The Ecologist Briefing Document

The Social and Environmental Effects of Large Dams

WHY DAMS?

Dams and other water projects are popularly seen as playing a vital role in economic development.

— By supplying hydro-electricity, dams supply the 'power to progress'.

— By providing water for irrigation, they help boost food production, enabling more mouths to be fed in an increasingly hungry world.

— And by regulating the flow of rivers, they help reduce flood damage.

But do dams achieve those basic objectives?

THE PACE OF CONSTRUCTION

The pace of dam construction has accelerated since World War II. About 38 per cent of the money loaned by the World Bank for agricultural development schemes has been for irrigation projects—and 90 per cent of that lending has occurred in the last ten years.

By 1990, the worldwide total of dams over 150 metres in height is expected to have reached 113, of which 49 will have been built during the 1980s.

Today, modern technology enables us to build dams of a size and complexity which would have staggered the ancients..

— In Egypt, the Aswan High Dam is seventeen times heavier than the great pyramid of Cheops.

— In Ghana, the Volta Dam impounds a reservoir the size of the Lebanon.

For the future, even more ambitious schemes are planned.

— In China, a 1,265 kilometre canal will divert water from the Yangtse River to the arid north. The scheme is expected to irrigate 3.8 million hectares of farmland and to guarantee regular water supplies to a further 1.3 million ha.

— In India, a series of canals will divert water from the Brahmaputra, the Ganges and the Indus Rivers to drought-prone regions in Western, Central and Southern India. Those canals will radiate out from the 2,000 mile-long Ganges/Calvery River Canal, which will run down almost the entire length of the country.

— In the USA, a plan to bring water from the East of Texas to the arid and semi-arid western region of the state is still in the offing. Two canals are proposed—one of 600 kilometres and one of 1,200 kms. Together they will make up the Texas Water System. Although the scheme was turned down by a local referendum in 1969, a revised version (no less ambitious) has been proposed.

THE LURE OF HYDRO-POWER

Power—and in particular cheap power—is considered a *sine qua non* of development.

On the face of it, hydro-power is extremely cheap. At 1,000 dollars per kilowatt of installed capacity, hydro-electricity costs far less than power from a thermal plant, let alone a nuclear reactor.

Just over 123,000 megawatts of hydro-electricity is currently under construction. Dams capable of adding a further 239,000 megawatts are in the planning stage.

If all the energy contained in the rivers of the world was to be harnessed by dams, then an estimated 73,000 terawatt-hours (one terawatt being equivalent to one trillion watt-hours) of electricity could be produced every year. That's equal to the power of 12,000 nuclear reactors.

Technical difficulties, however, preclude much of that energy being exploited. Nonetheless, the World Energy Conference considers it possible to tap 19,000 terawatt-hours a year—as against the 1,300 terawatt hours produced today.

Third World governments have embarked on massive schemes to exploit to the full the energy of their rivers.

— In Brazil, the Itaipu Dam on the Parana River will alone generate 12,600 megawatts—the equivalent output of 13 large nuclear power stations.

— China's Sanxia Dam on the Yangtse River is still more ambitious. Once completed, the dam will generate 40 per cent of the country's current electricity output—providing 25,000 megawatts, equivalent to the output of 25 nuclear power stations.

THE LURE OF IRRIGATION

Irrigated agriculture is one of the most productive farming systems known to man.

In 1982, the UN Food and Agricultural Organisation (FAO) estimated that 220 million ha. were under irrigation. FAO hopes to bring another 100 million ha. under irrigation by the turn of the century.

Even that rate of expansion will leave many hungry, say some agronomists. Bruce Stokes of the Washington-based Worldwatch Institute argues that 70 million ha. will need to be brought under irrigation within the next decade to keep pace with food demand.

With 50 per cent of the earth's surface classified as 'arid' or 'semi-arid', there is little hope of increasing the amount of irrigated land without also increasing water supplies.

But where will the water come from?

To date, the answer to that question has generally been to tap groundwater resources. But there is a limit to the number of wells which can be sunk—and that limit appears to have been exceeded in many parts of the world.

— In the southwestern United States, the huge Ogallala aquifer will be depleted by 40 per cent within the next 20 to 40 years if farmers continue to extract water from it at present rates.

— Already, as a result of overexploitation of groundwater reserves, many farms in the US southwest have been taken out of production. Farmers cannot afford to pay for the irrigation water.

Two other sources of water remain. One—desalinated seawater—is prohibitively expensive. The other—rainwater—is too diffuse and unpredictable to rely upon.

Large dams compensate for that unpredictability. They store water where it is needed for when it is needed.

SO WHAT'S WRONG WITH DAMS?

In a world where millions go to bed hungry and where few have access to even the cheapest material goods, it must seem churlish to question the building of large-scale dams and other water projects.

If we ceased to build such dams, would we not be condemning still more people to death by starvation?

And if the experts insist that dams provide the route to prosperity for all, who are we to gainsay them?

Unfortunately, there is another side of the dam-building coin, a side which is rarely shown to the public. It portrays a picture of massive ecological destruction, of social upheaval, disease and impoverishment.

RESETTLEMENT—THE FIRST BLOW

One of the inevitable consequences of flooding an area is that those who previously lived there have to be moved.

— Ghana's Volta Dam saw the evacuation of some 78,000 people from over 700 towns and villages.

— Lake Kainji in Nigeria displaced 42,000 people.

— The Pa Mong project in Vietnam uprooted 450,000 people.

Future projects involved the resettlement of still more people.

— China's Three Gorges Dam scheme will displace 1,400,000 people.

— In the Philippines, proposals to build 40 new large dams over the next 20 years could affect the homes of over 1.5 million people.

If the past is anything to go by, those resettlement programmes will bring nothing but untold human misery. Indeed, few experts have a good word to say for past schemes. As Professor William Ackermann told an international conference on dams in 1976:

"From the human point of view, relocation has been one of the least satisfactory aspects of reservoir projects . . . Settlement schemes have a high failure rate around the world. Even where planning is effective, some (especially the aged) will never come to terms with their new homes. For them, the transition period ends only with death."

To politicians, the idea that resettlement might be unwelcome to local people is often incomprehensible.

At the height of the controversy over Sudan's Jonglei Canal—a canal which critics claimed would destroy the way of life of local nomads—Sudan's Southern Regional President, Abel Alier, told the local regional assembly: "If we have to drive our people to paradise with sticks, we will do so."

That intolerance of local feelings—combined with a dogmatic belief in the benefits of technological progress—is a feature which has characterised all too many resettlement schemes.

Bloodshed is not always avoided. The Philippines Government, for example, brought in units of both the army and the police to crush opposition to the Chico Dam project. Arbitrary arrests were common, and it is alleged that the government forces were responsible for assassinating one of the chief opponents of the dam, Apo

Pangat Macli-ing Dulag. In the event, the Chico project was cancelled—at least for the time being.

LACK OF COMPENSATION AND INFERIOR LAND

Lack of compensation and resettlement on inferior lands are common features of resettlement schemes.

