Irrigated Agriculture Development under Drought and Water Scarcity

Chief Editor:

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INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE

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Foreword

Water insecurity can have devastating effects on economies and jeopardize the well-being of entire populations, especially the poorest and most vulnerable. It remains a major challenge for many countries today, especially in the context of a changing climate.

Water availability for and its availability in the near and long term societal needs determine the vulnerability of a society to the extreme situation of both dry and wet periods. Temporary deficit of water availability over demand results in drought. While the water scarcity results in slow economic progress, particularly in the agrarian societies, the impacts associated with droughts result from numerous climatic and societal factors that define the level of societal resilience. Many other factors contribute to changing vulnerability. Mitigating the effects of drought lies at the forefront of the objectives of International Commission on Irrigation and Drainage. Issues of water scarcity and droughts have been dealt by technical Working Groups consisting of experts from ICID member countries and partner organizations.

In 1996, two erstwhile Working Groups, namely, Working Group on 'Highly Water Stressed Areas and the Working Group on 'Impact of Drought on Irrigated Agriculture' were merged to create a new Working Group on Irrigated Agriculture under Drought and Water Scarcity (WG-IADWS) under the chairmanship of Prof. Farhoudi (Iran), which I had the privilege to preside over since 2000. The WG covered the following areas: Develop/select appropriate indices to describe and quantify the implications of drought and aridity in relation to agricultural, ecological, social, economic and political issues; Develop guidelines for ´Assessment of drought on irrigated agriculture' and 'Development of policies and management strategies for various drought and water scarcity situations'; Investigate the application of long term weather forecasting for drought prediction and economic viability of drought early warning systems; and Investigate and report on suitable technologies and agro-irrigation practices for the utilization of non-conventional water resources under conditions of drought and water scarcity.

A number of internal and international workshop were organized by the WG on related topics such as 'Water Scarcity and Dry Land Agriculture' (2002, Montreal, Canada); 'Drought Management Strategies' (2003, Tehran, Iran); 'Drought Management Strategies in Different Countries' (2003, Montpellier, France); 'Water Harvesting and Sustainable Agriculture' (Moscow, Russia); 'Guidelines for Crop Production under Water Limiting Conditions'; 'Irrigation under Drought and Water Scarcity' (2006, Kuala Lumpur, Malaysia). Some of these workshops were organized in collaboration with other WGs such as ERWG and WG-PQW. The Working Group completed its mandate in 2007.

The WG has been disseminating its outputs through its website (http://www.wg-iadws.icidonline.org); through workshops organized at various events; papers presented; brief compilation on ‘water status of member countries’ and contributing to guidelines etc.

The present publication “Irrigated Agriculture Development under Drought and Water Scarcity” is a consolidated outcome of the contributions of the experts associated with the working group activities over the years and not limited to the names listed in the ‘Contributions’ section. It also takes into account the later developments that have taken place, particularly in the field of drought early warning which explains to some extent a delay in bringing out this publication. I am hopeful that this publication, brought out in electronic format, will be continued to be periodically revised.

Dr. Saeed Nairizi
President, ICID

Preface

Civilizations have learnt to live and survive in arid and desert areas in many parts of the globe. On the other hand droughts in the past have often resulted in famines. Increasing water scarcity and more frequent and severe droughts due to population growth on one side and changing climate on the other put pressure on the rainfed as well as irrigated agriculture. Agriculture water management in such conditions need to be based on an appropriate mix of traditional knowledge and modern technology.

This publication on 'Irrigated Agriculture Development in Droughts and Water Scarcity', is an attempt to learn lessons from long traditions of living with water scarcity, use them in meeting the challenges of more frequent and severe droughts. The publication, which is an outcome of sharing the knowledge in managing water scarcity and droughts around the world, is expected to provide lessons learnt in one part of the world to provide solutions in similar situations, which may be new in other part of the world.

As various institutions and organizations focus on this important issue that impact a number of SDGs and new technologies emerge, the knowledge that is ever evolving need to be updated. Therefore this publication is being published on line and will be retained as a living document and various sections revised and updated from time to time. In particular the Appendices, which present various technologies and evolving knowledge, would be updated from time to time.

I would like to thank Dr D K Paul and Mr M L Baweja for reshaping and editing the various chapters based on very valuable technical papers presented by various contributors, and acknowledge the discussions and suggestion provided by various experts.

I hope this publication will add to the repository of knowledge on the subject and help NCs in achieving their objectives.

Avinash C Tyagi
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Acknowledgements

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Chapter 1 - Introduction

1.1 Rainfall, the source of all freshwater

Water is the most basic requirement for the biological survival of all types of life. One may be able to live without food for several days but it is not possible to survive without water for more than a few days. It is needed for the health of the environment, food security, human and animal health, industry and energy. Water exists as surface water, soil moisture, and groundwater. It differs in quantities and qualities, it varies in time and space, it has a long term trend and it leads to unexpected and unpredictable extreme events.

The average annual precipitation over our planet is estimated to be about 1050 millimetres per year and varies spatially from less than 120 millimetres to a maximum of more than 3600 millimetres per year depending on geographical location. The subtropical regions that do not contain any mechanism for lifting air masses and are dominated by subsiding air that results from global circulation patterns experience scanty rainfall. Some of these areas are deserts. Certain continental areas tend to be dry because of their distance from moisture sources. Polar areas are dry because cold air cannot hold as much moisture as warm air. On the other hand mountain ranges near water sources can receive high rainfalls because of orographic uplift, provided the prevailing winds are in their favour. This can also result in a sharp reduction in rainfall in regions adjacent or on the leeward slopes of these areas, a phenomenon commonly known as the rain shadow effect.

Water provides the basis for agriculture and forestry and affects the environment. Because of the highly uneven distribution of water, people as well as flora and fauna tend to congregate near places where water is available in requisite quantity. That is why most cities and commercial canters as well as rural settlements have grown in and around reliable sources of water. Water bodies have always occupied a central place in our ethos, civilization and culture.

The availability of freshwater is one of the biggest threats facing humankind. Water demands are increasing, and the competition for water among urban, industrial, and agricultural sectors is growing. This situation is especially serious in the arid and semi-arid areas, due to low rainfall and limited renewable water resources. On the other hand, over exploitation of groundwater reserves and salinization of soil and water resources will exacerbate the gloomy future of available water resources in these regions.

1.2 Droughts and water scarcity

During recent decades, drought has exceeded any other natural disaster in number and frequency. At the present time, 40 percent of the population of the world is confronted with periodic droughts, affecting many of the arid and semi-arid countries in the north of Africa, parts of India, the north of China, the Middle East, Mexico, Middle Asia, Australia, Canada, south west of Europe, and the western United States. Severe climatic changes, increase of greenhouse gases, and El Niño/Southern Oscillation (ENSO) phenomena are responsible for these droughts.

Whatever the reasons for drought, the fact is droughts cause serious problems and adversely affect the economy by reducing or even eliminating agricultural production, herds of cattle, energy generation, and domestic and industrial water supply thereby threatening economic and environmental activities and in extreme cases the human survival.

Agriculture is the sector where water scarcity has the greatest relevance as it accounts for 70 percent of global freshwater withdrawals. Under the combined pressure of population growth, changes in dietary habits and higher nutritional needs the food consumption is increasing in most regions of the world. It is expected that 60 percent more food will be needed between now and 2050 to satisfy the demand of an eventual population of more than 9 billion people. The net result is that agricultural water use is increasing the severity of water scarcity in some areas, and causing water scarcity even in areas that are relatively well endowed with water resources.

Increasing water scarcity due to population pressures and more frequent and severe droughts puts pressure both on the rainfed as well as irrigated agriculture. It is important that the water in agriculture is managed efficiently, particularly under increasing water scarcity, in more uncertain climate and in order to bring stability in production.

1.3 Irrigated Agriculture

Irrigated agriculture ensures food production to meet the requirements of six billion people on the planet. The highest yields that can be obtained from irrigation are more than double the highest yields that can be obtained from rainfed agriculture. Even low-input irrigation is more productive than high-input rainfed agriculture.

Irrigated agriculture on 20 percent of the cultivated land contributes 40 percent of the total food production. Globally, rainfed agriculture is practised on 80 percent of cultivated land, and is thus prone to seasonal or prolonged water deficits, aridity and droughts. In water-scarce tropical regions such as the Sahelian countries, rainfed agriculture is practised on more than 95 percent of cropland. One reason is that, in these areas, conventional irrigation development of food crops may be extremely costly and hardly justified in economic terms.

The competition for water among various sectors deprives agriculture from additional resources. It is estimated that by 2050, agricultural share of water in the dry areas will drop to about 50 %. This situation will seriously threaten food security and sustainability of production in the dry areas and its social and economic development. Already this is occurring in many countries of the world with a tendency to overexploit limited water resources. The increasing pressure on water will, unless carefully tackled, damage the already fragile environment and will stimulate hydro political conflicts and regional instability, particularly between countries with shared water resources (El-beltagy, 2000).

Declining agricultural share of water resources in water scarce areas seems inevitable. On the other hand, over exploitation of groundwater reserves and salinization of soil and water resources will further exacerbate the gloomy future of available water resources in these regions. Prospects for developing new water resources feasible for profitable agriculture do not look promising in the dry areas. Unless scientific breakthroughs in the cost of desalinating seawater occur, very little new water is expected to be available for irrigation purposes. With this situation the only option available to cope with increasing water scarcity is to increase agricultural water productivity. That is to “produce more with less water”. Achieving this goal was found to be possible only by substantially increasing the efficiency and effectiveness with which available water resources are used.

1.4 Aims and Scope

ICID Working Group on Irrigated Agriculture under Drought and Water Scarcity was setup to compile extended knowledge on coping with drought in dry regions where irrigated agriculture is the prime source of agricultural production. This publication is based on the various case studies and other good practices shared among the members of the working group over the years. Essentially, the study was guided by the question: What can be done to manage irrigation water shortages so that the negative impact on communities can be relieved or minimised?

The purpose of this report is twofold. First, to review the drought management practices that are being followed and to share the new approaches that can tackle the challenge of increased frequency. Second, to indicate where and how agricultural water management can play a more proactive and effective role in response to increasing concerns over global scarcity.

Chapter 2 discusses the inter-relation and distinctions between often confused terms of aridity, water scarcity and drought.

Drought as an extreme hazard can be prevented from turning into a disaster by following risk management principles, by focusing on reducing exposure and vulnerability and increasing resilience to the potential adverse impacts of climate extremes, even though risks cannot fully be eliminated. Although mitigation of climate change is not the focus of this report, adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change.

Adverse impacts of droughts can be reduced if certain preventive actions could be taken in advance thereby reducing the vulnerability as well as the exposure of the economic activities to drought event. Monitoring and early warning of the drought can help in implementation of a well-developed response plan. Chapter 3 presents the Drought and Early Warning Systems that help in reducing the adverse impacts and prevent the situation turning into a disaster. The drought early warning system is supplemented with the river flow and reservoir inflow forecast systems. Appendix provides the case study of the Nile Hydrological Forecast System.

Chapter 4 on Vulnerability and Agricultural, Social and Environment Impacts of Drought presents the factors that are responsible for the adverse impacts of droughts. While most of these vulnerabilities can be reduced through various interventions, the ones that impact agriculture are discussed in brief. Appendix provides a case study on the drought damage assessment in Iran.

The drought management strategy is presented in Chapter 5. The character and severity of impacts from climate extremes depend not only on the magnitude and severity of drought but also on exposure and vulnerability of the society. The chapter is supported by Appendix on Rainwater Harvesting; Appendix on the use of Saline water in Agriculture; Appendix on use of Wastewater; Appendix on Desalination. These Appendices include the shared experiences from various countries.

One of the most promising tools in the hand of all responsible parties of the society would be a well-developed national drought framework, in which all the relevant concepts, methods, steps, technologies, and sources of the fight against drought are summarized. Within such a framework all the necessary information would need to be collected which is important for drought prevention, and which can be used at the onset of drought to reduce the adverse impacts and damages. The overall framework in which such actions should be taken is discussed in Chapter 6.

Chapter 2 - Water Scarcity and Drought

Water scarcity is a normal situation that exists over long duration while drought is the result of an extreme event. But dryness is expressing the situation restricted to low water scarcity in a region, and is a permanent feature of climate within a geological, social and environmental situation. The ways the two situations are managed are quite different although some of the basic elements can be common. The water scarcity and drought situation in a few selected regions and countries is presented in Appendix I, which provides a glimpse of aridity, water scarcity and drought situations in some of the countries of the Middle East and North Africa: Egypt, Jordan, and Libya; in SADC region; in Asia: Iran and India; and OECD countries: Australia and France. Various means by which the water scarcity is tackled in some of the countries and the shortcomings of the present practices have also been shared.

2.1 Aridity

Arid environments are extremely diverse in terms of their land forms, soils, fauna, flora, water balances, and human activities. Because of this diversity, no practical definition of arid environments can be derived. However, the one binding element to all arid regions is aridity. Aridity is usually expressed as a function of rainfall and temperature

Aridity index = p/ETP

Where: p = precipitation; and ETP = Potential Evapotranspiration, calculated by method of Penman, taking into account atmospheric humidity, solar radiation, and wind.

Three arid zones can be delineated by this index: namely, hyper-arid, arid and semi-arid. The hyper-arid zone (arid index 0.03) 4.2 percent of the total land area of the world, comprises dryland areas without vegetation, with the exception of a few scattered shrubs. Annual rainfall is low, rarely exceeding 100 mm. The rains are infrequent and irregular, sometimes with no rain during long periods of several years.

The arid zone (arid index 0.03-0.20), 14.6 percent, is characterized by pastoralism and no farming except with irrigation. For the most part, the native vegetation is sparse, being comprised of annual and perennial grasses and other herbaceous vegetation, and shrubs and small trees. There is high rainfall variability, with annual amounts ranging between 100 and 300 mm.

The semi-arid zone (arid index 0.20-0.50), 12.2 percent, can support rain-fed agriculture with more or less sustained levels of production. Sedentary livestock production also occurs. Native vegetation is represented by a variety of species, such as grasses and grass-like plants, fortes and half-shrubs, and shrubs and trees. Annual precipitation varies from 300-600 to 700-800 mm, with summer rains, and from 200-250 to 450-500 mm with winter rains. Arid conditions also are found in the sub-humid zone (arid index 0.50-0.75).

2.2 Water Scarcity

In the past, hydrologists typically assessed scarcity by looking at the population - water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m^3 per person. When annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity, and below 500 m^3 "absolute scarcity" (Falkenmark and Widstrand, 1992; UN-Water, 2006b). This approach appears too simplistic and does not take into account, the various development actions that can be undertaken to improve the situation.

In its publication on 'Coping with water scarcity: An action framework for Agriculture and food security' (FAO, 2012), water scarcity is defined to occur when demand for freshwater exceeds supply in a specified domain.

Water scarcity = an excess of water demand over available supply (FAO, 2012)

This condition arises as consequence of a high rate of aggregate demand from all water-using sectors compared with available supply, under the prevailing institutional arrangements and infrastructural conditions. It is manifested by partial or no satisfaction of expressed demand, economic competition for water quantity or quality, disputes between users, irreversible depletion of groundwater, and negative impacts on the environment.

Water scarcity is both a relative and dynamic concept, and can occur at any level of supply or demand, but it is also a social construct: its causes are all related to human interference with the water cycle. It varies over time as a result of natural hydrological variability, but varies even more so as a function of prevailing economic policy, planning and management approaches. Scarcity can be expected to intensify with most forms of economic development, but, if correctly identified, many of its causes can be predicted, avoided or mitigated. The three main dimensions that characterize water scarcity are:

(a) Physical Water Scarcity: where the physical lack of water available to satisfy demand exist;
(b) Economic Water Scarcity: where the lack of infrastructure development that controls storage, distribution and access exist; and
(c) Organizational Water Scarcity: where the institutional capacity to provide the necessary resources exists.

The availability of freshwater is one of the biggest threats facing humankind. Water shortages as well as demand are increasing, and the competition for water among urban, industrial, and agricultural sectors is growing. This situation is especially serious in the arid and semi-arid areas, due to low rainfall and limited renewable water resources. Presently, about 80 % of the available water in the dry and semi-dry areas, where nearly one-third of world's population live, is used for agriculture.

2.3 Drought

Drought is a temporary aberration, unlike aridity, which is a permanent feature of climate. Seasonal aridity, that is, a well-defined dry season, also needs to be distinguished from drought, as these terms are often confused or used interchangeably.

Drought itself is a random variable like rainfall representing one extreme end of the of precipitation process as a part of the hydrological cycle. Drought must be considered a relative, rather than an absolute, condition. It occurs in both high and low rainfall areas and virtually all climate regimes. Drought is often associated only with arid, semi-arid and sub-humid regions by scientists, policymakers and the public. In reality, drought occurs in most countries, in both dry and humid regions.

Often, drought may be defined in terms of the differences between water supply and water demand time series. The supply time series may be represented by a river flow and the demand time series - by the demand of a particular user (e.g. irrigation) or by the total demand of all users. When demand exceeds supply, the water shortages occur, which represent the starting point of a drought.

In dealing with drought phenomenon, one important aspect is that drought does not lend itself to a simple single "definition". It is, indeed, a relative concept and may vary from place to place or from discipline to discipline i.e. agriculture, hydrology, environment, etc. The popular definition of droughts means a situation where there is lack of sufficient moisture, water or rainfall for normal activities.

Drought has different meanings to different people, depending on how a water deficiency affects them. As a result, droughts have been classified into many different types. Deficiency of rainfall for an extended period of time leading to hardship is described as meteorological drought where as low water level or stream flow in rivers and streams or lower water table in open wells, tube wells compared to long term normal is termed as hydrological drought. In agriculture drought is described in terms of reduced yields resulting from insufficient soil moisture (Dracup et al., 1980). The more commonly used terms for droughts are:

(a) Meteorological drought: generally defined in terms of lower than average precipitation for some extended time period. This is a common basis for defining drought but it fails to consider the influences of antecedent conditions, evapo- transpiration and the time-lag factors of hydrologic response.
(b) Agricultural drought: refers to a shortage of water in the root zone of crops such that the yield of plants is reduced considerably.
(c) Hydrologic drought: generally defined in terms of low levels of stream flow, reservoir storage, ground water or some combination.

Box 1. Aridity, water scarcity and drought in southern and South Africa

Water scarcity affects rain fed crop production and directly threatens the livelihood of millions of people, particularly in developing countries, and

The Green Revolution which revolutionised agriculture in South East Asia, enabling many countries to become self-sufficient in food production, has not achieved the same results in sub-Saharan Africa. Since the 1970s, food production levels in this region have either remained stagnant or have declined especially in Sub-Saharan Africa. Agriculture is generally the largest user of rainwater. In South Africa, for example, about 70 % of the rainfall is used to produce food, natural fibres and forestry products, involving large numbers of people in a productive way. in some countries, while at the same time the population continued to grow at alarmingly high rates and thus increasing the demand for food.

The SADC, which accounts for at least 70% of sub-Saharan Africa's GNP and has about a third of its population, share this downward trend in food production with its northern neighbours in sub-Saharan Africa. The decline in the productivity of the agricultural sector in the SADC is alarming in view of the key role this sector plays in the national economies of its member states. In the 1980s, agriculture, on average, contributed 34% to the region's GNP, employed about 80% of its labour force and accounted for 26% of its foreign export earnings. In the southern part of the SADC, the agricultural sector's contribution to GNP varies greatly from 4% in both Botswana and South Africa, 10% in Namibia, 13% in Swaziland, 14% in Zimbabwe, and 17% in Lesotho to 40-50% in Mozambique. In approximately two decades from now, all countries in Southern Africa will experience either water stress or absolute water scarcity.

In a country such as South Africa it is predicted that total water demand will increase by more than 50% by the year 2030 (Ballance & King 1999). Depending on “worst-case” and “best-case” scenarios, it is further estimated that South Africa will experience the equivalent of permanent drought somewhere between 2002 and 2040 (Yeld 1997).

Given the existing water shortages in Southern Africa and the projected increase in demands for water from a growing population, it is doubtful if governments in this region will be able to increase water allocations to the irrigated agriculture sector. This sector already accounts for more than 60% of the total water usage in Southern Africa and is further identified as one of the major water polluters in the region, where water quality is very important given the inadequate quantity of water supplies. Along with an increase in demands from the domestic and industrial sectors, the irrigated agriculture sector will in the near future, also have to compete for water with hydro-electricity schemes, especially in the riparian states of the Zambezi River Basin where tension already exists in some areas (SADC, 1994).

In South Africa a National Consultative Drought Forum was established in 1992, made up of representatives of government, church organisations, trade unions and NGOs. The Forum led to a shift from an exclusive emphasis on commercial farmers to a more comprehensive programme that includes rural farmers, rural poor and farm workers. Policy changes included greater equity for recipients of assistance. Drought policies have increasingly focussed on improving levels of self-reliance, reducing risk in the agricultural sector and stabilising income. A National Drought Management Committee was established in 1995 with similar structures at the provincial and local levels of government. The primary objectives of this committee are to develop national disaster management policy, propose and review new legislation, promote community participation in disaster management, promote the establishment of an integrated disaster information system and ensure risk reduction at the national level.

Irrigated agriculture accounts for only 10% of cultivated land in South Africa on which it produces 35% of all domestic foods and 85% of all agricultural exports. The major irrigated crops are pasture, wheat, lucerne, maize, sugar cane, citrus, deciduous fruits and vegetables. Irrigation efficiency in the country is estimated to be around 50% and approximately 35% of irrigation system losses return to river systems. This return water in general is nutrient enriched and polluted with agro-chemicals that in turn affect water quality in rivers and streams (DWAF, 2000).

In order to assess the degree of severity the most appropriate parameter for drought related hardship in a given drought incidence, is not sufficient to give a simple qualitative appraisal. A quantitative parameter or index is necessary to characterize the intensity of the drought event. Because there is no single definition for drought, so its time of onset and termination, duration and severity characteristics are determined as indicators of drought to provide crucial means of assessing and monitoring drought. Based on those parameters and area of interest several indices are used to describe the features of drought and their harmful impacts on both the environment and the living organisms. Some of the well-known indices used in drought studies, monitoring and management are briefly described in next Chapter.

Drought is the result of an abnormally dry period that lasts long enough to cause an imbalance in hydrologic processes (storage and consumption). Reduced precipitation or increased temperature, either alone or together, can cause drought. Dryness and drought is the result of the special interaction between natural and social environment. Each drought differs in magnitude, duration, severity, frequency and beginning and termination period of drought. It takes place in almost every climate on earth, even the rainy ones. It has greater effects in dry and water-deficient regions and is a global threat, but it has not been studied in detail in many regions and countries.

2.4 Climate Change and Droughts

Global warming will effect changes in the hydrological cycle thereby impacting the water balance, increased water temperatures, sea level rise. A number of components of the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff. Climate projections show that potential change in precipitation and temperature brought about by climate change could affect runoff and most importantly an increase in the frequency of extremes, such as floods and droughts.

The fourth assessment report of the states that, “more intense and longer droughts have been observed over wider areas since 1970’s, particularly in the tropics and subtropics”. Obviously, the socio-economic consequences have been, and will continue to be, dramatic and this indicates the great risk that human communities are facing around the globe due to climate change. It is widely believed that by 2050, many parts of the world will face increased risk of recurrent droughts and devastating floods.

There is medium confidence that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration. This applies to regions including southern Europe and the Mediterranean region, central Europe, central North America, Central America and Mexico, northeast Brazil, and southern Africa. Elsewhere there is overall low confidence because of inconsistent projections of drought changes (dependent both on model and dryness index). Definitional issues, lack of observational data, and the inability of models to include all the factors that influence droughts preclude stronger confidence than medium in drought projections.

In particular, Climate change and drought conditions have long been recognized as key determinants for success in the agro-food sector.

Chapter 3 - Drought Monitoring and Early Warning System

Droughts present one of the major risks to agriculture production and the economic well-being of the dependent rural population. Drought risk is a function of the intensity and duration of the periods of below normal rainfalls and the vulnerability of the agriculture system and the population and is inversely proportion to their resilience. For the sustainability of development, the drought risks need to be managed in such a way that they have minimum adverse impacts on the society.

3.1 Drought Risk Management

Preparedness through building resilience in the systems through mitigation measures and then be able to predict and provide early warning of the creeping droughts forms the protection phase of the cycle (Figure 1). The response to the drought situation and the preparedness to do that determines the impacts of drought and how the process of recovery and reconstruction is affected. There is a definite need to develop efficient initiatives relevant to all phases of the drought cycle, from preparation for future droughts in good seasons; effective preparation during drought periods; alert and drought onset; management during drought periods; to the recovery period after drought episodes (O'Meagher et al. 1998: 244).

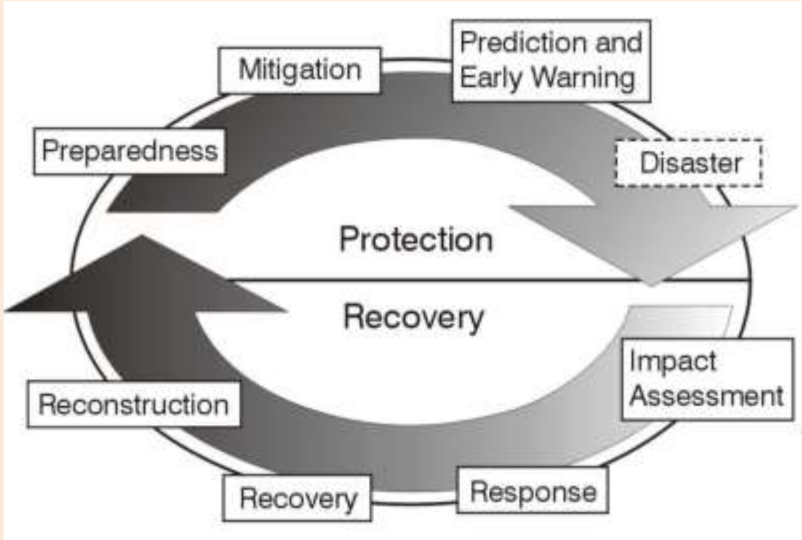

Figure 1. Cycle of disaster management
(Source: National Drought Mitigation Center, University of Nebraska, Lincoln, Nebraska, USA)

A drought management plan has essentially three components:

(a) monitoring and early warning;
(b) risk assessment; and
(c) mitigation and response.

Drought monitoring and early warning is major components of drought risk management, as it provides the foundation on which timely decisions can be made by decision makers at all levels (i.e., farmers to national policy makers). Informed decisions on drought risk can only be made if the correct information is available. Information that would assist in the early warning of drought conditions is a first point of reference since early warning systems and assessment of climate trends is important in taking timely actions, thereby alleviating the impacts of drought.

Given drought's slow onset or creeping characteristics, monitoring all components of the hydrological system is the only mechanism we have for detecting drought's early onset and its potential impacts on sectors, regions, and population groups. Figure 2 illustrates how drought forecasting and early warning provides longer lead time for the preparatory and response actions. This information serves as the basis for management decisions during both the developing and receding phases of drought, including the timing for the start-up and shut-down of mitigation and emergency response programs that are part of the drought preparedness plan.

3.2 Drought Monitoring

Drought monitoring consists of five major steps (Wilhite 1993b):

(a) Inventory of data availability and current observation networks
(b) Determining primary user needs and developing and/or modifying current data and information delivery systems;
(c) Defining drought and developing response triggers;
(d) Developing an early warning system; and
(e) Identifying drought management areas.

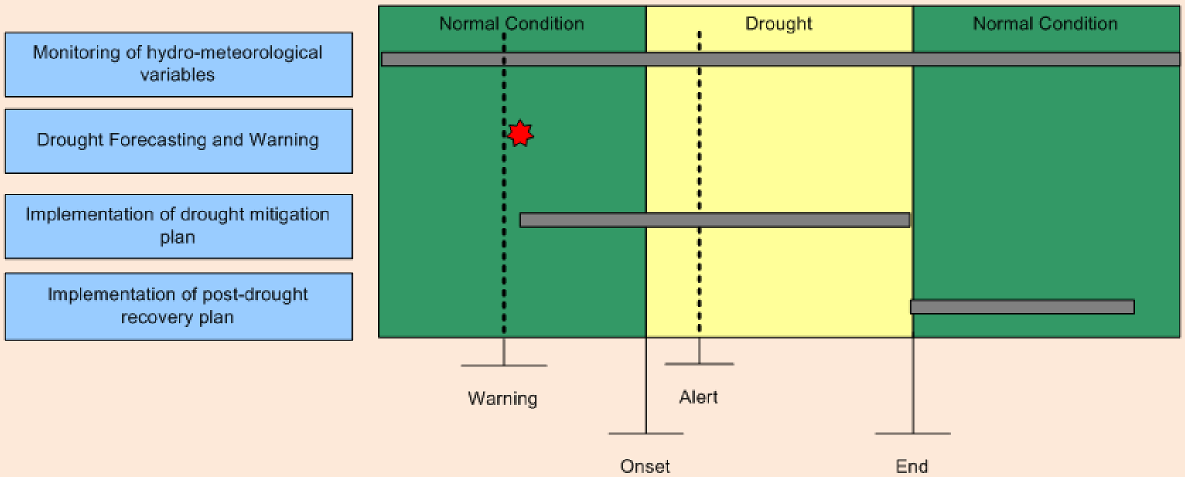

Figure 2. Drought monitoring and forecasting framework

3.3 Drought Indices

In order to assess the degree of severity which is the most appropriate parameter for drought related hardship of a given drought incidence, it is not sufficient to give a simple qualitative appraisal. Drought is best defined by indicators or indices based on parameters such as temperature, precipitation or their impacts on vegetation or reservoir level. A quantitative index is necessary to characterize the intensity of the event. Parameters describing the characteristics of droughts such as time or date of initiation, termination, duration, severity and intensity are determined on the basis of these indices. These parameters make it easier to describe a drought and device its management tools.

Droughts have three distinguishing features: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure from normal of a climatic parameter such as precipitation, an indicator such as the reservoir level or an index.

There are numerous natural drought indicators that should be monitored routinely to determine the onset and end of drought and its spatial characteristics. Based on those parameters and area of interest several indices are used to describe the characteristics of drought and their harmful impacts.

No drought index is ideal for all regions or tasks. In most cases, it is useful to consider more than one index, examine the sensitivity and accuracy of indices, the correlation between them, and explore how well they complement each other in the context of specific research or drought management task. A regional drought index that clearly relates meteorological or hydrologic events in several locations over a large geographical area to the economic and social loss probably does not exist.

In the absence of a clear relationship between an index and the impact it has on socio-economic conditions, the indicators to be used for monitoring the phenomenon can be complex, requiring data of different nature. But, the data needed for comprehensive assessment of drought is lacking in many parts of the world and, therefore, simple indexes are much preferred.

3.3.1 Drought Indices derived from meteorological and soil data

Drought indices are normally developed as time integrated meteorological or stochastic hydrologic variables compared to “normal” conditions. Continuous functions of rainfall and/or temperature, river discharge or other measurable variable is often used. A drought index value is typically a single number, far more useful than raw data for decision making. Rainfall data are widely used to calculate drought indices, because long-term rainfall records are often available. Rainfall data alone do not reflect the spectrum of drought related conditions, but often serve as a pragmatic solution in data-poor regions.

(a) Standardized precipitation index (SPI)

McKee et al. (1993) also defined the criteria for a drought event for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less, Table 3.1.

Table 3.1. Drought intensity classification based on SPI values

SPI Values	Drought Intensity
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry
SPI Values	Drought Intensity

The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event is termed it’s “magnitude of drought”

The National Drought Mitigation Centers in many countries are using the Standardized Precipitation Index, (www: wmo.org) to monitor moisture supply conditions. Distinguishing traits of this Standardized Precipitation Index, as per WMO guidelines, is that it identifies emerging droughts months sooner than the Palmer Index and that it is computed on various time scales.

(b) Palmer Drought Severity Index (PDSI)

Palmer Drought Severity Index is based on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit and is a soil moisture algorithm (a model), which uses precipitation, temperature data and local 'Available Water Content (AWC)' of the soil at specific locations. It provides measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months as a measure of meteorological drought index. AWC is effectively a "model parameter" which has to be set at the start of calculations. Calculations result in an index (PDSI), which indicates standardized moisture conditions and allows comparisons to be made between locations and between months. PDSI is calibrated for relatively homogeneous regions. It responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account stream flow, lake and reservoir levels, and other longer-term hydrologic impacts. This technique has wide acceptance though the Potential Evapotranspiration is approximate estimate using the Thornthwaite method.

Table 3.2. Drought intensity classification by Palmer Index

Palmer Index	Intensity
4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extreme drought

The PDSI varies roughly between -4.0 and +4.0, (Table 3.2). The Palmer Index has typically been calculated on a monthly basis; in addition, weekly Palmer Index values (actually modified PDSI values) are also calculated for the climate divisions during every growing season. The Palmer Index is popular and has been widely used for a variety of applications across the United States. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture. Details of PDSI calculation may be found in Palmer (1965).

The Palmer Drought Severity Index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but the Palmer is better when working with large areas of uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index, which takes snow pack and other unique conditions into account.

(c) Crop Moisture Index (CMI)

The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions developed from procedures within the calculation of the PDSI it is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week. Developed by Palmer, 1968, a PDSI derivative, the CMI reflects moisture supply in the short term across major crop-producing regions and identifies potential agricultural droughts.

Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture conditions across major crop-producing regions. The CMI responds rapidly to changing conditions. Because it is designed to monitor short-term moisture conditions affecting a development of crop it helps in irrigation scheduling. But the CMI is not a good long-term drought monitoring tool. This limitation prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extend over several years.

A number of other indices, which focus on soil water availability for crops, have been developed. As a rule, these methods calculate soil moisture balance with a 1, 5, 7 or 10-day time steps and then compute some integral measure (an index) which indicates the degree to which the crop water requirement have been met. These group of indices includes FAO water satisfaction index (Frere and Popov, 1979), Agro-hydro potential (Petrasovits, 1990), Index of Moisture Adequacy (IMA - Rao et al., 1981; Sastri, 1993), Moisture Availability Index (MAI -Heddinghaus, 1991). Tate et al (2002) lists some other similar indices. These indices are normally developed for the purpose of agro-meteorological crop monitoring and yield prediction.

(d) Deciles as indices

Deciles as indices are developed by grouping monthly precipitation occurrences over a long-term precipitation record into tenths of the distribution into deciles, so that, by definition, “much lower than normal” weather cannot occur more often than 20% of the time. It is widely used in Australia having long climatic data record and provides an accurate statistical measurement of precipitation. Decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System because it is relatively simple to calculate and requires less data and fewer assumptions than the Palmer Drought Severity Index.

In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20–25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months. This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. Developed by Gibbs and Maher in 1967, one disadvantage of the decile system is that a long climatological record is needed to calculate the deciles accurately.

(e) Percent of normal and other rainfall deficiency indices

There are multiple definitions of a drought based on the percent or a proportion of normal. These indices are simple by definition, easy to calculate and are easily understood by general audience. “Normal” may be and usually is set to a long-term mean precipitation value. It may be calculated for a day, a month, a season or a year and is considered to be 100%. The same percent of normal may have different specific impacts at different locations and therefore it is a bit of a simplistic measure of precipitation deficit. Also, what is normal, may be perceived differently in different regions.

They are normally region-specific and explicitly set locally appropriate rainfall limits and duration of rainless periods for the definition of droughts of different extremity. On this basis, Bates (1935) suggested to define droughts in USA when annual precipitation is 75% of normal or monthly precipitation is 60% of normal. Hoyt (1936) used less than 85% of normal threshold for any time series. Banerji and Chabra meteorologist considered severe drought conditions in the State of Andhra Pradesh, India to be coincident with seasonal rainfall deficit of more than 50% (which means rainfall of less than 50% of normal). Ramdas (1950), also in India, considered a drought to arrive when actual rainfall for a week is half of normal or less. Another definition from India suggests that annual rainfall < 75% of the average may be regarded as a drought. Applying these definitions, about 13% of Indian Territory is in a drought every 3 years on average.

Droughts in South Africa are defined as periods with less than 70% of normal precipitation. This becomes a disaster or severe drought when two consecutive seasons experience 70% of normal rainfall or less. There are many other similar indices and associated drought definitions.

3.3.2 Hydrologic drought indices

Most of the indices described in the above section are derived solely from the meteorological observations - precipitation and temperature. Droughts may also be assessed and monitored using other types of data (e.g. river flow). In river hydrology, droughts are often referred to as periods of 'low flow' defined as flow of water in a stream during prolonged dry weather in the International glossary of hydrology (WMO, 1974) and is an integral component of a flow regime of any river.

Hydrologic drought indices assimilate large number of data on rainfall, snow pack, stream flow, soil moisture and other water supply and availability indicators into a comprehensible big picture. From the water resources management perspective, it is important to define the reference flow levels and indicators of drought severity (what drought duration and/or flow deficit constitutes mild or severe drought). There are several indices that measure how much precipitation or stream flow for a given period of time has deviated from historically established norms. Most water supply planners find it useful to consult one or more indices before making a decision as the case in the United States and in Australia.

Hydrologic drought may be defined in terms of the differences between water supply and water demand time series. The supply time series may be represented by a river flow and the demand time series - by the demand of a particular user (e.g. irrigation) or by the total demand of all users. When demand exceeds supply, the water shortages occur, which represent the start of a drought. Tate provided examples on supply-demand issues related to reservoir operations, while Smakhtin lists multiple other references on the topics of low-flow spell and storage-yield analyses Apart from the river flow, reservoir storage is also a useful indicator of water shortages, due to data availability often on a daily or weekly basis. At the same time, these data are strongly influenced by the reservoir operation rules.

Most hydrological drought indices are largely based on the stream flows (2). Stream flow deficit in respect of normal conditions may not be the true representative particularly in the river systems with diversion of virgin flows. Drought is therefore characterized by more factors than just low flows The analysis of river flow data for any purpose, including drought management is however often hampered by the lack of such data, shorter records available (compared to rainfall, for example), artificial influences (e.g. catchment land-use change, effluents, abstraction), etc. In addition, in the context of Southwest Asia, flow data are often of poor quality and are not easily available from relevant authorities, at least at present. Drought indices and definitions based solely on flow or reservoir storage are normally designed for reservoir operation and are seldom (if at all) used as triggers for drought relief, or for drought monitoring over vast territories. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. Some of them are described in the following.

(a) Surface water supply index

Surface Water Supply Index (SWSI), developed in the state of Colorado, where mountain snow-pack is a key element of water supply, represents water supply conditions unique to each basin represented by: snow pack, stream flow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI can be computed with only one of the components i.e., snow-pack, precipitation, and reservoir storage depending on the season of the year. During the summer months, stream-flow replaces snow-pack as a component within the SWSI equation.

SWSI incorporates both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. Like the Palmer Index, the SWSI is centered on zero and has a range between -4.2 and +4.2 (Table 2.2). The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan.

(b) Reclamation drought index

Reclamation Drought Index (RDI) developed by the Bureau of Reclamation in USA as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought and trigger to release drought emergency relief funds. Like the SWSI, the RDI is calculated at the river basin level, incorporating temperature as well as precipitation, snow-pack, stream-flow, and reservoir levels as input. The RDI differs from the SWSI in that it builds a temperature-based demand component and duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors. The RDI values and severity designations are similar to the SPI, PDSI, and SWSI.

(c) Other hydrologic drought indices

Stream flow Drought Index (SDI), Groundwater Resource Index (GWI), or Surface water supply index (SWSI) are too simplified for describing hydrologic drought. The index has to be studied from a multiple perspective. An integrated index based on river flows, groundwater levels, storage positions (including snow packs), and reservoir inflows is considered most appropriate.

The hydrologic drought indices (HDI) depend on the purpose of hydrologic monitoring and prediction such as: Reservoir Operation and water allocation; Irrigation Management and scheduling; water supply for drinking water sources; and cooling water supplies etc. At the same time HDI for assessing the severity of droughts have to be different than that used for early warning purpose.

3.3.3 Drought indices derived from Remote Sensing Data

Several indices for monitoring drought have been developed over the past few decades using remote sensing data based on sensors fixed in satellites or aeroplanes. They are calculated from the reflectance in different bands and may be obtained for each pixel (the size of a pixel depends upon the resolution of the sensor). These indices have a few advantages over conventional climate-data related indices described above, as they "cover" large areas and may show how drought is progressing over the area. While this is particularly important in data scarce regions are not the direct measures of drought conditions and such indices may not be sensitive to actual meteorological conditions on the ground. They have to be "calibrated" against available ground/climate data. Some of these indices may lag vegetation response to drought.

(a) Normalized difference vegetation indexes (NDVI)

Normalized difference vegetation indexes (NDVI) is calculated as the reflectance in the near infrared and red bands respectively and ranges form -1 to 1.

The NDVI is calculated from these individual measurements as follows:

$$NDVI = (NIR – VIS) / (NIR + VIS)$$

Where, VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions, respectively.

Drought severity may be evaluated as the difference between the NDVI for the current month (e.g. January) and a long-term mean NDVI for that particular month (e.g. a 20-year long mean NDVI for January). Negative departure from the mean NDVI points to months, which are dryer than usual. The more negative the departure, drier is the month. Positive departure (difference) from the mean NDVI indicates otherwise.

(b) Enhanced vegetation index (EVI)

The enhanced vegetation index (EVI) is developed for use with MODIS data (Huete et al. 2002). Unlike NDVI, it takes the advantage of multiple bands.

The EVI calculated as:

EVI = G* [NIR- NIR(Red)]/ [NIR + C1*NIR(Red) - C2*NIR(Blue)+L]

where NIR(Red) and NIR(Bue) are atmospherically-corrected or partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectance, L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy, and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the MODIS-EVI algorithm are; L=1, C1 = 6, C2 = 7.5, and G (gain factor) = 2.5.

EVI is more sensitive in high biomass regions and ensures the improved monitoring through a reduction in atmosphere influences. At the same time, it is computationally intensive and is not widely used at present.

