

ENVIRONMENTAL IMPACT OF IRRIGATION: A REVIEW

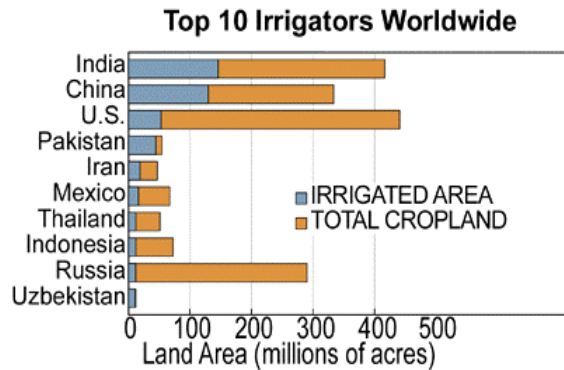
Claudio O. Stockle
State of Washington Water Research Center
Washington State University
PO Box 643002
Pullman Washington 99164-3002
Phone: 509/335-5531; Fax 509/335-1590
E-mail: stockle@wsu.edu

Introduction

Irrigated lands contribute significantly to the world agriculture output and food supply. Estimates in 1986 indicated that about half of the increase in agricultural production in the previous 35 years had come from irrigated land, about one-third of the world's crops were grown on the one-sixth of the cropped area which was irrigated, and the irrigated land was, on average, more than twice as productive as rain-fed land. Figures from 1996 estimated that developed countries, on average, irrigated 10% of their agricultural area, and countries in



development 23%, and combined they irrigated 18% of the total agricultural area. The share of agricultural area irrigated in Latin America and the Caribbean (LAC) region in 1996 was 11%. United Nation's predictions of global population increase to the year 2025 require an expansion of food production of about 40-45%. Irrigation agriculture will be an essential component of any strategy to increase the global food supply. However, overall growth of new irrigated areas will be slow. Growth of irrigated land is expected to occur mainly in developing countries, increasing their share from about 80% to 90% of the world's irrigated land. Much effort will be needed to increase the efficiency of existing irrigation systems.



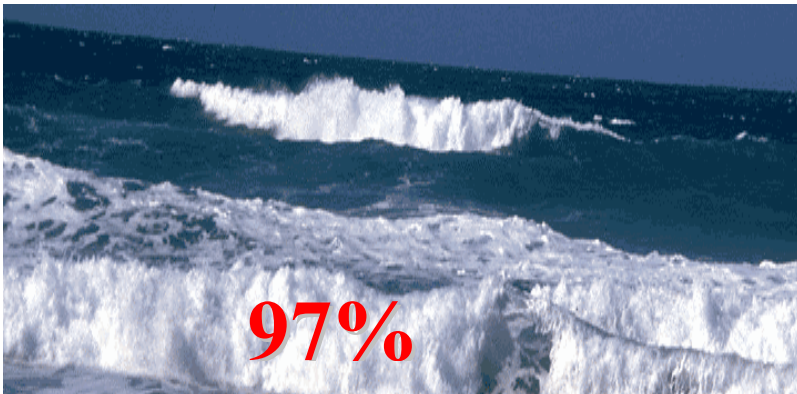
SOURCE: UN FAO AGROSTAT database, 1998

There is no question about the value of irrigated agriculture. Society has for long time supported the development and improvement of irrigation. However, there is an increasing trend to make irrigated agriculture accountable for its impact on the environment as well as to critically evaluate the water use in the agricultural sector compared with other competing uses. Improving the environmental performance of irrigation agriculture is also important for its long-term sustainability. The aim of this article is to review different aspects of the

environmental impact of irrigation and avenues for improvement. A collage of materials, text and figures from different sources were used to produce this article, which are listed in the reference section.

Water, A Scarce Resource

Although water on earth is abundant, 97% of the world's water lies in the ocean and seas, 2% of all water is in glacial ice, and only 1% of all water is available for human use. About 108,000 cubic kilometers (km³) precipitate annually on the earth's surface. It is estimated that 60% of the earth's annual precipitation evaporates directly back into the atmosphere, leaving 47,000 km³ flowing toward the sea. However, much of the flow occurs in seasonal floods. It is estimated that only 9,000 to



14,000 km³ may ultimately be controlled. At present, only 3,400 km³ are withdrawn for use.

