*Water Resources Development, Vol. 9, No. 1, 1993* 3

# Water for Agricultural Development: Opportunities and Constraints

ASIT K. BISWAS

*76 Woodstock Close, Oxford, UK and International Development Centre, University of Oxford, UK*

ABSTRACT *Globally around 70% of all water used is for agricultural development. Thus, if the world's food crisis is to be successfully resolved, enough water of appropriate quantity and quality will be necessary. Water scarcity is already a serious issue in many arid and semi-arid countries, and the problem is likely to intensify significantly in the future. Agriculture also affects water quality in many ways. The paper analyses the present status of the impacts of use of pesticides and nitrate fertilizers from different parts of the world.*

## Introduction

During the past decade more and more decision-makers have become increasingly aware of the importance of water for the continuing well-being of people and development of countries, especially those located in arid and semi-arid regions. In developing countries, ranging from Algeria to Zimbabwe, and in parts of developed countries like the arid western and south-western parts of the USA, the general public as well as planners and decision-makers have now begun to appreciate the critical importance of a reliable water supply for their future survival and sustainable development.

On the basis of analyses carried out, it is now clear that, compared with the earlier generation of water projects, new and/or additional sources of water are becoming scarce, more expensive to develop, require more expertise and technological know-how for planning, design, implementation and operation, and often could result in more social and environmental disruptions. Thus, not surprisingly, there is an increasing realization that water can no longer be considered to be a cheap and plentiful resource, which can be used, abused or squandered without much concern for future human welfare. Like oil some 20 years ago, the days when water could be considered to be inexpensive and abundant are now virtually over for nearly all arid and semi-arid countries. During the next two decades, water will undoubtedly become a critical resource for the future development and survival of the arid and semi-arid countries, so much so that all the indicators point to increasing tension between many neighbouring countries over the use of international rivers, lakes and aquifers.

## Water Crisis

Many countries are already facing a water crisis, though the intensity and extent of that crisis could vary from one country to another. If the current trends continue, the water crisis will become widespread in most arid and semi-arid countries by the early part of the 21st century. There are many reasons, which are interrelated, that are contributing to this crisis, and only the four major ones will be discussed here.

First is the global population which is continuing to increase at an alarming rate. Present estimates indicate that the current global population is likely to double to 10.64 billion by the year 2050. Developing countries, which are all in tropical and semi-tropical regions, will account for some 87% of this population, or 9.29 billion.

While there is no one-to-one relationship between population and water requirements, it is clear that, with a substantial increase in world population, total water requirements for different types of uses will increase as well. Furthermore, past experiences indicate that as standard of living increases, so too does the per capita water requirement. Hence, if the present poverty alleviation programmes succeed, national water requirements will increase further—a fact which has often been overlooked by our policy-planners, both nationally and internationally.

Second, the amount of fresh water available on an economic basis to any country on a long term basis is limited. Since nearly all the easily available sources of water have now been developed or are in the process of development, the unit costs of future projects can only be higher. For example, recent review of domestic water supply projects supported by the World Bank indicates that the cost per cubic metre of water for the next generation of projects is often two to three times higher than for the present generation. This is an important consideration, since many developing countries are now saddled with very high levels of debt burdens, and the amount of new investments available, both internally and externally, is limited. In addition, the demands and competition for whatever funds are available are intense. These factors, both individually and collectively, are bound to effect the next and later generations of various types of water projects, probably adversely in most cases.

Third, as human activities increase, more and more waste products are contaminating available sources of water. Among the major contaminants are untreated or partially treated sewage, agricultural chemicals and industrial effluents. These contaminants are seriously affecting the quality of water, especially for domestic use. Already many sources of water near urban centres of developing countries have been severely contaminated, thus impairing their potential use in a cost-effective manner.

