DRAINAGE DEVELOPMENT IN A CHANGING ENVIRONMENT: OVERVIEW AND CHALLENGES[1]

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ABSTRACT

Irrigated agriculture is expected to play a major role in reaching the broader development objectives of achieving food security and improvements in the quality of life, while conserving the environment, in both the developed and developing countries, especially in the prospect of global population growth from almost 6 billion today to, at least, 8 billion by 2025. In this context, the constraints posed by land and water scarcity and the associated need to increase the carrying capacity of the land in a sustainable manner will require significant enhancements in efficiency and flexibility of irrigation and drainage systems in the next few decades.

In most of the world's irrigated and rainfed lands drainage facilities were developed on a step by step basis over the centuries. In many of the systems structures have aged or are deteriorating and, consequently, they need to be renewed or even replaced and thus, redesigned and rebuilt. Drainage systems, in the past, were conceived for a long life, on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, designers and managers need to systematically re-examine planning principles, design criteria, operating rules and management policies for new drainage systems.

With reference to these issues, the report, on the basis of the available information, gives an overview of current and future (time horizon 2025s) drainage development and drainage needs around the world. Moreover, the paper analyses the latest results of four of the most advanced General Circulation Models (the Geophysical Fluid Dynamic Laboratory, Princeton, USA, the Goddard Institute of Space Sciences, USA, the Oregon State University, USA, the United Kingdom Meteorological Office, UK)to assess the hydrological impacts of global warming, due to the greenhouse effect, on the drainage planning and design process. Finally, a five-step planning and design procedure able to integrate and factor, within the drainage development process, the hydrological consequences of climate change, is proposed.

1 INTRODUCTION

Both surface and subsurface drainage have expanded rapidly in developed countries over the last two centuries. It was not until late in the nineteenth century that emphasis began to be placed on drainage in the developing world. Nowadays, in many cases the structures are aging or deteriorating. So, they need to be renewed or even replaced and thus redesigned and rebuilt, in order to achieve improved sustainable production. Moreover, the environmental conditions have changed dramatically in the last half century. In the older irrigated lands of the temperate zone groundwater levels have risen to produce waterlogging in many areas. In arid climates this process has caused excessive salinity buildup in crop root zones and created yield reductions or caused land abandonment in severe cases. In humid and sub-humid tropics, population pressures and the need to adopt more intensive and higher input crop husbandry have led to a sharper focus on flood control and flood alleviation measures. Most of these factors are well known and linked to uncertainties associated with climate change, world market prices and international trade. These uncertainties call for continued attention and suitable action on many fronts, if productivity and flexibility in agricultural systems are to be improved. In this context, the effects of climate change may play an important role in may regions. Availability of reliable hydrological data is an essential prerequisite for the rational planning, design and management of water resources.

Drainage systems were designed for a long life, on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Although an anthropogenically-induced climate change is expected to have significant impacts on drainage systems, the range of uncertainty as to how these climate impacts, at the geographic scales of interest, affect the drainage development process is still great. Moreover, the absence of a uniform understanding makes it difficult to assess the adequacy of existing planning principles and design criteria, in the light of these potential changes. Therefore, planners, designers and decision-makers need to review the strengths and weaknesses of current trends in drainage development and rethink technology, institutional and financial patterns, research thrust and manpower policy, so that service level and system efficiency can be improved in a sustainable manner.

2 DRAINAGE AND AGRICULTURE

Drainage is a crucial instrument for achieving sustainable development of both irrigated and rainfed agriculture throughout the world.

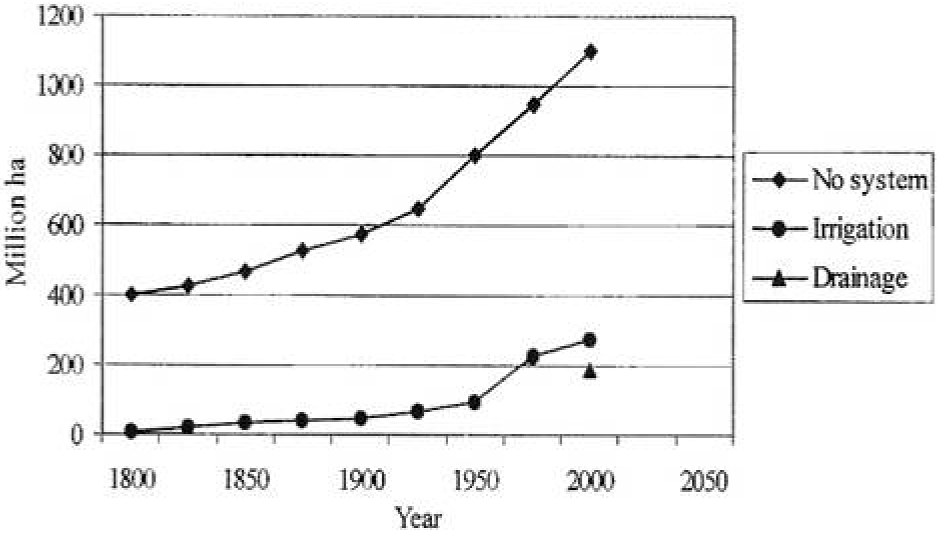

Figure 1 Development of cultivated area in the world without a water management system and under irrigation and the presently drained area (Schultz, 2001).

In Figure 1 the development of the cultivated area, irrigation and drainage since the beginning of the nineteenth century is given (Schultz, 2001). The total cultivated area on earth is about 1,500 ha. At about 1,100 million ha agricultural exploitation takes place without a water management system. However, in a certain part of these areas methods like water harvesting, or soil treatment may be applied. From these areas 45% of crop output is being obtained. Presently irrigation covers more than 270 million ha and is responsible for 40% of crop output. It uses about 70% of water, withdrawn from global river systems. Drainage of rainfed crops covers about 130 million ha and contributes to about 15% of crop output. In about 60 million ha of the irrigated lands there is a drainage system as well (Smedema, 1995). Some key figures of the 10 countries with the largest drained areas are given in Table 1.