Another aspect of the water picture is the uneven geographical distribution of its availability around the globe. Chronic scarcity of water is experienced or expected in large parts of Africa and the Middle East, the northern part of

China, parts of India and Mexico, the western part of the USA, north-east Brazil, and in the former Soviet Union and the Central Asian republics. Scarcity of water gives rise to conflicts across country borders (e.g. in the Nile basin and in the Middle East) and between different interests (e.g. irrigation, industrial and domestic use).

On the other hand, the availability of water resources must be contrasted with an increasing world population. The world population in 1900 was 1.6 billion, increasing to 2.5 billion by 1950 and 6.1 billion by the year 2000. Despite a general decline in fertility rates, world population is still growing rapidly. It is projected that world population will reach between 7.5 and 10.5 billions by 2050, depending on future growth rate scenarios. The population in the LAC region should almost reach 700 million people by 2025 from 475 million in 1997. The world population is expanding rapidly, with corresponding increased pressures on the food supply and the environment. Competition for water is becoming critical, and environmental degradation related to water usage is serious. The number of people living in water-stressed countries is projected to climb from 500 million to three billion by 2025.

Agriculture is the major user of freshwater, with a world's average of 71% of the water use. There are large regional variations, from 88% in Africa to less than 50% in Europe. In the LAC region, 73% of the water use is for agricultural purposes. However, the large and growing proportion of the population living in urban areas will put considerable pressure for continued transfers of water out of agriculture to supply growing urban centers. Other competing uses include hydroelectricity, protection of aquatic ecosystems (e.g., restoration of native salmon runs in the US Pacific Northwest), and recreation.

Meeting the crop demands projected for 2025 could require an additional 192 cubic miles of water, a volume nearly equivalent to the annual flow of the Nile 10 times over. No one yet knows how to supply that much additional water in a way that protects supplies for future use and minimizes environmental impact. Severe water scarcity presents the single biggest threat to future food production. Even now many freshwater sources (underground aquifers and rivers) are stressed beyond their limits. As much as 8 percent of food crops grows on farms that use groundwater faster than the aquifers are replenished, and many large rivers are so heavily diverted that they don't reach the sea for much of the year. As the number of urban dwellers climbs to five billion by 2025, farmers will have to compete even more aggressively with cities and industry for shrinking resources.

Irrigated Agriculture: Sources of Environmental Impact

The benefits of irrigation have resulted in lower food prices, higher employment and more rapid agricultural and economic development. The spread of irrigation has been a key factor behind the near tripling of global grain production since 1950. But irrigation and water resource development can also cause social and environmental problems.

Irrigation represents an alteration of the natural conditions of the landscape by extracting water from an available source, adding water to fields where there was none or little before, and introducing man-made structures and features to extract, transfer and dispose of water. Irrigation projects and irrigated agriculture practices can impact the environment in a variety of ways. For this review we will distinguish the following sources of environmental impact: a) construction of irrigation projects, b) water supply and operation of irrigation projects, and c) irrigated agriculture management practices.

Environmental impact derived from the construction of irrigation projects

Before 1900 only 40 reservoirs had been built with storage volumes greater than 25 billion gallons;



today almost 3,000 reservoirs larger than this inundate 120 million acres of land and hold more than 1,500 cubic miles of water. The more than 70,000 dams in the U.S. are capable of capturing and storing half of the annual river flow of the entire country.

In many nations, big dams and reservoirs were originally considered vital for national security, economic prosperity and agricultural survival. Until the late 1970s and early 1980s, few people took into account the environmental consequences of

these massive projects. Today, however, the results are clear: dams have destroyed the ecosystems in and around countless rivers, lakes and streams. On the Columbia and Snake rivers in the northwestern U.S., 95 percent of the juvenile salmon trying to reach the ocean do not survive passage through the numerous dams and reservoirs that block their way. More than 900 dams on New England and European rivers block Atlantic salmon from their spawning grounds, and their populations have fallen to less than 1 percent of historical levels. Perhaps most infamously, the Aral Sea in central Asia is disappearing because water from the Amu Darya and Syr Darya rivers that once

sustained it has been diverted to irrigate cotton. Twenty-four species of fish formerly found only in that sea are currently thought to be extinct.

The development of irrigation projects results in an alteration of the current condition of the landscape. Depending on the nature of the projects, many questions regarding environmental impact may arise. A few examples follow.