Since comprehensive water quality monitoring programmes in nearly all developing countries are either in their infancy or even non-existent, a clear picture of the status of water pollution and the extent to which water quality has been impaired for different potential uses is simply not available at present. On the basis of the anecdotal and very limited information available, it can be said that the problem is already very serious near centres of dense population, especially for groundwater and lakes and for some rivers as well. It should be noted that once groundwater is contaminated, it cannot be easily decontaminated. Furthermore, for developing countries, cost-effective technologies simply do not exist for removing pollutants such as nitrates from sources of drinking water. Equally, alternatives such as forcing people, through regulations, to use bottled water for babies because of high nitrate contents in local drinking water are not feasible because of widespread poverty (Biswas, 1991).

The fourth major factor is the increasing delays that are likely to be witnessed in coming decades in implementing new water projects. In addition to escalating project costs, lack of investment funds and increasing technical complexities of new development projects, social and environmental considerations will significantly delay project initiation time, certainly more than what has been witnessed in earlier decades. Issues like proper resettlement of people, inundation of forests and earthquake implications have already to varying degrees affected the implementation of projects such as the Narmada Valley and the Tehri Dam in India and the Three Gorges Dam in China. Such delays have to be considered from now on as normal rather than exceptions, unless water projects can be designed and constructed in a more environmentally sound fashion than has been achieved in the past.

All these developments, when taken together, will mean that water professionals will come under increasing pressure to make the management process more effective than it has ever been at any time during human history. However, the transition period available to us to improve significantly the management process is likely to be short—certainly no more than a decade, or at most two. While technological problems may be comparatively easy to overcome, political, institutional and social constraints are likely to be very difficult to resolve. Herein may lie the most difficult challenge facing water management in the 21st century.

## Agricultural Water Use

Since the dawn of human history, global water use has continued to increase, and the trends in recent decades have been no exception. If the 20th century is considered as a whole, total water use is expected to show a nearly ten-fold increase as shown in Figure 1 (adapted from Shiklomanov, 1988). This rate of increase, of course, is significantly higher than the rate of population growth during the present century.

This inflationary figure, however, does not mean that all different types of water use have increased in the past, or are likely to increase in the future, by the same amount. As the structure of economic activities changes in various countries, and as new sources of water become more scarce and more expensive to develop than ever before, continuing trade-offs occur between various uses. For example, in 1900, agriculture accounted for nearly 90% of all water used globally. Its percentage share has continued to decline steadily, and is expected to account for about 62% by the year 2000. All the current trends indicate that this percentage share will continue to decline for some time during the post-2000 period.

In contrast, because the value-added aspect of water is much higher for industry than in agriculture, and as the phase of industrialization has accelerated in many countries in recent years, the percentage share of total industrial water use during the 20th century is expected to increase four-fold, from 6% to 24%. This trend is likely to continue, at least for the early part of the 21st century.

