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

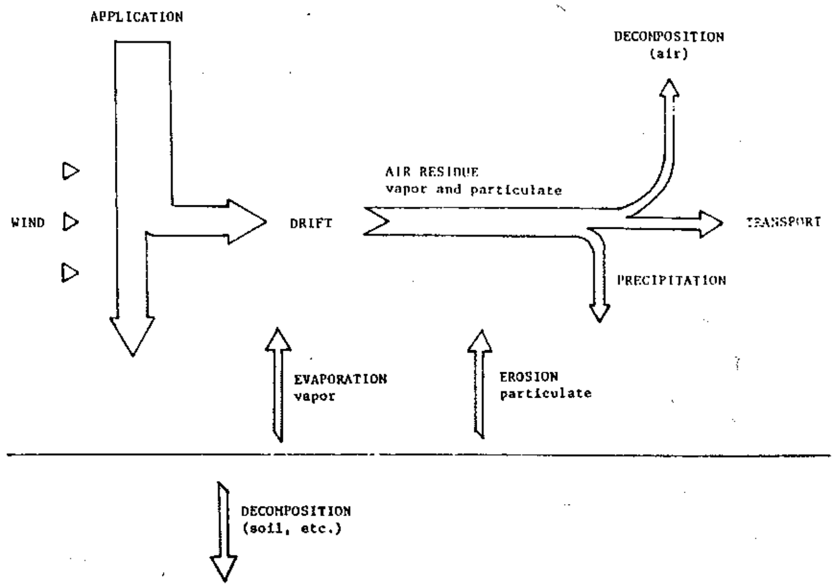


Figure 29: Sources and Fate of Airborne Residues Related to Pesticide Applications (Seiber, et al., 1980)

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.

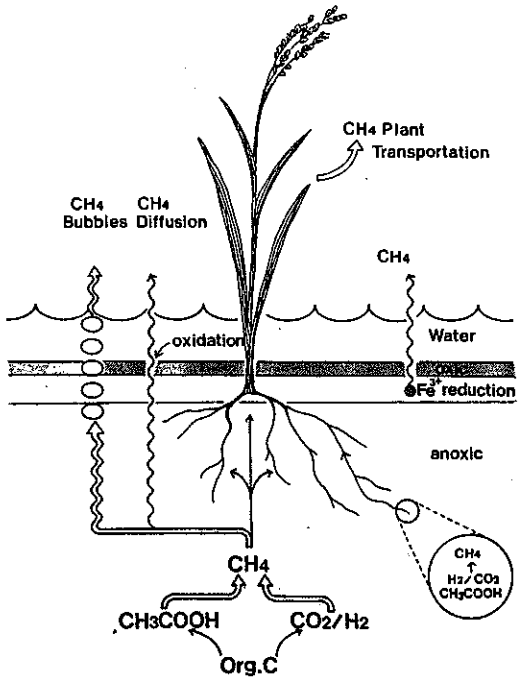
Special attention must be paid to areas with high rates of organic matter and N-turnover such as (tropical) rainforests, areas with marked dry-wet seasons (semiarid regions) as well as heavily N-fertilised areas. It is estimated that some 10-20% of the applied nitrogen fertiliser is released into the 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

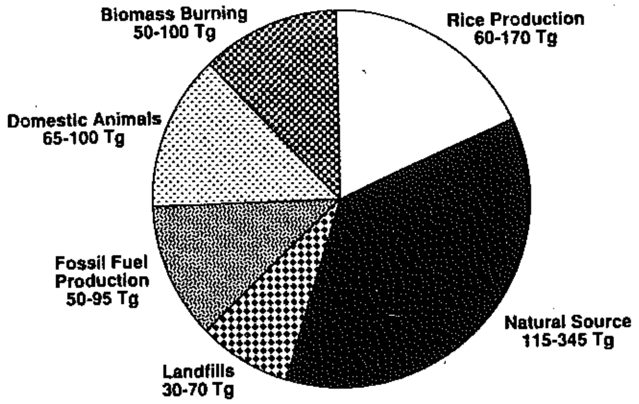


Fig. 3–4. Current global annual emissions of CH_4 by source. (teragrams CH_4 yr^{-1}). Human activities in the agricultural sector (domestic animals, rice production, and biomass burning) are major sources of atmospheric CH_4. Natural sources from wetlands, oceans, and lakes probably contribute less 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

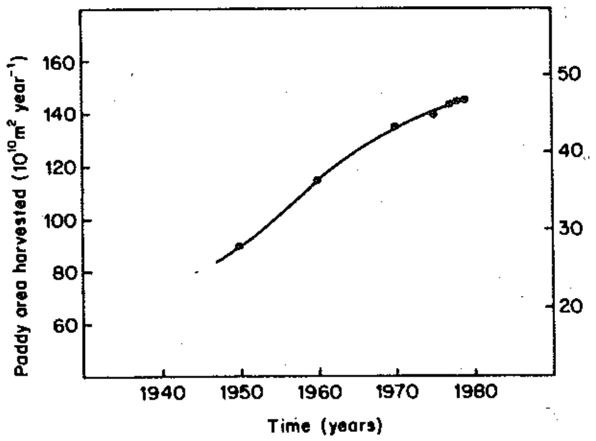


Figure 15.30 Temporal increase of the harvested area of rice paddies and the corresponding global CH_4 emission. The calculated Ch_4 emission rates do not take into account the possible influence of mineral nitrogen fertilizer on the CH_4 production rates in paddy soils (Seiler *et al.*, 1984)

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

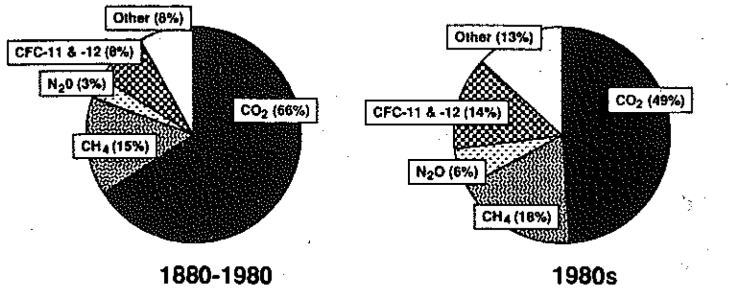


Fig. 3-1. Relative contributions to the increase in the greenhouse effect. Greenhouse gases other than CO_2 account for about half of the increases in the greenhouse effect in the 1980s. The "other" category includes halons, tropospheric O_3, and stratospheric water vapor (sources—1880–1980: Ramanathan 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 short-wave radiation in the shading areas (eg windbreaks),
- Slight interception of long-wave outgoing radiation through the whole day (effect on evaporation, temperature),
- Slight effect on temperature: 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

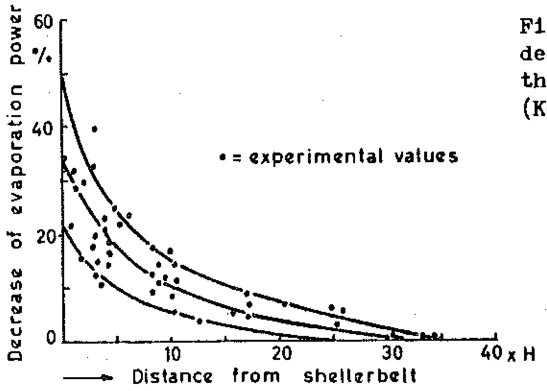


Figure 56 - The dependence of the decrease of evaporation power upon the distance from shelterbelt (Konstantinov and Struser, 1953)