1. What is the social impact of relocating inhabitants of a given area to accommodate a new irrigation project (for example, relocating those living on the area to be inundated by a new reservoir)?
2. What is the impact of the new project on wildlife, particularly endangered species, and on archeological patrimony?
3. What is the impact of infrastructure associated with the construction and operation of the project (roads, power lines, canals, etc)?
4. Will reclaimed and/or recycled construction materials be used, including aggregate, rebar, lumber, and asphalt?
5. Will construction materials used be reclaimed and reused in future projects rather than being disposed of?
6. Are there alternative materials available to reduce hazardous and toxic materials use during construction?
7. Does the construction plan provide for erosion and sediment control, does it minimize the disturbance of vegetation and soil, and does it include revegetation of disturbed areas?
8. Does the project use existing structures to the extent possible and avoid sensitive habitats?
9. Will seepage be minimized or eliminated by selecting canal and ditch materials that prevent seepage?

Environmental impact derived from the water supply and the operation of irrigation projects

Irrigated agriculture depends on supplies from surface or ground water. The environmental impact of irrigation systems depends on the nature of the water source, the quality of the water, and how water is delivered to the irrigated land.

Withdrawing ground-water may cause the land to subside, aquifers to become saline, or may accelerate other types of ground-water pollution. Withdrawing surface water implies changes to the natural hydrology of rivers and water streams, changes to water temperature, and other alterations to the natural conditions, sometimes deeply affecting the aquatic ecosystems associated with these water bodies.

An excessive withdrawal of water for irrigation is clearly impacting the environment in some areas. For example, the Colorado river often contains essentially no water by the time it crosses the border into Mexico, owing to both urban and agricultural withdrawals. In fact, in most years, the Colorado

River doesn't make it to the ocean. This has consequences for the river and its riparian ecosystems, as well as for the delta and estuary system at its mouth, which no longer receives the recharge of fresh water and nutrients that it normally did. The same is true for the Yellow River in China. The San Joaquin River in California is so permanently dewatered that trees are growing in its bed and developers have suggested building housing there. In the last 33 years, the Aral Sea has lost 50% of its surface area and 75% of its volume, with a concomitant tripling in its salinity, owing largely to diversion of water from its feeding rivers for irrigating cotton. Groundwater is being mined. In the US, about 20% of the irrigated agricultural area is watered by pumping in excess of recharge. Texas has lost 14% of its irrigated acreage since 1980 as a result of aquifer depletion. In India's Punjab, pumping exceeds recharge by 1/3, causing water tables to drop by 1 m/yr or more.

Salinity in waters is a natural occurrence because of weathering of saline parent materials derived from seawater deposits and other sources. The quality of the water supplies varies, but water sources with significant salinity will impact the quality of the irrigated land and the sustainability of agricultural production supported by this land, particularly when poor management is present.

In 1982, salinization affected about 196,550 square km (0.7 percent) of the agricultural soils in Central America and Mexico, and 1,291,630 (7.6 percent) in South America. Argentina and Chile have about 35 percent of their irrigated lands affected by salinity whereas 30 percent, or 250,000 ha, of the coastal region of Peru under irrigation is impacted by this problem. In Brazil, 40 percent of the irrigated land in the northeast is affected by salinity as a result of improper irrigation. Natural and man-induced salinity in Cuba covers about 1.2 million ha. In Mexico, about 12.4 percent of the country's irrigated acreage, was reported wholly or partially affected by salinization in 1980.

Due to water shortages, contaminated wastewaters are frequently used for irrigation. For example, since the beginning of the century, about 90,000 ha of agricultural land in the Tula Valley has been irrigated with wastewater from Mexico City. In Lima, 2,000 ha of vegetable crops are irrigated with urban wastewaters. In Sao Paulo, the contaminated waters from the Tietê River are used to irrigate vegetable gardens downstream from the urban core. In Santiago, 62,000 ha of vegetables used to be grown using water from three courses located downstream from Santiago's sewage outflow. The reuse of wastewater for irrigation is imperative in the Middle East. It is also the most popular form of wastewater and nutrient recycling from dairy and other confined animal operations.