— Only those living on the actual site of Indonesia's Asahan Dam will be compensated for the loss of their land. As a result, 60 per cent of those being resettled will receive nothing at all.
— Those families being resettled in Sri Lanka's Mahaweli scheme will receive just £90 in compensation. The Victoria Dam, funded by Britain, will flood 123 villages. A minimum of 45,000 people will be affected.
— For landless squatters, the problem of compensation is aggravated by their lack of legal rights. In Brazil, between one-and two-thirds of those squatters affected by the Tucurui project will be unable to claim compensation. "The treatment of squatters could provoke enormous hardship for the large numbers—possibly 10,000—of already impoverished people to be displaced by the reservoir," says Dr Robert Goodland, a senior ecologist at the World Bank.
— Although every farmer resettled under Ghana's Upper Volta project was to receive 12 acres, the land clearing got so behind that only 8,000 acres out of an intended 54,000 acres were cleared before flooding. Many had to rely on food hand-outs.

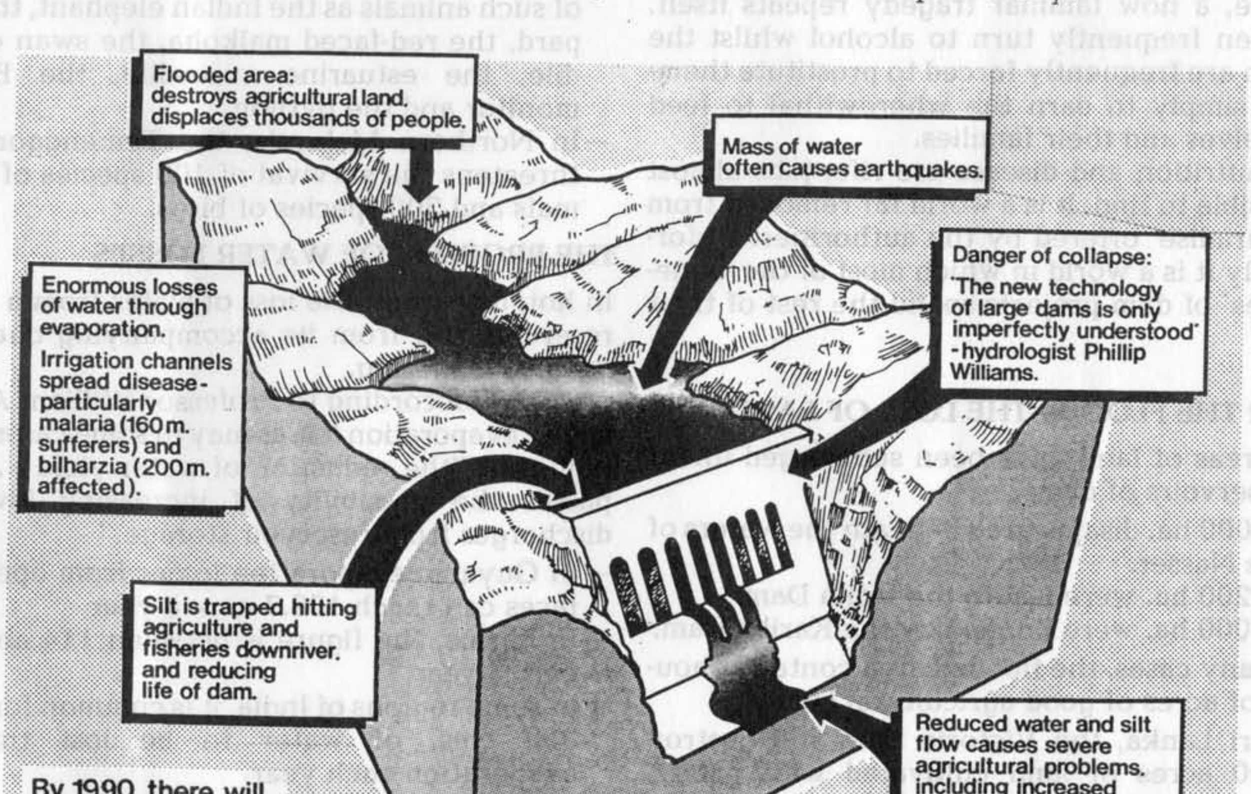
ETHNIC DIFFERENCES IGNORED

Once resettled, those who have been moved often have to contend with planning authorities who are indifferent to their cultural traditions.

— At New Halfa, the area designated to receive the 30,000 Sudanese Nubians uprooted by the Aswan Dam, three major ethnic groups were settled together.

Two of those groups were pastoralists, whilst the third consisted of agriculturalists. The result was numerous and bitter disputes over land rights. In 1974, the army had to be called in to keep the peace.

One settler likened the New Halfa project to "a cage where the government put a lamb and a wolf and asked them to figure out one way or another to live peacefully."



INAPPROPRIATE HOUSING

The housing provided under resettlement schemes is a frequent source of conflict.

- At New Halfa, many families received two-room houses, which were too small to accommodate all their members. The houses also ignored the basic social requirement of the settlers—in particular the need for women to be secluded from men, a tradition that was fundamental to their Islamic beliefs.
- In Ghana, the houses provided as part of the Upper Volta Resettlement scheme were equally unsatisfactory. Among other things, their design failed to take into account the fact that the local people were polygamous. "In the traditional family house, the wives had separate rooms," reports Stanley Johnson, now working for the European Commission. "The new houses offered only one room for the man and all the wives."

THE ROAD TO THE SLUM

Deprived of their traditional culture, and stripped of the support of their communities, many of those who are resettled drift towards the cities.

There, a now familiar tragedy repeats itself. The men frequently turn to alcohol whilst the women are frequently forced to prostitute themselves simply to earn the wherewithal to feed themselves and their families.

Malnutrition and disease are rife, jobs almost impossible to find. It is a world far removed from the 'paradise' offered by the authorities. Unfortunately it is a world in which most of the 'beneficiaries' of dam projects spend the rest of their lives.

AFTER THE FLOOD—THE LOSS OF LAND

Vast areas of land have been submerged under the reservoirs of dams.

- 400,000 ha. disappeared beneath the waters of Lake Nasser.
- 848,200 ha. were lost to the Volta Dam.
- 510,000 ha. were flooded by the Kariba Dam.

In many cases, the flooded area contains thousands of acres of good agricultural land.

- In Sri Lanka, the Victoria Dam will destroy 3,000 acres of land cultivated with paddy, tobacco, vegetables and other food crops; 2,000 acres cultivated with mixed fruit, cocoa, coffee, coconut, spices, tubers and soft wood; and 2,000 acres in big and small estates of cocoa, coffee, pepper, rubber, coconut, sugar cane and soft wood.
- In India, the Srisailam Hydroelectric Scheme near Hyderabad flooded some 107,000 acres of farmland.

In addition, dams have also caused the flooding of thousands of acres of valuable forests.

- India's Narmada Valley Project, which involves the building of 30 major dams, will drown 150,000 acres of forest, including 35,000 acres of teak forest.

LOSS OF WILDLIFE

The inevitable loss of wildlife as a result of impounding a dam is rarely seen as a reason for foregoing a project. Indeed, dams are often sited in 'protected' areas.

- The Nam Choan Dam in Thailand will flood approximately 4 per cent of the Thung Yai Wildlife Sanctuary. If the dam goes ahead, then the largest population of Asian elephant in Thailand, as well as other threatened species, such as the gaur and the tapir, could face destruction.
- The projected area for Sri Lanka's Mahaweli scheme contains parts of three wildlife sanctuaries. The scheme will seriously disrupt valuable wetland habitats along the banks of the Mahaweli, in addition to affecting the habitat of such animals as the Indian elephant, the leopard, the red-faced malkoha, the swan crocodile, the estuarine crocodile, the Bengal monitor and the python.
- In Northern Malaysia, the Temenggor Dam threatens the survival of 100 species of mammals and 300 species of birds.