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

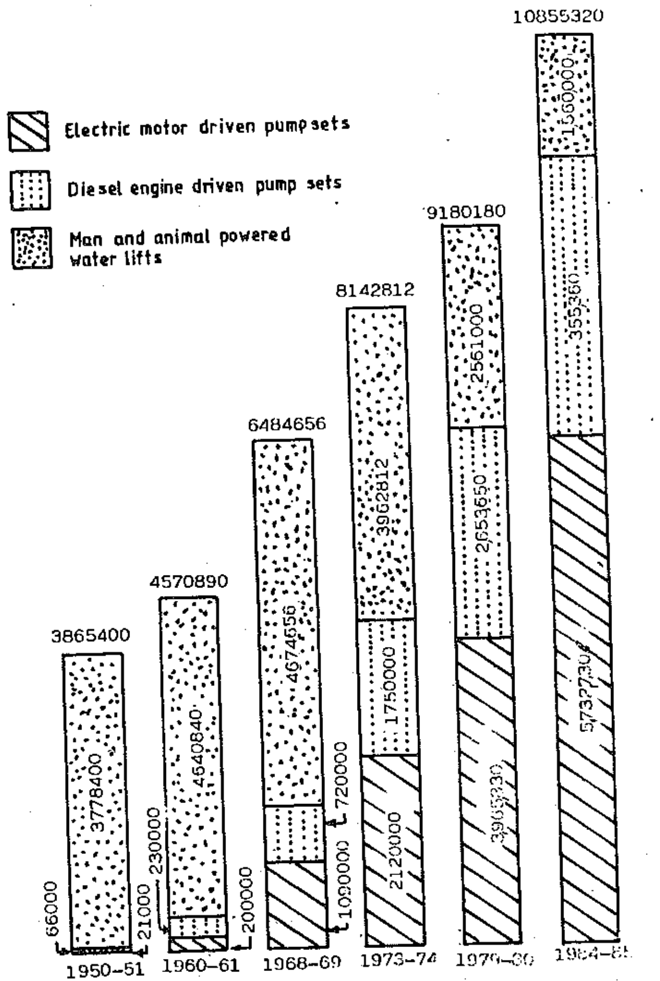


Figure 2. Progressive mechanization in water lifting for irrigation. The figures at the top of the bars show the total number of pumps and water lifts

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Source: Michael in ICID 1990

Fig. 7-2

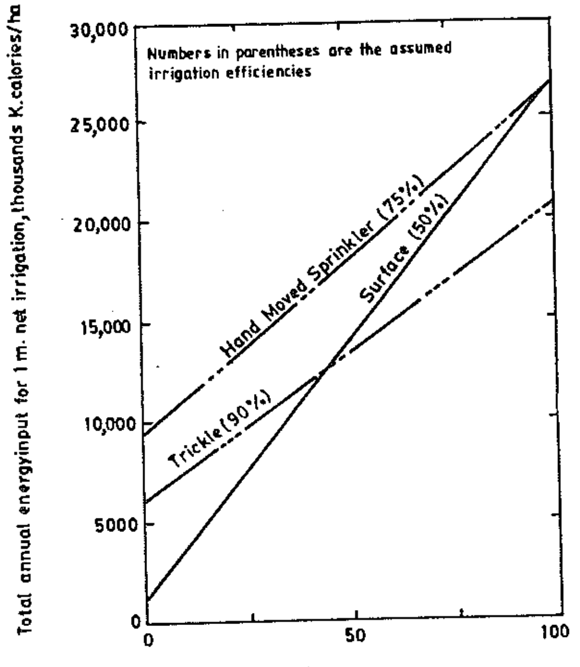


Figure 3. Energy requirement for different irrigation application methods (Exigence d'energie pour des méthodes d'application différentes de l'irrigation.

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-

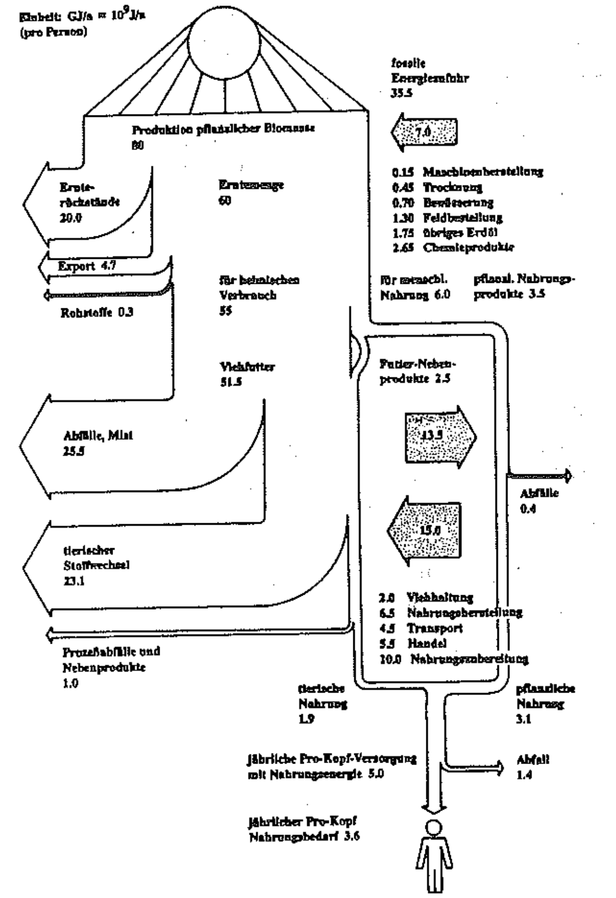
Fig. 7-3

(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.

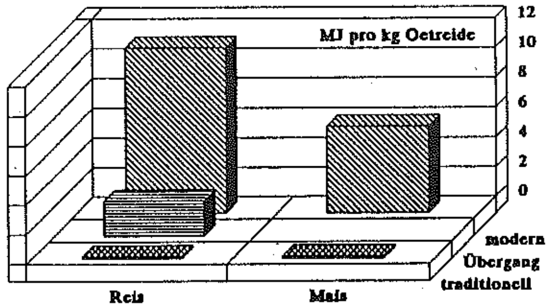
Traditionelle landwirtschaftliche Methoden erfordern einen wesentlich geringeren Einsatz an kommerziellen (vor allem fossilen) Energien. Ähnliches gilt auch für extensive Viehhaltung. Die unrationelle Energienutzung in der modernen Landwirtschaft läßt sich nur durch höhere Hektarerträge rechtfertigen.

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 efficicency 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/Cairncross 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 excreta 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.