With respect to agricultural production, the role of drainage is considered in three major agro-climatologic zones (Schultz and De Wrachien, 2002):

- arid and semi-arid regions
- humid tropical zone
- temperate zone

Dependent on the local conditions, different types of drainage systems with different levels of service will be appropriate (Schultz, 1993).

Table 1 Indicative key figures for the 10 countries with the largest drained area (international Commission on Irrigation and Drainage, 2001, and database CEMAGREF)

Country	Population (x10^6)	% of population in agriculture	Total area (10^6 ha)	Arable land (10^6 ha)	Drained area (10^6 ha)
Brazil	168	19	851	66	8
Canada	31	3	997	46	10
China	1267	68	960	96	29
Germany	82	3	36	12	5
India	998	61	329	170	13
Indonesia	209	50	190	30	15
Japan	127	4	38	5	3
Pakistan	152	48	80	22	6
Poland	39	23	32	15	4
USA	276	2	936	188	47
Total	3349		4449	650	142
World	6000		13000	1512	190

2.1 Arid and semi-arid regions

The prospects of increasing the gross cultivated area in these regions are limited by the dwindling number of economically attractive sites for large-scale irrigation and drainage projects. Moreover, the threat of waterlogging and salinization hangs over nearly every irrigation scheme; apparently irrigation systems have failed because of lack of adequate drainage. Intensification of agriculture relies upon irrigation, but the poor efficiency of many irrigation systems pledges for significant improvements in agricultural water use and management. Therefore, the required increase in agricultural production will necessarily rely largely on major improvements in the construction, operation, management and performance of existing irrigation and drainage systems (De Wrachien, 2001). Some excellent agriculture is practiced today in some semi-arid and arid areas, such as the Indus Valley in Pakistan, the Nile delta and central and southern California. The physical constraint that threatens sustainable agricultural development is limited drainage capacity. This requires dealing effectively with the twin menaces of waterlogging and salinization.

The extent of agricultural areas suffering from waterlogging and salinization on a global scale has not been well documented. It is estimated that these phenomena are a serious threat to some 100-120 million ha of irrigated land in arid and semi-arid regions. The available data suggest that some 20-30 million ha of irrigated land in this zone are already significantly affected and that the problem is growing by 0.5-1.0 million ha per year (Smedema, 2000).

2.2 Humid tropical zone

In the humid tropical zone agriculture is practiced mainly in lowland plains. It is severely constrained by flooding and submergence caused by monsoons. The consequences are low yields, limited crop choices and constraints to introduction of mechanization and other modern farming techniques. A distinction is generally made in cultivation during the wet and the dry monsoon. During the wet monsoon cultivation is, normally, possible only with a drainage system, although quite often irrigation is also applied to overcome dry spells. In the dry monsoon irrigation is required to make possible good yields. When systems are well coordinated and their efficiency improved to enable the cultivation of crops during both the wet and the dry seasons, irrigation and drainage systems are generally applied. Open drainage canals are used where the rainfall intensity is so high that pipe drainage will almost always have insufficient capacity or become very expensive. In some countries, as in Japan, experience shows the combination of open and pipe drainage systems in order to achieve a better control of surface and groundwater for the cultivation of mixed crops-rice followed by dry crops.

Large lowland areas along coasts and in the river flood plains often need to be reclaimed. Reclamation includes water management measures based on balanced drainage and equilibrium with the environment, in line with national and international nature-conservation policies.

Another increasing problem is the pollution of drainage systems due to the uncontrolled discharge of urban and industrial wastewater and the uncontrolled application of fertilizers and pesticides in agriculture. On the whole, heavy rainfall, overflowing rivers and flooding from upstream areas represent the major constraints to agricultural development in the humid and sub-humid tropics.

This zone is estimated to cover 100-200 million ha (IPTRID, 2001). The area is not expanding, but with higher demands put on agricultural production systems, more farmers increasingly require better flood protection and drainage.

2.3 Temperate zone

Agriculture in the Temperate Zone is to a large extent rainfed. Crops evapo-transpirate water taken directly from rainfall and use soil moisture in dry spells. To maintain groundwater table levels within desired limits drainage systems were installed. A major effect of the drainage systems is to allow for timely land preparation: agricultural machinery can access to land early in the season, cultivate and prepare it for sowing. The cultivation period is thus extended, which is of importance because the daily sunlight periods in parts of the Temperate Zone represent the crucial production factor. As rainfall is unevenly spread, supplementary irrigation may be required depending on location and production systems. Groundwater of generally good quality is often used for irrigation. The field drainage system is generally of subsurface type, but in soils with a low permeability surface drainage systems may be applied. In clay soils pipe drains and, sometimes, mole drains may be used, while the peat soils are generally drained with open field drains. Flood control has been achieved virtually everywhere in the Temperate Zone by dykes along rivers and the sea.

In several countries environmental laws and regulations have been, or are being made to control the application of fertilizes and pesticides in such a way that the drainage effluents are acceptable for the receiving water bodies. Many of the world’s current drainage systems have been installed in the developed countries of the temperate humid zone, especially in Europe and North America. Two hundred years ago, drainage programs focused on bringing waterlogged and low-lying areas into production; more recently, up to the 1980s, they have been carried out on a widespread intensive basis. The present situation is that, with 25-30 % of agricultural land drained, the installation rate is falling.