(c) Vegetation condition index (VCI)

Vegetation condition index (VCI) was first suggested to show how close the current month's NDVI is to the minimum NDVI calculated from the long-term record of remote sensed images (Kogan, 1995). Where this is calculated from the long-term record (e.g., 20 years) for that month (or week), it is the index of the current month (week). The condition (health) of vegetation presented by VCI is reported in percent and may serve as an approximate measure of how dry the current month is. In the case of extremely dry month, the vegetation condition is poor and the VCI is close or equal to zero. The VCI of 50% reflects a fair vegetation condition. At optimal condition of vegetation the VCI is close to 100%. At this condition, NDVI for the current time step (month, week) is equal to NDVI max.

(d) Temperature conditions index (TCI)

The TCI is calculated similar to VCI. However, in contrast to the VCI, the TCI includes the deviation of the current month's (week's) value from the recorded maximum. The low TCI value (close to 0%) indicates the very high temperature in that month or week. Consistently low TCI values over several consecutive time intervals point to drought occurrence.

3.3.4 Developing Standardized Drought Severity Index

Based upon the above discussion and analysis it is felt that for clarity and comparing drought of different severity and between years and location a standardized drought severity index is best suitable for South Asia & East African situation where monsoon plays dominant role in the economy. A Standardized Drought Severity Index can be developed as per the standardization process for drought analysis in the pattern of PDSI for better comparison of climate change and drought occurrence over a long period. Drought Severity Index readily gives a quantitative estimation of rainfall deficiency over different locations and years.

Any normally distributed variable Xi (µ, ð) can be standardized as Zi (0, 1) e.g., having zero mean and unit variance (Haan, 1979). Drought severity values of each year can be standardized accordingly, as follows:

Standardized drought index, Zi = (Xi -Xdef)/ ðdef

where Xi = rainfall deficit in the year compared to long time average
Xdef = statistical mean of seasonal deficit rainfall series
ðdef = standard deviation of deficit rainfall series.

As per above methodology the Standardized Drought Severity Index can be determined for any hydrological event including deficit of rainfall event termed as meteorological drought. The quantitative drought severity classification was done for a sub-humid drought prone East Indian condition in Hazaribagh district using long time daily rainfall (1913-92) (Paul, 1994). He classified drought severity in 5 different classes based on mean and standard deviation of annual rainfall series as given in the Table 3.3.

Table 3.3. Classes of Drought Severity Index

Range of the index	Class
1.54 to 0.54	Incipient drought
0.54 to -0.46	Large drought
-0.46 to -1.46	Severe drought
-1.46 to -2.46	Disastrous drought
<-2.46	Extreme drought

3.3.5 Multi-year Drought Characterization

The spell of wet or dry periods may be analysed as per run theory Yevjevich (1967) performed on any time series data with any temporal resolution. A number of consecutive time intervals where the selected variable (rainfall, discharge or flow volume) has lower values than a reference level, indicate the duration of a drought event. Uninterrupted sequence of dry periods coincides with a “drought” of length equal to the number of dry periods within the same event. For each such event, the sum of deviations of the variable from the reference level represents the cumulative deficit amount (drought severity). This deficit divided by the duration is the measure of drought intensity.

Once all the drought events in the available time series are identified and their characteristics values are calculated, a frequency analysis is performed on them. This analysis allows the return periods of these drought characteristics to be estimated and its probability of occurrence known. The procedure may be repeated for different reference time series or discharges.

As is seen in the tropical climate countries drought effect is not as severe as in the dry and arid regions: but drought may extend during crop growing rainy seasons for longer periods/seasons for more than 1 or 2 years running. The multi-year (2, 3, 4, 5, and 6 years) drought severity values were analyzed and reported (Paul, 2004) as determined by adding the consecutive drought severities as multi year drought severity. He reported that mean severity values of multiyear drought increases linearly from 189.37 to 1694.7 for 1 year to 6 year continuous drought period (1965-1970). This signifies that a multi-year drought is more variable in severity, which increases, as drought is prolonged due to precipitation deficiency. The drought intensity increases gradually but with marked decrease in variability, signifying that as multi-year drought sets in, the intensity steadily increases with decreased standard deviation leading to greater drought stress. The longest duration drought of six years duration was also the same (1964 to 1969) period making it as the extreme drought.

3.4 Drought Early Warning and Prediction

Short and long term policy plans for drought management involves the three primary organisational components: monitoring, assessment of impact, and response. In order to effectively mitigate the impacts of drought, an efficient monitoring system of drought conditions is the first requirement. Informed decisions on drought risk reduction can only be made if the correct information is available. Information that would assist in the early warning of drought conditions is a first point of reference since early warning systems and assessment of climate trends is important in taking timely actions, thereby alleviating the impacts of drought (Sabetraftar & Abaspour 2003: 59).

Recent efforts to improve drought monitoring and early warning in the United States and other countries have provided new early warning and decision-support tools and methodologies in support of drought preparedness planning and policy development. To date, monitoring and early warning systems have been based on a single indicator or climatic index. The focus with regards to drought management policy has been particularly on determining when drought support should be triggered, as the political sensitivity is heightened during distress and calamity.

Preparedness for drought should form an important part of national water, agriculture and disaster management policies. Many different entities and organizations are responsible for drought preparedness and planning – including water resource agencies, water and energy utilities, farmers, land managers, community planners, state and municipal authorities, emergency managers, and public at large. Drought monitoring systems could benefit government agencies, research institutions and NGOs involved in drought management and provide decision support tools.

3.4.1 Climate Monitoring and Prediction

The short and long term management strategies to combat drought should include climate forecasting, monitoring design and implementation of common monitoring and forecasting system with a view to minimize the drought impacts through development of early warning system, and to adopt an integrated water supply and demand management to combat drought. The monitoring component has five main functions (Wilhite 1993b: 98-100):

(a) Inventory data availability and current observation networks.
(b) Determining primary user needs and developing and/or modifying current data and information delivery systems.
(c) Defining drought and developing response triggers.
(d) Developing an early warning system.
(e) Identifying drought prone areas.

Within the context of an early warning system and the provision of information on the weather the National Meteorological Agency in the country provide the basic information. For example, under the National Water Resources Strategy the drought management strategy with objectives particularly aimed at improving and implementing early warning systems and compiling drought indicator maps of drought situations (Backeberg & Viljoen 2003: 14). The NWRS makes provision for the assurance of adequate rainfall data through collaboration of DWAF, the National Disaster Management Centre, the South African Weather Services and the Agricultural Research Centres (DWAF 2002: 27).

To cater to the climate information needs of various sectors, World Meteorological Organization in collaboration with other UN Agencies and partners has launched a Global Framework for Climate Services.

3.4.2 The Rainfall Estimation and prediction

Satellite images, as well as rain-gauge data are generally used to estimate the rainfall over the water basin and to study the effects of different meteorological conditions on the inflow-outflow if various reservoirs. One of the most important applications of remote sensing is to estimate rainfall from satellite images. This is crucially important for the all river Basins particularly those with only few observation stations.

The Nile Forecasting System (NFS), described in more details in Appendix II receives three different spectral bands of satellite images: infrared, visible and water vapour. There are different approaches for estimating rainfall from satellite images. NFS uses many of these techniques. They are mainly based on cold cloud duration and cloud top temperature in addition to other parameters. Currently, infrared cloud top temperature data obtained from the European Space Agency (ESA) geostationary METEOSAT 5 satellite positioned over Africa is the primary data utilized in preparation of the precipitation estimates. Surface observations of precipitation obtained from the Global Telecommunication System (GTS) of the World Meteorological Organization are the secondary data type utilized in the scheme.

There are several statistical models available to forecast time series data especially reservoir flow depending on time series analysis and flood characteristics. NFS which depends on simulating the rainfall conditions over the whole basin from satellite images and then uses a hydrological model to calculate and route the resulting runoff to key points along the river course taking into account the different sources, sinks and abstractions along the system and the soil moisture conditions. The NFS then utilizes rainfall data from previous years to estimate the flood for a future period (3-12 months) and provides confidence limits on the given forecasts.

3.4.3 Hydrological Forecasting

An early warning system should be able to predict hydrological conditions based on certain indices that characterize the impacts of the drought. The early warning system for hydrologic drought has to be based on the hydrologic drought indices (HDI) and their likely impacts. A hydrologic drought early warning system should ideally monitor and predict:

(a) meteorological information,
(b) soil moisture information,
(c) reservoir storage position,
(d) river flows,
(e) ground water levels,
(f) extent of wetlands and lakes,
(g) snow cover, and
(h) water temperatures.
(i) The chosen HDI indices have to be:
(j) sensitive to wide range of drought conditions,
(k) easily understood,
(l) carry physical meaning,
(m) be independent of area of application,
(n) reveal drought at shortest lag time of its occurrence, and
(o) based on readily available data.

While for meteorological drought early warning, climatic divisions are the most commonly used subdivisions at the state level, but they may not be appropriate for hydrologic drought monitoring. For the hydrologic droughts there is need to establish drought management units by subdividing in to the regions not only guided by political boundaries but also shared hydrological characteristics. The indices have to be based on conveniently sized units which are nearly homogeneous hydrological regions such as the command area of an irrigation project, spread of an aquifer, or a river basin that may be hydrologically more appropriate in order to take emergency measures. These subdivisions may be useful since they may allow drought stages and mitigation and response options to be regionalized.

It is also important to realize that the impact of hydrologic drought may extend beyond the areas affected by meteorological drought. At the same time, prediction of hydrological droughts becomes increasingly difficult due to changes in hydrologic characteristics of the response basin. For example, urbanization will impact the recharging of groundwater aquifers that in turn are likely to affect the lean season flows.

3.4.4 Hydrologic Forecast Modules

A typical hydrological forecasting system such as NFS is composed of 6 main components that perform following functions:

(a) data collection and assimilation,
(b) data management (NBHIS),
(c) rainfall estimation,
(d) hydrological simulation,
(e) river flow forecasting, and
(f) GIS functions.

The seasonal hydrologic forecast system consists four components as illustrated in the Figure 3. The pre-forecast processor creates the initial condition for the forecast. This can be done using the hydrologic model (VIC) forced with observational atmospheric forcing. In our case, the observational atmospheric forcing comes from the real-time NLDAS. The spin up period is set to 2 years. Other possible alternatives are remote sensing, data assimilations. The Atmospheric Ensemble Processor is the unit to create atmospheric forcing for the forecast period in an ensemble fashion. This critical unit determines the skill of the seasonal forecast. Our current method is to merge seasonal forecasts from multiple climate models with climatology in a Bayesian framework. This merging produces a pdf of monthly total precipitation at 1/8 degree. Then multiple member ensemble is selected from the probability distribution function.

Each module runs the forecast component a number of times for the same future dates, starting with current simulated state variables for the hydrological system but with different values for future precipitation. The ESP module uses precipitation values of historical years; the deterministic module uses fixed percentages of climatological precipitation. The various future discharge traces produced by the forecast component runs are analysed to give a probable future discharge-time curve and a corresponding envelope of uncertainty. The ESP module provided a reliable stream flow forecasting capability to support improved operations of the Aswan High Dam in the NFS: the APP-V gives the inputs and outputs of ESP module and shows the grid rainfall estimates (daily, weekly, monthly or annually) and hydrograph plots at key locations like Khartoum, Malakal, and Dongala.

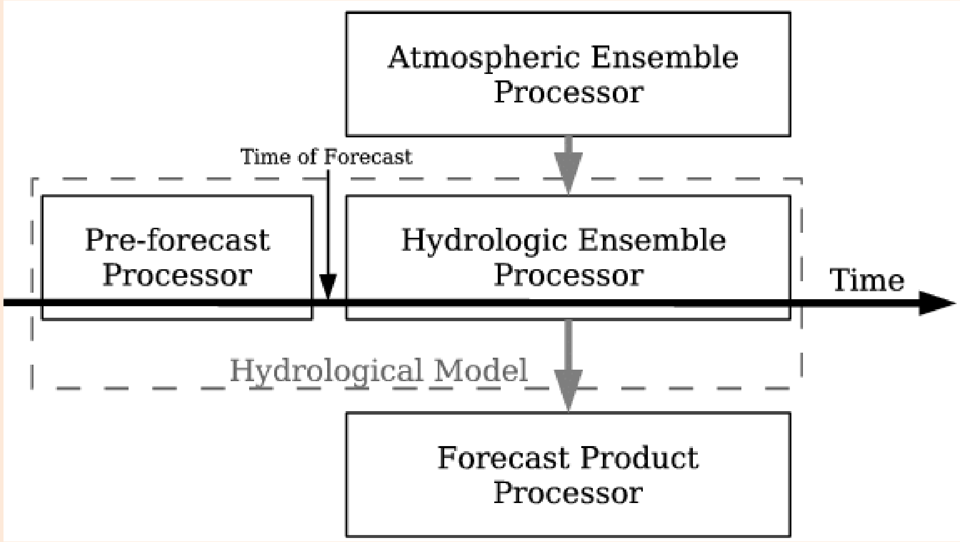

Figure 3. Drought forecasting framework

3.4.5 The Hydrological Simulation Models

The entire river system is simulated using a variety of hydrological distributed models: water balance, hill slope and channel routing and stochastic models. The simulation outputs are soil moisture, hill slope and channel flow states based on the available precipitation estimates. The model also runs with varying inputs to determine the effects of various future precipitation scenarios on discharge flow rates.

The two main approaches used to simulate river runoff by mathematical models are: ‘Lumped Parameter Models’ and ‘Distributed Parameter Models’. The Lumped Parameter Models are simple, flexible and easily adjustable but they require input and output information for a long period of time to calibrate parameters for every basin, usually with a watershed area of 5 000 to 10 000 km^2.

Distributed Parameter Models include more physical parameters, but they require much more geographical information. The NFS is a distributed modeling system which divides the basin into grids. It is a grid-based soil moisture account model that calculates the discharge of the River Nile and its tributaries using a daily time step. It is based on the quasi-rectangular grid at the METEOSAT satellite projection. The average grid cell size is 5 km x 5 km. For each grid cell, approximately 25 km2 in size, the transformation from rainfall to runoff is simulated by a water balance model, a hill-slope routing model, and a channel routing model.

EWS for hydrologic drought face numerous challenges. Data and information on water supply, including seasonal forecasts, must be integrated to provide decision makers with a comprehensive picture or representation of current conditions and future outlooks. This will require much greater coordination between meteorological, hydrological, and agricultural services. Second, improved delivery systems must be developed to get information in the hands of decision makers in a timely manner.

The greatest challenge facing many EWS is how to ensure that their information is taken seriously by decision makers and acted on to ensure a timely response. Early warning information is most likely to be used if it is trusted. And it is most likely to be trusted if the decision makers have a stake in the system and really understand it. There are a number of ways of strengthening this link. First and foremost, the EWS must make its information accessible and easy to interpret, and they must deliver a clear, consistent message to decision makers so that they can act on this information.

3.5 Global Integrated Drought Monitoring and Prediction System

Drought warning and prediction systems are still the least developed systems among other natural disasters primarily because of the complex processes involved in drought onset and development. At present, in many countries information on drought onset and development is not readily available to responsible agencies and to the gener al public. A drought monitoring system requires the use of datasets (rainfall, temperature) and many other drought-related indices and Remote Sensing data. This calls for collaborative action and for input from relevant national agencies and can be reproduced nationally, or regionally.

The near-real time drought-monitoring and reporting system has been developed in many regions using drought-related characteristics (indices), which are derived from remote-sensing data. In most cases a method that combines different drought indices: SPI, soil moisture anomalies and vegetation productivity anomalies etc. are used to identify not only areas affected by agricultural drought but also areas with the potential to be affected.

In recent years, several research and operational drought monitoring models have been developed. On a regional scale, there are a number of drought monitoring tools tailored for local to continental scale applications such as, the U.S. Agency for International Development (USAID) Famine Early Warning System Network (FEWS Net) (11), United States Drought Monitor (12), African Drought Monitor (13), and the University of Washington Experimental Surface Water Monitor (14,15). The European Drought Observatory (EDO) provides drought-relevant information such as maps of indicators derived from different data sources for example: precipitation measurements, satellite measurements, modelled soil moisture content; using different tools that help in analyzing the information.

The Global Integrated Drought Monitoring and Prediction System (GIDMaPS) provides drought information based on multiple drought indicators. The system provides meteorological and agricultural drought information based on multiple satellite-, and model-based precipitation and soil moisture data sets. The probabilistic forecasts provide essential information for early warning, taking preventive measures, and planning mitigation strategies. GIDMaPS includes a near real-time monitoring component and a seasonal probabilistic prediction module. The data sets include historical drought severity data from the monitoring component, and probabilistic seasonal forecasts from the prediction module. GIDMaPS data sets are a significant extension to current capabilities and data sets for global drought assessment and early warning. Results indicate that GIDMaPS data sets reliably captured several major droughts from across the globe.

GIDMaPS's data records are standardized drought indices in which a negative (positive) value indicates a relatively dry (wet) spell. The monitoring component of GIDMaPS provides information on drought severity in both the original standardized scale and the so-called D-scale12. The prediction component offers probability of drought occurrence computed for different drought severity levels. For example, the prediction component provides the probability of a drought index below −0.8 or D1 drought severity.

GIDMaPS is developed to provide drought information based on multiple drought indices and input data sets and includes a seasonal probabilistic prediction component that supports risk knowledge. The probabilistic forecasts offer essential information for early warning, preventive measures, and mitigation strategies. GIDMaPS provides both monitoring and prediction components, as well as a data dissemination interface. However, like any dynamic model, global seasonal drought forecasts exhibit very high uncertainty and low seasonal prediction skill (52–54). The purpose of GIDMaPS is not to replace the currently available dynamic models. Rather, information should be used as additional source of drought information to improve current capabilities in drought monitoring and prediction.

3.6 Triggering Response to Early Warning

Where drought is a frequent occurrence, the more that can be done in advance the better, in terms of contingency planning and identifying clear institutional and decision-making responsibility for an emergency response. The onset dates and drought intensity levels are used to define EW statements at three levels: advisory, alert and emergency. A phased response could be promoted by the EWS by establishing a sequence of descriptive terms for water supply alert levels, such as “advisory,” “alert,” “emergency,” and “rationing”. Strict monitoring of the rainfall regime especially during its onset phase is capable of revealing danger signals in the rainfall regime early enough to enable mitigation. Such mitigation is critical for the management of agricultural productivity in the predominantly rainfall-dependent farming systems.

In considering emergency response measures such as rationing, distribution of drinking water etc., it is important to pre-assess the vulnerability of group of users and systems as the impacts of drought may vary significantly from one area to the next, depending on the sources and uses of water in the hydrologic unit and the degree of planning previously undertaken.

Multi-purpose reservoirs have conflicting requirements. For example, the flood moderation function and the developing drought situation require different actions. Similarly, the hydroelectric generation priorities compel continuous release of water thereby reducing water availability. However, in all cases water supply for drinking water requirements for present as well as during the currency of the drought has to be given top priority. In certain cases this drinking water requirements could also be partially met through other sources such as groundwater.

All the operational entities (i.e., local utilities, states, river basin commissions) engaged in managing water should set operational procedures to be followed for each of the situation. From the water resources management perspective, it is important to define the reference flow levels and indicators of drought severity. While these indicators would normally differ from region to region, some existing definitions of water shortages may serve as a starting point (Dracup, 1980). Apart from the river flow, reservoir storage is also a useful indicator of water shortages. At the same time, these data are strongly influenced by the reservoir operation rules.

While these indicators would normally differ from region to region, some existing definitions of water shortages may serve as a starting point (Dracup, 1980). A deep shortage - when annual runoff is lower than the mean, by at least one standard deviation. A continuous shortage - when annual volumes are lower than the mean, during at least 4 consecutive years. An extended shortage - when a deep or continuous shortage extends over the entire region under consideration. The same threefold definition approach may be modified and extended to attempt to define drought using data with temporal resolution smaller than 1 year.

Chapter 4 - Drought Vulnerability and Agricultural, Economic, Social and Ecologic Impacts Warning System

Impacts associated with droughts are the result of numerous climatic factors and a wide range of societal factors that define the level of societal resilience. Population growth and redistribution and changing consumption and production patterns are two of the factors that define the vulnerability of a region, economic sector or population group. Many other factors, such as poverty and rural vulnerability, weak or ineffective governance, changes in land use, environmental degradation, environmental awareness and regulations, and outdated or ineffective government policies are a few of the factors that also contribute to changing vulnerability.

4.1 Moving from crisis management to risk management

Devastating impact of recurrent droughts in the past few decades and the inability of many governments to effectively reduce impacts in the short-term and vulnerability to drought in the long-term, underline the fact that policy-makers have in the past paid scant attention to the development of drought management programmes. Traditionally, governments and policy-makers have tended to view drought as a transient event caused by climatic aberrations. This perspective has resulted in high priority being accorded to drought mitigation plans by policy-makers, governmental and non-governmental development agencies while a drought is in progress. However, once the rains have returned, political interest in the drought drops to insignificant levels with political attention being shifted elsewhere (Glantz, 1987: 37-38).

Recent developments in drought policies in the more developed countries are to view agricultural droughts as a normal farming risk, to focus more on pro-active risk management than on reactive crisis management, to apply a continuous strategy involving pro-active as well as reactive measures and a package of measures (relief, preparedness and mitigation), and to involve all government levels and affected people and to decentralise wherever possible.

As a general rule of thumb, the impact of drought is minimal in industrialised nations, where efficient and adequate drought shock absorbers have been developed through sound early warning disaster preparedness policies. On the other hand, developing countries – especially those in Africa – rely heavily on crisis management: post-disaster relief and rehabilitation efforts, which increase their vulnerability to the severe impacts of droughts and other natural disasters.

Crisis management only addresses the symptoms of drought, as they manifest themselves in the impacts that occur as a direct or indirect consequence of drought. Risk management, on the other hand, is focused on identifying where vulnerabilities exist (particular sectors, regions, communities or population groups) and addresses these risks through systematically implementing mitigation and adaptation measures that will lessen the risk associated with future drought events.

Drought impacts are not as visual as the impacts of other natural hazards, making it difficult for the media to communicate the significance of the event and its impacts to the public.

4.2 Need to evaluate drought impacts

The effective management of drought by governments has become very important in view of the rising costs of drought relief programmes within the crisis management approach, the unwillingness of international donor agencies to help with every drought, and the devastating impacts of droughts on human and natural resource bases in countries. It is therefore important that policy makers and governments direct efforts at improving the ability of local communities, the farming sector and industries in drought-prone areas, to deal with conditions of drought in the future. This, along with proper governmental management of drought, can greatly reduce the political, economic, social and environmental impacts of droughts on societies.

Worldwide, socio-economic damages resulting from natural disasters have escalated dramatically since the 1960s. Likewise, the social, economic and environmental costs and losses associated with drought are also increasing rapidly.

Recurrent droughts and increasing water scarcity have in recent years emphasised the need to reorganise governmental water management in developing countries, especially those situated in the arid and semi-arid realms. Governmental water strategies therefore need to address the economic and social aspirations of both rural and urban communities in such a way that it does not negatively impact on the sustainability of the country's natural resource base.

Governments in the arid realm play a key role in the management and distribution of water resources in times of scarcity. It is therefore important that governments develop and implement integrated water resources management policies to ensure the creation of effective water management structures at both national and local levels. In Africa in particular, water is likely to become the most pressing issue in decades to come as droughts and a rapid growing human population join forces to deplete available fresh water resources. Suffice it to say that in the future, as demand increases and resources become scarcer, water will increasingly become the limiting factor in social and economic development across the subcontinent.

4.3 Vulnerability: the common denominators in drought impacts

Main socio-economic and political aspects that come into play in drought impact evaluation provide a backdrop to the formulation of policy guidelines - two prominent dimensions are addressed, namely vulnerability to drought and mitigation measures on a macro and micro level respectively.

Understanding the underlying causes of vulnerability is also an essential component of drought management because the ultimate goal is to reduce risk for a particular location and for a specific group of people or economic sector.

What concerns many scientists and policy makers is not only the diversity and complexity of drought impacts, but also society’s low level of preparedness for future events. The degree of vulnerability of different nations – and, in fact, different communities and households in the same country – varies significantly from one to another. This should be seen from the viewpoint that vulnerability is closely linked with social characteristics such as ethnicity, religion, stratification, gender and age – all of which influence access to power and resources (Downing & Bakker 2000:223).

In addition, regional and global pressures such as population growth, urbanization, foreign debts, civil strife, war, epidemic disease, and export promotion have an effect on local conditions. Although some of these pressures have a universal character, others again are specific to a certain region or society. Addressing the problem of managing water shortages effectively must therefore evaluate, in context, the relative importance of the contributing causes for each locality.

Marginal lands, by their very nature, are likely to be more vulnerable to adverse rainfall conditions. Aggravating the situation is the fact that indigenous agricultural and other natural resource management practices that evolved to suit historical rainfall patterns may no longer be sustainable. Vulnerability to drought under these conditions is therefore likely to increase in the shorter term, before households and economies have fully adapted to the changing climatic conditions. Increased land use has put much more stress on the environment because of dryland degradation and (eventually) desertification. Consequently, the environment is now much less able to withstand drought events. Even a mild drought becomes a serious problem, forcing rural people to seek refuge in the urban areas. Migration is thus often stimulated by greater availability of food and water elsewhere. People usually migrate to urban areas within the stressed area, or to regions outside the affected area. However, when the drought has abated, most of these persons seldom return home, depriving rural areas of valuable human resources necessary for economic development. Many of those left on the farms are women and the elderly who find it difficult to become employed elsewhere (Sporton et al. 1999).

4.3.1 Physical characteristics

Physical characteristics that can be associated with vulnerability are:

(a) Hydrological and climatic regimes that are marginal for agriculture and livestock;
(b) Highly seasonal hydrological regimes that is strongly dependent on seasonal rainfall;
(c) High rates of sedimentation leading to reduction of surface water resource storage.
(d) Topography and land use patterns that supports soil erosion; and
(e) Lack of variety of climatic conditions across the country, which can provide options for relocation in drought risk reduction strategies (unisdrafrica.org, 2005).

To further explore the issue of vulnerability to drought, it is necessary to determine, amongst others, who exactly constitute the affected marginal groups and/ or sectors in society when it comes to drought vulnerability and look into the group variations as well. Once these aspects have been addressed, it will be possible to compile a profile of determinants of vulnerability to drought and water scarcity – determinants that, in their turn, can be useful to formulate policy guidelines for drought evaluation. In sub-Saharan Africa, rural people are the most vulnerable to drought. Approximately 75% of the population in African countries are rural, the majority of whom are small farmers and produce about 70% of agricultural output in the region (Ladele 1999). These small farmers are largely poor and illiterate, and at the mercy of harvest failures, the loss of cattle or the loss of earning potential.

Drought and water scarcity simply implies that specific categories of vulnerable people and social sectors can be defined. Although the precise boundaries of vulnerability vary between cultures and environments, it is desirable to prepare a “vulnerability catalogue” – at least for food security and water access in developing countries – which may help differentiate between at least three social levels of particular vulnerability: individual level; rural communities, and urban communities household level.

In rural areas, at least three prominent categories of vulnerable households can be delineated and the outcome of a drought may be different for different groups, even in the same region:

(a) Smallholder farmers: may be resource-poor with limited access to land, on marginal lands, and with varying degrees of access to financial and development assistance;
(b) Landless labourers: relying on temporary employment are often at the margin of poverty, with little ability to accumulate savings or invest in more productive and sustainable activities. In general, the rural landless (without a non-agricultural income) are typically more sensitive to food shortages, with less on-farm storage and buffering capacity than landowners;
(c) Destitute people: have been forced out of economic activities, often because of ill health, old age, retrenchment, natural disasters, and other causes.

On the urban environment to which they have migrated, they place an ever-increasing pressure on the social infrastructure and economic resources, thereby enhancing greater poverty and social unrest. It is believed that for the first time in human history, the number of people living in cities will soon surpass those in rural areas, thereby causing a further upward spiral in water consumption (Sadeq 1999:19). At least three distinct groups of vulnerable households may be identified in urban areas.

The unemployed destitute in urban areas may be incorporated into (often informal) social welfare systems, but suffer significantly in times of drought when their numbers grow too large and if relief fails to target their pressing needs.

Underemployed poor people, comparable to landless labourers in rural areas, are living on the margins of survival. A gradual deterioration in the economy during periods of drought can affect this group, often leading to a major but largely hidden crisis.

Refugees are the most visible group of vulnerable people, usually swelling in numbers after an environmental hazard such as a prolonged drought. They may also be vulnerable to further hazards, for instance while temporarily staying in camps with inadequate protection against floods, heat and frost, amongst others. This group nevertheless tends to benefit from its visibility and various formal channels of international aid.

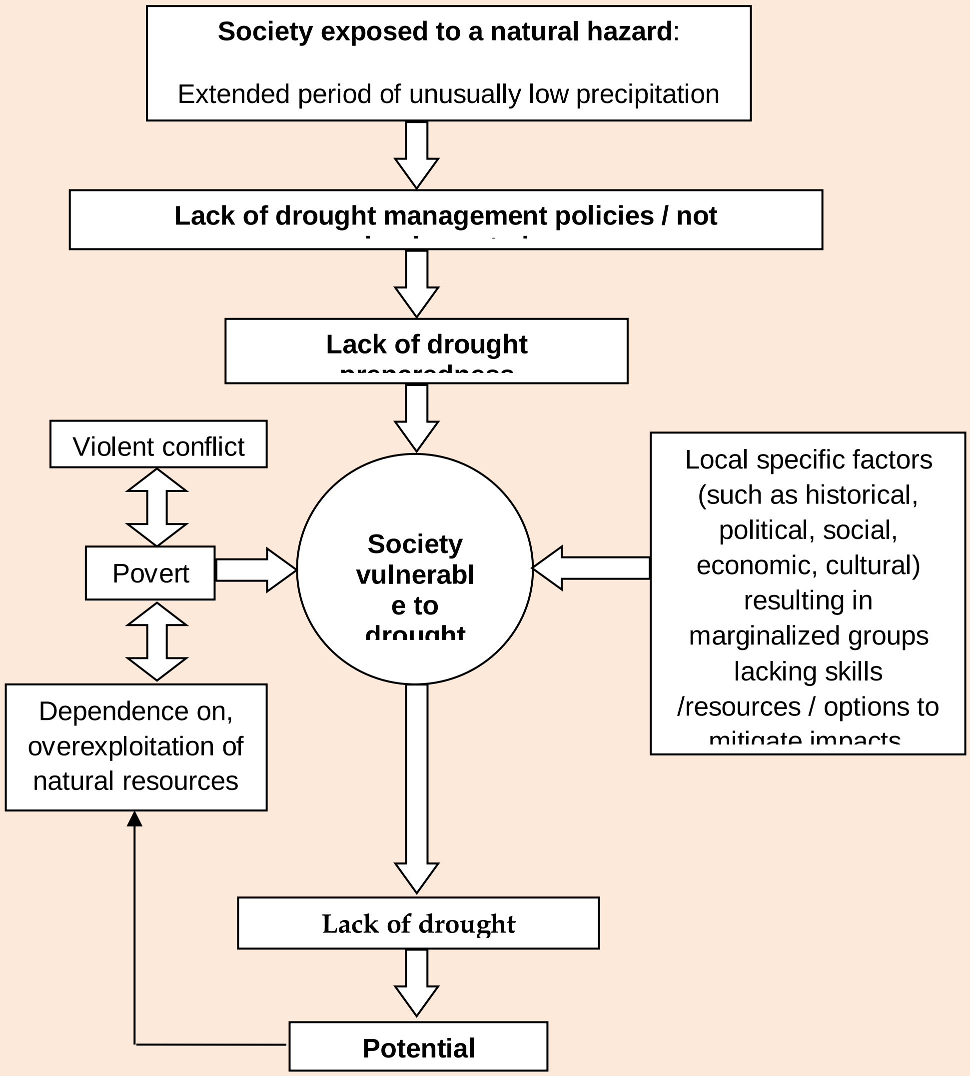

Figure 4.1. Drought Vulnerable society
Source: U.N. Inter-Agency Ad-Hoc Working Group on Drought (unisdrafrica.org, 2005)

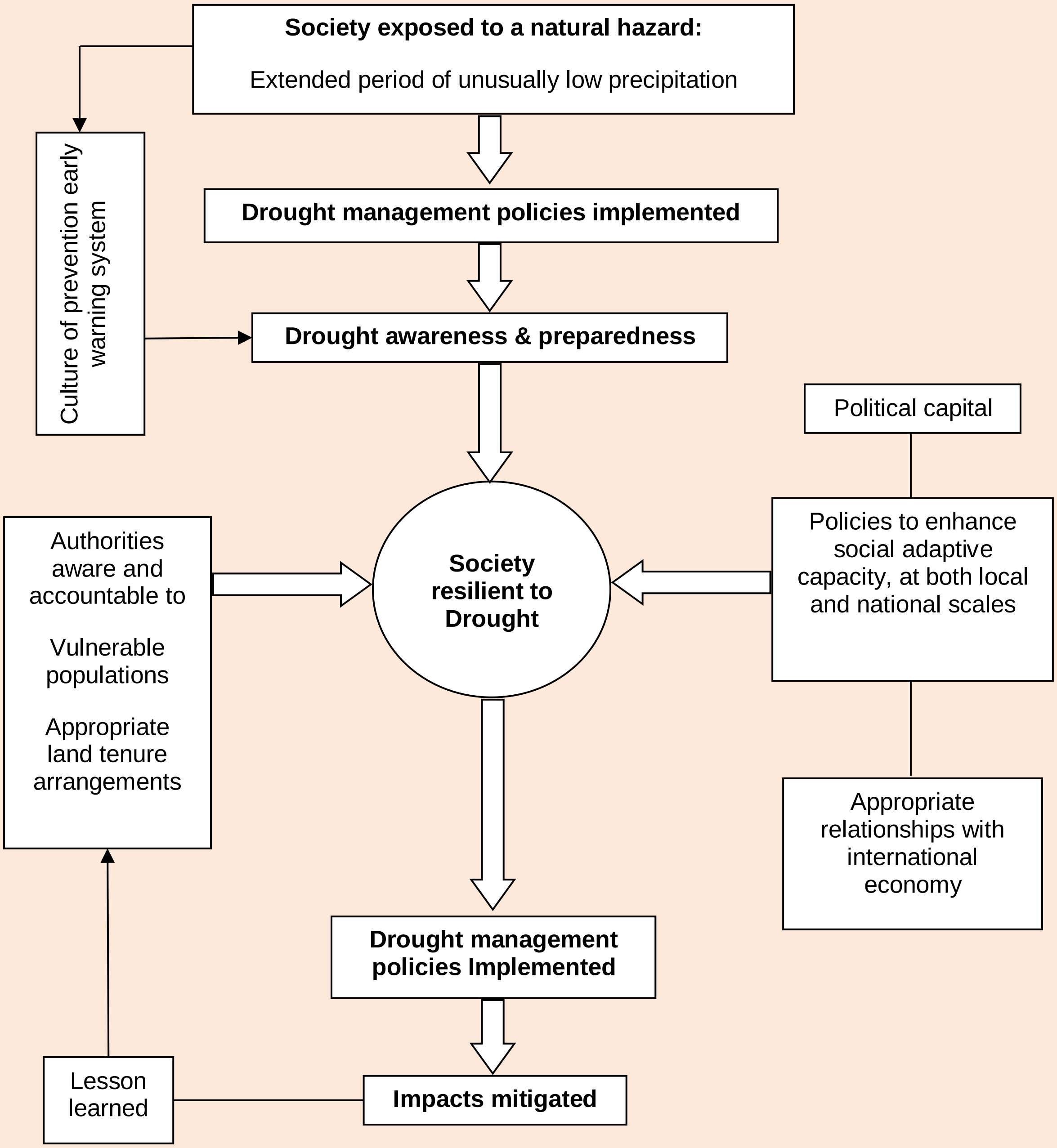

Figure 4.2. Drought resilient societies
Source: U.N. Inter-Agency Ad-Hoc Working Group on Drought (unisdrafrica.org, 2005)

4.3.2 Societal characteristics

(a) Societal characteristics that aggravate vulnerability include:
(b) Poverty and low income levels;
(c) Conflicts, wars and pandemics;
(d) High dependence on rain-fed systems;
(e) High population densities and other factors that inhibit population mobility and societal security;
(f) Increasing demands for water;

(g) Lack of skilled labor, inadequate water supply and irrigation systems and poor planning and management;
(h) Absence of appropriate land use planning and management;
(i) Lack of water control infrastructures that make provision for water supply security and irrigation;
(j) Lack of maintenance and deterioration of water supply and irrigation infrastructures;
(k) Lack of appropriate and empowered institutions;
(l) Inexperience of communities to cope with droughts; and
(m) Unwillingness of communities to live with some drought risks as a trade-off against beneficial services or goods.

Both societal and physical characteristics of vulnerability reinforce each other differently at different levels of severity in different parts. Some countries are affected more severely than others. The Figures 4.1 and 4.2 also summarize the conditions that lead to either high drought vulnerability or to drought resilient communities (unisdrafrica.org, 2005).

4.4 Impacts of drought

Drought impacts are non-structural and extend to large geographical regions. The recent drought events highlighted the vulnerability of our societies to this natural hazard. Owing to the creeping nature of drought, its effects often take weeks or months to appear. Precipitation deficits generally appear initially as a deficiency in soil water; therefore, agriculture is often the first sector to be affected. If no precipitation period continues, then users who rely on surface water (i.e., reservoirs and lakes) will suffer first followed by those who rely on subsurface water (i.e., ground water). Obviously, the length of the recovery period is a function of the intensity of the drought, its duration, and the quantity of precipitation received following the drought period. The case study on evaluation of damage due to droughts in Iran is presented in Appendix III.

4.4.1 Economic Impact of droughts

One way to measure the impact of a disaster is to look at changes in Gross National Product (GNP) or Gross Domestic Product (GDP). Over the last few decades, specific droughts have reduced GNP by at least one percent in countries of East Africa, Europe, North America, South America, South eastern Asia/Australia, Southern Asia, and West Africa. Measures of GDP over time show that economic downturns often materialize after a drought. For example, in the year after the 1984 droughts in Sub-Saharan Africa, the GDP for Mali, Niger, and Ethiopia fell by 9%, 18%, and 7%, respectively. After the drought of 1983, the GDP of Zimbabwe declined by 3% (Benson and Clay in Micheal et al, 2004).

Because most Sub-Saharan African economies are driven primarily by agriculture, the effects of droughts are direct and can be large. In such countries, a majority of the population is employed in agriculture or pastoralism, and the sector's cash crops contribute to foreign-exchange earnings. The agricultural losses were experienced by both rural and commercial farmers, as a lack of rains hampered the maize crop and shortage of irrigation water caused a sharp decline in commercial wheat production (one of Zimbabwe's more important export crops) (Micheal et al, 2004).

Economic impacts of drought are influenced by a country's stage of economic development. Least developed or semi-subsistence economies have large agricultural sectors which are shaken immediately by meteorological or agricultural drought. The result is a decline in GDP, agricultural exports, employment opportunities, and domestic purchasing power. The remainder of the economy tends to be less affected due to non-existence of economic linkages between the sectors. A similar situation arises in dualistic countries, which have large capital-intensive extractive sectors not closely linked to other sectors such as agriculture. In Niger (a dualistic economy), GDP fell by 17% in 1984 and the profitability from the agricultural sector declined by 35%. In contrast, industry and manufacturing output increased in the same year. Economic recovery may occur relatively quickly in these countries because of simplified sectoral needs (SADC, 1993 in Micheal et al, 2004).

Developing or intermediate economies are the most vulnerable to drought. Economic diversity occurs through development of labour intensive, low-tech manufacturing and industrial sectors. There often is a dependency on domestic natural resources and imported capital in countries such as Zambia, Nigeria, and Zimbabwe. In 1992, the GDP of Zimbabwe fell by 8% in real terms in which the agricultural sector directly accounting for only 3% decline in GDP. This illustrates agriculture's importance within the overall economy. Complex economies such as South Africa have smaller agricultural sectors relative to the economy as a whole, and drought shocks are more easily absorbable (Micheal et al, 2004).

In addition to a country's stage of economic development that can be measured via GDP, vulnerability to drought is also influenced by the proportion of rain fed agriculture and livestock production, level of exports, the amount of arid land, and the levels of household self-provisioning (Benson and Clay in Micheal et al, 2004).

4.4.2 Agricultural impacts

Agricultural drought is regarded as lack of sufficient moisture qualitatively, in the crop root zone in soil profile for normal/ high productivity (Ritchie and Henderson, 1972). Not much study has been taken up for quantifying agriculture drought characteristics for drought understanding in terms of its duration and severity.

Though Crop Moisture Index (CMI), a PDSI derivative reflects moisture supply in the short term across major crop-producing regions and identifies potential agricultural droughts. CMI uses a meteorological approach to monitor week-to-week crop whereas the PDSI monitors long-term meteorological wet and dry spells. The CMI was designed to evaluate short-term moisture conditions based on the mean temperature and total precipitation for each week, as well as the (CMI) value from the previous week. Though CMI responds rapidly to changing temperature and precipitation which commonly displayed the weekly CMI across the United States but it cannot be said to denote agricultural drought or moisture deficit values to compare moisture conditions at different locations. The principal demerits of CMI is, it only monitors short-term moisture conditions affecting the development of crop, but is not a good long-term drought monitoring tool. This limitation prevents the CMI from being used for monitoring moisture conditions outside the general growing season, especially in droughts that extend over several years (Mannocchi and Mecarelli. 1991) which is the case lately in the Asian and African countries.

(a) Maximum agricultural drought duration and severity

Though it is presumed that drought severity depend on duration which is found to be an independent random variable but the correlation of agricultural drought to severity is not very well understood because of the complex soil-water-atmosphere-plant inter-relationship as well as the temporal variation of agricultural drought. Accordingly maximum observed agricultural drought severity (in mm) and corresponding maximum durations in weeks show a linear regression of the form:

$$Y = 28.56 + 24.95\ X$$

Where, Y = drought severity, mm

X = drought duration in weeks

The agricultural drought severity values are positively correlated with drought duration (correlation coefficient of 0.64) signifying that increasing durations of agricultural drought definitely leads to increase in severity.

(b) Extreme agricultural drought

Peak values of any hydrological variable are important from rainwater management & cropping system design and planning point view as it is the extreme which plays a deciding role (Gupta and Duckstein. 1975) in success or failure of any design (Chow, 1964 and Haan, 1977). In agriculture the high severity plays a crucial role because of its devastating effect on the crop especially in a traditional sub humid tropical region like Eastern India.