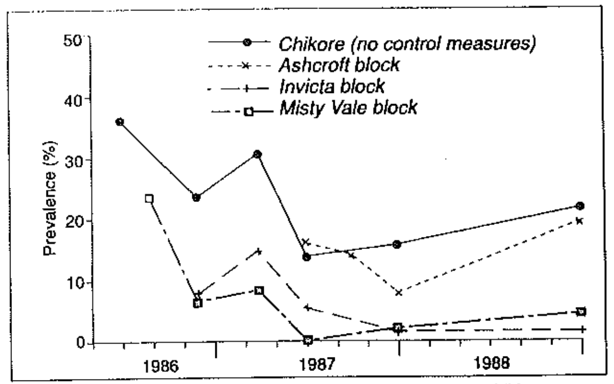
Case Studies

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

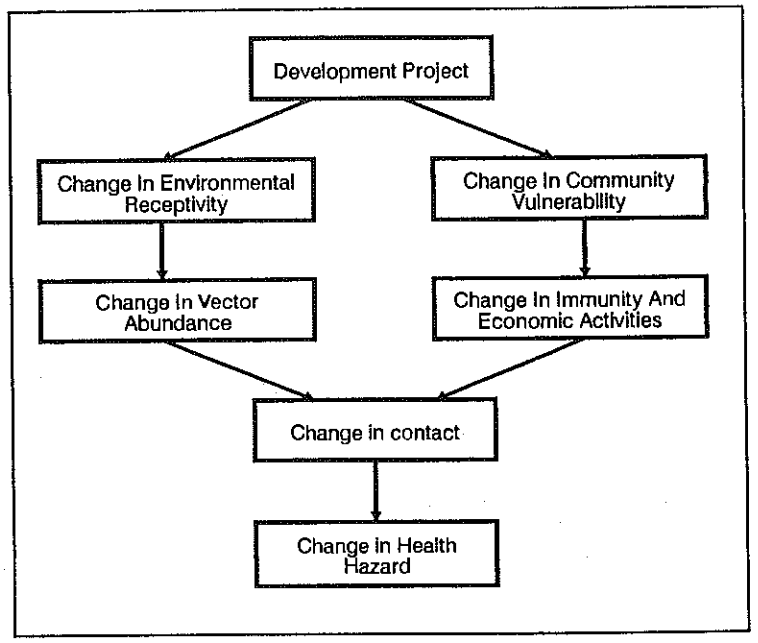


Prevalence of schistosome haematobium in adults and non-school children. Control of aquatic snails is contributing towards a reduction in schistosomiasis transmission in two pilot areas, but other factors are counteracting this in the third.

Source: Chimbari et al. in: Wooldridge ed. 19

Fig. 8-2

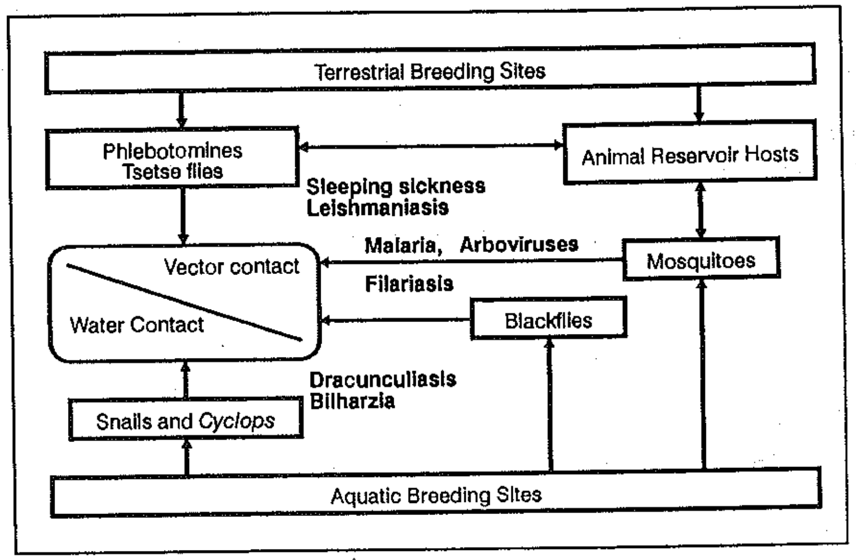
Figure 2-1 How development can affect health.



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.

Principal disease	Arid and semi-arid lands	Rain forests	Riverain vegetation	Savanna woodlands	Irrigation ditches and canals	Lakes and ponds	Wetland rice cultivation	Rivers and streams	Human settlements	Coastal plains
Arboviruses:										
Dengue		●							●	
Haemorrhagic Dengue									●	
Yellow fever		●							●	
Encephalitic							●			
Dracunculiasis						●				
Filariasis:										
Bancroftian		●							●	●
Brugian		●			●				●	●
Loiasis		●								
Onchocerciasis					●			●		
Leishmaniasis:										
Cutaneous	●	●								
Visceral	●	●							●	
Malaria		●	●		●	●	●	●	●	●
Schistosomiasis					●	●	●	●	●	
African trypanosomiasis			●	●						

Fig. 8-5

Table 2-4
Association between vector, disease and water.

Principal disease	Culicine mosquito	Anopheline mosquito	Simuliid blackfly	Tabanid horsefly	Phlebotomine sandfly	Tsetse fly	Cyclops	Water snail
Arboviruses:								
Dengue	●							
Haemorrhagic Dengue	●							
Yellow fever	●							
Encephalitic	●							
Dracunculiasis							●	
Filariasis:								
Bancroftian	●	●						
Brugian	●							
Loiasis				●				
Onchocerciasis			●					
Leishmaniasis:								
Cutaneous					●			
Visceral					●			
Malaria		●						
Schistosomiasis								●
African trypanosomiasis						●		

The vector's relationship with water	Culicine mosquito	Anopheline mosquito	Simuliid blackfly	Tabanid horsefly	Phlebotomine sandfly	Tsetse fly	Cyclops	Water snail
Breeds in water	●	●	●					
Breeds in wet ground				●				
Breeds in damp ground					●	●		
Lives near water	●	●	●			●		
Found in drinking water							●	
Entire lifecycle in water								●
Lives elsewhere					●	●		

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

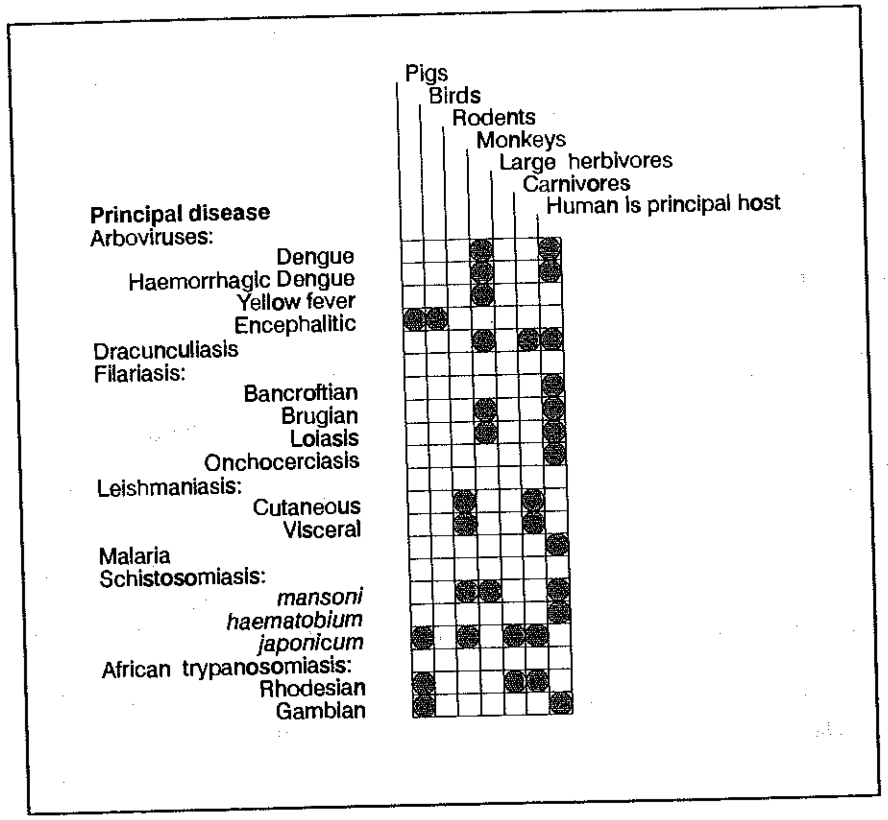
8.2.4 Habitat of Vectors and Transmission Factors