3 CURRENT STATE OF DRAINAGE DEVELOPMENT

Both surface and subsurface drainage have expanded rapidly in developed countries over the last two centuries. It was not until late in the nineteenth century that emphasis began to be placed in the developing countries. The early works were in the deltas of Asia and other newly developed irrigated areas. There were reasons why early irrigators were slow to introduce drainage into irrigation systems. In the arid zones, the planned cropping intensities were often low and groundwater tables were situated far below the crop root zones. In the humid zone, crops that would tolerate periodic inundations were selected. It was logical to defer expenditure on drainage until the need for it arose. The conditions in the older irrigated areas have changed dramatically in the second half of the last century. Water tables have risen to produce waterlogging in many areas. In arid climates, this process caused excessive salinity buildup in crop root zones and created yield reductions or caused land abandonment in severe cases. In humid zones, there were economic pressure to diversify cropping away from what was almost a rice monoculture. Due to the above-mentioned pressures agricultural drainage developed differently with various features in different countries. The salient aspects of drainage development in a few significant countries are herewith described (Framji and Mahaja, 1969, Field, 1990, Chauhan, 2000, Dam, 2000, Sarwar, 2000, Ahmad, 2002, Jhorar, 2002).

3.1 Canada

Drainage and reclamation were carried out in Canada, to protect coastal marshlands by tide waters and floods, starting from the seventeenth century. During 1940s, the reclamations structures fell into disrepair and large areas of good marsh land were again flooded by tides. Later on, the provincial and federal governments, in pursuance of the marsh land rehabilitation act, passed in 1948, took up programs of further reclamation measures.

Currently, the most serious problems in irrigation districts is the presence of saline soils. Seepage from irrigation canals causes the water table to rise and salts to appear in the surface. This is overcome by lining of canal, surface and subsurface drainage and land levelling.

3.2 China

A large proportion of China’s low-lying lands are under the threat of submersion under water due to poor drainage. Since 1949 efforts have been made on regulation of several low-lying areas going under inundation. For the ameliorations of these lands different methods are used in different situations. In mountainous areas of upper valleys, reservoirs are constructed and soil and water conservation measures undertaken. For hill-lands in middle valleys, terraces are built to let rain water seep into subsoil. For the low-lying lands subject to submergence ditches are systematically dug for drainage in areas wherever outlets for gravity drainage are available. Where drainage is not practical the land is protected with earth dykes or bottom lands are levelled to act as flood detention basins. In coastal plains dykes are built for the prevention of tidal flows and sluices are provided for stoppage of tidal inflows.

3.3 India

Waterlogging and salinity were first noticed in the upper region of Rechana Doab soon afterward the opening of lower Chenab canal in 1892. Later on, in 1925 the Punjab government constituted a committee to study and report on the extent and cause of waterlogging. Since independence the Land Reclamation Irrigation and Power Research Institute of Amritsar had taken up this work. Research and investigation programs have been carried out up today in this field, the most significant of which are listed beneath:

- Drainage studies at Baramati experimental plot with deep drains to release subsurface water into the drain;
- Pilot polder project, in Saurashtra with the co-operation of The Netherlands, for reclamation of saline lands in coastal plains;
- Investigations carried out at Central Soil Salinity Research Institute of Karnal on the reclamation of alkali soils, using both tile drains and open ditches;
- Studies on the reclamation of saline soils in heavy textured clay loam soils using subsurface drainage systems in the Bidaj District;
- Studies carried out by the Harayana Agricultural University on vertical tube wells;
- Investigations on the effectiveness of subsurface drainage systems in removing toxic acidic substances and improving the crop productivity in the Kerala command area.
- Studies on the effects of enhanced conjunctive use of surface and groundwater on soil salinity in the Sirsa Irrigation Circle, in cooperation with The Netherlands.

3.4 Italy

A number of drainage projects were carried out before sixteenth century. In 1896 a national survey reveled that, at that time, Italy had 1 million ha of swampy lands. The innovation of the mechanical drainage system allowed the reclamation of these lands. The main aim of the reclamation at that time, was to control water-related vector-borne diseases and reduce the incidence of malaria in the agricultural areas. In Emilia from 1869 to 1950, the Central Authority reclaimed more than 0.2 million ha of swampy areas and made cultivation possible in additional 0.2 million ha under natural meadows and pastures which were periodically flooded. More recently, in the Po Valley, farmers responded to the introduction of improved drainage by shifting from arable crops to orchards.

3.5 Pakistan

In Pakistan the potential need of drainage was realized since the time large scale diversion works were constructed. Starting from unsuccessful attempts on lining the canals, steps were taken to provide for seepage drains along the main canals. Surface drains were also constructed to remove storm water and reduce groundwater recharge. In 1954, a comprehensive hydrological ground water and soil research was carried out in Indus plains. The survey indicated that more than 4.5 million ha were poorly drained or waterlogged and 6.5 million ha were affected by salinity. After this investigation drainage and reclamation were implemented through projects known as Salinity Control and Reclamation Projects (SCARP).The main aims of the SCARP projects were to combat waterlogging and salinity through lowering of the groundwater table and increase in the irrigation supplies by using the pumped groundwater directly of mixed with canal water. As a result, in fresh groundwater areas, about 14,000 tubewells (covering about 2.6 million ha of irrigated land) were constructed in the 1960s and 1970s. Initially, the implementation of the SCARPs was moderately successful and the problems of waterlogging and salinity were somewhat arrested and reserved.

In the last ten years five SCARP have been carried out in an area of 2 million ha. Besides, surface drainage was taken up for more than 1.0 million ha in Gulam Mohammad Command area and 0.25 million ha in other projects. Within the fourth project an important study has been realized, in cooperation with The Netherlands, to develop a transient model approach to improve design procedures for subsurface drainage systems in relation to adopted irrigation techniques for improving crop yields in the Rechna Doab Command area.

