3,878 | — | 670 | 5,679 |
| Chad | 2,417 | — | 3,728 | 2,122 | 8,267 |
| Egypt | 3,283 | 4,077 | — | — | 7,360 |
| Ethiopia | 319 | 10,289 | — | 425 | 11,033 |
| Gambia | — | 150 | — | — | 150 |
| Ghana | 200 | — | — | 118 | 318 |
| Guinea | — | 525 | — | — | 525 |
| Guinea-Bissau | — | 194 | — | — | 194 |
| Kenya | 3,501 | 909 | — | 448 | 4,858 |
| Liberia | — | 362 | 44 | — | 406 |
| Libyan Arab Jamahiriya | 905 | 1,552 | — | — | 2,457 |
| Madagascar | 37 | — | — | 1,287 | 1,324 |
| Mali | — | 2,770 | — | — | 2,770 |
| Mauritania | 150 | 490 | — | — | 640 |
| Morocco | 42 | 1,106 | — | — | 1,148 |
| Namibia | 562 | — | 1,751 | — | 2,313 |
| Niger | — | — | 11 | 1,378 | 1,489 |
| Nigeria | 455 | 210 | — | 5,837 | 6,502 |
| Rhodesia | — | — | — | 26 | 26 |
| Senegal | 141 | 624 | — | — | 765 |
| Sierra Leone | — | 307 | — | — | 307 |
| Somalia | 1,043 | 526 | 3,754 | 279 | 5,602 |
| Sudan | — | 2,138 | — | 2,736 | 4,874 |
| Tunisia | 990 | — | — | — | 990 |
| United Republic of Cameroon | — | — | — | 671 | 671 |
| United Republic of Tanzania | — | 2,954 | — | 583 | 3,537 |
| Zaire | — | 53 | — | — | 53 |
| Zambia | — | — | — | 863 | 863 |
| *South Asia* | | | | | |
| Afghanistan | 2,924 | 177 | — | — | 3,101 |
| Bangladesh | — | 2,479 | — | 538 | 3,017 |
| Burma | 634 | — | — | — | 634 |
| India | 2,979 | 20,243 | — | 574 | 23,796 |
| Iran | 24,817 | 1,582 | — | 686 | 27,085 |
| Iraq | 6,679 | 47 | — | — | 6,726 |
| Israel | 28 | — | — | — | 28 |
| Jordan | 74 | 106 | — | — | 180 |
| Kuwait | 209 | — | — | — | 209 |
| Muscat and Oman | 290 | — | — | — | 290 |
| Pakistan | 1,103 | 9,353 | — | — | 10,456 |
| Qatar | 225 | — | — | — | 225 |
| Sarawak | — | 1,538 | — | — | 1,538 |
| Saudi Arabia | 6,002 | — | — | — | 6,002 |
| Sri Lanka | 180 | 20 | — | — | 200 |
| Syrian Arab Republic | — | 532 | — | — | 532 |
| United Arab Emirates | 1,089 | — | — | — | 1,089 |
| *North and Central Asia* | | | | | |
| China | 7,307 | 28,914 | — | 437 | 36,658 |
| Mongolia | 3,728 | 342 | — | — | 4,070 |
| Solomon Islands | — | 238 | — | — | 238 |
| U.S.S.R. | 11,430 | 39,662 | 30,062 | 89,566 | 170,720 |
| *South-East Asia* | | | | | |
| Democratic Kampuchea | — | 1,291 | — | — | 1,291 |
| Indonesia | — | 13,213 | — | — | 13,213 |
| Malaysia | — | 3,040 | — | — | 3,040 |
| Socialist Republic of Viet Nam | — | 983 | — | — | 983 |
| Thailand | — | 1,456 | — | — | 1,456 |
| *Australasia* | | | | | |
| Australia | 16,567 | 702 | 38,111 | 301,860 | 357,240 |
| Fiji | — | 90 | — | — | 90 |

Table 17: Irrigated land damaged by salinisation in the top five irrigators and the world estimate for mid 1980s.

Table 3-1 c

| Country | Area damaged (Mha) | Share of irrigated land damaged (per cent) |
|---|---|---|
| India | 20.0 | 36 |
| China | 7.0 | 15 |
| United States | 5.2 | 27 |
| Pakistan | 3.2 | 20 |
| Soviet Union | 2.5 | 12 |
| Sub-total | 37.9 | 24 |
| World | 60.2 | 24 |

Source: Postel (1990).

Table 11: Global extent of human-induced salinisation.

Table 3-2 a

| Continent | Light (Mha) | Moderate (Mha) | Strong (Mha) | Extreme (Mha) | Total (Mha) |
|---|---|---|---|---|---|
| Africa | 4.7 | 7.7 | 2.4 | - | 14.8 |
| Asia | 26.8 | 8.5 | 17.0 | 0.4 | 52.7 |
| South America | 1.8 | 0.3 | - | - | 2.1 |
| North and Central America | 0.3 | 1.5 | 0.5 | - | 2.3 |
| Europe | 1.0 | 2.3 | 0.5 | - | 3.8 |
| Australasia | - | 0.5 | - | 0.4 | 0.9 |
| Total | 34.6 | 20.8 | 20.4 | 0.8 | 76.6 |

Source: Oldeman, et al. (1991b).

Table 10: Human-induced soil degradation for the World.

Table 3-2b

| Type | Light (Mha) | Moderate (Mha) | Strong (Mha) | Extreme (Mha) | Total (Mha) | Total (Per cent) |
|---|---|---|---|---|---|---|
| Loss of Topsoil | 301.2 | 454.5 | 161.2 | 3.8 | 920.3 | |
| Terrain Deformation | 42.0 | 72.2 | 56.0 | 2.8 | 173.3 | |
| WATER | 343.2 | 526.7 | 217.2 | 6.6 | 1093.7 | 55.7 |
| Loss of Topsoil | 230.5 | 213.5 | 9.4 | 0.9 | 454.2 | |
| Terrain Deformation | 38.1 | 30.0 | 14.4 | - | 82.5 | |
| Overblowing | - | 10.1 | 0.5 | 1.0 | 11.6 | |
| WIND | 268.6 | 253.6 | 24.3 | 1.9 | 548.3 | 27.9 |
| Loss of nutrients | 52.4 | 63.1 | 19.8 | - | 135.3 | |
| Salinization | 34.8 | 20.4 | 20.3 | 0.8 | 76.3 | |
| Pollution | 4.1 | 17.1 | 0.5 | - | 21.8 | |
| Acidification | 1.7 | 2.7 | 1.3 | - | 5.7 | |
| CHEMICAL | 93.0 | 103.3 | 41.9 | 0.8 | 239.1 | 12.2 |
| Compaction | 34.8 | 22.1 | 11.3 | - | 68.2 | |
| Waterlogging | 6.0 | 3.7 | 0.8 | - | 10.5 | |
| Subsidence organic soils | 3.4 | 1.0 | 0.2 | - | 4.6 | |
| PHYSICAL | 44.2 | 26.8 | 12.3 | - | 83.3 | 4.2 |
| Total (Mha) | 749.0 | 910.5 | 295.7 | 9.3 | 1964.4 | 100 |
| (Per cent) | 38.1 | 46.1 | 15.1 | 0.5 | | |

Source: Oldeman et al. (1991b).

Source: from Ghassami et al. 1993 (draft)

Table 3-3 a

Table 18: Global estimate of secondary salinisation in the world's irrigated lands.

| Country | Cropped area[a] (Mha) | Irrigated area[a] (Mha) | Share of irrigated to cropped area (per cent) | Salt affected land in irrigated area[b] (Mha) | Share of salt affected to irrigated land (per cent) |
|---|---|---|---|---|---|
| China | 96.97 | 44.83 | 46.2 | 6.70 | 15.0 |
| India | 168.99 | 42.10 | 24.9 | 7.00 | 16.6 |
| CIS | 232.57 | 20.48 | 8.8 | 3.70 | 18.1 |
| United States | 189.91 | 18.10 | 9.5 | 5.63 | 31.1 |
| Pakistan | 20.76 | 16.08 | 77.5 | 4.22 | 26.2 |
| Iran | 14.83 | 5.74 | 38.7 | 1.72 | 30.0 |
| Thailand | 20.05 | 4.00 | 19.9 | 0.40 | 10.0 |
| Egypt | 2.69 | 2.69 | 100.0 | 0.88 | 33.0 |
| Australia | 47.11 | 1.83 | 3.9 | 0.16 | 8.7 |
| Argentina | 35.75 | 1.72 | 4.8 | 0.58 | 33.7 |
| South Africa | 13.17 | 1.13 | 8.6 | 0.10 | 8.9 |
| Sub-total | 842.80 | 158.70 | 18.8 | 31.09 | 20.0 |
| World | 1473.70 | 227.11 | 15.4 | 45.4 | 20.0 |

Source: (a) Data for 1987 from FAO (1989); (b) Data for 1980s from different sources referred to in part two of this publication.

Source: Ghassami et al. 1993 (draft)

Table 3-3 b

Pakistan: Indus Basin, (1954), river salinity is low; increasing groundwater salinity in downstream stretches. totally 18 Mio ha, 10% saline, 24% partly saline

Upper Indus: 11 Mio ha, saline 6%, partly saline 14%

Lower Indus: 7 Mio ha, saline 18%, partly saline 39%

annual increase in damage: 20,000 ha (1950s); 40,000 ha (1960s)

in total out of 29 Mio arable land 23% are salt affected. (FAO 1971)

Totally, some 40% of irrigated soils are affected by waterlogging, of which some 14-17% are seriously affected (watertable within 1.5m). About 40% of the total areas have saline groundwater. (Anver in: ICID (STS-B2) 1991).

Iran. 16.8 Mio ha are arable land; 7 Mio ha are saline (naturally or human-made)

Iraq 3.6 Mio ha arable; 1.9 Mio cultuivated (1962), 50% are strongly saline (declined yields at all degrees), in irrigated areas 20-60% are affected by salinity, less often in northern parts (higher rainfall).; major cause: waterlogging, use of saline water; high sodicity and alkalinity in places; drainage systems are only recently introduced, hence, and accumulation of salts and built-up of soil salinity and shallow water table over millennia (Dieleman 1977).

Saudi Arabia: Large scale problems in new development schemes, due to lack of drainage systems; traditional systems only affected by sewage from big schemes

Libya. Large scale problems in some new developed schemes: use of saline irrigation water, lack of drainage systems, selection of unsuitable soils (primary salinity); development of suitable land with minor problems; often excellent water quality, artificial or natural drainage of new systems created ocassionally problems of waterlogging and salinization in adjacent traditional irrigation.

Haiti. Large scale development may create problems if inherent soil properties are not considered and under poor water management; analysis revealed that -after 22 years development - slightly saline soils are desalinized and problems aggrevated in soils already saline prior to irrigation (Petermann 1986)

Jordan. About 12% of Jordan Valley soils are affected (recently developed areas) (FAO 1970).

Syria. 8 Mio ha arable land; some 6.6. Mio ha are cultuivated, some 0.5 Mio irrigated; 50% of irrigated areas (0.22 Mio ha) in Euphrates/Khabour Valleys are affected by salinity: 10% pf area abandoned, 15% high and 25% moderate yield losses in 1970s. (FAO 1970).

Egypt. About 0.8 Mio ha, ie 30% of arable land is affected by salinity, waterlogging and insufficient natural darainage (FAO 1970). In New Valley irrigated soils: 25% are non-saline, 50% moderately saline; 25% strongly saline (either top- or subsoils); under continuous irrigation with good management soils become desalinized under irrigation initial salt contents are moderately high, ocassionally extremely high; extreme secondary salinization on low lying areas without drainage; proper selection of irrigated areas, average water management practices and adequate draiange can avoid degradation.

Table 3-3 c

| Country | Area (10⁶ km²) | Population (10⁶) | Average annual rainfall (mm) | Average annual runoff: Volume ($10^9$ $m^3$) | Average annual runoff: Depth (mm) | Average annual runoff: Percent of rainfall (%) | Annual water use: Total volume ($10^9 m^3$) | Annual water use: Volume used for irrigation ($10^9 m^3$) | Cultivated land: Total ($10^6$ ha) | Cultivated land: Irrigated ($10^6$ ha) | Irrigation-induced salt affected land ($10^6$ ha) | Main affected areas | Major causes | Major magagement options | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Argentina | 2.8 | 32 | 515 | 914 | 330 | 64 | 26 | 19 | 35.8 | 1.5 | 0.58 | San Juan, Mendoza, Salta and Rio Negro Provinces. | Extensive irrigation without drainage facilities. | Improving drainage facilities and irrigation systems. | |
| Australia | 7.7 | 17 | 465 | 397 | 52 | 11 | 15 | 10 | 47.1 | 1.8 | 0.16 | Murray Basin and southwest of Western Australia. | Land clearing, extensive irrigation, construction of hydraulic structures. | In Murray Basin: Interception schemes and disposal of saline drainage and groundwater to evaporation basins. In Western Australia: reforestation. | (a) In the irrigated areas 0.65 x $10^6$ ha have water tables shallower than 2m. (b) 0.80 x $10^6$ ha are affected by dryland salinity. (c) salinisation of water resources in the Murray Basin, Western Australia and South Australia, is a major problem. |
| China | 9.6 | 1134 | 630 | 2600 | 272 | 43 | 444 | ~~300-400~~ 389 | 100.0 | 48.0 | 6.70 | Huang-Huai-Hai Plain (containing 3.06 Mha salt affected land out of a total 20 Mha irrigated). | Excessive irrigation without adequate drainage facilities. | Conjuctive use of surface and groundwater resources. | |
| CIS | 22.4 | 291 | 531 | 4740 | 215 | 40 | 344 | 195 | 232.6 | 20.5 | 3.70 | Central Asia, Ukraine, Caucasus region and Volga Basin. | Excessive irrigation without adequate drainage facilities. | Increasing irrigation efficiency by lining irrigation canals, using efficient irrigation methods, automation of irrigation systems, using subsurface drainage methods (tile drainage and vertical drainage) and changes in agricultural practices. | |
| Egypt | 1.0 | 52 | 0 | 0 | 0 | 0 | 38 | 34 | 2.7 | 2.7 | 0.88 | Nile Valley and Delta. | Extensive perennial irrigation. | Development of surface and sub-surface pipe drainage facilities. | Egypt has practically no surface runoff. The 55.5 x $10^9$ $m^3$ of the Nile water is Egypt's share from the Nile Basin. |
| India | 3.3 | 850 | 1250 | 1897 | 577 | 46 | 552 | 460 | 169.0 | 42.1 | 7.00 | Punjab, Haryana, Utar Padesh, Bihar, Rajastan, Madhyapradesh. | Excessive irrigation without drainage facilities. | Conjunctive use of surface and groundwater, improved irrigation and drainage. | |
| Iran | 1.6 | 56 | 243 | 71.5 | 43 | 18 | 75 | 73 | 14.8 | 5.7 | 1.72 | Many irrigation projects including Zarrineh-Rud, Moghan, North Ahwaz, Khalafabad, Shadgan, Doroudzan and Isfahan. | Low rainfall, high potential evaporation, inadequate irrigation and drainage facilities, irrigation with low quality water. | Improving irrigation and drainage facilities, conjunctive use of surface and groundwater, improved agricultural practices. | |
| Pakistan | 0.8 | 112 | 348 | 175 | 220 | 63 | na | 123 | 20.4 | 17.6 | 4.22 | Indus River Basin. | Extensive use of surface water for irrigation and inadequate drainage facilities. | Conjunctive use of surface and groundwater, improving drainage facilities, disposal of saline drainage waters to the sea. | |
| South Africa | 1.2 | 36 | 502 | 53.5 | 44 | 9 | 12 | 9 | 13.2 | 1.1 | 0.1 | Breede, Fish and Sundays River Basins. | Irrigation on soils with sub-surface salt contents. | Improved irrigation and drainage systems. | Salinisation of surface water resources supplying the main population centres, and the industrial, mining and agricultural sectors is a much more important issue compared to land salinisation. Salt affected rivers include Breede, Berg, Fish and Vaal. Salinisation is mainly due to increased human activity such as the discharge of industrial, mining and municipal effluents to the river system, as well as return flow from irrigation schemes and the phenomenon of dryland salinity. |
| Thailand | 0.5 | 56 | 1550 | 171 | 333 | 21 | na | na | 20.0 | 4.0 | 0.40 | Khorat and Sakon Nakhon Basin in Khorat Plateau, Lam Pao and Nong Wai. | Land clearing, reservoir construction, salt making and irrigation. | Reforestation, banning salt making, controlling groundwater depth, land levelling and surface mulching. | (a) Dryland salinity affects 2.85 x $10^6$ ha mainly in Khorat Plateau. (b) Irrigated land salinity is mainly limited to Lam Pao and Nong Wai irrigated areas. |
| USA | 9.4 | 250 | 762 | 1930 | 206 | 27 | 551 | 120 | 224.5 | 19.7 | 5.63 | Colorado River Basin, San Joaquin Valley, Imperial Valley, Coachella Valley, Lower Rio Grande | Excessive irrigation without adequate drainage facilities | On-farm physical improvement and irrigation managenment, water pricing and irrigation management, blending drainage water with good quality surface water, disposal of drainage water to evacpoation basin. | Salinity of the Colorado River and disposal of irrigation return flow in San Joaquin Valley are among the major issues. |
| World | 149.0 | 5292 | 800 | 46 768 | 314 | 39 | 4132 | 2680 | 1473.70 | 227.11 | 45.40 | Arid and semi-arid regions of the world, including countries such as: Argentina, Australia, China, Egypt, India, Iran, Iraq, Pakistan, Thailand, The United States and the Soviet Union. | Excessive irrigation without adequate drainage facilities, land clearing and construction of hydraulic structures. | Improving surface and sub-surface drainage facilities, conjunctive use of surface and groundwater resources, and improving farm management. | 45.4 x $10^6$ ha of land affected by human induced salinisation represents only the salt affected land in the world irrigated areas. |

Source: Ghassami et al. 1993 (draft)

na: Not available

Table 3-3

Table 8.8. Soil loss under different vegetal covers

| Cover | Slope (per cent) | Soil loss ($kg\,m^{-2}\,y^{-1}$) | |
|---|---|---|---|
| Primary tropical rain forest | — | 0.009 | (1) |
| Secondary tropical rain forest | — | 0.013 | (1) |
| | 7 | 0.003 | (2) |
| Temperate mixed woodland | 19 | 0.005 | (3) |
| Dense savanna grass | 4 | 0.005–0.02 | (2) |
| Lucerne | 9 | 0.025 | (4) |
| Blue grass | 9 | 0.007 | (4) |
| Maize (shifting cultivation plot) | — | 0.03 | (1) |
| Maize (1st year in maize/oats/ clover rotation) | 9 | 4.4 | (4) |
| Maize (with grass bunds) | — | 0.7 | (5) |
| Maize (no conservation) | — | 1.2 | (5) |
| Maize (rows up and down slope) | 9 | 9.4 | (4) |
| Maize (on subsoil) | 9 | 12.8 | (4) |
| Coffee (clean weeded) | — | 2.2 | (5) |
| | — | 1.8–5.5 | (5) |
| Banana | 7 | 1.5 | (2) |
| Banana (trash mulch) | — | 0.05 | (5) |
| Manioc | 7 | 9.0 | (2) |
| Sorghum | 2 | 0.3–1.2 | (2) |
| | — | 2.6–5.2 | (5) |
| Cotton | 2 | 0.05–1.9 | (2) |
| Ground nuts | 2 | 0.3–1.2 | (2) |
| Crotalaria | 7 | 4.0–5.0 | (2) |
| Upland rice (1st year) | — | 0.017 | (1) |
| Upland rice (12th year) | — | 0.289 | (1) |
| Bare soil in humid tropics | 7 | 10.0–17.0 | (2) |
| Bare soil in savanna | 4 | 1.8–3.0 | (2) |
| Bare soil in temperate climate | 19 | 1.0 | (3) |

After (1) Kellman, 1969; (2) Roose, 1971; (3) Morgan, 1977; (4) FAO, 1965; (5) Temple, 1972b.

Source: Kirkby/Morgan ed. 1980

Table 3-4

Table 8.1. Recommended values for maximum permissible soil loss ($kg\,m^{-2}\,y^{-1}$)

| | |
|---|---|
| Meso-scale (e.g. field level) | |
| Deep fertile loamy soils; values used in the Mid-West of USA | 0.6–1.1[a] |
| Thin, highly erodible soils | 0.2–0.5[b,c] |
| Very deep loamy soils derived from volcanic deposits, e.g. in Kenya | 1.3–1.5[b] |
| Soil depths: 0–25 cm | 0.2[d] |
| 25–50 cm | 0.2–0.5[d] |
| 50–100 cm | 0.5–0.7[d] |
| 100–150 cm | 0.7–0.9[d] |
| over 150 cm | 1.1 |
| Probable realistic value for very erodible areas, e.g. mountains in the tropics | 2.5 |
| Macro-scale (e.g. drainage basins) | 0.2 |
| Micro-scale (e.g. construction sites) | 2.5 |

After [a] Wischmeier and Smith (1965); [b] Hudson (1971); [c] Smith and Stamey (1965); [d] Arnoldus (1977).

Source: Kirkby/Morgan ed. 1980

Table 3-5

**Table 1.1** Rates of erosion in selected countries ($kg\,m^{-2}\,y^{-1}$)

| | Natural | Cultivated | Bare soil |
|---|---|---|---|
| China | < 0.20 | 15.00–20.00 | 28.00–36.00 |
| USA | 0.003–0.30 | 0.50–17.00 | 0.40– 9.00 |
| Ivory Coast | 0.003–0.02 | 0.01– 9.00 | 1.00–75.00 |
| Nigeria | 0.05 –0.10 | 0.01– 3.50 | 0.30–15.00 |
| India | 0.05 –0.10 | 0.03– 2.00 | 1.00– 2.00 |
| Belgium | 0.01 –0.05 | 0.30– 3.00 | 0.70– 8.20 |
| UK | 0.01 –0.05 | 0.01– 0.30 | 1.00– 4.50 |

*Sources*: Bollinne, 1978; Browning, Norton, McCall and Bell, 1948; Fournier, 1972; Jiang, Qi and Tan, 1981; Lal, 1976; Morgan, 1981a; Rao, 1981; Roose, 1971.

Source: Morgan 1986

Table 3-6

Table 1.5: TOTAL ESTIMATED ANNUAL COSTS OF SOIL EROSION ON JAVA (US$ million)

| | West Java | Central Java | Yogyakarta | East Java | Java |
|---|---|---|---|---|---|
| On-Site | 141.5 | 29.1 | 5.7 | 138.6 | 315.0 |
| Off-Site | | | | | |
| Irrigation System Siltation | 1.7-5.7 | 0.8-2.7 | 0.1-0.5 | 1.2-4.0 | 7.9-12.9 |
| Harbor Dredging (1984/85) | 0.4-0.9 | 0.1-0.3 | - | 0.9-2.2 | 1.4-3.4 |
| Reservoir Sedimentation | 9.0-41.3 | 3.5-16.3 | - | 3.8-17.3 | 16,3-74.9 |
| Total | 152.6-189.4 | 33.5-48.4 | 5.8-6.2 | 144.5-162.1 | 340.6-406.2 |

Source: World Bank (1989a).