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 relationship to water is explained in Fig. 8-5. Parasites which have non-human hosts are indicated in Fig. 8-6. The method of transmission together with the life cycle of the parasite determines whether a low or high frequency of contact (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 <u>on-site effects</u> 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 floodpools 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:

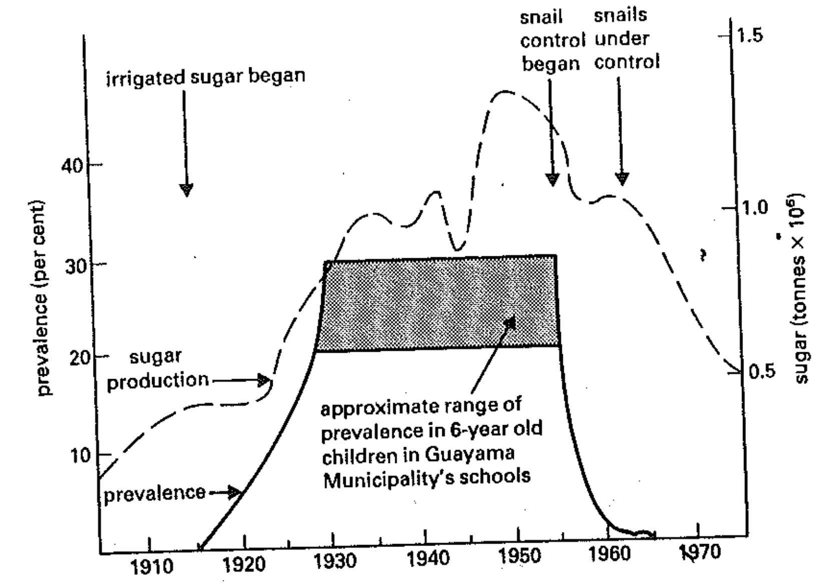
Blackfly (onchocerciasis): all spillway structures provide potential breeding sites; downstream scouring of river beds, caused by changes in flow regime (example: River Nile), may expose rock which forms a suitable breeding habitat.

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

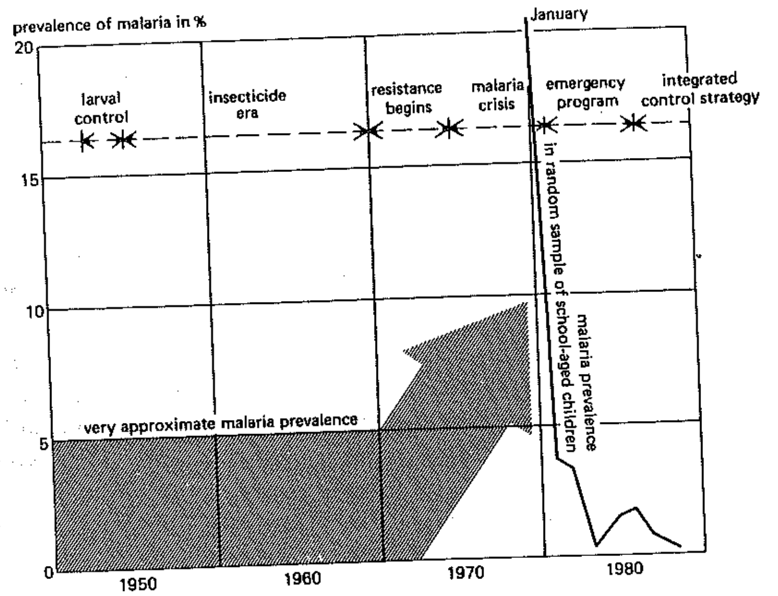


Figure 4.3 Pesticide resistance and prevalence of malaria

Sources: Oomen et al. 1988 Vol. 2

Fig. 8-9

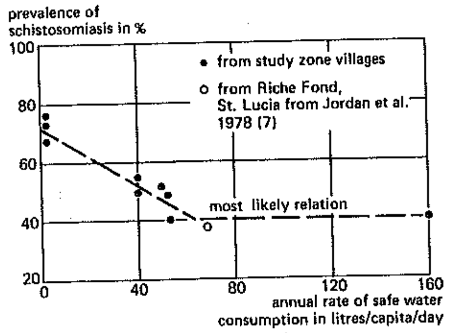


Figure 4.5 Prevalence of *Schistosoma mansoni* in villages in the 'Study Zone' versus their annual mean experience of safe water consumption, 1981 – 1982

<u>Case Studies</u> Diseases and water resources development & irrigation projects

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 <u>without</u> 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.

<u>Puerto Rico</u>: 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).

<u>Sudan</u>. 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

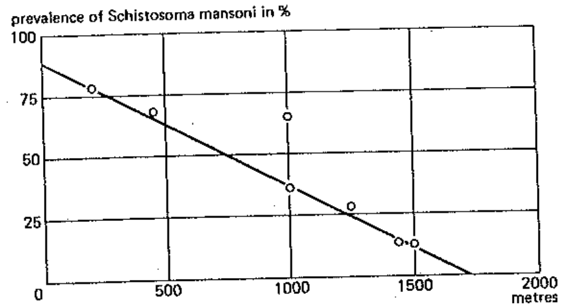


Figure 4.6 Prevalence of *Schistosoma mansoni* versus distance to nearest minor canal in small villages, without safe water supply, in 'Study Zone', 1981-1982, prior to intervention with comprehensive strategy

Fig. 8-11

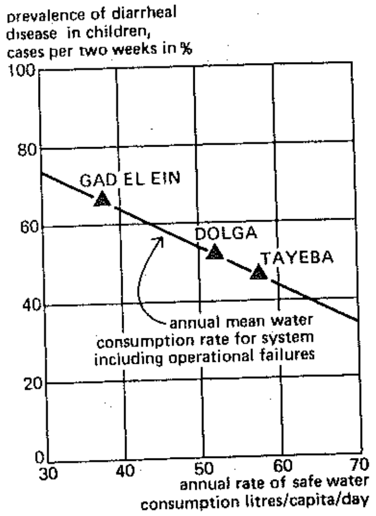


Figure 4.8 Relation of prevalence of diarrhoeal diseases and safe water consumption for intensive study villages, 1981