The preceding percentage figures are global averages. There are, of course,

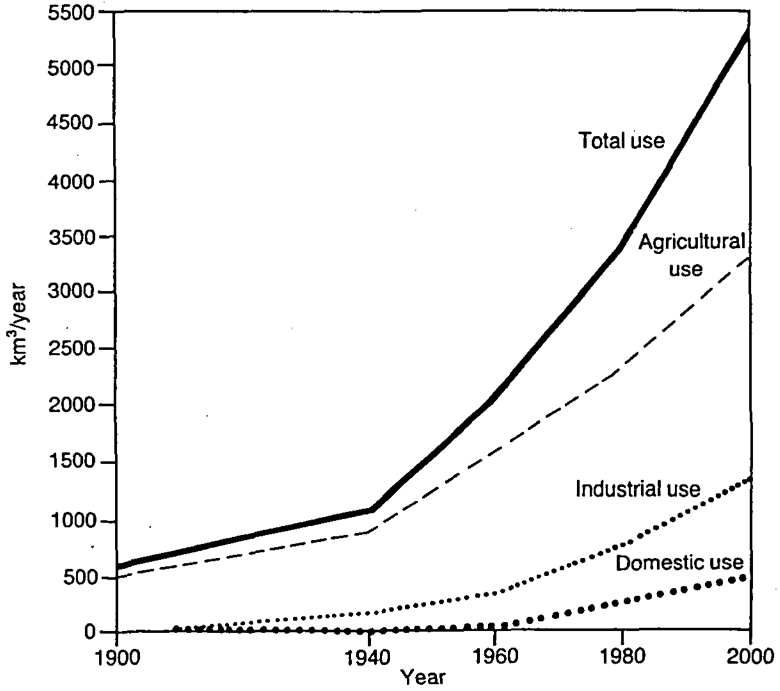

**Figure 1.** Expected increase in total water use during the 20th century. *Source*: Adapted from Shiklomanov, 1988.

considerable variations in water use patterns in individual countries, depending on their levels of socio-economic development, appropriate physical and climatic factors and other relevant considerations. For example, in major agrarian economies of countries like India and Egypt, agricultural water use still accounts for more than 80% of all water used. However, corresponding figures for an advanced industrialized country like the USA is less than half of such estimates.

Thus, it is clear that during the next two to three decades, and possibly much longer, we will be facing contradictory trends. On the one hand, the percentage of water available for the agricultural sector will continue to decline but, on the other hand, there will be tremendous pressure to increase food production to feed a burgeoning global population, requiring more and more water. Herein will lie the biggest challenge facing the water profession: how can water management be made increasingly more efficient so that the same or higher levels of agricultural production can be achieved with less and less quantum of water? Potential solutions like water pricing and better water conservation and irrigation management practices have to be taken seriously. The days of providing lip-service to these critical issues are now truly over.

The impending crisis can be viewed as an opportunity that will force our profession to break through the log-jam of technical apathy and political inertia that currently prevents us from implementing innovative new policies such as water pricing and cost recovery, and will force us to make hard choices such as radical changes in the structures of our water management institutions, which can no longer properly serve the new and more demanding conditions. These policies may neither be politically expedient nor likely to be 'enthusiastically' championed by many sectors of our existing water institutions. The days of "business as usual" are rapidly coming to an end. We need development and implementation of radically new, rational water policies.

## Agriculture and Water Quality

Agriculture is not only the major user of water; agricultural practices also have major impacts on water quality, which could restrict both future water availability and uses.

Agricultural activities have numerous impacts on water quality. Similarly water quality considerations have important implications for agricultural activities. Generally speaking, the major direct impacts of agricultural activities on water quality are the following:

(1) alterations in sediment load due to changes in land use practices;
(2) changes in salinity due to agricultural activities;
(3) water quality deterioration due to anthropogenic chemicals like nitrates and pesticides;
(4) possible eutrophication of water bodies due to leaching of fertilizers; and
(5) water quality degradation of water due to agro-processing industries.

The individual impacts of the above-mentioned factors vary from place to place depending on a number of factors, which could change from time to time for many reasons, including management practices.

If quality of water is to be considered for agricultural uses, the following four important factors need to be taken into account:

(1) the salinity of water being used for irrigation;
(2) the presence of certain chemicals or trace elements that could affect yields, or make some crops unsuitable for human and/or animal consumption;
(3) the levels of concentration of sodium (high) or calcium (low) which could reduce the rate of infiltration of irrigation water; and
(4) the extent of bacterial and viral contamination of water, especially where wastewater is used for irrigation.

For reasons of space, only one major water quality issue will be considered here:

### Pesticide and nitrate contamination

While the impacts of agricultural activities on water quality in terms of sediments and salinity have been important considerations for many decades, concern with pesticides and nitrate contamination has been of comparatively recent origin. With the advent of the Green Revolution, use of fertilizers and pesticides per unit area has increased significantly. Even so, until recently, the extent of water quality deterioration due to increasing use of agricultural chemicals was considered to be minor, and its potential overall impact was seriously underestimated.

During the past decade, contamination of water by pesticides and nitrates has become an important concern in Europe and North America, especially for groundwater. This is because a substantial amount of groundwater is currently used for domestic purposes. For example, groundwater accounts for 73% of domestic consumption in the former Federal Republic of Germany, 70% in The Netherlands and 30% in Great Britain. In the USA, groundwater is the primary source of domestic water supply for over 90% of the rural population and for about 50% of the total population. It is thus essential that groundwater be protected from various pollutants which affect its quality. This is especially imporant when groundwater is used as the primary source of water for human consumption, since quality of drinking water used has direct and major implications for human health.