The operation of irrigation water supply systems can affect the environmental performance of irrigated agriculture. Systems that deliver water continuously or in a fixed schedule are less efficient and/or limit management options available for irrigators compared to on-demand water delivery operations. The operation and management of irrigation water delivery systems must include proper monitoring and reduction of seepage and other water losses in the system, particularly if they are a significant component of recharge of raising water tables. The combination of low water quality supply and raising water tables will eventually lead to waterlogging and salinization, threatening the sustainability of existing irrigation systems. Proper attention to the quality and amount of irrigation return flows is also important to identifying and mitigating possible impacts on receiving waters.

Questions regarding the irrigation water supply and environmental impacts that may arise include:

1. Are there provisions to ensure that the quality of the supplied water does not contribute to salinity buildup on the irrigated land?
2. Will groundwater extraction rates be kept at or below recharge rates to prevent drawdown and related subsidence and habitat destruction?
3. Will surface water diversion reduce groundwater discharge?
4. Will the diversion rate have an adverse effect on downstream flow rates or downstream water temperature?
5. Will water distribution systems and management be conducive to the implementation by farmers of sound irrigation and agronomic practices that minimize the environmental impact of irrigation?

Environmental impact derived from irrigated agriculture management practices

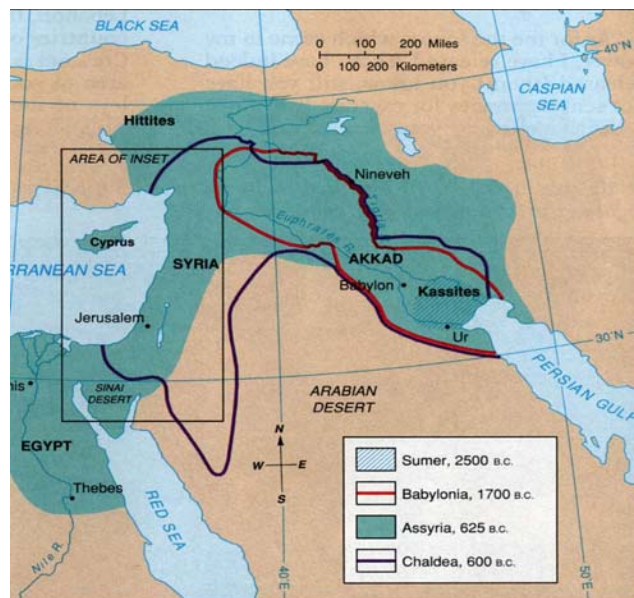


In the US, agriculture is the leading source of water quality impairment of rivers and lakes, and third in importance for pollution of estuaries. 72% of river length and 56% of lake area assessed by the US Environmental Protection Agency are impacted by agriculture. Both dryland and irrigated agriculture contribute to this situation.

In addition to problems of waterlogging, salinization, and erosion that affect irrigated areas, the problem of downstream degradation of water quality by salts, agrochemicals and

toxic leachates is a serious environmental problem. Salinization of water resources is possibly a greater concern to the sustainability of irrigation than is that of salinization of soils, per se.

Six thousand years ago farmers in Mesopotamia started diverting water from the Euphrates River. Thus, Sumerians went on to form the world's first irrigation-based civilization. However, Sumeria was one of the earliest civilizations to crumble in part because of the consequences of irrigation. Sumerian farmers harvested plentiful wheat and barley crops for some 2,000 years, but the soil eventually succumbed to salinization. Many historians argue that soil salinization and the decline in food supply figured prominently in the society's decline.



The social, economic and ecological disaster that has occurred in the Aral Sea and its drainage basin since the 1960s is the world's largest modern example of how poorly planned and poorly executed agricultural practices have devastated a once productive region. The Aral Sea basin includes Southern Russia, Uzbekistan, Tadjikistan, and part of Kazakhstan, Kirghiztan, Turkmenistan, Afghanistan, and Iran. Although there are many other impacts on water quality in the region, improper agricultural practice is the root cause of this disaster. Virtually all agriculture is irrigated in this arid area. Elements contributing to the problem include increase in irrigation area and water withdrawals, use of unlined irrigation canals, rising groundwater, extensive monoculture and excessive use of



persistent pesticides, increased salinization and salt runoff leading to salinization of major rivers, increased frequency of dust storms and salt deposition, discharge of highly mineralized, pesticide-rich return flows to main rivers, and excessive use of fertilizers. Some of the environmental impacts include decline in Aral Sea levels by 16 m since 1960, decline of the Aral Sea volume by over 70%, destruction of commercial fishery, major decline and extinction of animal, fish, and vegetation species, salt content of major rivers exceeding standards by factor of 2 to 3, high levels of turbidity in major water sources, high levels of pesticides and phenols in surface waters, and several others.