Fig. 8-12

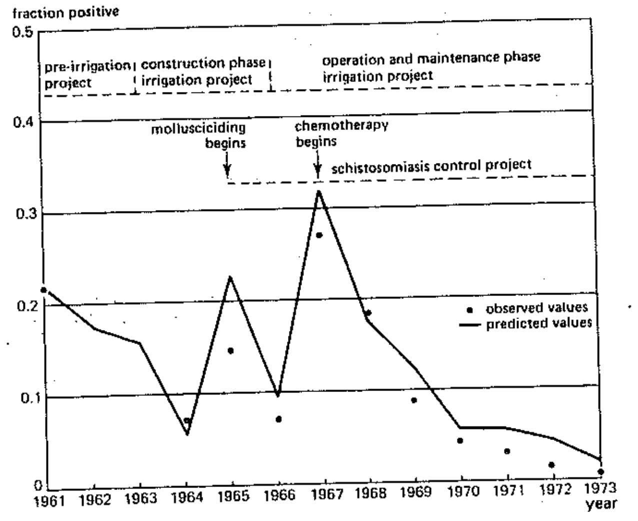


Figure 4.22 Bilharzia prevalence in the Dez Irrigation Scheme. 1961-1973

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 molluscicidіng) 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

Irrigation Development Planning

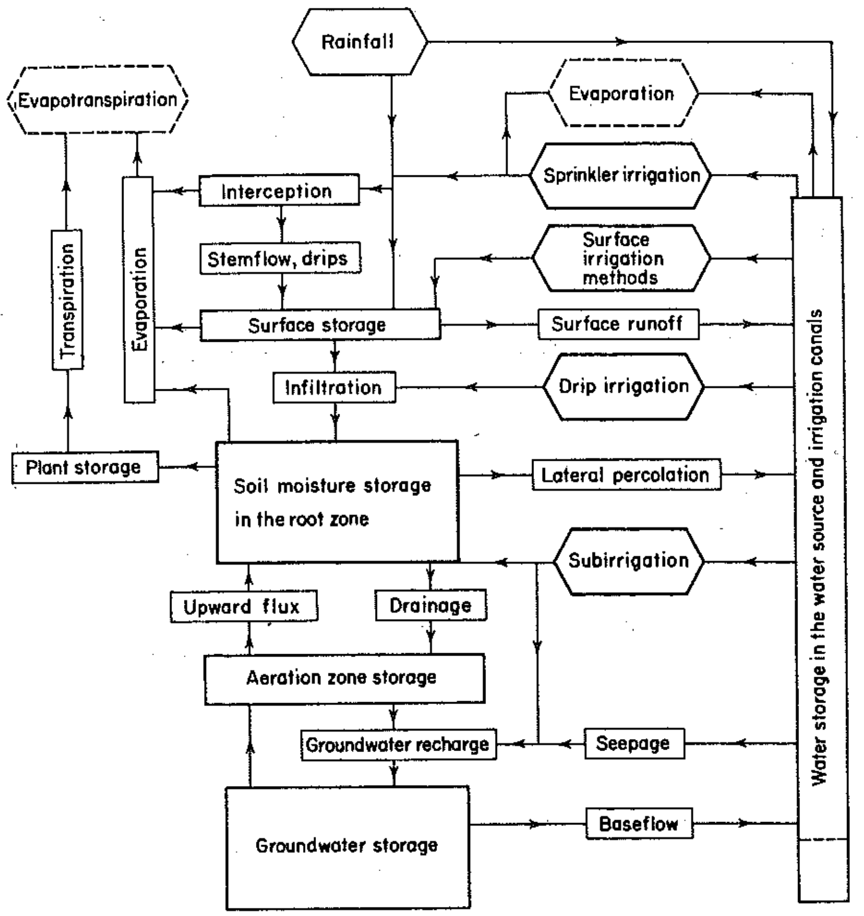


Figure 5.1 The field hydrological cycle as influenced by irrigation

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.
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		Land degradation if activity not suited to site
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		
- Manure, slurry	Excess: accumulation of phosphates, copper (pig slurry)	Nitrate, phosphate (by use of excess slurry)		Eutrophication leads: i) to excess algae and water-plants	ii) to oxygen depletion affecting fish	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:

Fig

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

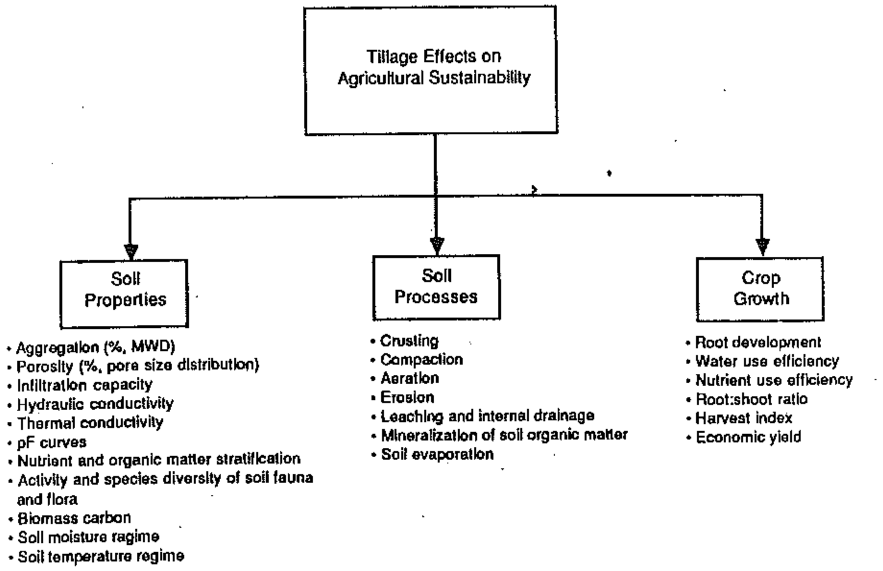


Fig. 2. Tillage effects on agricultural sustainability.

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Fig. 9-4

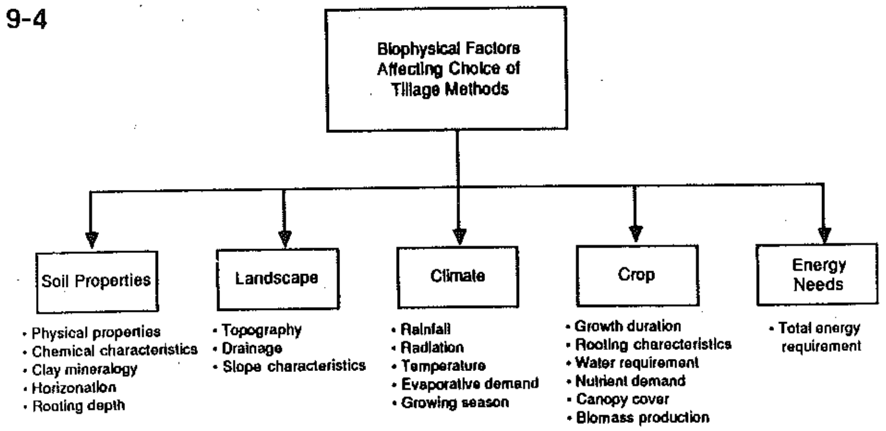

Fig. 1. Factors affecting choice of tillage methods.