For allocation of water to various competing water uses for crops and animals in the farming systems planning, the planner often faces the problem about quantifying the real time crop water requirement during the season; but this information is generally lacking in most of the situation under severe drought condition.

The peak or the maximum drought severity at the three stages of crop (rice) growth is of importance (O'Toole et al, 1979).

As was analyzed (Paul et al, 2002) the frequency of maximum severity consequently soil moisture deficit is more prevalent in the initial and terminal phases of crop growth periods than at intermediate phase. Drought at the terminal phase seems to follow a cyclic pattern and in the last 25 years the drought severity was quite frequent, table 2.4. It is also seen that severe intermediate drought occurred frequently in the last 25 years compared to preceding period. Intermediate drought was less prevalent in the 1st and 2nd 25 years quarters of the century (1912-92). The results show that the distribution of drought severities at initial, intermediate and terminal phases follow different types of distributions. At 1%, 5%, 20%, and 50% probability the drought severity and soil moisture deficits were quantified. It is expected at the initial phase to be 230 mm, 190 mm, 160mm and 120mm respectively. At terminal phase it is expected to be 180 mm, 160mm, 130mm and 80mm respectively: where as it is expected to be less at 150mm, 120mm, 80mm and 30mm for intermediate phase agricultural drought. The severity amounts thus obtained are for upland rice, which could be used for any other seasonal crops of similar duration and genotypes, with certain modifications (Ghildayal et al, 1982). It is seen that the drought severity at initial phase is higher than intermediate drought. The depth of soil moisture deficit is also very high for terminal drought but much lesser than at initial drought.

4.4.3 Social, economic and political impact

In order to formulate policy guidelines for the evaluation of social, economic and political impacts of drought and aridity, it is necessary to identify and synthesize the main issues. More specifically, the focus, firstly, falls on the identification, analysis and synthesis of common denominators in the socio-economic and political arenas that come into play in drought impacts. It also becomes necessary to have a synoptic review of current national and international legal and policy frameworks.

It is proposed to enumerate the main socio-economic and political aspects that come into play in drought impact evaluation. In this regard - and to provide a backdrop to the formulation of policy guidelines - two prominent dimensions are addressed, namely: vulnerability to drought and mitigation measures on a macro and micro level respectively.

The degree of vulnerability of different nations – and, in fact, different communities and households in the same country – varies significantly from one to another. This should be seen from the viewpoint that vulnerability is closely linked with social characteristics such as ethnicity, religion, stratification, gender and age – all of which influence access to power and resources. In addition, regional and global pressures such as population growth, urbanization, foreign debts, civil strife, war, epidemic disease, and export promotion have an effect on local conditions. Although some of these pressures have a universal character, others again are specific to a certain region or society. Addressing the problem of managing water shortages effectively must therefore evaluate, in context, the relative importance of the contributing causes for each locality (Backeberg, 2003). What concerns many scientists and policy makers is not only the diversity and complexity of drought impacts, but also society's low level of preparedness for future events (Viljoen and Backeberg,2004)

4.4.4 Ecological impacts

One of the most dangerous and harmful effects of drought is exerted on the natural resources, habitats and ecosystems. These damages have not been studied deep enough and discussed properly in the past, the issue has been raised only in recent years.

Special attention should be paid to combine environmental effects, such as the increasing pollution and the increasing volume of various wastes, in particular toxic wastes and materials in the environment. These combined and complex effects can become stronger during drought periods, mainly caused by the much lower dilution and natural purification capacity of the recipients. Economic estimation of these damages is much more difficult than of other indirect drought impacts, at most of the countries there are no data available in this field at the moment.

Chapter 5 - Drought Management Strategy

5.1 Drought Management Plan

In order to reduce the impacts of droughts and water scarcity, the main thrust has to be on balancing the supply and demand of water whether on a long-term basis in case of water scarcity or temporarily in case of droughts. The overall objective of the process is to improve the reliability of the available water resources to meet the demands. In arid and semi-arid regions the situation gets exaggerated although the water use practices help in meeting drought situation.

Mitigation and prevention of potential damages due to frequent and more severe droughts is becoming more and more important in those countries facing with frequent occurrence of severe dry periods. Both the development and the implementation of a comprehensive drought policy is the responsibility of every national government.

At the state or national level, governments may respond to drought in three ways: pre-drought mitigation programmes for impact reduction; post-drought relief programmes to provide emergency assistance to victims; and preparedness or contingency planning to develop institutional capacity to respond in a more timely and effective manner and to reduce impacts.

The absence of adequate drought management planning, monitoring and implementation of the programs could (and in many ways will) result in the following problems (National Department of Agriculture, 2003):

Increase in the disaster impact and consequences with more and extended hardship

(a) Delayed economic recovery with avoidable financial strain and delayed reconstruction
(b) Avoidable additional loss of life, property and community infrastructures with prolonged disruption in essential services
(c) Greater possibility of epidemics
(d) Enhanced chance of political instability

It is necessary to formulate drought management plan for every country for drought mitigation for decreasing its devastating effect on food, fibre, livestock and employment security. These aspects have to be the prime consideration for a long time by the policy planners all over the world.

The complex phenomenon of drought needs a complex and interdisciplinary approach in drought mitigation as well. It is an inclusive process that must include all the relevant state departments (e.g. Agriculture, Environmental Affairs and Water Affairs in the case of South Africa), as well as relevant non-governmental agencies such as agricultural unions and water user associations. While the drive to develop a national drought policy should come from the central government, governmental structures on the provincial and local levels should also be involved in the process from the beginning, since these structures play a crucial role in disaster relief through the mobilisation of local resources (Abrams, 1997; Wilhite, 1993b: 92).

Once the basic framework of drought plan for a country or region is in place, a process of policy formulation can develop to ensure that all those interested, especially those defending the public interest, are able to play their roles. As a general rule, the more open the process of policy formulation, the more likely it will be that the policies will respond to the public interest and that their implementation will be successful even when they seem to be incorrect from a technical point of view (Carman, 2005). The combination of planned measures is not fortuitous, but their selection has to be based on optimization and modelling.

The drought management plan also gives explicit indications of the roles of the different institutions involved and the timely implementation of various measures. First of all, it necessitates a sound system for monitoring water resources and its close linkage to the planned measures. The water usage for higher crop production has to be encouraged, through policy measures. Prospects for developing new water resources feasible for profitable agriculture do not look promising in the dry areas. Unless scientific breakthroughs in the cost of desalinating seawater occur, very little new water is expected to be available for irrigation purposes. In addition to a large array of possible technical measures, facilities and operational rules, it requires a review of the regulations and institutions related to water resources to adapt the legal and institutional framework to the conditions of water scarcity and frequent droughts.

5.2 Water Policies and Drought Management

Agricultural activity has always included adaptation conditions like drought. As the availability of fresh water is one of the biggest threats facing most of the countries particularly in the dry and semi dry areas and where about 80% of the available water is used in agriculture. The management of water resources has to consider the following aspects:

(a) Availability of fresh waters for drinking, agriculture, irrigation, municipalities, industries etc

(b) Quantifying the requirements of water for use by various users during the normal and drought period

(c) Prioritisation of water resources use including fresh water, waste water, saline water and water to be made available by desalinisation of sea water as per formulation of national guidelines and water acts.

(d) Non-sustainable development and improper use of natural resources have increased the vulnerability of concerned societies to the extent that even a small abnormality leads to acute distress.

It is necessary that there should be some kind of legally tenable Water Policy to provide guidelines for adopting long term measures to be followed by various stake holders to tide over such contingencies without much hardship to the people of the country. The Ministry of Water Resources and Irrigation (MWRI) of Egypt, one of the oldest country practicing irrigated agriculture has formulated such a national water policy with overall objectives to utilize the available conventional and non-conventional water resources efficiently and to develop additional water resources to be prepared for such drought and water scarcity conditions. Similarly, National Water Policy has been adopted and formulated some other countries including India and China also more or less with the same overall objectives. The main areas of the national water policy and its implementation procedures are:

(a) Integration of Water Resources Management consisting use of fresh, waste and saline water

(b) Decentralization and enhancing the role of Stakeholders' Participation and

(c) Public-Private Partnership approach.

The water management policy needs to address a multitude of issues, including, management of supplies (to improve water availability in time and space); Management of demands (efficiency of water use, sectoral interactions with economic activities); balancing competing demands (urban-rural; upstream-downstream; national-provincial); and preservation of the integrity of water-dependent ecosystems. The current management policies are assessed and modifications and enforcements are affected.

5.3 Drought mitigation strategies

To achieve the objectives of drought management, most of the countries are forced to take various mitigation measures encompassing water harvesting, watershed development, improved irrigation coverage and efficiency as well as find ways and means to use waste water, saline water and promote desalination of sea water.

5.3.1 Macro and Micro level strategies

Drought mitigation strategies need to be clearly distinguishable at both the macro and micro levels. There are few links between these two levels – particularly in developing countries – which severely compromises the effectiveness of drought preparedness and mitigation in these countries. The macro level mainly relates to institutional responses at the national level and thus inter alia state policies and programmes, while the micro level focuses mainly on the household or community level.

Although local people's contingency plans are ill documented, there is nevertheless evidence to suggest that the use of local strategies is far from random, but rather imbedded in well-established cultural value systems and practices. In some cases, these practices are directly linked to a profound sacred status attached to many rivers, pools and water sources. Since such perceptions constitute a powerful mechanism for protecting water resources and coping with drought, it is important to take note of these.

Davies (2000:5) mentions that all local strategies – whether adopted at individual, household or community level – are part of wider contingency plans, reinforced by indigenous information and diagnosis. Although monitoring indigenous coping strategies is regarded an essential and effective element of drought management and the development of early warning systems, examples of actual strategies are rare and not well reported. In addition, monitoring coping strategies is a complicated process and necessitates detailed understanding of local livelihood systems. As a result, the monitoring of local coping strategies and development of indicators are often rejected by national policy makers and planners on the grounds of cost, time and lack of sound scientific requirements. The challenging question therefore is: How can multiple rural perspectives and perceptions of drought be taken into account in public policy formulation?

5.3.2 Long-term and short term strategies

Drought planning for the future should include provision for long-term and short-term measures for a detailed contingency drought policy. Long-term planning involves mitigation that provides adequate drought protection levels, while short-term response measures will reduce the need for additional water development and withdrawals at the expense of the environment.

Preparedness for response to drought is strongly recommended by drought researchers to be part of a pro-active drought management system instead of resorting to reactive actions. Pro-active planning can substantially reduce drought impacts. Water demand reduction can, for example, increase water supplies available for agricultural irrigators. However, demand reduction is a universally available option for preparedness measures.

There is, in fact an entire range of community-based coping mechanisms to help people withstand periods of severe drought. Amongst these are gifts of food to impoverished kin, credit to buy food and other necessities etc. Even after a period of drought has ended, reciprocal mechanisms are maintained to redistribute assets in an attempt to aid the recovery of poorer households. These include the loaning of seed, tools and food, the loaning of cattle to reconstitute herds, and other informal forms of credit assistance.

What is also important to note, is that in countries with dualistic farming sectors like South Africa (a highly developed commercial farming sector and a small subsistence farming sector) the measures can differ to be effective. For instance, diversification of farming activities and insurance against drought may be feasible measures for commercial farmers, but not necessarily for subsistence farmers.

5.4 Approaches for drought mitigation

A drought mitigation policy must seek to create conditions that will help tackle water scarcity by laying stress on adopting good water management practices (Kijne et al, 2003). It is crucial to plan for optimal use of water resources achieving higher efficiency of water use in the agricultural sector, promoting water reuse and changing wasteful water use patterns (Sabetraftar & Abbaspour 2003: 59)

Generally two broad approaches are adopted for drought mitigation viz supply side interventions and demand management.

(a) Supply Side Interventions

(i) Developing new water supplies through:
(ii) construction of storage tanks, dams, and reservoirs,
(iii) new solutions to harvest rainwater,
(iv) recharge the groundwater storage,
(v) construction of wells and canals
(vi) water transfers,
(vii) Developing innovative solutions to increase the water supply:
(viii) artificial precipitation and desalinate seawater,
(ix) developing salt tolerant crops that can be irrigated with saline water,
(x) conjunctive use of surface and groundwater.
(xi) use of non-conventional water resources such as
(xii) saline water,
(xiii) treated wastewater, and
(xiv) desalinated brackish,

(b) Demand management intervention

(i) Adopting more efficient demand management system i.e.
(ii) reducing water losses,
(iii) development of cropping pattern for less water consumption,
(iv) modification of water demand at farm level,
(v) using low water consumption systems in industry and urban development,
(vi) developing appropriate regulations and guidelines.
(vii) Managing supplies and demands in real-time (i.e. reallocation of supplies among different users at crises time to ease water constraints)

A combination of response options including both supply management and demand management should be considered with an open mind to achieve resilient and flexible solutions for adaptation to the changing conditions as they unfold.

5.4.1 Supply Side Interventions

5.4.1.1 Rainwater Harvesting

Where water is scarce, the rainwater management can address this problem by increasing the water available to crops under rainfed conditions, and thereby increasing yields. Water scarcity in the West Asia and North Africa is the severest in the world and is on the increase. The most important natural resource in this region is rainfall and rainwater harvesting has been an ancient practice that improves the efficiency of rain by concentrating it for proper use through techniques specific for a region.

Rainwater harvesting is defined as the concentration of rainwater through runoff into smaller target areas for beneficial use (Oweis, 2004). The components of any water harvesting system include:

(a) catchment area which is part of the land that contributes some or all its share of rainwater to a target area outside its boundaries,

(b) storage facility, a place where runoff water is held from the time it is collected until it is used. Storage can be in surface reservoirs, subsurface reservoirs, in the soil profile, or in groundwater aquifers, and
(c) target area, where the harvested water is used.

As rain water harvesting is an ancient tradition and has been used for millennia in most dry lands of the world, many different techniques have been developed. Various techniques of rainwater harvesting which range from watershed to on-farm or in-field harvesting to groundwater recharging are discussed in Appendix IV.

Rainwater harvesting is particularly advantageous in the following circumstances:

(a) in arid areas suffering from desertification, water harvesting can improve the vegetative cover and can help to halt further environmental degradation.
(b) in the semi-arid environments, where low and poorly distributed rainfall normally make agricultural production difficult, water harvesting can make farming possible despite the absence of other water resources.
(c) in the semi-arid areas, where crops can be produced but with low yields and a high risk of failure. Here water-harvesting systems can provide enough water to supplement rainfall and so to increase and stabilize production.
(d) in areas where water supply for domestic and animal production is not sufficient. These needs can be satisfied with water harvesting.

The specific benefits listed above lead, in turn, to many other non-tangible and indirect socioeconomic gains. These include the stabilization of rural communities; reduced migration of rural people to cities; use and improvement of local skills; and improvement in the standard of living of the millions of poor people living in drought-stricken areas (adopted from Oweis, 2004).

5.4.1.2 Use of non-conventional sources of water

Role of non-conventional water is well recognized under drought and water scarcity condition especially in the arid and semi-arid regions such as the Mediterranean countries. Many researchers and scientific institutions have intensively investigated the use of non-conventional water in irrigation and the way to practice and manage it. The information gathered so far, the globally gained experiences and the research findings all resulted in notable developments of the use of non-conventional water for irrigation and demonstrated the high potentiality for its use.

In most of the arid and semi-arid regions such as the Mediterranean countries, the highest portion of the water resources is allocated for irrigation. Non-conventional water could be used as a substitute for freshwater in irrigation. Implementation of non-conventional water in irrigation is still a big challenge due to the complexity of the systems. Planning and management of agricultural reuse operations of non-conventional water resources needs to take into account the socio-economic, institutional, organizational, legal, regulatory, environmental and technical aspects.

Agricultural use of non-conventional water is more easily accepted and implemented in water-shortage areas where irrigation is already practiced. However, skills development, appropriate institutions and strong extension services are required. Participatory ‘bottom up’ approach is a cornerstone issue governing success and/or failure in any reuse irrigation project. Water user associations should be involved and associated in the planning and management process to ensure the success of the project. The farmers usually succeed in developing appropriate strategies to make the best use of the available water in order to maximize the agriculture production.

The non-conventional water sources are:

(i) Saline water or agriculture drainage water
(ii) Reuse of farm run-off
(iii) Reuse of wastewater
(iv) Desalination of brackish or sea water

(a) Use of saline water

Reusing agricultural drainage water implies an increase of global irrigation efficiency, but also entails the degradation of the water quality, which affects the physical and chemical properties of the soils, reduces crop yield and pollutes the returned flows to the hydrological ecosystem. The water quality requirements of irrigation water and the effect of using saline water are discussed in Appendix V.

Moderately saline/sodic waters can be used for irrigation where control of soil salinity/solidity in the crop root zone is by means of leaching and drainage of dissolved salts. Saline water is being used in a number of countries which are briefly described in Appendix V C. However, where brackish water is the only resource available, prior desalination is needed.

Finally, sustainability and success of non-conventional water uses depends on sound implementation and management. Poor planning and management might bring high health and environmental risks, and undesired economic and social consequences. During the planning and management phases, the ecological, social and economic aspects should be considered in order to assure social and economic viability of any reuse activities.

Box 2: Research in soil salinity

The Institute for Advanced Mediterranean Agronomic Studies in Bari (Italy) and many other worldwide research institutes, centers, and universities in the arid and semi-arid regions are giving non-conventional water resources practices and management the priority in their research programs. There are intensive research programs on the use of saline/sodic water for irrigation. The experience gained demonstrates that saline/sodic water can be used effectively for the production of selected crops under the right conditions.

In Egypt intensive research programs, together with field experiments, have been carried out for reusing agricultural drainage water. Monitoring and evaluation programs are under continuous development on a well-established research base. National guidelines for optimal use of drainage water and strategies for its reuse under the Egyptian conditions have been set up. In Morocco and Tunisia intensive research programs for the use of treated wastewater in irrigation are ongoing. The findings of the programs demonstrate the suitability of reuse of treated wastewater in irrigation when appropriate practices are adopted.

In India, the Central Soil Salinity Research Institute (CSSRI), a part of the Indian Council of Agricultural Research (ICAR) system is involved. About 7.3 million hectares of India's land area is afflicted with the twin problems of alkalinity and salinity coupled with Water logging, which seriously reduce agricultural productivity and has grave implications for Indian food security system. CSSRI researches therefore focused on reclamation and sustainable management of salt affected soils and on the rational use of poor quality waters in agriculture.

In Iran, National Salinity Research Center (INSRC) and Agricultural Engineering Research Institute (AERI) are responsible for conducting research programs on reclamation of salt affected soils and sustainable use of saline/sodic/waste waters in agriculture.

The United States Salinity Laboratory (USSL) is a National Laboratory for basic research on the chemistry, physics, and biology of salt-affected soil-plant-water systems. The mission of its staff is to develop, through research, new knowledge and technology dedicated to the solution of problems of crop production on salt-affected lands, sustainability of irrigated agriculture, and degradation of surface- and ground-water resources by salts, toxic elements, pesticides, and pathogens released from animal wastes.

(b) Reuse of run-off

Level basins, when properly designed and managed, often attain very high irrigation efficiencies. Problems can arise when the infiltrated depth exceeds the soil water holding capacity or when the crops are sensitive to waterlogging. Both cases could benefit from allowing part of the applied water to run off the basin. This water can be reused for on-farm irrigation of the subsequent basin. Such a setup will be referred to as the "runoff rescue" (RR) system. Zapata (2000) described and evaluated, an RR system composed of five adjacent terraced basins. The basins were connected by outflow points located at the upstream and downstream ends of the fields. To provide terms for comparison, the performance resulting from conventional irrigation (without RR) of each basin was estimated using a simulation model. The RR system showed reductions of 14, 16, and 24% in irrigation time, infiltrated depth, and recession time, respectively. The average increments for distribution uniformity and application efficiency were 2 and 9%, respectively.

(c) Reuse of wastewater

Many farmers have considered using treated sewage effluent as a source of water. The used water is normally purified and supplied to the next recipient. A number of projects use reclaimed water for irrigation of food crops, ornamentals, golf courses, and residential areas. The minimum required standard for wastewater treatment have to be followed.

In many developing countries, untreated wastewater is also being used for irrigation. For example, over 80% of Pakistani communities with a population of over 10,000 inhabitants use untreated wastewater which is driven by the absence of a suitable alternative water source, wastewater's high nutrient value, reliability and its proximity to urban markets. Ensink et al (2004) discusses the results of two case studies in Pakistan highlighting the impact of untreated wastewater use on health, environment and income.

While treated sewage effluent contains large amounts of nitrogen and phosphorus, it also has high concentrations of sodium salts. Consequently, if not managed carefully, salinity and sodicity can increase. Reuse of treated and untreated wastewater in irrigation has a high positive potential to environmental relief and social and economic development. Irrigation with treated sewage effluent causes large increases in nitrate-N, small increases in exchangeable Mg, Na and K, and small decreases in SOC. Salinity increased only in the 0.1-0.6 m depth.

Reusing wastewater without good planning can cause soil quality problems in the long term, due to building up salinity and heavy metals. It also results in health risks due to the exposure of farmers, consumers and neighboring communities to infectious diseases. Therefore, the various risk factors must be converted into actions of attenuation and regulations associated with good practices. WHO has issued guidelines for safe use of wastewater in agriculture? It is essential for countries to develop guidelines that are adapted to their individual social, economic and environmental context taking a holistic approach.

Use of Wastewater as an Irrigation Source has to adhere to following:

(a) Formulating national policies and strategies: The wastewater re-use constitutes an important and integral component of the comprehensive water management programs, so countries should have national policies and strategies relating to wastewater management in general and wastewater re-use for agriculture, in particular compatible with the national water management and irrigation policy, national health policy, sanitation and sewage policy, national agricultural policy and national environmental protection policy.

(b) Realistic standards and regulations: The standards and regulations must be developed to address country specific issues and they should be achievable and enforceable among both polluters and administrators. (UNEP, 1991; Mara and Cairncross, 1989).

(c) Developing and applying holistic and appropriate health guidelines: Wastewater reuse can potentially increase the public health risks. The relative risk factors that change as water supply and sanitation improve should be reconciled with other health measures.

(d) Appropriate institutional and administrative mechanism: As safe water treatment, disposal and reuse are the responsibility of different organizations at various administrative levels, often under different ministries, the mechanism for coordination and collaboration should be clearly and unambiguously described.

(e) Promoting research: Continuous research that captures all social, economic, and political aspects centered on the livelihoods of farmers and an understanding of economic value of wastewater use in urban and peri-urban agriculture should be carried out.

(f) Capacity development: Education programs for all stakeholders to confront realities bringing awareness about raising strategies of wastewater use and training of all personnel engaged in technical, environmental and socio-economic aspects of wastewater reuse.

Both the public and members of the water industry need to overcome phobias that generally prevail when it comes to using reclaimed waste water. To improve reusing and recycling there is need to improve community understanding of water quality and overcome irrational. A coordinated education program is urgently needed (Simpson, 1998) in order to overcome psychological barriers (Van Leeuwen and Murdoch, 1994). More details and the guidelines for wastewater use in agriculture are provided in Appendix VI.

(d) Desalination of brackish and sea water

Water desalination is a well-established technology mainly for drinking-water supply in water scarce regions such as the Near East. Among the options for augmenting freshwater resources is the desalination of salty groundwater, brackish drainage water and seawater. Distilling drinking-water from seawater has been studied over many centuries by Mediterranean and Near East civilizations. Large-scale solar pounding to serve as domestic drinking-water was practiced more than 100 years ago in Egypt (Abu Zeid, 2000). Intensive research for large-scale commercial desalinating technologies began in the United States of America in the early 1960s (Buros, 1999). Plants have been developed since the 1970s, starting with some countries of the Persian Gulf because of their ready availability of energy and relevant scarcity of freshwater resources.

Since the 1960s, saline desalination has been technically feasible. However, to-date, the energy required and the high cost of desalinating brackish waters and seawater have been the major constraints on large-scale production of freshwater from saline waters. Environmental costs relating to the safe disposal of residual brines – to be added to investment and O&M costs – are also an important issue concerning the development of water desalination, especially in plants far from estuaries and the sea.

However, in regions with scarce freshwater resources, water desalination for municipal and industrial uses is being applied increasingly as desalinating costs decline and the costs of surface and groundwater supplies increase. In high-capacity plants, reductions in energy consumption and operational costs are expected through the introduction of new equipment for energy recovery and through improvements in RO membrane technology.

Desalinated brackish waters and seawater are not widely used for irrigated agriculture because of the costs involved. However, in some countries, they are used for high-value horticultural cash crops (greenhouses production). As irrigated agriculture does not require the strict standards that apply for drinking-water requirements, opportunities appear to exist for blending high-quality desalinated water with lower-quality waters. In this way, the final cost of a cubic meter of irrigation water can be reduced. Moreover, the desalination of saline waters for urban supply will also have a considerable impact on the production of low salt-content wastewater to be treated subsequently, with lower costs for use in irrigated agriculture.

However, it has proven much less economic for agricultural application than the reuse of treated wastewater, even where the capital costs of the desalination plants are subsidized. A brief oversight of the use of desalinated water, its related environmental issues, the financial models being used and its use in agriculture is given in Appendix VII.

5.4.1.3 Precautions in use of non-conventional resources

Research on the potentials, limitations and hazards of the use of non-conventional water in irrigation was undertaken in relative isolation and no mechanism existed for coordination of the research work and effective utilization of the research findings. There is no universal approach to achieve salinity control in irrigated agriculture; it varies from country to another depending on economic, climatic, social and hydro-geological conditions (Abdel-Azim and Allam, 2004). Haphazard and uncoordinated management of the use of non-conventional water resources in irrigation could in the long run, seriously affect crop production; deteriorate soil productivity and create serious environmental problems and health risks.

As a first step, a monitoring program has to be put in place to identify areas with environmental and health risks as a result of use of poor quality of water in irrigation. It helps identifying priority actions that will reduce the health risks. In some areas short term action may be required to change practices. These short term actions can be separated into pollution control actions and protection actions. Pollution control actions are measures to reduce the non-conventional water in areas that are already polluted. Protection measures are required to prevent vulnerable areas not to be polluted in the future.

Long term actions that will reduce pollution and enhance the reuse potential are required to be identified and supported. At present, generally there is no clearly defined policy and strategy on the use of non-conventional water in irrigation. To enhance the reuse potential of non-conventional water, following action areas need to be addressed:

Policy

(a) Develop a strategy for the use of non-conventional water in irrigation within the country, that should activate the role of policies and institutions in creating demand for technology to ensure the sustainability of irrigated agriculture with non-conventional water;
(b) Formulating strategy for establishing appropriate monitoring programs for the use of non-conventional water in irrigation;

Management

(a) Integrated management of water of different qualities at farm level, irrigation systems and drainage basins with the explicit goals of increasing agricultural productivity, achieving optimal efficiency of water use, preventing on-site and off-site degradation and pollution, and sustaining long term production potential of land and water resources;
(b) Development and use of mathematical models to relate crop yield to irrigation management under saline/sodic conditions that could be applied under a wide variety of field conditions;
(c) Incorporation of salinity into groundwater flow models to predict the development of not only water logging but also of soil water salinity in order to plan appropriate water management strategies;
(d) Developing general guidelines, setting up a universal strategy and use systemic indicators for assessing, monitoring and evaluating the sustainability of non-conventional water reuse.

Research

(a) Conducting a comprehensive and coordinated research on potentials and hazards of the use of non-conventional water for irrigation incorporating environmental, institutional, political and social and economic concerns;
(b) Conducting and fostering coordinated and multi-disciplinary basic and applied research program on the sustainable use of non-conventional water sources in irrigation and its related problems and obstacles;
(c) Providing facilities for research workers and improving the Institutional Capacity Building;
(d) Establishing a working relationship between national, regional and international institutions dealing with the reuse of non-conventional water through the formulation of networks;

Mitigating risk factors

(a) Planning Aspects

- Strengthen the participation of the beneficiaries
- Monitoring the quality of non-conventional water and reinforce existing regulation

(b) Economic Aspects

- Establish cost-beneficiate analysis
- Insure that reuse policy is profitable to the farmers

(c) Organizational Aspects

- Encourage cooperation between different institutions
- Establish services contacts between the manufacturing institution and local expertise institution

(d) Regulation aspects

- Establish norms and standards for the reuse of non-conventional water
- Limit the parameters to be monitored

(e) Technical and agronomical aspects

- Encourage the drip irrigation system
- Optimize the recycling of the nutrient elements included in water
- Develop a strategy for the storage of wastewater

(f) Sanitary aspects

- Develop analytical methods for monitoring persistent contaminants
- Improve research techniques for parasites and virus
- Develop a methodology and monitoring evaluation system of the impact of the reuse on the soil, crops and ground water

(g) Awareness raising

- Establish awareness and education programs for farmers, engineers and technicians
- Develop handouts on different aspects of the reuse of treated non-conventional water

5.4.2 Demand Side Management

The aims of ‘more efficient’ and ‘more productive’ use of water are two sides of the same coin. Efficiency emphasizes the ‘process’ and is a dimensionless ratio between outputs and inputs, while productivity puts the emphasis on the ‘output’ and in the case of water productivity is measured in terms of units per volume of water. Under this type of demand management, users are encouraged to reduce water losses and waste, cut out low value water applications, and maximize the value obtained from their remaining water. ‘Value’ in this context includes non-monetary benefits as well as values estimated by ‘willingness to pay’ and other economic valuation techniques.

The term ‘water use efficiency’ is sometimes used in a narrow sense as the ratio between beneficial use and water withdrawals. This applies to the notion of ‘water supply efficiency’ or ‘irrigation efficiency’, where the difference is analysed between water withdrawn and the physical losses resulting from leakage from pipes and canals and wastage through excessive or inappropriate application for the crop or productive process. Appreciating the real scope for water savings by reducing these losses is an important issue in water demand management, but can only be identified through water accounting procedures.

Reduction of losses in distribution systems is still justifiable in many cases. Excessive levels of losses and leakages reflect failures of infrastructure or its management, and cause financial costs (for producing, pumping and transporting. Equal importance should be given to proper and judicious use of the available water resources/harvested water so as to achieve “more crops per drop” and at the same time also meet other societal and environmental requirements. Some of the possible methods to achieve this include:

Deficit irrigation

(a) Improved irrigation techniques
(b) Improved water use efficiency
(c) Increasing irrigation efficiency
(d) Crop irrigation management

(e) Precipitation management

(f) Crop water use

5.4.2.1 Deficit Irrigation Approach

This approach aims at obtaining maximum production per unit of irrigation water especially where only a limited amount of water is available for a relatively large area so that maximum water use efficiency is achieved. Though the production from a unit area declines as the same amount of water is used to irrigate progressively larger area, the overall production and water-use efficiency is increased.

Table 5.1 shows the effect of supplemental irrigation on increasing water-use efficiency on pearl millet production (Narain et al, 2000). It was reported that yield increase of up to 44% for rainfed upland rice during maturity stage can be achieved by application of only one supplemental irrigation of 10 cm (Paul, 2011); similarly 37% yield increase in winter crop at the crown root initiation phase (nizer- var T-9 and pigion pea-var BG 65) is possible with one supplemental irrigation from a small water harvesting structure).which stored water for 6-7 months and supplied 3 to 4 supplemental irrigation during frequent dry spells in a drought year. Interim fishery as done profitably,(Paul, 191,2005) for 13 years(1980-1993) with a cost benefit ratio of 1:1.28 yielded a net benefit to farmer INR 51,000 (US$ 1240/ha)

Table 5.1. Effect of increased area under supplemental irrigation (same amount of irrigation water) on pearl millet production

Medium annual rainfall (266 mm) Low annual rainfall (173 mm)

Irrigation (mm/ha)	Area (ha)	Yield (kg)	Irrigation (mm/ha)	Area (ha)	Yield (kg)
292	1.0	3620	341	1.0	3540
145	2.0	5380	209	1.6	4528
73	4.0	7560	117	2.9	5829
0	1.0	1400	0	1.0	1080

5.4.2.2 Improving Irrigation Techniques: Drip and Sprinkler Systems

The conventional methods of flood irrigation are generally inefficient under light textured undulating soils of the water scarce regions.

Sprinklers and micro-sprinklers are most suitable for narrow spacing crops (wheat, mustard, barley, spices etc.). The system helps in saving sufficient amount of water (at least 20 %). Sprinkler system of irrigation gave 33 and 37 % higher yield as compared to check basin and border strip methods of irrigation, respectively (Sharma, 2001). However, high wind speed and use of saline water may restrict its application in arid regions.

Drip irrigation applies water directly to the crops'' root zone and is not affected by high wind speed. Though initial cost of the system is relatively high, it is quite pertinent to the water scarce regions. This method is more suitable for wider spacing crops and orchards and yield increases by 40-50 % are common for different crops. Water soluble fertilizers (fertigation) can also be applied through drip irrigation. The drip irrigation has a special utility in the arid and semi-arid region where groundwater is generally saline. Daily irrigation by drip forces the salts to the side and below the root zone, thereby allowing gainful utilization of water having a relatively high salt content.

Use of subsurface drip irrigation has progressed from being a novelty employed by researchers to an accepted method of irrigation of both perennial and annual crops (Ayars et al., 1999). After nearly four decades of research and development, subsurface drip irrigation has revolved into an irrigation method with high potential for efficient and economical productivity (Phene, 1995).

5.4.2.3 Improving Water Use Efficiency

In recent years there has been an intensification of public debate around the issue of water allocation to agricultural, domestic and environmental uses as well as allocation between the industries within the agricultural sector. These factors give added importance to the question of water use efficiency over and above the direct importance for the manager of making optimum use of a limited production resource. Water use efficiency and water productivity means raising crop yields per unit of water consumed. Over the past five decades, this has been achieved largely through higher crop yields per hectare. But, with the declining crop yield growth, attention has turned to the potential offered by improved management of water resources. Although there is considerable scope for increasing water use efficiency through this avenue, it is not as large as is commonly thought (Kijne et al., 2003).

To address the global challenge of achieving more crop per drop (Paul,2011), considerable potential exist to increase water use efficiency and water productivity and a range of technologies and water management practices are available to use water more effectively at various levels of the water-yield pathway (Figure 5.1). The potential of the difference options are as following:

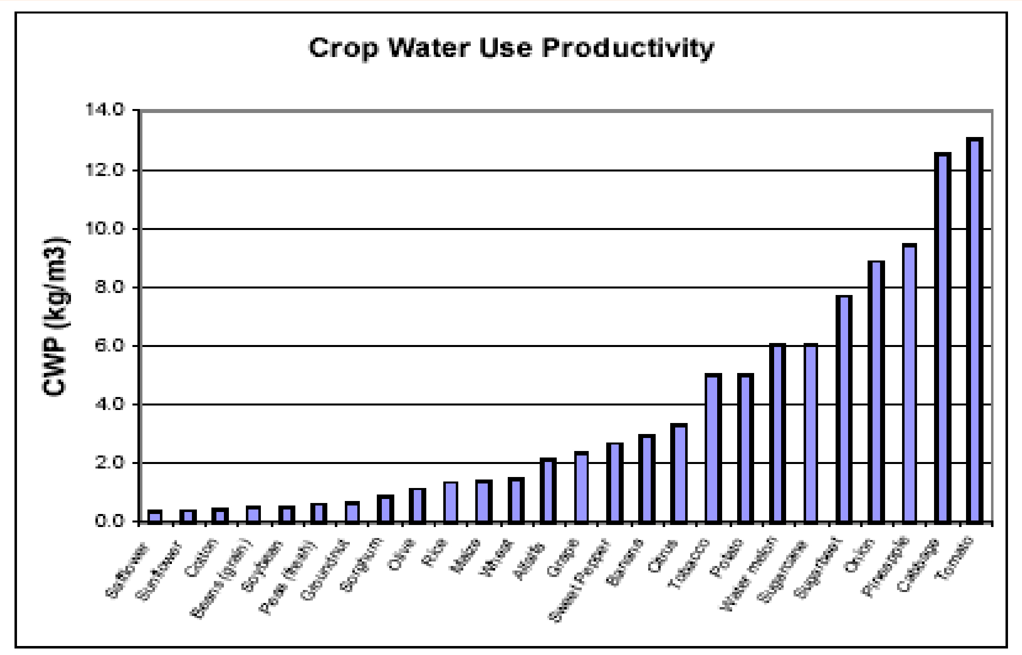

Figure 5.1. Potential water use productivity of some crops (Adopted from Smith, 2000).

Water conveyance efficiency in the main system varies between 95 to 60 % percent. Upgrading and modernization of the main system reduces water losses and increases main irrigation system efficiency. However, farm irrigation efficiencies range between 95 to 40 percent with an average of 80 %. Management of the system is carried out by Water Users Group and individual farmers. Farm irrigation losses can be importantly reduced by re-alignment of farm and field channels, including canal lining and the introduction of on-farm regulating structures. Also, a majority of the world irrigated areas is surface irrigation with an average field irrigation efficiency below 60 percent (Bos and Nugteren 1978) and constitutes an area with the greatest potential for improvement of water use efficiency. However, sprinkler and micro irrigation systems can achieve 70 and 80 % efficiencies respectively

5.4.2.4 Crop water productivity

The timely and adequate application of water to the crop play a key role in the achieving good water use efficiency and productivity. Much irrigation research has been devoted to this field and a range of devices and techniques are available to assist farmers in introducing more efficient scheduling procedures. Adoption of such techniques in the farmers field have been, however, disappointing as scheduling methods have been too complex or time consuming and irrigation supply often unreliable in time and supply.

Crop water use efficiency values are between 70 and 80 %. Scope for a reduction in evaporation losses will be in most cases restricted. Options to reduce evaporation losses include a reduction of the exposure of soil to direct radiation by various covers and mulching materials, by weeding and soil cultivation, by reducing the wetting frequencies or by reducing wetted areas (drip and sub-surface drip). Further scope exists through selective breeding programs aiming at the promotion of varieties that will achieve a rapid leaf growth and soil coverage to reduce evaporation losses in the initial stages of crop growth and at a promotion of root development to extend to greater depth and with larger root density and to achieve a more effective water storage in the root zone.

Present yield levels under irrigation are below potential and considerable scope still exists to raise yields while maintaining or even reducing present levels of water use. As demonstrated in Figure 5.2 this can be obtained in the first place through a further increase in yield by the introduction of high yielding varieties combined with optimal inputs to sustainable levels of fertility and pest control and in particular the provision of a secure and optimal water supply. Micro irrigation provides the conditions where such accurate levels of water and fertility supply can be achieved. Agricultural research has over the past decades ensured a steady increase in yield levels through a highly effective plant genetic selection programme. New micro bio-biology and bio-technological developments are likely to sustain also in the future further growth in yield levels and productivity. Yields under optimal water supply are likely to increase but also there is potential to increase yields under reduced water supply and to limit the adverse effects of water stress. Great expectations are raised with the potential created by bio-technology which would allow intervening directly in the plant development and morphological characteristics, which can have a large potential impact on enhancing water use productivity. Some are real, some are reasonable though uncertain, and some are likely imaginary, at least in the near future. One of the major expectations is to improve yield performance of crops under drought-prone and adverse environments and/or moving up the ceiling of potential productivity.

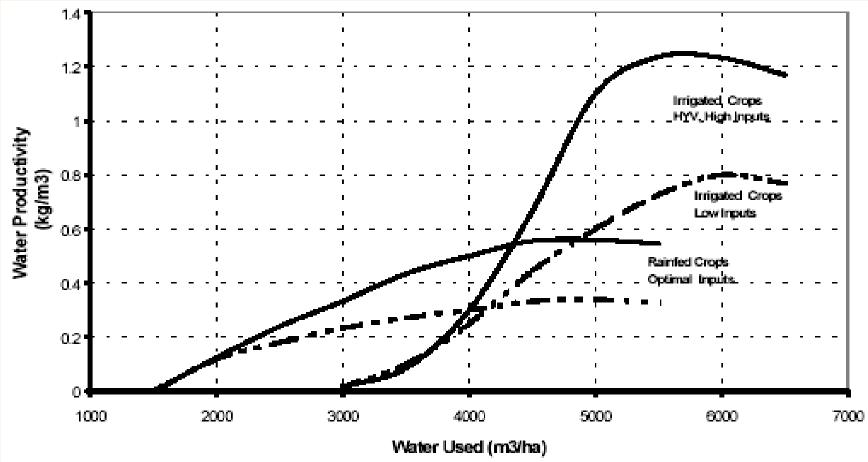

Figure 5.2. Water use productivity of high-yielding and drought resistant crops (Adopted from Smith, 2000).

So far research has been mainly successful in increasing crop water productivity by improving the harvest index. Further options with advanced selection procedures and biological engineering, however, exist to improve water productivity by increasing photosynthetic productivity (psp) and respiration efficiency (re).

5.4.3 Reservoir operations under drought conditions

Water resources management is concerned with providing adequate water to meet various demands, particularly during the periods of shortages. Careful planning is of vital importance in order to make the best use of stored water. Given that most of the reservoirs are multi-purpose, operating these systems under reduced supplies during droughts pose multiple challenges. Reservoir operating policies if supported by early warning systems can derive the best benefit by satisfying the system's objectives.

In reservoir operations monthly or seasonal constraints are usually used, based on the idea that the same water releases must be provided on a specific month every year. Operating rules generally provide a schedule indicating what releases are to be made and what storage volumes are to be maintained at any time of the year. Although this may be a reasonable demand constraint, if there is an indication for a potential drought it may be necessary to adopt a conservative policy in early months of the year. A special approach in reservoir operation is necessary when dealing with a drought. Water supply managers prefer applying water restrictions before the impending drought of longer duration to avoid longer duration shortages, called hedging (3). The objective is to release the minimum possible amount of water from the reservoir that will satisfy the downstream demands thereby conserving water storage for a better water balance during the period of a drought. However, hedging rules for triggering reduction, onset and magnitude of reduction needs to be quantified and has to be based on the characteristics of the impending drought situation based on water storage and reservoir inflows, minimum water release imposed by critical demands etc.