The management of water application systems as well as the suitability of related agronomic practices has a dramatic influence on the environmental impact of irrigated agriculture. Constraints in the water delivery systems (e.g., continuous versus on-demand water supply), extremely low water quality of the irrigation water supply, and limitations to investment on improved technologies exacerbate the environmental damage derived from irrigation and limit the options available to farmers for mitigating the problem. Regardless of the nature of the problem, improved management and technologies are the main tools available to ensure the sustainability and productivity of irrigated lands.

Salinity

All irrigation water contains dissolved salts derived as it passed over and through the land, and rain water also contains some salts. These salts are generally in very low concentration in the water itself. However, evaporation of water from the dry surface of the soil leaves the salts behind. Salinization is especially likely to become a problem on poorly drained soils when the groundwater is within 3 m or less of the surface (depending on the soil type). In such cases, water rises to the surface by capillary action, rather than percolating down through the entire soil profile, and then evaporates from the soil surface.

Salinization is a worldwide problem, particularly acute in semi-arid areas, which use large amounts of irrigation water and are poorly drained. These conditions are found in parts of the Mideast, in China's North Plain, in Soviet Central Asia, in the San Joaquin Valley of CA, and in the Colorado

River Basin. Salinization reduces crop productivity. In the US, salinization may be lowering crop yields on as much as 25-30% of the nation's irrigated lands. In Mexico, salinization is estimated to be reducing grain yields by about 1 million tons per year, or enough to feed nearly million people. In extreme cases, land is actually being abandoned because it is too salty to farm profitably.

Salinity has been associated with irrigated agriculture since its early beginnings. One reason is that irrigation often exacerbates the effects of salinity, which occurs naturally. Estimates indicate that roughly one-third of the irrigated land in the major irrigation countries is already badly affected by salinity or is expected to become so in the near future. Present estimates for India range from 27% to 60% of the irrigated land, Pakistan 14%, Israel 13%, Australia 20%, China 15%, Irak 50%, Egypt 30%. Irrigation-induced salinity occurs in large and small irrigation systems alike. In recent years, many farmers have been abandoning their rice fields in Sahelian irrigation schemes due to the incidence of salinity.

Salinity is often linked with the rise of groundwater tables resulting from excess irrigation and poor drainage in large-scale, perennial irrigation systems. The resulting shallow water tables bring salts to the upper layers of the soil profile. That salinity can also be induced by the use of pumped groundwater of marginal or poor quality has been realized only more recently. In these cases, the physical process underlying salinization is the absence of a downward soil water flux of sufficient magnitude to leach the salts from the root zone.

Saline soils contain sufficient soluble salts to adversely affect the growth of most plants. With a predominance of sodium on the exchange complex and a low concentration of salts in the infiltrating water, the infiltration rate and permeability can be severely, and in some cases, irreversibly reduced. Leaching and drainage cause salt loading of the water resource into which the effluent is discharged. The volume needing disposal can be reduced through improved irrigation management and reuse of drainage outflow for irrigation.

The technical problems that have led to irrigation-induced salinity include poor on-farm water use efficiency; poor construction, operation and maintenance of irrigation canals causing excessive seepage losses, and inadequate or lack of drainage infrastructure or, if drainage facilities are present, their poor quality of construction, operation, and maintenance (e.g., drainage systems in the Lluta Valley, Chile).

Waterlogging

Waterlogging usually results from overuse and/or poor management of irrigation water. Lining and covering of water conduits from the storage dams to the point of delivery improves water usage and at the same time reduces the risk of a rise in the water-table in many irrigated areas. This procedure needs to be applied to the 11 million hectares of land in Asia that have been degraded through waterlogging, but it would also benefit areas suffering from salinization. Waterlogging and salinization impacts can be further reduced in most cases by more investment in education and



management capacity rather than in drainage and soil improvement works.

Worldwide, about 10% of all irrigated land suffers from water logging. As a result, productivity has fallen about 20% in this area of cropland. Drainage problems affect large areas of land in Latin America; in many cases these problems are compounded by salinization. Thus, in Argentina 555,000 ha are in need of drainage. In Peru 60,000 ha in the coastal region and 34% of the cultivated lands in the upper jungle (Ceja de Selva) - or 150,000 ha - are affected by drainage problems; and in Costa Rica, projects for rehabilitation through drainage exceed 60,000 ha.