3.6 United States of America

Drainage is used in basically two connotations. The first is in the context of reclamation of swamplands and marsh regions, by removing excess surface and groundwater from the soil to make waterlogged lands suitable for cultivation. The second connotation is applied to irrigation practices. In this case, drainage is necessary to maintain the watertable below the plant root zone to provide a favorable salt balance.

The history of drainage development in the USA can roughly be divided in two periods, before and after the 1960s, respectively. During the first period, which substantially started in the eighteenth century, much drainage development took place, driven almost exclusively by agricultural interest and strongly promoted and supported by government policies. Initially, most of the drainage was for reclamation of waterlogged lands, while later on it became more a mixture of surface and subsurface drainage development. Much of the country’s current drainage infrastructure dates from this period.

After the 1960s, the drainage systems became more influenced by the changing environmental ethics. A number of laws and policies were adopted to protect the remaining wetlands and to constrain environmentally undesirable drainage developments. The rate of drainage development slowed down and became much more selective.

Going into statistics, it may be indicated that in 1920 there were 25 million ha in drainage projects which increased: in 1940 to 35 million ha, in 1960 to 41 million ha, and in 2000 to 47 million ha.

3.7 The Netherlands

The installation of flood control and drainage systems has a long history in the Netherlands. The primary function was to provide safe and habitable country with optimum growing conditions for crops. Most drainage systems are subsurface, evacuating excess water towards open drains. In the past, windmills lifted the water from these to secondary and main drains, from where it was finally disposed of in rivers and the sea. The unending struggle with the water formed the landscape, which consists of polders, drained lakes, innumerable canals, pumping stations and small and large hydraulic structures.

Valuable experience was obtained as drainage development went through a continuous process of technological innovations. Windmills were replaced by pumping stations and clay drain pipes were substituted by perforated plastic pipes. Institutions and policies on drainage and flood control evolved accordingly. The 3000 Water Boards that existed in the middle Ages were merged into fewer than 100 existing today. The driving forces behind the establishment of an integrated water quantity and quality management policy, were concerns about salinity intrusion, point-source pollution from municipalities, industries and upstream international sources, agricultural pollution, groundwater depletion and nature conservation and navigation requirements.

4 PROSPECTS OF MEDIUM TERM DEVELOPMENT

The above salient aspects give a brief history of development of drainage in different countries. It has not been possible to cover all the countries. Nonetheless, the picture indicates that drainage has a culture to travel from material of stones, ditches, clay tiles, to plastics pipes and from reclamation of flooded areas and marshes to drainage of waterlogged irrigated lands and that the process has taken a long time to develop to this stage and has been fruitfully utilized and practiced by developing countries.

On the basis of the above-presented figures and the available recent database on the world’s total cropped area and the areas irrigated and drained, a rough compilation of the state of drainage development of the world’s cropland may be made as in Table 2.

Table 2 State of drainage development of the World's cropland (Smedema 2000, modified)

	Not drained (without drainage facilities)	Drained (with drainage facilities)	Total World Cropland
	Million ha		
Irrigated	200	60	
Rainfed	1100	130	
Total	1300	190	1500

The currently drained area of 190 million ha has been developed aver a period of roughly two centuries. The current rate of drainage development is unknown but estimated to be in the order of 0.5 – 1.0 million ha for year (including upgrading and rehabilitation). Considering that the continuing agricultural development will make improved drainage increasingly needed, as well as affordable, for the 2025s time horizon, the following projection can be made (Smedema, 2000):

4.1 Irrigated Land

In irrigated agriculture drainage is essential under most conditions. It is essential to combat water logging and salinity. Pilot projects in waterlogged and salinized areas need to be established in order to verify available technologies and provide training for personnel. Groundwater monitoring, water balance studies and conjunctive use of surface and groundwater should be encouraged as well. The above-described issues tackle the root cause of the major drainage problems encountered in irrigated agriculture. To be effective they have to be translated into actions through the formulation of appropriate programs. In this context, a realistic medium term drainage program is conceived to involve the development of 10-15 million surface drainage and 2-3 million ha of subsurface drainage, almost all located in the developing countries. The contribution of the world's food production of such a program would roughly be equivalent to that of some 3-4 million ha of irrigated land.

4.2 Rainfed Land

In rainfed agriculture, drainage is required to increase and sustain agricultural production by preventing any temporary waterlogging and flooding of lowlands. It is estimated that about one-third of the world's rainfed cropland is naturally not well enough drained and would benefit from investment in improved drainage. This suggests that some 250-300 million ha of rainfed cropland are still in need of improved drainage of which 25-30 million ha would seem to be a reasonable target for a medium term program. Most of this land would be located in the humid tropical zone of southeastern Asia, as it is, mainly, in this area that drainage has remained under-developed (with only some 4% of the land being provided with drainage facilities) and, therefore, offers the best prospects (IPTRID, 1994). Estimating that the improved drainage would increase yields by 20-30 %, the increased food production of such a program is assessed to be equivalent to some 6-7 million ha of extra rainfed cropland.