Contamination of groundwater by agricultural chemicals is being observed increasingly in areas that are intensively farmed, irrespective of whether they are irrigated or non-irrigated. In addition to routine use of agricultural chemicals, i.e. non-point sources, a comprehensive analysis should include point sources like manufacturing sites, transport/transfer facilities, commercial storage, mixing, formulating, rinsing and disposal sites as well as major spill sites. On the basis of existing information, it can be said that 39 pesticide compounds have been detected in 34 states in the USA or Canadian provinces (Cohen *et al.*, 1986; Holden, 1986). If, however, other chlorinated hydrocarbon compounds and their metabolites are included, the situation becomes much worse: over 70 compounds in 31 states or provinces (Hallberg, 1989).

Based on available information, it is difficult to get a clear overall picture of pesticide contamination of groundwater, even in North America or Europe: the situation is significantly worse in the developing world (Biswas, 1992), for several reasons. First, monitoring of pesticides in groundwater is of comparatively recent origin. Studies carried out so far are so varied in design that it is not possible to make an overall generalization. Second, numerous pesticides have been used in the past and no determined attempt has been made to look for them all in water bodies because of technical and economic constraints. The monitoring and detection processes have mostly focused on chemicals that are toxic and mobile, often under directives of regulatory agencies like the US Environmental Protection Agency (EPA). Third, measurements of concentrations of pesticides in terms of only μg per litre are difficult and require special equipment, techniques and procedures for sampling and analysis. Nearly all developing countries currently do not have either the expensive equipment necessary or the sophisticated expertise required to initiate a country-wide monitoring programme. Fourth, even in the few Western industrialized countries where pesticide concentrations in water are being monitored, attention is mostly focused on the presence of the parent compounds. Very few studies are currently available which also monitor the presence of metabolites. This is important since, even if the parent compounds may not leach into the groundwater, metabolites may do so. Fifth, the level of use of pesticides in developing countries is significantly less than in developed countries, but pesticide use in many developing countries has been increasing steadily in the recent past. It is logical to assume that with higher pesticide use rates in such countries, more and more agricultural chemicals would leach into groundwater, and thus contaminate the sources.

On the basis of the above five reasons, it can be confidently predicted that the number of pesticide compounds and their metabolites found in groundwater will continue to increase steadily in the future, especially in those developing countries where irrigated agriculture is most prevalent. Accordingly, it is highly likely that pesticide contamination of groundwater will be observed in an increasing number of geographical areas in the future.

There are many factors which affect the leaching of pesticides to water bodies. Among the main factors are properties of individual pesticides, soil characteristics, hydrogeological conditions, climatic factors and cropping patterns which dictate type, rate and timing of application of pesticides. Because of so many variables, it is not possible to make generalized comments on the extent of pesticide leaching to water bodies or on potential concentration levels.

At our present state of knowledge, not enough is known about the impacts of pesticides on human and animal health. This is because the extent and level of toxicological research on all of the currently approved list of pesticides is grossly inadequate. Furthermore, very limited information is available on the synergistic effects of different combinations of pesticides. There are also methodological problems in terms of extrapolation from high doses of consumption, skin contact or inhalation of volatile chemicals over short time periods to long periods of low levels of sustained use and exposure. Additional uncertainties are contributed by the complexities inherent in translating health impacts from animal studies in laboratories to human beings in the real world. To all these uncertainties must be added the overall problems associated with analysis and perception of risks, which have important social, economic, institutional, political and emotional implications.