Agricultural runoff

One of the main non-point sources of water pollution is runoff from agriculture. Runoff of agricultural chemicals is primarily a localized problem where agricultural input use is high. The consumption of fertilizers in LAC has increased rapidly over the last 30 years, from 16 kilogram per ha in 1966 to 62 kilogram per ha in 1996. However, fertilizer application is still below the levels of developed countries. In 1996, the consumption of fertilizers per ha of farmland amounted to 89 kg globally and 113 kg in the United States. However, the experience in LAC is diverse. In a few countries, application rates are extremely low, including Bolivia with 5 kilogram per ha and Haiti with 9 kilogram per ha in 1996. In other countries of the region, however (for example, Chile, Colombia, Costa Rica, El Salvador or Uruguay) the consumption of fertilizers is similar to that of developed countries.

Not only nutrients and other chemicals are transported with irrigation runoff waters. Soil erosion and subsequent transport of sediments (and adsorbed chemicals) is caused by runoff of excess irrigation water from cropland. Soil erosion decreases the productivity of the land. Furrow irrigation causes more erosion than sprinklers or drip irrigation. Sediments transported by irrigation tail waters eventually return to streams and rivers, negatively impacting canals and other water conveyance structures, causing sedimentation of reservoirs and other structures, affecting the durability and uniformity of sprinkler and drip irrigation systems, and creating significant problems to fish habitat and aquatic ecosystems.



The impact of agricultural runoff on water quality is well documented in the US and other countries. Data on water pollution in developing countries are limited. Further, such data are mostly aggregated, not distinguishing the relative proportion of point and non-point sources. The water quality database that is available often is of little value in pollution management at the river basin scale, and is not useful for determining the impact of agriculture relative to other types of anthropogenic impacts.

Impact on groundwater

Infiltration of irrigation water in excess of available root zone storage will penetrate beyond the reach of roots and eventually recharge groundwater. Nitrates, salts, and other chemicals dissolved in the

soil water will move with the water. Crops with high water and N requirements tend to increase the potential risk of nitrate pollution to groundwater. Light-textured soils and intensive production of shallow-rooted crops under irrigation can lead to considerable nitrate losses by leaching.

In the US, nitrate in groundwater is highest in areas of well-drained soils and intensive cultivation of row crops. Areas such as the Northeast, Great Plains and along the West Coast have been found to have high nitrate concentrations in groundwater. In the Northwest, the Quincy-Pasco area of Washington State is reported as highly polluted by N, with non-point sources from agriculture often cited as a significant contributing factor. This area, cultivated with row crops on well-drained soils, receives high rates of irrigation and fertilizer application. In the Central Columbia Plateau of Washington State, fertilizers are the source of 84% of nitrate inputs. Other sources of nitrate include cattle feedlots, food-processing plants, septic tanks, and treated wastewater.

Data on groundwater pollution in developing countries, resulting from excess chemical input and irrigation, is not well documented, but it is likely to show an increasing trend as irrigated agriculture worldwide becomes more intensively managed. According to various surveys in India and Africa, 20 to 50% of wells contain nitrate levels greater than 50 mg/l and in some cases as high as several hundred mg/l. In some developing countries, it is wells in villages or close to towns that often contain the highest N levels, suggesting that domestic excreta are the main source, though livestock wastes are particularly important in semi-arid areas where drinking troughs are close to wells.

Public health impacts

Polluted water is a major cause of human disease. According to the World Health Organization, as many as 4 million children die every year as a result of diarrhea caused by water-borne infection. The bacteria most commonly found in polluted water are coliforms excreted by humans. Surface runoff and improperly designed rural sanitary facilities contribute to this problem.

The use of untreated (or poorly treated) human wastewater for irrigation purposes contributes to direct contamination of food. In many developing countries there is little or no treatment of municipal sewage, yet urban wastewater is increasingly being used for irrigation. The most common diseases associated with contaminated irrigation waters are cholera, typhoid, ascariasis, amoebiasis, giardiasis, and enteroinvasive E. Coli. Crops that are most implicated with spread of these diseases are ground crops that are eaten raw such as cabbage, lettuce, strawberries, etc.