4.3 Challenges for Drainage Systems in a Changing Environment

The above assessment of future drainage needs suggests that the contribution of drainage development to the world's food supply would be rather modest in the medium term perspective. Implementation of an envisioned program of improved drainage for the 2025s time horizon is predicted to increase the food production of the irrigated area by some 1.0-1.5 % and of the rainfed area by some 0.5-1.0% , while the global weighted average would be only in the order of 1%. Although the absolute values of these figures may be disputed, there should be no doubt that drainage no longer plays the important role in the food production process that it played in the past. Drainage, however, plays and will play an important role in maintaining present levels of food production. This applies to rainfed land, the productivity of much of which would fall substantially without the provided drainage, but especially to the irrigated land. Without drainage, a large part of the irrigated land in the arid and sub-arid zones (probably up to one third) would not be sustainable and would be doomed to degrade into waterlogged and/or salinized wasteland. Added to this, the systems have to withstand the pressure of changing needs, demands and social and economic evolution. Consequently, the infrastructure of most drained areas needs to be renewed or even replaced and, thus, redesigned and rebuilt, in order to achieve improved sustainable production. This process depends on a number of common and well-coordinated factors, such as a new and advanced technology, environmental protection, institutional strengthening, economic and financial assessment, research thrust and human resource development. Most of these factors are well known, and linked to uncertainties associated with climate change, world market prices and international trade. In this context, the effects of climate change may play an important role (Schultz and De Wrachien, 2002). Availability of reliable hydroclimatic data is an essential prerequisite for the rational planning, design and management of drainage systems. These systems were designed for a long life on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, designers and managers need to systematically re-examine planning principles design criteria, operation rules, contingency plans and water management policies. All the above factors and constraints compel engineers and decision-makers to review the strengths and weaknesses of current and future trends in drainage and rethink technology, institutional and financial patterns, research thrust and manpower policy so that service levels and system efficiency can be improved in a sustainable manner.

5 THE CHANGING ENVIRONMENT: CLIMATE TRENDS, HYDROLOGY AND WATER RESOURCES

Global climate change has become an important area of investigation in natural sciences and engineering, and water resources has often been cited as an area in which climate change may be particularly important for decision-making. A change in the global climate would have major impacts on both the quantity and quality of water available for human use. According to the Intergovernmental Panel on Climate Change (IPCC, 1996a) a greenhouse warming would affect precipitation patterns, evapo-transpiration rates, the timing and magnitude of runoff and the frequency and intensity of storms. A rise in sea level associated with such a warming could affect flooding of coastal lands and related drainage and reclamation measures. In addition, temperature and precipitation changes would affect demands for water for irrigation and other purposes. Although a climate change is expected to have significant impacts on water resources, the range of uncertainty as to these climate impacts, at the geographic scales of particular interest, would affect the water resources planning and management process, is great. In contrast to the considerable work that has been devoted to examining the potential impacts of global climate change on water resources systems, relatively little has been done to review the adequacy of existing water planning principles and evaluation criteria in the light of these potential changes.

In this context, and with reference to the agricultural sector, the absence of a uniform understanding and application of basic evaluation principles, has hindered, up to now, the prospects for developing an integrated assessment to account for the linkages between climate change and planning and design criteria of irrigation and drainage systems. The challenge today is to identify short-term strategies, in planning and design procedures, in the face of long-term uncertainty. The question is not, what is the best irrigation and drainage development over the next fifty or hundred years, but rather, what is the best development for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

5.1 Trends in Climate Change

5.1.1 The greenhouse effect

Over the long-term, the Earth's climate has been changing due to a number of natural processes, such as gradual variation in solar radiation, meteorite impacts and, more importantly, sudden volcanic eruptions in which solid matter, aerosols and gases are ejected into the atmosphere. Ecosystems have adapted continuously to these natural changes in climate, and flora and fauna have evolved in response to the gradual modifications of their physical surroundings, or have become extinct. Human beings have also been affected by and have adapted to changes in local climate, which, in general terms, have occurred very slowly. Over the past century, however, human activities have begun to affect the global climate. These effects are due not only to population growth, but also to the introduction of technologies developed to improve the standard of living. Human-induced changes have taken place much more rapidly than natural changes. The scale of current climate forcing is unprecedented and can be attributed to greenhouse gas emissions, deforestation, urbanization, and changing land use and agricultural practices. The increase in greenhouse gas emissions into the atmosphere is responsible for the increased air temperature, and this, in turn, induces changes in the different components making up the hydrological cycle such as evapo-transpiration rate, intensity and frequency of precipitation, river flows, soil moisture and groundwater recharge. Mankind will certainly respond to these changing conditions by taking adaptive measures such as changing patterns in land use. However, it is difficult to predict what adaptive measures will be chosen, and their socio-economic consequences (De Wrachien, Ragab and Giordano, 2002).

5.1.2 Climate change scenarios

Current scientific research is focused on the enhanced greenhouse effect as the most likely cause of climate change in the short-term. Until recently, forecasts of anthropogenic climate change have been unreliable, so that scenarios of future climatic conditions have been developed to provide quantitative assessments of the hydrological consequences in some regions and/or river basins. Scenarios are "internally-consistent pictures of a plausible future climate"(Wigley, et al., 1986). These scenarios can be classified into three groups:
hypothetical scenarios;

- climate scenarios based on General Circulation Models (GCMs);
- scenarios based on reconstruction of warm periods in the past (paleoclimatic reconstruction).
- The plethora of literature on this topic has been thoroughly summarized by IPCC (IPCC, 1992).

The scenarios of the second group have been widely utilized to reconstruct seasonal conditions of the change in temperature, precipitation and potential evapo-traspiration at basin scale over the next century. GCMs are complex three-dimensional computer-based models of the atmospheric circulation, which provide details of changes in regional climates for any part of the earth. Until recently, the standard approach has been to run the model with a nominal "pre-industrial" atmospheric carbon dioxide (CO_2) concentration (the control run) and then to rerun the model with doubled (or sometimes quadrupled) CO_2 (the perturbed run). This approach is known as "the equilibrium response prediction". The more recent and advanced GCMs are, nowadays, able to take into account the gradual increase in the CO_2 concentration through the perturbed run.

To examine climate change over the three major agro climatic zones, due to the enhanced greenhouse effect, the most recent results of the following GCMs have been mainly used in the present report (in alphabetical order):

- the Geophysical Fluid Dynamic Laboratory (GFDL), Pinceton, USA (Weatherald and Manabe 1986);
- the Goddard Institute of Space Sciences (GISS), USA (Hansen and Takahashi, 1984);
- the Oregon State University (OSU), USA (Schlesinger and Zhas, 1989);
- the United Kingdom Meteorological Office (UKMO), Hadley Centre, Bracknell, UK (Ragab and Prudhomme, 2002).