THE PROBLEM OF WATER LOSSES

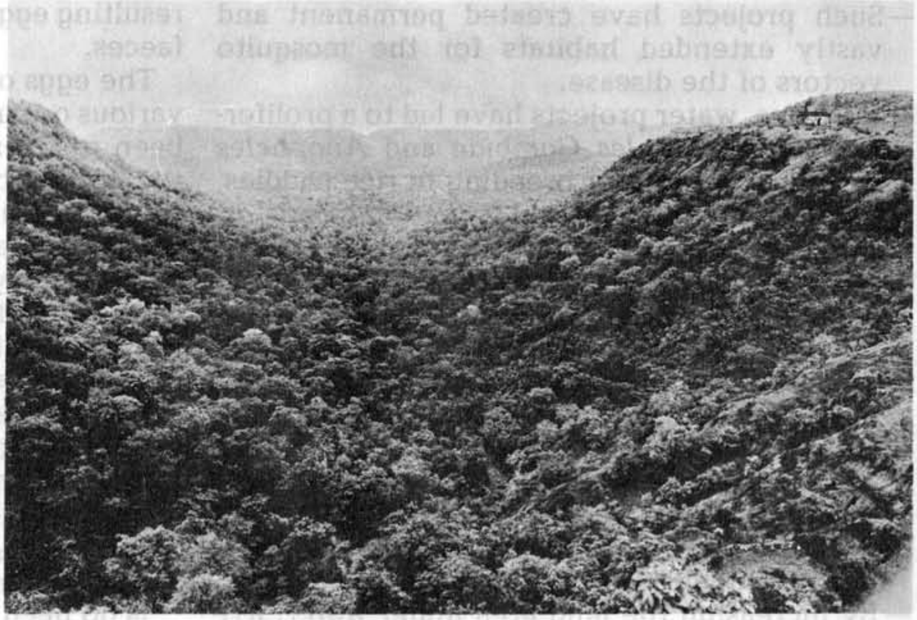
In hot, dry areas, the loss of water from a dam's reservoir and from its accompanying channels can be staggering.

Indeed, according to Professor William Ackermann, evaporation losses may in some cases be so high that "the reduction of water yield . . . surpasses the possibility of increasing low-flow discharges from reservoir storage."

- In Guyana, evaporation losses from open surfaces can reach 139.7 cms. a year.
- In Burma, the figure is between 114 and 152 cms. a year.
- In some regions of India, it is common for up to 300 cms. of water to be lost through evaporation each year.

Building vast reservoirs in areas where evaporation rates are high is thus inviting trouble.

In Egypt, Lake Nasser loses a minimum of 15 billion cubic metres a year to evaporation—enough water to irrigate two million acres of farmland.



The catchment area of India's Narmada River, Madyha Pradesh. Much of this forest will be flooded when the Narmada Dam Project is completed.

ASHISH KOTHARI

The problem is often exacerbated by increased rates of evapotranspiration as a result of the invasion of reservoirs by aquatic weeds.

In Egypt, the Ministry of Irrigation now accepts that evapotranspiration caused by aquatic weeds leads to water losses equivalent to 40 per cent of the gain obtained by the High Dam at Aswan.

Seepage from irrigation canals is also a major cause of water losses. In some cases, planners have underestimated seepage rates by 100 per cent.

— In 1967, it was found that between 13 and 19 per cent of the water transported along India's Upper Bari Doab Canal was lost to seepage. In the plains of Uttar Pradesh and the Punjab, such losses were as high as 36 per cent.
— In Egypt, during the summer, the main irrigation canals lose some 1,500 million cubic metres through seepage every year—approximately 10 per cent of the water available for irrigation.
— In many areas of the Middle East, anything between 10 and 70 per cent of the total volume of water conveyed through irrigation canals can be lost to seepage.

Although in theory, seepage losses can be cut to a minimum, the cost of installing the necessary technology is prohibitive—at least for the majority of Third World countries.

DAMS AND DISEASE

In terms of disease and consequent human suffering, the toll exacted by water development projects has been truly appalling.

When a river is dammed and a large artificial lake is created, those forms of life which were adapted to the previous riverine ecosystem are likely to disappear. In their place, other species will emerge. Some will thrive in the lake, others in the irrigation channels which it feeds.

Many of those new species play an integral part in the transmission of disease.

In particular, large-scale water projects have greatly increased the incidence of waterborne diseases, notably malaria and schistosomiasis.

MALARIA

In spite of the efforts of the World Health Organisation (WHO), malaria remains one of the most widespread and lethal diseases in the world.

Every year, malaria kills one million people.

At any given moment, 160 million people—the equivalent of the entire population of Japan, Malaysia and the Philippines—suffer from the disease.

In man, malaria is caused by four species of parasite, all belonging to the genus *Plasmodium.*

The parasite has a complicated life-cycle. Reproducing only within mosquitos of the genus *Anopheles,* the parasite must pass an 'asexual' phase within humans.

When an infected mosquito bites a human, thousands of plasmodium parasites are released into the blood.

Those parasites incubate in the human liver, eventually releasing their offspring into the bloodsteam, where they invade the red corpuscles.

Swamps, marshes and stagnant pools are ideal breeding grounds for malaria's mosquito vectors.

The introduction of modern, perennial irrigation schemes has greatly favoured both the incidence and the lethality of malaria.

— Such projects have created permanent and vastly extended habitats for the mosquito vectors of the disease.
— In Africa, water projects have led to a proliferation of *Anopheles Gambiae* and *Anopheles Funestas,* the former breeding in rice paddies, the latter in drainage and irrigation canals. *A. Gambiae* has the reputation of being the most efficient of all the malarial mosquitos, biting man in preference to other animals.
— In South Asia, irrigation schemes have favoured the mosquito which acts as the vector for both the *Plasmodium Vivax* and the *Plasmodium Falciparum* parasites.
— Because perennial agriculture makes possible two crops a year, it correspondingly increases the period during which mosquitos have habitats in which to breed.
— By increasing the land area under water, irrigation schemes also increase the total mosquito population—and hence the likelihood of infection.
— Irrigated agriculture also changes the biting habits of mosquitos. As the local human population increases and crops take over from livestock, so the mosquitos switch from biting animals to biting humans.

Unfortunately, once the conditions for malaria have been established, the disease is virtually impossible to control.

Not least among the problems, is the remarkable ability of mosquitos to develop genetic resistance to the insecticides currently used to destroy them.

In 1981, the World Health Organisation (WHO) reported that 51 species had developed resistance to one or more insecticide.

As a result, there has been a resurgence of malaria in many countries in which it was once thought to have been practically eliminated.

SCHISTOSOMIASIS

In 1947, an estimated 114 million people suffered from schistosomiasis. Today, 200 million people are affected—the equivalent of the entire population of the USA.

The disease is caused by parasitic flatworms, known as 'schistosomes'. Three common species infect man: *S. Haematobium, S. Mansoni* and *S. Japoni.*

The larvae of the schistosomes develop within the bodies of freshwater snails.

When people swim or wade in water contaminated by infected snails, the larvae bore through their skin and enter their blood stream.

From there, they move to the liver, where they mature in a few weeks and mate. The resulting eggs leave the human body via urine or faeces.