Because of the lack of a long period of reliable data on the potential health impacts of different pesticides, their toxicological evaluation and setting of permissible standards for water used for domestic purposes are difficult tasks under the best of circumstances. In a directive issued in 1980, the Council of the European Community (EC) established a maximum admissible concentration of 0.1 μmg/l of any single pesticide in drinking water, and of 0.5 μg/l as the maximum permissible limit for possible combinations of all pesticides and related chemicals. In 1984, these standards were incorporated into Dutch legislation. West Germany followed suit in 1986, but implementation of the standards was postponed till 1989 in order that analytical procedures could be developed to measure reliable pesticide concentrations below the limit value of 0.1 μg/l. In many EC countries, however, there is considerable opposition to establishing these standards, mainly because they were based on detection limits of chemical analysis and not on toxicological considerations. The overriding philosophy behind the creation of these limits was that no pesticide residues should be present in domestic water, and *not* the extent of knowledge available in terms of impacts on human health.

There are further differences between the member nations of the EC. For example, The Netherlands has blacklisted 31 different pesticides whose use is not allowed in groundwater protection areas. However, a similar blacklist prepared by West Germany in 1985 contains some 70 pesticides. Interestingly, when these two blacklists were prepared, very few of the listed pesticides were subjectd to field trials or to monitoring (Leistra & Boesten, 1989).

The World Health Organization (WHO 1984, 1988) and the US EPA have used a different approach to the limits of pesticide residues in drinking water. The method used by WHO and EPA is to establish an acceptable daily intake (ADI) of pesticide residues in all food and drinks. The ADI is determined by long-term toxicological studies in terms of no-observed-effect level. It is then multiplied by a safety factor, e.g. 0.01. A part of this ADI is then earmarked for domestic water. In the WHO (1988) guidelines, 10% of ADI was reserved for herbicides and 1% for bio-accumulating pesticides like chlorinated hydrocarbons. Viewed in this fashion, WHO guidelines values are significantly higher than the 0.1 μg/l EC directive.

In contrast to pesticides where many different types of chemicals are involved, the main concern with fertilizers in terms of water quality management is undoubtedly nitrates. Also, nitrates have been studied more intensively than pesticides. This, however, does not mean that fertilizers do not contain other contaminants. For example, phosphate fertilizers contain varying concentrations of zinc, manganese, boron or molybdenum, all of which are considered to be important plant nutrients, as well as potential water quality contaminants like arsenic, cadmium, chromium, copper, nickel, lead, selenium and vanadium. Similarly, many trace elements are present in pesticides as well. However, well-documented cases of serious water quality contamination by trace elements from fertilizers and pesticides are very limited. To the extent that water contamination takes place, it could be due to anionic trace elements (primarily oxyanions). Generally cationic trace elements like heavy metals do not accumulate in water bodies. In terms of agricultural activities, the most serious trace metal contamination is in the soil due to continued application of sewage sludges and/or treated wastewater (Biswas & Arar, 1988).

Uncontaminated groundwater generally contains less than 3 mg N/l, and, if this level is exceeded, human activity can be suspected, unless there are other possible natural explanations. Also, it has been observed that nitrate concentrations decrease with groundwater depths; they are also highest at the top of the water table and decrease with depth. This means that in older irrigated areas, which generally have shallow water tables (less than 30 m), nitrate contamination is often prevalent due to leaching through the vadose zone.

In most European countries, the maximum permissible nitrate concentration in drinking water is 50 mg/l. This level is fixed on the basis of hygienic and toxicological factors. In both Europe and the USA, nitrate concentration of groundwater in many areas has increased steadily over the past three decades, the causes, rates of increase and their current levels varying from area to area. The present levels exceed the acceptable limits in many regions to the extent that, in a state like Nebraska alone, babies in 38 towns must be given bottled water due to high levels of nitrate concentrations in domestic water supply.

Use of excessive nitrogen fertilization not only increases the nitrate concentration in groundwater but also could adversely affect the quantity and quality of crops produced. This means that farmers have to bear higher costs for fertilizers used as well as loss of revenue due to poor quality and quantity of products. Results of a demonstration project of over 16 000 ha of primarily irrigated corn in Nebraska indicate that yields can be maintained by reducing average nitrogen fertilizer application rate by up to one-third from 262 to 174 kg/ha. Unquestionably, the solution of the twin problems of using optimal nitogen fertilizer application to increase crop yields and protection of water quality lies in adopting better soil and water management practices.