Doolette/Magrath 1990

Table 3-7

PESTICIDE IMPACT ON THE ENVIRONMENT 431

Table 12-1. Relation of physicochemical properties to environmental behavior.

| Physical chemical data | Related to |
|---|---|
| Solubility in water | Leaching, degree of adsorption, mobility in environment, and uptake by plants |
| Partition coefficient | Bioaccumulation potential, and adsorption by organic matter |
| Hydrolysis | Persistence in environment or biota |
| Ionization | Route and mechanism of adsorption or uptake, persistence, and interaction with other molecular species |
| Vapor pressure | Atmospheric mobility, and rate of vaporization |
| Reactivity | Metabolism, microbiological, and photochemical and autochemical degradation |

Source: Madhun/Freed in: Cheng ed. 1990

Table 3-8

Table 2-1. Pesticide sources and environmental exposure pathways.

| Pesticide source | Transport process | Exposure pathway | Receptor (Population at risk) |
|---|---|---|---|
| Canopy | Volatilization | Inhalation/skin contact | Human, animals |
| Crop residue | Volatilization | Inhalation/skin contact | Human, animals |
| Soil surface | Volatilization | Inhalation/skin contact | Human, animals |
| Root zone and below | Volatilization | Inhalation/skin contact | Human, animals |
| Grain/foliage | Manufacturing/feeding† | Food/ingestion | Human, animals |
| Crop residue | Overland flow† | Surface water (potable water)/ingestiou | Human, fish |
| Runoff | Overland flow† | Surface water (potable water and food chain) | Human, fish |
| Eroded soil particles and formulation—bound | Overland flow† | Ingestion surface water (food chain)/ingestion, contact | Fish |
| Leachate-dissolved-bound on colloidal particles | Leaching/percolation† | Groundwater (potable water)/ingestion | Human, animals |

† Environmental flux of concern to either on-site or off-site receptors. After Bailey et al. (1985).

Source: Himel et al. in Cheng ed. 1990

**Table 3-9**

Table 14-1. Status of knowledge concerning pesticide fate processes.

I. Transformation processes
- A. Sorption
  - 1. Hydrophobic pesticides
    - Causative factors known
    - Sorbate—hydrophobic, low water solubility
    - Sorbent—organic matter content
    - Predictor—$K_{oc}$ or $K_{ow}$ × fraction of organic matter; well-tested relationship
    - Isotherm behavior—variable—reversible or irreversible, linear or nonlinear
    - Desorption—kinetically controlled
  - 2. Hydrophilic pesticides
    - Causative factors not well known
    - Sorbate—acidic in character, pKa
    - Basic in character, pKb
    - Ionic
    - Sorbent—not well known
    - Lewis acid-base character or complexation capability
    - Predictor—prototype, not tested
    - Desorption—not well understood
- B. Microbial transformations
  - 1. Hydrophobic and hydrophilic pesticides in an oxidizing environment
    - Causative factors known—temperature, pH, nutrient, and moisture content
    - Mechanisms known for major families
    - Transformation products known (their environmental behavior not well characterized)
    - Organism specificity—essentially known
    - Kinetics—well known
  - 2. Hydrophobic and hydrophilic pesticides in an anaerobic environment
    - Causative factors—Eh, pH, $O_2$ nutrient content—not well known
    - Redox chemistry not well understood
    - Kinetics—not well defined
    - Organism specificity—not well known
- C. Chemical transformations
  - 1. Hydrophobic and hydrophilic pesticides in an oxidizing environment
    - Structure-reactivity relationships fairly well known
    - Causative factors—pH, temperature, ionic strength—well known
    - Surface catalytic properties of heterogeneous media surfaces—early definitive stage
    - Mechanisms—hydrolysis, (acid, base, and neutral) substitution, elimination, and ring cleavage—well known
    - Kinetics—generally well known
    - Products—generally well known
  - 2. Hydrophilic and hydrophobic pesticides in an anaerobic environment
    - Causative factors not well known
    - Mechanisms—early definitive stage
    - Kinetics—not well known
    - Products—not well known
- D. Photolysis
  - 1. Water
    - Causative factors—fairly well known
    - Role of Fe, Mn, and DOC content currently being defined
    - Mechanisms—known for major families
    - Predictor—prototype available
  - 2. Soil surface
    - Causative factors, pathways, mechanisms, known, research in its infancy
  - 3. Foliar or crop residue surface
    - Similar stage as photolysis on soil surface
    - Effect of leaf morphology and biochemical character on process not defined
- E. Bioaccumulation/biomagnification
  - Causative factors not entirely known
  - Data on hydrophobic pesticide bioaccumulation/magnification known
  - Predictor—first-generation pharmacokinetic prototype available for fish

II. Transport processes
- A. Volatilization
  - 1. Soil surface
    - Causative factors—vapor density, soil matrix properties, and meteorological conditions—well known
    - Predictors—screening level simulation models available
  - 2. Foliar surface
    - Causative factors not well known
    - Predictor—not available
- B. Drift
  - Causative factors—partially known
  - Predictor—simulation models
- C. Erosion/pesticide overland flow
  - Causative factors—generally well known for solution and sediment-bound pesticides
  - Predictor—simulation models available
- D. Washoff
  - Causative factors—partially known
  - Predictor—prototype model available
- E. Infiltration
  - Causative factors—known
  - Predictor—equations available
- F. Percolation and leaching in subsoil
  - Causative factors—generally known except for spatial variability of soil properties
  - Predictor—coupled advective/dispersion model with linear or nonlinear/reversible or irreversible sorptive algorithms are available. Generally, not well tested. Transfer function model available but not well tested.
- G. Groundwater/pesticide transport in aquifer
  - Causative factors not well-defined
  - Predictor—1, 2, and 3D models available, not widely tested
- H. Aeolian pickup and transport
  - Causative factors generally known
  - Applicable pesticides—sorbed pesticide
  - Predictor—models available, but in question and being re-evaluated

**Source: Bailey in Cheng ed. 1990**

## Table 3-10

Table 2. Effects of Salts on Adsorption of Herbicides by Soils and Soil Components[a]

| Adsorbent | Herbicide | Salt effect: Ionic strength <1 | Salt effect: Ionic strength >1 | Experimental conditions | |
|---|---|---|---|---|---|
| Montmorillonite Na | Fenuron | –[b] | + | NaCl | |
| Montmorillonite Na | Fenuron | 0 or – | + | NaCl | |
| Montmorillonite Mg | Monuron | | | $MgCl_2$ | Identical concentrations |
| Montmorillonite Ca | | | | $CaCl_2$ | |
| Soils | Terbutryne | – | + | NaCl | Identical ionic strength |
| | Atrazine | | | KCl | |
| | | | | $CaCl_2$ | |
| Goethite | 2,4-D | – | + | NaCl | |
| Soils | 1,3,5-triazines | + | | KCl | Identical ionic strength |
| | Substituted ureas | | | $NH_4Cl$ | |
| | | | | $CaCl_2$ | |
| Soils | Picloram | + | | KCl | Identical concentrations |
| | | | | $CaCl_2$ | |
| Soils | Prometryn | + | | NaCl | Identical concentrations |
| | Fluometuron | – | | $CaCl_2$ | |

[a] After Calvet (1980).
[b] 0 = no effect; – = the adsorption decreases as the ionic strength increases; + = the adsorption increases with the ionic strength.

## Table 3-11

Table 1. Effect of the Temperature on the Adsorption of Herbicides by Organic Materials, Minerals, and Soils[a]

| Adsorbent | Herbicide | Effect of temperature |
|---|---|---|
| Montmorillonite (pH 8.5) | Simazine | –[b] |
| Illite | 2,4-D | – |
| Montmorillonite | 2,4-D | 0 |
| Montmorillonite Na | Paraquat | 0 |
| Vermiculite Na | Paraquat | + |
| Peat | Monuron | 0 |
| | Simazine | 0 |
| | Atrazine | 0 |
| | 2,4-D | 0 |
| Humic acid | Atrazine | + |
| Humic acid Lignin | Atrazine | + |
| Humic acid | Atrazine | + |
| Charcoal | Prometon | 0 |
| | 2,4-D | – |
| Soils | 1,3,5,-triazines | – |
| Soils | Alachlor | – |
| Soils | Picloram | – |
| Soils | 12 dinitroanilines | – |

[a] After Calvet (1980).
[b] 0 = no effect; – = adsorption decreases as temperature increases; + = adsorption increases with temperature.



## Table 3-12

Table 7. Half-Life (Days) of Some Paddy Herbicides in Flooded Soils[a]

| Herbicide | In laboratory experiments[b] | In paddy fields[c] |
|---|---|---|
| 2,4-D | 30–40 | 33, 48 |
| 2,4-D ethyl | <1 hr | |
| MCPA | 3, 4, 7, 7, 15, 20 | 7, – |
| MCPA ethyl | 7–14 | |
| Phenothiol | <1 | .5 |
| Dalapon | 3–5, 14–21 | 10–15, 20–31 |
| PCP | 5, 10–17, 12–70 (mean 30), 60 | 3–10, 6–7, 10–17 |
| Benthiocarb | 7–100 (mean 40) | 3–8, 7, 8, 11, 62 |
| Molinate | 7, 15, 18, 30 | <1, <5, <5, <5, <9, 11 |
| Swep | 2–9, 10–11, 7–14 | <10 |
| Propanil | <1–1, 1, 5 | <1–1 |
| Naproanilide | 5, 6 | 2, <4, 4 |
| Napropamide | 49, 56 | <20, 20 |
| Butachlor | 9–30 | 6, 8 |
| Credazine | 90–150 | 22, 45 |
| Trifluralin | 9, 10, 22, 45 | 10, 45 |
| Nitrofen | 3–35 (mean 11) | ~14 |
| Chlornitrofen | 7–35 (mean 15), 17, 35 | 7, 9, 12, 13, ~14 |
| Chlomethoxynil | 7–35 (mean 15), 30 | 7–8 |
| Bifenox | 4, 4 | 4, 4 |
| Oxadiazon | 75, 93–98 | |
| Bentazone | 5, 33, 45 | 15, 15 |
| Simetryn | <37, 63 | |
| Prometryne | 100, 120 | |
| Paraquat | >180 | >180 |
| Diquat | >150 | |

[a] Data collected from various sources; after Crosby, 1983.
[b] Each chemical was mixed with soil and incubated at 25 to 30°C in dark.
[c] Persistence in soils in paddy rice fields in Japan. Most herbicides were applied in May or June.

## Table 3-13



Table 8. Fate of Molinate When Applied in Paddy Soils[a]

| Process | Estimated loss (%) |
|---|---|
| Soil adsorption and metabolism | <10 |
| Plant uptake and metabolism | < 5 |
| Aqueous microbial metabolism | < 1 |
| Hydrolysis | < 1 |
| Photolysis | 5–10 |
| Volatilization to atmosphere | 75–85 |

[a] After Crosby (1983).

Sources: Yaron et al. 1985

Table 3-14



Tab. 2.7.3/4: Mittlere Gehalte (mg/kg) einiger Mikro-Nährelemente und potentiell toxischer Elemente in Gesteinen (n. WEDEPOHL 1984, Lockersedimente n. BLUME, BRÜMMER 1984)

| | As | Be | Bi | Cd | Co | Cr | Cu | Hg | Mn | Mo | Ni | Pb | Se | Sn | Tl | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kontinentale Kruste | 3.4 | 2.9 | .08 | .10 | 19 | 88 | 35 | .02 | 800 | 1.5 | 45 | 15 | .08 | 2.5 | .49 | 109 | 69 |
| Ultrabas. Gesteine | 1 | | | .05 | 150 | 1 600 | 10 | .03 | 1 600 | 0.3 | 2 000 | 1 | | 0.5 | .06 | 40 | 50 |
| Basalte, Gabbro | 1.5 | 0.6 | .04 | .10 | 48 | 168 | 90 | .02 | 1 390 | 1 | 134 | 3.5 | .09 | 1.5 | .08 | 251 | 100 |
| Gneise, Glimmersch. | 4.3 | 3.8 | .10 | .10 | 13 | 76 | 23 | .02 | 600 | (1.5) | 26 | 16 | .08 | 2.5 | .65 | 60 | 65 |
| Granit, Gesteine | 1.5 | 5.5 | .19 | .09 | 4 | 12 | 13 | .03 | 325 | 1.8 | 7 | 32 | .04 | 3.5 | 1.1 | 94 | 50 |
| Grauwacken | 8 | 3 | .07 | .09 | 20 | 50 | 45 | .11 | 750 | 0.7 | 40 | 14 | 0.1 | (3) | .20 | 67 | 105 |
| Tonsteine | 10 | 3 | .13 | .13 | 19 | 90 | 45 | .45 | 850 | 1.3 | 68 | 22 | 0.5 | 2.5 | .68 | 130 | 95 |
| Kalke | 2.5 | (0.5) | .02 | .16 | 2 | 11 | 4 | .03 | 700 | 0.4 | 15 | 5 | .19 | (.2) | .05 | 20 | 23 |
| Sandsteine | 1 | | | .05 | 0.3 | 35 | 5 | .03 | 50 | 0.2 | 2 | 7 | | | .08 | | 15 |
| Löß | 6.5 | | | (.2) | 9 | 67 | 15 | .02 | 300 | 1.2 | 28 | 34 | | 1.8 | | 64 | 53 |
| Geschiebemergel | 8 | | | 0.3 | 7 | 35 | 15 | .04 | 400 | 1 | 18 | 20 | | 3.4 | | 29 | 40 |
| Meerschlick | 11 | | | 0.3 | 8 | | 15 | .01 | 460 | | 22 | 43 | | | | | 96 |
| Sande | 1.3 | | | 0.1 | | 1.5 | < 3 | < .01 | 46 | 1 | 5 | 10 | | 3 | | 3.3 | 11 |

( ) wenige Daten

Table 3-15



Tab. 2.7.3/6: Natürliche und anthropogene Quellen der atmosphärischen Belastung, Angaben in $10^8$ g/a (nach LANTZY und MCKENZIE 1979, aus MERIAN 1984)

| | natürlich | | | anthropogen | | | |
|---|---|---|---|---|---|---|---|
| Element | Kontinent. Staub Fracht | Vulkan Staub Fracht | Vulkan Gas Fracht | Indust. Partikel Emission | Fracht d. foss. Brennstoffe | gesamte anthrop. Emission | Atmosph. Interferenz-faktor[1]) |
| Al | 356 500 | 132 700 | 8.4 | 40 000 | 32 000 | 72 000 | 15 |
| Ti | 23 000 | 12 000 | – | 3 600 | 1 600 | 5 200 | 15 |
| Sm | 32 | 9 | – | 7 | 5 | 12 | 29 |
| Fe | 190 000 | 87 750 | 3.7 | 75 000 | 32 000 | 107 000 | 39 |
| Mn | 4 250 | 1 800 | 2.1 | 3 000 | 160 | 3 160 | 32 |
| Co | 40 | 30 | 0.04 | 24 | 20 | 44 | 63 |
| Cr | 500 | 84 | 0.005 | 650 | 290 | 940 | 161 |
| V | 500 | 150 | 0.05 | 1 000 | 1 100 | 2 100 | 323 |
| Ni | 200 | 83 | 0.0009 | 600 | 380 | 980 | 346 |
| Sn | 50 | 2.4 | 0.005 | 400 | 30 | 430 | 821 |
| Cu | 100 | 93 | 0.012 | 2 200 | 450 | 2 630 | 1 363 |
| Cd | 2.5 | 0.4 | 0.01 | 40 | 15 | 55 | 1 897 |
| Zn | 250 | 108 | 0.14 | 7 000 | 1 400 | 8 400 | 2 346 |
| As | 25 | 3 | 0.1 | 620 | 160 | 780 | 2 786 |
| Se | 3 | 1 | 0.13 | 50 | 90 | 140 | 3 390 |
| Sb | 9.5 | 0.3 | 0.013 | 200 | 180 | 380 | 3 878 |
| Mo | 10 | 1.4 | 0.02 | 100 | 410 | 510 | 4 474 |
| Ag | 0.5 | 0.1 | 0.0001 | 40 | 10 | 50 | 8 333 |
| Hg | 0.3 | 0.1 | 0.001 | 50 | 60 | 110 | 27 500 |
| Pb | 50 | 8.7 | 0.012 | 16 000 | 4 300 | 20 300 | 34 583 |

[1]) $\text{Interferenzfaktor} = \frac{\text{totale anthropogene Emission}}{\text{totale natürliche Emission}}$

Sources: Blume ed. 1992

Table 3-16

Tab. 2.7.3/17: Physiologische Notwendigkeit und potentielle Toxizität für Pflanzen und Tiere (n. ADRIANO 1986).

| | Ernährungs-physiologisch essentiell bzw. nützlich | | Potentiell toxisch für | | Bemerkung |
|---|---|---|---|---|---|
| Element | Pflanze | Tiere | Pflanze | Tiere | |
| Ag | – | – | | + | |
| As | – | + | + | + | Wirkt bei Pflanzen in geringeren Konz. toxisch als bei Tieren |
| B | + | – | + | | |
| Ba | – | ? | | | |
| Be | – | – | + | + | Bindungsformen wichtig |
| Bi | – | – | + | + | |
| Cd | – | – | + | + | Bereits in geringen Konz. toxisch, Anreicherung über Nahrungsketten |
| Co | + | + | + | + | relativ ungiftig, starke Anreicherung über Nahrungsketten |
| Cr | – | + | + | | Bindungsformen entscheidend für Toxizität $Cr^{VI}$ sehr giftig |
| Cu | + | + | + | | Org.-komplexe Bindung in Böden |
| Hg | – | – | | + | Anreicherung über Nahrungsketten |
| Mn | + | + | | | Löslichkeit im Boden stark Redoxabhängig |
| Mo | + | + | | + | In Pflanzen stark angereichert, bereits in geringem Überschuß für Tiere toxisch |
| Ni | – | + | + | + | Sehr mobil in Pflanzen, relativ ungiftig |
| Pb | – | – | + | + | Weit verbreitet über die Atmosphäre |
| Sb | – | – | | + | Relativ unlöslich |
| Se | + | + | + | + | Bereits in geringem Überschuß für Tiere toxisch, synergistische, antagonistische Wirkungen mit anderen Spurenelementen |
| Sn | – | + | | + | Relativ ungiftig, geringe Pflanzenaufnahme |
| Tl | – | – | | – | Sehr mobil in Pflanzen |
| V | + | + | | + | Bereits in geringem Überschuß toxisch |
| W | – | – | | | Geringe Gehalte in Boden und Pflanzen, unlöslich |
| Zn | + | + | | | Weite Spanne zwischen Pflanzenbedarf u. Toxizität. Für Tiere besteht oft Mangel |

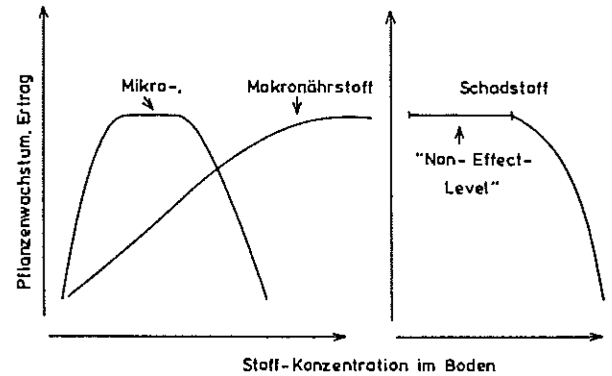



Abb. 2.7.3/10: Einfluß der Konzentration von Mikro- und Makronährstoffen sowie Schadstoffen auf Pflanzenwachstum und Ertrag (schematische Darstellung, n. BRÜMMER 1989)

Source: Blume ed. 1992

Table 3-17 a

Tab. 2.7.3/18: Transferkoeffizient Boden-Pflanze, normale Gehalte in Böden, normale und kritische Konzentrationen von Schwermetallen im Pflanzenmaterial (Bezug auf T.S.) (aus SAUERBECK 1985, n. KLOKE et al. 1984; ergänzt).

| Element | normal in Böden mg/kg | Grenzw.[1]) in Böden mg/kg | Transfer-Koeffizient Boden-Pflanze | normal in Pflanzen | krit. für Pflanzenwuchs | krit. als Tierfutter |
|---|---|---|---|---|---|---|
| Cd | 0.01 – 0.7 | 3 | 1 – 10 | < 0.1 – 1 | 5 – 10 | 0.5 – 1 |
| Co | 1 – 10 | (50) | 0.01 – 0.1 | 0.01 – 0.5 | 10 – 20 | 10 – 50 |
| Cr | 2 – 50 | 100 | 0.01 – 0.1 | < 0.1 – 1 | 1 – 2 | 50 – 3 000 |
| Cu | 1 – 40 | 100 | 0.1 – 1 | 3 – 15 | 15 – 20 | 30 – 100 |
| Hg | 0.01 – 0.5 | 2 | 0.01 – 0.1 | < 0.1 – 0.5 | 0.5 – 1 | > 1 |
| Ni | 2 – 50 | 50 | 0.1 – 1 | 0.1 – 5 | 20 – 30 | 50 – 60 |
| Pb | 0.1 – 20 | 100 | 0.01 – 0.1 | 1 – 5 | 10 – 20 | 10 – 30 |
| Tl | 0.01 – 0.5 | (1) | 1 – 10 | < 0.5 – 5 | 20 – 30 | 1 – 5 |
| Zn | 3 – 50 | 300 | 1 – 10 | 15 – 150 | 150 – 200 | 300 – 1 000 |
| As | 0.1 – 20 | (20) | 0.01 – 0.1 | < 0.1 – 5 | 10 – 20 | > 50 |
| B | 3 – 100 | (25) | 1 – 10 | 5 – 30 | > 75 | 150 |
| Be | 0.2 – 40 | | 0.01 – 0.1 | 0.01 – 0.5 | > 1 | ? |
| F | 20 – 400 | (200) | 0.01 – 0.1 | 1 – 5 | > 50 | 40 – 200 |
| Mo | 0.2 – 5 | | 0.1 – 10 | 0.1 – 3 | > 100 | 10 – 58 |
| Se | 0.01 – 5 | (5) | 0.1 – 10 | 0.1 – 2 | 10 – 20 | 4 – 5 |
| Sn | 1 – 20 | | 0.01 – 0.1 | ? | > 60 | ? |
| V | 0.01 – 200 | | 0.1 – 1 | 0.1 – 1 | 10 | 10 – 50 |

[1]) Grenzwerte der Klärschlammverordnung; ( ) in Diskussion

Table 3-17 b



Tab. 2.7.3/21: Schwermetallgehalte von belastungsgefährdeten Böden Nordrhein-Westfalens im Einflußbereich verschiedener Belastungsursachen (Angaben in mg/kg Boden, Erklärung teilweise im Text, n. KÖNIG und KRÄMER 1985).