Nitrogen levels in groundwater have grown in many parts of the world as a result of intensification of farming practice, particularly in irrigated lands. Nitrate levels have grown in some countries to the point where more than 10% of the population is exposed to nitrate levels in drinking water that are above the 10 mg/l guideline designed to prevent methaemoglobinaemia to which infants and elderly are particularly susceptible. Although the problem is less well documented, nitrogen pollution of groundwater appears also to be a growing problem in developing countries.

There is a linkage between increase in malaria in several Latin American countries and reservoir construction. Schistosomiasis, a parasitic disease affecting more than 200 million people in 70 tropical and subtropical countries, has been demonstrated to have increased dramatically in the population following reservoir construction for irrigation and hydroelectricity.

Questions regarding environmental performance of irrigated agriculture management practices

Improved field irrigation practices are a critical factor in mitigating the effect on the environment of existing irrigation projects. Many questions may arise regarding the environmental performance of field irrigation (and associated agronomic) practices. A few examples follow.

1. Will measures be taken to limit pesticide, herbicide, and petroleum-based fertilizer use, including using organic fertilizer, planting pest-resistant crops, and alternating crops and planting cycles?
2. Will soil loss prevention measures be taken to prevent wind and water erosion, including planting vegetative windbreaks, practicing contour plowing, and maintaining soil moisture? These practices reduce offsite sedimentation, nutrient pollution, and water quality degradation.
3. Will irrigation periods be restricted to evenings, nights, and early mornings to prevent excessive water loss due to evaporation and reduce peak power demands?
4. Will water application rates be minimized to prevent surface runoff, over watering, and nutrient leaching?
5. Will soil moisture content, temperature, humidity, time of day, wind, and evapotranspiration rate be considered in determining the most efficient time to irrigate?
6. Have drip irrigation and other water conserving application techniques been evaluated for implementation?
7. Do water cost and allotment factors encourage conservation? Are financial incentives or disincentives, such as an increasing per unit cost, provided to promote conservation?
8. Will agricultural runoff be managed to prevent impacts from excess nutrients and chemical pesticides and herbicides?
9. Will filter strips or other methods be used to remove sediments, organic matter, and other pollutants from runoff and waste water?
10. Can the drainage water be reclaimed and reused?
11. Will water from subsurface drainage systems be evaluated for contaminant levels and the best management practice selected for its handling?

How Can We Mitigate the Environmental Impact of Irrigation?

As the world's population continues to grow, dams, aqueducts and other kinds of infrastructure will still have to be built, particularly in developing countries where basic human needs have not been met. But such projects must be built to higher standards and with more accountability to local people and their environment than in the past. And even in regions where new projects seem warranted we must find ways to meet demands with fewer resources, minimum ecological disruption and less money.

FAO has estimated that the potential exists, based on physiography and soil conditions, for an eventual total of 400 million hectares of irrigated land, three-quarters of which would be in the developing countries. Irrigated areas are 2.5 times more productive than rain-fed agricultural land, and there is a strong presumption that their extent (some 300 million hectares at present) will increase. However, expansion beyond present levels is constrained by the shortage of suitable land, limited water supplies and the high cost of installing large-scale irrigation schemes. In many cases it is

more effective to improve the management and production efficiency of existing irrigated areas than to open up new irrigation schemes.

The largest single consumer of water is agriculture, and this use is largely inefficient. Water is lost as it is distributed to farmers and applied to crops. Consequently, as much as half of all water diverted for agriculture never yields any food. Thus, even modest improvements in agricultural efficiency could free up large quantities of water. Growing tomatoes with traditional irrigation systems may require 40 percent more water than growing tomatoes with drip systems. Even our diets have an effect on our overall water needs. Growing a pound of corn can take between 100 and 250 gallons of water, depending on soil and climate conditions and irrigation methods. But growing the grain to produce a pound of beef can require between 2,000 and 8,500 gallons.

Shifting where people use water can also lead to tremendous gains in efficiency. Supporting 100,000 high-tech California jobs requires some 250 million gallons of water a year; the same amount of water used in the agricultural sector sustains fewer than 10 jobs, a stunning difference. Similar figures apply in many other countries. Ultimately these disparities will lead to more and more pressure to transfer water from agricultural uses to other economic sectors. Unless the agricultural community embraces water conservation efforts, conflicts between farmers and urban water users will worsen.