The eggs of all three species tend to spread to various organs whilst still in the body. They have been recovered from the brain, the spinal cord, the lungs, bladder, appendix, rectum, uterus, spleen and liver.

The dramatic spread of schistosomiasis over the last 35 years is largely the result of large-scale water development schemes. Such schemes provide ideal habitats for both fresh water snails and the schistosome parasite.

The connection between schistosomiasis and water projects is so well established that Professor Gilbert White, a leading authority on ecological problems, writes:

> "The invasion by schistosomiasis of irrigation schemes in arid lands is so common that there is no need to give examples. The non-invasion of schemes in a region where the disease exists is exceptional."

Not only is the snail vector's habitat greatly extended by water development projects but the conditions are also created for much longer breeding periods.

— In Kenya, schistosomiasis now affects almost 100 per cent of those children living in irrigated areas near Lake Victoria.
— In the Sudan, the massive Gezira irrigation scheme, had a general infection rate of 60-70 per cent in 1979, with the rate amongst schoolchildren reaching over 90 per cent. All in all, 1.4 million people were affected.
— After the building of the Aswan High Dam, the infection rate rose to 100 per cent in some communities.

Few doubt that the disease is on the increase. Letitia Obeng of the United Nations Environment Programme warns that the current incidence of schistosomiasis is "only the thin end of the wedge."

DAMS AND FISHERIES

Where fisheries have been set up in the reservoirs of dams, they have generally enjoyed only short-term success.

— At Lake Volta, a very large fishing industry was developed immediately after inundation. But catches rapidly fell off as the submerged vegetation below the lake rotted away and nutrients became less and less readily available.
— The experience at Lake Kariba is similar. Five years after the lake was formed, some 2,000 fishermen were landing 3,628 tonnes of fish a year. Ten years after closure, no more than

907 tonnes of fish were caught. Efforts to restock the lake with new species proved a dismal failure.

A dam's impact on fisheries does not begin and end with the fate of the fish in its reservoir. In terms of fish yields, the loss of fish throughout the river basin as a whole can, in most cases, equal—or even exceed—the temporary gains made in the dam's reservoir.

* Dams tend to reduce the catch of migratory fish by preventing them from reaching their spawning grounds.
* Dams reduce the flow of rivers—with disastrous consequences for fishlife downstream.
* Water development projects involving irrigation schemes have led to an increase in the salinity of many rivers. In some cases, the salt content of the lower reaches is now so high that freshwater fish cannot survive.
* The building of a dam traps silt which was previously washed downstream. That silt contains nutrients which are vital to the survival of fisheries in the lower reaches of the river and in the sea beyond.
* The invasion of reservoirs and their associated canals by aquatic weeds seriously reduces fish yields both upstream and downstream of dams. The weeds affect fish populations in a number of ways.

— By increasing water losses to evaporation, they reduce the amount of water available for fisheries.
— By virtue of their sheer mass, they reduce the effective capacity of the reservoir, hence restricting the habitat available for fish life.
— When they rot and die, they use up valuable oxygen.
— By diminishing the sunlight both at the surface of a reservoir and in the waters below, weeds reduce the biological productivity of a reservoir.
— By tangling nets and fouling the propellors of boats, weeds interfere with fishing activities.
— And, finally, the herbicides used to eliminate weeds lead also to the loss of fish life.

Unfortunately, the herbicides used to control aquatic weeds are not the only chemicals which are likely to pollute a lake and its water-ways and thus affect fish life.

— In India, pesticide use has led to the complete loss of fish life in some rivers, estuaries and reservoirs.
— In Thailand, in 1983, more than a million fish were killed by pesticides in Suphanburi province. The incident has been described as Thailand's "worst man-made ecological disaster."

Even without considering the reduction in fish catches attributable to the ecological disruption caused by a dam, it is doubtful whether the fisheries provided by a man-made lake can compensate for all the food resources lost to flooding.

In that respect, the work of Eugene Balon is particularly relevant. He points to the protein value:

* Of the fish caught in a river before it is impounded;
* Of the crops in the farmland which is flooded;
* And of the wild game which inhabited the often extensive croplands, rangelands, and forests that are drowned by a reservoir.

When those food resources are taken into account, argues Balon, dams may well cause a net loss in available protein.

DAM FAILURES

It is only recently that we have started building large dams. Our experience is thus largely with small dams.

Even small dams have not proved particularly reliable. One per cent of them fail every year.

The consequences of such failures have often been serious despite the small size of the dams involved.

— When the Teton Dam collapsed in 1976, it caused the death of 14 people, together with over 1 billion dollars worth of damage. It was only 95 metres high.
— The failure of the 23 metres high Johnstown Dam in Pennsylvania killed over 2,000 people.

The incidence of dam failures is likely to increase in the future. As Ferdinand Budweg, a noted Brazillian engineer points out,

"The number of new dams in countries with little or no experience in the design, construction and operation of dams increases from year to year. Lack of experience may lead to the repetition of errors and serious mistakes."

So too, as appropriate sites for building dams begin to run out, dams will increasingly be constructed in less and less suitable places. Failures due to improper siting have already occurred.

— The Malpasset Dam near Frejus in France failed because it was built in the wrong place. This despite warnings from engineers. Its collapse, in 1959, caused the death of 421 people.
— Peru's Tablachaca Dam is seriously threatened by a landslide. In 1983, the slip moved towards

the dam at a rate of 70 mm. a day, causing serious concern in Lima.

Dams fail for other reasons too.

* 'Over-topping' during period of flood is probably the most common cause. Such over-topping caused the collapse of India's Machau II Dam in 1979. It also led to the near failure of Pakistan's Tarbella Dam in 1975.
* Shoddy workmanship is another factor. The failure of the St. Francis Dam in California has been attributed to faulty foundations. Design errors were apparently also largely responsible for the collapse of the Teton Dam. Shoddy workmanship is a perennial problem throughout the Third World.
* Sabotage may also be a cause of dam failures. Several attempts were made to blow up the Cabora Bassa Dam prior to the independence of Mozambique.
* Finally, many dams fail as a result of 'pilot project syndrome'—the tendency of engineers to assume that the technology used to build small dams can be used, with little or no modification,

Transplanting rice in the Phillipines. Had the Chico Dam Project gone ahead, these tribal lands would have been flooded—and a unique agricultural system destroyed. The dam was stopped after massive local resistance.

to build large dams. In fact, as the hydrologist Philip Williams points out, "The new technology of large dams is only imperfectly understood."

DAMS AND EARTHQUAKES

The pressure applied to often fragile geological structures by the vast mass of water impounded by a large dam can—and often does—give rise to earthquakes.

The first hint that dams could cause earthquakes came in the late 1930s, when increased seismic activity was recorded after the Lake Mead reservoir was impounded by the Boulder Dam.

By 1968, major earthquakes had occurred at four large reservoirs:

— At Hsingengkiang in China (magnitude 6.1 on the Richter scale) in 1962;
— At Kariba in Rhodesia (magnitude 5.8) in 1963;
— At Kremesta in Greece (magnitude 6.3) in 1966;
— And at Koyna in India (magnitude 6.5) in 1967.

Originally it was thought that earthquakes could only be induced when a reservoir was being filled—or immediately after it reached its maximum height.

But earthquakes can also occur when a reservoir is emptied and then refilled. Cases in point: the earthquakes which hit France's Vouglans Dam and Corsica's Alensani Dam.