| Element | Grundbelastung | Normalgehalte[1]) | Klärschlamm | Straßen | Emission (Rhein-Ruhrgebiet) | Überschwemmung | Erzabbau | Grenzwerte[2]) |
|---|---|---|---|---|---|---|---|---|
| Cd | 0.8 | 0 – 1 | 0.8 | 0.9 | 1.4 | 2.7 | 3.7 | 3 |
| Zn | 110 | 0 – 50 | 120 | 160 | 250 | 480 | 610 | 300 |
| Pb | 50 | 0 – 20 | 40 | 65 | 70 | 150 | 810 | 100 |
| Cu | 20 | 0 – 20 | 35 | 18 | 40 | 75 | 30 | 100 |
| Cr | 30 | 0 – 50 | 70 | 30 | 35 | 60 | 30 | 100 |
| Hg | 0.30 | 0 – 1 | 0.25 | 0.35 | 0.35 | 1.10 | 0.43 | 2 |
| Ni | 50 | 0 – 50 | 23 | 17 | 21 | 39 | 25 | 50 |

[1]) Normalgehalte nach KLOKE (1980) [2]) Grenzwerte der Klärschlammverordnung

Table 3-18

Tab. 2.7.3/19: Relative Akkumulation von Schwermetallen in eßbaren Pflanzenteilen verschiedener Obst- und Gemüsearten (n. BERGMANN 1988)

| Akkumulation hoch | mittel | niedrig | sehr niedrig |
|---|---|---|---|
| Salat (*Lactuca sativa*)<br>Spinat (*Spinacia oler.*)<br>Mangold (Beta vulgaris var.*cicla*)<br>Endivie (*Cichorium endivia*)<br>Kresse (*Lepidium latifol.*)<br>Möhren (*Daucus carota*) | Grünkohl (*Brassica oler.* var. *acephala*)<br>Kohl (*Brassica oler.*)<br>Rote Rüben (*Beta vulg. conditiva*)<br>Steckrüben (*Brassica rapa*)<br>Rettich (*Raphanus sativus*)<br>Kartoffel (*Solanum tuberosum*) | Kopfkohl (*Brassica oler.*)<br>Zuckermais (*Zea mays*)<br>Broccoli (*Brassica oler. italica*)<br>Blumenkohl (*Brassica oler.* var. *botrytis*)<br>Rosenkohl (*Brassica oler. gemmifera*)<br>Sellerie (*Apium graveolens*)<br>Beerenfrüchte | Bohnen (*Phaseolus*)<br>Erbsen (*Pisum sativum*)<br>Melonen (*Cucumis melo*)<br>Tomaten (*Lycopersicum esculentum*)<br>Paprika (*Capsicum annuum*)<br>Eierfrüchte (*Solanum melongena*)<br>Kernobst, Steinobst |

Sources: Blume ed. 1992

## Table 3-19

Tab. 2.8.4/2: Wasserqualitätsvergleiche (in mg/l) nach AUTORENKOLLEKTIV, 1972; VEH u. EDOM, 1981; BAUMANN et al., 1976; GTZ, 1984

| Stoffe | Trinkwasser | Abwasser häuslich | Kanaleinleitung | Landw. Ansprüche |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| $KMnO_4$-Verbr. | 0 – 12 | 500 – 1 450 | – | 12 – 4 000 |
| $BSB_5$ | 0 – 4 | 200 – 400 | 500 | 25 – 50 |
| Leitf. $\mu S \times cm^{-1}$ | 100 – 400 | 1 800 – 4 200 | – | 750 – 3 000 |
| Salzkonz. | 50 – 250 | 1 200 – 2 700 | – | 500 – 1 900 |
| Reaktion, pH | 6.5 – 8.5 | 7.8 – 8.6 | 6.5 – 10.0 | 5 – 8 |
| Gesamt-Rückst. | 100 – 1 000 | 500 – 1 400 | – | 5 000 |
| Glühverlust | 5 – 65 | 200 – 1 000 | – | * |
| Org.geb. Kohlenst. | 5 – 40 | 50 – 420 | – | * |
| Kjeldahl-N | 0 – 15 | 4 – 50 | – | * |
| Mineral.-N | 5 – 10 | 5 – 55 | – | * |
| Gesamt-P | 0.01 – 1.5 | 10 – 50 | – | * |
| Phosphat-P | 0.001 – 0.1 | 1 – 15 | – | * |
| Nitrat-N | 0 – 20 | 0.2 – 20 | – | 1 – 10 |
| Nitrit-N | 0 – 0.06 | 0.05 – 0.1 | 6 | 1 |
| Ammonium-N | 0 – 0.4 | 5 – 50 | 80 | 25 – 120 |
| Chlorid | 0 – 250 | 100 – 1 000 | 500 | 140 – 350 |
| Sulfat | 0 – 150 | 50 – 150 | 300 – 600 | 300 |
| Hydrogencarbonat | 1 – 100 | 1 200 | – | 2 – 10 |
| Natrium | 10 – 50 | 50 – 450 | – | 20 – 50 |
| Kalium | 2 – 10 | 10 – 80 | – | * |
| Calzium | 15 – 70 | 30 – 80 | – | * |
| Magnesium | 0 – 60 | 10 – 20 | – | * |
| Eisen | 0 – 0.20 | 0.1 – 0.7 | 5 | 2 – 20 |
| Sauerstoff | 6 – 12 | 0 – 5 | – | Sättigung |
| Ges. Härte, mmol $l^{-1}$ | 0.4 – 5.5 | 2 – 10 | – | * |
| Carb.-Härte mmol $l^{-1}$ | 0.4 – 2.2 | 3.9 – 7.6 | – | * |
| Kohlendioxid | 1 | – | – | – |
| Cyanide | 0.05 | 0.01 – 0.05 | 0.1 – 20.0 | 0.05 – 1.0 |
| Chrom III | 0.05 | 0.025 – 0.05 | 3 | 0.01 – 1.0 |
| Chrom VI | – | – | 0.5 | – |
| Zink | 0 – 15 | 5 – 15 | 5 | 1 – 10 |
| Kupfer | 0 – 1.5 | 0.1 – 1.0 | 2 | 0.2 – 5.0 |
| Cadmium | 0 – 0.006 | 0.005 – 0.01 | 0.5 | 0.1 – 1.0 |
| Arsen | 0 – 0.2 | 0.01 – 0.05 | 1 | 0.1 – 2.0 |
| Sulfit-Schwefel | 0 – 0.05 | 0.05 – 0.1 | 2 – 5 | – |
| Aktives Chlor | 0 – 0.3 | – | 5 | 0.3 – 1.0 |
| Gesamt-Phenol | 0 – 0.001 | 0.002 – 0.5 | 50 – 100 | 5 – 250 |
| Teer | 0 | 0 | 10 | – |
| Fette, Öle | 0 | 20 – 40 | 250 | 5 – 10 |
| Waschakt. Sub. | 0 | 0.5 – 10 | 10 | 50 – 200 |
| Lösungsmittel | 0 | – | 1 | – |
| Aluminium | 0 – 0.05 | – | = | 5 – 20 |
| Blei | 0 – 0.3 | 0.05 – 0.2 | 2 | 0.5 – 10 |
| Fluoride | 0 – 1.5 | 2 – 20 | 60 | 1 – 15 |
| Quecksilber | 0 – 0.004 | 0 – 0.05 | 0.05 | 0.001 – 0.02 |
| Selen | 0 – 0.008 | 0 – 0.005 | 1 | 0.001 – 0.02 |
| Nickel | 0 – 0.05 | 0 – 0.02 | 4 | 0.2 – 2.0 |
| Antimon | 0 – 0.01 | – | – | – |
| Barium | 0 – 0.1 | – | – | 1 – 4 |
| Silber | 0 – 0.01 | – | – | – |
| Mangan | 0 – 0.1 | 0 – 0.05 | – | 0.5 – 10 |
| Bor | – | 1 | – | 1 – 2 |
| Beryllium | – | – | – | 0.1 – 0.5 |
| Kobalt | – | – | – | 0.2 – 5.0 |
| Lithium | – | – | – | 2.5 – 5.0 |
| Molybdän | – | 0 – 0.005 | – | 0.01 – 0.05 |
| Vanadium | – | – | – | 0.1 – 1.0 |
| Zinn | – | – | 5 | – |
| Urochrome | 0 – 0.2 | 20 – 60 | 50 | – |

Legende: Spalte 2: Streubreite aktueller Trinkwasserqualität Europas
Spalte 3: Abwasserqualität der Bundesrepublik Deutschland
Spalte 4: Angaben zur Einleitung i.d. öffentliche Kanalnetz
Spalte 5: Angaben f.d. landw. Abwasserverwertung
– = keine Angaben i.d. Literatur = = keine Begrenzung f.d. Stoff
* = Pflanzennährstoff, Bodenverbesserung, hohe Konz. erwünscht

Source: Blume ed. 1990

## Table 3-20 a

**Wastewater agricultural nutrients**

| Nutrients | kg/1,000m³ |
|---|---|
| N | 50 |
| P | 10 |
| K | 30 |

mg/l ≙ g/m³
50 ≙ 600
10
30

Source: Shuval et al. 1986

## Table 3-20 b

**Table 2.4** Typical properties of primary effluents (Thomas and Law 1977)

| Constituent | Concentration | |
|---|---|---|
| | Range | Median |
| | mg/l | |
| *Solids* | | |
| Total dissolved | 200–1500 | 500 |
| Total suspended | 50–150 | 100 |
| BOD | 65–200 | 135 |
| COD | 150–750 | 335 |
| *Nitrogen* | | |
| Total | 10–60 | 40 |
| Free ammonia | 7–40 | 30 |
| Nitrate | — | <0.1 |
| Phosphorus, total | 5–17 | 8 |

Source: Feigin et al 1991

Table 3-21 a

**Table 2.2** Concentration of trace elements in raw and treated municipal effluents and the permissible level in irrigation water[a] and upper limit for drinking water for livestock[b]

| Element | Raw wastewater | | Primary effluent | | Secondary effluent | | Water quality criteria for irrigation[c] | | Upper limit for drinking water (livestock) |
|---|---|---|---|---|---|---|---|---|---|
| | Range | Median | Range | Median | Range | Median | Long-term | Short-term[d] | |
| | mg/l | | | | | | | | |
| Aluminium (Al) | — | — | — | — | — | — | 5.0 | — | 5.0 |
| Arsenic (As) | < 0.0003–1.9 | 0.085 | < 0.005–0.03 | < 0.005 | < 0.005–0.023 | < 0.005 | 0.1 | 10.0 | 0.2 |
| Beryllium (Be) | — | — | — | — | — | — | 0.1 | — | 0.1 |
| Boron (B) | < 0.123–20.0 | — | < 0.01–2.5 | 1.0 | < 0.1–2.5 | 0.7 | 0.75 | 2.0 | 5.0 |
| Cadmium (Cd) | < 0.0012–2.1 | 0.024 | < 0.02–6.4 | < 0.02 | < 0.005–0.15 | < 0.005 | 0.01 | 0.05 | 0.05 |
| Chromium (Cr) | < 0.0008–83.3 | 0.400 | < 0.05–6.8 | < 0.05 | < 0.005–1.2 | 0.02 | 0.1 | 20.0 | 1.0 |
| Cobalt (Co) | — | — | — | — | — | — | 0.05 | — | 1.0 |
| Copper (Cu) | < 0.0001–36.5 | 0.420 | < 0.02–5.9 | 0.10 | < 0.006–1.3 | 0.04 | 0.20 | 5.0 | 0.5 |
| Fluorine (F) | — | — | — | — | — | — | 1.0 | — | 2.0 |
| Iron (Fe) | — | — | — | — | — | — | 5.0 | — | Not needed |
| Lead (Pb) | 0.001–11.6 | 0.120 | < 0.02–6.0 | < 0.2 | 0.003–0.35 | 0.008 | 5.0 | 20.0 | 0.1 |
| Lithium (Li) | — | — | — | — | — | — | 2.5 | — | — |
| Manganese (Mn) | — | — | — | — | — | — | 0.2 | — | 0.05 |
| Mercury (Hg) | < 0.0001–3.0 | 0.110 | 0.0001–0.125 | 0.0009 | < 0.0002–0.001 | 0.0005 | — | — | 0.01 |
| Molybdenum (Mo) | < 0.0011–0.9 | — | < 0.001–0.02 | 0.007 | 0.001–0.0018 | 0.007 | 0.01 | 0.05 | — |
| Nickel (Ni) | 0.002–111.4 | 0.230 | < 0.1–1.5 | < 0.1 | 0.003–0.6 | 0.004 | 0.2 | 2.0 | — |
| Selenium (Se) | < 0.002–10.0 | 0.041 | < 0.005–0.02 | < 0.005 | < 0.005–0.02 | < 0.005 | 0.02 | 0.05 | 0.05 |
| Vanadium (V) | — | — | — | — | — | — | 0.1 | — | 0.1 |
| Zinc (Zn) | < 0.001–28.7 | 0.52 | < 0.02–2.0 | 0.12 | 0.004–1.2 | 0.04 | 2.0 | 10.0 | 24.0 |

[a]Chang and Page (1983); Page and Chang (1985).
[b]Ayers and Westcot (1985).
[c]The maximum concentration is based on a water application rate of 1200 mm/yr. In cases of higher rates, the maximum concentration should be adjusted accordingly.
[d]For use on fine-textured soils.



Table 3-21 b

**Table 3.16** Range in concentrations of selected trace elements in dry digested sewage sludges[a] (Chaney 1989)

| Element[b] | Reported range Minimum | Maximum | Typical median sludge | Typical soil | Maximum domestic sludge |
|---|---|---|---|---|---|
| As | 1.1 | 230 | 10 | — | — |
| Cd | 1 | 3410 | 10 | 0.1 | 25 |
| Cd/Zn, % | 0.1 | 110 | 0.8 | — | 1.5 |
| Co | 11.3 | 2490 | 30 | — | 200 |
| Cu | 84 | 17 000 | 800 | 15 | 1000 |
| Cr | 10 | 99 000 | 500 | 25 | 1000 |
| F | 80 | 33 500 | 260 | 200 | 1000 |
| Fe, % | 0.1 | 15.4 | 1.7 | 2.0 | 4.0 |
| Hg | 0.6 | 56 | 6 | — | 10 |
| Mn | 32 | 9870 | 260 | 500 | — |
| Mo | 0.1 | 3700 | 20 | — | 35 |
| Ni | 2 | 5300 | 80 | 25 | 200 |
| Pb[c] | 13 | 26 000 | 250 | 15 | 500 |
| Sn | 2.6 | 329 | 14 | — | — |
| Se | 1.7 | 17.2 | 5 | — | — |
| Zn | 101 | 49 000 | 1700 | 50 | 2500 |

[a]Composting using wood chips as a bulking agent generally produces composted sludge 50% as high in trace elements as a digested sludge from the same treatment plant.
[b]mg/kg unless otherwise noted.
[c]Sludge Pb concentration has dropped significantly during the 1980's in the USA due to reduction of leaded gasoline.

Sources: Feigin et al. 1991

Table 3-22 a



Tab. 2.7.3/18: Transferkoeffizient Boden-Pflanze, normale Gehalte in Böden, normale und kritische Konzentrationen von Schwermetallen im Pflanzenmaterial (Bezug auf T.S.) (aus SAUERBECK 1985, n. KLOKE et al. 1984; ergänzt).

| Element | normal in Böden mg/kg | Grenzw.[1] in Böden mg/kg | Transfer-Koeffizient Boden-Pflanze | normal in Pflanzen | krit. für Pflanzenwuchs | krit. als Tierfutter |
|---|---|---|---|---|---|---|
| Cd | 0.01 – 0.7 | 3 | 1 – 10 | < 0.1 – 1 | 5 – 10 | 0.5 – 1 |
| Co | 1 – 10 | (50) | 0.01 – 0.1 | 0.01 – 0.5 | 10 – 20 | 10 – 50 |
| Cr | 2 – 50 | 100 | 0.01 – 0.1 | < 0.1 – 1 | 1 – 2 | 50 – 3 000 |
| Cu | 1 – 40 | 100 | 0.1 – 1 | 3 – 15 | 15 – 20 | 30 – 100 |
| Hg | 0.01 – 0.5 | 2 | 0.01 – 0.1 | < 0.1 – 0.5 | 0.5 – 1 | > 1 |
| Ni | 2 – 50 | 50 | 0.1 – 1 | 0.1 – 5 | 20 – 30 | 50 – 60 |
| Pb | 0.1 – 20 | 100 | 0.01 – 0.1 | 1 – 5 | 10 – 20 | 10 – 30 |
| Tl | 0.01 – 0.5 | (1) | 1 – 10 | < 0.5 – 5 | 20 – 30 | 1 – 5 |
| Zn | 3 – 50 | 300 | 1 – 10 | 15 – 150 | 150 – 200 | 300 – 1 000 |
| As | 0.1 – 20 | (20) | 0.01 – 0.1 | < 0.1 – 5 | 10 – 20 | > 50 |
| B | 3 – 100 | (25) | 1 – 10 | 5 – 30 | > 75 | 150 |
| Be | 0.2 – 40 | | 0.01 – 0.1 | 0.01 – 0.5 | > 1 | ? |
| F | 20 – 400 | (200) | 0.01 – 0.1 | 1 – 5 | > 50 | 40 – 200 |
| Mo | 0.2 – 5 | | 0.1 – 10 | 0.1 – 3 | > 100 | 10 – 58 |
| Se | 0.01 – 5 | (5) | 0.1 – 10 | 0.1 – 2 | 10 – 20 | 4 – 5 |
| Sn | 1 – 20 | | 0.01 – 0.1 | ? | > 60 | ? |
| V | 0.01 – 200 | | 0.1 – 1 | 0.1 – 1 | 10 | 10 – 50 |

[1] Grenzwerte der Klärschlammverordnung; ( ) in Diskussion

Tab. 2.8.4/5: Entzüge von Spurenelementen durch die Vegetation bei Abwasserbewässerungen (n. ISKANDAR, 1981)

Table 3-22 b

| Element | Konz. in Pflanzen $mg \times kg^{-1}$ | Ernte-entzug $g \times ha^{-1} \times a^{-1}$ | Abwasser zufuhr $g \times ha^{-1} \times a^{-1}$ | Relation Zufuhr zu Entzug v.H. |
|---|---|---|---|---|
| As | 1 | 3 | 60 | 5 |
| B | 50 | 150 | 12 000 | 1.25 |
| Cd | 0.5 | 1.5 | 60 | 2.5 |
| Cr. ges. | 0.5 | 1.5 | 300 | 0.5 |
| Cu | 15 | 45 | 1 200 | 3.75 |
| Hg | 0.02 | 0.06 | 11 | 0.55 |
| Mo | 1 | 3 | 60 | 3 |
| Ni | 5 | 15 | 240 | 6.25 |
| Pb | 2 | 6 | 600 | 1 |
| Se | 0.5 | 1.5 | 60 | 2.5 |
| Zn | 50 | 150 | 1 800 | 8.3 |

Ertragsbasis für Ernteentzug: 3000 kg · $ha^{-1}$ TS;
Abwassergabe: 1 200 mm · $a^{-1}$

Sources: Blume et al 1992

Table 3-23

**Table 3.20** Movement of viruses through soil in relation to wastewater application (After Frankenberger 1985)

| Virus type | Nature of fluid | Nature of medium | Flow rate | Distance of travel | Percentage of removal |
|---|---|---|---|---|---|
| T1, T2, f2 | Distilled water with added salts | 9 types of soils from California | 0.078–0.313 ml/min | 45–50 cm | > 99 |
| Poliovirus 1 | Distilled water, $10^{-5}$ N Ca and Mg salts | Dune sand | 1–2 ml/min | 20 cm | 99.8–99.9 |
| Poliovirus 2 | Distilled water | Low humic latosol | 4.1–5.7 $m^3 m^{-2} day^{-1}$ | 4–15 cm | 96–99.3 |
| Poliovirus 2 | Secondary effluent | Sandy gravel | — | 60 m | 100 |
| Coxsackie | Spring water | Garden soils | — | 90 cm | 50 |
| T4 | Distilled water | Low humic latosol | 4.1–5.7 $m^3 m^{-2} day^{-1}$ | 4–15 cm | 100 |
| T7 | Secondary treated | Sandy forest | — | 19.5 cm | 99.6 |
| Indigenous enteric | Secondary effluent | Loamy sand soil | Intermittent avg: 0.02 cm/min | 3–9 m | 100 |

Source: Feigin et al. 1991

Table 3-24

**Table 3.3 Movement of bacteria through soils**

| *Nature of fluid* | *Type of organism* | *Soil type* | *Maximum distance of travel* (m) |
|---|---|---|---|
| Tertiary treated wastewater | Coliforms | Fine to medium sand | 6.1 |
| Secondary effluent on percolation beds | Faecal coliforms | Fine to loamy sand to gravel | 9.1 |
| Primary sewage in infiltration beds | Faecal streptococci | Silty sand and gravel | 183 |
| Inoculated water and sewage injected subsurface | *Bacillus stearothemophilis* | Crystalline bedrock | 28.7 |
| Sewage in buried latrine intersecting groundwater | *Bacillus coli* | Sand and sandy clay | 10.7 |
| Canal water in infiltration basins | *Escherichia coli* | Sand dunes | 3.1 |

Source: Frankenberger (1984)

Source: Pescod/Arar 1988

Table 3-25

**Table 4.2. Survival times of selected excreted pathogens in soil and on crop surfaces at 20–30 °C**

| Pathogen | Survival time (days) | |
|---|---|---|
| | In soil | On crops |
| **Viruses** | | |
| Enteroviruses[a] | < 100 but usually < 20 | < 60 but usually < 15 |
| **Bacteria** | | |
| Faecal coliforms | < 70 but usually < 20 | < 30 but usually < 15 |
| *Salmonella* spp. | < 70 but usually < 20 | < 30 but usually < 15 |
| *Vibrio cholerae* | < 20 but usually < 10 | < 5 but usually < 2 |
| **Protozoa** | | |
| *Entamoeba histolytica* cysts | < 20 but usually < 10 | < 10 but usually < 2 |
| **Helminths** | | |
| *Ascaris lumbricoides* eggs | Many months | < 60 but usually < 30 |
| Hookworm larvae | < 90 but usually < 30 | < 30 but usually < 10 |
| *Taenia saginata* eggs | Many months | < 60 but usually < 30 |
| *Trichuris trichiura* eggs | Many months | < 60 but usually < 30 |

[a] Includes poliovirus, echovirus, and coxsackievirus.

From Feachem et al. (1983), reproduced by permission of the World Bank.



Source: Mara/Caircross 1989

Table 3-26

**Table 3.18** Survival of pathogens in soils[a] and crops[b]

| Organism | Survival time in soils (days) | Survival on crops (days) |
|---|---|---|
| Coliforms | 38 | < 30 (< 15)[c] |
| Streptococci | 35–63 | |
| Fecal streptococci | 26–77 | |
| Salmonellae | 15– > 280 | < 30 (< 15) |
| *Shigella* spp. | — | 10 (< 5) |
| *Vibrio* cholerae | — | 5 (< 2) |
| *Salmonella typhi* | 1–120 | |
| Tubercle bacilli | > 180 | |
| Leptospira | 15–43 | |
| *Entamoeba histolytica* cysts | 6–8 | < 10 (< 2) |
| Enteroviruses | 8–175 | < 60 |
| *Ascaris* ova | Up to 7 years | |
| Hookworm larvae | 42 | < 60 (< 30) |
| *Brucella abortus* | 30–125 | |
| Q-fever organisms | 148 | |

Source: Feigin et al. 1991

Table 3-27

Survival times of excreted pathogens in feces, night soil, and sludge at 20-30° C

| Pathogen | Survival time (days) |
|---|---|
| Viruses | |
| Enteroviruses*/ | <100 but usually <20 |
| Bacteria | |
| Fecal coliforms | < 90 but usually <50 |
| Salmonella spp. | < 60 but usually <30 |
| Shigella spp. | < 30 but usually <10 |
| Vibrio cholerae | < 30 but usually < 5 |
| Protozoa | |
| Entamoeba histolytica cysts | < 30 but usually <15 |
| Helminths | |
| Ascaris lumbricoides eggs | Many months |

*/ Includes polio-, echo-, and coxsackieviruses.