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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, semiarid 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 Africa, 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 increased and decreased yields 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

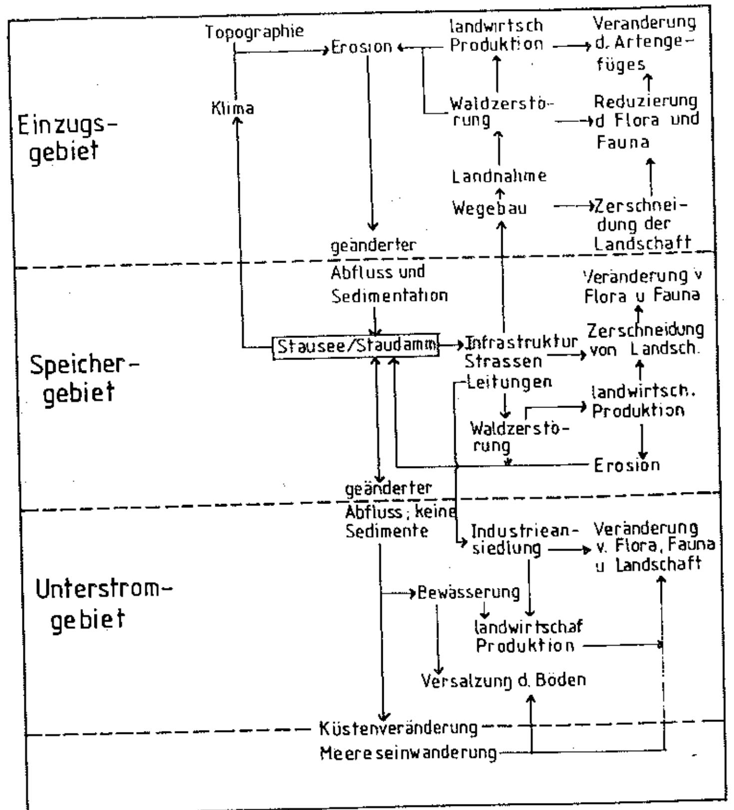
Critical review in: Goldsmith/Hildyard 1984; Various case studies in: Goldsmith/Hildyard ed. 1985

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

UMWELTBEREICHE ENVIRONMENT / ACTIVITIES MASSNAHMEN	NATÜRLICHE UMWELT (NATURAL RESOURCES)											NUTZUNGSBEREICH (HUMAN USE)						HUMANBEREICH (SOCIO-ECONOMIC ASPECTS)				
	Physisch-Geograph. Bereich								Biologischer Bereich													
	Klima CLIMATE	Erosion	Sedimentation	Versalzung SALINIS.	Wasserqualität WATER QUAL.	Grundwasser GROUNDW.	Abflußverhalten FLOW	Seismik	Eutrophierung	Versumpfung WATER-LOGGING	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			◯				

▨ Übergeordnete Maßnahme, unabhängig von der Nutzung   ◯ großer Einfluß   ○ mittlerer Einfluß   o geringer Einfluß

Matrix I (Grobmatrix)

— 129 —

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

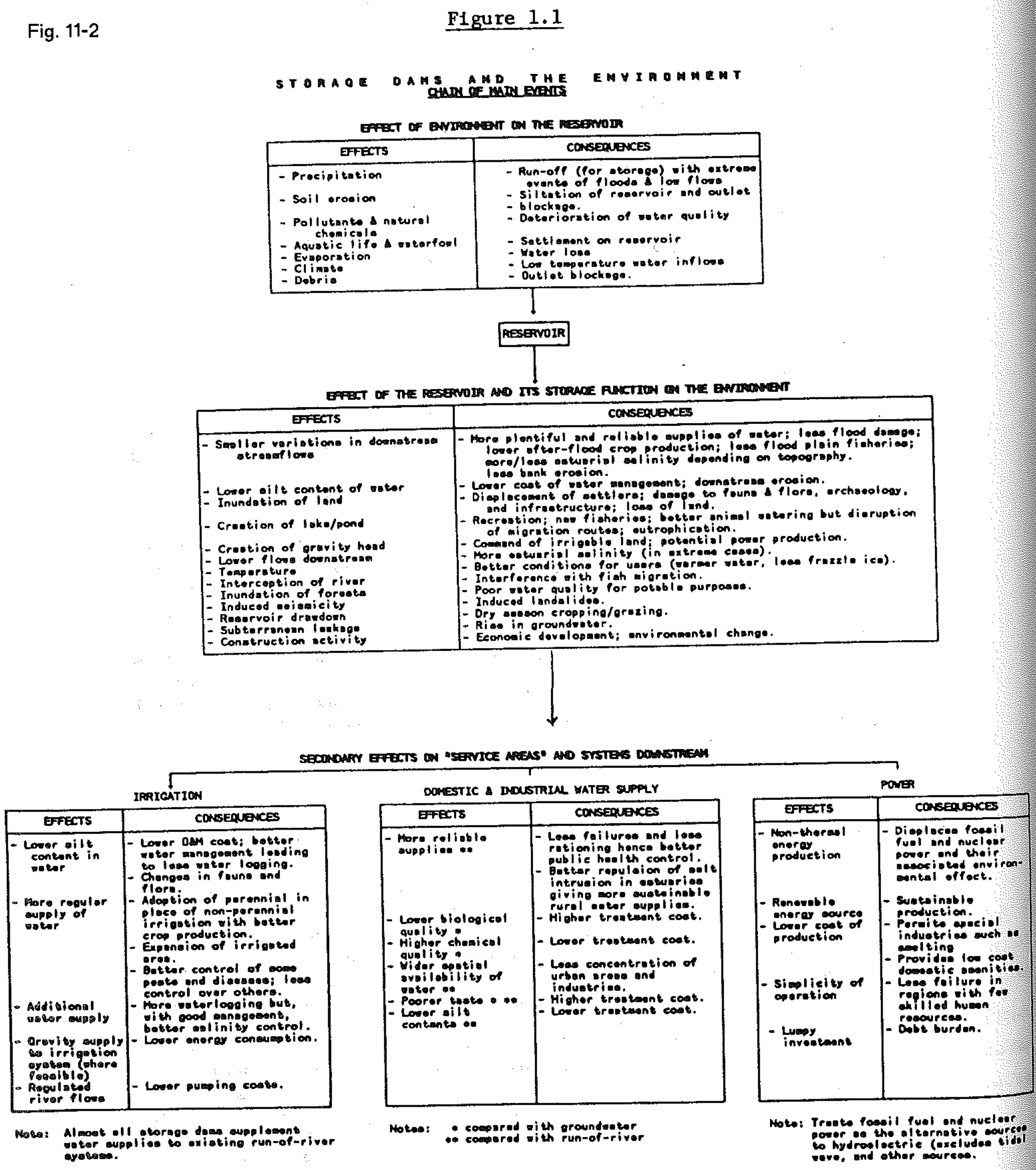


Figure 1.1

STORAGE DAMS AND THE ENVIRONMENT
CHAIN OF MAIN EVENTS

EFFECT OF ENVIRONMENT ON THE RESERVOIR

EFFECTS	CONSEQUENCES
- Precipitation - Soil erosion - Pollutants & natural chemicals - Aquatic life & waterfowl - Evaporation - Climate - Debris	- Run-off (for storage) with extreme events of floods & low flows - Siltation of reservoir and outlet - blockage. - Deterioration of water quality - Settlement on reservoir - Water loss - Low temperature water inflows - Outlet blockage.