Reservoir operations under drought situation not only require monitoring but also prognostic information about stream flow potential in the coming season to develop proactive strategies such as restrictions and hedging. An operating policy that can effectively respond to developing drought situation should be based on observations of all the available hydrologic indicators. A decision has to be made as to what the optimal operating policy should be for the severity level identified based on the Early Warning System. Reservoir studies make extensive use of mathematical models to form optimal operating policies based on probabilistic multi-model stream flow forecasts developed using climatic information generated through early warning systems. These models must be flexible enough to accommodate daily changes, so that the operating policy can be adjusted as the drought situation changes.

Before any reservoir operation policies for drought management can be implemented, it is necessary to establish a methodology for identifying drought and assessing its level of severity based on (a) the magnitude of a drought event, (b) the duration of a drought event, and (c) the conditional probability that a drought event of a certain severity will advance to a drought event of higher severity.

Chapter 6 - Framework for Drought and Water Scarcity Management

6.1 Water resources management

Effective management of drought and water scarcity has assumed a very important place in achieving the sustainable development goals of zero hunger and poverty alleviation. The rising costs of drought relief programmes within the crisis management approach point out to the imperative to focus more on pro-active risk management approach, where vulnerability of the activity that is likely to be impacted by droughts is reduced. Time is here to move away from reactive crisis management and move towards a risk management approach.

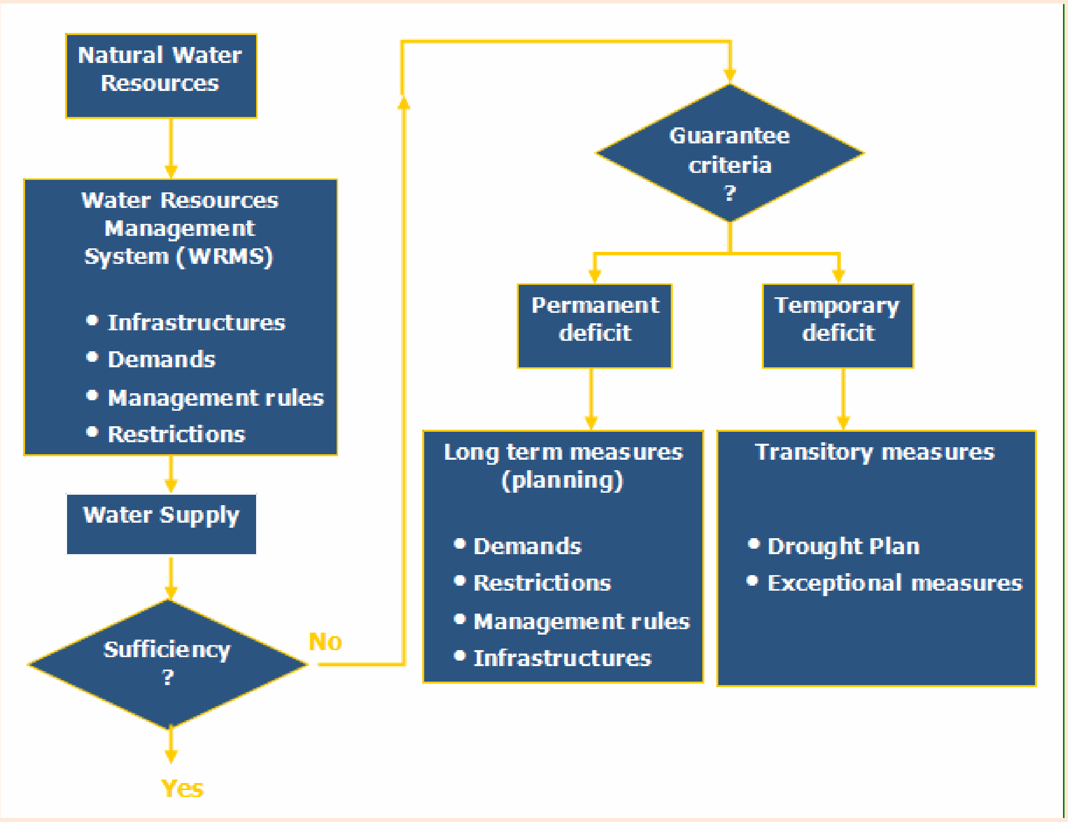

Figure 6.1. Water Management System

Water management is an art of balancing water supply and water demand for various socio-economic needs. The natural water resources availability is variable in nature both in time and space while the demand is almost constant throughout the year. Various options available for meeting the continuous and ever increasing water demands of a community, basin or a country lies in making it available at the place and in time of demand are:

(a) Storing temporally and spatially variable natural water supply; and/or

(b) Transfer of water from the place of its availability to the place of its demand.

In developing and managing water resources, the main objective is to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. The water so managed by putting in place the required infrastructure, and operated through a set of management rules, if it meets the needs at all given times, is considered to be successful. Water resources development and utilisation in most of the developing countries is of utmost importance for their socio-economic upliftment, poverty alleviation programs and food security. A sovereign country no doubt will preserve its basic right of deciding its own priority of developmental needs and most suited options.

If the supply does not meet the demand, it results in deficit. In case the water deficit is temporary, under extreme hydro-meteorological conditions, that is if a drought situation develops, it has to be managed by implementing drought preparedness plans. However, where there is permanent deficit it results in water scarcity situation. Water security requires continuous adaptation of water systems to the growing demands and changing climatological conditions due to the dynamic physical and economic conditions. That is why the water scarcity, i.e., the lack of water availability against water demand is described in terms of physical scarcity, economic scarcity and organizational water scarcity.

Water scarcity and drought situations lead to a fall in the share and allocation of water for agriculture. Particularly, in scarcity situations agriculture has to do more with little. Strategies to deal with water scarcity and drought combined with a risk management approach, supplement each other.

6.2 Framework for managing water scarcity and drought

Policies and interventions that deal with the water scarcity also have a positive impact on dealing with the drought situations. Moving away from reactive crisis management to one that is focused on a proactive risk-based approach is required for dealing with the emergency situations created by droughts. The framework for managing the two requires:

(a) Aligning water, agriculture, and food policies,
(b) Adopting risk-based and Integrated Water Resources Management (IWRM) approaches,
(c) Increasing storages, and
(d) Reducing demand.

6.2.1 Aligning water, agriculture and food policies

At the national level the principles and guidelines imbedded in the Constitution filters down to influence policy at the sectoral level.

Since water scarcity and drought deals with issues such as access to and control over scarce water resources, it is imperative to imbed any policy framework in this regard into the wider policy framework that addresses these issues. With this in mind, framework cannot be detached from the constitutional and wider policy framework in which it is to be applied.

Rainfall, in particular, can be unpredictable and highly variable. There will always be dry and wet years and within those years there will be wet and dry periods. Many societies cope with variability by growing rainfed crops in wet periods, by investing in irrigation, and by building reservoirs with over-year storage to secure drinking water supplies for cities. Whatever steps are taken it is not possible to eliminate all water-related risks. This may be technically possible but may be too expensive.

Drought planning and water crisis management need to be proactive, because the overall policy, legislation and specific mitigation strategies should be in place before a drought or water crisis affects the regular use of the country's water resources. Proactive planning needs to be executed through interactive management, because planning for future drought situations can never be sufficiently accurate.

Reforming water policy by improving incentives for efficient use of agricultural water as part of a broader strategy to achieve water security, is an area of critical importance in the mitigation planning for future drought situations. Research has shown, however, that pricing water for irrigation farmers is inherently difficult, and rural constituencies often show political resistance to higher prices. Although higher prices may be to the detriment of poor consumers and farmers, increasing water scarcity and declining financial resources for water development make such reform essential (Rosegrant & Ringler 2004). It is possible, however, to design water-pricing systems in ways that introduce incentives for water use, recover operating and maintenance costs, and protect or even increase farm incomes.

6.2.2 Adopting risk based approach

The most common approach that has largely been followed over the years, both by developing and developed nations, is centred on post-impact government (or non-government) interventions. These interventions are normally in the form of relief measures and emergency assistance programmes aimed at providing monetary or other specific types of assistance (e.g. livestock feed, water, food) to the victims (or those experiencing the most severe impacts) of the drought. This reactive approach is seriously flawed from the vulnerability perspective since the recipients are not expected to and do not change behaviours or resource management practices as a condition of the assistance.

The framework for management of water scarcity and drought should shift the paradigm from one traditionally focused on reactive crisis management to one that is focused on a proactive risk-based approach that is intended to increase the coping capacity of the community and thus create greater resilience to future episodes of drought. The framework should address to arrest the vicious downward spiral of vulnerability reduction puts the socially weaker sections of the society into poverty trap.

The risk-based approach seeks to increase water security, reduces vulnerabilities resulting from climate variability and water stress. The risk-based approach to water security looks at how societies cope with variability. It requires development and implementation of pre-impact programmes or measures that are intended to reduce vulnerability and impacts, preparedness plans developed in advance of drought and maintained between drought episodes.

Since the vulnerability of the socio-economic activities in a given region are intertwined with the water availability, and the frequency of the hydrologically extreme events such as droughts, no blueprint approach is possible in all the cases. It is unlikely that a single set of options can be designed as the ‘optimal’ solution, nor is a particular option to be seen as desirable – or possible – in all contexts. It is important that policy makers and governments direct efforts at improving the ability of local communities, the farming sector and industries in drought-prone areas, to deal with conditions of drought in the future. This, along with proper governmental management of drought, can greatly reduce the political, economic, social and environmental impacts of droughts on societies.

Irrigation provides resilience to the agriculture against uncertainty of rainfall. The degree of moderation of impact of drought in a given situation would be largely guided by the following:

(a) The relative importance of the irrigation sector in a country’s (or region’s) economy, as well as the composition and relative importance of other sectors.
(b) The quantity, distribution (inter- and intra-year) and security of a country’s precipitation, and other water sources.
(c) The physical, institutional, social and political infrastructure to manage water in general and irrigation water shortages and the impacts thereof in particular.
(d) The social vulnerability of communities to handle (overcome) periods of water shortages.
(e) The level of development of a country and the value of its total resource base.

6.2.3 Integrated water resources management approach

Governments in the arid and semi-arid realm play a key role in the management and distribution of water resources in times of scarcity. It is therefore important that governments develop and implement integrated water resources management policies to ensure the creation of effective water management structures at both national and local levels. The developmental approach seeks to increase water security over time. Integrated planning offers opportunity to enhance management of water demand.

IWRM helps to foster economic growth and sustainable agricultural development, promote democratic participation in governance. IWRM, although a difficult process, is emerging as an accepted alternative to a sectoral approach. It requires infrastructure, enabling environment, and institutional arrangements. It identifies outcomes that are achieved over time through a combination of policies and projects.

The importance of understanding the hydrological cycle when designing water policies cannot be over-emphasized. The interrelationship between surface water and groundwater, between upstream and downstream catchments, between quality and volumes, and the importance of water re-use within river basins – all these have implications for the effectiveness of proposed actions. Water accounting provides a sound basis for evidence-based strategy development and adaptation, as more evidence becomes available. A failure to understand the hydrological implications of proposed actions may lead to unexpected consequences, and well intentioned, but ill-informed, strategies for coping with water scarcity can have perverse impacts on the way water is distributed within the river basin, without achieving the expected savings.

6.2.4 Increasing storages

A recent report from the International Water Management Institute (IWMI) indicates that even with best irrigation efficiency, the world needs an extension of irrigated areas by building more dams and storages. Dams of all sizes - small, medium and large are an essential component of overall and integrated water management systems. They divert water, they retain it over long periods of time to use it effectively and they moderate floods and alleviate impacts of droughts. They provide for the timely and continuous supply of water needed to meet the irrigation demands of crops, livestock and human beings.

Storages provide insurance against uncertainty due to climatic variability, can help reduce variability in season’s low flows in rivers and basically save societies from economic upheavals and losses due to flood and drought. A major portion of water stored behind dams in the world is withdrawn for irrigation which mostly comprises consumptive use, that is, evapotranspiration (ET) needs of irrigated crops and plantations. On the submerged land, there are often possibilities for seasonal irrigation. A majority of dams built in the world are multipurpose in nature, but irrigation is the largest user of the waters withdrawn. This does not necessarily mean that irrigation is also the biggest user of storage. The dams were responsible a few decades ago, for bringing under cropping, additional areas and ushering in the green revolution through high yielding crops and application of fertilisers, imparting food security in the face of ever growing population.

Dams have solved many problems of communities served and have provided basis for economic development that has sustained itself. Employment opportunities have been generated, incidence of poverty has been reduced, rural population including nomads has been stabilised locally and migration of rural unemployed population to urban centres has been reversed. Food security to ever growing population, protection from floods and droughts to chronically vulnerable areas and generation of the cleanest form of energy, namely hydropower, are some other benefits of water resources development. The total amount of water remaining available in a basin with small size reservoirs is considerably lower due to relatively large scale evaporation, than that from a river basin with larger water storages.

Appropriate decision support tools for analysing and, if favourable, implementing water resources schemes involving large dams, should be developed, with due regard to overall national interests, individual basin plans, safe designs and strict monitoring. Larger a facility, the benefits, costs, and risks are usually larger.

But while planning a facility, effort is made for maximising benefits and minimising costs and risks. All these are directed to ensure continued food security through improvement and extension of irrigated and drained areas, increase in productivity and transformation of the rural development scenario throughout the world.

6.2.5 Reducing Demand

Diversion of water for agriculture occupies the largest share of water use globally, and particularly in societies and economies that are agriculture based. Efficient use of water in agriculture is essential in meeting the demand through sustainable irrigation management. Particularly, in the case of physical scarcity the only means to bridge the gap between the supply and demand is by managing demand. Where water is scarce, particular attention should be paid to the re-use potential of recoverable non-depleting uses at every stage of planning, designing and implementing multipurpose water supply and use schemes (UN-Water, 2009). Various options that are available, particularly in meeting agricultural sector are: crop productivity increase; reduction of losses; water re-use and recycling; inter- and intra-sectoral allocation; desalination and in many cases food import (virtual water).

These interventions are limited by various physical, economic and organizational capacity of the country or a region. Furthermore, there are no 'one-size-fits-all' solutions to increasing water security, and that appropriate measures will depend on local conditions and available coping capacity. Therefore, a framework to guide the actions of the governments and the communities that lays down the broad principles are presented.

6.3 Drought policy and preparedness plans

6.3.1 Drought policy

Both the development and the implementation of a comprehensive drought policy are the responsibility of central government. It is an inclusive process that must include all the relevant state departments (e.g. Agriculture, Environmental Affairs and Water Affairs in the case of South Africa), as well as relevant non-governmental agencies such as agricultural unions and water user associations.

Risk management and proactively factoring in the possibility of drought by individual farmers is strongly emphasised both in the Disaster Management Policy, the Agricultural Policy as well as the Drought Management Strategy. This place the onus on farmers to manage risks associated with events such as droughts, as well as to insure against the impacts of natural disasters such as droughts.

A comprehensive approach to drought management is needed to counteract the major setbacks of drought impacts namely the direct loss of existing national assets and the diversion of national resources and effort from ongoing subsistence and development in an effort to achieve adequate recovery from drought. In developing a comprehensive approach there needs to be a balance between prevention, mitigation, preparedness, response, recovery and disaster-related development (National Department of Agriculture 2003: 18).

While the drive to develop a national drought policy should come from the central government, governmental structures on the provincial and local levels should also be involved in the process from the beginning, since these structures play a crucial role in disaster relief through the mobilisation of local resources (Abrams, 1997; Wilhite, 1993b: 92). The 10 steps in developing a drought policy and preparedness plans are:

Step 1: Appoint a national drought management policy commission

Step 2: State or define the goals and objectives of a risk-based national drought management policy

Step 3: Seek stakeholder participation; define and resolve conflicts between key water use sectors, considering also transboundary implications

Step 4: Inventory data and financial resources available and identify groups at risk

Step 5: Prepare/write the key tenets of the national drought management policy and preparedness plans, including the following elements: monitoring, early warning and prediction; risk and impact assessment; and mitigation and response

Step 6: Identify research needs and fill institutional gaps

Step 7: Integrate science and policy aspects of drought management

Step 8: Publicize the national drought management policy and preparedness plans and build public awareness and consensus

Step 9: Develop education programmes for all age and stakeholder groups

Step10: Evaluate and revise national drought management policy and supporting preparedness plans

Policy on drought management in South Africa is closely linked to policy on disaster management and is essentially a component of the latter. Within the framework of the Policy on Disaster Management, a National Drought Management Strategy has to be formulated that is in line with the Disaster Management Act (no 57 of 2002). A key component of the National Drought Management Strategy is that drought management is not the responsibility of the national government, but should be an integrated effort of the National and Provincial Departments of Agriculture, local governments, the farming community, the private sector and civil society (National Department of Agriculture 2003: 8).

6.3.2 Response based on preparedness plans

Drought has both a physical and a social component. Therefore, social factors such as level of development, demographics, water demands and government policies determine vulnerability to the effects of drought (Nairizi 2003). If drought impacts are to be mitigated, strategies towards this end should incorporate these factors. O'Meagher (1998: 245, 250) emphasises in this regard that there is a need for a more integrated approach to drought risk management that would 'integrate and articulate risk management, welfare and economic efficiency objectives'. Particularly in the South African context with its sector of subsistence and developing farmers, an integrated approach that takes factors such as nutritional, health, welfare, employment and water factors into account needs to be considered.

6.4 Enabling Environment

Once the basic framework is in place, a process of policy formulation can develop. However, even if all elements are in place, there is no guarantee that the policies will be appropriate. It is important to ensure that all those interested, especially those defending the public interest, are able to play their roles. As a general rule, the more open the process of policy formulation, the more likely it will be that the policies will respond to the public interest and that their implementation will be successful. Policies defined in an arbitrary and authoritarian manner against the will of the population are destined for failure, even when they seem to be correct from a technical point of view (Carman, 2005).

(a) Knowledge based strategies
(b) Institutional structure with appropriate linkage
(c) Roles and responsibilities of basin and other water sector organisations at different levels in the government, nongovernment and private sectors
(d) Effective co-ordination mechanisms
(e) Appropriate economic instruments

6.4.1 Knowledge base strategies

A clear understanding of the causes and effects of water scarcity as well as the droughts their causes and the vulnerability of the society that turn them into disasters is required. The strategies to deal with them need to be based on a knowledge base. The management framework should be founded on such an understanding both at national and local levels. A detailed accounting of water supply and demand should be used as the starting point, and the basis for identifying, adapting and developing coping strategies. This should recognize that there are limits to the water that can be exploited, and that there might be multiple causes for water scarcity (on either demand or supply sides), all of which vary in time and space. It is also important to understand linkages with the different sectors of the economy, as the prime causes of water scarcity are likely to lie outside the water domain (e.g. economic or agricultural policies that encourage unsustainable use of water resources). It is therefore important to base strategies on the best evidence available. Information is a critical element for mediating and conferring power within societal relations. Without correct information society has no basis on which to challenge factual errors or biased positions.

6.4.2 Institutional arrangements

A policy can only be implemented if certain institutional arrangements are put in place to give effect to the policy. With regards to water policy, the establishment of the National Water Resource Strategy is instrumental in practically outlining the strategies, processes and arrangements necessary to achieve the objectives of the National Water Policy. Similarly, the Drought Management Strategy would give effect to the principles and objectives of the Policy on Disaster Management as far as this policy pertains to drought. In the same way, drought mitigation, early warning and management would benefit from the explanation of institutional arrangements, clarifying the institutions to be set up, the processes to be followed and planned interventions.

The development of a national drought policy should entail the recognition of drought as a consistent natural hazard; cooperation with state and local stakeholders; the creation of a regional forum to assess regional needs and resources, identify critical areas and interests, provide reliable and timely information and coordinate state actions; and the appointment of a single national agency to coordinate drought preparedness and drought response. For government to react effectively to disasters in general, and drought in particular, it needs to centralise its drought-related activities within a single committee or institution charged with the overall management of drought during both drought periods and "normal" climatic conditions. Such a committee/institution must be multidisciplinary and must have the necessary authority to act.

6.4.3 Water governance and institutional capacity

As supply reaches its limits in an increasing number of regions, demand-management options become more prominent in coping with water scarcity, which calls for stronger and more effective institutions. Water scarcity will also arouse tensions between users, with the likelihood of negative impacts on politically weak and marginal social groups and on the environment. Strong institutions will be needed to guarantee equitable distribution of benefits among different categories of water users.

There is, in fact an entire range of community-based coping mechanisms to help people withstand periods of severe drought. Amongst these are gifts of food to impoverished kin, credit to buy food and other necessities, and fostering of children by wealthier households. Even after a period of drought has ended, reciprocal mechanisms are maintained to redistribute assets in an attempt to aid the recovery of poorer households. These include the loaning of seed, tools and food, the loaning of cattle to reconstitute herds, and other informal forms of credit assistance.

Local strategies – whether adopted at individual, household or community level – are part of wider contingency plans, reinforced by indigenous information and diagnosis Davies (2000:5). Although monitoring indigenous coping strategies is regarded an essential and effective element of drought management and the development of early warning systems, examples of actual strategies are rare and not well reported. In addition, monitoring coping strategies is a complicated process and necessitates detailed understanding of local livelihood systems. As a result, the monitoring of local coping strategies and development of indicators are often rejected by national policy makers and planners on the grounds of cost, time and lack of sound scientific requirements. The challenging question therefore is: How can multiple rural perspectives and perceptions of drought be taken into account in public policy formulation?

6.4.4 Community participation

For a community to become resilient, poverty must be eradicated and families must have a stable income to meet their basic needs and to enable them to face any economic crisis caused by drought. In the rural areas of developing countries, community structures and capacity should be strengthened to assist communities in overcoming the difficulties associated with prolonged periods of drought and water scarcity. If special attention is given to women in development programmes, particularly in training and credit facilities, rural development can also reduce gender inequality while improving food security. This will also help to reduce the burden on urban areas to supply job opportunities to rural migrants during times of drought.

People’s social perceptions of drought – or any other hazard - are contained in complex narratives of assumed cause and effect that suggest a multiple range of “truths” and “realities”. Taking (rural) people’s perceptions seriously is therefore of crucial importance for a number of very practical reasons. It is, first of all, widely recognised that technicians, scientists and policymakers do not have all the answers and that local understandings are often important in helping to clarify the complexity of issues. In addition, for policies dealing with drought to be effective they must have legitimacy and the administrators must be trusted. Taking cognisance of people’s risk perceptions is fundamental, as people will respond to what they believe to be the case, rather than to the views of scientists.

From the foregoing it is possible to outline a number of principles that should be considered in formulating guidelines in order to evaluate the impacts of drought and water scarcities.

(a) Equilibrium must be sought between the carrying capacity of the natural resources, particularly water resources, the size of the population and the amount and type of economic activities.
(b) Policy responses should therefore focus rather on local cultural knowledge that can assist in the evolution of new attitudes and behaviours consistent with achieving sustainability than on cultural factors that may impede such advances (O ’Meagher 1998: 251). There are currently very few links between macro and micro levels – particularly in developing countries – which severely compromises the effectiveness of drought preparedness and mitigation in these countries.
(c) Solutions to minimise the negative consequences of irrigation droughts will be country and area specific, not only because the relative composition (importance) of causes and impacts may differ, but also because the economic, social, cultural and political circumstances will/may differ. In this regard, mention should be made of differences in resources available for disaster relief, differences in socially and culturally acceptable systems, approaches, policies and strategies; difference in knowledge, as well as differences in infrastructure.

A large share of water to meet new demands will have to come from programmes aimed at saving water from current inefficient consumption patterns. This implies a comprehensive reform of water policies with cost implications for all users. Such reforms, however, may clash with, amongst others, cultural and religious beliefs in many countries that treat water as a free good. If not considered carefully, water policy reforms might therefore easily instigate conflict between indigenous communities and the authorities. Additional research is necessary to assist in formulating of specific policies in any given country. At the same time however, rural perceptions on water consumption and utilisation should be recognised as part of a valid indigenous local knowledge system, and should as such be accommodated in policy formulation.

Appendix I

A.I Water Scarcity and Drought Situation in Different Countries

This Appendix provides a glimpse of aridity, water scarcity and drought situations in some of the countries of the Middle East and North Africa: Egypt, Jordan, and Libya; in SADC region; in Asia: Iran and India; and OECD countries: Australia and France. Various means by which the water scarcity is tackled in some of the countries and the shortcomings of the present practices have also been shared.

A.I.1 Middle East and North Africa

The Middle East and North Africa (MENA) region extends over 17 countries, representing a total land mass of 9.5 million square kilometres i.e., 7 % of the total world land area. The problem of water shortage in dry-land farming is caused by low annual rainfall and unfavourable distribution of rainfall through the year. The rainfall does not suffice to support dry farming trees and crops.

A micro–catchment consists of two elements: the runoff area and the infiltration basin. Micro–catchments–water-harvesting (MCWH) for increasing crop production on dry-lands has been the subject of considerable research for the last several decades. Tavakoli (2004) conducted a study during the 1999-2003 on farmer field on split–split –factorial plot design for five replications. The treatments included two MCWH methods (small basins and semi-circular bunds), three catchments sizes (25m2 (5*5, R=2m); 49m2 (7*7, R=2.85m) and 81m2 (9*9, R=3.7m)), three runoff area treatments (Natural, cleared and smoothed, wetting and compacting) and two-infiltration area (Natural, soil mixed with polymer as 1 kg/tree). Results indicated that survival percentage of trees at farmer fields was about 35-55 % but at this project it was 99.9%. Polymer had no significant effects on increasing water saving. Although small basin (9*9) + compacted + without polymer treatment was the best results but based on economic analysis, small basin or semi-circular bunds (7*7) + compacted + without polymer treatment are recommend.

A.I.2 Egypt

Egypt is a highly arid country and The Nile, Egypt's only river, provides 97% of the country's water requirements. The remaining 3% come from ground water and rainfall. The Nile River Basin consists of the White and the Blue Nile. The Blue Nile which constitutes only around 10% of the entire Nile Basin area, however, contributes about 60% of its total mean annual flow measured at the High Aswan Dam (Sutcliffe and Parks 1999). Thus, runoff variability in upstream countries, such as Ethiopia where most of the Blue Nile flow is generated, is of great importance to the sustainable development of downstream countries such as Sudan and Egypt (Yates and Strzepek 1998; Tafesse 2001). The increasing water demand of upstream countries in the Nile Basin coupled with climate change impacts can affect the availability of water resources for downstream countries and in the basin.

The seasonal and annual fluctuation of the River Nile's natural flow may cause tremendous difficulties for Egypt. Early information about the river flows was always necessary for short term planning in order to work out strategies to cope with water shortage and drought.

The Ministry of Water Resources and Irrigation (MWRI) of the Arab Republic of Egypt continuously strives to develop and improve the use of the country's limited water resources. It was recognized that the MWRI could not fulfil such task without the support of an operational hydrological monitoring and forecasting system for the River Nile. This would be needed in particular when the available inflow into the Aswan High Dam reservoir approaches, or becomes less than, the agricultural, industrial and domestic demand.

When the demand approaches or exceeds the available supply, the supply would have to be augmented by over-year storage. In those cases a reliable seasonal forecast of the magnitude of the expected supply, this is the inflow into the Aswan High Dam reservoir, becomes extremely valuable. Short-term forecasts become very valuable, both in magnitude and timing, for operating the reservoir when it is nearly full or nearly empty.

A.I.3 Jordan

Jordan is facing the most serious water shortages in the Middle East. It is an arid country located east of the Jordan River with a land area of about 90,000-km. Contour stone terraces have been widely used by Jordanian farmers in the hilly areas for soil and water conservation purposes. Traditionally, farms were subjected to systematic deep ploughing to break up the surface rocks and then remove stones for installation of terraces. This method is very expensive and cause complete disturbance to the area that may enhance soil erosion.

A new land reclamation method for water harvesting has been experimented in the hilly parts of Jordan since 1999. Abu-Zreig (2004) in an experimental project attempted to adopt a new reclamation method for highlands of Jordan using water harvesting techniques. The study watershed located to the North West side of the country around the city of Ajlun in a mountainous area ranging from 500 - 1250 m above sea level with steep slopes, valleys, and numerous springs. Traditional water harvesting systems used in the study areas include: Ajlun, Terracing, Concrete catchment area with Cistern, Collection Ponds, Muwaggar. Water harvesting systems adopted in this research include: Runoff storage pond, Contour tree bunds, Semi-circular earth bunds, Water spreading structure, and Contour ridges. Three sites with various slope, soil characteristics and topography have been chosen for experiments. The method consists of designing semi-circular stone bunds randomly based on the micro topography of land. Semi-circular bunds were located at areas having deep soil pockets and adequate runoff rocky area. In this method no deep ploughing was necessary and lands were subjected to minimum disturbance. This method has many advantages including minimizing soil erosion and maximizing rainfall harvesting due to the high runoff efficiency from runoff rocky areas, promoting biodiversity yet having similar cropping density to that of traditional method. In addition the cost of this method was about 85% less than that of the traditional conservation methods used by the Jordanian farmers.

Field evaluations showed that semi-circular bunds were very effective in capturing runoff and preventing soil erosion from the cropping areas. The soil moisture in the cropping areas was about 7% higher than that in the control areas. Field measurements showed that soil depth in some of the cropping terraced areas increased by about 3 cm at the end of the 2003/2004 rainy season. Based on the experimental results, Abu-Zreig (2004) recommends that construction of low cost semi-circular stone terraces increased the area of agricultural land and increased land value. Water catchment systems are essential to solve crucial social problems mainly in rural areas with scarcity of water and lack of basic crops and forage.

The introduction of random semi-circular stone terraces to farmers in Jordan was successful. Many farmers are adopting this method in to their farm land which was previously considered marginal land. Semi-circular terraces have proven to be effective in reducing soil erosion and increasing moisture level in the cropping areas. Field measurements have shown that semi-circular stone terraces improve the survival rates of medicinal plants to 90% and also increase moisture level in the cropping area by about 7%. A successful application of water harvesting depends mostly on their compatibility with land use and population practices.

A.I.4 Libya

The rainfall drops from 350 mm near Mediterranean coast in the north to less than 100 mm in the central zone, where semi-desert/ desert climate dominates. Because of non-existence of any regular river or perennial stream, is one of the most water scarce countries. Rainfall is the major source of livelihood of the farming communities in the country. Razzaghi et al. (2004) studied attempted to evaluate and document rainwater harvesting practices in the past and to present results of an experiment was conducted in the same environment in order to demonstrate the usefulness of appropriate water harvesting technique that suits to the country environment.

The experiment aims at real-time testing and evaluating the two potential micro-catchment rainwater harvesting techniques in order to improve bio-mass production in a certain agro-climatic and geo-physical environment, which largely prevails in the northern areas of Libya. The project aimed at studying the old traditional methods used in rainwater harvesting, evaluating them technically and economically as a first stage, then initiated a strategic research aimed at developing methods and approaches for optimum utilization of rainwater techniques by developing those techniques and introduces new ones. In this framework, as a first stage, the formed team for this purpose conducted a field survey and comprehensive compilation of old and modern techniques utilized in rainwater harvesting existing in the western area of Libya. They were classified according to the size of catchment area and water storing method, whether being in soil, in ground reservoirs or behind dams.

Following completion of this stage, members of the team carried out some field experiments, by applying rainwater harvesting techniques such as Negarim basin and contour ridges in developing natural pasture in semi-arid region in western part of Libya using Atriplex shrubs. Although tangible results were not achieved in the first year of the experiments carried out in 1998/1999 season due to scanty rain, as quantity and density, but by the end of 2000/2001 season a good growth of the shrubs used in the experiment have been noticed compared with the ones planted outside the techniques.

A.I.5 Southern Africa

The climate is semi-arid with an average rainfall of nearly 500 mm, which is highly variable. Annual rainfall amount declines from above 800 mm in the East to below 200 mm in the West. Although variations occur between years, clear cycles of approximately 9-10 years below average rain followed by above average rain, have been observed in summer rainfall areas. Droughts of varying extent are a regular occurrence in South Africa. Various combinations of meteorological, hydrological and agricultural droughts are regularly experienced in South Africa, particularly in the periods 1925 to 1933, 1962 to 1971 and 1982 to 1995, droughts had wide-ranging negative socio-economic impacts. During the last mentioned drought period, financial assistance in the form of livestock reduction in extensive grazing areas, pasture conversion on low potential arable land, debt consolidation or debt write-off in mainly rain-fed maize production areas and water quota subsidy schemes on government irrigation schemes, were provided by the Department of Agriculture. Although it prevented financial ruin of many farmers and stabilized rural economies, it also highlighted the disparities between conservation and exploitation farming as well as the distortions that are introduced with subsidization of agricultural enterprises.

It can justifiably be argued that, if seasonal or periodic droughts are a normal phenomenon, then planning and operation of farming activities must adapt to these circumstances. Agricultural policy regarding drought management in South Africa has therefore changed away from intervention with subsidies towards assistance with providing better information. This shift in public policy has taken place within a broader new approach to disaster management, where drought is recognized as one potential natural disaster.

The challenge is now to ensure that research and extension provides the necessary information and knowledge, which will enable farmers to follow sustainable management practices within a farming systems approach. In addition, reliable early warning systems must be implemented, which will also enable farmers to correctly and timely adapt to expected changes in the climate and weather. Unfortunately, however, insufficient research and extension capacity is currently available to address these challenges. The first corrective step has now been taken with formulation of the draft. If past cyclical rainfall patterns will continue, indications are that the next drought period in South Africa is imminent. A sense of urgency must therefore be created to ensure that both farmers and public servants are prepared for the next drought event. The real test of the success of the new drought management policy in South Africa therefore still lies ahead (Backeberg and Viljoen, 2003).

A.I.6 Ethiopia

Tigray is one of the most degraded and drought prone areas of Ethiopia with recorded famine evidences in the last two centuries. Moisture stress is particularly severe due to the erratic and insufficient rainfall. In marginal rainfall areas of Ethiopia, recurrent dry soil conditions have been attributed to low infiltration of rainwater and high runoff due to soil surface sealing and crusting properties. This runoff water should be conserved in the soil in order to sustain crop growth conducted a field study in Alemaya catchment, Eastern Ethiopia, using four rates of residue cover (0, 2, 4, and 8t/ha of wheat residue) with the objective of evaluating the effect of rainfall characteristics and crop residue management on runoff for two main rainfall seasons. The combined runoff data for the two seasons showed that runoff decreased non-linearly with an increase in the percentage residue cover. The result also showed that the minimum amount of residue required to effectively conserve rainwater depends on the storm characteristics in general and rainfall intensity in particular. In almost all the cases a residue cover of 2 t/ha (62% surface cover) effectively reduced runoff with the exception of two storms where at least a residue rate of 4 t/ha (76%) was required, because of exceptionally high intensity storms.

The runoff generated from a given area is a function of the rainfall characteristics. Relationships between runoff and rainfall characteristics, such as the amount, erosive nature of the ground and kinetic energy were established from the two-year data set that could be used for prediction of runoff under similar soil and climatic conditions. The results from this study indicate that residue cover is an important factor in reducing runoff for this particular soil and climate condition. However, it was observed that the effectiveness and the amount of surface cover depend on the rainfall characteristics in general and the intensity in particular.

The regional Government established in 1994 the Commission for Sustainable Agriculture and Environmental Rehabilitation in Tigray (CoSAERT) to construct 500 dams and to irrigate 50,000 ha up to 2004. So far about 44 earthen dams with related irrigation facilities have been constructed, while 47 are designed. A research is underway in two of the schemes, Gumsalasa and Korir, with a major objective to develop an integrated approach and modelling tool for sustainable land and water development and management in Tigray. Preliminary results show that with a potential reservoir capacity of 50.7 million m^3, the 44 dams have a potential irrigable area of about 2,965 ha of which about 1,418 ha is currently being irrigated. This actually irrigated area is smaller than the designed one due to insufficient design data, inadequate water management practices and rainfall fluctuations from year to year.

Irrigation development in the two schemes offers a large potential to generate a considerably increased income, which clearly shows the important role of irrigation in the improvement of the livelihood of the region's poor farmers. The inadequate water management practices, especially with respect to allowing the individual farmers to decide the delivery time is threatening the sustainability of the schemes. The effect of this mismanagement is two-fold. On the one hand, the excessive water application is causing irrigation water to be wasted and less area irrigated. On the other, it causes waterlogging and gradual accumulation of salts on the fields. Therefore, studies related to the impacts of the existing practices on the sustainability of the irrigation schemes are vital. The existing restrictive measures seem to be always victimizing the downstream, lower reach farmers. This practice is not equitable and socially fair. Therefore, the possibility of introducing other mechanisms such as extending the irrigation interval, reducing the delivery time, and reducing the area irrigated by the individual farmers has to be studied (Yazew et al.)

A.I.7 Iran

In arid and semi-arid regions of south of Iran, most of irrigation water is provided from groundwater resource. Recently, demand for water has increased because of development of agricultural sector, so that more water is pumped and water balance of groundwater of most areas are going to be negative. This means the natural recharge from precipitation is less than discharge from water table. Artificial recharge is used for water harvesting to sustain agricultural activities of these areas by diverting surface runoff during rainfall which flow through Wadis. Since 1990, about 56 projects were chosen and constructed in the southern provinces (Fars, Bushehr and Kohkiluye-o- Boyrahmad) and harvested approximately about 102 MCM per year. This volume of water recharged to groundwater table of catchment areas. Each project consists of all or some of these structures: diversion dam, levee, diversion channel, settling basin and ponds. Surface runoff of catchment's area flow through Wadis and divert to settling basin and impound in ponds. Impounded water gradually infiltrates into the groundwater and recharges it. Farjood and Malekzadeh (2004) discussed, site investigation, site selection and some design criteria of these groundwater artificial recharge projects. Based on their study, the method of artificial water recharge is a method to make maximum use of the limited precipitation in arid and semi-arid regions.

Although enough data gathering and scientific research has not been carried out on these projects, but farmers are very satisfied with the results of these projects. As a result, people and farmers using underground water for agriculture are ready to take part in the investments of such projects. A distinguished advantage of these projects relative to other projects of water harvesting like dam construction, is its low cost and short construction period. The rise in water table level, one to two years after finishing the project is detectable. Controlling flood hazard and stopping salty ground water attack on fresh ground water aquifers are other advantages of these projects.

One way to increase ground water quality and quantity wherever accepted good quality floodwater is available for recharging is a recharging system. However in practice, like many other natural resource projects, this system has some real difficulties. Among the main difficulties is clogging phenomenon, which occurs through sedimentation by fine particles over the surface of water spreading systems. The extent of this sedimentation clogging can be monitored through infiltration measurements in the system. Boroomand Nasab et al. (2004) investigated a floodwater-spreading system that is constructed and started to work since 1997 on the eastern part of Dehloran colluvium plain in Iran.

The objective was to measure and monitor the variation of the infiltration and clogging phenomenon. The vertical variation as well as flow direction variation of the infiltration is studied. The vertical variation of infiltration of the sediment is measured at five surfaces, (1) at the surface of the whole sediment deposited since 1997 when the system is started to operate, (2) at the surface where the new deposited sediment is removed, (3) at the surfaces when 10, 20, and 30 cm of the previous natural sediment are removed. To monitor infiltration in the flow direction, infiltration is measured in the desilting basin, spreading channel, spreading basin, and control points. Double ring method was used to measure infiltration at these surfaces. The statistical analysis showed that sedimentation significantly decreased the surface infiltration of the desilting basin when compared with the data obtained from the control points. With removal of the top 10 cm of the natural surface showed that the infiltration rates were significantly increased. Therefore, in order to decrease the adverse effects of sedimentation on reduction of the infiltration rate in the desilting basin, the results of the experiment recommend removing the recent sediment of the basin and also ploughing the top 10cm of the natural surface below the removed sediment. The ploughing is effective to lessen the clogging phenomenon of the sediment.

Agro-climatic approach to increasing the rangeland productivity proves to be one of the trends in effective use of natural rangelands and in the improvement of their productivity and sustainable development. By doing these measure, the rangeland yield can increase to optimum level corresponding to the potential possibility for providing adequate moisture for a given region. There is a different degree of runoff of atmospheric precipitation from the surface of the rangelands that can be used to meet their moisture requirements. As a result of irrational rangeland management for a long period of time in Iran, the vast areas of natural rangelands have been degraded to a considerable extent.

Rangavar et al. (2004) studied runoff coefficient and soil stored moisture coefficient of autumn-winter and spring precipitation during 1996-2000, in Sanganeh experimental area, 70 Km in the North East of Khorasan province of Iran. A number of 23 elements of the relief were studied with a total number of 80 runoff plots. Four groups of them are distinguished with respect to the type of soil, the vegetation, and their slope. Based on the results of their study, the accumulation of moisture in the soil occurs from the beginning of winter, in December 50%, in January 78% and in February 73% of the total amount of precipitation. The amount of moisture spent on the total evaporation in winter averages 33%, while the surface runoff is insignificant 2%. In spring, the ratio of the utilization of the atmospheric precipitation alters substantially. Thus, in March and April, the amount of moisture spent on total evaporation averages 62%, the infiltration of moisture into the soil is 37, and only 1% is spent on surface runoff. In table A.I.1 values of Coefficients of accumulation (Ka), Evaporation (Ki), and Run-off (Kr) on experimental section Sanganeh in winter and spring of 1996–2000, and in table A.I.2 possible runoff volume with different inter–row width, (Distance between plants in row 1 m) are provided respectively. These coefficients can be used for other rangelands rehabilitation with similar conditions. On the basis of this research, a model was also made to determine best distance between rows of planting in artificial pastures for optimum production and water requirement.

A.I.8 Pakistan

The incidence of drought is becoming an increasing problem in Pakistan. Qureshi and Smakhtin (2004), reviews the extent and effectiveness of indigenous strategies for mitigating the effects of drought. The incidence of drought in Pakistan is becoming increasingly common with substantial consequences on food security, livestock production, environment and natural resources. During the last 5 years, the country suffered from the worst drought of its history. Due to low and erratic rainfalls, the provinces of Baluchistan and Sindh are more vulnerable to droughts. During the past drought some 2.5 million livestock died and the national growth rate plunged from an average of 6% to below 3%.

Table A.I.1. Coefficients of Accumulation (Ka), Evaporation (K i), and Run-off (Kr) on Experimental Section Sanganeh in winter and spring of 1996 – 2000.