Table 3-28

Survival times of excreted pathogens in freshwater and sewage at 20-30° C

| Pathogen | Survival time (days) |
|---|---|
| Viruses[a/] | |
| Enteroviruses[b/] | <120 but usually <50 |
| Bacteria | |
| Fecal coliforms[a/] | < 60 but usually <30 |
| Salmonella spp.[a/] | < 60 but usually <30 |
| Shigella spp.[a/] | < 30 but usually <10 |
| Vibrio cholerae[c/] | < 30 but usually <10 |
| Protozoa | |
| Entamoeba histolytica cysts | < 30 but usually <15 |
| Helminths | |
| Ascaris lumbriocoides eggs | Many months |

a. In seawater, viral survival is less, and bacterial survival is very much less than in freshwater.
b. Includes polio-, echo-, and coxsackieviruses.
c. V. cholerae survival in aqueous environments is still uncertain.

Table 3-29

Factors affecting survival time of enteric bacteria in soil

| Soil factor | Effect on bacterial survival |
|---|---|
| Antagonism from soil microflora | Increased survival time in sterile soil |
| Moisture content | Greater survival time in moist soils and during times of high rainfall |
| Moisture-holding capacity | Survival time is less in sandy soils than in soils with greater water-holding capacity |
| Organic matter | Increased survival and possible regrowth when sufficient amounts of organic matter are present |
| pH | Shorter survival time in acid soils (pH 3-5) than in alkaline soils |
| Sunlight | Shorter survival time at soil surface |
| Temperature | Longer survival at low temperatures; longer survival in winter than in summer |

Source: Adapted from Gerba, Wallis, and Melnick (1975).

Sources: Shuval et al. 1986

**Table 1. Relative stability of pesticides in flooded and nonflooded soils.**

| Pesticide | Concentration (ppm) | Soil samples | Time (days) for 50% disappearance | |
|---|---|---|---|---|
| | | | Flooded | Nonflooded |
| **Insecticides** | | | | |
| BHC ($\gamma-$, $\alpha-$, $\beta-$, $\delta-$) | 5 | 4 | 20 | No degradation in 28 days[a] |
| DDT | 20 | 4 | 10–45 | No degradation in 28 days[b] |
| Methoxychlor | 30 | 4 | 5–40 | 90[b] |
| Heptachlor | 15 | 4 | 15–85 | 90[b] |
| Chlordane | 15 | 4 | No degradation in 90 days | No degradation in 90 days[b] |
| Dieldrin | 15 | 4 | No degradation in 90 days | No degradation in 90 days[b] |
| Endrin | 20 | 1 | 8 | No degradation in 60 days[b] |
| | 20 | 3 | No degradation in 60 days | No degradation in 60 days[b] |
| | — | 8 | <25 | >55[c] |
| Aldrin | 20 | 4 | 60 | 35–50[b] |
| Parathion | 50 | 4 | 2–9 | No degradation in 15 days[d] |
| Diazinon | 10 | 3 | 15 | 36[e] |
| Isoxathion | 30 | 1 | <20 | 40[f] |
| Carbofuran | 30 | 1 | 20 | 95[g] |
| Sevin | 30 | 2 | 13 | 27[h] |
| **Herbicides** | | | | |
| PCP | 100 | 7 | 30 | 50[i] |
| Nitrofen | 10 | 5 | 11 | 50[i] |
| CNP | 10 | 5 | 15 | 50[i] |
| Chlomethoxynil | 10 | 5 | 16 | 50[i] |
| Benthiocarb | 20 | 5 | 30–60 | 10–26[i, j, k] |
| Swep | 5 | 5 | 7 | 2[i] |
| Propanil | 1 | 1 | 1 | 1[i] |
| Picloram | 1 | 2 | 60–180 | 90–180[l] |
| 2, 4, 5-T | 10 | 1 | 45 | 30[l] |
| | 10 | 1 | 17 | 84[l] |
| 2, 4-D | 20 | 1 | 28 | 9[l] |
| | 20 | 1 | 36 | 36[l] |
| Amiprophos | — | 1 | 10 | 80[m] |
| Trifluralin | 1.3 | 1 | 3–10 | 150[n] |
| Benefin | 2.3 | 1 | 4 | 40[o] |
| **Fungicides** | | | | |
| PCNB | 100 | 3 | 20 | No degradation in 60 days[p] |
| DCNA | 100 | 3 | 5–30 | No degradation in 60 days[p] |
| Hinosan | 50 | 1 | 4 | 10[q] |
| Kitazin P | 10 | 1 | 14 | 10[r] |

[a]Yoshida and Castro, 1970. [b]Castro and Yoshida, 1971. [c]Gowda and Sethunathan, 1976. [d]Sethunathan and Yoshida, 1973c. [e]Sethunathan, unpublished data, 1971. [f]Nakagawa et al., 1975. [g]Venkateswarlu et al., 1977. [h]Venkateswarlu and Sethunathan, unpublished data, 1977. [i]Matsunaka and Kuwatsuka, 1975. [j]Chen et al., 1976. [k]Ishikawa et al., 1976. [l]Yoshida, 1975b. [m]Tomizawa, 1975. [n]Probst et al., 1967. [o]Probst and Tepe, 1969. [p]Wang and Broadbent, 1973. [q]Rajaram and Sethunathan, 1976. [r]Tomizawa et al., 1976.

Table 4-1a

Tab. 10: Nettoprimärproduktion von Teilökosystemen in g C (Annahme: 1 g C = 2 g Trocken-Biomasse). Nach Lieth, Whittaker u. Likens, Likens, Wetzel u. a., in: Riepl

| Ökosystem | Produktivität in $g C \cdot m^{-2} \cdot Jahr^{-1}$ | Flächenausdehnung in % | % der Erdproduktion |
|---|---|---|---|
| Erde total | ca. 150–180 | 100 % | 100% |
| *marine Ökosysteme* | Ø ca. 75 | 71 % | 32– 35% |
| offener Ozean | 1– 200 | 65 % | |
| Auftriebsgebiete | 200– 500 | 0,1% | |
| Kontinentalsockel | 100– 300 | 5 % | |
| Korallenriffe usw. | 250–2000 | 0,1% | |
| Flußmündungsgebiete | 100–1750 | 0,3% | |
| *terrestrische Ökosysteme* | Ø ca. 370–400 | 27 % | 61– 67% |
| Gletscher, Kältewüsten, Trockenwüsten | 0– 5 | 4,5% | |
| Tundra | 5– 200 | 1,5% | |
| Halbwüsten, Buschwüsten | 5– 125 | 3,3% | |
| borealer Nadelwald | 100– 750 | 2,2% | |
| sommergrüner gemäßigter Laubmischwald | 200–1250 | 1,3% | |
| warmtemperierter Mischwald | 300–1250 | 0,9% | |
| Hartlaubwald, Trockenbüsche, Waldsteppen | 125– 750 | 1,6% | |
| tropisches Grasland (Steppen u. Savannen) | 100–1000 | 2,8% | |
| warmgemäßigtes Grasland (Steppen, Wiesen) | 100– 750 | 1,7% | |
| regengrüne Monsunwälder | 300–1750 | 1,4% | |
| tropische Regenwälder | 500–1750 | 3,2% | |
| → Kulturland | 50–3500 | 2,6% | |
| *limnische Ökosysteme* | Ø ca. 125 | 4,0 % | 2,7–3,2% |
| Flüsse und Seen | 1–2500 | 2,0% | 0,3–0,6% |
| Sümpfe und Marschen | 400–1750 | 2,0% | 2,4–2,6% |

Abb. 22. Zusammenhang zwischen Flächenertrag und Naturschutzwert beim Rauhfutterbau.
Quelle: HAMPICKE 1988, Abb. 3, p. 14. kStE (Kilo-Stärkeeinheit, in der Rindermast gültig) und GJ NEL (Gigajoule Nettoenergie Laktation in der Milchkuhfütterung) sind Nettoenergiemaße, die auch den Wert des Futters berücksichtigen. Bei gleichem Brennwert enthält 1 kg gutes Heu mehr kStE bzw. GJ NEL als 1 kg schlechtes Heu.

Source: Kinzelbach 1989

**(R1.11) Durch Landwirtschaft ist die für den Menschen verfügbare Erntemenge pro Fläche stark erhöht worden. Gegenüber der Sammlerkultur hat sie sich etwa vertausendfacht.**

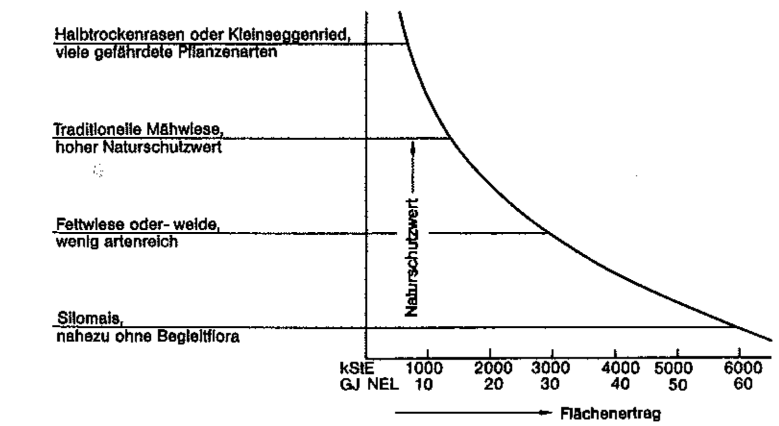
Figur 4-1 b

| | Ernteertrag $kJ/m^2 \cdot a$ | erford. Fläche $m^2$/Mensch |
|---|---|---|
| Sammlerkultur | 1 - 40 | 400000 |
| Landwirtsch. ohne Energiezufuhr | 100 - 4000 | 4000 |
| Getreideanbau mit Energiezufuhr | 4000 - 40000 | 400 |
| Algenkulturen mit Energiezufuhr | 40000 - 160000 | 40 |

Source: Boesel 1990

Figur 4-1c






Source: Hampicke 1991

Table 4-2

**Table 4: The impact of dams on fish, pasture, and agriculture production on African floodplains**

| Floodplain | Area in 1960 (ha) | Area remaining in 2020 (ha) | Expected loss of production |
|---|---|---|---|
| Senegal delta | 300,000 | 30,000 | 90% |
| Senegal valley | 550,000 | 55,000 | 90% |
| Niger delta | 3,000,000 | 2,700,000 | 10% |
| Niger valley | 300,000 | 150,000 | 50% |
| Sokoto and Rima | 100,000 | 50,000 | 50% |
| Hadejia Komadugu | 380,000 | 38,000 | 90% |
| Logone | 1,100,000 | 660,000 | 60% |

*(Modified after Drijver & Rodenburg, 1988)*

Source: Dugan 1990

Table 4-3

| **Verursacher** (Landnutzer und Wirtschaftszweige) | Zahl der betroffenen Pflanzenarten* |
|---|---|
| Landwirtschaft | 513 |
| Forstwirtschaft und Jagd | 338 |
| Tourismus und Erholung | 161 |
| Rohstoffgewinnung und Kleintagebau | 158 |
| Gewerbe, Siedlung, Industrie | 155 |
| Wasserwirtschaft | 112 |
| Teichwirtschaft | 79 |
| Verkehr, Transport | 71 |
| Abfall- und Abwasserbeseitigung | 71 |
| Militär | 53 |
| Wissenschaft, Bildung, Kultus | 40 |
| Lebensmittel- und pharmazeutische Industrie | 8 |

Übersicht 7. Ursachen und Verursacher des Rückgangs von Pflanzenarten der Roten Liste in der Bundesrepublik Deutschland

| **Ursachen** (Ökofaktoren) | Zahl der betroffenen Pflanzenarten* |
|---|---|
| Änderung der Nutzung | 305 |
| Aufgabe der Nutzung | 284 |
| Beseitigung von Sonderstandorten | 255 |
| Auffüllung, Bebauung | 247 |
| Entwässerung | 201 |
| Bodeneutrophierung | 176 |
| Abbau und Abgrabung | 163 |
| Mechanische Einwirkungen | 123 |
| Entkrautung, Rodung, Brand u. a. | 115 |
| Sammeln | 103 |
| Gewässerausbau und -unterhaltung | 68 |
| Aufhören von Bodenverwundungen | 59 |
| Einführung von Exoten | 43 |
| Luft- und Bodenverunreinigung | 38 |
| Gewässereutrophierung | 36 |
| Gewässerverunreinigung | 35 |
| Schaffung künstlicher Gewässer | 27 |
| Herbizidanwendung, Saatgutreinigung | 26 |
| Verstädterung von Dörfern | 22 |
| Aufgabe bestimmter Feldfrüchte | 8 |

Source: Hampicke 1991

Table 4-5

**Table 6: Principal threats to protected wetlands in Asia.**

| Threat | Incidence (% of sites) |
|---|---|
| Illegal hunting | 48 |
| Drainage or conversion of land for agricultural purposes and human settlement | 45 |
| Illegal fishing and/or overfishing | 32 |
| Cutting of wood for domestic purposes | 29 |
| Pollution from domestic sewage, industrial waste, pesticides and fertilizers | 26 |
| Overgrazing by domestic livestock | 23 |
| Commercial logging | 19 |
| Cutting of aquatic vegetation for fodder, fuel etc. | 15 |
| Harvesting of eggs of waterbirds and/or reptiles | 15 |
| Eutrophication | 12 |

*Source: Data are taken from 69 protected Asian wetlands of international importance considered to be under moderate to severe threat (modified from Scott and Poole, 1989).*

Dugan 1990

Table 4-6

**Table 5: Examples of Threats to Protected Wetlands**

| Threat | Example |
|---|---|
| Groundwater abstraction | The Tablas de Daimiel National Park (Spain) has for several years experienced an acute shortage of water caused in large part by use of groundwater for irrigated agriculture in the surrounding land (Llamas, 1988). |
| Dams | In Tunisia, the water supply of Lac Ichkeul, a Ramsar and World Heritage site, has been reduced through dam construction in the catchment (Hollis, 1986) |
| Pollution | In Brazil, gold mining in the basin of the Paraguay river has resulted in severe mercury pollution of the waters of the Pantanal. |
| | The delicately poised wetland ecosystems of Everglades National Park are threatened by nutrient runoff from poalland converted to agriculture and by altered water flows into the Park. |
| Siltation | The wetlands of Gonarezhou National Park in Zimbabwe are subject to silting and pollution because of agricultural activities in the basin of the Lundi and Sabi rivers which feed the park (IUCN/UNEP, 1987). |
| Drainage | In Uruguay, approximately one third of the Bañados del Este, a Ramsar site and Unesco Biosphere Reserve, has been drained for agriculture. |

Source: Dugan 1990

Table 4-7

*Table 3. Productivity per $100m^3$ of water for a natural floodplain (inner delta of the Niger) and an irrigated rice scheme (Office du Niger)[1]*

| | Niger inner delta | | | | | Office du Niger | |
|---|---|---|---|---|---|---|---|
| | Meat | Milk | Fish | Rice | Total | Rice | Total |
| Total weight (t) | 10 | 118 | 100 | 78 | | 100 | |
| Weight/$100m^3$ (g) | 44 | 506 | 427 | 235 | | 5 003 | |
| Value/$100m^3$ ($) | 0.02 | 0.20 | 0.17 | 0.03 | 0.42 | 0.55 | 0.55 |
| Protein/$100m^3$ (g) | 8 | 17 | 77 | 18 | 119 | 190 | |
| Energy/$100m^3$ (kcal) | 83 | 318 | 401 | 853 | 1 656 | 13 749 | |
| Inputs/$100m^3$ ($) | | | | | | 0.12 | |
| Fertilizer | 0 | 0 | 0 | 0 | 0.01 | | |
| Management | 0 | 0 | Very small | | 0.08 | | |
| Oxen etc. | 0 | 0 | Very small | | 0.03 | | |
| Profit margin per $100m^3$ ($) | | | | | 0.42 | | 0.43 |
| Loss of interest per $100m^3$ ($) | | | | | 0.00 | | 1.08 |
| Net profit per $100m^3$ ($) | | | | | + 0.42 | | − 0.65 |

1. The assumptions underlying this table are detailed in Drijver and Marchand, 1985.
*Source:* Drijver and Marchand, 1985.

**Source: Hoolis et al. 1988**

Table 4-8

*Table 2. Wetland functions and their human utilization*

| Role | Elements | Function | Importance to humankind | Unwise use |
|---|---|---|---|---|
| Store/sink | Rare, threatened or endangered plant and animal species and communities | Genetic diversity<br>Recolonization source | Gene pool<br>Science/education<br>Tourism<br>Recreation<br>Heritage | Excessive or uncontrolled harvest<br>Damage removal or pollution |
| | Representative plant and/or animal communities | Ecological diversity<br>Habitat maintenance | Gene pool<br>Science/education<br>Tourism<br>Recreation<br>Heritage | Excessive or uncontrolled harvest<br>Damage removal or pollution |
| | Peat | Nutrient, contaminant and energy store<br>Habitat support<br>Water storage | Fuel,<br>Palaeo-environmental data<br>Horticultural use<br>Heritage<br>Medicinal products | Drainage<br>Harvest faster than accumulation<br>Destruction |
| | Human habitation sites | Archaeological remains | Heritage/cultural<br>Scientific<br>Recreation | Destruction<br>Lowering the water-table |
| Pathway | Terrestrial nutrients, water and detritus | Food chain support<br>Habitat support | Food production<br>Water supply<br>Waste disposal | Interruption or abnormal change of flows<br>Pollution |
| | Tidal exchanges of water detritus and nutrients | Food chain support<br>Habitat support<br>Nursery for aquatic organisms | Fish, shellfish and other food production<br>Waste disposal | Pollution<br>Barriers to flow<br>Dredge and fill |
| | Animal populations | Support for migratory species including fish | Harvest<br>Recreation<br>Science | Overexploitation<br>Interruption of migration routes<br>Obstruction<br>Habitat degradation |
| | Lakes and rivers | Waterways | Navigation | Obstruction<br>Reduced flows and levels |
| Buffer | Water bodies, vegetation, soils and depressions | Flood attenuation | Reduced damage to property and crops | Filling and reduction of storage capacity |
| | Water bodies, vegetation, soils and depressions | Detention and retention of nutrients | Food production<br>Improved water quality | Removal of vegetation<br>Drainage and flood protection |
| | Water bodies, vegetation, soils and depressions | Groundwater recharge and discharge | Water supply<br>Habitat maintenance<br>Effluent dilution<br>River fisheries<br>Navigation | Reduction of recharge<br>Overpumping<br>Pollution |
| | Water bodies and peat | Local and global climate stabilization | Equable climate for agriculture and people | Desiccation |
| | Water bodies | Large volume<br>Large area | Cooling water | Drainage<br>Filling<br>Thermal pollution |
| Producer | Production of plants | Food, materials and habitat for migratory species and grazing animals | Harvest of timber, thatch fuel and food<br>Science<br>Recreation | Overgrazing<br>Overexploitation<br>Drainage<br>Excess change to dry land or other agricultural uses |
| | Animal production | Fish, shellfish, grazing and fur-bearing animals | Harvest and farming | Overexploitation<br>Excess change<br>Habitat degradation |
| | Organic matter | Methane production<br>Nutrient cycling | Fuel<br>Plant growth | Drainage<br>Desiccation |
| Sink | Lakes, deltas floodplains | Sediment deposition and detention | Raised soil fertility<br>Clean downstream channels<br>Improved water quality downstream | Channelization<br>Excess reduction of sediment throughout |
| | Lakes, swamps and marshes | Bio-chemical self-purification<br>Nutrient accumulation | Natural filter for contaminants<br>Treatment of organic wastes, pathogens and effluents | Destruction of the ecosystem<br>Over-loading of the system |

*Source:* Hollis et al., 1987.