The models differ as to the way in which they handle the physical equations describing a atmospheric behaviour. The important elements are the interactions between land and water surfaces and the fluxes of energy, water and CO_2. The description of these processes, for large areas, is often based on small-scale field data or models that cannot be valid for the large grid cells that subdivide the areas modelled (of the order of 300x300 to 1000x1000x km2). The upscaling problem is one of the main reasons for the different results of the models. All the scenarios are for time horizons ranging from 2040s to 2050s

5.1.3 Arid and semiarid regions

The arid and semiarid regions are particularly vulnerable to climate change, such that any changes in precipitation patterns will have significant impacts on hydrological regimes and water resource systems (Leavesley et al., 1992, Shiklomanov 1994). For example an increase in mean annual air temperature by 1-2°C. and a 10% decrease in precipitation could reduce annual river runoff by up to 40-70%. These conclusions were based on estimates for river basins in areas of water deficit in the USA, Canada, Australia, Russia, Africa and South America (Table 3).

Table 3 Results of assessments of impacts of climate change on annual river runoff (basins and areas of water deficit) (Shiklomanov, 1999)

Climate change scenario			
Region and basin	Temperature (°C)	Precipitation (%)	Change in annual runoff (%)
Mean for seven large basins in the western USA	+2	-10	-40 to -76
Colorado River, USA	+1	-10	-50
Peace River, USA	+1	-10	-50
River basins in Utah and Nevada, USA	+2	-10	-60
River basins in the steppe zones of European Russia	+1	-10	-60

In analyses of the hydrological consequences of global warming in arid regions, particular attention has been paid to the Sahel, where the severe droughts of recent decades have already caused critical situations and highlighted the inadequacy of most water management systems.

The greenhouse effect, due to higher CO_2 concentrations, affects strongly plant physiology and transpiration capacity (at higher CO_2 concentrations, transpiration tends to decrease). Such factors have been stressed for rives basins in Arizona (Idso and Brazel, 1984), and for watersheds in Australia (Aston, 1984) and in Pakistan (Ahmad, 2002).

With regard to irrigation and drainage practices, Easterlin, et al. (1991) found that the direct effect of higher CO_2 concentration would be to increase rainfall, leading to a reduction in crop water requirements, but this depends to a large extent on the type of vegetation. For example, Kimball et al. (1993) found that an increase in CO_2 of up to 550 parts per million would reduce the evapo-transpiration of winter wheat by about 11%.

5.1.4 Humid tropical zone

The impacts of global warming on water resources in humid tropical regions have been assessed mainly on the basis of studies and investigations carried out on river basins of the following countries: India, Indonesia, Sri Lanka, Uruguay, Venezuela, Vietnam (IPCC, 1995). GCMs were used in each case where river basin responses were estimated from hypothetical scenarios. The quantitative conclusions differ somewhat. For example, in a study of the Uruguay River, Tucci and Damiani (1991) compared the results of GISS, GFDL and UKNO GCMs for the case of double CO_2 concentration. The Authors concluded that all three models underestimated the amounts of precipitation, but that GISS model better reflected the historical situation. Nonetheless, with global warming of 1-2°C, the total runoff in likely to increase.

5.1.5 Temperate zone

The most significant changes in hydrological regimes are likely to occur in the seasonal distribution of runoff, rather than in mean annual values. There is a general consensus that the greatest increases in runoff would occur in winter, due to the combined effects of higher temperatures reducing snow cover, and increases in the frequency of occurrence and the intensity of storms (Leavesley, et al., 1992, and Arnell 1995). Such effects would be most acute in regions where at present river regimes are dominated by spring snowmelt. Thus, there would be a shift in the frequency of floods and low flows, with such extreme occurring more often in winter and summer, respectively.

For the former Soviet Union, for example, Shiklomanov and Lins (1991) showed that with a temperature increase of 1°C, the total annual river runoff could increase by about 7%, and with an increase of 2°C the runoff of large river systems could increase by 10-20%. Similar conclusion have been drawn for regions with comparable physiographic conditions such as Belgium, Canada, Poland, Scotland.

In summary, the materials submitted to the IPCC for temperate humid regions indicate that global warming will tend to increase mean annual runoff. In regions where runoff is derived mainly from spring snowmelt significant changes in seasonal and monthly runoff can be expected. In this case the streamflow distribution throughout the year would be more vulnerable to changes in air temperature than in annual precipitation.

5.2 Impacts of Climate Change in the Hydrological Cycle

Under warmer conditions the hydrological cycle will become more intense, stimulating rainfall of greater intensity and longer duration, causing longer prolonged periods of floods and droughts. Increases in maximum floods are likely to occur in north-western USA and northeaster Canada. Significant increases in runoff maxima may be expected in north-western Europe, and increases in winter runoff minima and reduced spring snowmelt in eastern Europe. The global warming is likely to intensity the variability of the Asian monsoon region, increasing the frequency of floods and droughts. In Australia there would be greater variability in the extreme parameters of precipitation and river runoff (Australian Bureau of Meteorology, 1991).

The hydrological consequences of global warming include changes in river runoff and the water balance, as well as in other parameters such as the total water availability, water levels, and maximum and minimum discharges, which, in turn, would affect planning, design and management of water resource systems.

Sea level rise and changes in river runoff will cause the flooding of many low-lying coastal areas. Changes in the processes of delta formation would also contribute to the salinization of irrigated lands near the lower reaches of rivers and estuaries, due to the saltwater intrusion.