Recently, the lowering of the water level in reservoirs has been linked with earthquake activity. The implications of that finding are clear. As David Simpson, an expert on reservoir-induced seismicity, notes:

"One of the obvious ways of decreasing danger downstream of a dam—the rapid emptying of the reservoir—may, in fact, increase the danger of triggering a further increase in the level of (earthquake) activity."

It is difficult to establish the geological conditions under which induced earthquakes will occur.

Nonetheless, a general pattern has emerged. Areas most at risk appear to be those with "strike-slip or normal faulting". Least at risk are "areas of low strain accumulation."

That said, however, the Aswan Dam is situated in such a 'low-strain' area—yet, in 1981, it experienced an earthquake of magnitude 5.6 on the Richter scale. So too, the Akosombo and Bratsk Dams have experienced induced earthquakes despite being in low risk areas.

Such is the paucity of our knowledge of induced seismicity that David Simpson concludes: "All large reservoirs must to some extent be considered potential sources of induced activity."

Such warnings, however, do not seem to have had any influence on current dam building programmes.

The Indian government, for example, is at present constructing a large dam at Tehri on the Bhagirathi River in the mid-Himalayas—an area of marked seismic activity. To make matters worse, the rocks of the river gorge where the dam is to be built already appear heavily cracked.

In the light of our present knowledge of reservoir induced seismicity it is difficult to see how the Indian government can justify the Tehri scheme.

Nor is Tehri the only dam under construction which is likely to cause earthquakes. Worldwide many dams are being built—or planned—in areas of seismic activity.

It is surely only a question of time before one of those dams causes a truly serious earthquake—perhaps killing tens of thousands of people.

As Jean-Pierre Rothé, the French seismologist, remarks: "By building dams, Man is playing the sorcerer's apprentice. In trying to control the energy of rivers, he brings about stresses whose energy can be suddenly and disastrously released."

THE MYTH OF FLOOD CONTROL

Floods are a serious problem in many river basins —particularly those affected by monsoons and typhoons.

In Asia alone, floods destroy about 4 million hectares of crops a year. The lives of some 17 million people are affected.

All the evidence suggests that floods are becoming more destructive and more frequent— this despite massive expenditure on flood control schemes.

Such flood control schemes generally involve the building of embankments—in order to contain flood waters within rivers—or reservoirs in order to store flood waters for release at a later date. Embankments, dams and other similar devices are referred to as 'structural controls'.

There is now an increasing body of evidence that structural controls do little or nothing to reduce the ravages of floods. On the contrary, they exacerbate the problem by increasing the severity of flooding.

—In India, nearly a billion dollars was spent on structural controls between 1953 and 1979. Yet the National Commission on Flood Control estimates that the area ravaged by floods has almost doubled in the last 30 years.

B.B. Vohra, President of the Environmental Planning Commission, is scathing of structural controls. "The building of spurs and embankments is no answer to the problem of floods," he says. Rather than solving the flood problem, the building of embankments merely "creates the illusion of doing so".

—In the USA, the devastation caused by floods has increased in spite of the vast amount of money spent on flood controls. Between 1933-1976, the US Government spent over $12 billion on structural controls. Yet, over the same period, the average annual cost of flood damage has risen from $350 million to between $3.5 and $4 billion. That increase cannot be explained by inflation alone. In many instances, flood controls have made the damage done by floods more devastating. Professor Charles Belt of St. Louis University, for instance, points out that the floods which ravaged the Mississippi Basin in 1973 contained less water than a previous less destructive flood. If the floods caused so much damage in 1973, it was largely because of the leves and navigation structures which had been built along the river.

That flood control embankments actually increase the severity of floods is easily explained.

By containing a river within concrete embankments, one does not reduce the total volume of flood waters. One does, however, dramatically increase the river's rate of flow.

When a flood occurs, the waters are literally propelled downstream. Inevitably the damage down in the floodplains downstream is correspondingly increased.

It is for that reason that Dr Maurice Arnold of Philadelphia's Bureau of Outdoor Recreation argues that such structural controls as channels or canals should be regarded not as flood control mechanisms but as "flood threat transfer devices."

DEFORESTATION, EROSION AND FLOODS

The problem of floods has been compounded by deforestation. Cutting down forests increases dramatically the risks of flooding.

When a catchment area of a river is heavily forested, the elaborate root system of the trees acts as a giant sponge, soaking up rainfall and releasing it slowly to the river below.

Once deforested, run-off in the catchment area is vastly increased. According to UNESCO, the watershed of one river released between 1 and 3 per cent of the total rainfall in the area when forested. Once the trees had been cut down, between 97 and 99 per cent of the rainfall was released.

During heavy rainfall, the volume of water carried by rivers in deforested areas can be massive. The pressure put on flood control embankments is tremendous.

Deforestation has another serious consequence. It causes severe erosion, increasing the silt load of rivers.

Where a river is channelled through embankments, that silt simply accumulates. The height of the river bed is thus raised until, eventually, it becomes higher than the surrounding land.

Where China's Yellow River crosses the Yellow Plains, the river's bed is now 5 to 10 metres above ground level.

Such silting up further increases the pressure on embankments, whose height must be raised year after year in order to prevent flooding.

But raising the height of embankments does not solve the problem indefinitely. In the long run, it can only increase the severity of future floods. For when a breach occurs, the result is disaster.

The terrible floods which have ravaged India and China in recent years have been attributed to increased run-off and erosion in the catchment areas of large rivers.

- In China, the three major rivers of Sichuan Province carry an estimated 250 million tons of silt. Much of that silt has been washed from land which has been deforested. Significantly, even the provincial authorities have blamed the recent spate of floods in the area on deforestation.
- In India, reports *The Economist*, erosion has largely offset the protective value of embankments. As a result, the building of embankments has "proved no more than a temporary palliative" to the problem of flooding.

BUILDING ON FLOODPLAINS: ASKING FOR TROUBLE?

During periods of heavy rainfall, free-flowing rivers regularly burst their banks and inundate their flood plains.

In times gone by, people very sensibly avoided building permanent settlements on flood plains.

Today, however, people have been persuaded that—so long as enough money is spent on structural controls—it is safe to build on the flood plains of the wildest rivers.

Significantly, the 1969 United Nations Conference on Floods singled out the intensified use of flood plains as a major cause of the increased costs of floods in North America and Western Europe.

So too, Professor D.I. Sikka of the Department of Major Multi-Purpose Projects in Madhya Pradesh blames the terrible damage caused in India by the floods of 1971—and indeed those of more recent years—on the intensified use of flood plains.

ONLY ACTING WHEN DISASTER STRIKES

Structural controls have other drawbacks. They are extremely expensive.

In India, $900 million are budgeted for flood control measures over the next few years. Even that vast sum is regarded by experts as woefully inadequate. some $1,300 million are said to be required for the Ganges River Basin alone.

More often than not, funds are only allocated for flood control schemes when disaster looms. "Parliamentary indignation is roused only when the waters are at their highest: demands and pledges alike being quietly shelved once the deluge has disappeared," comments India's *The Statesman.*

THE TRADE OFF BETWEEN FLOOD CONTROL, HYDROPOWER AND IRRIGATION

When dams are used to control floods, there is often a conflict between the need to keep reservoirs low for flood control purposes and to keep them high in order to generate electricity and provide water for irrigation.

The result is a 'trade-off' between the three competing demands—with those who wish the reservoirs to be kept high invariably winning the day.