**Source: Hollis et al. 1988**

Table 15.40 Contribution of tropical areas to the global flux ($10^{12}$ g/yr) of $CH_4$, $N_2O$, $H_2$, and CO between different ecosystems and the atmosphere (After Seiler and Conrad, 1985)

**Table 5-1**

| | Total | Tropical areas |
|---|---|---|
| $CH_4$ emission by rice paddies | 70–170 | 67–162 |
| $CH_4$ emission by wetlands | 11–57 | 9–46 |
| $CH_4$ emission by ruminants | 72–99 | 20–50 |
| $CH_4$ emission by termites | 2–5 | 2–5 |
| $CH_4$ emission by biomass burning | 53–97 | 42–78 |
| $CH_4$ uptake by soils | 32 | 25 |
| $N_2O$ emission from soils | 4.5–17 | 3–15 |
| $N_2O$ emission from fertilized rice paddies | <0.1 | <0.1 |
| $H_2$ uptake by soils | 70–110 | 30–40 |
| CO uptake by soils | 190–580 | 70–40 |
| CO emission by plants | 50–100 | 40–75 |
| CO production by photochemical oxidation of $CH_4$ and NMHC | 700–2200 | 560–1800 |

Source: Lal ed. 1991

**Table 5-2**

Table 15.39 Global production rates ($10^{12}$ g/yr) of individual sources for atmospheric $CH_4$ (After Seiler and Conrad, 1985)

| | 1950 | 1960 | 1970 | 1975 |
|---|---|---|---|---|
| Sources | | | | |
| Ruminants | 49 – 69 | 56 – 81 | 65 – 92 | 72 – 99 |
| Paddy fields | 43 – 106 | 56 – 135 | 65 – 158 | 69 – 167 |
| Swamps | 11 – 57 | 11 – 57 | 11 – 57 | 11 – 57 |
| Other biogenic sources | 8 – 20 | 8 – 21 | 9 – 22 | 9 – 22 |
| Biomass burning | 41 – 74 | 47 – 84 | 51 – 91 | 53 – 97 |
| Leakage of natural gas | 3 – 4 | 7 – 10 | 14 – 20 | 19 – 29 |
| Coal mining | 20 | 24 | 28 | 30 |
| Other nonbiogenic sources | 1 | 1 | 1 | 1 – 2 |
| Total production | 176 – 351 | 210 – 413 | 244 – 469 | 264 – 503 |
| Sinks | | | | |
| Reaction with OH | 210 | 230 | 270 | 290 |
| Flux into stratosphere | 44 | 48 | 56 | 60 |
| Soils | 24 | 26 | 30 | 32 |
| Total decomposition | 278 | 304 | 356 | 382 |

Source: Lal ed. 1991

**Table 5-3**

Table 1. Atmospheric concentrations, increase, residence time, sources and sinks for major greenhouse gases, and their contribution to global warming. (adapted from Bouwman, 1990)

| | $CO_2$ | $CH_4$ | $N_2O$ | $O_3$ | CFCs |
|---|---|---|---|---|---|
| Residence time (yr) | 100 | 8-12 | 100-200 | 0.1-0.3 | 65-110 |
| Annual increase (%) | 0.5 | 1 | 0.2-0.3 | 2.0 | 3.0 |
| Concentration in 1985 | 345 ppmv | 1.70 ppmv | 300 ppbv | na | 0.18-0.28 ppbv |
| Radiative absorption per ppm of increase | 1 | 32 | 150 | 2000 | > 10 000 |
| Contribution (%) to global warming | 50 | 19 | 4 | 8 | 15 |
| Total source | 6.5-7.5 Gt C | 400-640 Tg $CH_4$ | 11-17 Tg N | – | – |
| Biotic sources (%) | 20-30 | 70-90 | 90-100 | – | – |
| Major sources (in Gt or Tg) | fossil fuel (5.7), deforestation (1-2) | paddies (60-140) wetlands (40-160) ruminants (65-100) termites (10-100) landfill sites (30-70) oceans/lakes (15-25) biomass burning (50-100) fossil fuel (50-95) | cultivated soils (3?) natural soils (?) fossil fuel (?) | atmospheric | manmade |
| Sinks (in Gt or Tg) | atmosph. accum. (3.5) oceans (< 1), biosphere (?), charcoal formation (?) | atmosph. accum. (50) soil oxidation (32) atmosph. chemistry (300-650) | atmosph. accum. (2.8) atmosph. chemistry (10.5) soils (?) | atmosph. accum. atmosph. chemistry | atmosph. accum. atmosph. chemistry |

Source: from Scharpenseel ed. 1990

Table 5-4

*Tabelle 6/2*
Zeitliche Veränderungen verschiedener Merkmale im überfluteten Reisboden (nach TAKAI u. a., 1956)

| Merkmal bzw. Größe | Inkubationsdauer (in Tagen) | | | | |
|---|---|---|---|---|---|
| | 0 | 2 | 8 | 13 | 21 |
| Ionisiertes Fe (mg/100 g) | 0 | 20 | 103 | 114 | 95 |
| $Fe^{++}$ (% von $Fe^{++} + Fe^{+++}$) | 43 | 59 | 76 | 84 | 78 |
| Aerobe Bakterien (in 1000/g) | 34 | 110 | 53 | 62 | 65 |
| Anaerobe Bakterien (1000/g) | 22 | 23 | 170 | 130 | 45 |
| Sulfatreduz. Bakterien (1000/g) | 0,3 | 1,3 | 1,8 | 4,8 | 2,3 |
| S'' (mg/100 g) | 0,2 | 0,2 | 2,8 | 12,5 | 16,2 |
| $NO_3$-N (mg/100 g) | 0,5 | 0 | 0 | 0 | 0 |
| $NH_4$-N (mg/100 g) | 0,4 | 3,4 | 7,8 | 8,8 | 9,6 |
| Gaszusammensetzung (ml/25 g) | | | | | |
| $O_2$ | 0,80 | 0 | 0 | 0 | 0 |
| $N_2$ | 2,17 | 2,00 | 2,29 | 4,50 | 3,37 |
| $CH_4$ | 0 | 0 | 3,67 | 12,40 | 15,07 |
| $H_2$ | 0 | 0,01 | 0.53 | 2,96 | 3,30 |
| $CO_2$ | 20,9 | 43,0 | 56,4 | 56,6 | 50,3 |

Source: Pagel 1981

Table 5-5

TABLE 25.2 Production of hydrocarbons during first week of waterlogging soils. Production in μ g/kg soil

| *Soil* | *% organic matter* | $CH_4$ | $C_2H_4$ | $C_2H_6$ | $C_3H_6$ | $C_3H_8$ |
|---|---|---|---|---|---|---|
| Sand | 1·4 | 0·3 | 0·6 | 0·1 | 0·1 | 1·7 |
| Sandy loam | 3·9 | 3·1 | 5·5 | 0·5 | 1·0 | 1·6 |
| Gault clay | 5·0 | 12·5 | 7·6 | 0·6 | 1·0 | 1·6 |
| Loam from basalt | 9·8 | 17·9 | 13·3 | 0·5 | 1·2 | 1·7 |

Source: Russel 1973

Table 5-6

TABLE 25.3 The redox potentials associated with the production of different reduced substances in waterlogged soils

| *Chemical transformation* | *$E_h$ (at pH 7) in volts* | |
|---|---|---|
| | *From* | *To* |
| Disappearance of molecular oxygen | 0·6 | 0·5 |
| Disappearance of nitrates | 0·6 | 0·5 |
| Formation of $Mn^{2+}$ | 0·6 | 0·4 |
| Formation of $Fe^{2+}$ | 0·5 | 0·3 |
| Formation of sulphide | 0·0 | −0·19 |
| Formation of hydrogen gas | −0·15 | −0·22 |
| Formation of methane | −0·15 | −0·19 |

Russel 1973

Table 8-1

Table 8.2 Environmental classification of water-related infections

| Category | Infection | Pathogenic agent |
|---|---|---|
| 1. Faecal–oral (water-borne or water-washed) | Diarrhoeas and dysenteries | |
| | amoebic dysentery | P |
| | balantidiasis | P |
| | *Campylobacter* enteritis | B |
| | cholera | B |
| | *E. coli* diarrhoea | B |
| | giardiasis | P |
| | rotavirus diarrhoea | V |
| | salmonellosis | B |
| | shigellosis (bacillary dysentery) | B |
| | yersiniosis | B |
| | Enteric fevers | |
| | typhoid | B |
| | paratyphoid | B |
| | Poliomyelitis | V |
| | Hepatitis A | V |
| | Leptospirosis | S |
| | Ascariasis | H |
| | Trichuriasis | H |
| 2. Water-washed: | | |
| (a) skin and eye infections | Infectious skin diseases | M |
| | Infectious eye diseases | M |
| (b) other | Louse-borne typhus | R |
| | Louse-borne relapsing fever | S |
| 3. Water-based: | | |
| (a) penetrating skin | Schistosomiasis | H |
| (b) ingested | Guinea worm | H |
| | Clonorchiasis | H |
| | Diphyllobothriasis | H |
| | Fasciolopsiasis | H |
| | Paragonimiasis | H |
| | Others | H |
| 4. Water-related insect vector | | |
| (a) biting near water | Sleeping sickness | P |
| (b) breeding in water | Filariasis | H |
| | Malaria | P |
| | River blindness | H |
| | Mosquito-borne viruses | |
| | yellow fever | V |
| | dengue | V |
| | others | V |

B = bacterium
H = helminth
P = protozoon
M = miscellaneous
R = rickettsia
S = spirochaete
V = virus

**Source: Hillman in Rydzewski ed. 1987**

Table 8-2

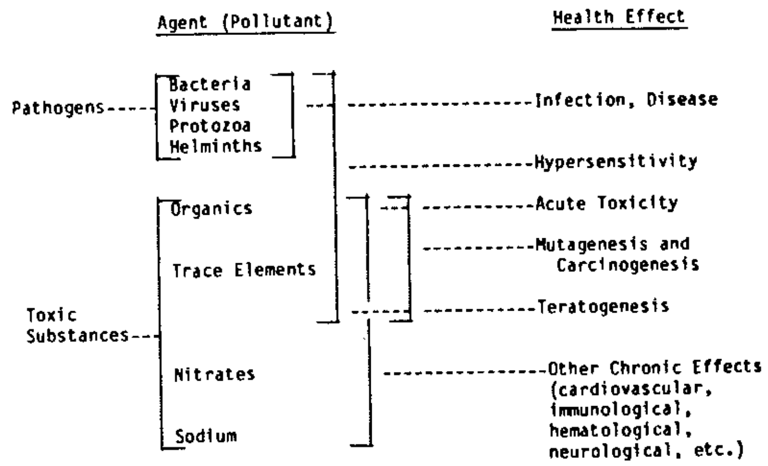



**Fig. 3.24** Major health effect of pollutants (Kowal 1983)

**Source: Feigin et al. 1991**

Table 8-3

**Table 4.1 Environmental classification of excreted infections**

| Category and epidemiological features | Infection | Environmental transmission focus | Major control measure |
|---|---|---|---|
| I. Non-latent; low infective dose | Amoebiasis<br>Balantidiasis<br>Enterobiasis<br>Enteroviral infections<br>Giardiasis<br>Hymenolepiasis<br>Hepatitis A<br>Rotavirus infection | Personal<br>Domestic | Domestic water supply<br>Health education<br>Improved housing<br>Provision of toilets |
| II. Non-latent; medium or high infective dose; moderately persistent; able to multiply | *Campylobacter* infection<br>Cholera<br>Pathogenic *Escherichia coli* infection<br>Salmonellosis<br>Shigellosis<br>Typhoid<br>Yersiniosis | Personal<br>Domestic<br>Water<br>Crop | Domestic water supply<br>Health education<br>Improved housing<br>Provision of toilets<br>Treatment of excreta before discharge or reuse |
| III. Latent and persistent; no intermediate host | Ascariasis<br>Hookworm infection<br>Strongyloidiasis<br>Trichuriasis | Yard<br>Field<br>Crop | Provision of toilets<br>Treatment of excreta before land application |
| IV. Latent and persistent; cow or pig as intermediate host | Taeniasis | Yard<br>Field<br>Fodder | Provisions of toilets<br>Treatment of excreta before land application<br>Cooking, meat inspection |
| V. Latent and persistent; aquatic intermediate hosts(s) | Clonorchiasis<br>Diphyllobothriasis<br>Fascioliasis<br>Fasciolopsiasis<br>Gastrodiscoidiasis<br>Heterophyiasis<br>Metagonimiasis<br>Opisthorchiasis<br>Paragonimiasis<br>Schistosomiasis | Water | Provision of toilets<br>Treatment of excreta before discharge<br>Control of animal reservoirs<br>Control of intermediate hosts<br>Cooking of water plants and fish<br>Reducing water contact |

*Source*: Feachem et al. (1983).

Source: Mara/Cairncross 1989

TABLE 2-13

Basic epidemiological features of excreted pathogens by environmental category

| Pathogen | Excreted load[a] | Latency[b] | Persistence[c] | Multiplication outside human host | Median infective dose ($ID_{50}$) | Significant immunity? | Major nonhuman reservoir? | Intermediate host |
|---|---|---|---|---|---|---|---|---|
| CATEGORY I | | | | | | | | |
| Enteroviruses[d] | $10^7$ | 0 | 3 months | No | L | Yes | No | None |
| Hepatitis A virus | $10^6$ (?) | 0 | ? | NO | L(?) | Yes | No | None |
| Rotavirus | $10^6$ (?) | 0 | ? | No | L(?) | Yes | No(?) | None |
| Balantidium coli | ? | 0 | ? | No | L(?) | No(?) | Yes | None |
| Entamoeba histolytica | $10^5$ | 0 | 25 days | No | L | No(?) | No | None |
| Giardia lamblia | $10^5$ | 0 | 25 days | No | L | No(?) | Yes | None |
| Enterobius vermicularis | Not usually found in feces | 0 | 7 days | No | L | No | No | None |
| Hymenolepis nana | ? | 0 | 1 month | No | L | Yes(?) | No(?) | None |
| CATEGORY II | | | | | | | | |
| Campylobacter fetus ssp. jejuni | $10^7$ | 0 | 7 days | Yes[e] | H(?) | ? | Yes | None |
| Pathogenic Escherichia coli[f] | $10^8$ | 0 | 3 months | Yes | H | Yes(?) | No(?) | None |
| Salmonella | | | | | | | | |
| S. typhi | $10^8$ | 0 | 2 months | Yes[e] | H | Yes | No | None |
| Other salmonellae | $10^8$ | 0 | 3 months | Yes[e] | H | No | Yes | None |
| Shigella spp. | $10^7$ | 0 | 1 month | Yes[e] | M | No | No | None |
| Vibrio cholerae | $10^7$ | 0 | 1 month(?) | Yes | H | Yes(?) | No | None |
| Yersinia enterocolitica | $10^5$ | 0 | 3 months(?) | Yes | H(?) | No | Yes | None |
| CATEGORY III | | | | | | | | |
| Ascaris lumbricoides | $10^4$ | 10 days | 1 year | No | L | No | No | None |
| Hookworms[g] | $10^2$ | 7 days | 3 months | No | L | No | No | None |
| Strongyloides stercoralis | 10 | 3 days | 3 weeks (free-living stage much longer) | Yes | L | Yes | No | None |
| Trichuris trichiura | $10^3$ | 20 days | 9 months | No | L | No | No | None |
| CATEGORY IV | | | | | | | | |
| Taenia saginata and T. solium[h] | $10^4$ | 2 months | 9 months | No | L | No | No | Cow (T.saginata) or pig (T.solium) |
| CATEGORY V | | | | | | | | |
| Clonorchis sinensis[i] | $10^2$ | 6 weeks | Life of fish | Yes[j] | L | No | Yes | Snail and fish |
| Diphyllobothrium latum[i] | $10^4$ | 2 months | Life of fish | No | L | No | Yes | Copepod and fish |
| Fasciola hepatica[h] | ? | 2 months | 4 months | Yes[j] | L | No | Yes | Snail and aquatic plant |
| Fasciolopsis buski[h] | $10^3$ | 2 months | ? | Yes[j] | L | No | Yes | Snail and aquatic plant |
| Gastrodiscoides hominis[h] | ? | 2 months(?) | ? | Yes[j] | L | No | Yes | Snail and aquatic plant |
| Heterophyes heterophyes[i] | ? | 6 weeks | Life of fish | Yes[j] | L | No | Yes | Snail and fish |
| Metagonimus yokogawai[i] | ? | 6 weeks(?) | Life of fish | Yes[j] | L | No | Yes | Snail and fish |
| Paragonimus westermani[i] | ? | 4 months | Life of crab | Yes[j] | L | No | Yes | Snail and crab or crayfish |
| Schistosoma S.haematobium[h] | 4 per milliliter of urine | 5 weeks | 2 days | Yes[j] | L | Yes | No | Snail |
| S.japonicum[h] | 40 | 7 weeks | 2 days | Yes[j] | L | Yes | Yes | Snail |
| S.mansoni[h] | 40 | 4 weeks | 2 days | Yes[j] | L | ? | No | Snail |
| Leptospira spp.[k] | urine(?) | 0 | 7 days | No | L | Yes(?) | Yes | None |

Note: L Low ($\le 20^2$); M medium ($\approx 10^4$); H high ($\ge 10^6$).

? Uncertain.

a. Typical average number of organisms per gram of feces (except for Schistosoma haematobium and Leptospira, which occur in urine).
b. Typical minimum time from excretion to infectivity.
c. Estimated maximum life of infective stage at 20°–30° C.
d. Includes polio-, echo-, and coxsackieviruses.
e. Multiplication takes place predominantly on food.
f. Includes enterotoxigenic, enteroinvasive, and enterophathogenic E. coli.
g. Ancylostoma duodenale and Necator americanus.
h. Latency is minimum time from excretion by man to potential reinfection of man. Persistence here refers to maximum survival time of final infective stage. Life cycle involves one intermediate host.
i. Latency aud persistence as for Taenia. Life cycle involves two intermediate hosts.
j. Multiplication takes place in intermediate snail host.
k. For the reasons given in Chapter 1, Leptospira spp. do not fit any of the categories defined in Table 2-2.

Source: Shuval et al. 1986

TABLE 2-4

Table 8-5 a

Helminthic pathogens excreted in feces

| Helminth | Common name | Disease | Transmission | Distribution |
|---|---|---|---|---|
| Ancylostoma duodenale | Hookworm | Hookworm | Man -> soil -> man | Mainly in warm wet climates |
| Ascaris lumhricoides | Roundworm | Ascariasis | Man -> soil -> man | Worldwide |
| Clonorchis sinersis | Chinese liver fluke | Clonorchiasis | Man or animal -> aquatic snail -> fish -> man | Southeast Asia |
| Diphyllobothrium latum | Fish tapeworm | Diphyllobothriasis | Man or animal -> copepod -> fish -> man | Widely distributed, mainly in temperate regions |
| Enterobius vermicularis | Pinworm | Enterobiasis | Man -> man | Worldwide |
| Fasciola hepatica | Sheep liver fluke | Fascioliasis | Sheep -> aquatic snail -> aquatic vegetation -> man | Worldwide in sheep- and cattle-raising areas |
| Fasciolopsis buski | Giant intestinal fluke | Fasciolopsiasis | Man or pig -> aquatic snail -> aquatic vegetation -> man | Southeast Asia, mainly China |
| Gastrodiscoides hominis | n.a. | Gastrodiscoidiasis | Pig -> aquatic snail -> aquatic vegetation -> man | India, Bangladesh, Vietnam, Philippines |
| Heterophyes heterophyes | n.a. | Heterophyiasis | Dog or cat -> brackish water snail -> brackish-water fish -> man | Middle East, southern Europe, Asia |
| Hymenolepis nana | Dwarf tapeworm | Hymenolepiasis | Man or rodent -> man | Worldwide |
| Metagonimus yokogawai | n.a. | Metagonimiasis | Dog or cat -> aquatic snail -> freshwater fish -> man | East Asia, Siberia (USSR) |
| Necator americanus | Hookworm | Hookworm | Man -> soil -> man | Mainly in warm wet climates |
| Opisthorchis felineus | Cat liver fluke | Opisthorchiasis | Cat or man -> aquatic snail -> fish -> man | USSR, Thailand |
| O. viverrini | n.a. | | | |
| Paragonimus westermani | Lung fluke | Paragonimiasis | Pig, man, dog, cat, or other animal -> aquatic snail -> crab or crayfish -> man | Southeast Asia, scattered foci in Africa and South America |
| Schistosoma haematobium | Schistosome | Schistosomiasis; bilharziasis | Man -> aquatic snail -> man | Africa, Middle East, India |
| S. japonicum | | | Animals and man -> snail -> man | Southeast Asia |
| S. mansoni | | | Man -> aquatic snail -> man | Africa, Middle East, Central and South America |
| Strongyloides stercoralis | Threadworm | Strongyloidiasis | Man -> man | Mainly in warm wet climates |
| Taenia saginata | Beef tapeworm | Taeniasis | Man -> cow -> man | Worldwide |
| T. solium | Pork tapeworm | Taeniasis | Man -> pig (or man) -> man | Worldwide |
| Trichuris trichiura | Whipworm | Trichuriasis | Man -> soil -> man | Worldwide |

n.a. Not applicahle.

Viral pathogens excreted in feces

Table 8-5 b

| Virus | Disease | Can symptomless infections occur? | Reservoir |
|---|---|---|---|
| Adenoviruses | Numerous conditions | Yes | Man |
| Enteroviruses | | | |
| Polioviruses | Poliomyelitis, paralysis, and other conditions | Yes | Man |
| Echoviruses | Numerous conditions | Yes | Man |
| Coxsackieviruses | Numerous conditions | Yes | Man |
| Hepatitis A virus | Infectious hepatitis | Yes | Man |
| Reoviruses | Numerous conditions | Yes | Man and animals |
| Rotaviruses, Norwalk agent, and other viruses | Diarrhea | Yes | Probably man |

Source: Shuval et al. 1986

Table 8-5 c

Bacterial pathogens excreted in feces

| Bacterium | Disease | Can symptomless infection occur? | Reservoir |
|---|---|---|---|
| Campylobacter fetus ssp. jejuni | Diarrhea | Yes | Animals & man |
| Pathogenic Escherichia coli[a] | Diarrhea | Yes | Man[b] |
| Salmonella | | | |
| S. typhi | Typhoid fever | Yes | Man |
| S. paratyphi | Paratyphoid fever | Yes | Man |
| Other salmonellae | Food poisoning and other salmonelloses | Yes | Animals & man |
| Shigella spp. | Bacillary dysentery | Yes | Man |
| Vibrio | | | |
| V. cholerae | Cholera | Yes | Man |
| Other vibrios | Diarrhea | Yes | Man |
| Yersinia enterocolitica | Diarrhea and septicemia | Yes | Animals & man[c] |

a. Includes enterotoxigenic, enteroinvasive, and enteropathogenic E. coli.
b. Although many animals are infected by pathogenic E. coli, each serotype is more or less specific to a particular animal host.
c. Of the thirty or more serotypes identified so far, a number seem to be associated with particular animal species. There is at present insufficient epidemiological and serological evidence to determine whether distinct serotypes are specific to primates.

Table 8-5 d

TABLE 2-3

Protozoal pathogens excreted in feces

| Protozoon | Disease | Can symptomless infection occur? | Reservoir |
|---|---|---|---|
| Balentidium coli | Diarrhea, dysentery, and colonic ulceration | Yes | Man & animals (especially pigs and rats) |
| Entamoeba histolytica | Colonic ulceration, amoebic dysentery, and liver abscess | Yes | Man |
| Giardia lamblia | Diarrhea and malabsorption | Yes | Man and animals |

Source: Peachem et al. (1983).

Sources: Shuval et al. 1986

Table 8-6

**Table 2.11** Water-borne pathogens and their effect on health (Cowan and Johnson 1984)

| Group | Genus | Effects on human health |
|---|---|---|
| Bacteria | *Salmonella* | Typhoid fever, paratyphoid fever, enteritis, salmonellosis, food poisoning |
| | *Shigella* | Dysentery |
| | *Escherichia* | Enteritis (pathogenic strains) |
| | *Vibrio* | Cholera, enteritis, food poisoning |
| | *Clostridium* | Gas gangrene, tetanus, botulism, food poisoning |
| | *Leptospira* | Leptospirosis |
| | *Mycobacterium* | Tuberculosis, skin granuloma |
| Viruses | Poliovirus | Fever, poliomyelitis, enteritis |
| | Coxsackievirus A | Headache, muscular pain |
| | Coxsackievirus B | Nausea, meningitis |
| | Echovirus | Diarrhoea, hepatitis |
| | Adenovirus | Fever, respiratory infection, enteritis, inflammation of the eyes (conjunctivitis), involvement of central nervous system |
| | Reovirus | Common cold, respiratory tract infections, diarrhoea, hepatitis |
| | Hepatitis A virus | Infectious hepatitis (fever, nausea, jaundice) |
| Protozoa | *Entamoeba* | Amoebic dysentery |
| | *Giardia* | Giardiasis |
| Helminths Trematodes | *Schistosoma* | Schistosomiasis (Bilharzia) |
| Cestodes | *Taenia* | Tapeworm infestation in man, in cattle eating eggs (*T. saginata* or *T. solium*, respectively), eggs develop into the Cysticerus stage |
| Nematodes | Ascaris | Roundworn infestation |
| | *Anchylostomum* | Hook worm infestation |
| | *Heterodera* | Potato cyst eelworm |

Source: Feigin et al. 1991

Table 8-7

**Figure 4.1 Pathogen-host properties influencing the sequence of events between the presence of a pathogen in excreta or wastewater and measurable human disease attributable to excreta or wastewater use**

**EXCRETED LOAD**

- latency
- multiplication
- persistence
- treatment survival

↓

**INFECTIVE DOSE APPLIED TO LAND/WATER**

- persistence
- intermediate host
- type of use practice
- type of human exposure

↓

**INFECTIVE DOSE REACHES HUMAN HOST**

- human behaviour
- pattern of human immunity

↓

**RISKS OF INFECTION AND DISEASE**

- alternative routes of transmission

↓

**PUBLIC HEALTH IMPORTANCE OF EXCRETA AND WASTEWATER USE**

From Blum & Feachem (1985), reproduced by permission of the International Reference Centre for Waste Disposal.