These problems have not been adequately addressed yet in the available literature. Such assessments require multidisciplinary research that takes into account detailed forecast of changes in regional climate characteristics and water regimes under various environmental conditions.

5.3 Impacts of Climate Change on Water Resources

In assessing the hydrological impacts of global warming, the issue of water resources represents an important component of the process. Global warming could result in changes in water availability and demand, as well as in the redistribution of water resources, in the structure and in the nature of water consumption, and more intense disputes among different water uses. These impacts may be positive or negative, depending on the climate scenario adopted, the water management sector concerned and the environmental conditions.

In summary, for all developing countries with high population growth rates, the per capita water availability tends to decrease irrespective of the climate scenario (Dam, 1999). However, for many countries the various model results are inconsistent; this highlights the difficulty in formulating appropriate adaptive water management strategies if they are to be based on current predictions of the effects of climate change. The results of assessments of possible changes in irrigation and drainage water requirements for various world regions are, also, ambiguous and depend on the scenarios applied, on the methods of computation and on physiographic conditions. All this stresses the fact that factors other than climate will stimulate projects to ensure the availability of reliable water supplies in many parts of the world and that climate change may introduce still greater uncertainty in the development of methods for water resources management and control.

6 PLANNING AND DESIGN OF DRAINAGE SYSTEMS UNDER CLIMATE CHANGE

Impacts of a greenhouse warming that are likely to affect planning and design of water systems include changes in precipitation and runoff patterns, sea level rise, land use and changes in water demand and allocation. Drainage systems are particularly sensitive to change in precipitation, temperature and carbon dioxide levels. Despite recent advances in climate change science, great uncertainty remains as to how and when climate will change and how these changes will affect planning design and management of drainage systems at both the watershed and field levels. So, water authorities should begin to re-examine design criteria for the present and future planned drainage systems under a wide range of climatic conditions and explore the vulnerability of both structural and non-structural components of the systems to possible future climate change. Water authorities have relied in the past on the assumption that the future climatic conditions will not be different from the past ones. Drainage systems have been designed using historical information on temperature, precipitation and crop water requirements and expected to last 50 years or even longer. Past records of hydrological conditions may no longer be a reliable guide for the future. New planning principle, design criteria, operating rules, contingency plans and evaluation procedures are needed able to respond to new information with midcourse corrections and to include hedging strategies along with the option value of alternative courses of action. The challenge today is to identify short-term strategies to face long-term uncertainties. The question is not, what is the best course, for a drainage project over the next fifty years, but rather, what is the best scheme for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course (IPCC,1996b).

6.1 Current Planning Principles and Design Criteria

The planning and design of a drainage system should be viewed as an aspect of agricultural development concerning the private sector as well as the national economy. So, particular attention should be paid to:

- the importance of water for agricultural production in relation to national water use;
- historical water use practices;
- effect on the local hydrological environment;
- maintenance of water quality and quantity.

In this context, the process of determination of design parameters, selection of systems and materials, construction methods, operational and maintenance aspects has to proceed in a balanced way, in order to optimize designs and to take into account the interactions among land use, agricultural practices and the layout and characteristics of drainage networks (Storsbergen, 1993).

The choice of a drainage technique will depend on the environmental conditions. The available methods include deep and shallow tube wells, skimming wells, wide-spaced and narrow-spaced drain pipes, deep and shallow ditches, surface drainage or mole drains. Planners and designers have to incorporate sufficient flexibility into the networks to be able to cope with changes in the objectives of the schemes. These may be due to alteration of cropping patterns, agrarian structures, urbanization, infrastructure, agricultural practices, mechanization, hydrological regime, water management and water use trends.
Research on the planning and design of drainage systems has to deal with different aspects such as: design criteria and design methods, materials, construction, maintenance, control and inspection equipment, institutional and financial aspects of system construction, operation and maintenance. Because of the increasing scarcity of usable water resources, special attention should be focused on the control of disposal water. The objective of this process is to optimize the efficiency of available land and water resources use with the ultimate goal of enhancing crop yield and production. For a well planned and controlled drainage scheme, the following aspects need to be taken into account at the design stage:

- data on climate, cropping pattern, stream flow, surface and subsurface water regime, water demand for agricultural, industrial and municipal purposes;
- existing facilities (dams, canal systems and associated structures);
- design parameters for drainage works and all associated structures;
- future operational, maintenance and management procedures including monitoring, financial and administrative facilities.

Standardization of design procedures is necessary to allow for possible decentralization of the design process. This will facilitate construction supervision and establish the basis for a more rational and sustainable drainage scheme, with consequent benefits for its operation and maintenance. Design standards should be simple and precise, so as to provide designers with clear choices as to type of structure to be used and procedures to be followed.

In operational terms, the design of a drainage system may be divided in two phases: the selection of type and layout of the system and the determination of its hydraulics characteristics (discharge rates pumping capacity, pipe cross-sections and so). Two design criteria can be followed: the traditional empirical method and the optimization procedure (ICID, 1999).

6.2 Climate Change Impacts on Planning and Design

As stated above, greenhouse warming is likely to have major impacts on drainage systems. Possible impacts that may especially affect planning principles and design criteria include changes in precipitation and runoff patterns, sea level rise, flooding of coastal irrigated lands and land use. Warmer temperatures will accelerate the hydrologic cycle, altering rainfall, the magnitude and timing of runoff, and the intensity and frequency of floods and droughts. Higher temperatures will also increase evapo-transpiration rates and alter soil moisture and infiltration rates.