RESERVOIR

EFFECT OF THE RESERVOIR AND ITS STORAGE FUNCTION ON THE ENVIRONMENT

EFFECTS	CONSEQUENCES
- Smaller variations in downstream streamflows	- 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.
- Lower silt content of water	- Lower cost of water management; downstream erosion.
- Inundation of land	- Displacement of settlers; damage to fauna & flora, archaeology, and infrastructure; loss of land.
- Creation of lake/pond	- Recreation; new fisheries; better animal watering but disruption of migration routes; eutrophication.
- Creation of gravity head	- Command of irrigable land; potential power production.
- Lower flows downstream	- More estuarial salinity (in extreme cases).
- Temperature	- Better conditions for users (warmer water, less frazzle ice).
- Interception of river	- Interference with fish migration.
- Inundation of forests	- Poor water quality for potable purposes.
- Induced seismicity	- Induced landslides.
- Reservoir drawdown	- Dry season cropping/grazing.
- Subterranean leakage	- Rise in groundwater.
- Construction activity	- Economic development; environmental change.

SECONDARY EFFECTS ON "SERVICE AREAS" AND SYSTEMS DOWNSTREAM

IRRIGATION

EFFECTS	CONSEQUENCES
- Lower silt content in water	- Lower O&M cost; better water management leading to less water logging. - Changes in fauna and flora.
- More regular supply of water	- Adoption of perennial in place of non-perennial irrigation with better crop production. - Expansion of irrigated area. - Better control of some pests and diseases; less control over others.
- Additional water supply	- More waterlogging but, with good management, better salinity control.
- Gravity supply to irrigation system (where feasible)	- Lower energy consumption.
- Regulated river flows	- 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 **	- Less failures and less rationing hence better public health control. - Better repulsion of salt intrusion in estuaries giving more sustainable rural water supplies.
- Lower biological quality *	- Higher treatment cost.
- Higher chemical quality *	- Lower treatment cost.
- Wider spatial availability of water **	- Less concentration of urban areas and industries.
- Poorer taste * **	- Higher treatment cost.
- Lower silt contents **	- Lower treatment cost.

Notes: * compared with groundwater
** compared with run-of-river

POWER

EFFECTS	CONSEQUENCES
- Non-thermal energy production	- Displaces fossil fuel and nuclear power and their associated environmental effect.
- Renewable energy source	- Sustainable production.
- Lower cost of production	- Permits special industries such as smelting - Provides low cost domestic amenities.
- Simplicity of operation	- Less failure in regions with few skilled human resources.
- Lumpy investment	- 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:

<u>Egypt</u>. 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]

<u>Iraq</u>. 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

<u>Impacts of the Aswan High Dam in Egypt</u>

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

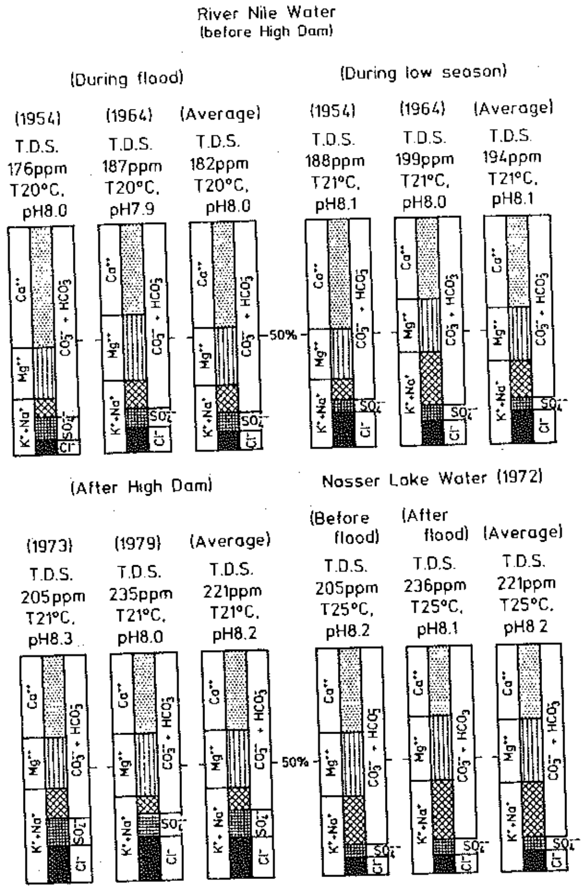


Fig. 1. Graphical representation of water chemical analyses

▨ $Ca(HCO_3)_2$

▥ $Mg(HCO_3)_2$

▩ $(Na+K)_2 HCO_3$

▦ $(Na+K)_2 SO_4$

■ (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:

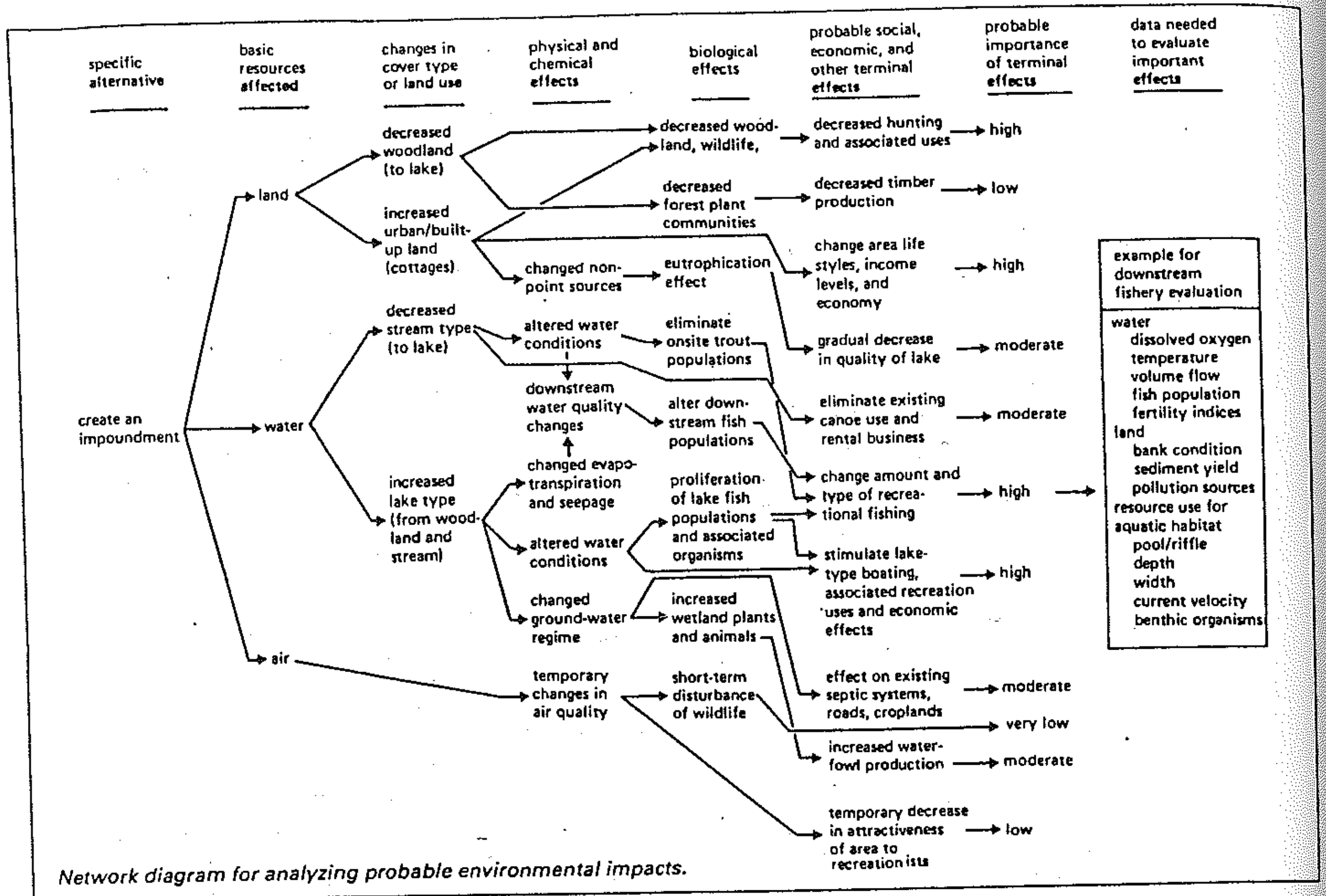
- stream channel degradation: releases of water low in silt resulted in stream bed degradation, bank erosion and meandering of the main stream. Scouring resulted in changes in the river cross section; the water surface elevation dropped 0.6 m downstream of Aswan High Dam, 1.0 m downstream of Naga-Hamadi 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.