New approaches to meeting water needs will not be easy to implement: economic and institutional structures still encourage the wasting of water and the destruction of ecosystems. Among the barriers to better water planning and use are inappropriately low water prices, inadequate information on new efficiency technologies, inequitable water allocations, and government subsidies for growing water-intensive crops in arid regions or building dams.

Several types of interventions aimed at preventing, mitigating, or reversing soil and water degradation at various levels within irrigated agriculture are possible. Some are applicable at field or farm level, others at system, regional, or subregional level. Examples of possible interventions are given below, categorized as policy, engineering, system management, and irrigation/agronomic practice interventions.

Policy Interventions

1. Introduce water and power pricing that better represent the market value of water.
2. Introduce transferable water entitlements.
3. Set limits for allowable groundwater recharge (amount and quality) and introduce penalties for exceeding these limits.
4. Provide incentives for land reclamation.

5. Require exhaustive environmental impact assessment for new irrigation projects.
6. Provide incentives for monitoring and reduction of the environmental impact of existing irrigation projects.

Engineering interventions

1. Incorporate environmental impact considerations in the design, construction, and operation of new irrigation projects.
2. Improve maintenance of irrigation infrastructure.
3. Construct drainage facilities.
4. Improve maintenance of existing drains.
5. Reuse waste and drain water, and find alternative ways to dispose drainage effluent.
6. Prevent or reduce canal seepage, i.e., through lining.

System management interventions

1. Improve the operation of existing irrigation and drainage infrastructure through introduction of management information systems, etc.
2. Enhance farmers' involvement in management and maintenance of irrigation and drainage facilities.
3. Evaluate the feasibility of implementing on-demand water delivery to farms.

Irrigation/agronomic practices interventions

1. Minimize water losses in the on-farm distribution system.
2. Improve irrigation systems performance to minimize deep percolation and surface runoff.
3. On-farm watercourse improvement and precision land leveling.
4. Implement more efficient irrigation methods (e.g. drip instead of surface irrigation).
5. Minimize sediment concentration in runoff water.
6. Grow different crops or introduce different crop rotations (i.e., less-water demanding crops, more drought- and salt-tolerant crops).
7. Irrigate according to reliable crop water requirement estimates and leaching requirement calculations.
8. Manage fertilizer programs so as to minimize nutrients available for detachment and transport.
9. Apply soil amendments and reclamation practices.

Final Remarks

The potential to increase substantially the irrigated area of the world is limited. Gains from new capacity are expected to be largely offset by losses such as waterlogging and salinization, as well as retirement of areas being irrigated by pumping water in excess of rates of recharge. In fact, most new water capacity is predicted to come from increasingly efficient use of existing supplies rather than harnessing of new supplies. On the other hand, managing existing irrigation projects so as to minimize their environmental impact is a requirement for long-term sustainability of irrigated agriculture. Both, improved water use efficiency and environmental stewardship are indeed complementary goals.

One area of concern is that developing countries could spend the next 50 years struggling to provide safe drinking water and sanitation to their exploding urban populations and enough irrigation water to maintain the high levels of food production needed to provide improved diets to a growing population, at the expense of their ability to restore and maintain their already damaged aquatic ecosystems.

The unresolved global warming issue could turn to be the major challenge for water development during the next 50 years, or it may not be. There is so much uncertainty in the scientific data and supporting models that it makes effective analysis very hard. Taken together, the current state-of-the-science suggests a wide range of potential concerns that should be addressed by national and local water managers and planners, climatologists, policymakers, and the public. Prudent decision-making requires consideration of potential climate change scenarios on long-term decisions regarding water use and environmental impact.

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Human impacts on Ecosystems (www.orst.edu/instruction/bi301)

International Water Management Institute (www.cgiar.org/iwmi)

International Water Resources Association (www.iwra.siu.edu)

Pacific Institute for Studies in Development, Environment and Security (www.pacinst.org)

The World's Water, Information on the World Freshwater Resources (www.worldwater.org)

United Nations Food and Agricultural Organization, Land and Water Development Division (www.fao.org/ag/AGL)

Universities Council on Water Resources (<http://www.uwin.siu.edu/ucowr>)

Pollution prevention/environmental impact reduction checklist for agricultural irrigation (<http://es.epa.gov/oeca/ofa/pollprev/agric.html>)