Uncertainties as to how the climate will change and how drainage systems will have to adapt to these change, are challenges that planners and designers are compelled to cope with. In view of these uncertainties, planners and designers need guidance as to when the prospect of climate change should be embodied and factored into the planning and design process. An initial question is whether, based on GCM results or other analysis, there is reason to expect that a region's climate is likely to change significantly during the life of a drainage system. If significant climate change is thought to be likely, the next question is whether there is a basis for forming an expectation about the likelihood and nature of the change and its impacts on the system. For example, in arid and semiarid areas, where runoff is particularly sensitive to temperature and precipitation changes, planners should pay special attention to potential climate impacts. The suitability and robustness of a system can be assessed by either running what if scenarios that incorporate alternative climates or through synthetic hydrology by translating apparent trends into enhanced persistence. In the absence of an improved basis for forming expectations as to the magnitude, timing and the direction of shifts in a irrigated area's climate and hydrology, it may be difficult to evaluate the suitability of further investments in drainage development, based on the prospects of climate change.

When there is ground for featuring reasonable expectations about the likelihood of climate changes, the relevance of these changes will depend on the nature of the project under consideration. Climate changes that are likely to occur several decades in the future will have little relevance for decisions involving drainage development or incremental expansions in present systems capacity. Under these circumstances planners and designers should evaluate the options under one or more climate change scenarios to determine the impacts on the project's net benefits. If the climate significantly alters the net benefits, the costs of proceeding with a decision assuming no change can be estimated. If these costs are significant, a decision tree can be constructed for evaluating the alternatives under two or more climate scenarios (Hobbs, et al., 1997). Delaying an expensive and irreversible project may be a competitive option, especially in view of the prospect that the delay will result in a better understanding as to how the climate is likely to change and impact the effectiveness and performance of the system.

Even in the absence of concerns about climatic change, the high costs of and limited opportunities for developing new large drainage projects, have brought a shift away from the traditional quite unbending planning principles and design criteria to meeting changing water needs and dealing with hydrologic variability and uncertainty. Efficient, flexible drainage systems designed for current climatic trends would be expected to perform efficiently under different environmental conditions. Thus, institutional flexibility that might complement or substitute for infrastructure investments is likely to play an important role in drainage system development under the prospect of global climatic change. Frederick et al. (1997) proposed a subsequent five-step planning and design process for water resource systems, to deal with uncertain climate and hydrologic events, that is likely to fit the development of large drainage schemes.

If climate change is identified as a significant planning issue (first step), the second step in the process would include a forecast of the impacts of climate change on the region's irrigated area. The third step involves the formulation of alternative plans, consisting of a system of structural and/or non-structural measures and hedging strategies that address, among other concerns, the projected consequences of climate change. Non-structural measures that might be considered include modification in management practices, regulatory and pricing policies. Evaluation of the alternatives, in the fourth step, would be based on the most likely conditions expected to exist in the future with and without the plan. The final step in the process involves comparing the alternatives and selecting a recommended development plan.

The planning and design process needs to be sufficiently flexible to incorporate consideration of and responses to many possible climate impacts. Introducing the potential impacts of and appropriate responses to climate change in planning and design of drainage systems can be both expensive and time consuming. The main factors that might influence the worth of incorporating climate change into the analysis are the level of planning, (local, national, international) the reliability of GCMs, the hydrologic conditions, the time horizon of the plan or life of the project. The development of a comprehensive multi-objective decision-making approach that integrates and appropriately considers all these issues, within the drainage project selection process, warrants further research on:

- understanding the processes governing global and regional climates and the links between the climate and hydrology;
- the impacts of increased atmospheric CO_2 on vegetation and runoff;
- the effect of climate variables, such as temperature and precipitation, on the demand of water especially for agricultural and landscape irrigation

7 CONCLUDING REMARKS

- Drainage is a crucial measure for achieving sustainable development of both irrigated and rain fed agriculture throughout the world.
- In irrigated agriculture, drainage is essential to combat waterlogging and salinity. Groundwater monitoring, water balance studies and investigations and conjunctive use of surface and groundwater should be encouraged. Pilot projects in waterlogged

and salinized areas need to be established in order to verify and test available technologies and provide training for personnel.

- In rainfed agriculture drainage is required to increase and sustain agricultural production by preventing any temporary waterlogging and flooding of lowlands. It is estimated that about one-third of the world's rainfed cropland would benefit from investments in improved drainage.
- It is estimated that by 2025s, drainage development would increase the world's food production by some 1.0%. This, compared to a projected 50% increase due to irrigation development, means that drainage no longer will play the important role, in the food production process, that it played in the past.
- Drainage, however, remains of critical importance to the maintenance of the present food production levels as without this measure, yields from much of the most productive rainfed land would fall drastically, while an estimated one third of the irrigated land in the arid zone is predicted to turn into waterlogged/salinized wasteland.
- Most of the world's drainage facilities were developed on a step-by-step basis over the centuries and were designed for a long life (50 years or more), on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, engineers and decision-makers need to systematically re-examine planning principles, design criteria, operating rules, contingency plans and water management policies.
- Possible impacts of climate variability that may affect planning principles and designs criteria includes changes in temperature, precipitation and runoff patterns, sea level rise, flooding of coastal irrigated and rainfed lands.
- Uncertainties as to how the climate will change and how drainage systems will have to adapt to these changes are issues that water authorities are compelled to cope with. The challenge is to identify short-term strategies to face long-term uncertainties. The question is not what is the best course for a drainage project over the next fifty years or more, but rather, what is the best scheme for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.
- The planning and design process needs to be sufficiently flexible to incorporate consideration of and responses to many possible climate impacts. The main factors that will influence the worth of incorporating climate change into the process are the level of the planning, the reliability of the forecasting models, the hydrological conditions and the time horizon of the plan or the life of the project.
- The development of a comprehensive approach that integrates all these factors within the drainage project selection, warrants further research on the processes governing climate changes, the impacts of increased atmospheric carbon dioxide on vegetation and runoff, the effect of climate variables on water demand for irrigation and the impacts of climate on drainage systems performance.

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