The trade-off frequently proves disastrous.

- In 1978, the authorities of a dam in West Bengal maintained the reservoir practically full even during the rains of May and June in order to generate the maximum hydro-electricity. The river's flood waters could not be contained within the reservoir. Inevitably, vast areas of West Bengal were flooded.
- More recently, the desire to keep reservoirs full led to the disastrous floods that ravaged California in 1983. Heavy snowfall during the winter led to increased run-off from the Rocky Mountains in the spring. The waters of the River Colorado swelled to almost unprecedented heights. Under pressure from the tourist industry, the farming lobby and the hydro-electricity authorities, the reservoirs along the Colorado were kept filled to the brim.

When a decision to lower the reservoirs was eventually taken, it was too late. Officials admitted that by releasing the flood waters, they were unleashing a controlled disaster' on the South West. Fifty-five thousand acres of farmland were flooded and an estimated $100 million worth of property destroyed.

DEALING WITH FLOODS: URGENT PRIORITIES

Serious floods are not acts of God. As Maurice Arnold wisely points out:

"Too often, flood policies and programmes are based on the assumption that flood disasters result from nature's actions, not man's, whereas in actual fact the misery and damage are mostly caused by human error—especially by poor land management and myopic flood-control strategies."

What then should be done? There are three areas where we can take immediate action.

* The deforestation of the catchment areas of the world's greatest rivers must be halted immediately.
* A massive and systematic programme of re-afforestation in such catchment areas is of the utmost urgency.
* And, finally, it is essential to take action to prevent the further development of the flood plains of the great rivers.

Above all, we need to develop a new attitude to floods and the problem of flood control.

We must abandon the illusion that floods can actually be eliminated by technological means.

Floods will continue to occur—regardless of the ingenuity of engineers. But floods need not prove disastrous.

On the contrary, throughout history, people have made use of floods to irrigate land and to fertilise their fields.

If floods could be brought once more under the joint control of the forests and the flood plains, we too might learn to live with floods.

SALTING THE EARTH: THE PROBLEM OF SALINISATION

All soils contain salt, the result of what geologists call 'weathering'. But if salt levels become too high, the land becomes toxic to plant life.

The problem is particularly serious in the dry tropics where there is simply not enough rainfall to flush out the salts which accumulate in the soil.

Groundwater provides the main reserve and source of salts circulating in the 'soil profile'. For that reason, it is essential that the water table beneath potentially saline soils be kept as low as possible.

If the water table is allowed to rise, then the groundwaters are drawn up to the surface through capillary action. On the way up, they add to their own salt load by dissolving the salts in the soil. The land becomes waterlogged with increasingly saline water.

As they approach the surface, the groundwaters quickly evaporate. The salts they contain are thus left behind to accumulate on the surface. It is not long before the whole area becomes covered with a white saline crust. The land is then said to be 'salinised'.

Even before the saline groundwaters reach the surface, they start affecting crop yields by interfering with the capacity of plants to take up moisture and oxygen.

But in many cases when the land becomes salinised, it is effectively dead forever.

IRRIGATION AND SALINISATION: THE INTIMATE CONNECTION

If arid lands are not to become salinised, it is essential that the 'water-salt balance' of the soil is maintained.

Water must not be allowed to accumulate in the soil. So too, salt must not be added to the soil unless an equal amount of salt can be flushed out of the land.

Irrigation schemes throw the delicate water-salt balance of many areas dangerously out of kilter.

* Perennial irrigation invariably raises the water table. In some areas, groundwater tables are rising at a rate of 3 to 5 metres a year. That rise in groundwater levels is caused primarily by water losses due to seepage from irrigation channels.
* Irrigation also adds directly to the salt load of soils through increasing the rate of evapotranspiration. Not only does irrigation increase the extent of vegetative cover—and hence the rate of transpiration—but it also requires water to be spread thinly over a wide area, thus raising direct evaporation losses. The result of such evapotranspiration is that the natural salts in water become concentrated in the soils.

  According to Professor Arthur Pillsbury of the University of California, three-quarters of the water applied each year to irrigate land in the US is lost to evapotranspiration. The result if a four-fold concentration of salts in the remaining water. Such water often contains more than 2,000 parts per million of salt.
* High evaporation rates also increase the salt burden of reservoirs and rivers. As a result, the water used to irrigate many areas is now in itself a significant factor in the spread of salinisation. According to Professor Victor Kovda of

the University of Moscow, the best irrigation water from rivers now contains 200 to 500 milligrams/litre of salts. "Supplying 10,000 cubic metres on 1 hectare of land during the irrigation season thus deposits 2 to 5 tons/ha of salts in soils," he notes. "After 10 to 20 years of irrigation, this amount becomes enormous—amounting to dozens and even hundreds of tons per hectare."

THE EXTENT OF THE PROBLEM

FAO estimates that at least 50 per cent of the world's irrigated land now suffers from salinisation.

Others put the figure even higher. Sixty to 80 per cent of irrigated land is salinised says Kovda. Between 1 and 1.5 million ha. succumb to salinisation every year. Significantly, much of that land is "in irrigated areas of high potential production."

According to one recent study, as much irrigated land is now being taken out of production due to waterlogging and salinisation as new irrigation schemes are bringing into production.

—In Pakistan, 25 million acres of the 37 million acres under irrigation are estimated to be salinised, waterlogged or both.

In the lower Indus, concentrations of salt in the groundwater have been found to reach 30,000 ppm—almost as salty as seawater.

All told, an estimated 100,000 acres are lost annually to waterlogging and salinisation in Pakistan—more than 100 hectares a day.

—Of the area earmarked to receive water via China's giant Yangtse Diversion scheme, 2.7 million hectares already suffer from salinisation.

A further 4.7 million hectares consists of potentially saline soil "which is most vulnerable to secondary salinisation if affected by detrimental factors."

—In Egypt, the problems of salinisation and waterlogging have been described as 'grave'.

A USAID mission reported in 1976 that 4.2 million feddans* were undergoing slight to severe effects from inadequate drainage, and unless something were done, all would be severely affected. Waterlogging alone is estimated to have reduced agricultural productivity by at least 30 per cent.

—More than 50 per cent of the 3.6 million hectares under irrigation in Iraq suffer from salinisation and waterlogging. Vast areas of South Iraq now "glisten like fields of freshly fallen snow", reports Erik Eckholm, the environmental writer.

—500,000 acres in Syria—half of the country's irrigated land—are waterlogged or salinised. In many locations, it is estimated that 70 per cent of the soils put under irrigation are potentially saline.

—In Iran, 15 per cent of the irrigated land is affected to some degree by waterlogging, salinity and alkalinity. Of the country's 16.8 million hectares of arable land, 7.3 million are estimated to be saline and 6.2 million are waterlogged.

—In India, the amount of land devastated by water and salt has been variously estimated at between 6 million and 10 million hectares—almost a quarter of the 43 million hectares under irrigation.

—In the US, Jan Van Schilgaarde, Director of the US Salinity Laboratory, considers that 25 to 35 per cent of the country's irrigated land suffers from salinity—and that the problem is getting worse. If no remedial measures are taken, the highly productive San Joaquin Valley could lose over a million acres of farmland in the next hundred years.

CAN SALINISATION AND WATERLOGGING BE AVOIDED?