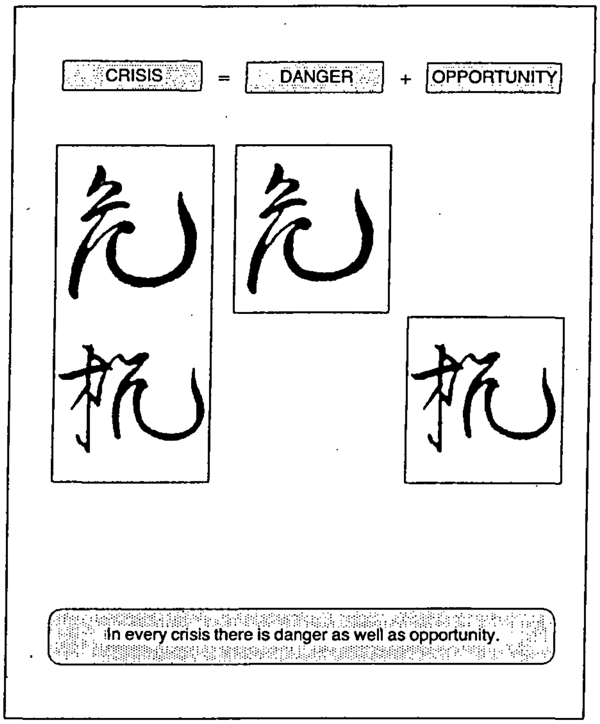

**Figure 2.** The Chinese word 'crisis'.

## Concluding Remarks

On the basis of the present analysis, it is clear that the water profession will face a critical problem in terms of efficient agricultural water management in the 21st century, the magnitude and complexity of which no earlier generation has ever had to face. In the run-up to the 21st century, the water profession has really two stark choices: to carry on as before with a 'business as usual' attitude with only some marginally incremental changes, thus endowing our future generations with a legacy of suboptimal agricultural water management practices, or to continue in earnest an accelerated effort to plan and manage agricultural water use efficiency and sustainably. We no logner have any soft options—only hard choices.

The Chinese word 'crisis' consists of two letters, which individually mean 'opportunity' and 'danger' (Figure 2). Thus, we may be facing a crisis of water availability for the agricultural sector in the 21st century, but this should be viewed as a golden opportunity, which would enable the water profession to develop and implement efficient water management practices for all sectors for the future welfare of mankind.

## References

Biswas, Asit K. (1991) Water for sustainable development in the 21st century: a global perspective, *International Journal of Water Resources Development*, 7, pp. 219–224.

Biswas, Asit K. (1992) Freshwater environment, 1972–1992, *Water International*, 17(2).

Biswas, Asit K. & Arar, A. (1988) *Treatment and Reuse of Wastewater* (London, Butterworths).

Cohen, S.Z., Eiden, C. & Lorber, M.N. (1986) Monitoring groundwater for pesticides, in: W.H. Garner *et al.* (Eds) *Evaluation of Pesticides in Groundwater*, Symposium Series 315, (New York, American Chemical Society), pp. 170–196.

Hallberg, G.R. (1989) Pesticides pollution of groundwater in the humid United States, *Agriculture, Ecosystems and Environment*, 26, pp. 299–367.

Holden, P. (1986) *Pesticides and Groundwater Quality: Issues and Problems in Four States* (Washington, DC, Boardof Agriculture, National Research Council, National Academy Press), 124pp.

Leistra, M. & Boesten, J.J.T.I. (1989) Pesticides contamination of groundwater in Western Europe, *Agriculture, Ecosystems and Environment*, 26, pp. 369–389.

Shiklomanov, I.A. (1988) Quoted in *UNESCO Sources No. 13* (1990) (Paris, UNESCO), 23pp.

WHO (1984) *Guidelines for Drinking Water Quality*, Vol. 1: *Recommendations*, (Geneva, WHO), 130pp.

WHO (1988) *Drinking Water Quality: Guidelines for Selected Pesticides*, Environmental Health 27, Regional Office for Europe (Copenhagen, WHO), 23pp.