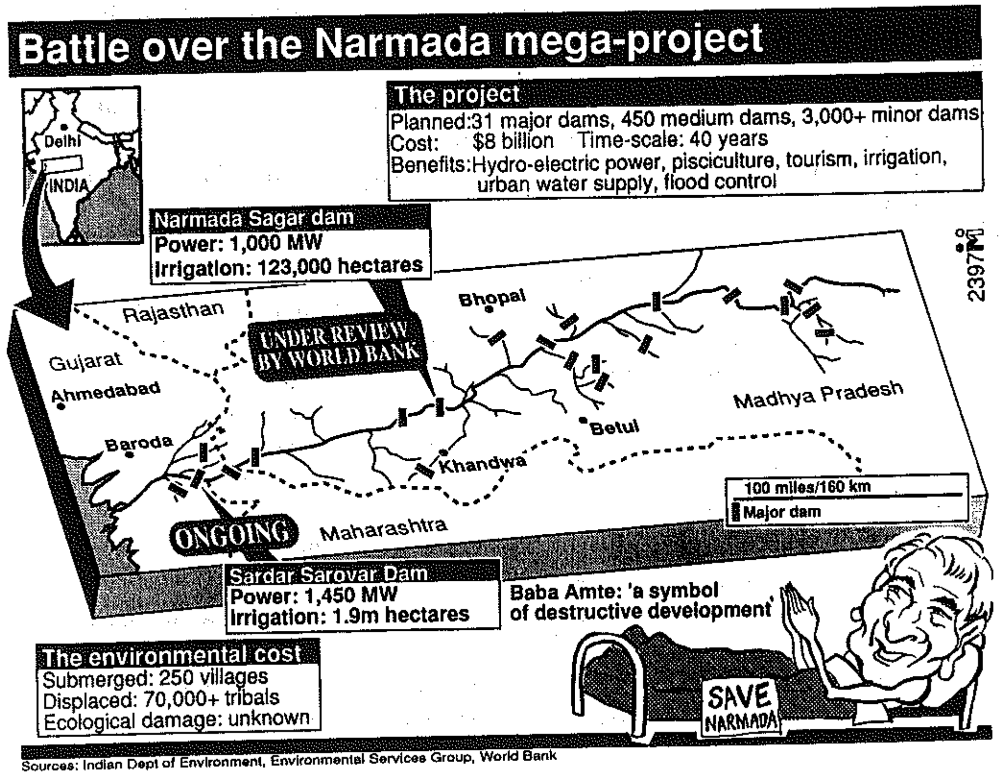
Fig. 11-4



Network diagram for analyzing probable environmental impacts.

Source: Canter 1983

Fig. 11-5



Battle over the Narmada mega-project

The project

Planned: 31 major dams, 450 medium dams, 3,000+ minor dams
Cost: $8 billion Time-scale: 40 years
Benefits: Hydro-electric power, pisciculture, tourism, irrigation, urban water supply, flood control

Narmada Sagar dam
Power: 1,000 MW
Irrigation: 123,000 hectares

Sardar Sarovar Dam
Power: 1,450 MW
Irrigation: 1.9m hectares

Baba Amte: 'a symbol of destructive development'

The environmental cost
Submerged: 250 villages
Displaced: 70,000+ tribals
Ecological damage: unknown

Sources: Indian Dept of Environment, Environmental Services Group, World Bank

D+C 1/93

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

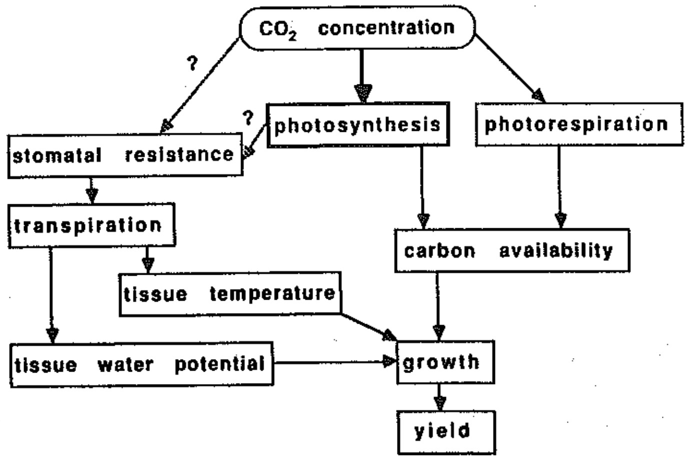


Fig. 4-1. A hierarchy of plant responses to [CO$_2$].

Fig. 12-2

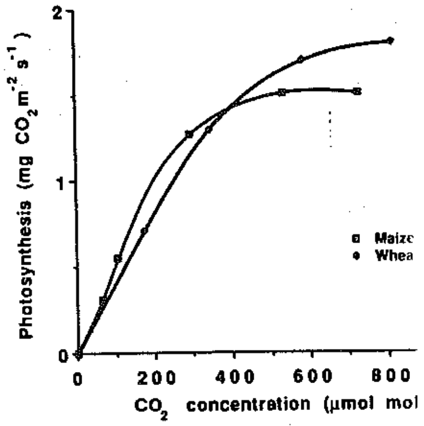


Fig. 4-2. Leaf net photosynthetic rate as a function of [CO$_2$] for m
ta & Moss, 1973).

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 phyotosynthesis, 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

- 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