Source: Mara/Caircross 1989

Table 8-8

TABLE 2-14

Epidemiological characteristics of enteric pathogens vis-à-vis their effectiveness in causing infections through wastewater irrigation

| Pathogen | Persistence in environment | Minimum infective dose | Immunity | Concurrent routes of infection | Latency soil development stage |
|---|---|---|---|---|---|
| Viruses | Medium | Low | Long | Mainly home contact and food and water | No |
| Bacteria | Short/medium | Medium/high | Short/medium | Mainly home contact and food and water | No |
| Protozoa | Short | Low/medium | None/little | Mainly home contact and food and water | No |
| Helminths | Long | Low | None/little | Mainly soil contact outside home and food | Yes |

Source: Shuval et al. 1986

Table 8-9

Table 8.1 Examples of increased prevalence of schistosomiasis resulting from water resource development projects

| Country | Project (year completed) | Preproject prevalence (%) | Postproject prevalence (%) | Schistosome species |
|---|---|---|---|---|
| Egypt[a] | Aswan dam (first) (1906) | 6 | 60 (3 yr later) | *S. haematobium*, *S. mansoni* |
| Sudan[b] | Gezira scheme (1925) | 0 | 30–60 (15 yr later) | *S. haematobium*, *S. mansoni* |
| Tanzania[c] | Arusha Chini (1937) | low | 53–86 (30 yr later) | *S. mansoni* |
| Zambia and Rhodesia[d] | Lake Kariba (1958) | 0 | 16 adults, and 69 children (10 yr later) | *S. haematobium*, *S. mansoni* |
| Ghana[d] | Volta Lake (1966) | low | 90 (2 yr later) | *S. haematobium* |
| Nigeria[d] | Lake Kainji (1969) | low | 31 (1 yr later) 45 (2 yr later) | *S. haematobium* |
| Iran[e] | Dez pilot irrigation project (1965) | 15 | 27 (2 yr later) | *S. haematobium* |

**Source: Hillman in Rydzewski ed. 1987**

Table 8-10

Table 2.1 Type of vector infection, diseases, and disease organism

| Type of vector infection | Disease | Disease organism |
|---|---|---|
| Mosquito-borne | Malaria | Protozoon |
| | Filariasis | Nematode |
| | Yellow fever | Viruses |
| | Dengue | (arbo viruses = |
| | Encephalitis | arthropod-borne |
| | Other arbo-viral infections | viruses) |
| Snail-borne | Schistosomiasis (bilharzia) | Trematode |
| | Clonorchiasis | Trematode |
| | Opisthorchiasis | Trematode |
| | Paragoniamiasis | Trematode |
| | Fascioliasis | Trematode |
| | Fasciolopsiasis | Trematode |
| Fly-borne | African trypanosomiasis (sleeping sickness) | Protozoon |
| | Onchocerciasis (river blindness) | Nematode |
| | Leishmaniasis (kala azar, oriental sore) | Protozoon |
| | Loiasis (various types) | Nematode |
| Miscellaneous | | |
| Water flea | Dracontiasis (guinea worm) | Nematode |
| Bug | American trypanosomiasis (Chagas' disease) | Protozoon |
| Louse/tick | Plague, louse-borne fevers, and other fevers (tick-borne, mite-borne) | Bacteria, spirochete, rickettsiae |

**Source: Oomen et al. 1990**

## Fact sheet for Schistosomiasis

| | |
|---|---|
| Common name | Bilharzia |
| Type of causal organism | Blood fluke, genus *Schistosoma.* |
| Important species | *Schistosoma haematobium, mansoni* and *japonicum.* |
| Vector | Aquatic snails mainly of the genera *Bulinus, Biomphalaria* and *Oncomelania*, respectively . |
| Transmission | Human contact with water containing infective stages which are shed from infected snails. Contact often occurs while bathing. |
| Environment | Fresh water associated with irrigation schemes, reservoirs and water holes. |
| Effect on human health | Heavily infected individuals feel unwell and weak and may have seriously diseased liver or bladder. |
| Diagnosis | Eggs are found in stool (*mansoni* and *japonicum*) and urine (*haematobium*). |
| Treatment | Effective curative drugs are available. |
| Economic importance | An estimated 200 million people are infected but heavy infection is patchy. However, both the distribution and the number of heavy infections are increasing. |
| Vector control | Removal of snail habitats or killing snails with chemicals. |
| Prevention | Provision of safe water sources and proper sanitation, reduced contamination of water with human faeces and urine, changes in human behaviour. |

## Fact sheet for Onchocerciasis

| | |
|---|---|
| Common name | River blindness |
| Type of causal organism | Filarial worm |
| Important species | *Onchocerca volvulus* |
| Vector | Blackflies of the genus *Simulium.* Important species include members of the *Simulium damnosum complex.* |
| Transmission | By the bite of blackflies which previously fed on infected humans. They bite during the day. |
| Environment | Within about 10kms of rivers and streams where the flies breed in clean, well aerated, fast flowing water. |
| Effect on human health | Intense itching, skin changes and swelling with blindness in the later stages. |
| Diagnosis | Examination of skin snips. |
| Treatment | Oral administration of a newly developed drug called Ivermectin. |
| Economic importance | Fear of blindness causes people to leave the river valleys. Severe disability due to blindness. |
| Vector control | Aerial spraying of breeding sites. Design of spillways and canals to reduce breeding. |
| Prevention | Repellents; vector control. |

## Fact sheet for Japanese Encephalitis

| | |
|---|---|
| Common name | J.E. |
| Type of causal organism | Virus |
| Vector | Mosquitoes in the genus *Culex.* |
| Transmission | Bite of mosquito. Animal reservoir in pigs and birds such as herons and egrets. |
| Environment | Ricefields. Night biting mosquitoes. |
| Effect on human health | Serious mental disturbances leading to brain damage and death. In epidemics children are the main victims. |
| Diagnosis | Difficult and specialised. |
| Treatment | Supportive only. |
| Economic importance | Only a small percentage of infected people develop symptoms. Epidemics could severely disrupt irrigation projects. |
| Vector control | Ricefield breeding mosquitoes are difficult to control. |
| Prevention | Avoid pig rearing near irrigation schemes; environmental management. |

## Fact sheet for Malaria

| | |
|---|---|
| Type of causal organism | Blood protozoon, genus *Plasmodium* |
| Important species | *Plasmodium falciparum, vivax, ovale* and *malariae.* |
| Vector | Mosquitoes of the genus *Anopheles*. There are one or two important species in each region. |
| Transmission | By the bite of mosquitoes which previously fed on infected humans. |
| Environment | Within 1-2kms of suitable breeding sites which include a wide variety of relatively clean water, depending on species. The mosquito bites at night. |
| Effect on human health | Fever and weakness are common. *P. falciparum* infection can lead to death if untreated. Partial immunity after long exposure. |
| Diagnosis | Examination of blood films. |
| Treatment | Effective prophylactic and curative drugs are available but there is increasing drug resistance. |
| Economic importance | Many hundreds of millions of people are infected or exposed but partial immunity is widespread. Can seriously undermine development projects, especially when non-immune settlers are involved. |
| Vector control | Source reduction; residual house spraying; environmental management. |
| Prevention | Prophylaxis; personal protection using bednets and repellents; vector control. |

## Fact sheet for Dengue and Dengue Haemorrhagic Fever

| | |
|---|---|
| Common name | Dengue and Dengue Haemorrhagic Fever (DHF) |
| Type of causal organism | Virus |
| Vector | Mosquitoes of the genus *Aedes*. A common species is *Aedes aegypti.* |
| Transmission | Human contact with day biting mosquitoes. |
| Environment | Urban areas, houses and gardens. |
| Effect on human health | Often affects children. DF is relatively mild but DHF is a serious complication requiring hospitalization and frequently results in death. |
| Diagnosis | Difficult and specialised. |
| Treatment | Supportive only. |
| Economic importance | Increasing numbers of epidemics in many tropical and sub-tropical areas. Great public concern. |
| Vector control | Destruction or emptying artificial containers twice per week. Insecticidal fogging can be used to halt an epidemic. |
| Prevention | Vector control. |

## Fact sheet for African Trypanosomiasis

| | |
|---|---|
| Common name | Gambian and Rhodesian Sleeping Sickness |
| Type of causal organism | Protozoon of the genus *Trypanosoma.* |
| Important species | *Trypanosoma gambiense* and *rhodesiense* |
| Vector | Tsetse flies, genus *Glossina.* |
| Transmission | There is an animal reservoir in some regions. |
| Environment | Savannah woodland and riverain vegetation of Sub-saharan Africa. The fly bites during the day. |
| Effect on human health | Mental disturbances, brain damage and death. |
| Diagnosis | Detection of parasite in blood film or other parts of the body. |
| Treatment | Supervised administration of drugs with toxic side-effects. |
| Economic importance | A similar disease is a major constraint on cattle production. The human disease is usually sporadic but devastating epidemics continue to occur. |
| Vector control | Environmental management; insecticide spraying; trapping. |
| Prevention | Prophylaxis; active case finding where no animal reservoir; reduced fly contact. |

Table 8-11 cont.

C-4 Guidelines for Forecasting Vector-Borne Disease

## Fact sheet for Yellow Fever

| | |
|---|---|
| Type of causal organism | Virus |
| Vector | Mosquito of the genus *Aedes*. A common species is *Aedes aegypti*. |
| Transmission | By the bite of mosquitoes which previously fed on infected humans or monkeys. |
| Environment | Either forests inhabited by monkeys or urban areas where the mosquito breeding site is artificial containers. The mosquito bites by day. |
| Effect on human health | Many infections may not produce symptoms but others are very serious. |
| Diagnosis | Difficult and specialised. |
| Treatment | Supportive only. |
| Economic importance | Occasional epidemics with widespread sickness and death. |
| Vector control | In urban areas artificial containers should be destroyed or emptied twice per week. Insecticidal fogging can be used to halt an epidemic. |
| Prevention | By vector control and vaccination of the human population. |

Appendix C - The Fact Sheets C-5

## Fact sheet for Lymphatic Filariasis

| | |
|---|---|
| Common name | Elephantiasis, Bancroftian filariasis, Brugian filariasis. |
| Type of causal organism | Filarial worms |
| Important species | *Wuchereria bancrofti*, *Brugia malayi*. |
| Vector | Mosquitoes of the genera *Anopheles*, *Aedes*, *Culex* and *Mansonia*. In urban areas the vector is usually *Culex quinquefasciatus* which breeds in water polluted with sewage. |
| Transmission | By the bite of mosquitoes which previously fed on infected humans or, in one very restricted area, on wild animals. |
| Environment | Mainly urban. Mainly night biting. |
| Effect on human health | Repeating fever. Legs and sometimes genitals become very swollen and infected in later stages. |
| Diagnosis | Detection of the worm larvae in a blood film. |
| Treatment | Oral administration of a cheap and effective drug known commonly as DEC. |
| Economic importance | Many millions of people are infected but are not sick while others suffer repeated fever. People with swollen limbs suffer much distress and have difficulty moving about. |
| Vector control | Source reduction by drainage and larviciding in urban areas; residual house spraying. |
| Prevention | By vector control or contact prevention. |

C-8 Guidelines for Forecasting Vector-Borne Disease

## Fact sheet for Visceral Leishmaniasis

| | |
|---|---|
| Common name | Kala Azar |
| Type of causal organism | Protozoon of the genus *Leishmania*. |
| Important species | *Leishmania donovani* |
| Vector | Sandflies, genus *Phlebotomus* in the Old World and genus *Lutzomyia* in the new world. |
| Transmission | Bite of sandfly. Animal reservoir in rodents and canines as well as people. |
| Environment | In and around houses in India, more rural areas elsewhere. |
| Effect on human health | Enlargement of liver and spleen. Can cause death if untreated. |
| Diagnosis | Detection of parasites in organ samples. Detection of antibodies. |
| Treatment | Supervised administration of drugs with toxic side-effects. |
| Economic importance | Epidemics have occurred in India but elsewhere cases are sporadic. |
| Vector control | Residual house spraying with insecticides where transmission is domestic. |
| Prevention | Destruction of canine reservoirs; vector control; repellents; resiting villages. |

Appendix C - The Fact Sheets C-9

## Fact sheet for Cutaneous Leishmaniasis

| | |
|---|---|
| Common names | Oriental sore, Espundia, Chiclero's ulcer |
| Type of causal organism | Protozoon of the genus *Leishmania*. |
| Important species | *Leishmania tropica, major, braziliensis* |
| Vector | Sandflies, genus *Phlebotomus* in the Old World and genus *Lutzomyia* in the new world |
| Transmission | Bite of sandfly. Many reservoir animals, especially colonial rodents. |
| Environment | Semi-arid regions where irrigation is likely; S. American forests. |
| Effect on human health | Open sore, self-healing in some regions, more serious in others. |
| Diagnosis | Microscopic examination of stained material extracted from the ulcer. |
| Treatment | Self-healing forms require no special treatment. Supervised administration of drugs with toxic side-effects. |
| Economic importance | Serious outbreaks reported on water development projects in some semi-arid regions. |
| Vector control | Residual house spraying. |
| Prevention | Destruction of animal reservoirs; vaccination. |

Source: Birley 1992

Table 8-12

Table 2-1
A broad indication of the vector-borne diseases naturally transmitted in each zoogeographical region.

**Mexico, Central and South America**
Widespread dengue and yellow fever, some bancroftian filariasis, some onchocerciasis, widespread cutaneous and restricted visceral leishmaniasis, widespread schistosomiasis (*mansoni*), widespread Chagas disease, widespread malaria.

**North Africa and Asia excluding India and S.E. Asia**
Widespread dengue, guinea worm, some bancroftian filariasis, widespread cutaneous and restricted visceral leishmaniasis, restricted schistosomiasis, malaria.

**India, S.E. Asia, the Indonesian and Philippine archipelago and Indian Ocean**
Widespread dengue, guinea worm, widespread bancroftian and brugian filariasis, some cutaneous and more visceral leishmaniasis, restricted schistosomiasis (*japonicum*), widespread malaria, Japanese encephalitis.

**New Guinea, Solomons, Vanuatu and other Islands of the Western Pacific**
Restricted dengue, widespread bancroftian filariasis, restricted schistosomiasis (*japonicum*), widespread malaria.

**Africa South of the Sahara, Madagascar and S.W. Arabia.**
Widespread dengue and yellow fever, bancroftian filariasis, loiasis, widespread onchocerciasis, restricted cutaneous and visceral leishmaniasis, widespread schistosomiasis, sleeping sickness, widespread malaria, guinea worm.

Table 8-13

Table 2-2
A broad indication of the distribution of disease between regions.

**Japanese encephalitis** is associated with rice growing and pig keeping in Asia, sometimes becoming more severe away from the equator.
**Yellow fever** is found in West Africa and South America, but not in Asia (although the vector is present).
**Malaria** is widespread in the tropics and sub-tropics, restricted by altitude.
**Sleeping sickness** is restricted to Africa, between the Sahara and the Zambezi river basin.
**American trypanosomiasis, or Chagas disease,** is restricted to Mexico, Central and South America. It is not specifically associated with water.
**Bancroftian and brugian filariasis** are associated with the humid tropics or coastal areas.
**Onchocerciasis** is restricted to West Africa, South and Central America and a few foci in East and Central Africa.
**Dengue fever** is spreading throughout the tropics and sub-tropics.
**Dengue haemorrhagic fever** is currently reported mainly from India, S.E. Asia, Philippines, the Caribbean and the Indian Ocean.
**Schistosomiasis** due to *S. mansoni* and *S. haematobium* is associated with the savannahs and semi-arid regions of Africa and the Middle-East and South America.
**Schistosomiasis** due to *S. japonicum* is restricted to South East Asia, China and the Philippines.
Other forms of schistosomiasis with very restricted distribution include *intercalatum* in Africa and *malayiensis/mekongi* in South East Asia.

Source: Birley 1992

Table 2-7
Distribution of mosquito-borne diseases.

Table 8-14

| Mosquito | Disease | Distribution |
|---|---|---|
| Subfamily: Anopheline<br>Genus: *Anopheles* | Malaria | Throughout tropics and sub-tropics |
| | Bancroftian filariasis | Asia and Africa |
| | Brugian filariasis | Asia |
| | O'nyong nyong virus | Africa |
| Subfamily: Culicine<br>Genus: *Culex* | Bancroftian filariasis | Throughout tropics |
| | Encephalitis virus | Asia, Americas, Europe, Africa |
| Subfamily: Culicine<br>Genus: *Mansonia* | Brugian filariasis | Asia |
| | Other arboviruses | Africa, Americas |
| Subfamily: Culicine<br>Genus: *Aedes* | Yellow fever virus | Africa, Americas |
| | Dengue virus | Asia, Americas, Africa |
| | Dengue Haemorragic | Asia , Americas |
| | Other arboviruses | Asia, Americas, Africa |
| | Bancroftian filariasis | Pacific |

Source: Birly 1992

# Appendix 2
## Geographical distribution of schistosomiasis

The list below shows the geographical distribution of schistosomiasis as published in WHO Bulletin 59(1), 1981. The maps overleaf show the geographical distribution of schistosomiasis as published in "The control of schistosomiasis" (a report of a WHO Expert Committee), WHO Technical Report Series No. 728, 1985, pp 17–18. There may well be other endemic areas, not yet reported, on islands and in small countries.

The latest and fullest information about the disease in a particular area may be obtained by writing to one or more of the following organisations:

- a School of Tropical Medicine related to, or working in, the country concerned;
- Pan-American Health Organisation regional office, Washington DC, USA;
- World Health Organisation regional office/HQ, Geneva, Switzerland;
- the British Museum (Natural History), South Kensington, London, UK;
- the Danish Bilharziasis Laboratory, Danmarks Akvarium, Copenhagen, Denmark.

| Country or area | Population[a] | | Notification of disease | Persons exposed to disease | | Endemicity of human schistosomiasis[b] | | | | Schistosomes of veterinary importance |
|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Total (thousands) | | No. | % of population | S. haematobium | S. mansoni | S. intercalatum | S. japonicum | |
| **Africa** | | | | | | | | | | |
| Algeria | 1977 | 17 910 | – | ... | ... | + | – | – | – | – |
| Angola | 1975 | 6 761 | + | ... | ... | + + + | + + | – | – | – |
| Benin | 1977 | 3 286 | + | ... | ... | + + + | + | – | – | – |
| Botswana | 1977 | 710 | – | 200 000 | 28.2 | + + | + | – | – | S. mattheei |
| Burundi | 1975 | 3 763 | – | 250 000 | 6.6 | – | + | – | – | – |
| Central African Republic | 1970 | 2 370 | + | 1 500 000 | 63.3 | + + | + + + | + | – | S. bovis |
| Chad | 1977 | 4 197 | – | 3 600 000 | 85.8 | + + + | + + | + | – | S. bovis |
| Congo[c] | 1977 | 1 440 | ... | ... | ... | + + | + | – | – | ... |
| Egypt | 1977 | 38 741 | – | 18 000 000 | 46.4 | + + + | + + + | – | – | ... |
| Ethiopia | 1977 | 28 981 | + | 9 000 000 | 31.0 | + + | + + | – | – | – |
| Gabon | 1970 | 500 | + | 263 000 | 52.6 | + + | + | + | – | – |
| Gambia | 1977 | 553 | – | 400 000 | 72.3 | + + + | – | – | – | – |
| Ghana | 1976 | 10 309 | – | 5 000 000 | 48.5 | + + + | + + | – | – | S. bovis |
| Guinea | 1967 | 3 702 | – | 1 500 000 | 40.5 | + + | + + | – | – | – |
| Guinea-Bissau | 1972 | 482 | + | 72 500 | 15.0 | + + | + | – | – | – |
| Ivory Coast | 1975 | 6 671 | + | ... | ... | + + | + | – | – | – |
| Kenya | 1977 | 14 337 | + | 6 000 000 | 41.8 | + + | + + | – | – | S. bovis S. mattheei |
| Liberia | 1974 | 1 503 | + | 700 000 | 46.6 | + + | + | – | – | – |
| Libyan Arab Jamahiriya | 1975 | 2 444 | + | 183 285 | 7.5 | + | + | – | – | – |
| Madagascar | 1970 | 6 750 | + | 5 783 503 | 85.7 | + + + | + + + | – | – | – |
| Malawi | 1977 | 5 572 | – | ... | ... | + + + | + + + | – | – | – |
| Mali | 1976 | 6 035 | + | 3 571 292 | 59.2 | + + + | + | – | – | – |
| Mauritania | 1976 | 1 481 | – | 375 000 | 25.3 | + + | – | – | – | – |
| Mauritius | 1977 | 909 | + | 200 000 | 22.0 | + | – | – | – | – |
| Morocco[c] | 1977 | 18 245 | ... | ... | ... | + + | – | – | – | ... |
| Mozambique | 1976 | 9 444 | – | ... | ... | + + + | + + | – | – | – |
| Namibia[c] | 1974 | 852 | ... | ... | ... | + + | + + | – | – | ... |
| Niger[c] | 1977 | 4 859 | ... | ... | ... | + + | – | – | – | ... |
| Nigeria | 1977 | 78 660 | + | 15 000 000 | 19.1 | + + + | + + | – | – | S. bovis S. mattheei |
| Rwanda | 1977 | 4 368 | – | ... | ... | – | + | – | – | – |
| Senegal | 1976 | 5 115 | – | 2 500 000 | 48.9 | + + + | + + | – | – | S. bovis |
| Sierra Leone[c] | 1977 | 3 470 | ... | ... | ... | + + | + | – | – | ... |
| Somalia | 1972 | 2 941 | – | 1 000 000 | 34.0 | + + | – | – | – | – |
| South Africa[c] | 1976 | 26 129 | ... | ... | ... | + + | + + | – | – | ... |
| Sudan | 1977 | 16 953 | – | 15 000 000 | 88.5 | + + + | + + + | – | – | S. bovis |
| Swaziland | 1976 | 499 | + | 270 000 | 54.1 | + + + | + | – | – | S. mattheei |
| Togo | 1977 | 2 348 | – | 1 953 778 | 83.2 | + + + | + + | – | – | – |
| Tunisia | 1977 | 6 065 | – | 169 515 | 2.8 | + | – | – | – | ... |
| Uganda | 1977 | 12 353 | – | 1 000 000 | 8.1 | + + | + + | – | – | S. bovis |
| United Republic of Cameroon | 1976 | 7 663 | – | 3 700 000 | 48.3 | + + | + + | + | – | S. bovis |
| United Republic of Tanzania | 1977 | 16 073 | – | 3 000 000 | 18.7 | + + + | + + | – | – | S. bovis |
| Upper Volta | 1975 | 6 144 | – | ... | ... | + + + | + | – | – | – |
| Zaire | 1977 | 26 376 | + | 10 000 000 | 37.9 | + | + + | + | – | – |
| Zambia | 1976 | 5 138 | – | ... | ... | + + + | + + | – | – | – |
| Zimbabwe[c] | 1977 | 6 740 | ... | ... | ... | + + + | + + | | | ... |
| **South America and the Caribbean** | | | | | | | | | | |
| Antigua | 1977 | 72 | – | ... | ... | – | + | – | – | ... |
| Brazil | 1977 | 112 239 | – | 30 475 000 | 27.1 | – | + + + | – | – | – |
| Dominican Republic | 1977 | 4 978 | + | 279 282 | 5.6 | – | + + | – | – | – |
| Guadeloupe | 1976 | 321 | – | ... | ... | – | + | – | – | – |
| Martinique | 1977 | 319 | – | ... | ... | – | + | – | – | – |
| Montserrat | 1974 | 12 | – | ... | ... | – | + | – | – | – |
| Puerto Rico | 1977 | 3 303 | + | 2 079 184 | 62.9 | – | + + | – | – | ... |
| St Lucia | 1975 | 112 | + | ... | ... | – | + | – | – | – |
| St Martin | 1972 | 5 | ... | ... | ... | – | + | – | – | – |
| Suriname | 1971 | 385 | – | 8 608 | 2.2 | – | + | – | – | – |
| Venezuela | 1977 | 12 737 | – | 4 000 000 | 31.4 | – | + + | – | – | |
| **Asia** | | | | | | | | | | |
| People's Republic of China | 1970 | 700 000 | ... | ... | ... | – | – | – | + + | ... |
| Democratic Kampuchea[c] | 1969 | 6 701 | ... | ... | ... | – | – | – | + | ... |
| Democratic Yemen | 1977 | 1 797 | – | 100 000 | 5.7 | + + | + | – | – | – |
| India[c] | 1977 | 625 818 | ... | ... | ... | + | – | – | – | ... |
| Indonesia | 1975 | 130 597 | – | 10 000 | 0.01 | – | – | – | + | – |
| Iran | 1977 | 34 374 | – | 150 000 | 0.4 | + | – | – | – | S. bovis |
| Iraq | 1977 | 12 171 | – | 5 310 000 | 43.6 | + + + | – | – | – | S. bovis |
| Japan[c] | 1977 | 113 863 | ... | ... | ... | – | – | – | + | ... |
| Lao People's Democratic Republic[c] | 1977 | 3 427 | ... | ... | ... | – | – | – | + | ... |
| Lebanon[c] | 1970 | 2 126 | ... | ... | ... | + | – | – | – | ... |
| Malaysia | 1977 | 12 600 | – | 1 000 000 | 7.9 | – | – | – | + | – |
| Philippines | 1977 | 45 028 | + | 3 961 000 | 8.8 | – | – | – | + + + | – |
| Saudi Arabia | 1974 | 7 013 | – | 1 000 000 | 14.3 | + + | + + | – | – | – |
| Syrian Arab Republic | 1977 | 7 845 | – | ... | ... | + + | – | – | – | – |
| Thailand | 1977 | 44 039 | + | ... | ... | – | – | – | + | S. spindale |
| Turkey | 1977 | 42 134 | – | ... | ... | + | – | – | – | – |
| Yemen Arab Republic | 1975 | 5 238 | + | 2 000 000 | 38.2 | + + | + + + | – | – | – |