It is rare to find irrigated areas which have avoided the twin problems of waterlogging and salinisation. Indeed, irrigated land has been degraded with such regularity that Kovda sees "increasing salinity in irrigated soils of arid lands" as being "practically universal".

Aloys Michel of the University of Rhode Island goes a step further. "Waterlogging and salinity, or both problems, will inevitably arise in all but the truly exceptional surface-water irrigation schemes."

The promoters of large-scale irrigation insist that salinisation and waterlogging are not the fault of perennial irrigation *per se*. On the contrary, they claim, the problems result from technical and administrative 'mistakes' which can easily be corrected in the future.

But, is it really possible to avoid waterlogging and salinisation in lands watered by large-scale irrigation schemes? And if so, how?

* One course is to line irrigation canals, thereby reducing seepage. Unfortunately, the cost of lining canals is exorbitant—one reason, why lining is rarely installed.

But, lining irrigation canals is by no means a certain method of reducing all seepage. For one thing, the lining does not last indefinitely: for another, its efficiency is largely dependent

* 1 feddan is equal to 1.038 acres.

on regular and thorough maintenance.

* Another strategy is to dig tube wells in order to pump out groundwater and thus lower the water table. A large number of such wells have been sunk in Pakistan, China and elsewhere.

Once again, however, their high cost has often proved an insurmountable problem. In addition, tube wells have a short life span and, with lined irrigation canals, they share the intractable problem of requiring regular maintenance if they are to work.

Where tube wells have been used, as in China, their successes in bringing down the water table appear short-lived.

Ironically, too, the excessive use of tube wells can, in itself, exacerbate the problem of salinisation. Where the water table is lowered too far (as has happened in certain parts of the South-western United States) aquifers can be so depleted that they become closed basins. Used irrigation water then accumulates in them.

* A third method for reducing the rate of salinisation is the introduction of 'overhead sprinklers'. Such sprinklers are said to minimise water use and, thus, rule out over-watering as a cause of waterlogging.

Nonetheless, sprinklers are not without their problems. In hot areas, the water can evaporate even before it hits the ground. And, sprinkler irrigation has been associated with increased pest outbreaks.

* The most effective means of combating waterlogging and salinisation is to build drains. Irrigation without drainage is now generally accepted to be little more than a recipe for ecological disaster.

But drainage is rarely installed in irrigation schemes.

Drainage was never installed in the various irrigation projects which have been set up in the Chambal areas of Rajhastan and Madhya Pradesh in India. Waterlogging quickly developed in the area.

In New South Wales, Australia, tiled drains have indeed been installed—but only for those irrigated lands under intensive horticulture. Other irrigated crops go undrained.

Even in America's San Joaquin Valley, some 60 per cent of farmers do not have adequate drainage facilities.

One reason for the reluctance of governments to install drainage lies in the expense involved.

The UN Food and Agricultural Organisation (FAO) estimates that installing effective drainage costs between 200 and 1,000 dollars per hectare of land.

The cost of drainage is usually underestimated when planning new irrigation schemes. "Costs for drainage are always under-estimated and when irrigation schemes overrun their budgets—which they always do—there is little money or interest left for drainage, "notes Carl Windstrand in his book, *Water Conflicts and Research Priorities.*

He goes on to quote Erik Eckholm who remarks: "The legacy of this continued defiance of reality is a stupendous loss of global agricultural output."

In fact, if the true cost of drainage were taken into account, then many water projects would cease to be economic.

SALINITY AND DOWNSTREAM AGRICULTURE

Lining canals, digging wells and introducing drainage are all measures undertaken to ensure that salts are flushed away from irrigated land.

But the flushed salts must go somewhere. Generally, they end up in the nearest river, thus increasing the river's salt content.

For farmers downstream of irrigation schemes, the problem is obvious. They must use increasingly saline water to irrigate their own fields.

Where river basins have been highly developed, downstream farmers must cope with other problems too.

* If there are cities upstream, their irrigation water is likely to be contaminated with domestic waste and industrial chemicals.
* Over-use of water upstream can severely restrict the flow of a river—in some cases to the extent that sea water is allowed to intrude into the Delta.

In some river basins, notably in Bangladesh, sea water has been known to intrude up to 100 kilometres inland.

Many downstream farmers in arid areas now find their livelihoods threatened by development upstream of them.

— Geography has condemned Pakistan's Sind province to being a 'sink' for the whole Indus Valley.

As a result of economic development within both Afghanistan and the Punjab—the two upstream states which share the Indus—its waters are increasingly polluted.

Although the Tarbella Dam was built to supply some 92 million acre feet of good quality water to the Sind, few experts expect the dam to provide a permanent solution to the problem.

The demand for good water has led to the Punjab's extensive groundwater reservoirs being mined on a large scale. But that supply will start running out by the end of the century.

"Sooner or later", says Aloys Michel, "the concentration of salts . . . is bound to increase downstream."

The only solution—or rather palliative—is to 'export' the highly saline waters directly to the sea or to allow them to accumulate in sinks along the desert margins.

The cost of either undertaking, however, would be enormous. It is hard to see how further salinisation can be avoided in the area.

—Like the Sind, Iraq is at the tail end of a shared water supply—the River Euphrates. The river also runs through Turkey and Syria.

Should plans to build new dams along the river go ahead, then, according to Professor Peter Beaumont of Bangor University, "the likely demand for water will be in excess of the available flow of the river."

Iraq will suffer most. Very little water will be left for her to use and what water there is will have high salt and pollution loads.

One consequence will be a corresponding fall in the quantity and quality of food produced in the area.

—Before it reaches South Australia, the River Murray flows first through the States of Victoria and New South Wales. Together, those two states contribute 64 per cent of the 1.1 million tons of salt carried by the river each year.

As a result of abstraction upstream, the amount of water reaching South Australia has been drastically reduced. What water does arrive is seriously polluted with agricultural and industrial wastes.

Irrigation water which seeps back into the Murray brings with it salts from underlying groundwaters. Because the groundwaters of South Australia are naturally saline—in some areas, they are saltier than sea water—the resulting salt load can be very high.

In an attempt to combat that problem, tiled drains were installed below irrigated lands in some areas, the water being pumped into 'evaporation basins' on the river flats. Those basins were not watertight, however, and highly saline water is already seeping out of them into the Murray.

The prospects for the future are grim. "In the face of rising salinity levels and increasing demand for good water for metropolitan Adelaide, the farmers' future looks decidedly shaky," comments M Bulter, a geographer at Adelaide College.

He goes on to warn: "Irrigated land will eventually be abandoned and farmers will lose a way of life."

—Northern Mexico is partly dependent for its water on two 'shared rivers'—the Rio Grande and the River Colorado. The water from both rivers is now so saline that it can only be used twice before it becomes too brackish for agriculture.

Salt concentrations in the Rio Grande have increased from 221 to 1691 ppm in recent years. If salinity levels in the River Colorado continue to rise at their present rate, then by the year 2010, the economic cost in terms of lost production and declining water quality will have exceeded $1.24 billion.

America has agreed to reduce the salinity levels of waters entering Mexico. To that end, a massive desalinisation plant is being built on the Mexican border at Yuma in Arizona.

Originally priced at $300 million, the plant is now expected to cost more than $1 billion.

At that price, irrigation water provided by the plant will cost some $800 per acre-foot, more than 35 times the current cost of irrigation water in the Imperial Valley of California.