Item no.	Brief characteristics of runoff	Area	Winter			Spring		
		M2	Ka	Ki	Kr	Ka	Ki	Kr
1	Hillsides with various exposure with slop of 20 to 30, soils- lithosols, Vegetation, Artemisia--, Poa bulbosa, Carex- and Salsola SP. Vegetation cover-10-20 %. Five plots	10	0.65	0.33	0.02	0.37	0.62	0.01
		20	0.66	0.33	0.01	0.37	0.62	0.01
		30	0.66	0.33	0.01	0.37	0.62	0.01
		40	0.66	0.33	0.01	0.37	0.62	0.01
		50	0.66	0.33	0.01	0.37	0.62	0.01
		Average	0.66	0.33	0.01	0.37	0.62	0.01
2	Hillsides with various exposure With average slop of 30-40 %, Soils- regosols, Rich vegetation- Artemisia--, Poa bulbosa, Carex-- and Salsola --. Vegetation cover, 70-80 %. Nine plots	10	0.63	0.33	0.04	0.36	0.62	0.02
		20	0.65	0.33	0.02	0.35	0.62	0.03
		30	0.65	0.33	0.02	0.37	0.62	0.01
		40	0.66	0.33	0.01	0.37	0.62	0.01
		50	-	-	-	-	-	-
		Average	0.65	0.33	0.02	0.36	0.62	0.02
3	One of the nine plot has a greater slop 50 % and almost No vegetation. Otherwise like group 2.	10	0.61	0.33	0.06	0.33	0.62	0.05
		20	0.63	0.33	0.04	0.35	0.62	0.33
		30	-	-	-	-	-	-
		40	0.65	0.33	0.02	0.37	0.62	0.01
		Average	0.63	0.33	0.04	0.35	0.62	0.03
4	Hillsides with various exposure and moderate slop, soil regosol 1 m. and thicker. Rich vegetation, Artemisia--, Poa bulbosa, and various salsola, Vegetation cover, 80 - 90 %. Eight plots	10	0.65	0.33	0.02	0.37	0.62	0.01
		20	0.66	0.33	0.01	0.38	0.62	0.00
		30	0.66	0.33	0.01	0.38	0.62	0.00
		40	0.66	0.33	0.01	0.37	0.62	0.01
		50	0.67	0.33	0.00	0.38	0.62	0.00
		Average	0.66	0.33	0.01	0.38	0.62	0.00
5	Two plots with mainly Carex SP. Otherwise like group 3	10	0.66	0.33	0.01	0.38	0.62	0.00
		20	0.66	0.33	0.01	0.38	0.62	0.00
		30	0.66	0.33	0.01	0.38	0.62	0.00
		40	0.66	0.33	0.01	0.38	0.62	0.00
		Average	0.66	0.33	0.01	0.38	0.62	0.00
6	Two plots with very gentle slope of 5-10 %, Main vegetation, Carex and Salsola	10	0.66	0.33	0.01	0.36	0.62	0.02
		20	0.65	0.33	0.02	0.37	0.62	0.01
		30	0.66	0.33	0.01	0.37	0.62	0.01
		Average	0.66	0.33	0.01	0.37	0.62	0.01
7	The only plot with no soil and vegetation, Surface-gravel with A, slop of 10-15 %. Consists of two run-off plots	10	0.65	0.33	0.02	0.35	0.62	0.03
		20	0.67	0.33	0.00	0.37	0.62	0.01
	Average parameters for section	Average	0.66	0.33	0.01	0.36	0.62	0.02
			0.65	0.33	0.02	0.37	0.62	0.01

Table A.I.2. Possible runoff volume with different inter–row width, (Distance between plants in row 1 m)

Inter- row Wide, (m)	Run-off coefficient	Volume of run-off with precipitation in spring (Feb.-May), (mm)							
		50	75	100	125	150	175	200	225
10	0.01	5	8	10	12	15	18	20	22
20		10	16	20	24	30	36	40	44
30		15	24	30	36	45	54	60	66
40		20	32	40	48	60	72	80	88
50		25	40	50	60	75	90	100	110
10	0.02	10	15	20	25	30	35	40	45
20		20	30	40	50	60	70	80	90
30		30	45	60	75	90	105	120	135
40		40	60	80	100	120	140	160	180
50		50	75	100	125	150	175	200	225
10	0.03	15	22	30	38	45	52	60	68
20		30	45	60	75	90	102	120	135
30		45	68	90	112	135	158	180	202
40		60	90	120	150	180	210	240	270
50		75	112	150	188	225	212	300	338
10	0.04	10	30	40	50	60	70	80	90
20		20	60	80	100	120	140	160	180
30		30	90	120	150	180	210	240	270
40		40	120	160	200	240	280	320	360
50		50	150	200	250	300	350	400	450
10	0.05	25	38	50	62	75	88	100	112
20		50	76	100	124	150	176	200	224
30		75	114	150	186	225	264	300	336
40		100	152	200	248	300	352	400	448
50		125	190	250	310	375	440	500	560
10	0.06	30	45	60	75	90	105	120	135
20		60	90	120	150	180	210	240	270
30		90	135	180	225	270	316	360	405
40		120	240	300	360	420	480	540	540
50		150	225	360	375	450	525	600	675

The communities living in the severe drought prone areas have indigenous ways of coping with the drought. These include Karezes, Spate irrigation systems, Khushkhaba systems, Bandat systems, recharging aquifers, and introducing new tillage practices. Qureshi and Smakhtin (2004) reviewed the extent and effectiveness of these coping strategies in mitigating the effects of drought. Their results revealed although farmers and communities are doing their best to live with droughts, their efforts were broken down because the drought lasted much longer than normally expected. As a result, incidences of poverty have increased many folds. There is strong need for cohesive efforts, both by the government and local communities, to develop short and long term strategies for drought management in this country.

For drought management, Qureshi and Smakhtin (2004) recommend in order increasing agricultural production and sustainability of irrigated agriculture, the overall strategy should be to increase the water capital and make better use of water. Government must take lead in putting in place the coordination mechanism providing effective oversight. Unfortunately, national-level integrated institutional mechanism is not operational in the country to coordinate drought related programs and to integrate them with on-going federal and provincial drought programs and the efforts of civil society, NGO’s etc. Unless such mechanism is developed, the country will continue to rely on emergency relief after drought.

There is a need to develop a National Drought Policy Commission. The commission should outline course of actions, which includes a preparedness initiative to help reduce the damages and cost of drought. Federal and provincial level partnerships should be developed to ensure that federal drought programs are better-coordinated and integrated with provincial and non-federal programs.

For the formulation of a strategy for the rehabilitation of irrigation systems, a comprehensive database and information systems should be established. This is absolutely necessary for the accurate and up to date assessment and identifying locations where rehabilitation work must be undertaken. Rehabilitation of irrigation systems should be given a priority. The whole irrigation system basin and sub-basin should be systematically surveyed and assessed.

This is necessary to ensure that traditional water rights and allocations are preserved and upstream and downstream impacts and conflicts are minimized and mitigated. This process should be completed with the consultation and participation of local farming community. Farmers should be encouraged to use water harvesting including more water storage structures both small and large. They should be trained in the use of modern water saving technologies and drought resistant crop varieties.

Although Balochistan has limited water resources, it does not make efficient use of what is available. Farmers are ignorant of actual crop water requirements and irrigation-scheduling practices are still largely based on the maximum amount of water a farmer can capture. Therefore, present irrigation practices of farmers include a tendency to over-irrigate. To address this very important issue, research studies focusing on the revision of irrigation planning based on maximum water saving should be initiated. Increasing demand for water has put enormous pressure on the groundwater resources. This coupled with the successive droughts lead to progressing drop in groundwater tables in different parts of Balochistan - to the extent that traditional groundwater irrigation systems (i.e. Karezes, Spate and Khushkhaba) have dried up. This over-exploitation of the resource has caused devastating impacts on drinking water supplies for urban and rural population. For the preservation of this future resource, the government needs to develop appropriate policies to effectively manage and monitor groundwater development and use. Steps should be taken for the revision and enforcement of water laws. Communities should be directly involved in the campaign of artificially recharging the aquifers and in the conjunctive use and management of surface and groundwater resources.

Balochistan has a history of drought of varying severity and will continue to experience it in the coming times. Traditional coping and mitigating strategies have been broken down under growing population pressures and the collapse of the rural economy. For poverty alleviation, farmers should be provided with the opportunities to generate off-farm incomes. Traditionally, the main sources of off-farm income have been hired labour, forest products and small-scale enterprises like carpet weaving, bee keeping, and handicrafts.

Appropriate institutional arrangements should be made for proper coordination of different ministries and line agencies involved in the management of water resources. The roles and responsibilities of these organizations should be clearly defined to avoid overlapping and to ensure effective management of water resources at all levels. A drought management plan is essential for government to ensure that appropriate institutional and legal structures are in place prior to the onset of drought conditions and that the necessary actions are well thought out in advance (Qureshi and Smakhtin, 2004).

A.I.9 India

The eastern part of India comprising states of Eastern Uttar Pradesh, Bihar, West Bengal, Orissa, eastern Madhya Pradesh, north Andhra Pradesh, Assam and NEH Region receive high rainfall. The average annual rainfall in this region ranges from 1008 to 3126 mm. The plains of these regions invariably suffer from excess of stagnating rainwater causing floods and flood related damages. The water resources potential of the eastern region has been grossly under-utilized and the irrigation coverage from major and medium irrigation projects in eastern region has been estimated from as low as 19% in Assam, 40% in Orissa, 43% in Bihar and 57% in West Bengal with regional average development being 44%. As most of the cultivated areas are mostly un-irrigated even a short spell drought adversely affects the stability of agricultural production. One of the major constraints in developing this potential is inadequate application of appropriate rainwater management technology (Paul, 2004).

A supplemental tank irrigation system as small farm reservoir was evolved and specific improved farming system for Chhotanagpur Plateau region at the research station (CRURRS) was evolved. Rainwater harvesting technology based on the water balance and water requirement of the crop and the catchment area to submergence area ratio was developed. Techno-economic feasibility of runoff harvesting and its use for supplemental irrigation conducted show that the best design and stability of the tank is achieved when 1:1 side slopes is used and the tank is located in the excess water drainage ways. Without any lining materials in the tank, the water can be stored up to end of December in the tank at clay loam soil area of the Hazaribagh district which necessitates the use of some cheap lining material or impermeable membrane like LDPE to hold water in the tanks up to the end of winter season (March).

Ground water recharging takes place only during June, July and August and the total recharge in a moderate rainfall year, in the upland areas with red loam soil and the clay loam soil was 224 and 174mm, respectively, with a net depletion of ground water of 29 and 33 mm, respectively in 1988. The depletion rate is faster in the post rainy season than in the proceeding summer months. Methodology of utilization of such rainwater harvesting system for ground water recharging for upland area utilizing incident rainfall was developed for an extended period (13 years). Consequently rain water management practices with upland rice based cropping (rice/red gram barley/lentil) under supplemental tank irrigation system were developed. Probability analysis of various hydrological parameters useful for rainfed crop planning was carried out and six types of distribution functions were tested using rainfall data for the period 1913 to 1987.

Analysis of rainfall record at Hazaribag for 80 years indicated 42 years as drought years, 12 years under incipient drought, 19 years under large drought, 7 years under severe drought, 3 years under disastrous drought and one under extreme drought. A severe, disastrous and extreme drought is expected every five, twenty and fifty years with a seasonal rainfall deficit of 282, 443 and 466 mm respectively as against the mean seasonal rainfall of 1168 mm at the specific situation of Hazaribagh. A new method of qualitative and quantitative estimation of meteorological drought was developed as an improvement over other known methods (Subramanyam's) taking into consideration mean seasonal rainfall and standard deviation of deficit year rainfall instead of annual rainfall series. Water table in heavy and light textured soil of the research farm at Hazaribag indicated that ground water contribution to upland paddy is limited from mid-August to September end.

Natural ground water recharging takes place only during June, July and August and the total recharge in a moderate rainfall year, in the upland areas with red loam soil and the clay loam soil was 224 and 174mm, respectively, with a net depletion of ground water of 29 and 33 mm, respectively in 1988. The depletion rate is faster in the post rainy season than in the proceeding summer months. Weekly water balance studies for the period 1913-92 indicated that

(a) evaporation demand is very high for the first five weeks(May 28-July 1) with no availability of stored rain water;
(b) precipitation is more than evapo-transpiration requirement during July 2 to August 20 indicating that surface run-off during this period can be stored and recycled at later stages of crop growth,
(c) evapo-transpiration requirement is more than precipitation during mid-season (August 21 - September 10) requiring supplemental irrigation which is available even in drought years (1981) from unlined tanks,
(d) evapo-transpiration demand is marginally less but weekly rainfall is reduced drastically resulting in severe moisture stress during crop maturation (September 18 - October 29).

In North- West Himalayan region of India, the annual rainfall is as high as 3000 mm with average of 1750 mm, of which 71 percent is received during tropical monsoon period i.e. July- August months and 79% of the total goes as runoff and stream flow (Sharma et al. , 2004). The rainfall distribution is erratic and uneven both spatially and temporally which results into acute water shortage for the use of both population and agriculture, soil loss and flash floods.

To combat this problem, on farm rain water harvesting is a common practice in the region with traditional methods which contribute 10 % of water availability for agriculture and 40% for the population use and it has further potential for contribution in water availability especially for the crop production with new site specific techniques which include construction of " nala bandhan", "tanka" farm pond, embankment –cum-dug structures / surface ponds and check dams for aquifer recharge and "Johar" or tanks for water storage. Roof rainwater harvesting is also tried in small dug out structures which are excavated in the hard rock and are commonly called as "Khattis" or "Dighis".

To have clean and hygienic water the harvesting done during the end of monsoon was found to be more suitable. In addition, good results of harvesting and storage are being achieved in ferro-cement water storage structures of different dimensions of 3 to 5 m deep and 1 to 3 m in diameter. Sharma et al (2004) found that, the most efficient and cheapest way of conserving rainwater at the agricultural farm was found to be in- situ runoff management, which also reduces soil losses and increases the opportunity time for ground water recharging. The average depth of runoff at 80 percent probability level was found to be 14 cm. It is observed that earthen embankment for rainwater harvesting has cost benefit ratio of 1.38:1. Hence it can economically be replicated. It is also observed that earthen check dam/reservoirs which are recommended across the streams to regulate run off for flood control, trapping silt, collecting water for irrigation and fish production and to recharge ground water has good potential for replication. Excavated dug-out ponds/ tanks are found most suitable for storing runoff in cultivated lands with inverted truncated pyramid shape having 1:1 side slopes with lining of polyethylene sheet of 200 micron buried under 20 cm thick soil at bottom and pitched with bricks.

The rainwater harvesting during monsoon and its use for irrigation during follow scarcity period was found to increase the crop yield by 20-30% during rabi season and additional water for population use by 60 % in the area. They conclude that the erratic and uneven distribution of rainfall both spatially and temporally, necessitates rainwater harvesting to increase and sustain the agricultural productivity. There is urgent need for flood protection and irrigation on farm lands below the hills through control and utilization of run off. Rehabilitation of upper watersheds through reduced run off and erosion from the hills through soil conservation and renegotiation should be done. For successful implementation of traditional and new On farm rainwater harvesting techniques, strengthening of Implementing Agency's capacity should be done for undertaking investigations and research of surface hydrology, groundwater and micro-watershed studies (Sharma et al., 2004).

In the western state of Gujarat, in India, construction of check dams have been taken up by government as well as the Non-government Organization (NGO). Government agencies involved are local government (Panchayat), forest, District Rural Development Agency and regular state Water Resource Department. Under public participation scheme of government of Gujarat (SPSJSY), major chunk under this scheme has constructed. Creation of water bodies increased irrigation, availability of drinking water for self and livestock, recharging of underground water due to pressure created by standing pool of water behind check dams. Another side of the coin, negative impacts are silting, weed growth, increased water related disease, attraction of wild life towards water bodies, loaded drains become barrier for wild life migration, wild life damaging the crops and attacking livestock etc.

Another negative impact will be the reduced flow in the downstream rivers and estuaries mostly in the starting years, as water will be stored behind check dams in initial years, part of which going into recharging process. Singh (2004) evaluate the impacts of check dams on environment: in the state of Gujarat in India. He concludes that coming to the water conservation, Check Dams are very effective tools, a very sustainable livelihood approach, to conserve and harvest the water. Lessons learnt while implementing large schemes have shifted the focus towards small check dams. Villagers are taking the concept seriously and getting them involved as community participation, benefits are clearly visible, new sense is prevailing and changes are felt. Environment though important is not so serious that we may start banging our heads. Impacts are felt but confinable with local factors. Here positive impacts are dominating over negative impacts and negative impacts manageable with mitigation.

With the advances in technology a numbers of preventive remedial and mitigating opening and measures are now available to prevent, reduce and even eliminate the possible adverse impacts. In Indian context the "environment" without these projects whether small or big will be more haunting and cruel than the environment which at least pave the way for the survival of millions (when say the water resources are developed with so called negative impacts).

A.I.10 Australia–Drought Policy of Queensland

Rainfall is the primary index used for drought monitoring in Australia, but there are difficulties in interpreting and using this index. Other indices under consideration are agronomic and include pasture growth, pasture biomass, live-weight gain, cash flow, soil moisture, and yield. Satellite imagery is being investigated as a monitoring tool for some of these. Drought exists if:

(a) the event is rare and severe (a rare event is considered to be one that is on average a once in 20-25 year occurrence);
(b) the event must cause a severe downturn in farm income (a downturn which is likely to occur in a region only four or five times in a century);
(c) this downturn must last for more than twelve months;
(d) the impact must be on a significant scale within a region or industry; and
(e) the event must not be predictable or part of a process of structural adjustment.

Severity is defined by the level of impact on farm income and the other dot points above. Each State of Australia has its own approach. Estimates of agricultural drought damage vary. One estimate is 1%GDP historically. Specific droughts are estimated to have significant economic impact e.g. the 1982/83 drought had an estimated cost of $6 billion, and the 1994/95 drought had an estimated cost of $3 billion. The Australian Government lends practical support to drought affected farmers and rural communities through employment services, free personal and financial counselling, income support and interest rate relief. All Australian States have assistance programs which complement the national program. On-farm strategies for drought management in Australia include: Water harvesting and on-farm storages, strategic irrigation, water efficient agronomic strategies, evaporation control measures, and stock management.

Existing drought policies in Australia are based on a single principle–farmer self-reliance, supported by Government assistance in exceptional circumstances (Horton, 2004). The National Drought Policy was established in 1992 and is a policy of developing self-reliance, subsequent reduction in reliance on relief programs, and maintenance of those relief programs until self-reliance is in place. Similarly the Drought Policy of the State of Queensland (DPI, 1992) has been in place since 1992, its goal being “to achieve a level of self-reliance within Queensland’s rural industries such that the risk of drought is adequately covered by sound property planning and management practices”.

A.I.11 France

Although south-western France gets more rain than many parts of the world, dry summers and autumns can occur in that area. Therefore, the objective of meeting the various water uses (drinking water, industry water, irrigated agriculture, tourism and fishing) while preserving the aquatic ecosystem needs some degree of scarce water management. CACG (a regional development agency as well as an irrigation service provider), has developed in conjunction with all its public partners (local authorities, government representatives, water users…) an appropriate system of water management. Using technical, economic and social tools, CACG aims at avoiding water crises even in times of scarcity. In 2002, dam’s storage was insufficient; in 2003, summer rainfalls were almost null. The analysis of these two "campaigns" where special water management decisions had to be made helps assessing the quality of this management and its scope for progress.

Appendix II

A.II The Nile Water Forecasting System

A.II.1 Introduction

The Nile Forecast Centre (NFC) was established in 1992 with the aim provide a real-time hydro-meteorological forecasting system for the Nile River Basin. In 2002, the Nile Forecast System (NFS) was to establish in order to provide tools to utilize the available hydrological and meteorological data and seek additional data in order to forecast the annual Nile inflow into Lake Nasser. This would help decision-makers to decide on the water release policy for the coming year. The NFC is developing and using hydrologic models that simulate the complete water balance for the entire Nile River Basin. The simulation ability developed would allow assessing the consequences for Egypt of planned, or actual, water abstractions and of works across the river in the upstream countries, in order to plan appropriate adjustment measures. Accurate assessment of the consequences of water conservation projects in the wetlands and marshes of the middle basin of the River Nile are also important.

Egypt being completely dependent on the Nile water, it is very important to have a reliable forecast system in place. It is obvious that forecasting the flow of the River Nile in Egypt is a unique and challenging task since practically all the runoff generating the River Nile originates from heavy rains falling in the upstream catchment areas which are completely outside Egypt's boarder, making the Nile catchment unique when making hydrological forecasts of inflows into the Aswan High Dam. Forecasting the inflows into the Aswan High Dam reservoir exclusively depends on rainfall-runoff and runoff/runoff stream flow processes occurring outside Egypt, i.e. in areas which are inaccessible for direct monitoring, measurements, and real data communication to the forecasting centre.

The NFS is a sophisticated real time, hydro-meteorological forecast system. It includes a stochastic model for the White Nile and a deterministic model for the Blue Nile. A control model simulating the Aswan High Dam operation was also developed. The most important feature is the model ability to simulate the consequences of changes in the river system and in the climatological and hydro-meteorological regime of the basin. The overall River Nile simulation model contributes and plays an important role in promoting regional cooperation by providing a reliable technical tool for settling conflicting water interests in the Nile River Basin.

A.II.2 Nile Forecast Centre of Egypt

Forecasts and information obtained from the Nile Forecast System will support improved operation of the Aswan High Dam, which will translate into much improved operation of the Nile irrigation delivery system in Egypt. The water delivery system includes operation of water control structures and strategies for water use, as well as planning and management of the water supply. To this end the NFS provides planners and decision-makers in Egypt with (Sayed and Saad, 2002):

(a) Data and information about hydrological and meteorological conditions of the Nile River Basin
(b) Strengthening cooperation amongst the Nile riparian countries in utilizing the river waters and exchanging information
(c) Analyses of different scenarios aiming at maximizing the benefits of the Nile waters upstream and their impacts on Egypt
(d) Timely forecasts and analyses of the River Nile inflows into Lake Nasser for optimizing the operation of the Aswan High Dam
(e) Analyses of different Aswan High Dam operation scenarios and their impacts downstream

(f) Development and utilization of new technologies to increase the accuracy of the inflow forecasts

(g) Implementing a monitoring system inside Egypt to forecast and alleviate the effects of flash floods

The NFS consists of hardware, software, and hydro-meteorological models. The philosophy behind the NFS is utilizing the remote sensing technology provided by the METEOSAT satellite for estimating the spatial rainfall distribution over the main Nile river catchments. Figure A.II.2 shows the general concept and schematic presentation of the NFS.

A series of hydrological models is being used to simulate the soil water exchange interface. Furthermore the NFS, through its distributed features, is capable of producing a flow hydrograph at any pre-defined location along the Nile course (Figure A.II.1). This model was introduced by Koren and Schaake (1992) and was further developed by Schaake et al. (1996). Surface and subsurface runoffs are subsequently input to the pixel's hillslope routing model, simulating the transfer of water towards the main channel. Rainfall and PET are differenced over those pixels and water balance models are then applied in a lumped sense to the whole lake or swamp area where the specific rating curves for lakes are applied. In addition, the NFS takes care of the operation of reservoirs at Roseries, Sennar, and Gabal-Awlia and abstractions for irrigation in Sudan used the NFS to assess the impact of climate change on the river flow.

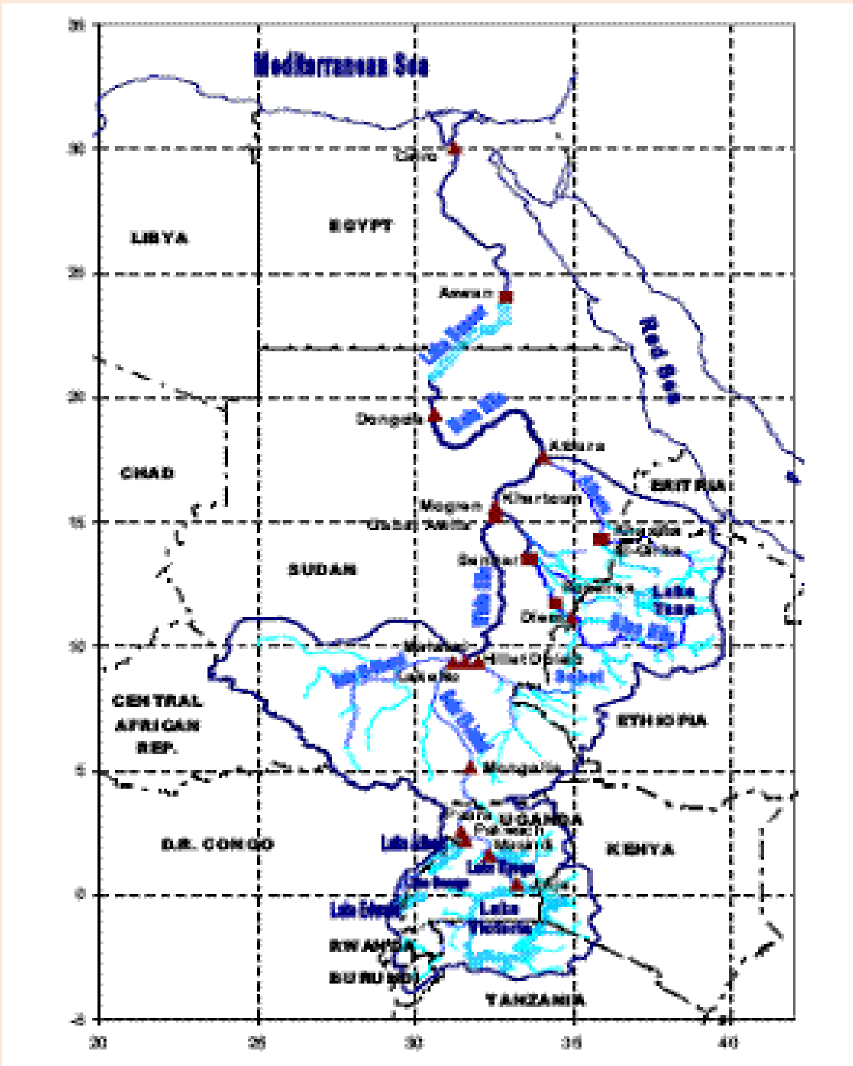

Figure A.II.1. Key Sites and tributaries of the Nile Basin.

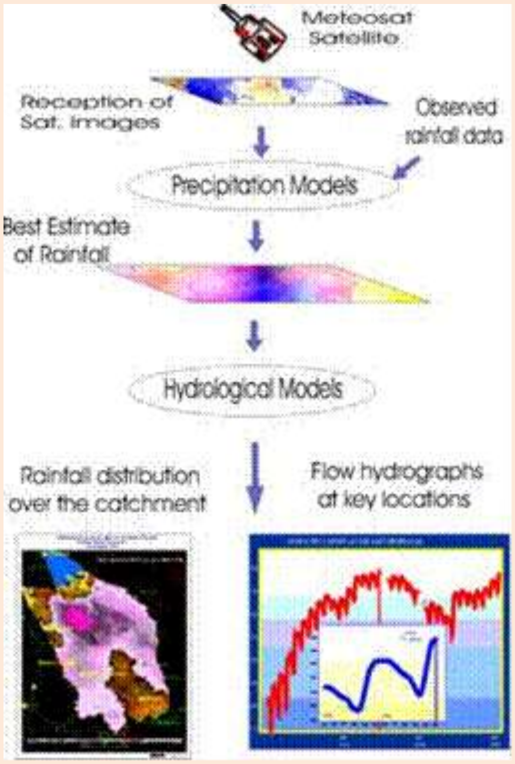

Figure A.II.2. General Concept of the Nile Forecast System (NFS)

A.II.3 Basic Components of the Nile Forecast System

The Nile Forecast System operated by the NFC utilizes advanced technologies including remote sensing and GIS for collecting and maintaining data and maximizing their use to provide inputs to distributed hydrological and meteorological models. It contains a number of program modules, utilities, and integrate Nile information described below.

A.II.3.1 METEOSAT Reception Unit

The center receives METEOSAT satellite images using a "Primary Data User System" (PDUS). These images are fed into a local area network for analysis and preparation (Figure A.II.3). The NFC utilizes the received satellite images, as well as rain-gauge data, to estimate the rainfall over the Nile Basin and to study the effects of different meteorological conditions on the Nile inflow.

A.II.3.2 Statistical Models for Forecasting

There are several statistical models available to forecast Nile inflows into Lake Nasser depending on time series analysis and flood characteristics. In addition, there is the Nile Forecasting System (NFS) which depends on simulating the rainfall conditions over the whole basin from satellite images and then uses a hydrological model to calculate and route the resulting runoff to key points along the river course taking into account the different sources, sinks and abstractions along the system and the soil moisture conditions (Figure A.II.4). It then utilizes rainfall data from previous years to estimate the flood for a future period (3-12 months) and provides confidence limits on the given forecasts.

In summary, the NFC is composed of 6 main components that perform following functions: rainfall, estimation, hydrological simulation, river flow forecasting, assimilation, data collection and management (NBHIS), GIS functions.

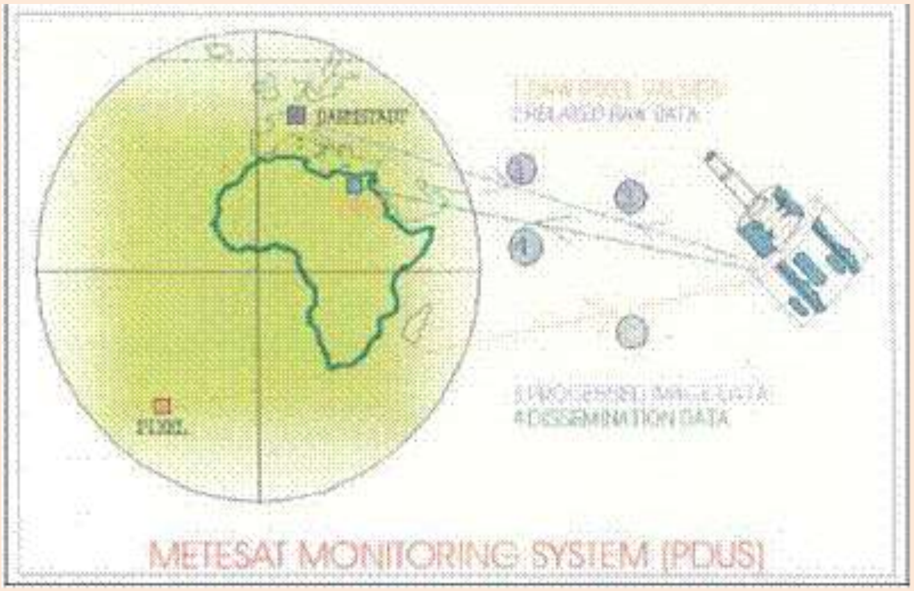

Figure A.II.3. Satellite Reception System (PDUS)

The NFS uses monthly potential evapotranspiration (PET) in the form of 12 long-term average maps as an input to the hydrological model. The source or averaging period of these data could not be traced from the available documentation. However, comparisons of the annual PET map with a map based on reference crop ET data from the FAO CLIMWAT database (FAO, 2000) revealed close resemblance (LNDFC, 2005). The inter-annual variability is not considered and the daily values are simply deduced by dividing the monthly total (for each pixel) by the number of days in a month. The insensitivity of hydrological performance to PET variability has generally been reported for several hydrological models. However, inter-annual variability of PET may be important for lakes and swamps.

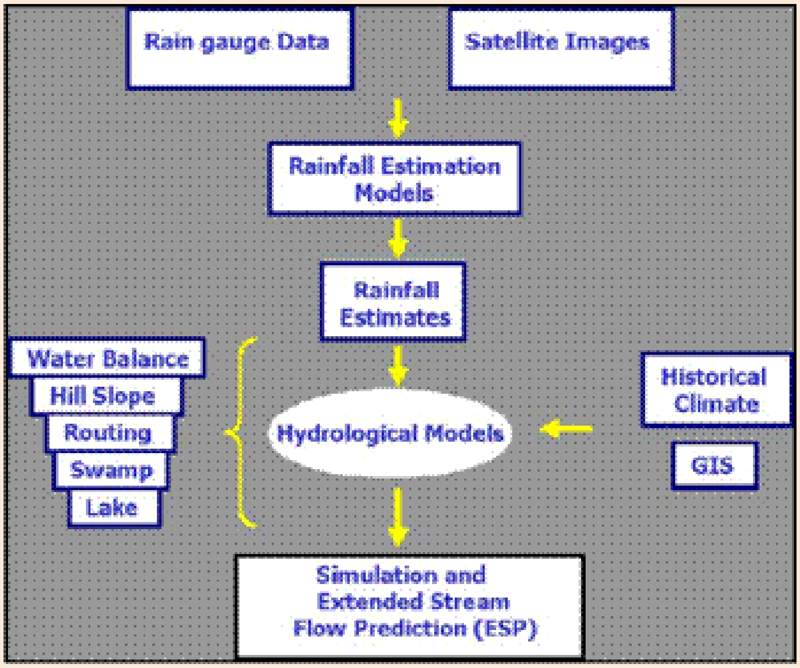

Figure A.II.4. Nile Forecasting System

A.II.3.3 Rainfall Estimation

One of the most important applications of remote sensing is to estimate rainfall from satellite images. This is crucially important for the Nile Basin where, at certain areas, there are only few observation stations. The centre receives three different spectral bands of satellite images: infrared, visible and water vapour. There are different approaches for estimating rainfall from satellite images. The centre utilizes many of these techniques. They are mainly based on cold cloud duration and cloud top temperature in addition to other parameters. Figure A.II.5 shows the basis of rainfall estimation techniques. Some of these techniques rely on infrared information only, others combine this information with visible and/or water vapour spectral bands.

Currently, infrared cloud top temperature data obtained from the European Space Agency (ESA) geostationary METEOSAT 5 satellite positioned over Africa is the primary data utilized in preparation of the precipitation estimates. Surface observations of precipitation obtained from the Global Telecommunication System (GTS) of the World Meteorological Organization are the secondary data type utilized in the scheme.

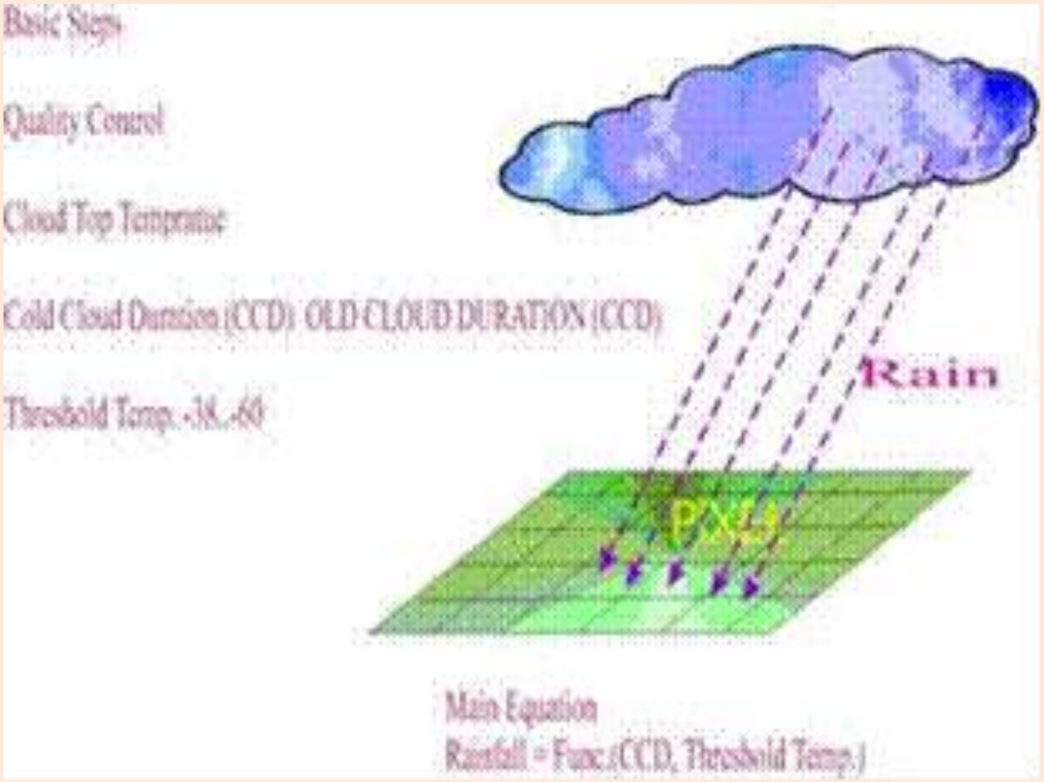

Figure A.II.5. Rainfall Estimation Concept

A.II.4 The MESO-ETA Model Application

The ETA model is a 50-layer model with 29 km resolution. Initial conditions come from the EDAS. The Meso-ETA became operational in early 1995 and produced 33-hour forecasts twice per day (so 2 times per day it predicts what's going to happen in the next 33 hours). The base times for these runs are 03Z and 15Z, in order to use updated boundary conditions from the AVN model. There has been an increase in the horizontal resolution of the Meso-ETA to 15 km and the number of levels to 70. Figure A.II.6 shows the area of focus towards the Nile Basin forecasting based on ETA schematization. Figure A.II.7 shows the density of rainfall on the Nile Basin in mm day-1, as predicted by the ETA Model.

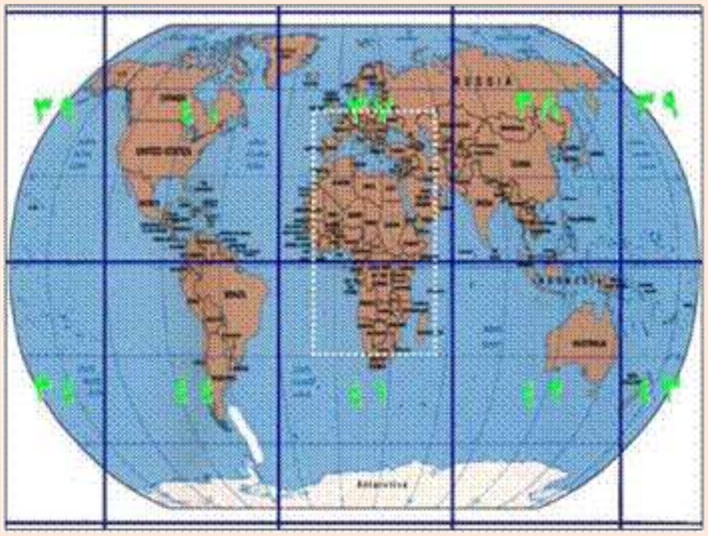

Figure A.II.6. Area of Focus toward the Nile Basin Forecasting based on ETA Schematization

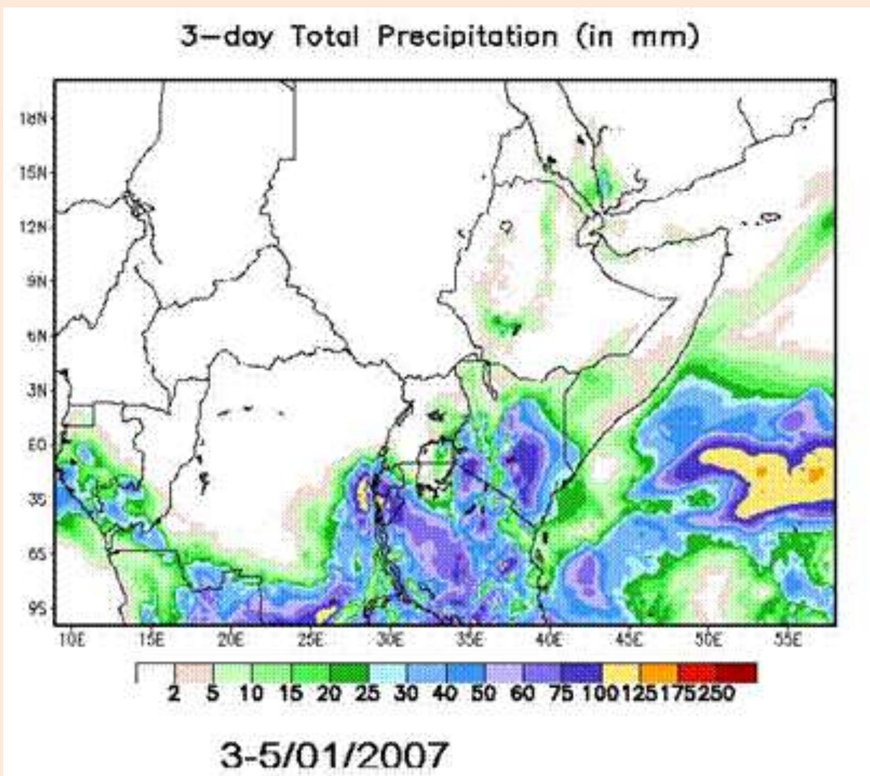

Figure A.II.7. Density of Rainfall on the Nile Basin in mm day-1 as predicted by the ETA Model

A.II.5 Decision Support System for the Aswan High Dam

The operation of the Aswan High Dam and the Old Aswan Dam complex is optimized for different operation scenarios using the Decision Support System for the Aswan High Dam (AHD-DSS) which utilizes forecasts from the NFS, or other sources, and studies the impacts on energy production and release policies of the Aswan High Dam.

A.II.6 Nile Basin Hydro-meteorological Information System (NBHIS)

The NBHIS presents one of the most important modules of the NFC. It contains an on-line hydrological and meteorological data base consisting of: 1) daily and monthly river stages and discharges, reservoir elevations and releases for many profiles along the River Nile for the longest possible historical record, and 2) daily meteorological data (temperature, dew point, wind, visibility and precipitation) for about 100 observation stations inside the River Nile catchment since 1992, and historical monthly precipitation grids for the period from 1940 to date. These data are used as inputs to the meteorological and climatological analyses, and to the hydrological simulation and forecasting system, for the calibration, and to allow the user to perform and evaluate simulation runs for a historical period. The database additionally forms a resource in its own right, accessible through the user interface.