[a] Latest official estimate (3).
[b] + – low endemicity; + + – medium endemicity; + + + – high endemicity.
[c] These countries did not respond to the questionnaire.
... Data not provided by country.

Source: Oomen et al. 1990

Table 1. Some estimates of crop losses due to pests of cultivated crops in selected African countries

**Table 9-1**

| Country | Crop | % Crop losses caused by | | | |
|---|---|---|---|---|---|
| | | Insects | Diseases | Birds | Weeds |
| Ethiopia | Coffee | - | 20-25 | - | - |
| | Sesame | - | 100 | - | - |
| | Sorghum | - | - | - | 35 |
| Gambia | Millet | - | 20-30 | - | - |
| Ghana | Rice | 25 | 5-50 | 9-25 | 20-80 |
| | Cassava | 10-80 | 50-100 | - | - |
| | Groundnuts | 12-50 | 5-25 | - | - |
| Kenya | Cashew | - | 30 | - | - |
| | Cereals | - | - | 12 | - |
| Mozambique | Rice | 50 | - | - | - |
| Nigeria | Cocoa | 15-25 | 30-90 | - | - |
| | Coffee | 30-80 | - | - | - |
| | Grain legumes | 10-95 | - | - | - |
| | Cotton | - | 20-50 | - | - |
| | Cereals | 15-25 | 10-20 | - | - |
| Sierra Leone | Swamp rice | 10-20 | 3-80 | - | - |
| | Irrigated rice | 30-50 | - | - | - |
| | Groundnuts | - | 10 | - | - |
| | Cowpea | 30 | - | - | - |
| Sudan | Rice | - | - | - | 69 |
| | Millet | 20-30 | - | - | - |
| Tanzania | Maize | 3-27 | 5-30 | - | - |
| | Sorghum | 4 | - | - | - |
| | Wheat | - | 30-100 | - | - |
| | All grain | - | - | 50-100 | - |

Table 2. Estimates of crop losses of stored products in some African countries, 1970

**Table 9-2**

| Country | Crop | % Loss |
|---|---|---|
| Burkina Faso | Legumes | 50-100 |
| Cameroon | Legumes | 10 |
| | Cereals | 10-20 |
| Egypt | Rice | 5 |
| Ghana | Legumes | 9-12 |
| | Cereals | 10-15 |
| | Yams | 15-40 |
| Nigeria | Legumes | 30-40 |
| | Maize | 20-30 |
| | Rice | 5 |
| | Yams | 20-67 |
| Sierra Leone | Rice | 5-10 |
| | Legumes | 8 |
| Tanzania | Legumes | 5 |
| Uganda | Legumes | 20-30 |
| | Cereals | 15-20 |

**Source: Youdeowei in Yaninek/Herren (IITA) 1989**

AGRICULTURE Checklist 1- KEY BIO-PHYSICAL FACTORS FOR AGRICULTURAL RESETTLEMENT

| | Quality of Information: Available, | | Current | | Reliable | |
|---|---|---|---|---|---|---|
| | yes | no | yes | no | yes | no |
| 1. **Physical Factors** | | | | | | |
| • Bio-climatic regime: | | | | | | |
| • Rainfall- total, seasonality and range of | | | | | | |
| • variation in annual rainfall | | | | | | |
| • Temperature and thermal regime | | | | | | |
| • Length of growing period | | | | | | |
| • Wind strength | | | | | | |
| • Evapotranspiration; | | | | | | |
| • Hydrographic setting - the location of the project in relation to the characteristics of the surrounding watershed management unit; | | | | | | |
| • Water resources | | | | | | |
| Surface water-total availability, seasonal variability and quality | | | | | | |
| Ground water-total availability, aquifer recharge rates, quality, potential pollution from agricultural wastes | | | | | | |
| Upstream/downstream externalities -forest clearance, flood plain, industry, urban centres | | | | | | |
| Drainage and use of drainage water | | | | | | |
| • Soils | | | | | | |
| Taxonomic classification | | | | | | |
| Chemistry and fertility | | | | | | |
| Physical structure | | | | | | |
| Texture | | | | | | |
| Impediments to mechanization - rocks, slopes, internal | | | | | | |
| drainage and susceptibility to erosion | | | | | | |
| • Landforms | | | | | | |
| Physiography - slopes | | | | | | |
| Drainage - network, internal, water table,Groundwater recharge | | | | | | |
| Active floodplain - definition, frequency | | | | | | |
| 2. **Biological Factors** | | | | | | |
| • Ecological Zone | | | | | | |
| Areas of major biological significance; | | | | | | |
| Biogeographic context | | | | | | |
| • Ecosystem stability and resilience. | | | | | | |
| Suitability for agriculture | | | | | | |
| Pests and diseases of crops and animals | | | | | | |
| • Land cover: including vegetation and land use; | | | | | | |
| • Protected Areas: | | | | | | |
| Existing national parks or equivalent reserves | | | | | | |
| Size, legal status, administration | | | | | | |
| Proximity to and representativeness of project area | | | | | | |
| Candidate areas requiring protection status: | | | | | | |
| Critical habitats - biota, watersheds | | | | | | |
| Riparian protection. | | | | | | |
| 3. **Natural Hazards and the risk of man-induced hazards**: | | | | | | |
| • Soil erosion, landslides, earthquakes, volcanism, | | | | | | |
| • potential human disease vectors, fire hazards. | | | | | | |

Source: Burbridge (FAO) 1988

Table 10-1 cont

AGRICULTURE Checklist 4- CROPPING SYSTEM

| | Quality of Information: Available, | Current | Reliable |
|---|---|---|---|
| | yes no | yes no | yes no |
| 1. Arable agriculture: | | | |
| Will new crops be introduced or will the cropping\system be based upon indigenous species? | | | |
| Will the cropping system be based upon irrigation or will it be rainfed ?; | | | |
| Has the system been field tested in the proposed location?; | | | |
| How much effort and skill will be required on the part of the settlers to establish and maintain the proposed cropping system ? | | | |
| Will the proposed settlers have the required skills and be able to supply the labour needed to sustain production ?; | | | |
| 2. Animal Husbandry: | | | |
| Would animals be part of the production system ?; | | | |
| Which type will be used for which purpose ?; | | | |
| Would crop and animal production be integrated ?; | | | |
| Will these animals be susceptible to local diseases, and | | | |
| is there a risk of introducing new diseases into indigenous stocks ?; | | | |
| Is there a programme for inspection of farm animals introduced into new areas ? | | | |
| 3. Power: | | | |
| What sources of power would be required by the production/cropping systems-human, animal, mechanical or would a mixture be used ?; | | | |
| Are there adequate supplies of labour, animals machines and the food/fuel and necessary services to maintain the required power at costs settlers are able to afford ?; | | | |
| Has provision been made for adequate fuelwood for cooking, heating and other purposes ?; | | | |
| 4. Tree crops: | | | |
| Where tree plantations are part of the production system, would a cover crop, ring weeding or clear weeding be applied ? | | | |

AGRICULTURE Checklist 5- INPUTS REQUIRED

| | Quality of Information: Available, | Current | Reliable |
|---|---|---|---|
| | yes no | yes no | yes no |
| 1. Agro-chemicals: | | | |
| Will chemical fertilizers, biocides and other materials be required to maintain the proposed production system ?; | | | |
| Could these materials pose a hazard to the environment and/or human health if handled inappropriately ?; | | | |
| Does the management plan make provision for the safe and effective use of these materials-for example, training farmers how, in what quantities and when to apply them ?; | | | |
| Will the use of these materials be monitored? | | | |
| Have these materials been tested in the proposed location to test their effectiveness and effect on soil, water, vegetation and animals ?; | | | |
| Are the proposed materials available at a cost which the settler will be able to afford, or will less desirable and potentially hazardous materials be substituted due to availability or cost ? | | | |
| 2. To what extent would resettled farmers depend on off-farm areas for their needs, for instance building materials, grazing for livestock, or water ?; | | | |
| | yes no | yes no | yes no |
| Is there a risk that these demands would lead to conflicts with the existing population and resource uses ? | | | |

Source: Burbridge (FAO) 1988

Table 10-1 cont

AGRICULTURE Checklist 2- SITE SELECTION

| | Quality of Information: Available, | Current | Reliable |
|---|---|---|---|
| | yes no | yes no | yes no |
| 1. Have land suitability studies been carried out in accordance with FAO procedures, including: | | | |
| classification; | | | |
| percentage of total area for each class; | | | |
| major limitations (slope, depth of soil ,etc) ?; | | | |
| Will the stumps be uprooted, winrowed and burned or left in situ ? | | | |
| 2. Soil conservation: | | | |
| Will soil conservation structures be required; if so,what types ?; | | | |
| How will they be constructed and maintained ?; | | | |
| Will a cover crop be planted immediately following land clearance?; | | | |
| 3. Irrigation and Drainage: | | | |
| Will irrigation be required ?; | | | |
| Have potential irrigation water sources been tested for quality and seasonal availability ?; | | | |
| Will the use of these sources reduce water supplies to other users ?; | | | |
| Has the potential for soil salinization and/or waterlogging been assessed?; | | | |
| Will drainage structures be required ?; | | | |
| Is there a suitable discharge for the drainage water ?; | | | |
| Have existing and potential water borne disease vectors been analyses ?; | | | |
| Does the management plan deal with the long-term operation and maintenance of the irrigation and drainage facilities ?; | | | |
| 4. Preparation for initial crops: | | | |
| How much of the land will be prepared and ready for planting by the settlers ? | | | |

AGRICULTURE Checklist 3- SITE PREPARATION

| | Quality of Information: Available, | Current | Reliable |
|---|---|---|---|
| | yes no | yes no | yes no |
| 1. Land clearance: | | | |
| What extent of site modification is required ?; | | | |
| Which method of clearance will be used-mechanical or hand ?; | | | |
| Is the expertise and experience in land preparation available ?; | | | |
| Will commercially valuable trees be harvested and other species salvaged ?; | | | |
| 2. Have existing rights of access to resources been identified | | | |
| 3. Have the current land use and vegetation cover been identified ?; | | | |
| 4. Will compensation be required for loss of land or access to resources ?; | | | |
| 5. What special management measures are required for sustainable use of the proposed location: | | | |
| soil and water conservation; | | | |
| potential pest and disease problems; | | | |
| adaptation of cropping systems; | | | |
| inputs required (agro-chemicals, extension services, new crop materials, etc.) ?; | | | |
| 6. What infrastructure will be required to make the sites viable for resettlement. including | | | |
| access-roads, canals, etc.; | | | |
| water; | | | |
| power; | | | |
| irrigation and drainage | | | |
| Will the provision of this infrastructure entail major environmental modifications to the site and surrounding areas? | | | |
| 7. Has the feasibility of establishing sustainable agricultural use on the proposed site been tested ?; | | | |
| 8. Has the carrying capacity of the proposed sites(s)been evaluated ?; | | | |
| 9. Does this capacity allow for population growth and demand for land and other resources stimulated by the project?; | | | |
| 10. Have alternative locations been explored and the comparative advantage of different sites assessed ? | | | |

Source: Burbridge (FAO) 1988

Table 10-2

**Table 1.** Costs and efficiencies of different types of modern irrigation system (Coûts et efficacités pour différents systèmes d'irrigation moderne)

| Method and Type | Equipment Initial Cost $ U.S./ha | Equipment Life yr | Annual Maintenance % of Cost | Efficiency % |
|---|---|---|---|---|
| Surface (Precision) | | | | |
| Basin(level) | 370 - 1,085 | con | 1 | 70 - 90 |
| Border | 370 - 1,085 | con | 1 | 70 - 85 |
| Furrow | 150 - 750 | con | 1 | 65 - 85 |
| Conveyance | | | | |
| Lined | 400 - 1,250 | 15 | 3 | --- |
| Piped | 800 - 2,500 | 20 | 1 | --- |
| Automation | 300 | 10 | 5 | --- |
| Sprinkle | | | | |
| Lateral | | | | |
| Hand-Move | 450 - 675 | 15 | 2 | 65 - 80 |
| End-Tow | 600 - 950 | 10 | 3 | 65 - 75 |
| Side-Roll | 800 - 1,100 | 15 | 2 | 65 - 80 |
| Side-Move | 950 - 1,350 | 15 | 4 | 65 - 80 |
| Hose-Fed | 450 - 675 | 5/20 | 3 | 60 - 80 |
| Traveling Gun | 950 - 1,200 | 10 | 6 | 55 - 70 |
| Center-Pivot | | | | |
| Standard (400 m) | 1,100 | 15 | 5 | 70 - 85 |
| w/Corner | 1,200 | 15 | 6 | 65 - 85 |
| Long (500 m) | 700 | 15 | 5 | 65 - 85 |
| Linear-Moving | | | | |
| Ditch-Feed | 1,100 - 1,300 | 15 | 6 | 65 - 85 |
| Pipe-Feed | 1,600 - 2,050 | 15 | 6 | 65 - 85 |
| Solid-Set | | | | |
| Portable | 2,700 - 3,250 | 15 | 2 | 65 - 75 |
| Permanent | 2,300 - 3,500 | 20 | 1 | 65 - 75 |
| Localized | | | | |
| Orchard | | | | |
| Drip/Spray | 2,200 - 3,500 | 10/20 | 3 | 75 - 90 |
| Bubbler | 2,500 - 4,000 | 15 | 2 | 60 - 85 |
| Hose-Pull | 1,200 - 1,800 | 5/20 | 3 | 65 - 90 |
| Hose-Basin | 1,500 - 1,800 | 7/20 | 2 | 55 - 80 |
| Row-crop | | | | |
| Reusable | 3,000 - 5,000 | 10/20 | 3 | 65 - 90 |
| Disposable | 1,850 - 3,000 | 1/20 | 20 | 60 - 80 |

Derived in a large part from the ASCE 1988 Report, "Selection of Irrigation Methods"

Source: Keller in ICID 1990

Table 11-1

## Ökologische Auswirkungen von Flußstauungen

| | Wahrscheinlichkeit des Eintreffens | Auswirkung auf Flußabschnitt | Zeitliches Verhalten | Möglichkeit zur Verhinderung | abhängig von | Bedeutung |
|---|---|---|---|---|---|---|
| Klima | sicher | Einzugs-, Speicher-, Unterstromgebiet | permanent | kaum | Fläche des Speichersees. Auswirkungen sekundärer Effekte im Einzugsgebiet | Änderung des Klimas in Richtung feuchterer Verhältnisse, beschränkt auf den regionalen Bereich |
| Hydrologie | sicher | Speicher-, Unterstromgebiet | permanent | nur begrenzt | Staumanagement, Wasserführung, Flußlänge, Seegröße | Verfüllung des Speichers mit Sedimenten, geändertes Verhalten des Stromes im Bereich unterhalb des Dammes, Flußdeltaveränderungen |
| Geologie/ Geomorphologie | eventuell | Speicher-, Unterstromgebiet | ? | ? | Größe und Tiefe des Stausees; tektonisches Verhalten | Erhöhung der Erdbebenaktivität, Veränderung der Sohlenerosion, Flußdeltaveränderungen |
| Pedeologie (Böden) | sicher | Einzugs-, Speicher-, Unterstromgebiet | permanent | begrenzt | Landnutzing im Einzugsgebiet und Speichergebiet, Bewässerung im Unterstromgebiet | Einfluß auf Sedimentationsrate im Speicher, Erosionsgefahr, Schaffung neuer Kulturlandschaft, Versalzung von Böden |
| Vegetation und Fauna | sicher | Einzugs-, Speicher-, Unterstromgebiet | permanent | begrenzt | Infrastruktur und Landnutzungsänderung, Waldraubbau | Verlust naturnaher Ökosysteme, Zerschneidung der Landschaft, Verlust genetischen Potenuals |

## Biologische Auswirkungen von Flußstauungen

| Gebiet | Wirkung |
|---|---|
| Einzugsgebiet | Änderung der Wanderungsmöglichkeit für Pflanzen und Tiere (Laichwanderung, Verbreitung von Samen und Früchten etc.);<br>Versumpfung des Stauwurzelbereichs;<br>Überschwemmungen von Uferbereichen nach heftigen Regenfällen (bei flachen Ufern), Rückstau in zuführende Gewässer;<br>Veränderungen im Artengefüge von Pflanzen und Tieren |
| Speichergebiet | tendenzielle Erhöhung des Trophiegrades; „Wassergüte und Wasserqualität" (1); verrottende Vegetation führt zu Faulschlamm- und Faulgasbildung in Tiefenbereichen;<br>Entwicklung lebensfeindlicher Wasserbereiche;<br>Versumpfung und Versalzung überschwemmter Uferbereiche;<br>Labilität des entstandenen See-Ökosystems in Produktivität, Artenvielfalt und Artengefüge der Pflanzen und Tiere;<br>Massenentwicklung einzelner Arten; vor allem verstärktes Wachstum von Algen und Wasserpflanzen |
| Unterstrombereich | Änderung der Wasserzusammensetzung, Anreicherung mit Faulgasen etc.;<br>Änderung der Wasserchemie und des Strömungsverhaltens bewirkt Selektionsprozeß für Tier- und Pflanzenarten;<br>Verringerung ehemaliger Überflutungen (Dauer, Nährstoffe, Sedimente, Ausdehnung etc.);<br>Erhöhung des Tideeinflußbereiches und Ausdehnung des Salzwassereinflusses auf Wasser und Land im Deltabereich;<br>Änderung der Wanderungsmöglichkeit für Tiere (vor allem Laichwanderung von Fischarten);<br>Änderung der Lebensbedingungen der aquatischen Tierwelt (Änderung der Wasserchemie und des Strömungsverhaltens. Selektionsprozeß für Tier- und Pflanzenarten) |

## Auswirkungen von Flußstauungen auf die Fischfauna

| Gebiet | Auswirkung |
|---|---|
| Einzugsgebiet | Ausbleiben von wandernden Arten;<br>Änderung im Artengefüge;<br>Eindringen von fremden Arten aus dem Speichergebiet |
| Speichergebiet | Ausbleiben von wandernden Arten;<br>Änderung im Artengefüge durch Änderungen der Biotopbedingungen;<br>Geänderte Artenkonkurrenz;<br>Eindringen/Einbringen neuer Arten und dadurch neue Artenkonkurrenz;<br>Eutrophierung verändert Nährstoffangebot und führt zu toxischen Bedingungen (Faulgase);<br>Uferform bestimmt neue Habitatsstrukturen und beeinflußt vor allem das Laichverhalten;<br>Sekundärer Einfluß durch Fischerei |
| Unterstrombereich | Geändertes Abflußverhalten;<br>Fehlende Sedimente führen zu Habitatsveränderungen;<br>Gefahr der Gasübersättigung (Gasblasenkrankheit);<br>Eintrag von toxischen Gasen und Stoffen aus verändertem Hypolimnion;<br>Änderungen von Überflutungsflächen führt zu verändertem Nahrungsangebot;<br>Änderung chem.-phys. Wasserkomponenten (Trübe, Temperatur, Dichte u.a.) führt zur Selektivität unter den Arten;<br>Änderungen im Delta/Mündungsbereich durch eindringendes Meerwasser führt zu Habitatänderungen |

Source: Dilger in Stüben ed. 1987

Figure 3.1 Environmental Aspects of Hydroprojects

| | | |
|---|---|---|
| 1. | HEALTH | Some water-related diseases can increase unless precautions are implemented (e.g. vector control, prevention) schistosomiasis, onchocerciasis, encephalitis, malaria, etc. Remediation usually impossible; prevention is the only cost-effective approach. |
| 2. | RESETTLEMENT | of people is expensive and time-consuming when done acceptably. The people can (and should) be better off afterwards. Can hydroprojects become regional development projects, which integrate rural development for people, with watershed management and irrigation? Resettlement of vulnerable ethnic unacculturated minorities should be avoided; if unavoidable, special precautions are necessary. |
| 3. | WILDLIFE | Extinction can be minimized by siting. Loss of wildlife can be mitigated by including a wildland management unit, equivalent to the inundated tract in the watershed. Biotic rescue can assist. |
| 4. | FISH | migrations (if any) will be impaired without passage facilities. Fish promotion in the reservoir can mitigate and produce more than before the project. |
| 5. | BIOMASS REMOVAL | related to whatever water quality is needed downstream, to fisheries, and to navigation. Valuable timbers and fuel should be salvaged; "opportunity cost" of lost timber and foregone use of inundated land should be internalized. |
| 6. | WATER WEEDS | proliferation can increase disease vectors, and transpiration increases water loss and impairs fish and water quality (e.g. Water Hyacinth (Eichhornia), Water Lettuce (Pistia)). Clogging impairs navigation, recreation and irrigation. Some potential to use weeds for compost, biogas, fodder. |
| 7. | WATER QUALITY | within reservoir and downstream; saline intrustions; water retention time (i.e. flow/volume), loss of flushing; decrease nutrients in estuary; pollution monitoring (agricultural leachates, industries). |
| 8. | EROSION | upstream leads to sedimentation which can impair storage; watershed management should be routine. Increased erosivity below dam. |
| 9. | DRAWDOWN STRIP | useful for recession agriculture (with disease and access precautions). |
| 10. | CULTURAL PROPERTY | Archeological, historic, paleontologic, religious and esthetic or natural unique values or sites should be conserved or salvaged. |
| 11. | MULTIPLE USE | can be optimized by tourism, irrigation, fisheries, recreation. Regulation improves seasonal rivers into perennnial waterways; advantages for drinking and irrigation. |
| 12. | NAVIGATION | may need special provisions such as locks, cleared shipping lanes, and access ramps if drawdown is large. Lake transport may become economically advantageous. |
| 13. | INDUCED SEISMICITY | Tectonic movements may increase or decrease; monitoring is becoming routine. |
| 14. | INTACT RIVERS | Hydro and other developments are better concentrated on the same rivers in order to preserve representative rivers in their natural states. |

Source: R. Goodland (1985).