EFFORTS TO COMBAT SALINITY: THE US EXPERIENCE

Much of the saline water from the farms in the Imperial Valley—where 500,000 acres are under irrigation—is channelled for 80 miles via the All-America Canal into the naturally salty, inland Salton Sea.

Few agricultural areas, however, have a Salton Sea at their disposal. Where no natural salt 'sink' exists, therefore, artificial evaporation basins have been built.

Those basins do not—and cannot—provide a lasting solution to the salt problem. In particular, they result in the contamination of groundwaters.

Saline water rapidly breaks down soils which are impermeable to fresh water, thereby rendering them permeable. Even building evaporation basins on impermeable land will not prevent the long-term contamination of groundwaters.

Nor does it help to line basins with an impervious material such as plastic or asphalt.

"Conceivably, such linings will be effective for as long as 50 years but, ultimately, one expects them to fail," warns Arthur Pillsbury. "In all probability, their lifetime when they are exposed to saline water will be shorter than their lifetime

UNITED NATIONS

Perrennial irrigation agriculture is notorious for causing waterlogging and salinisation

is when they are exposed to fresh water, for which they are normally tested."

Apart from evaporation basins, the other principal means of disposing of waste irrigation waters is via long-distance drainage canals.

— In Southern California, a 290-mile long 'master drain' has been half-built—at an estimated cost of over 1.2 billion dollars—in order to take the waste waters from the San Joaquin Valley directly to the Pacific.

The Canal will have the capacity to move more than 3 million tons of salt every year. If the canal is allowed to continue to the sea, the dumping of such massive quantities of salt will cause untold ecological damage in the delta area. The drainage water is also heavily contaminated with agricultural chemicals.

It is a moot point as to whether long-distance drainage canals actually avoid the further salinisation of water tables. Arthur Pillsbury for instance argues that such salinisation is only avoidable where the water table is semi-perched —that is, isolated from the deeper, main body of groundwater.

Three major schemes have been proposed in order to provide water to flush excess salts from the soil of the US south-west and—more important from the Government's point of view—to extend the amount of land under irrigation.

All three schemes involve importing vast quantities of water from other parts of the US. Two have run into financial difficulties and the third looks unlikely ever to get off the ground.

— The Peripheral Canal Project, which would bring water from Northern California to Southern California, at a cost of between $700 million and $1.3 billion, was vetoed down in a 1982 referendum.

— The Texas Water System, which was intended to bring water to the semi-arid and arid West of Texas, has also been vetoed by local taxpayers, who baulked at having to finance the $3.5 billion project.

— The North American Water and Power Alliance (NAWAPA) scheme is the most ambitious. It would divert water from Alaska and Northern Canada to various part of Canada, the US and Mexico. The drainage area of the scheme would be 1.3 million square miles and 160 million acre-feet of water would be diverted southwards for irrigation and 'water way control'.

The estimated cost of the project is $200 billion. If the experience of similar projects is anything to go by, the final cost could well be 3 to 4 times higher.

The scheme is likely to be strenuously opposed by environmentalists and by Alaska and Canada, neither of whom take kindly to the idea of their waters being diverted to the American Southwest. Indeed, it seems that there is little chance of the scheme ever coming into operation.

Significantly, however, Arthur Pillsbury argues that without the NAWAPA scheme, the future of the Southwest is extremely precarious. He describes the project as "the only concept advanced so far that will enable the lower reaches of western rivers to achieve the salt balance necessary for the long term health of western agriculture, on which the entire US and indeed the world has much dependence."

He goes on to warn: "Unless the lower rivers are allowed to reassert their natural function as exporters of salt to the ocean, today's productive lands will eventually become salt-encrusted and barren."

SALINISATION: NO TECHNOLOGICAL SOLUTION

By opting for technological solutions to what are essentially ecological problems, the further salinisation of lands throughout the world is ensured.

In effect, we have become trapped on a technological treadmill.

In that respect, the experience of the US Southwest is particularly eloquent. In their thirst for water, the inhabitants of the Southwest have sunk tube-wells and built huge reservoirs. In their fight against salinisation, huge fortunes have been spent on lining irrigation canals, digging drains and building evaporation ponds.

But those measures have singularly failed to solve the Southwest's problems. Salinisation is getting worse—and there is still not enough water to satisfy demand.

The search for new 'technological fixes' has now become increasingly desperate. River basin transfer schemes and genetically-engineered salt-tolerant crops have become the order of the day. But at what financial—let alone ecological—cost?

Sooner or later the technical fixes will run out. Even now many of the proposed schemes are too costly to implement. How long will it be before the region is transformed into a salt-encrusted desert? And how many other areas around the world will go the same way?

SEDIMENTATION: THE WAY OF ALL DAMS

Sooner or later, the reservoir of a dam must fill up with the silt and other detritus which the dam prevents from flowing downstream. When that happens, the dam must be decommissioned: indeed, without its reservoir, a dam is no more than a useless slab of concrete.

In temperate areas, the sedimentation of a reservoir is usually a slow process.

A study by Dr Cyberski of the State Hydrological-Meteorological Institute, Warsaw, for instance, reviewed sedimentation rates at 19 reservoirs in Central Europe. Cyberski found that their storage capacity (which ranged between 120 and 183,000 acre-feet) was depleted by sedimentation at an average rate of 0.51 per cent per annum.

In the tropics the situation is very different indeed. That difference can be explained, principally, by the devastating effect which deforestation has had on tropical soils.

Given the present rate of deforestation in the tropics (twenty-five acres of rainforest are lost throughout the world every minute of the day) it is hardly surprising that rivers in the region carry enormous quantities of silt.

Predictably, the rate of sedimentation in the tropics in recent years has been nothing short of disastrous.

- In India, the expected siltation rate of the Nizamsagar Dam in Andhra Pradesh was 530 acre-feet a year. The actual rate was closer to 8,700 acre-feet a year. Indeed, the dam's reservoir is already estimated to have lost 60 per cent of its storage capacity.
- Few of the other dams now operating in India (in 1978, there were 835, twenty-six of which provided more than two-thirds of the country's storage capacity) have escaped siltation problems: more important still, many have experienced siltation rates way above those predicted by their planners.
- In Haiti, the Peligre Dam on the Artibonite River was built to last 50 years: in fact, its reservoir has silted up so quickly that the dam will probably be decommissioned in 1986—after just 30 years of operation.
- In China, the Sanmenxia Reservoir, which was completed in 1960, had to be decommissioned in 1964 due to premature siltation. Worse still, the Laoying Reservoir actually silted up before its dam was completed.

Clearly, the premature sedimentation of reservoirs seriously affects the economics of a dam project.

If a dam's reservoir silts up several times more rapidly than predicted (or worse still, as at Laoying, before the dam even has a chance to function) the time over which the costs of the dam must be amortized is inevitably decreased—thus making nonsense of the calculations used to justify the dam's construction.

As today's dams silt up, so they will leave behind a vast muddy wasteland.

Compacted by the weight of a reservoir's waters, the fine particles of silt which have been deposited in the reservoir form a brick-hard pan as they build up.

Even when the last waters of the reservoir have drained away, the land beneath will not be suitable for basin irrigation or rain-fed agriculture.

Only a narrow strip close to the dam, where the coarser and thereby less compacted particles of silt are likely to have accumulated, will be suitable for cultivation.

An expanded version of this Briefing Document (24 pages) can be obtained from The Ecologist, Worthyvale Manor, Camelford, Cornwall, U.K., price £1.75.