A.II.7 Hydrological Simulation Models

The entire river system is simulated using a variety of hydrological distributed models: water balance, hill slope and channel routing and stochastic models. The METEOSAT coordinate system is used as a basic mapping system with a basic resolution of 5 km x 5 km. The simulation outputs are soil moisture, hillslope and channel flow states based on the available precipitation estimates. The model also runs with varying inputs to determine the effects of various future precipitation scenarios on discharge flow rates.

The two main approaches used to simulate river runoff by mathematical models are: ‘Lumped Parameter Models’ and ‘Distributed Parameter Models’. The Lumped Parameter Models are simple, flexible and easily adjustable but they require input and output information for a long period of time to calibrate parameters for every basin, usually with a watershed area of 5 000 to 10 000 km2. Distributed Parameter Models include more physical parameters, but they require much more geographical information.

In brief, the MWRI hydrologic model for the River Nile system includes a grid-based hydrologic model. For each grid cell, approximately 25 km2 in size, the transformation from rainfall to runoff is simulated by a water balance model, a hill-slope routing model, and a channel routing model. The model simulates the rainfall-runoff process. It has two layers which represent a shallow, fast-routing upper surface soil zone and a slower routing lower groundwater /saturated zone. The outflow is the total runoff (in mm), which is a combination of the surface and groundwater runoff. The hillslope model routs the runoff over land to the channel, effectively producing a time lag and some attenuation for the local runoff within a pixel. The channel routing model routes water from pixel to pixel and assign both a time lag and attenuation of the flow as it moves downstream. Figures A.II.8, A.II.9 and A.II.10 illustrate the concept of the water balance, hillslope, and the routing process.

The NFS uses a distributed modelling system with a grid-based soil moisture account model that calculates the discharge of the River Nile and its tributaries using a daily time step. It is based on the quasi-rectangular grid at the METEOSAT satellite projection. The average grid cell size is 5 km x 5 km.

The model calculates for each grid cell a water balance. The water that is available for runoff is routed to the outlet of the basin along the drainage system. The grid-based model covers some 40% of the Nile Basin. The arid areas of the basin, where runoff is insignificant, are not covered; neither are the major lakes, swamps and reservoirs, which are modelled separately by Lumped Parameter Models.

A recent evaluation of the NFS hydrological component Sayed and Saad (2002) compared simulated and observed daily flows showing a generally good agreement (93% and 90% of the observed daily variance explained by the simulation). The performance of the NFS hydrological component with regard to long-term simulations was also recently assessed for the purpose of conducting climate change scenarios (van der Weert, 2003). The results showed variable performance for different locations and time periods with strong linkages to the quality of monthly rainfall grids.

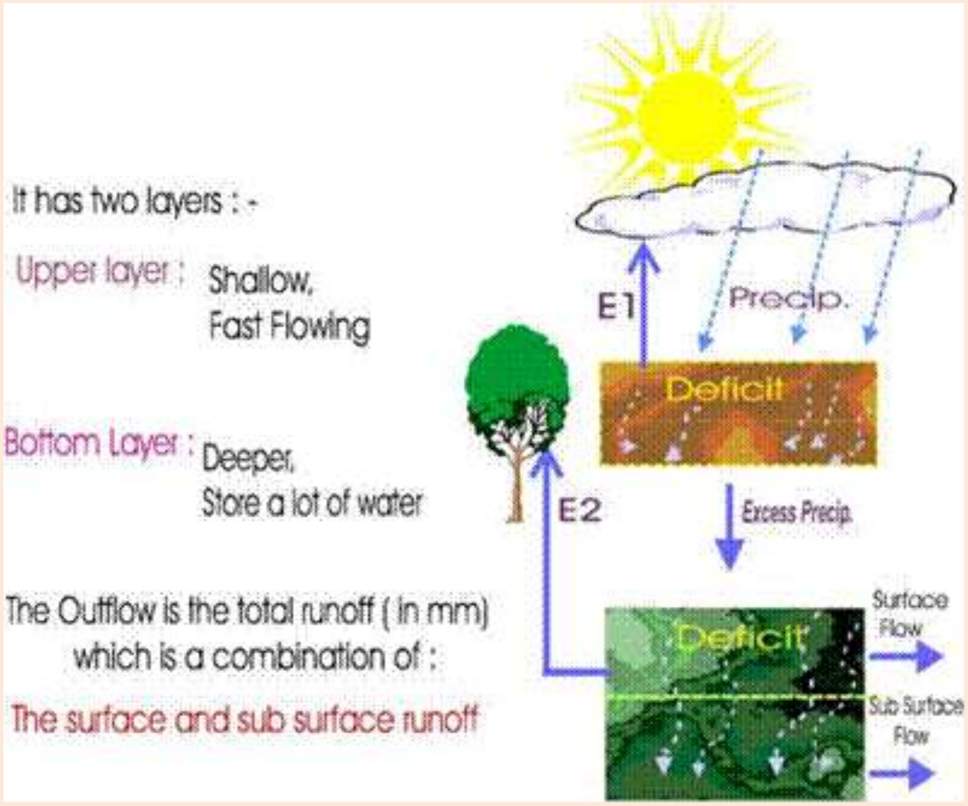

Figure A.II.8. Main Concept of Water Balance Model

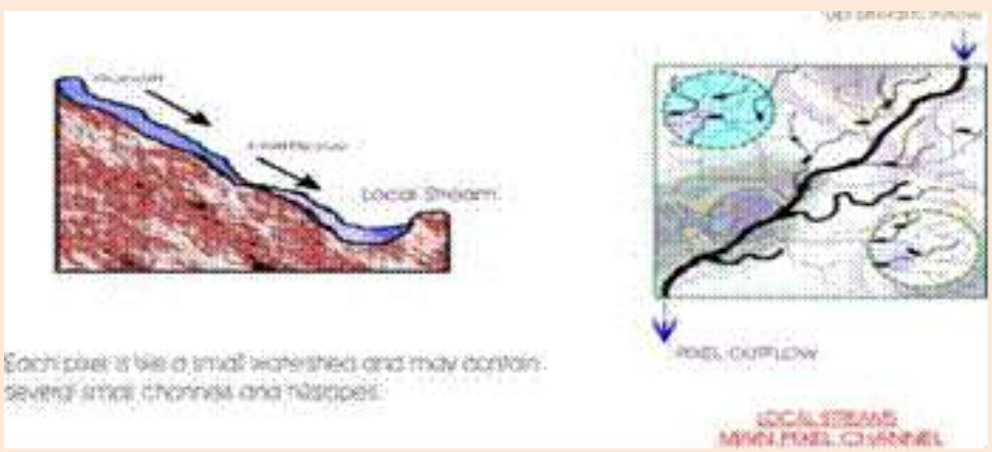

Figure A.II.9. Main Concept of Hillslope Model

A.II.8 Forecast Modules

There are two forecast modules: the Extended Streamflow Prediction (ESP) Forecast module; and the Deterministic Forecast module. Each module runs the forecast component a number of times for the same future dates, starting with current simulated state variables for the hydrological system but with different values for future precipitation. The ESP module uses precipitation values of historical years; the deterministic module uses fixed percentages of climatological precipitation. The various future discharge traces produced by the forecast component runs are analyzed to give a probable future discharge-time curve and a corresponding envelope of uncertainty.

The objective of the ESP model is to provide a reliable streamflow forecasting capability to support improved operations of the Aswan High Dam. Figures A.II.11 (a), and A.II.11 (b) show the inputs and outputs of ESP module. Figure A.II.11(c) shows the gridded rainfall estimates (daily, weekly, monthly or annually) and hydrograph plot at key locations like Khartoum, Malakal, and Dongala.

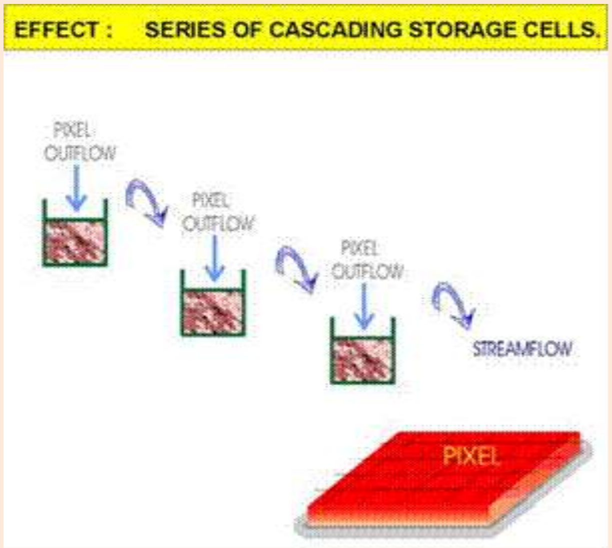

Figure A.II.10. Main Concept of Pixel Routing Model

A.II.9 Aswan High Dam Decision and Control System

The module utilizes Dynamic Programming as the optimization procedure on different trade-offs (spillage versus energy, evaporation versus energy …etc.) to provide an optimal relationship among total system outflows, total load and reservoir elevation. As an input, it takes a set of Extended Stream flow Prediction (ESP) forecasted traces for the profile at Dongala which is considered as an inflow profile for the Lake Nasser. The output is serving as a support for the operational management of the Aswan High Dam.

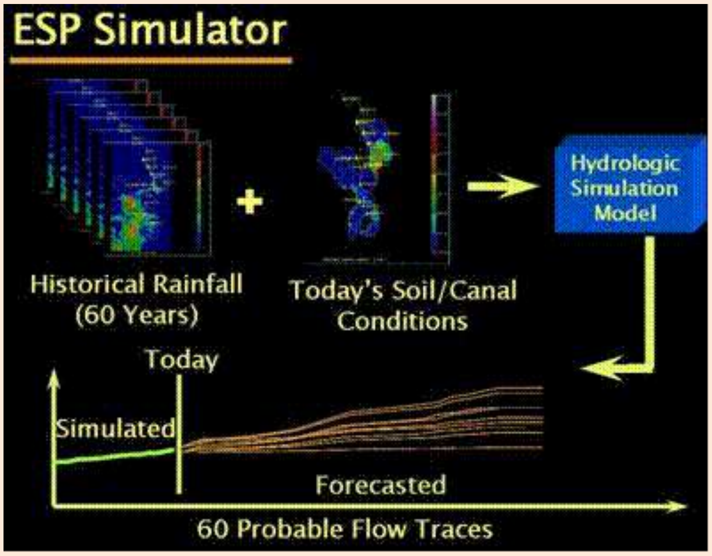

Figure A.II.11(a). Forecasting Module as Implemented in the NFC

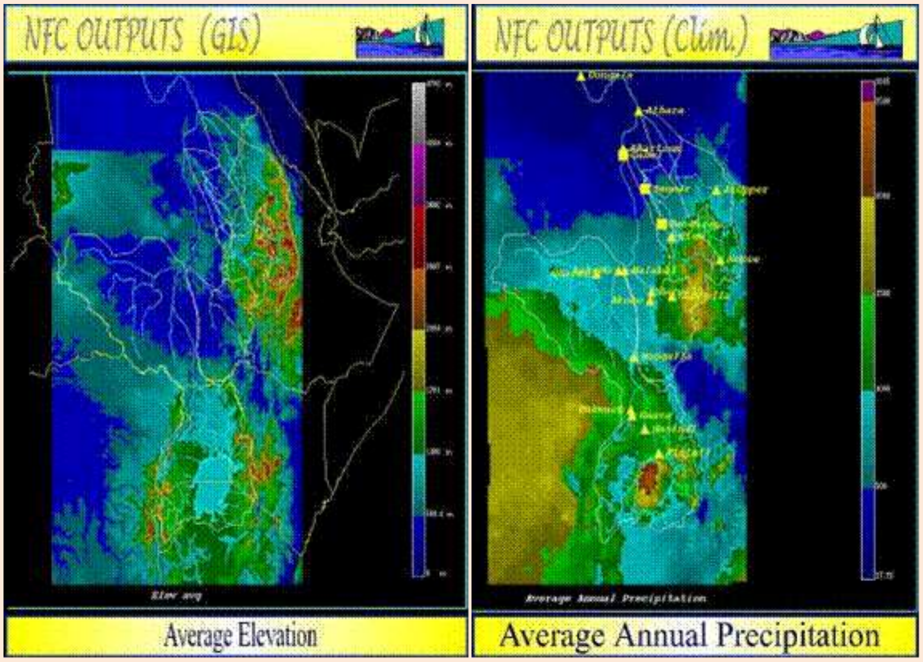

Figure A.II.11(b). Components of NFS Data Bases: GIS and Historical Rainfall Data

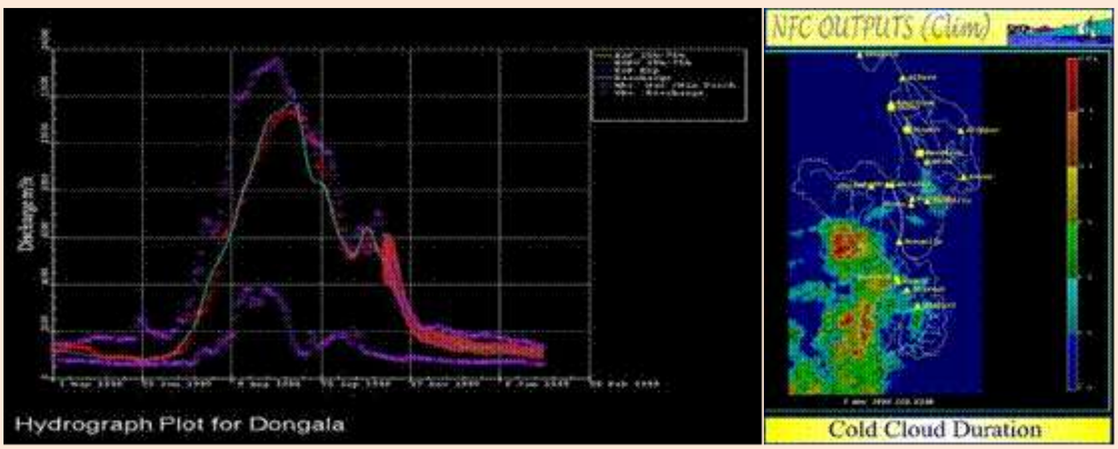

Figure A.II.11(c). Gridded Rainfall Estimates (daily, weekly, monthly or annually) and Hydrograph Plot at Key Locations like Khartoum, Malakal, and Dongala

A.II.10 GIS Database

The GIS database is primarily used by the user interface to augment displays with a geographical context. This database is also accessed by the forecast component to obtain information about elevations, channel connectivity, etc.

The NFS depends on a large hydro-meteorological database which includes:

(a) Meteorological data including raw and processed METEOSAT Satellite images as well as rain-gauge data, temperature, pressure, humidity for a number of gauging stations covering the Nile Basin;
(b) Hydrological data including daily river stages and discharges at key stations along the river in addition to operating rules for existing reservoir on the Blue and White Nile; and

(c) Soil Data sets (type, characteristics, properties etc).

Since the start of implementing the Nile Forecasting Center, a considerable effort has been made to gather different kinds of data sets that help in calibration and validation of different implemented models within the system. Examples of these data sets are:

(a) Satellite images (Infrared, Water Vapor and Visible images) that are received daily through the implemented system.
(b) Climatological data for all Nile riparian countries. These data are downloaded and decoded, then amended to update the data base. They include rainfall, due point, temperature, cloud cover, relative humidity etc. and, together with satellite images, are used to estimate rainfall over the Nile catchment area.
(c) Observed levels, flows, reservoir releases, water levels at different locations along the Nile.
(d) GIS data include soil type, elevation, of the River Nile (minimum, maximum and mean elevations), soil types and units, soil profile thickness, texture, root zone water storage, soil vegetation index, and ecology.
(e) Climatological data include maps for average monthly precipitation, average precipitation, average annual and monthly potential evapotranspiration, different maps for precipitation.

All data sets are archived for different time periods. The satellite and meteorological data are archived since 1992, i.e. since the NFC became operational. These data are of great value now, as it is one of the unique databases within the Nile Basin countries. It can be represented in different file formats and different graphs.

The extensive databases owned by the NFC of the MWRI of Egypt are the main source for making reliable predictions and future estimates. Also different models and techniques that have been developed within the centre make it easy for the centre to generate different outputs. There are two major output forms the centre produces:

A.II.11 Operational Outputs

(a) Daily rainfall estimation maps that represent rainfall distribution over the various sub-basins.
(b) Two weekly meteorological bulletins (in Arabic) that describe the rainfall and meteorological conditions along the Nile sub-basins together with extended forecast for expected rainfall over three days in advance.
(c) Decadal bulletin (in Arabic) that summarizes the metrological and hydrological conditions over the Nile sub-basins. This summary is accompanied with graphs that represent the observed data compared with absolute maximum, absolute minimum, maximum years, minimum years, and average values. The purpose of these graphs is to have a feeling for the existing conditions compared with previous conditions. The bulletin also updates forecasts issued in previous bulletins and, if necessary, gives out warnings for decision makers to take certain actions towards the operation of the Aswan High Dam. The importance of such bulletins appears more in severe flood years or in drought years and also in cases when the lake is full or about to be dry.
(d) Monthly bulletin that is issued in Arabic and in English. This bulletin represents a comprehensive summary of the flood season since its start.
(e) Non-operational outputs are tools for water resources planning and management along the River Nile. The importance of these tools appears in supporting decision makers in negotiations for water allocation through trade-off analysis and quantification of the benefits and consequences of initiating any projects along the River Nile.

A.II.12 Conclusion

Given the importance of water management in Egypt, the main task of the Nile Forecast Centre is to simulate the consequences of changes in the climatological and hydro-meteorological regime of the Nile basin on the Nile river system. The NFS performance is satisfactory for the Blue Nile through conceptual and physically distributed hydrological models, which reflects the NFS historical development and design objectives However, additional data records can be used to improve the model in these other sub-basins via calibration. The distributed nature of the system enables the study of the hydrological behaviour of any particular catchment. The developed simulation ability allowed assessing the consequences of planned, or actual, water abstractions (for Egypt) and of works across the river in the upstream countries, in order to plan appropriate adjustment measures. The same consideration applies to accurate assessment of the results of water conservation projects in the wetlands and marshes of the middle basin of the River Nile.

The modelling approach considered in the NFS allowed the centre to explore the consequences of climate change, and related changes in the atmospheric circulation pattern, in the Nile Basin. Through the system's flexibility, the ability to estimate the consequences of climate, precipitation, and river system changes in upstream countries.

Information and data sets produced by the NFC regarding soil moisture conditions, evapotranspiration, and stream flow could be exchanged with any of the other nine riparian countries. On a yearly basis, the NFC issues a comprehensive analysis of the performance and accuracy of the forecast system results. Since the establishment of the centre in 1991, the experience gained in forecasting and dealing with different flood situations is remarkable. The MWRI key decision-makers are gaining more reliability in the various analyses prepared by the centre.

Appendix III

A.III Drought Damage Assessment: A Case Study from Iran

The damages due to drought were very severe during the 3-year drought cycle of 1998-2001. The damages increased as the drought continued from one season to the next. For example, while the 1999-2000 damages were estimated at $ 1.7 billion, corresponding estimates for the 2000-01 season were about $ 2.6 billion. A wide variety of crops and agricultural products were affected. The type and intensity of the damages varied in different provinces and regions. This Appendix provides a brief overview of the damage assessment approach in Iran based on this drought incident.

A.III.1 Water Resources

The fall in the seasonal precipitation rate during the 3-year drought cycle was significant. The consequent shortage of drinking water was the most serious problem from the public health and comfort point of view. In more than 270 cities, including the capital Tehran, water scarcity reached a crisis point and, therefore, it was rationed. Several thousands of villages ran out of drinking water and were either evacuated or served by tankers, in different time intervals. The government estimate was that 90% of the population experienced some degree of drinking water shortage. Among other problems, water delivery by tankers caused some contamination problems. For example, one report from Kermanshah province stated that in 757 samples of rural drinking water samples, 43% had bacteriological contamination.

In general, the rate of the surface water flow in the water years of 1998 – 99 and 1999 – 2000 showed a decline of, respectively, 41.5% and 55.5% relative to the long-term average. Accordingly the two-year average declined by 48.5%. Thousands of springs and the traditional Qanat systems went dry. The biggest decline in runoff water was in Rabech-Bahookalat basin (81%). Flow reductions of more than 50% were recorded for Hamoon-Mashkil, Hamoon-jazmourian, the Salt Lake, the Orumieh Lake, Kal-meran, Mond, Karkheh, Marzi-e-Gharb and Sefid Roud. During the last drought cycle, downstream sections of many rivers dried up for different length of time and others had drastic reduction in their flow rate. Due to low or noflow rates, some stagnant bodies of water became polluted.

As to the groundwater resources, significant depletions were observable in the aquifers of the Central, Eastern and Southern watersheds. A general survey revealed a ground water deficit of about 6.9 km^3 during the first two years of the drought cycle compared with the long-term average. For the 2000-01 water-year, overdrafts from aquifers were estimated at about 11 km^3, leading to substantial lowering of water tables. This drawdown led to increased energy requirement for pumping and increase in water salinity.

A.III.2 Agriculture and Livestock Impacts

Orchards and rain fed crops were hit the worse. Many livestock were lost or sold prematurely, with consequent lighter weights and monetary losses to the herders. The incidence of plant pests and diseases increased and it was so high that some agricultural authorities provided incentives for the people to collect larva and mature pests and sell them to the government. Some detail data on agricultural losses of drought are reported in Table A.III.1 and Table A.III.2 (Siadat and Shiati, 2001). (Please note that the exchange rate for Rials at the time was about Rls8000= $1).

Table A.III.1. Some agricultural and livestock losses and damages reported for different provinces during 2000-01 season drought.

Province	Region	Some drought consequences
Khorasan	Province	Preliminary estimates of losses up to 2 million tons of agricultural products. 30,000 ha of dryland orchards and vineyards destroyed. 36,000 ha of orchards under water stress. 5% of livestock in drought-stricken parts have died. 30% of livestock in the province have been affected. Silk production damaged.
	Shirvan	100% loss of production from 11,500 ha irrigated fields, including 8,000 ha of wheat and barley. 20,000ha of dry land crops at risk. 600 ha of vineyards are under water stress.
	Birjand	Complete loss of rainfed crops (only 2000 ha out of 16000 ha were planted this year and even this is lost completely). 15,000 heads of nomadic livestock have died.
	Gonabad	40% reduction in the number of livestock Many raisers are giving up.
	Torbat heydarieh	3000 ha of pistachio orchards are at the risk of water stress.
	Bardskan and Jajrom	Damages are in the order of Rls 81B.
	Bojnoord	Losses to agriculture and livestock estimated at Rls 469 B.
	Khaf	Livestock damages estimated at Rls 90B.
	Nehbandan	Estimated losses amount toRls 142B.
	Ghayen	Wheat yield and cultivated area lowered by 50%.
Sistan and Baluchestan	Province	63% decrease in total crop harvest. Fruit production of 7000ha, including citrus and bananas, have been destroyed. 8000-12000 tons of fish catch from Hamoon is lost due to drying of the lake. Fodder production is lowered by one third. Damages to agriculture estimated at Rls 1200B
	Iranshahr	Rice cultivation reduced from 1500ha to 750ha. 1000ha of rain-fed land abondoned.
	Chabahar	27,000 heads of livestock die due to drought.
	Nikshahr	About 70,000 goats, 19,000 sheep, 1450 cattle, and 62 camels have died.
Fars	Province	100% loss of rainfed crops in warm regions. 30% of irrigated land under Doroodzan dam lacks water. Yield losses of irrigated fields estimated at 10-100%. 450,000 tons decrease in wheat production. Damages to orchards between 20 to 80%. 70% reduction in range land production. Livestock death 10-15 %, weights loss of live animals 10%. Loss of fish in Kor river and Bakhtegan Lake.
	Fasa	50% reduction in area cultivated to wheat, cotton, and summer vegetables.
	Marvdasht	Losses of agricultural crops nearly Rls 323B.
	Estahban	5000 ha of rainfed fig at the risk of severe drought damage.
	Firoozabad	37,000 ha of rainfed wheat and barley completely destroyed.
	Kazeroon	Agricultural losses are estimated at Rls 55 B.

Province	Region	Some drought consequences
	Larestan	Drought damages are over Rls 78 B.
Fars(conti'd)	Eghlid	Losses are nearly Rls 266B.
	Darab	Agricultural and livestock damages amount ot Rls 350B.
	Nairiz	5000 ha of irrigated wheat and barley was abondoned. Production of 10,000 ha of rainfed and irrigated orchards severely reduced.
Charmahal and Bakhtiari	Boroojen	Local authorities banned production of summer crops (including potato and sugar beet) on 8,000 ha, out of a total of 14000 ha normally cultivated to these crops.
Kerman	Province	Agricultural losses are estimated at Rls 4,000B. Cultivated area is reduced for beans and pea (90%), potato (60%), cotton (50%), alfalfa and sugar beet (30%). 55% yield losses for wheat and barley. 101,000 ha of orchards have been damaged and many others will have reduced yield. Production losses are estimatd at 94,000 tons. 162,000ha of annual crops have been lost. 15% of sheep and goats have died. Dairy production by small animals lowered by 80%, cattle dairy lowered by 5%.
	Bafgh	1100 ha of date plantations are damaged.
	Bardsir	Wheat production lowered by nearly 50%.
	Jiroft	Total damages of the last year estimated atRls 560B Current year damages in cold region estimated at Rls 61B Crop losses are between 50-60%.
	Baft	Livestock losses estimated at 30%.
	Sirjan	Agricultural losses nearly Rls 475B.
	Zarand	Agricultural and livestck damages in the order of Rls 169B.
Kordestan	Province	Some 80,000 tons of rangeland production have been lost with an estimated value of Rls 28B. Production of rainfed wheat and barley down by 30%.
	Ghorveh	Dryland wheat production is completely lost.
Bushehr	Province	Damages are estimated at Rls 402B.
Semnan	Province	Agricultural production down by 25-45% Damages to agriculture, rangelands, and livestock almost Rls 290B. 3-4% losses of the livestock of Nomadic herders.
Isfahan	Province	Last year damages to agriculture estimated at Rls 2300B. Predictions are higher for the current season. Nearly 100,000 farmers have lost their earnings and jobs. Extensive reduction in area of irrigated wheat (34,790 ha) and rice (11,578ha). Total cultivated area that has been damaged is almost 130,000 ha.
Hormozgan	Province	Livestock and agricultural losses are put at, respectively, Rls 297.1B and Rls 512.7B. Citrus production, particularly lime, down by about 30%.
Guilan	Province	30% of rangelands damaged estimated loss of 40,000 tons.
East Azarbaijan	Province	175 ha of fish culture damaged. Losses in agriculture and livestock are estimated at Rls 875B.
	Malkan	12,000 ha of agricultural lands have been affected. Drought damages to 130,000ha estimated between 25-30%.
	Bonab	

A.III.3 Environmental impacts

Generally speaking, environmental aspects of drought damages are probably the worst and, yet, the least recorded and the last to be considered in "compensation" programs. During the last drought cycle of 1998-01 in Iran, natural resources such as rangeland, lagoons, and wetlands experienced grave losses. Biodiversity was severely damaged both in terms of animal and plant species. Around some wildlife reserves, natural vegetation was almost completely grazed by the protected species such as gazelle that faced food shortage. Some of these and other wild animals were lost due to lack of adequate water. Even camels, which are considered to be drought tolerant, suffered losses and the increased abortions of these animals were attributed to drought and water scarcity. Some reports said that a number of medicinal herbs were severely withered or grazed in areas like Kerman and Yazd. The unique coastal communities of Mangroves in the southern coasts were being cut to feed the hungry animals in the Hormuzgan Province. The rate of recovery of these communities is slow and there is the risk of irreversible damage to them.

Certain areas of the country, like Kerman, are home to Asiatic Cheetah, a very rare animal on the verge of extinction. Some of these animal species may have been lost completely in certain locations. A report by UN Mission to Iran (2001) warned that " the forced migration of wildlife is creating new refuges where there are too many of them and competition is created". Such competition may seriously change the natural balance to the benefit of some species and eradicate some others.

Table A.III.2 Agriculture Damages in different Regions

Province	Region	Some of drought consequences
West Azarbaijan	Mahabad	50% loss of crop harvest. Damages estimated at Rls 30B. Losses of wheat and pulses nearly 19,000 and 1,370 tons, respectively.
	Province	Wheat production predicted to be down by about 100,000 tons.
Yazd	Province	Damages to agriculture include Rls 250B in orchards, Rls 100B in annual crops, and Rls 192B to livestock. 32,000 ha of agricultural lands have been affected.. Rangeland damges estimated at Rls 68B.
	Maybod	Damages in the order of Rls 5B.
Kuhkiloyeh and Boirahmad	Province	Wheat and barley losses estimsted at 40-45%on 37,000ha. Agricultural and livestock lossesestimated at Rls 191B. Substantial loss of fish life and migration of fish in rivers to Persian Gulf.
	Gachsaran	Yield losses on 22500ha wheat and 2700ha of barley (both rain-fed).
Golestan	Province	Estimated damages to agriculture between 65-70%.
	Gonbad Kavoos	Predicted yield loss for wheat and barley are, respectively, 63,000 and 11,000 tons.
Tehran	Firooz Kooh	900ha of dryland crops cmpletely destroyed. 53% losses in 7000ha of irrigated fields. Damages to livestock industry estimated at Rls 1.6B.
	Damavand	Honey production has decreased.
Mazandaran	Neka	5000ha of rice land at the risk of being abondoned.
Khuzestan	Province	Damages estimated at Rls 594 B.
	Dezful	80% of about 29,000 ha rain-fed wheat is destoyed.
Kermanshah	Province	15,000ha of cereal crops in warm regions have been damaged.
Ilam	Province	56,000ha of farm lands badly damaged.
Zanjan	Province	Rice cultivated area is decreased from 4500 ha to 2400 ha. Area under rainfed crops lowered by 30-60%. Substantial losses in 16,200 ha of orchards. Damages are estimated at Rls 619B.

The gravest environmental damages were inflicted upon lagoons and wetlands. Some of these are registered sites of International significance as recognized by Ramsar Convention. At least 14 of such wetlands were completely dry in 2001, including, Hammon in Sistan and Bluchestan Province, Bakhtegan, Arzhan, and Kaftar in Fars Province, Gavkhoni in Isfahan and Helleh in Bushehr. Hundreds of thousands of fish died in these wetlands and many piles of dead fish were shown on national TV. Also, it was feared that once the migratory birds return, they may not find the insects and plant species they used as feed.

A.III.4 Social aspects

Social impacts of drought are variable in different communities and places and depend on many factors such as the number of population, economical status of the community, technological facilities available to the people prior to drought, and the health and hygiene standards prevailing in the region. During the last drought cycle, different types of social problems developed in various parts of the country. While lack or inadequacy of drinking water forced many villagers to migrate to cities and towns, many urban communities had already ran into water shortage and were suffering from water rationing, poor water quality, low water pressures in the pipes, and warmer environments. Social unrests due to inadequate water supply were reported in a number of cities and sub-urban areas. The worst sufferings were experienced in remote villages where water deliveries by tankers were not timely or adequate.

Migration of villagers to the cities led to many social problems for them as well as for the urban areas. There were some reports indicating increased rates of crimes in the cities, particularly those near the borders. Drug trafficking across the border towns increased. Hundreds of thousands of farmers and livestock herders lost their jobs and had to move to urban areas to find a job for their living. Many others who stayed in the village changed their jobs to carpet weaving and other handicrafts. Their way of life changed completely. Some livestock raisers moved their herd to new areas and this caused conflicts between them and the local herders.

Food security became a serious problem both at the national and local scales. In Sistan and Baluchestan, the situation was so grave that the government provided 10 kg of flour for each person in that province free of charge. The food import figures rose to the maximum ever in the trade history of the country. The wheat imports of 2001, for example, rose to 7 million tons, which put the country in the top of the list of the world wheat importers. Death of fish in the lagoons, rivers, and wetlands caused both economical strains and food shortage problems for some local communities.

Fortunately, health and hygiene issues did not become a serious problem on the national scale, although there were reports of local diarrhea diseases and measles. In other places, skin and eye infections were reported as a result of lower sanitary conditions due to water shortage

A.III.5 Economic impact

Estimated economical losses for the 1998-01 drought years are, respectively, $1.6 B, $2.1B, and $2.6B. Most of these economic losses were in agriculture and livestock sectors, the details of which are reported in the previous sections. However, other sectors were also affected directly and indirectly. Tourist industry was among the top industries that were hit by the drought. Damages to the landscape together with the higher temperatures and fear of water shortage in certain touristic regions discouraged many tourists from taking trips. For certain regions, like Isfahan, where tourism plays an important role in the local economy, drought was a real catastrophe. Besides, tourism helped the local famous handicraft industry in that city and drought inflicted heavy losses on that as well.

Economic strains on the government were very high. Hundreds of millions of Dollars were allocated to cash compensation to some farmers and livestock raisers or relief programs such as water delivery by tankers. Besides, the increased food imports imposed great pressures on the hard currency budget of the government. Some development programs had to be sacrificed in order to provide funds for the emergency situation that had raised. Consequently, a number of development programs were delayed, which further aggravated economical losses.

The lesson learned in this respect, once again, was that preparedness is the key to successful mitigation of drought impacts. Proactive programs for protection of wildlife during drought are of great importance and government agencies should pay due attention to this issue and take the necessary actions before the next drought spell occurs.

Appendix IV

A.IV Rainwater Harvesting Techniques

This Appendix presents various methods of rain water harvesting within the overall framework of Watershed Development that are aimed to address various uses from drinking water to agriculture. Some of the socio-economic considerations and how it is applied in different countries are also presented briefly therein. A few examples of water harvesting from India, Iran, Jordan and Libya are also presented briefly.

A.IV.1 Rainwater harvesting methods

As rain water harvesting is an ancient tradition and has been used for millennia in most dry lands of the world, many different techniques have been developed. Most of these are for irrigation purposes, while others are to conserve water for human and animal consumption. The same techniques sometimes have different names in different regions and others have similar names but, in practice, are completely different. Water-harvesting methods are classified in several ways, mostly based on the type of use or storage, but the most commonly used classification is based on the size of the catchment. A simplified classification is shown in Figure A.IV.1.

Sharma, and Smakhtin (2004), argue that large-scale application of rain water harvesting measures in drought-prone areas may be seen as a strategic tool for drought mitigation, if it is realized through the adoption of relevant policies and investments at different levels such as user, watershed, urban locality, district, state and country. The following are the major prerequisites for success in implementing rainwater harvesting in dry lands:

(a) Farmer's participation in all phases of the project: planning, development, implementation, operation and maintenance.
(b) The project should be simple and appropriate to their existing farming operations for ready acceptability to the beneficiaries.
(c) Demonstrations and training are needed to support newly introduced systems or practices.
(d) Clear land tenure and property rights so as to avoid conflicts over both land and water in the planning process.
(e) Downstream water rights ensured when adopting macro-catchment and floodwater-harvesting systems.

A.IV.2 Watershed management approach

Effective rainfall is often only a fraction of the total rainfall received in particular under conditions of high rainfall. In such case, provisions for diversion of excess of rainfall through drainage may be required in order to avoid crop damage. In arid and semi-arid conditions, measures on water conservation are, however, important means to increase water use efficiency both in irrigated and rainfed production. Various options exist to increase precipitation efficiency by water conservation techniques, which will reduce runoff (bounding), increase rainfall infiltration (ridging, mulching), increase the root zone (deep-ploughing, biotechnology) and/or increase soil–moisture retention in the soil (soil-structural improvements). The introduction of fallow combined with weeding, will allow rainwater to be accumulated in the soil. Furthermore, the selection of crops with a more extensive rooting system will result in a larger part of the soil profile being effectively used for soil water storage. Introduction of water conservation techniques may require investment in land shaping for bounding, ridging and deep ploughing. Important is the establishment of a proper extension support to introduce, adapt and sustain water savings technologies.

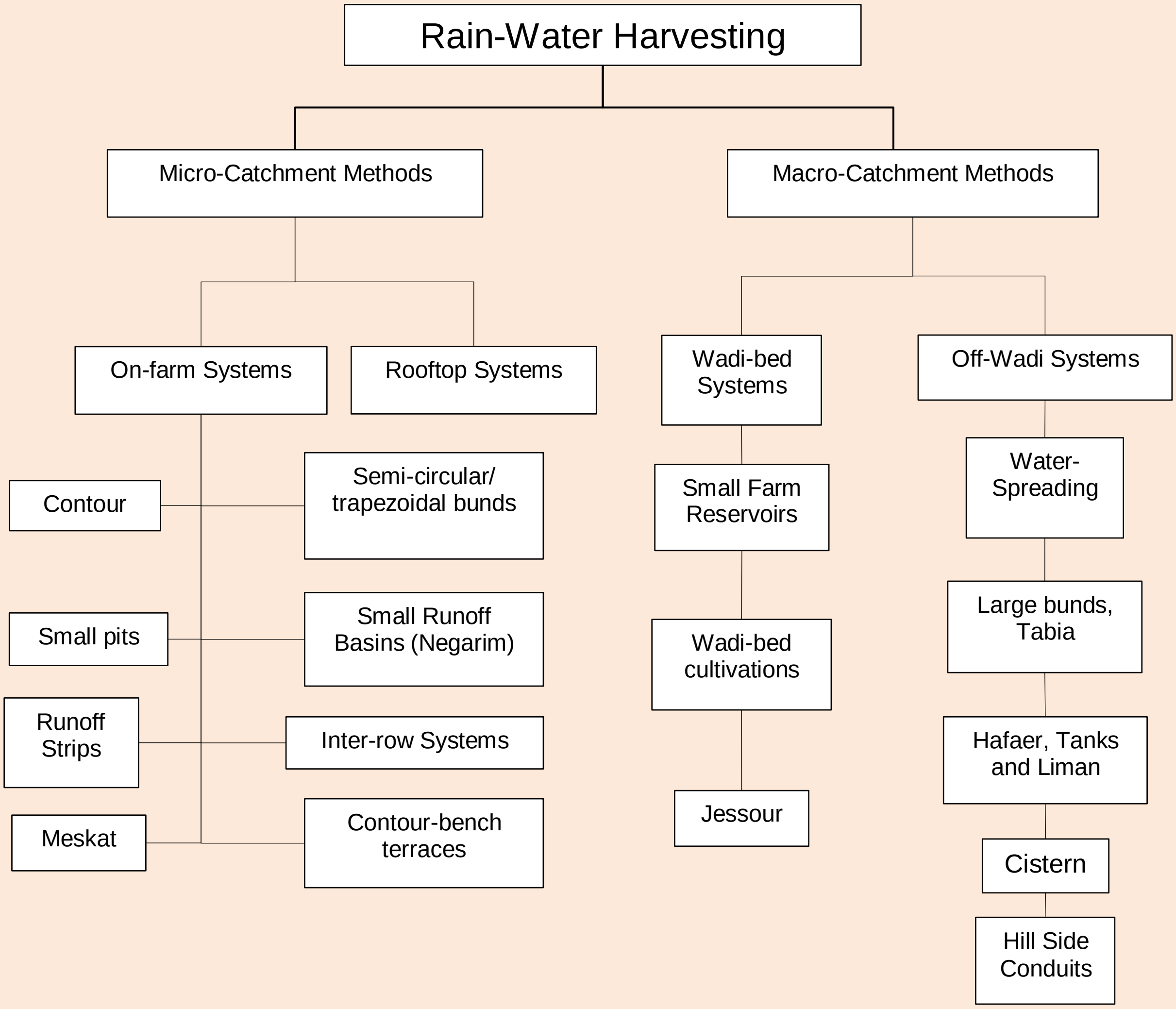

Figure A.IV.1. Classification of rainwater harvesting systems (adopted from Oweis, 2004)

Development of water resources demands an integrated watershed management approach. The design water amount should allow maximum economic, social and environmental return. Individual farmers, communities, or public agencies, may implement rainwater-harvesting systems. Individual farmers usually construct micro-catchment systems. This is a simple and low-cost approach, although farmers may experience some difficulty with elements requiring precision, such as following the contour lines or determining maximum slope. Communities may be involved in micro- and macro-catchment or floodwater-harvesting systems, typically through a project planned locally with the help and guidance of the government.

Public agencies are usually needed for large-scale macro-catchment and floodwater harvesting schemes. Government services or contractors are used in this approach. Usually machinery is used and local labor are employed in developing countries. Initial cost is relatively high. This is a top-down approach, however, and there is a risk that the scheme will not be accepted or maintained by farmers. Poor management and lack of maintenance are main reasons for the failure of water-harvesting projects. Large-scale systems require the creation of a local association to manage the facility and liaise with the appropriate government agencies. Guidelines and procedures for the operation and maintenance of all components of the water-harvesting system are needed at the outset of the project. Overall, rainwater harvesting, in the absence of sufficient water resources, is essential for any sustainable development of the drier environments. Its adoption by farmers on large scale, however, faces substantial difficulties.

The major difficulty is the wide adoption of these techniques. This is mainly caused by low direct benefits compared to social and environmental benefits which take time to be felt by the farmers. On account of the risk and uncertainties involved, the farmer may need to be convinced of the benefits of water harvesting. The most important form of benefit is increased income from the sale of additional produce. Micro-credit schemes or other forms of subsidy may still be needed to finance the construction, operation and maintenance of systems before the benefits from additional crop production are attained. With appropriate policies and regulations, micro-credit may also be used to support the creation of local groups, and human-capacity building through demonstrations, training, extension services and dissemination of information. Subsidies may also be needed to compensate farmers for their contribution to improvements in the national environment and socioeconomics resulting from rainwater harvesting projects.

Watershed management approach for increasing fresh water availability and (only 30% of its rainfall of 88cm/per year is stored) a broad developmental procedure for rain dependent areas (consisting about 65% of its 329 sq km geographical area) is adopted in India since Sixth plan period (1985-91) by the planning Commission and a twenty five years perspective plan is prepared (Paul, 1995). The program is implemented as Integrated Watershed Management Programme (IWMP) by the Ministry of Rural Development, Department of Land Resources (DOLR) is the funding agency. A participatory approach is followed with the participation of all the people living in a micro watershed delineated as per drainage basin within a part of the revenue block (consisting of clusters of villages administered by a Revenue Official and governed by a elected body named as Panchayat) formed into an Watershed Association (WA).