Source: Dixon et al. 1989

Table 11-2b

## Impacts on Water

**Alteration of River Flows**

1. reduction of floods
2. increase of minimum flows

**Modification of Water Quality**

1. reduction of turbidity
2. reduction of sediment transport
3. modification of the contents of dissolved gases
4. depletion of oxygen - at early stages
5. oversaturation - (low temperatures)

**Possibility of Generation of Induced Seismicity**

**Eutrophication of Water Bodies**

**Evaporation versus Evapotranspiration**

**Reservoir Stability and Riverbed Erosion**

## Impacts on vegetation

**Loss of Individuals within the Reservoir Area**

**Modification of Plants Habitats**

## Impacts on Fauna

**Ichthyofauna - Consequences of Alterations of their Living Media**

1. lentic fish (still waters)
2. lotic fish (running waters)
3. migratory fish
4. semiaquatic mammals
5. water mammals
6. reptiles
7. water fowl

## Impacts on Human Activities

**Displacement of Populations**

**Modification of Population Activities**

1. extractivist
2. agricultural
3. urban occupations
4. transportation means and facilities

**Reduction of Agriculture and Cattle Raising Lands**

1. increase of irrigation possibilities
2. potential increase in fish production

**Flooding of Archaeological and Cultural Sites and Landmarks**

## Impacts on Public Health

**Waterborne Diseases**

**Multiplication of Vectors**

1. insects
2. mollus

Source: Rangeley in: LeMoigne et al. (WB) 1989

Table 4.1: Selected Environmental Effects and their Economic Impacts

| Environmental Effect | Economic Impact | Benefit (B) Cost (C) | Representative Valuation Technique |
|---|---|---|---|
| **Environment on Dams** | | | |
| 1. Soil erosion - upstream, sedimentation in reservoir | reduced reservoir capacity; change in capacity; change in water quality; decrease in power | B,C | change in production, preventive expenditures, replacement costs. |
| **Dams on the Environment** | | | |
| 1. Chemical water quality - changes in reservoir and downstream | increased/reduced treatment cost reduced fish catch, loss of production | B,C | preventive expenditures, changes in production. |
| 2. Reduction in silt load, downstream | loss of fertilizer, reduced siltation of canals, better water control | B,C | replacement costs, preventive expenditures avoided. |
| 3. Water temperature changes (drop) | reduction of crop yields (esp. rice) | C | changes in production. |
| 4. Health - water related diseases (humans and animals) | sickness, hospital care care, death; decrease meat and milk production | B,C | loss of earnings, health care costs. |
| 5. Fishery - impacts on fish irrigation, spawning | both loss and increase in fish production | B,C | changes in production, preventive expenditures. |
| 6. Recreation - in the reservoir or river | value of recreation opportunities gained or lost, tourism | B,C | travel cost approach, property value approach. |
| 7. Wildlife and biodiversity | creation or loss of species, habitat and genetic resources | B,C | opportunity cost approach, tourism values lost, replacement costs. |
| 8. Involuntary resettlement | cost of new infrastructure, social costs | B,C | replacement cost approach, "social costs", relocation costs |
| 9. Discharge variations, excessive diurnal variation | disturbs flora and fauna, human use, drownings, recession agriculture | C | relocation costs, changes in production. |
| 10. Flood attenuation | reduces after flood cultivation; reduces flood damage. | B,C | changes in production, flood damages avoided. |

Source: Dixon et al. 1989

Major Environmental Factors

Not all dam projects have significant adverse environmental consequences. Whether or not they exist, however, must be determined. One approach to identification of likely environmental factors is to examine the three broad regions associated with any dam project: the dam and its reservoir, the upstream area, and the downstream area. (Figure 1.1 is one representation of this concept.) Some environmental factors are common to all regions, others to only one or two. Similarly, not all of the factors listed necessarily pertain to all dams, nor will all of them necessarily be found in any one dam. For example, some impoundment areas may not include villages, agricultural land, or marketable timber, but the possibility should be considered.

The following listing is a brief summary of major factors. Detailed discussions are found in many sources; in particular, the International Commission on Large Dams (ICOLD) has produced several excellent references (ICOLD, 1981, 1985, 1987) as has the American Society of Civil Engineers (1978). The 1981 ICOLD Bulletin, Dam Projects and Environmental Success, discusses general environmental problems and remedies, health problems, beneficial side effects, and monitoring and control of project. The 1985 Bulletin, Dams and the Environment: Notes on Regional Influences, focuses on the particular environmental concerns in each of three climatic regions: temperate; tropical, sub-tropical and arid; and severe winter environments.

The Dam And Impoundment Area

Specific provisions must be made to eliminate or mitigate environmental damage in the impoundment area during and after construction. Some of these effects are the responsibility of the contractor and others are the responsibility of various government agencies.

Provisions should be incorporated into construction tenders so that the eventual contractor clearly recognizes its responsibility for construction related impacts. The Bank has formalized instructions for contractors that cover many points, including the following:

- location of borrow areas and borrow pits;
- air and water pollution from construction equipment, earth movement, and living quarters;
- screening of laborers for imported water-related diseases;
- solid waste disposal;
- siting of contractor facilities and other infrastructure to minimize destruction of the natural landscape; and,
- noise pollution.

Other environmental effects found in the dam and impoundment area may be the responsibility of the contractor, the project authority, or various government agencies. These environmental impacts can be both negative and positive and include the following:

- Population influx, associated with the need for labor for construction, may cause problems including pollution and a variety of linked social effects including health, security, and impact on local cultures;
- Direct effects on people: reservoir creation may involve inundation of houses, villages, farms and infrastructure such as roads and transmission lines. When people are involved, involuntary resettlement is required. Involuntary resettlement imposes major social and economic costs; it requires particular attention and has been the subject of special in-depth consideration by the World Bank (see Cernea, 1988a, 1988b, and Cernea and Le Moigne, 1989 for details on the Bank's policy and operational guidelines regarding the planning, economic analysis, and implementation of involuntary resettlement);
- Cultural/historical sites: inundation of sites or areas of historic, religious, aesthetic or other particular cultural value, and sites of archeological and paleontological significance requires special attention. (For World Bank experiences with cultural property, see Technical Paper No. 62, Goodland and Webb, 1987);
- Inundation of agricultural land, especially highly productive bottom lands;
- Inundation of forest land, may mean the loss of valuable timber and species diversity. Salvage lumbering can recover some of this potential loss and provide other reservoir benefits; species loss may not be replaceable;
- Inundation of wildlife habitat, particularly habitat of threatened species with consequent impact on biological diversity;
- Inundation of potentially valuable mineral resources;
- Inundated vegetation: biomass left in the reservoir can affect water quality if the water is to be used for potable purposes, reservoir fishing (for example, through interference with nets), operation and longevity of dam and associated machinery (e.g., effect of floating debris, chemical reactions, and wear on turbines);

Source: Dixon et al. 1989

Table 11-4 cont.

- o **Water weeds**: Proliferation of water weeds can increase disease vectors, affect water quality and fisheries, increase water loss (through transpiration), affect navigation, recreation and fishing, and clog irrigation structures and turbines;

- o **Fisheries**: The dam will block fish migrations in the river, although fish ladders may sometimes be practical. Substantial new reservoir fisheries are often possible if carefully planned and managed. In the Saguling reservoir in Indonesia, for example, the reservoir fishery helped those resettled to restore or even surpass their previous income levels. Similar results have been observed elsewhere including Thailand (Nam Pong) and in Gujarat, India;

- o **Water quality** within the reservoir is, in part, dependent on what happens upstream and retention time within the reservoir. Quality may be affected by salt accumulation, eutrophication from weeds and biomass decay, turbidity, pollution from agricultural, industrial and human wastes, and fish processing. By trapping sediment, the reservoir provides better quality water downstream with less suspended matter. See Garzon (1984) for a fuller discussion of water quality in hydroelectric projects;

- o **Health**: Establishment of the reservoir and associated water management structures (e.g., canals and ditches) can create conditions fostering establishment and spread of water-related diseases such as schistosomiasis, onchocerciasis, encephalitis, and malaria. Prevention, where possible, is essential, since treatment to eliminate most disease vectors is difficult (or impossible) and expensive once they become established. In other cases, availability of regulated water supplies for municipal and industrial use (M and I) can have major beneficial effects;

- o **Effect of drawdown regime**, which may create agricultural possibilities, as well as health, recreational, aesthetic,and access problems;

- o **Seismicity** may be induced by large reservoirs;

- o **Ground water level** in the surrounding area may be altered;

- o **Local climate** may be modified by large reservoirs, especially in terms of humidity and local fog;

- o **Temperature** of released water may be higher or lower than ambient river temperature (depending on pattern of release); this will have varying impacts on downstream water users;

**Upstream Considerations**

A variety of upstream considerations can affect the dam and its reservoir. While not directly "caused" by the dam, these effects may be induced or exacerbated by the dam. For example, dam construction and reservoir filling may provide access to a previously remote and inaccessible area. The induced population in-migration may lead to increased agricultural or mining activities with major implications for soil erosion, sedimentation, and water quality. Some of the more important upstream considerations follow:

Sedimentation is a major problem for many dam projects. Unfortunately, our knowledge of sediment delivery patterns is imperfect and much of the sediment flowing into a reservoir may have started its movement some time ago. These questions are discussed in detail in Mahmood (1987). There is no question that reservoirs will gradually fill with sediment, the question is at what rate and what can be economically done (if anything) to influence that rate. Dead storage capacity is built into most reservoir designs to act as low cost, and effective, sediment traps.

Increased population settlement and economic development in the upper catchment or watershed usually increase soil movement. The timing and ultimate impact of this increased movement on the reservoir varies greatly from case to case.

The major sources of sediment are the following:

- o **Existing sediment**: sediment resulting from previous natural or induced erosion remains in the bed of watercourses and elsewhere in the watershed area, and will continue to flow into the reservoir, particularly in periods of heavy rainfall (especially in "young" geological areas, such as the Himalayas);

- o **Unusual natural sedimentation**: natural events such as volcanic activity, earthquakes, mudslides, typhoons and "100 year precipitation events" may cause heavy sedimentation regardless of watershed management measures;

- o **Road building and other construction**, not necessarily associated with the dam project, can cause soil erosion and associated sedimentation;

- o **Erosion** from (usually unplanned) clearance of vegetation, logging, and cultivation by people who have moved into the watershed areas as a direct or indirect result of the construction of the dam project. This is largely a planning and regulation problem.

Changes in land use caused directly or indirectly by the dam and dam construction, primarily from increases in population due to planned or unplanned resettlement from inundated areas or elsewhere. These changes may also go on without the project; the question is the rate of change. In-migration from both downstream and outside the river basin area is often facilitated by the project (improved access due to new roads and water transport). The resource and environmental effects include the following:

- o **Cultivation on unsuitable sites**, often unplanned, using unstable or otherwise unsuitable lands (e.g., steep slopes, poor soils) leading to soil erosion and sedimentation;

Source: Dixon et al. 1989

Table 11-4 cont.

- **Logging**, usually unplanned and often illegal, which results in denudation, unsustainable exploitation of the resource, and erosion;
- **Poaching**, i.e., illegal, unsustainable exploitation of wildlife;
- **Denudation of vegetation** for cultivation, fuel collection, and logging;
- **Loss of wildland and wildlife habitat**, with impact on endangered species and reduction of biological diversity;
- **Negative impacts on aesthetic and scenic qualities** of the area and the potential for certain recreational uses. The reservoir, however, may create recreational benefits;
- **Pollution** from settlements and cultivation;

**Changed watershed hydrology**. The changes in land use patterns, if extensive enough, may affect the timing and magnitude of runoff, especially during major storm events. Changed vegetative patterns may also influence dry season stream flow. Hamilton and King (1983) discuss the relationships between surface cover and hydrology in detail.

**Salt inflows** from the watershed may accumulate in the reservoir and affect water quality. Similarly, catchment runoff may carry increased quantities of agricultural chemicals and fertilizer with resultant impacts on reservoir water quality.

**Downstream Considerations**

Numerous impacts are felt downstream. Many are positive and are the reasons why dams are built---increased irrigation, improved water control, hydropower generation and water supply benefits. Whether they are considered direct or indirect project effects, there are other environmental and resource impacts that can be both positive and negative. Among these are the following:

- **Impact on river fishery** due to changes in flow regime, effect of dam blocking fish migration, changes in water quality (e.g., loss of nutrients trapped by dam, pollution from irrigation return flow, and increased water turbidity);
- **Effect on traditional flood plain cultivation** through changes in flow and flooding regime, and loss of annual "top dressing" fertilization from limited flooding. Control of severe flooding can also yield benefits through reduced crop and property losses;
- **Impact on other water projects**: changes in stream flow and water releases from the dam affect dams and irrigation projects elsewhere in the lower basin. The impacts can be both positive and negative. Reduced silt content in water, for example, will lower downstream O & M costs and permit better water management; lower silt levels also decrease potable water treatment costs. On the other hand, weed growth in existing canals may increase with perennial water supplies;
- **Impact on municipal and industrial water supply** downstream can have both positive and negative effects depending on water quantity and quality;
- **Stream bed changes** are one possible, but not a common result of the changed water flow and sediment load. This includes the possibility of increased stream bed erosion below the dam due to "hungry" water (with reduced silt loads) being released from the dam;
- **Effect on estuarine and marine fisheries** and marine biota, including endangered species, through change in flow regime, change in water quality (e.g., pollution from toxic chemical and salts from irrigation return flow to river) and loss of nutrients;
- **Salt intrusion** into estuarine and lower river basin areas may result from sustained or seasonal reduction in river flow;
- **Groundwater level changes**: Higher levels due to the high water levels in the reservoir. Downstream, in old flood plain areas, the groundwater level may fall but in irrigated areas, it may rise;
- **Health problems** from water-related diseases or parasites (similar health problems may also occur in the reservoir itself), primarily from irrigation and associated canals;
- **Effects on wildlife and wildlands** through loss of or change in habitat may result in an impact on biological diversity.

**Assessing Likely Importance**

Identification of likely environmental or resource impacts is the first step. Once they have been identified, it is necessary to assess or evaluate which impacts are important and need to be taken into account. Not all impacts are of equal importance and limits on data and resources (money, trained staff, time) mean that decisions must be made on which impacts to consider further.

Certain effects are so obviously important that they will always be included in the expanded analysis: involuntary resettlement is one example. Others may or may not be important. For example, the reservoir may flood a tropical forest and destroy this diverse ecosystem. Are similar areas available nearby? Are there any endangered species that may be driven to extinction? Are there unique cultural or historic sites such as the Abu Simbel monument that was moved to prevent its inundation by Lake Nasser created by the Aswan High Dam?

Given a trained multidisciplinary study team, the most important effects are usually well identified and quantified. Experience from similar projects in the same country or in geographically similar settings can provide valuable guidance and the Bank has considerable in-house expertise on these topics. Assessment is a skill, not a check-list activity.

Source: Dixon et al. 1989

Table 11-5

| Table I—Checklist of potential impacts from impoundment projects |
|---|
| *Construction phase* |
| Sediment pollution and stream siltation |
| Pesticides, petrochemicals, and other potential pollutants |
| Quantification of erosion and sediment generation |
| Relevant criteria for sediment pollution |
| Protection of water quality during construction—general |
| Erosion and sediment control techniques |
| Treatment of polluted water from construction site |
| Activity scheduling |
| Components of solid waste from construction operations |
| Disposal of chemicals and containers |
| Summary of solid waste impacts |
| Air pollution sources at construction sites |
| Noise generators at impoundment construction site |
| Typical construction noise levels |
| Rough estimation of noise impacts |
| Damaging effects of noise |
| *Impoundment area* |
| Probable land use impacts |
| General methodology for evaluating land use changes and impacts |
| Loss of stream and bottom land |
| Relocation impacts |
| Recreational development—general |
| Secondary air pollution impacts (parking, and so on) |
| Solid waste generation at recreational areas |
| Impact of land inundation on impoundment water quality |
| Organic decomposition and dissolved oxygen deficiency |
| Solution of iron and manganese |
| Loss of wildlife habitat |
| Assimilative capacity changes—general |
| Primary determinants |
| Critical water quality conditions |
| Effects of stratification and density currents |
| Eutrophication and associated impacts |
| Consideration of evaporation |
| Shift from river to lake environment and reduction of species diversity |
| Sedimentation in impoundment |
| Modelling of impoundment water quality |
| Estimating significance of site conditions with respect to impoundment water quality |
| Potential for erosion in reservoir |
| Relationship of morphometry to potential eutrophication and weed problems |
| Nutrient sources and loadings |
| Quantification of influent water quality |
| Changes in point and diffuse pollution sources |
| Probability of water quality problems in stratified reservoirs |
| Evaluation of reservoir fisheries |
| Summary of water quality parameters that may be affected by impoundment and relevant criteria |
| Thermal criteria for fisheries |
| *Downstream and areas of water use* |
| Influence of land acquisition policy on reservoir development |
| Induced development in region |
| Land use impacts caused by increased flood protection |
| Land use impacts of irrigation impoundments |
| Evaluation of water pollution from irrigation |
| Policy concerning use of flood plains |
| Prevention of water quality degradation from irrigation projects |
| Impacts of water quality changes on downstream biota |
| Impact of dam as barrier |
| Flow regime changes—general |
| Quantification of hydrographic modification |
| Seasonal and diurnal flow variations |
| Minimum release requirements |
| Low-flow augmentation analysis |
| Effects on riparian vegetation |
| Flow requirements for salmon and other species |
| Temperature changes—general |
| Important categories of fish species |
| Effects of outlet location and impoundment operation |
| Possible thermal effects on downstream species composition |
| Thermal criteria for fisheries |
| Effects on downstream uses |

Source: Canter 1983

Table II—Checklist of bio-physical and cultural environment factors for impoundment projects

| Category | Sub-category | Factor |
|---|---|---|
| Terrestrial | Population | Crops |
| | | Natural vegetation |
| | | Herbivorous mammals |
| | | Carnivorous mammals |
| | | Upland game birds |
| | | Predatory birds |
| | Habitat/land use | Bottomland forest[1] |
| | | Upland forest[2] |
| | | Open (non-forest) lands[3] |
| | | Drawdown zone |
| | | Land use |
| | Land quality/ Soil erosion | Soil erosion |
| | | Soil chemistry |
| | | Mineral extraction |
| | Critical community relationships | Species diversity |
| Aquatic | Populations | Natural vegetation |
| | | Wetland vegetation |
| | | Zooplankton |
| | | Phytoplankton |
| | | Sport fish |
| | | Commercial fisheries |
| | | Intertidal organisms |
| | | Benthos/Epibenthos |
| | | Waterfowl |
| | Habitats | Stream[4] |
| | | Freshwater lake[5] |
| | | River Swamp[6] |
| | | Non-river Swamp[7] |
| | Water quality | pH levels |
| | | Turbidity |
| | | Suspended solids |
| | | Water temperature |
| | | Dissolved oxygen |
| | | Biochemical oxygen demand |
| | | Dissolved solids |
| | | Inorganic nitrogen |
| | | Inorganic phosphate |
| | | Salinity |
| | | Iron and manganese |
| | | Toxic substances |
| | | Pesticides |
| | | Faecal coliforms |
| | | Stream assimilative capacity |
| | Water quantity | Stream flow variation |
| | | Basin hydrologic loss |
| | Critical community relationships | Species diversity |
| Air | Quality | Carbon monoxide |
| | | Hydrocarbons |
| | | Oxides of nitrogen |
| | | Particulates |
| | Climatology | Diffusion factor |
| Human Interface | Noise | Noise |
| | Aesthetics | Width and alignment |
| | | Variety within vegetation type |
| | | Animals—domestic |
| | | Native Fauna |
| | | Appearance of water |
| | | Odor and floating materials |
| | | Odor and visual quality |
| | | Sound |
| | Historical | Historical internal and external sites |
| | Archaeological | Archaeological internal and external sites |

1. A composite of the species associations; percentage mast-bearing trees; percentage covered by understory; diversity of understory; percentage covered by groundcover; diversity of groundcover; number of trees ≥16 in diameter per acre, percentage of trees ≥16 in diameter; frequency of inundation; edge (quantity); and edge (quality).
2. A composite of the following: species associations; percentage mast-bearing trees; percentage coverage of understory, diversity of understory; percentage coverage of groundcover, diversity of groundcover; number of trees ≥16 in diameter/acre; percentage of trees ≥16 in diameter; quantity of edge; and, mean distance to edge.
3. A composite of the following: land use; diversity of land use; quantity of edge; and, mean distance to edge.
4. A composite of the following: sinuosity; dominant centrarchids; mean low water width; turbidity; total dissolved solids; chemical type; diversity of fishes; and, diversity of benthos.
5. A composite of the following: mean depth; turbidity; total dissolved solids; chemical type; shore development; spring flooding above vegetation line; standing crop of fish; standing crop of sport fish; diversity of fish; and, diversity of benthos.
6. A composite of the following: species associations; percentage forest cover; percentage flooded annually; groundcover diversity; percentage of groundcover; and, days subject to river overflow.
7. A composite of the following: species associations; percentage forest cover; percentage flooded annually; groundcover diversity and percentage of groundcover.

Source: Canter 1983