A Project Implementation Agency (PIA) is appointed from/among the Developmental Line Departments (Soil Conservation, Agriculture etc), Voluntary Organisations (Non-Governmental Organisation VO/NGO) with adequate experiences. Various natural resource management activities are taken up as per National Rainfed Area Authority (NRAA) guidelines (2008) for optimization of soil and water conservation and utilization for production and productivity improvement in agriculture, fishery, animal husbandry, horticulture and other sectors. Generation of employment and lively hood opportunities for landless and marginal land holding people organized into various User’s Group and Self Help Groups in the project area is one of the main objectives. The IWMP in India is taken with large outlay of more than US$ 300 Million per year and expected to rejuvenation of its neglected rural areas with improvements in water storage and ground water recharge status with significant social and environmental benefits.

A.IV.3 On farm water storage

Increasing demands for water from all sectors of the economy means that irrigated agriculture (the single biggest user of water) has to develop more efficient ways of using the water that is made available. Farmers in many catchments are therefore turning to on-farm water storage's (OFWS's) as a means of capturing as much water as they can and in providing them with increased options for managing limited water supplies. Bristow et al. (2000) describe a newly developed prototype software package (Dam Ea$y) that couples biophysical and economic modeling tools in a way that enables analysis of various scenarios regarding investment in OFWS and the likely benefits that can accrue from such investments. Both economic and environmental issues (in this case nitrate leaching) associated with the installation and management of OFWS's are addressed, as are future development needs of Dam Easy.

On farm storage of large volumes of water has become an increasingly important water management tool for irrigators. Above-ground "ring tanks" are commonly constructed for this purpose. Because of the value of water stored, and the resulting hazards of failure, the importance of correct construction and maintenance of these storages cannot be over-emphasized. Unfortunately, too many storages have failed, due to factors which could have been prevented. Barrett (1998) provided the guidelines to show farmers and contractors how these factors may be overcome to produce safe storages. The Guidelines cover investigation, design, construction and maintenance aspects.

A.IV.4 Adopting water harvesting

Different traditional and innovative techniques are available in different countries for runoff farming water harvesting, surface storage water harvesting and groundwater recharge. Water harvesting is of particular importance in arid and semi-arid regions, which are also drought prone. Rainwater harvesting measures if adopted on a large scale may alleviate water scarcity even during severe drought years. However studies which systematically describe water harvesting measures in different countries and regions, document successful experiences in large scale implementation of such measures and quantify their potential to alleviate the effects of droughts of different extremity are limited. Sharma and Smakhtin (2004) studied the utility of various water harvesting measures in the context of proactive approach to drought management and mitigation with examples primarily from South Asia. Sharma and Smakhtin (2004) conclude indications are that rainwater-harvesting measures when adopted on a large scale may minimize the risk of water scarcity even during severe drought years but such studies are few and scattered. Further research is needed to ascertain to what extent these interventions help to withstand droughts and to what extent shall cover the deficit.

Potential of water harvesting in different countries and regions is not yet fully understood, quantified and implemented. Potential of water harvesting as a strategic tool for drought mitigation can be realized through a policy framework to develop institutional mechanism to water harvesting at different levels such as user, watershed, urban locality, district, state and central level by having representatives from local level people’s institutions, NGOs and concerned government departments. They suggests that large-scale application of water harvesting measures in drought-prone areas may be seen as a strategic tool for drought mitigation, if it is realized through the adoption of relevant policies and investments at different levels such as user, watershed, urban locality, district, state and a country.

A number of studies have revealed low adoption rates of water conservation technologies or new innovations among smallholder farmers in developing areas. The reason might be that only one or two of the five pillars of sustainability were considered, instead of all five (agronomic productivity, crop production risk, conservation of natural resources, economic viability and social acceptability).

In tropical sub humid to semi-arid region like in India, creation of water conservation and storage structures led to improved water availability in terms of additional surface storage and ponds and also greater recharge of ground water (Paul, 2004). The change of land usage from rangeland to rain fed farming, that happens without study and research causes the loss of rainwater in the form of surface runoff. Considering the slope of rain fed farming lands in most areas which is usually much more than FAO recommendations, applying improved agricultural practices could decrease the volume of surface runoff and use rainwater at dropping point.

Applying improved agricultural practices could decrease the volume of surface runoff and consequent soil erosion and use rainwater at dropping point. From the results of this research it was concluded that:

(a) The perpendicular plough significantly reduces surface runoff in all slope classes.
(b) The amount of reduction (at %1 significance level) was 82 and 86.9 percent for 0-12 and 12-20 percent slopes respectively.
(c) The amount of reduction (at %5) was 40 percent for 20-40 percent slope.
(d) The volume of surface runoff produced from perpendicular plough of 12-20 and 20-40 percent was significantly lower (at %1) compared to parallel plough of 0-12 percent.
(e) The volume of surface runoff produced from perpendicular plough of 20-40 percent was significantly lower (at %1) compared to parallel plough of 12-20 percent.

A.IV.5 Ground Water recharging

Artificial recharge techniques have become a pragmatic approach to augment depleting ground water resources. Floodwater spreading may be considered as a method of water harvesting too. Utilization of floodwater for groundwater recharge can be a reliable solution. As, this will improve both groundwater quality and quantity, Goodarzi and Daghigh (2004) from survey on a flood spreading project in Iran, found that

Governmental executive organizations are responsible for use of simple and low cost methods for reclamation of land, natural resources, and environment. The flood spreading project has been accepted by some local NGO` s in arid a semi-arid regions of the country.

Executive organizations are normally interested in a short time periods. NGO` s are eager to extend such simple approaches with low investment. Executive organizations and NGO` s can participate in providing funds, to encourage local people to co-operate as voluntary labors in several stage of executive works, especially in non-agricultural seasons. It may be easy for executive organizations and NGO` s to help project managers in planning, design, and implementation.

Most of the necessary construction and plantation material may be supplied with low transportation cost. More specific to this project, incoming sediment carried with the floodwaters impedes smooth recharge into the aquifers and must be properly dealt with. Regular maintenance and appropriate funding should be carefully planned for since most water resources projects suffer from lack of attention in their long-term existence. Goodarzi and Daghigh (2004) conclude that, mechanisms to assure sustainability may include:

(a) Government loans with low interest rate should be made available for implementation of similar projects where needed.

(b) Local co-operative communities have the opportunity to receive bank load to implement large-scale projects for their community.

(c) Design and construction standards must be developed for easy application.

(d) More economically optimized structures should be proposed.

(e) Plants with higher-value are to be researched for adaptation in various regions.

One way to increase ground water quality and quantity wherever accepted good quality floodwater is available for recharging is a recharging system. However in practice, like many other natural resource projects, this system has some real difficulties. Among the main difficulties is clogging phenomenon, which occurs through sedimentation by fine particles over the surface of water spreading systems. The extent of this sedimentation clogging can be monitored through infiltration measurements in the system. Boroom and Nasab et al. (2004) investigated a floodwater-spreading system that is constructed and started to work since 1997 on the eastern part of Dehloran colluvium plain in Iran. The objective was to measure and monitor the variation of the infiltration and clogging phenomenon. The vertical variation as well as flow direction variation of the infiltration is studied.

The vertical variation of infiltration of the sediment is measured at five surfaces, (1) at the surface of the whole sediment deposited since 1997 when the system is started to operate, (2) at the surface where the new deposited sediment is removed, (3) at the surfaces when 10, 20, and 30 cm of the previous natural sediment are removed. To monitor infiltration in the flow direction, infiltration is measured in the desilting basin, spreading channel, spreading basin, and control points. Double ring method was used to measure infiltration at these surfaces. The statistical analysis showed that sedimentation significantly decreased the surface infiltration of the desilting basin when compared with the data obtained from the control points. With removal of the top 10 cm of the natural soil showed that the infiltration rates were significantly increased. Therefore, in order to decrease the adverse effects of sedimentation on reduction of the infiltration rate in the desilting basin, the results of the experiment recommend removing the recent sediment of the basin and also ploughing the top 10cm of the natural surface below the removed sediment. The ploughing is effective to lessen the clogging phenomenon of the sediment.

A.IV.6 In-field rainwater harvesting

Hensley et al. (2000) proposed an in-field rainwater harvesting (IRWH) technique for the rural farmers located east of Bloemfontein, South Africa. This technique combines the advantages of water harvesting, no-till and basin tillage to stop ex-field runoff completely on high clay soils. (Van Rensburg, et al., 2004). This technique is called the in-field rainwater harvesting technique (IRWH). Water conserved this way explained the significant increase in crop yields obtained with the IRWH technique in comparison with the conventional (ploughing) method (CON). Although significantly higher crop yields were obtained with the new IRWH technique, it was realized that the full agronomic potential was not yet obtained. Evaporation dominates the hydrological cycle and measures such as mulches could be used to control evaporation and also siltation of the basins. Van Rensburg, et al. (2004), reviewed some of the important agronomic and conservation aspects of the in-field rainwater harvesting technique. They focused on the nature or design of the IRWH system.

The function of both the basin and catchment area are also studied. It was concluded that the function of the basin area is threefold, viz. to (i) stop ex-field runoff completely, (ii) maximize infiltration and (iii) store the collected water in the soil layers beneath the evaporation sensitive zone. The catchment area has a dual function. Firstly, it is designed to promote in-field runoff and secondly to act as a storage medium for water. It was also realized that the full agronomic potential of the IRWH technique has not yet been reached, due to the fact that the main source of water loss is evaporation. Evaporation dominates the hydrological cycle in semi-arid environments. Hence, different type of mulches was studied over a period of three years to restrict evaporation. The effect of mulch type on yield is described by an infiltration ratio of the basin versus the runoff area. Their results give a fresh outlook on mulch management within water harvesting systems.

The in-field rainwater harvesting technique (IRWH), developed by ARC-ISCW researchers at Glen combines the advantages of water harvesting, no-till, basin tillage and mulching on high drought risk clay soils, Figure A.IV.2. This innovative water conservation technique has the potential to reduce total runoff considerably, resulting in increased yields due to increased plant-available water (Botha et al., 2004).

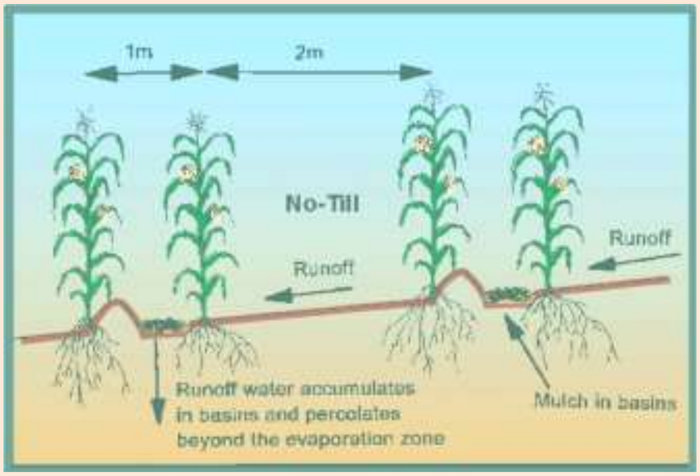

Figure A.IV.2. Diagrammatic representation of the in-field rainwater harvesting technique.

The question that needs to be answered can be stated as follows: Is the in-field rainwater harvesting (IRWH) technique sustainable? Short-term agronomic productivity was measured with on-station trials conducted at the Glen Experimental Station, and on-farm trials and demonstrations on croplands and homesteads in rural villages around Thaba Nchu in the Free State Province of South Africa (Botha et al., 2004). In these experiments the IRWH technique was compared with normal conventional tillage (CON). The sustainability of the two crop production techniques in the specific agro-ecological and socio-economic environment present in the rural villages around Thaba Nchu gave the following results: long-term agro-ecological and short-term socio-economic data indicated that the IRWH technique was sustainable but the CON was not.

A.IV.7 Socio economic considerations

Water-harvesting projects do not depend solely on good engineering and suitable agronomy for their success, socio-economic considerations are just as important. In the drier environments people have been living at subsistence level for centuries and have developed their own priorities for their way of life and survival. It is of the utmost importance, therefore, to take their values, perceptions, attitudes and preferences into consideration rather than try to impose solutions on them. One effective way of introducing and developing water-harvesting projects is first to go to the prospective beneficiaries, talk to them, learn from them, and show willingness and potential to serve them. If the scheme really meets their needs, then interventions can be planned with them, starting with what they know and building on it, using what they have. It is important to make them feel that the project is their own and that it will be of real use to them. Another important issue is land ownership. This can often be a problem, since much of the land requiring structural interventions may be communally used or owned by the state. In these circumstances, individual farmers have little incentive to initiate costly development. The suitability of an area for water-harvesting depends on its being able to meet the basic technical requirements of the system. In addition, whatever technique is selected must be compatible with local social conditions and farming practices. In general local crop or tree species are best adapted to the environment and should have priority over introduced species. Water harvesting may, however, allow farmers to grow species previously considered too risky. Improved varieties may be suitable, provided their introduction follows research and adaptation programs that prove their viability. The crops and trees selected should be capable of integration with the local farming system and able to withstand the 2–3 days of water logging that are typical in most water-harvesting systems after heavy storms. Maize, for example, is not suitable. The design of the water-harvesting system should ensure, with reasonable probability, that a specific amount of water is available for the designated use. It is important to emphasize that in the drier environments, it is not always necessary for the potential water demand to be fully met, as crops may be grown economically, and produce, without their water needs being completely satisfied.

A.IV.8 Examples of water harvesting

Although several positive examples have been registered, in numerous cases the water harvesting projects have not achieved their expected goal as the technologies and designs were not suitable for either the environment or the cultural habits of the beneficiaries. In addition, operation and maintenance of the schemes turned out to be either too costly and/or time-consuming. Palmier (2004) reviewed the difficulties in implementing the former water harvesting techniques in Latin America and the Caribbean is presented emphasizing the most frequent errors which often cause failures. Palmier (2004) provided some themes for further research in order to improve technical aspects of water harvesting projects. He concludes that with respect to the implementation of large-scale water harvesting projects as a part of a rural development strategy to supply drinking water for human and livestock consumption in rural communities and to provide water for agriculture, the main reasons for mandatory Environmental Impact Assessment are: interdisciplinary nature, as institutional, social, economic, physical, technical and environmental issues are considered in order to proceed an adequate planning; uncertainties, as agricultural projects have a complex interactions with natural systems and many of the intrinsic uncertainties would be addressed to obtain a long-term beneficial effect; feedback mechanisms, which would provide crucial information to enable planners to revise or adjust the project cycle; and importance of local knowledge, which can be fully incorporated by making provision for the assessment of indigenous environmental knowledge, by understanding local resource-use details and by use of local value sets to evaluate predicted impacts. Palmier (2004) recommends, the experience already acquired is fundamental for the design and implementation of water harvesting programs, and the adoption of a pilot project is a useful and convenient starting point, especially in areas with limited data. Potential synergies can be achieved by the establishing of guidelines for the systematic application of the well-known and approved phases of Environmental Impact Assessment – namely screening, scoping, prediction and mitigation, management and monitoring, auditing, in the implementation of water harvesting projects and by the definition of a comprehensive performance criteria for different water harvesting techniques on the basis of social and economic indicators.

(i) India

In North- West Himalayan region of India, the annual rainfall is as high as 3000 mm with average of 1750 mm, of which 71 percent is received during tropical monsoon period i.e. July- August months and 79% of the total goes as runoff and stream flow (Sharma et al. , 2004). The rainfall distribution is erratic and uneven both spatially and temporally which results into acute water shortage for the use of both population and agriculture, soil loss and flash floods. To combat this problem, on farm rain water harvesting is a common practice in the region with traditional methods which contribute 10 % of water availability for agriculture and 40% for the population use and it has further potential for contribution in water availability especially for the crop production with new site specific techniques which include construction of “ nala bandhan”, “tanka” farm pond, embankment –cum-dug structures / surface ponds and check dams for aquifer recharge and

"Johar" or tanks for water storage. Roof rainwater harvesting is also tried in small dug out structures which are excavated in the hard rock and are commonly called as "Khattis" or "Dighis". To have clean and hygienic water the harvesting done during the end of monsoon was found to be more suitable. In addition, good results of harvesting and storage are being achieved in ferro-cement water storage structures of different dimensions of 3 to 5 m deep and 1 to 3 m in diameter. Sharma et al (2004) found that, the most efficient and cheapest way of conserving rainwater at the agricultural farm was found to be in- situ runoff management, which also reduces soil losses and increases the opportunity time for ground water recharging. The average depth of runoff at 80 percent probability level was found to be 14 cm. It is observed that earthen embankment for rainwater harvesting has cost benefit ratio of 1.38:1. Hence it can economically be replicated. It is also observed that earthen check dam/reservoirs which are recommended across the streams to regulate run off for flood control, trapping silt, collecting water for irrigation and fish production and to recharge ground water has good potential for replication. Excavated. dug-out ponds tanks are found most suitable for storing runoff in cultivated lands with inverted truncated pyramid shape having 1:1 side slopes with lining of polyethylene sheet of 200 micron buried under 20 cm thick soil at bottom and pitched with bricks. The rainwater harvesting during monsoon and its use for irrigation during follow scarcity period was found to increase the crop yield by 20-30% during rabi (Winter) season and additional water for population use by 60 % in the area. They conclude that the erratic and uneven distribution of rainfall both spatially and temporally, necessitates rainwater harvesting to increase and sustain the agricultural productivity. There is urgent need for flood protection and irrigation on farm lands below the hills through control and utilization of run off. Rehabilitation of upper watersheds through reduced run off and erosion from the hills through soil conservation and renegotiation should be done. For successful implementation of traditional and new On farm rainwater harvesting techniques, strengthening of Implementing Agency's capacity should be done for undertaking investigations and research of surface hydrology, groundwater and micro-watershed studies (Sharma et al., 2004).

Floodwater spreading for irrigation and the artificial recharge of groundwater is an ancient art that has supported the desert-dwelling Iranians for millennia. Kowsar (2004), presents Flood water spreading (FWS) concepts, a simple description of an FWS system, an evaluation of the most important channel in any FWS system, rates of flow are used in designing FWS systems, and illustrative examples of how simple systems. Harnessing of wild floods, however, necessitated modifications of the old designs.

Check dams in Gujarat

Check dams in Gujarat are taken up on hand by governmental as well as the non Govt Organization (NGO). Govt agencies involved are local Govt (Panchayat), forest, District Rural Development Agency and regular state Water Resource Dept. Under public participation scheme of Govt of Gujarat (SPSJSY) Govt has constructed major chunk under this scheme. Creation of water bodies increased irrigation, availability of drinking water for self and livestock, recharging of underground water due to pressure created by standing pool of water behind check dams. Another side of the coin, negative impacts are silting, weed growth. Increased water related disease. Wild life is attracted towards water bodies. Loaded drains become barrier for wild life migration, wild life damaging the crops and attacking livestock.

Another negative impact will be the reduced flow in the rivers and in the estuaries mostly in the starting years, as water will be stored behind check dams in initial years, part of which going into recharging process. Singh (2004) evaluate the impacts of check dams on environment: in the state of Gujarat in India. He concludes that coming to the water conservation, Check Dams are very effective tools, a very sustainable livelihood approach, to conserve and harvest the water. Lessons learnt while implementing large schemes have shifted the focus towards small check dams. Villagers are taking the concept seriously and getting them involved as community participation, benefits are clearly visible, new sense is prevailing and changes are felt.

Environment impacts are felt but confinable with local factors. Here positive impacts are dominating over negative impacts and negative impacts manageable with mitigation. With the advances in technology a numbers of preventive remedial and mitigating opening and measures are now available to prevent, reduce and even eliminate the possible adverse impacts. In Indian context the "environment" without these projects whether small or big will be more haunting and cruel than the environment which at least pave the way for the survival of millions (when say the water resources are developed with so called negative impacts).

(ii) Libya

Because of non-existence of any regular river or perennial stream, Libya is one of the most water scarce countries. Rainfall is the major source of livelihood of the farming communities in the country. The rainfall drops from 350 mm near Mediterranean coast in the north to less than 100 mm in the central zone, where semi-desert/ desert climate dominates. Razzaghi et al. (2004) studied attempted to evaluate and document rainwater harvesting practices in the past and to present results of an experiment was conducted in the same environment in order to demonstrate the usefulness of appropriate water harvesting technique that suits to the country environment. The experiment aims at real-time testing and evaluating the two potential micro-catchment rainwater harvesting techniques in order to improve bio-mass production in a certain agro-climatic and geo-physical environment, which largely prevails in the northern areas of Libya.

The project aimed at studying the old traditional methods used in rainwater harvesting, evaluating them technically and economically as a first stage, then initiated a strategic research aimed at developing methods and approaches for optimum utilization of rainwater techniques by developing those techniques and introduces new ones. In this framework, as a first stage, the formed team for this purpose conducted a field survey and comprehensive compilation of old and modern techniques utilized in rainwater harvesting existing in the western area of Libya. They were classified according to the size of catchment area and water storing method, whether being in soil, in ground reservoirs or behind dams.

Following completion of this stage, members of the team carried out some field experiments, by applying rainwater harvesting techniques such as Negarim basin and contour ridges in developing natural pasture in semi-arid region in western part of Libya using Atriplex shrubs. Although tangible results were not achieved in the first year of the experiments carried out in 1998/1999 season due to scanty rain, as quantity and density, but by the end of 2000/2001 season a good growth of the shrubs used in the experiment have been noticed compared with the ones planted outside the techniques.

(iii) Jordan

Jordan is facing the most serious water shortages in the Middle East. It is an arid country located east of the Jordan River with a land area of about 90,000-km. Contour stone terraces have been widely used by Jordanian farmers in the hilly areas for soil and water conservation purposes. Traditionally, farms were subjected to systematic deep ploughing to break up the surface rocks and then remove stones for installation of terraces. This method is very expensive and cause complete disturbance to the area that may enhance soil erosion.

A new land reclamation method for water harvesting has been experimented in the hilly parts of Jordan since 1999. Abu-Zreig (2004) in an experimental project attempted to adopt a new reclamation method for highlands of Jordan using water harvesting techniques. The study watershed located to the North West side of the country around the city of Ajlun in a mountainous area ranging from 500 - 1250 m above sea level with steep slopes, valleys, and numerous springs. Traditional water harvesting systems used in the study areas include: Ajlun, Terracing, Concrete catchment area with Cistern, Collection Ponds, Muwaggar. Water harvesting systems adopted in this research include: Runoff storage pond, Contour tree bunds, Semi-circular earth bunds, Water spreading structure, and Contour ridges. Three sites with various slope, soil characteristics and topography have been chosen for experiments.

The method consists of designing semi-circular stone bunds randomly based on the micro topography of land. Semi-circular bunds were located at areas having deep soil pockets and adequate runoff rocky area. In this method no deep plowing was necessary and lands were subjected to minimum disturbance. This method has many advantages including minimizing soil erosion and maximizing rainfall harvesting due to the high runoff efficiency from runoff rocky areas, promoting biodiversity yet having similar cropping density to that of traditional method. In addition the cost of this method was about 85% less than that of the traditional conservation methods used by the Jordanian farmers. Field evaluations showed that semi-circular bunds were very effective in capturing runoff and preventing soil erosion from the cropping areas.

The soil moisture in the cropping areas was about 7% higher than that in the control areas. Field measurements showed that soil depth in some of the cropping terraced areas increased by about 3 cm at the end of the 2003/2004 rainy season. Based on the experimental results, Abu-Zreig (2004) recommends that construction of low cost semi-circular stone terraces increased the area of agricultural land and increased land value. Water catchment systems are essential to solve crucial social problems mainly in rural areas with scarcity of water and lack of basic crops and forage. The introduction of random semi-circular stone terraces to farmers in Jordan was successful. Many farmers are adopting this method in to their farm land which was previously considered marginal land. Semi-circular terraces have proven to be effective in reducing soil erosion and increasing moisture level in the cropping areas. Field measurements have shown that semi-circular stone terraces improve the survival rates of medicinal plants to 90% and also increase moisture level in the cropping area by about 7%. A successful application of water harvesting depends mostly on their compatibility with land use and population practices.

(iv) Iran

In arid and semi-arid regions of south of Iran, most of irrigation water is provided from groundwater resource. Recently, demand for water has increased because of development of agricultural sector, so that more water is pumped and water balance of groundwater of most areas are going to be negative. This means the natural recharge from precipitation is less than discharge from water table. Artificial recharge is used for water harvesting to sustain agricultural activities of these areas by diverting surface runoff during rainfall which flow through Wadis.

Since 1990, about 56 projects were chosen and constructed in the southern provinces (Fars, Bushehr and Kohkiluye-o- Boyrahmad) and harvested approximately about 102 MCM per year. This volume of water recharged to groundwater table of catchment areas. Each project consists of all or some of these structures: diversion dam, levee, diversion channel, settling basin and ponds. Surface runoff of catchment's area flow through Wadis and divert to settling basin and impound in ponds. Impounded water gradually infiltrates into the groundwater and recharges it. Farjood and Malekzadeh (2004) discussed, site investigation, site selection and some design criteria of these groundwater artificial recharge projects.

Based on their study, the method of artificial water recharge is a method to make maximum use of the limited precipitation in arid and semi-arid regions. Although enough data gathering and scientific research has not been carried out on these projects, but farmers are very satisfied with the results of these projects. As a result, people and farmers using underground water for agriculture are ready to take part in the investments of such projects. A distinguished advantage of these projects relative to other projects of water harvesting like dam construction, is its low cost and short construction period. The rise in water table level, one to two years after finishing the project is detectable. Controlling flood hazard and stopping salty ground water attack on fresh ground water aquifers are other advantages of these projects.

Nikkami et al. (2004) conducted a research plan in sloppy areas of the Sohrain Gharacharian floodwater spreading research station in Zanjan province of Iran. During 2002-2003, 11 rainfall events that caused surface runoff were monitored in 1.8x22 meter erosion plots. Two plough treatments of in slope direction and perpendicular to slope direction and 3 slope classes of 0-12, 12-20, and 20-40 percent plots were under regional wheat planting in 3 replicated under randomized complete block design. The volume of surface runoff from these 18 plots was measured in the tanks located at the end of each plot. Results demonstrated that the perpendicular plough significantly reduces surface runoff in all slope classes. The amount of reduction (at %1 level) was 82 and 86.9 percent for 0-12 and 12-20 percent slopes respectively.

The amount of reduction (at the level of %5) was 40 percent for 20-40 percent slope. The volume of surface runoff produced from perpendicular plough of 12-20 and 20-40 percent was significantly lower (at the level of %1) compared to parallel plough of 0-12 percent. The same result was noted when comparing volume of surface runoff from perpendicular plough of 20-40 percent to parallel plough of 12-20 percent. Nikkami (2004), conclude, the slope of rain fed farms in most areas is usually more than FAO recommendations.

Appendix V

A.V Water Quality and Use of Saline Water in Irrigation

This Appendix provides the quality requirements for irrigation water, principles of use of saline water in irrigation, research on use of saline water in irrigation and some salinity standards prevalent in Australia, Algeria, Cyprus, Greece, Egypt, India, Iran, Israel, Jordan, Morocco, Syria, Tunisia, Turkey, and USA.

A.V.1 Water quality for irrigation

The problems vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

Salts in soil or water reduce water availability to the crop to such an extent that yield is affected. However, relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next. Also, certain ions (Sodium, Chloride, or Boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields. Finally, excessive nutrients reduce yield or quality; unsightly deposits on fruit or foliage reduce marketability; excessive corrosion of equipment increases maintenance and repairs.

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate.

The two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content. A high salinity water will increase infiltration. A low salinity water or a water with a high sodium to calcium ratio will decrease infiltration. Both factors may operate at the same time. Secondary problems include crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problems.

An Infiltration problem related to water quality in most cases occurs in the surface few centimeters of soil is linked to the structural stability of this surface soil and its low calcium content relative to that of sodium. In some cases, water low in salt can cause a similar problem but this is related to the corrosive nature of the low salt water and not to the sodium content of the water or soil. In the case of the low salt water, the water dissolves and leaches most of the soluble minerals, including calcium, from the surface soil.

A.V.1.1 Salinity

Salinity problem exists if salt accumulation in the crop root zone to a concentration that causes a loss in yield. In irrigated areas, these salts often originate from saline, high water table or from salts in the applied water. If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought, such as wilting, or a darker, bluish-green color and sometimes thicker, waxier leaves. Symptoms vary with the growth stage, being more noticeable if the salts affect the plant during the early stages of growth. In some cases, mild salt effects may go entirely unnoticed because of a uniform reduction in growth across an entire field.

Salts that contribute to a salinity problem are water soluble and readily transported by water. A portion of the salts that accumulate from prior irrigations can be moved (leached) below the rooting depth if more irrigation water infiltrates the soil than is used by the crop during the crop season. Leaching is the key point to controlling a water quality-related salinity problem. Over a period of time, salt removal by leaching must equal or exceed the salt additions from the applied water to prevent salt building up to a damaging concentration. The amount of leaching required is dependent upon the irrigation water quality and the salinity tolerance of the crop grown.

Salt content of the root zone varies with depth. It varies from approximately that of the irrigation water near the soil surface to many times that of the applied water at the bottom of the rooting depth. Salt concentration increases with depth due to plants extracting water but leaving salts behind in a greatly reduced volume of soil water. Each subsequent irrigation pushes (leaches) the salts deeper into the root zone where they continue to accumulate until leached. The lower rooting depth salinity will depend upon the leaching that has occurred.

Following irrigation, the most readily available water is in the upper root zone-a low salinity area. As the crop uses water, the upper root zone becomes depleted and the zone of most readily available water changes toward the deeper parts as the time interval between irrigations is extended. These lower depths are usually more salty. The crop dose not respond to the extremes of low or high salinity in the rooting depth but integrates water availability and takes water from wherever it is most readily available. Irrigation timing is thus important in maintaining high soil-water availability and reducing the problems caused when the crop must draw a significant portion of its water from the less available, higher salinity soil-water deeper in the root zone. For good crop production, equal importance must be given to maintaining a high soil-water availability and to leaching accumulated salts from the rooting depth before the salt concentration exceeds the tolerance of the plant.

A.V.1.2 Toxicity

Toxicity problems occur if certain constituents (ions) in the soil or water are taken up by the plant and accumulate to concentration high enough to cause crop damage or reduced yields. The degree of damage depends on the uptake and crop sensitivity. The permanent, perennial-type crop (tree crops) is the more sensitive.

The ions of primary concern are chloride, sodium and boron. Although toxicity problems may occur even when these ions are in low concentrations, toxicity often accompanies and complicates a salinity or water infiltration problem. The degree of damage depends upon the duration of exposure, concentration by the toxic ion, crop sensitivity, and the volume of water transpired by the crop. In a hot climate or hot part of the year, accumulation is more rapid than if the same crop were grown in a cooler climate or cooler season when it might show little or no damage.

Toxicity can also occur from direct absorption of the toxic ions through leaves wet by overhead sprinklers. Sodium and chloride are the primary ions absorbed through leaves, and toxicity to one or both can be a problem with certain sensitive crops such as citrus. As concentration increase in the applied water, damage develops more rapidly and becomes progressively more severe.

Several other problems related to irrigation water quality occur with sufficient frequency for them to be specifically noted. These include high nitrogen concentrations in the water which supplies nitrogen to the crop and may cause excessive vegetative growth, lodging, and delayed crop maturity; unsightly deposits on fruit or leave due to overhead sprinkler irrigation with high bicarbonate water, water containing gypsum, or water high in iron; and various abnormalities often associated with an unusual pH of the water. Vector problems (mosquitoes) often originate as a secondary trouble related to a low water infiltration rate, to the use of wastewater for irrigation, or to poor drainage. Suspended organic as well as inorganic sediments cause problems in irrigation systems through clogging of gates, sprinkler heads and drippers. They can cause damage to pumps if screens are not used to exclude them. More commonly, sediments tend to fill canals and ditches and cause costly dredging and maintenance problems. Sediment also tends to reduce further the water infiltration rate of an already slowly permeable soil.

A.V.2 Using low quality water in irrigation

Many researchers, scientists, organizations, institutions and authorities have advocated the concept of using saline and saline/sodic water for irrigation to increase food production. So, there have been a number of different water quality guidelines related to irrigate agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. Hopefully, each new set of guidelines has improved our predictive capability. For example, Food and Agricultural Organization (FAO) publication 29 (Ayers and Westcot, 1985) and 48 (Rhoades et al., 1992), ASCE Manuals and Reports on Engineering Practice No. 71 (Tanji, 1990), the Drainage Reuse Technical Committee (The San Joaquin Valley Drainage Implementation Program and The university of California Salinity/Drainage Program) and ICID (2004) provide comprehensive information and guidelines on management practices for agricultural water and salinity problems. The guidelines presented here have relied heavily on previous ones but are modified to give more practical procedures for evaluating and managing water quality-related problems of irrigated agriculture.

A.V.2.1 Water Quality Guidelines

Guidelines for evaluation of water quality for irrigation emphasize the long-term influence of water quality on crop production, soil conditions and farm management. These guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater.

Laboratory determination and calculations needed to use the guidelines along with the symbols used. Analytical procedures for the laboratory determination are given in several publications; USDA Handbook No. 60 (Richards, 1954), Rhoades and Clark 1978, FAO Soils Bulletin (Dewis and Freitas, 1970), and Standard Methods for Examination of Waters and Wastewaters (APHA, 1980). The method most appropriate for the available equipment, budget and number of samples should be used. Analytical accuracy within ±5 percent is considered adequate.

The Sodium Adsorption Ratio (SAR) is calculated from the Na, Ca and Mg and reported in me/l. The following equation is used for this propose:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad (1)$$

Where; Na, Ca and Mg are sodium, calcium and magnesium concentration in me/l that obtain from the laboratory water analysis.

A.V.2.2 Problems in use of saline water

In arid and semi-arid regions or in drought conditions there aren't adequate water supplies of usable quality. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals. These salts are carried with the water to wherever it is used. In the case of irrigation, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop.

The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Use of saline water requires several changes from standard management practices such as selection of appropriate crops, improvements in water and soil management, adjustments in crop rotations and in some cases, the adoption of advanced irrigation technology. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use.

The problems that results vary both in kind and degree, and are modified by soil, climate and crop, as well as by the skill and knowledge of the water user. As a result, there is no set limit on water quality; rather, its suitability for use is determined by the conditions of use which affect the accumulation of the water constituents and which may restrict crop yield. The soil problems most commonly encountered and used as a basis to evaluate water quality are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems.

Salts in soil or water reduce water availability to the crop to such an extent that yield is affected. However, relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next. Also, certain ions (sodium, chloride, or boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields. Finally, excessive nutrients reduce yield or quality; unsightly deposits on fruit or foliage reduce marketability; excessive corrosion of equipment increases maintenance and repairs.

A.V.2.3 Plant response to saline water

All plants do not respond to salinity in a similar manner. Some crops can produce acceptable yields at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. The ability of the crop to adjust to salinity is extremely useful. In areas where a build-up of soil salinity cannot be controlled at an acceptable concentration for the crop being grown, an alternative crop can be selected that is both more tolerant of the expected soil salinity and can produce economical yields. There is an 8 to 10-fold range in salt tolerance of agricultural crops. This wide range in tolerance allows for a much greater use of moderately saline water much of which was previously thought to be unusable. It also greatly expands the acceptable range of water salinity (ECw) considered suitable for irrigation. The relative salt tolerance of most agricultural crops (common fields, vegetative, forage and tree crops) is known well enough to give general salt tolerance guidelines. During the last 100 years, many experiments have been carried out for modeling the salt tolerance of crops. For example, Mass and Hoffman (1977) and van Genuchten and Hoffman (1984) proposed such models.

An infiltration problem related to water quality occurs when the normal infiltration rate for the applied water or rainfall is appreciably reduced and water remains on the soil surface too long or infiltrates too slowly to supply the crop with sufficient water to maintain acceptable yields. Although the infiltration rate of water into soil varies widely and can be greatly influenced by the quality of the irrigation water, soil factors as structure, degree of compaction, organic matter content and chemical make-up can also greatly influence the intake rate. The two most common water quality factors which influence the normal infiltration rate are the salinity of the water (total quantity of salts in the water) and its sodium content relative to the calcium and magnesium content. High salinity water will increase infiltration. Low salinity water or a water with a high sodium to calcium ratio will decrease infiltration. Both factors may operate at the same time.

Brackish water can be used for irrigation of a broad variety of crops. However, under arid and semi-arid conditions associated with low annual precipitation and high solar radiation intensive evaporation from the soil surface takes place. Therefore, salt could accumulate in the root zone if leaching is not maintained, resulting in poor yields. To alleviate salt accumulation saline water could be applied using drip irrigation (especially subsurface drip irrigation), thus driving the saline front to below the main root zone. Several researchers examined this concept in orchards worldwide. However, successful examples of the use of saline/sodic water in irrigation in the world (Mediterranean region, the United States, India, etc.) are available.

A.V.3 Salinity of soils

A salinity problem exists if salt accumulation in the crop root zone to a concentration that causes a loss in yield. In irrigated areas, these salts often originate from saline, high water table or from salts in the applied water. Yield reduction occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time. If water uptake is appreciably reduced, the plant slows its rate of growth. The plant symptoms are similar in appearance to those of drought, such as wilting, or a darker, bluish-green color and sometimes thicker, waxier leaves. Symptoms vary with the growth stage, being more noticeable if the salts affect the plant during the early stages of growth. In some cases, mild salt effects may go entirely unnoticed because of a uniform reduction in growth across an entire field.

When the build-up of soluble salts in the soil becomes or is expected to become excessive, the salt can be leached by applying more water than that needed by the crop during the growing season. This extra water moves at least a portion of the salts below the root zone by deep percolation. Leaching is the key factor in controlling soluble salts brought in by the irrigation water. Over time, salts removal by leaching must equal or exceed the salt additions from the applied water or salts will build up and eventually reach damaging concentrations. The questions that arise are how much water should be used for leaching and when should leaching be applied? To estimate the leaching requirement, both the irrigation water salinity (ECw) and the crop tolerance to soil salinity (ECe) must be known. The water salinity can be obtained from laboratory analysis while the ECe should be estimated from appropriates crop tolerance data given in the guidelines. The necessary leaching requirement (LR) can be estimated from the several equation (for example, Rhoades, 1974; and Rhoades and Merrill, 1974).

A.V.3.1 Crop tolerance to soil salinity

All plants do not respond to salinity in a similar manner. Some crops can produce acceptable yields at much greater soil salinity than others. This is because some are better able to make the needed osmotic adjustments enabling them to extract more water from a saline soil. The ability of the crop to adjust to salinity is extremely useful. There is an 8 to 10-fold range in salt tolerance of agricultural crops. This wide range in tolerance allows for a much greater use of moderately saline water much of which was previously thought to be unusable. It also greatly expands the acceptable range of water salinity (ECw) considered suitable for irrigation.

The relative salt tolerance of most agricultural crops is known well enough to give general salt tolerance guidelines. Tolerances for many common fields, vegetative, forage and tree crops gives the latest tolerance values for crops grown under semi-arid irrigated agriculture. Where insufficient data exist to give numerical values for tolerance, a relative rating has been assigned to the crop, based on field experience, limited data or observations. General groupings for tolerance are shown in the schematic diagram in Figure 3.3. The relative tolerance ratings, even if based on a limited amount of data, are useful for comparisons among crops.

During the last 100 years, many experiments have been carried to determine the salt tolerance of crops. For example, Mass and Hoffman (1977) carried out a comprehensive analysis of salt-tolerance data and concluded that crop yield as a function of the average root-zone salinity could be described reasonably well by a piecewise linear response function characterized by a salinity threshold value below which the yield is unaffected by soil salinity and above which yield decrease linearly with salinity. The following equation (Mass and Hoffman, 1977) expresses the straight line salinity effect on yield:

$$Y = 100 - b(ECe - a)$$

Where;

Y = relative crop yield (percent)
ECe = salinity of the soil saturation extract in dS/m
a = salinity threshold value
b = yield loss per unit increase in salinity

The values for (a) and (b) are given by Mass in his original paper but can also be determined. Figure A.V.1 illustrates relative yield decrement as a function of soil salinity for a several crops according to Mass and Hoffman (1977) equation. Also, a smooth S-shaped response function, as proposed by van Genuchten and Hoffman (1984), describes this relation is:

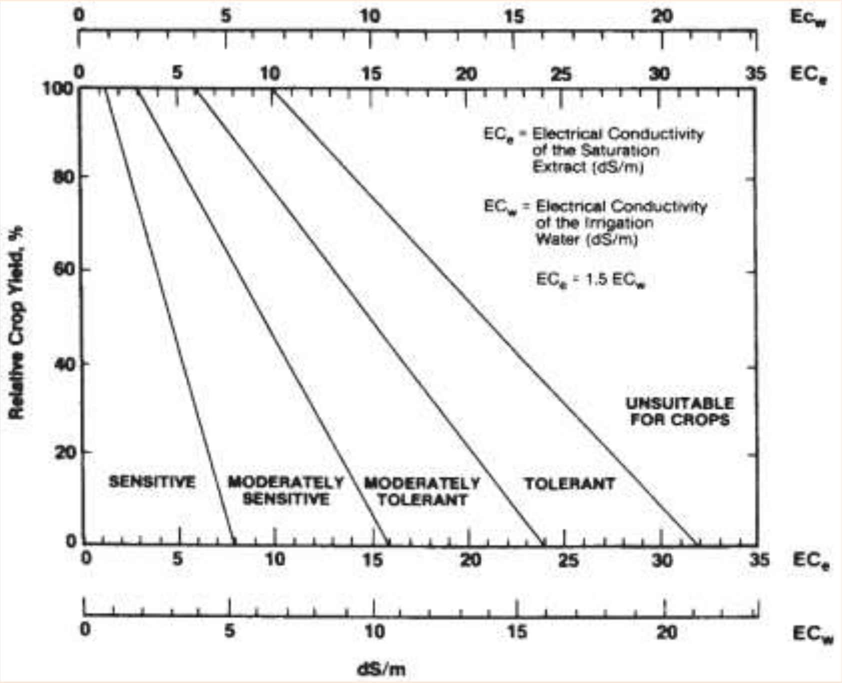

Figure A.V.1. Division for relative salt tolerance ratings of agricultural crops (Mass, 1984)

$$Y / Y_m = 1 / \left[1 + (C / C_{50})^P\right]$$

Where;

Y	= actual yield
Ym	= yield under non-saline conditions.
C	= average root-zone salinity
C50	= soil salinity at which yield is reduced by 50 %
P	= an empirical constant

The curve shown in Figure 3.5 is for wheat with an average value of P=3 and C50 =23.9 dS/ m. van Genuchten and Gupta (1993) reported that the value of P in equation (3) is closed 3 for most crops.

A.V.3.2 Soil-salinity control by leaching

When the build-up of soluble salts in the soil profile becomes or is expected to become excessive, the salt can be reached by applying more water than that needed by the crop during the growing season. This extra water moves at least a portion of the salts below the crop root zone by deep percolation (leaching). Leaching is the key factor in controlling soluble salts brought in by the irrigation water. Over time, salts removal by leaching must equal or exceed the salt additions from the applied water or salts will build up and eventually reach damaging concentrations. The questions that arise are how much water should be used for leaching and when should leaching be applied?

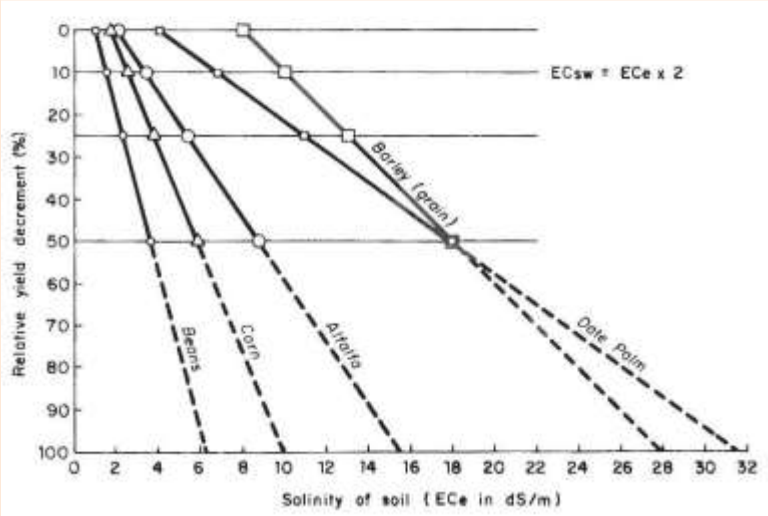

Figure A.V.2 Relative yield decrement as a function of soil salinity for several crops (According to Mass and Hoffman, 1977)

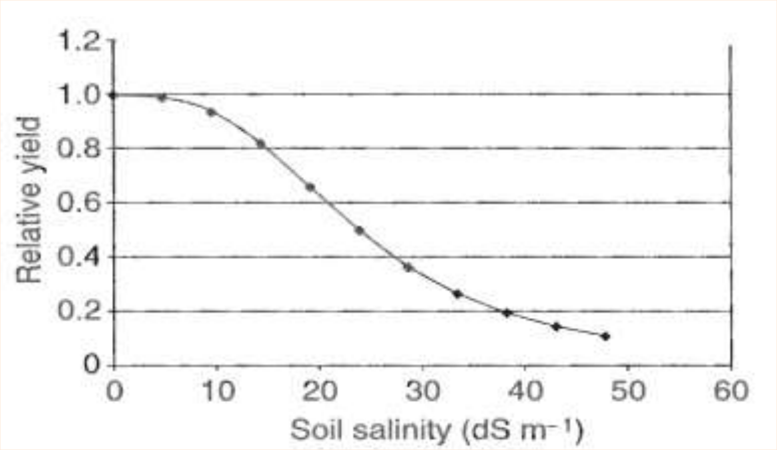

Figure A.V.3 Relative yield decrement as a function of soil salinity for wheat (According to van Genuchten and Hoffman, 1984)

To estimate the leaching requirement, both the irrigation water salinity (ECw) and the crop tolerance to soil salinity (ECe) must be known. The water salinity can be obtained from laboratory analysis while the ECe should be estimated from appropriates crop tolerance data. The necessary leaching requirement (LR) can be estimated from the following equation for a particular crop (Rhoades, 1974; and Rhoades and Merrill, 1974):

$$LR = \frac{ECw}{5(ECe) - ECw}$$

Where;

LR	=	the minimum leaching requirement needed to control salts within the tolerance (ECe) of the crop with ordinary surface method of irrigation
ECw	=	salinity of the applied irrigation water in dS/m
ECe	=	average soil salinity tolerance by the crop as measured on a soil saturation extract

ECe can be obtained for the given crop and the appropriate acceptable yield. It is recommended that the ECe value that can be expected to result in at least a 90 percent or greater yield be used in the calculation. However, for water in the moderate to high salinity range (>1.5 dS/m), it might be better to use the ECe value for maximum yield potential (100 percent) since salinity control is critical to obtaining good yields.

The total annual depth of water that needs to be applied to meet both the crop demand and leaching requirement can be estimated from the following equation;

$$AW = \frac{ET}{1 - LR}$$

Where;

AW = depth of applied water (mm/year)
ET = total annual crop water demand (mm/year)
LR = leaching requirement expressed as a fraction (leaching fraction)

A.V.4 Research in use of saline water in irrigation

Many researchers, scientists, organizations, institutions and authorities have advocated the concept of using saline and saline/sodic water for irrigation to increase food production. So, there have been a number of different water quality guidelines related to irrigate agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. Hopefully, each new set of guidelines has improved our predictive capability. These guidelines have relied heavily on previous ones but are modified to give more practical procedures for evaluating and managing water quality-related problems of irrigated agriculture. Guidelines for evaluation of water quality for irrigation emphasize the long-term influence of water quality on crop production, soil conditions and farm management. These guidelines are practical and have been used successfully in general irrigated agriculture for evaluation of the common constituents in surface water, groundwater, drainage water, sewage effluent and wastewater. They are based on certain assumptions which are given immediately following its. These assumptions must be clearly understood but should not become rigid prerequisites.

Some national research stations, centres, and institutes related to salinity/alkalinity in selected countries are shown in Table A.V.1. Also, successful examples of the use of saline/sodic water in irrigation in the Mediterranean region, the United States, and India will be discussed in detail in the following sections.

Under arid and semi-arid conditions associated with low annual precipitation and high solar radiation intensive evaporation from the soil surface takes place where salinity and alkalinity can develop and salt could accumulate in the root zone if leaching is not maintained, resulting in poor crop yields. To alleviate salt accumulation saline water could be applied as brackish water can be used for irrigation in a broad variety of crops. Subsurface drip irrigation divesting the saline front to below the main root zone. Oron et al (1995) examined this concept in a mature pear orchard.

Moreno et al (2001) evaluated the effects of irrigation with high and moderately saline waters on soil properties and the growth and yield of cotton and sugar beet crops in a farm study in Spain during 1997-98. Local soils have a high clay content, high salinity, and a shallow, extremely saline water table. After irrigating cotton with highly saline water, soil salinity increased, however after 5 irrigations with fresh water, soil salinity was reduced to its original level. Irrigating sugar beet with highly saline water increased soil salinity but not to the same level as cotton. Irrigation with saline water did affect crop development for both crops and had less impact on crop yield. Results indicate that two supplementary irrigations with saline water can represent water saving of 25% without serious problems; however continuous irrigation with saline water in these conditions would seriously impact on the water table. In the Egyptian deserts and rural areas there is a shortage of fresh water in spite of the presence of large sources of brackish water. Solar energy is abundant in these remote areas of Egypt. Ahmad and Schmid (2002) introduced a feasibility study of water desalination in these areas using photovoltaic energy as the primary source of energy. Two major approaches to sustaining high agricultural productivity in a saline environment involve either modifying the environment to suit available crops or to modify the crops to suit the environment. Tyagi (2003), discusses the issues arising from the use of these approaches as related to the use of marginal-quality water, at both field and irrigation system level. Results of field studies indicate that appropriate technological interventions can increase water productivity in saline environments.

Table A.V.1 Research stations and institutes related to salinity in selected countries

Country	Research Station/Institute
Australia	Tatuara Research Stations, Victoria
Cyprus	Agricultural Research Institute, Nicosia
Egypt	Drainage Research Institute, Cairo
	National water Research Centre, Cairo
India	Central Soil Salinity Research Station, Karnal (Haryana).
	Haryana Agricultural University, Hisar. ICAR Project on Use of Saline Water. Central Arid Zone Research Institute Jodhpur.
Iran	Soil Fertility and Soil Survey Institute, Tehran Agricultural Engieering Research Institut, Karj National Salinity Research Center, Yazed
Iraq	Arab Centre for the Studies of Arid Zones and Dry Lands (ACSAD), Damascus
	Soils Directorate, Douma, Damascus.
	Institute for Research on Natural Resources, Abu Gharaib
Israel	Institute of Applied Research Ben-Gurion, Negev.
	Negow Institute for Arid Zone Research, Beer Sheva.
Japan	Arid Land Research Center□□Tottori
Jordan	Reclamation Experimental Station, Quatrana
Lebanon	Agricultural Research Institute, Tal Amara Station.
	Aldeh Research Station.
Pakistan	Water and Soil Investigation Division West Pakistan Water and Power Development Authority (WAPDA), Lahore.
	Tando Jam Research Station, Hyderabad (Sindh).
	University of Agriculture, Faisalabad.
	International water logging and salinity Research institute, Lahore
Spain	IRNAS, CSIC, Serville
Sudan	Gezira Research Station, Wad medani
Syria	Soils Department, Faulty of Agriculture, University of Aleppo.
The Netherlands	Institute for land Reclamation and improvement (ILRI), Wageningen.
Tunisia	Research Center for Utilization of Saline Waters for Irrigation (CRUESI)
United Arab	Soil Salinity Laboratory, Bacos Alexandria.
Republic	Soils Department, Orman, Giza.
	Institute of Land Reclamation, Alexandria University.
United Kingdom	Institute Of Hydrology, NERC, Walling Ford.
United States	US Salinity Laboratory, River side, California.
United Arab Emirates	International Center for Biosaline Agriculture (ICBA). Dubai, United Arab Emirates.

Chaibi and Jilar (2004) discuses results from a field evaluation of a roof desalination process for green houses. Afonso et al. (2004) reports on research into the technical-economic feasibility of brackish groundwater treatment by reverse osmosis for potable water production. Soria et al. (1998) studied the impact of salinity on the fruit yield and water consumption of tomatoes grown in gravel in a polyethylene greenhouse in Spain. Yield decreased with increasing salinity, even the lowest salinity decreased fruit yield by 43%. Dabbagh (2001) discusses the water crisis in the Arab World and it is compared with the oil crisis when industrial nations adopted policies and research programs in order to reduce dependence on oil and reduce its costs. This experience provides lessons for better utilization of desalinated water. Thompson and Hume (1997) investigated the effect of increasing the supply water salinity on the infiltration properties of rice soils for a range of soil types and water table depths in the Murray Valley NSW in Australia. It is recommended that channel water supply salinities not exceed 0.5-0.6 dS/m). Ali et al. (2000) conducted a study to demonstrate the performance of LEACHC as an irrigation management tool. Whilst the model is adaptable to variant conditions, the study was undertaken in an extremely arid area with a high saline water table.

Irrigated agriculture is dependent on an adequate water supply of usable quality. However, in arid and semi-arid regions or in drought conditions there aren't adequate water supplies of usable quality. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts present in relatively small but significant amounts. They originate from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals carried with the irrigation and remain behind in the soil as water evaporates or is used by the crop.

The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Use of saline water requires several changes from standard management practices such as selection of appropriate crops, improvements in water and soil management, adjustments in crop rotations and in some cases, the adoption of advanced irrigation technology. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use.

A.V.5 Use of saline water for irrigation in different countries

Considerable amounts of saline or saline/sodic water are available in various countries of the world. Although saline and saline/sodic water could be successfully used for irrigation without long term hazardous consequences to crops or soils by applying improved management practice, irrigation with such water is still only marginally practiced. Globally around 43 countries, mostly from arid and semi-arid regions, are using saline and saline/sodic water for irrigation and crop production. The Southern Mediterranean, Middle-East, North and South-East of Africa, Indian Subcontinent countries, and the United States of America are using saline and saline/sodic water in irrigation purely by necessity, rather than by choice.

(i) Algeria

The possibilities of using drainage water with a relatively high salt concentration (9 dS/m), SAR value of 15.7 and pH of 8 were experimented for the development of salt land in the Biskard area in the southeast of Algeria. Drainage water is an important source for the irrigation of palm trees due to its presence in relatively high quantities exceeding three millions m^3 year-1. The experience demonstrated the successful use of drainage water in irrigation through an appropriate irrigation and leaching scheduling, the addition of soil amendments to avoid soil sodicity, the selection of the palm tree varieties and the irrigation method. The availability of substantial quantities of drainage water offers the best guarantee for increasing the irrigated area in the south of Algeria.

(ii) Australia

Salinity has long been recognized as a problem in many parts of Australia and much irrigation have to consider using marginally saline quality ground waters. Australia has been one of the pioneers of waste/saline water irrigation. Australia has 465 mm of average annual rainfall with 11 % runoff. The country is divided into 12 drainage divisions. The Murray-Darling is the major river system (Murray 2500 km and Darling 2500 km) in the south eastern/southern region. Ground water occurs in sedimentary, surficial and fractured rock aquifers. The country is divided into 69 ground water provinces. Many areas locally in arid, semiarid, temperate and tropical zones are heavily dependent on ground water, although it contributes 18%

and surface water contributes 82% of water use in Australia. In many parts of South Australia there are vast supplies of saline water near the surface.

Ground water is largely used in the Perth province, followed by the Great Artesian Basin. Bore well yields in sedimentary and shallow alluvial aquifers range from 1-100 lps, while bore yield in fractured rock aquifers is less than 3 lps. The water quality is defined into four salinity classes: (1) fresh TDS < 500 mg/l, (2) marginal TDS=500-1500 mg/l, (3) brackish TDS=15005000 mg/l, and (4) saline TDS > 5000 mg/l. The divertible brackish and saline groundwater is about 30 % of the total ground water resource. The salinity problems are mainly associated with high ground water levels. Rapid and widespread salinization of dry land and annual pastures in areas with high ground water levels in Victoria are predicted. Native Eucalyptus woodlands on the flood plains of the lower River Murray are with shallower water tables and reduced flooding. Lakebed cropping (Seventy cultivation permits, 80 % lakes larger than 2000 ha) is done in New South Wales. The Shepparton land and water management plan in Victoria envisaged the irrigation with saline water (Sampson, 1996).

Australia faced the grieving process among the community (Shock, denial, anger and acceptance) in northern Victoria and southern New South Wales for the use of saline water for irrigation during 1960-70, acceptance began to appear as the government intervened with Salinity Management Plans. The large circles are irrigation areas using centre pivot sprinkler system. In Western Australia, wind erosion harms the agricultural land and over half of the divertible surface water is affected by salinity. Water up to 3500 mg/l TDS is satisfactory for apples and short term irrigation of wines. In northern Australia, twenty-two species of mangrove were identified in the Adelaide river flood plain in relation to salinity and water logging conditions. At Ahuchr reclamation station, 22 % yield reduction was found for ECe increase from 4.8 to 15 dS/m for irrigation of sugar beet crop. At Half Tappch while ECe was higher than 5 dS/m, a 50 % yield reduction was found for sugarcane crop. Irrigation is carried out on extensive alluvial plans. Inherent high salinity of some of these soils has resulted in the development of shallow regional saline ground water. However, the drainage waters are reused by pumping into canal systems, used in irrigation.

(iii) Cyprus

The scarcity of water is a serious constraint in Cyprus. In semi-arid region of this country the irrigation with the marginal waters causes soil salinity. The pressurized irrigation with sprinkler and mini-sprinkler is a common practice. The modern irrigation system permits the use of saline water in irrigation and fertigation. The greenhouse crops are grown with ECw of 2 to 3 dS/m with high yields. The winter rainfall is a good source of leaching salts. Extensive researches have been undertaken for evaluating the effects of sulphate waters for irrigation on soil and crops during years 1984 to 1998 (Papadopoulous, 1998). Leaching of salts was achieved by winter rainfall, river water or water of the same borehole.

The water scarcity together with the high cost associated with collecting and using the limited surface rainwater for irrigation has become a real constraint in Cyprus. Therefore, alternative water resources, innovative approaches and new technologies are sought to help solving the problem. Development of more efficient irrigation methods to save water by better utilization, irrigation with saline water and reclamation and use of treated municipal waste water, are promising alternative and innovative approaches. By irrigating with modern irrigation systems, crops are grown successfully and higher yield is obtained with more saline waters. Experimental data suggest that, with proper irrigation and fertilization management, some problems associated with salinity can be alleviated and occasionally overcome by selecting crops that are semi-tolerant or tolerant to salinity.

(iv) Egypt

About 5 thousand million m^3 of saline drainage water is used for irrigating about 405,000 ha of land (Table A.V.2). About 75 % of the drainage water discharged into the sea has a salinity of less than 3000 mgl-1. The policy of the Government of Egypt is to use drainage water directly for irrigation if its salinity is less than 700 mgl-1; to mix it 1:1 with Nile water (180 to 250 mgl-1) if the concentration is 700 to 1500 mgl-1; or 1:2 or 1:3 with Nile water if its concentration is 1500 to 3000 mgl-1; and to avoid reuse if the salinity of the drainage water exceeds 3000 mgl-1. The annual average volume of available drainage water is about 14 thousand million m^3. The policy of the Ministry of Water Resources and Irrigation is to make full use of each drop of drainage water by the year 2017 (Table A.V.3). Some large-scale projects, using drainage water as the main source of irrigation water, are currently being implemented.

The techniques and technologies used in drainage practices are under continuous development on a well-established research base. The development and verification of design drainage criteria for local conditions is always a concern with the progress of drainage projects to cover new areas. Pilot areas are designed to meet specific changes in the hydrological, soil or cropping conditions. A dynamic monitoring program to validate the accuracy of the used criteria is essential. A modern computerized database was established to store all relevant collected data and information. The introduction of an integrated water management approach is the most reliable procedure for water resources management. Much research work has been, and still being, carried out to improve drainage implementation including testing and evaluation of new materials and machinery and the adoption of new techniques to cope with the local conditions. Equally, emphasis is given to determine the effects of the re-use of drainage water in irrigation on soils and their productivity for a range of crops. The environmental impacts are carefully monitored and investigated. Health and ecological measures are of concern. Social aspects, particularly those related to women as important users of water are progressively coming to the centre of attention.

Table A.V.2. Reuse of drainage water in the Nile Delta during 1995/2003

Total Reuse		Western Delta		Middle Delta		Eastern Delta		Year
EC	Q	EC	Q	EC	Q	EC	Q	
1.77	4266.3	1.42	705.9	1.79	1814.6	1.89	1745.9	1995-96
1.81	4433.6	1.31	642.5	1.85	1947.9	1.94	1843.2	1996-97
1.66	4170.1	1.35	632.4	1.77	1801.3	1.66	1736.3	1997-98
1.43	5033.5	1.07	738.3	1.52	2168.3	1.48	2126.9	1998-99
1.72	4736.8	1.97	1183.6	1.64	1891.4	1.64	1661.8	1999-00
1.72	4847.3	1.92	1058.3	1.76	1958.8	1.57	1830.2	2000-01
1.71	5289.1	1.76	1062.8	1.67	2199.8	1.74	2026.5	2001-02
1.92	5287.4	1.76	875.6	1.90	2082.4	2.00	2329.3	2002-03

Here, Q: Drainage water discharge (million m^3 month-1), EC: Drainage water salinity (dS m-1)

Table A.V.3. Maximum possible drainage water reuse in Nile Delta (million m^3).

Possible to be reused	Currently Reused	Available Drainage Water	Region
1519.02	2049.89	4083.65	Eastern Delta
2881.06	2007.73	5849.14	Middle Delta
2384.33	1123.56	3819.15	Western Delta
6784.41	5181.18	13751.94	Total

In general, Egypt has a policy to use brackish and saline ground water with EC up to 4.5 dS m-1 and reuse of drainage ground water with EC= 6 dSm-1 with SAR values of 10 to 15 in blending or cyclic mode with good quality water (Quarto and Meroz, 2004).

(v) Greece

Water resources are limited temporally and spatially. The total water consumption in 1990 was 5500 million meter cube per year. Water consumption increases by more than 3 % annually. The major water use is in irrigation, with a percentage of 85 %, while domestic use is 11 % and industrial use is about 4 %. The continued increase of domestic and irrigation water demand can only be met through an integrated water management scheme that includes the use of all sources including non-conventional waters. Imbalance of water demand and water supply is often experienced, especially in the coastal and south eastern regions, due to temporal and spatial variations of the precipitation, the increased water demand during the summer months because of tourism and irrigation, and the difficulty of transporting water due to the mountainous terrain (Karamanos et al., 2004).

(vi) India

India is a vast country with an area of 328.78 Mha with a coastline of 5690 km. The average annual rainfall is 1170 mm with total of about 31.70 Mha of arid land spread over Rajasthan 61.9 %, Gujarat 19.6 %, Punjab 4.6 %, Haryana 4 %, Maharashtra 0.4 %, Karnataka 2.7 % and Andhra Pradesh 6.8 %. Ground water resources play a major role in irrigation and other water supplies. Nearly 48 % of the irrigation is provided by ground water and 52 % by surface water with depleted ground water levels (5-15 m) in many areas of India as a result of over exploitation of fresh water. The characteristics features of the ground water are described as good, marginal and poor and further the poor quality waters have been sub-classified as saline, sodic and saline/sodic.

The Central Soil Salinity Research Institute (CSSRI), Karnal has prepared a ground water quality map of India. Ground water quality zones include good water (ECiw < 2, SAR < 10), saline water (ECiw >4, SAR < 10), high SAR saline water (ECiw > 2, SAR <10) and alkali water (ECiw variable, RSC > 2.5). Though large spatial variations are encountered at small intervals, about 32 to 84 % of the well waters in different states of India have been rated to be poor in quality. High salinity ground waters largely occur in arid parts of the north-western states of India like Rajasthan, Gujarat, Haryana and parts of Punjab. Associated with salinity, ground water in some pockets contains toxic levels of B, F, NO3, Se and Si etc. The alkali waters are found prominently in the semi-arid zones of Indian states where the annual average rainfall varies between 500-700 mm.

The Bureau of Indian Standards (BIS) has classified quality of irrigation water vide BIS: 11624(1996) on the basis of ECiw into four classes: (1) Low salinity water ECiw below 1.5 dS/m. (2) Medium salinity water ECiw 1.5 to 3 dS/m, (3) High salinity water ECiw 3 to 6 dS/m, and (4) very high salinity water ECiw above 6 dS/m. Guidelines recommended for saline irrigation waters are given in Table A.V.4. The brackish and saline waters are used for irrigation in almost all the northwestern states of India, which are located in the arid and semi-arid zones (Tanwar et al., 1985). The semi-arid and arid regions of contain brackish and saline ground water while the coastal states brackish and saline ground water. The different states are following different classification of salinity of ground water for irrigation purposes with upper limit of salinity from 2.25 dS/m (Uttar Pradesh) to 65 dS/m (Rajasthan).

All India Coordinated Research Project (AICRP) on the management of salt affected soils and use of saline water in agriculture with the CSSRI under Indian Council of Agriculture and Research (ICAR) have produced useful research results on effects of different salinity waters on various crops experimented at different centres in India with varying agro climatic conditions with different salinity limits for irrigation waters for agricultural crops.

The UNDP/FAO project on saline water studies in Haryana (India) supports saline ground water use in the central and western districts. Farmers operate their shallow tube wells in saline water areas (ECiw 2-8 dS/m) to irrigate wheat, cotton, millet and mustard crops, including paddy. Saline water is used by blending with canal water or directly in cyclic mode (Tanwar and Kruseman, 1985). The blending process is more frequently used for saline water irrigation in canal commands.

Table A.V.4. Guidelines for saline irrigation waters in India. (Source: Minhas and Tyagi, 1998)

Soil texture (% clay)	Crop tolerance	Upper limits of ECiw (dS/m) in rainfall regions (mm)		
		<350 mm	350-550 mm	550-750 mm
Fine soil	Sensitive	1.0	1.0	1.5
(>30)	Semi-tolerant	1.5	2.0	3.0
	Tolerant	2.0	3.0	4.5
Moderately	Sensitive	1.5	2.0	2.5
Fine soil	Semi-tolerant	2.0	3.0	4.5
(20-30)	Tolerant	4.0	6.0	8.0
Moderately	Sensitive	2.0	2.5	3.0
Coarse soil	Semi-tolerant	4.0	6.0	8.0
(10-20)	Tolerant	6.0	8.0	10.0
Coarse	Sensitive	-	3.0	3.0
(<10)	Semi-tolerant	6.0	7.5	9.0
	Tolerant	8.0	10.0	12.5

Ground water resources play a major role in irrigation and other water supplies. Nearly 48 % of the irrigation is provided by ground water and 52 % by surface water. According to CGWB, the ground water levels have dropped 5-15 m in many areas of India as a result of over exploitation of fresh water. The states of Haryana, Punjab, Delhi, Rajasthan, Gujarat, Uttar Pradesh, Karnataka and Tamil Nadu contain saline ground water. Table A.V.5 gives the estimates of annual replenish able recharge in the areas of 8 states underlain with saline ground water. The percentage rating of ground water for 4 states of the North India is given in Table A.V.6. The characteristics features of the ground water are described as good, marginal and poor and further the poor quality waters have been sub-classified as saline, sodic and saline/sodic.

Table A.V.5. Estimates of annual replenish able recharge in areas underlain by saline ground water. (Source: CGWB, 1992 and Minhas, 1998)

State	Total area of state sq km	Area underlain by saline GW (EC>4 dS/m)	Annual replenish able recharge (MCM/Yr)
Haryana	44212	11438	2452
Punjab	50353	3058	1351
Delhi	1485	140	32
Rajasthan	342239	141036	4025
Gujarat	196024	24300	2179
Uttar Pradesh	294411	1362	354
Karnataka	191791	8804	1015
Tamil Nadu	130060	3300	407
Total	1250575	193438	11765

Table A.V.6 Water resources and their quality and yield statistics of north-west states of India using poor quality waters. (Source: CGWB (1992)

Characteristic	Uttar Pradesh	Haryana	Punjab	Rajasthan
Net irrigated area (%)	59	73	94	29
Canals	30.1	48.9	38.3	35.1
Wells	65.5	50.8	61.6	23
Use of poor quality waters	1.28	0.38	0.38	0.39
Rating of ground water quality				
Good, (%)	27	33	59	16
Marginal (%)	20	8	22	16
Poor (%)	43	55	19	68
Characteristic features of poor quality waters				
Saline (%)	NA	24	22	16
Sodic (%)	NA	30	54	35
Saline/sodic (%)	NA	46	24	49

The CSSRI Karnal has prepared a ground water quality map of India. Ground water quality zones include good water (ECiw < 2, SAR < 10), saline water (ECiw >4, SAR < 10), high SAR saline water (ECiw > 2, SAR <10) and alkali water (ECiw variable, RSC > 2.5). Though large spatial variations are encountered at small intervals, about 32 to 84 % of the well waters in different states of India have been rated to be poor in quality. High salinity ground waters largely occur in arid parts of the north-western states of India like Rajasthan, Gujarat, Haryana and parts of Punjab. Associated with salinity, ground water in some pockets contains toxic levels of B, F, NO3, Se and Si etc. The alkali waters are found prominently in the semi-arid zones of Indian states where the annual average rainfall varies between 500-700 mm.

The Bureau of Indian Standards (BIS) has classified quality of irrigation water vide BIS: 11624(1996) on the basis of ECiw into four classes: (1) Low salinity water ECiw below 1.5 dS/m. (2) Medium salinity water ECiw 1.5 to 3 dS/m, (3) High salinity water ECiw 3 to 6 dS/m, and (4) very high salinity water ECiw above 6 dS/m. Guidelines recommended for saline irrigation waters are given in Table A.V.7 (Minhas and Gupta, 1992). The brackish and saline waters are used for irrigation in almost all the northwestern states of India, which are located in the arid and semi-arid zones (Tanwar et al., 1985). The semi-arid and arid regions of the states of Rajasthan, Haryana, Punjab, Uttar Pradesh, Gujarat, Maharashtra, Andhra Pradesh and Karnataka contain brackish and saline ground waters. Kerla, Tamil Nadu, partly Andhra Pradesh, Orissa, and West Bengal contain brackish and saline ground water as the coastal states. The different states are following different classification of salinity of ground water for irrigation purposes with upper limit of salinity from 2.25 dS/m (Uttar Pradesh) to 65 dS/m (Rajasthan).

All India Coordinated Research Project (AICRP) on the management of salt affected soils and use of saline water in agriculture with the Central Soil Salinity Research Institute (CSSRI) Karnal under Indian Council of Agriculture and Research (ICAR) have produced useful research results since 1972. The effects of different salinity waters on various crop yields were experimented at different centers in India with varying agroclimatic conditions, Karnal, Hisar, Agra, Kanpur, Jobner Jodhpur, Indore, Bapatla, Dharwad, etc.). Salinity limits for irrigation waters for agricultural crops are given in Table A.V.8.

Table A.V.7. Guidelines for saline irrigation waters (RSC<2.5 me/1) in India (Source: Minhas and Tyagi, 1998)

Soil texture (% clay)	Crop tolerance	Upper limits of ECiw (dS/m) in rainfall regions (mm)		
		<350 mm	350-550 mm	550-750 mm
Fine soil	Sensitive	1.0	1.0	1.5
(>30)	Semi-tolerant	1.5	2.0	3.0
	Tolerant	2.0	3.0	4.5
Moderately	Sensitive	1.5	2.0	2.5
Fine soil	Semi-tolerant	2.0	3.0	4.5
(20-30)	Tolerant	4.0	6.0	8.0
Moderately	Sensitive	2.0	2.5	3.0
Coarse soil	Semi-tolerant	4.0	6.0	8.0
(10-20)	Tolerant	6.0	8.0	10.0
Coarse	Sensitive	-	3.0	3.0
(<10)	Semi-tolerant	6.0	7.5	9.0
	Tolerant	8.0	10.0	12.5

.

Table A.V.8. Salinity limits of irrigation waters for agricultural crops (Source: AICRP-CSSRI (2000))

Crop	Location	Soils	Years	Previous crop	ECiw (dS/m) for relative yield in %		
					100	90	75
Cereals							
Wheat	Agra	Sl	6	Bajra (pearl Millet)	6.6	10.4	16.8
	Afra	Sl	2	Toria	4.3	6.6	11.0
	Dharwad	Scl	5	Sorghum	3.4	7.0	12.9
	Hisar	Sl	5	Sorghum/fallow	6.1	8.7	13.0
	Indore	Cl	8	Maize	4.7	8.7	15.2
	Jobner	Ls	4	Fallow	8.3	11.7	17.5
	Karnal	S	5	Fallow	14.0	16.1	19.5
Barley	Agra	Sl	2	Fallow	7.2	11.1	18.0
Rice	Bapatal	Scl	6	Kharif rice	2.2	3.9	6.8
			3	Rabi rice	1.8	2.9	4.8
Maize	Dharwad	Scl	5	Sorghum	3.7	7.8	14.5
	Indore	Cl	7	Wheat	2.2	4.7	8.8
Pearl-millet	Agra	Sl	4	Wheat	5.4	9.0	15.0
Italian-millet	Bapatla	S	5	Kh. S. flower	2.4	4.6	8.2
			4	Ra. Ita. Millet	2.5	4.9	8.7
Sorghum	Agra	Sl	3	Mustard	7.0	11.2	18.1
	Dharwad	Scl	6	Wheat	2.6	5.1	9.1
Oilseeds							

Crop	Location	Soils	Years	Previous crop	ECiw (dS/m) for relative yield in %		
					100	90	75
Mustard	Agra	Sc	6	Sorghum	6.6	8.8	12.3
	Baptala	Scl	5	Soybean	3.8	7.9	14.7
	Jobner	Ls	2	Guar	6.6	13.5	-
Sunflower	Dharwad	Scl	5	Maize	3.3	6.8	12.6
Sunflower	Bapatla	Sl	3	Mustard	3.5	7.2	13.4
Groundnut	Bapatla	S	5	It. Millet	1.8	3.1	5.3
Soybean	Bapatla	Scl	3	Mustard	2.0	3.1	5.0
Legumes							
Pigeonpea	Agra	Sl	6	Onion	1.3	2.3	3.9
Clusterbeans	Bapatla	Sl	3	Variable	3.2	4.5	6.8
	Jobner	Ls	2	Mustard	3.9	6.6	11.1
Berseem	Agra	Sl	5	Rice/sorghum	2.5	3.2	4.4
Vegetables							
Onion	Agra	Sl	5	Pegeonpea	1.8	2.3	3.3
	Bapatla	S	5	Variable	5.1	6.0	7.5
Potato	Agra	Sl	5	Okra	2.1	4.3	7.8
Tomato	Bapatla	S	3	Variable	2.4	4.1	6.9
Okra	Agra	Sl	5	Potato	2.7	5.6	10.5
	Bapatla	S	2	Variable	2.1	3.9	6.7
Brinjal	Bapatla	S	2	Variable	2.3	4.1	7.1
Fenugreek	Jobner	Ls	3	Pearl-millet	3.1	4.8	7.6
Chillies	Bapatla	S	2	Variable	1.8	2.9	4.9
	Jobner	Ls	3	Variable	4.5	7.5	12.5
Coriander	Bapatla	S	3	Variable	2.9	5.8	10.7
Bitter goud	Bapatla	S	3	Variable	2.0	3.4	5.8
Bottle	Bapatla	S	3	Variable	3.2	4.5	6.8

The UNDP/FAO project on saline water studies in Haryana (India) has surveyed saline ground water use in the central and western districts. Farmers operate their shallow tube wells in saline water areas (ECiw 2-8 dS/m) to irrigate wheat, cotton, millet and mustard crops, including paddy. Saline water is used by blending with canal water or directly in cyclic mode (Tanwar and Kruseman, 1985). The blending process is more frequently used for saline water irrigation in canal commands.

(vii) Iran

Iran covers an area of 164.8 Mha. The average elevation of the country is above 1500 m and the rate of evaporation exceeds 2000 mm annually, which leads to upward movement of soluble salts. It is estimated that about 15 % of the entire land surface of Iran is salt affected, which are connected with salty shallow ground waters. Salinization of soils has aggravated by human activities, overgrazing, deforestation and irrigation with saline waters without adequate drainage and leaching. All soils on flat plains and low lands are practically somewhat salt affected. The crop yields are depressed by the toxicity of salts. The saline soils are concentrated on central deserts, coastal areas along the Persian Gulf and the Gulf of Oman and low lands of Khazestan Province. The precipitation decreases from northwest to southwest. Large scale irrigation development brings vast quantities of moderately saline water to large areas of agricultural land.

Adequate drainage is an important need. Water quality classification for irrigation in Iran is shown in Table A.V.9 (Abrishamdar and Moustoufeizadeh, 2005). However, crop classification in relation to ECe, crop yield sensitivity and soil groups as adopted in Iran is given in Table A.V.10.

Table A.V.9 Water Quality Classification for Irrigation in Iran. (Source: Yekom Engineering Consultant Company (2004))

Classification	Salt Concentration (TSS) mg.l-1	Electrical Conductivity (EC) dS.m-1
Non-Saline	500<	0.7<
Slightly Saline	1500-500	2.5-0.7
Brackish	5000-1500	8-2.5
Saline	8000-5000	12-8
very saline	13000-8000	20-12
Hyper Saline	13000>	20>

Table A.V.10. The main crops classification related to soil salinity and crop yield adopted in Iran.(Source: ICID Communication with National Committee)

Electrical conductivity dS/m	Crop yield sensitivity to salinity	Soil groups related to salinity
0 to 2	Soil salinity effect on crops is negligible	Non - Saline
2 to 4	The performance of crops sensitive to salinity may be limited	Low - Saline
4 to 8	The performance of crops sensitive to salinity will be limited	Moderate - Saline
8 to 16	Those crops tolerant to salinity would have acceptable performance	Strongly - Saline
< 16	Just a few crops which are extremely tolerant to salinity have economic performance	Extremely - Saline

The irrigation rate with saline water was increased (10 % for each 1000 mg/l increase in soluble salt content) to produce higher crop yields. The low treatment equal to the consumptive use of water requirement of the crop was associated with the lowest yields and in 75 % cases the salt content of the soil increased during the growing season. The quality of irrigation water was about 3000 mg/l TDS and irrigation treatments vary from consumptive use requirement to consumptive use plus 75 % (FAO, 1970). Intensive research studies are carried out in Iran on long term effect of using saline water on soil salinity and sodicity (Feizi and Ragab, 1998; Cheraghi et al., 2009; Sharifi Mood and Mirzaei, 2011; Cheraghi et al., 2011; Rezaei et al., 2011) and effect of saline water in pressurized (sprinkler/trickle) irrigation on alfalfa, cotton, pistachio and etc. yields and soil chemical/physical properties (Abrishamdar and Moustoufeizadeh, 2005; Ghorbani Nasrabad, 2011; Eslami, 2011).

(viii) Israel

Israel covers an area of 2.07 Mha. Saline water irrigation is being practiced in the Negev desert highlands of Israel for 25 years. Most crops are irrigated by sprinklers. The drip irrigation has resulted in a breakthrough in desert agriculture. Large areas of sand dunes can now be developed into an agricultural land using saline water for irrigation (Bustan et al., 1998). The sprinkler and drip irrigation practices are extensively adopted in this country. The majority of the saline ground water is used in the ECw range of 2 to 8 dS/m. Average annual rainfall exceeds 200 mm in over half of the country and is about 500 mm in main agricultural area.

Most of the rainfall occurs in the winter season. The saline water is diluted before use as much of the saline water is introduced into the national water carrier system. Extra water, equivalent to about 25 to 30 % in excess of evapotranspiration is typically given for leaching.

Israel follow the general and basic recommendations: (1) light and medium textured soils can be irrigated with saline water in the range of the salt tolerance of the crops, and (2) heavy soils can be irrigated with waters having ECw values of up to 3.5 to 5.5 dS/m under artificial drainage system and with application of gypsum (FAO, 1992). In the Arava Valley of Israel, where annual rainfall generally less than 25 mm, peppers, melons, tomatoes, potatoes, onions, sweet corn, and alfalfa are grown commercially with surface drip and sprinkler irrigation techniques, using moderately saline ground waters ranging in salinity from 2 to 4 dS/m (Oster, 1994). The threshold salinities for these crops range from 1.2 dS/m for onion to 2.5 dS/m for tomato. Where tow waters with different salinities are available, the lower salinity water is used for irrigation during germination and seedling establishment. Sprinkler irrigation is commonly used for 2 to 3 weeks during the seedling and early stages of crop growth to leach the seed bed and obtain uniform plant stands. Therefore, surface drip irrigation is used. Drip irrigation simplifies the use of saline waters for irrigation: low soil salinities are maintainable in the major portion of the root zone provided the crop and the drip line are located along the same line, and soil-water contents can be constantly maintained at high levels. "The drip irrigation method provides the best possible conditions of total soil-water potential for a given quality of irrigation water" (Shalevet, 1994). However, farmers must be aware that salts accumulate at the perimeters of the wetted area and that tillage practices to incorporate crop residues and form new seed-beds can also incorporate these salts into the seed zone. Consequently, extra irrigation for leaching during seeding germination and plant establishment may be necessary to re-establish satisfactory soil salinity levels in the root zone.

(ix) Jordan

Irrigated agriculture consumes 70 % of the available water, competing with the rapid growth of urban and industrial demand. Therefore, saline water is a highly valuable source of water for irrigation. A major challenge to agriculture is the optimal utilization of brackish water and treated wastewater without causing adverse effects to the environment and at the same time reducing the amount of fresh water consumption for food production. It is expected that within the next twenty years, the proportion of non-conventional water will be more than 30 % of the total available water resources. Research findings regarding crop production indicated that for sweet corn, irrigation with saline water of less than 3.5 dS m-1 has not caused significant reduction in yield. The tolerance threshold of soil salinity for relative yield of onion varies from 2.43 to 3.6 dS m-1. Drainage water is used for irrigating garlic and onion with careful management.

Brackish water with salinities ranging between 3 and 11 dS m-1 is used in the southern Jordan valley. Experience indicates that yield production will differ from one crop to another depending on crop salt tolerance degree. A limiting factor for using brackish water in irrigation is the salt accumulation in the soil. Therefore, available fresh water for leaching is required. A leaching fraction of 30 % during the peak water consumption period reduced the impacts of saline irrigation on both soil and plant. Another solution is the alternation irrigation, fresh water is used during the sensitive germination and emergence stages until the crop stand is established, then, irrigation is practiced with saline water.

(x) Morocco

In Morocco there are approximately 7.7 million hectare of arable land, of which one million hectare is irrigated and the rest is under rain fed agriculture. Poor soil physical conditions, soil salinity, low water quality and water stress are considered major limitation for agriculture development. Rational use of irrigation water, by adopting adequate drip irrigation for high value cash crops and the use of supplemental irrigation is widely recommended to stabilize and to improve crop yield. However, with the scarcity of high quality water resources, the use of non-conventional water is not only a necessity, but also an inevitable option to alleviate the water crisis. The potential of wastewater in this country is shown in Figure AV.4. In the Agadir region, sand infiltration systems are used to treat wastewater to be reused in agriculture and landscaping. This technology generates high nitrate concentration in the effluent. To tackle the salinity problem and to diminish its hazardous negative effect on both soil productivity and crop production, an intensive research program was conducted to establish appropriate land, water and crop management under saline irrigation practices. The contribution of the farmers in facing the salinity problem through improving the local technologies cannot be denied.

The knowledge and the experience gained from the research work indicated that the cultivars, the growing media, the climatic conditions and the salt level of the irrigation water all affect the final yield. The experience of Morocco on the use of saline water as an irrigation source clearly indicates the high potentiality in its use if proper management is developed for specific crops under specific climatic and soil conditions. Experience indicates that salinity problems can be tackled and sustainable solutions can be achieved by improving the local technologies the farmers are using, by introducing simple techniques such as sowing time, selection of cultivars tolerant to salinity, application of organic manure, modified soil media. Such simple techniques can have a great impact on the marketable yield and quality of the product.

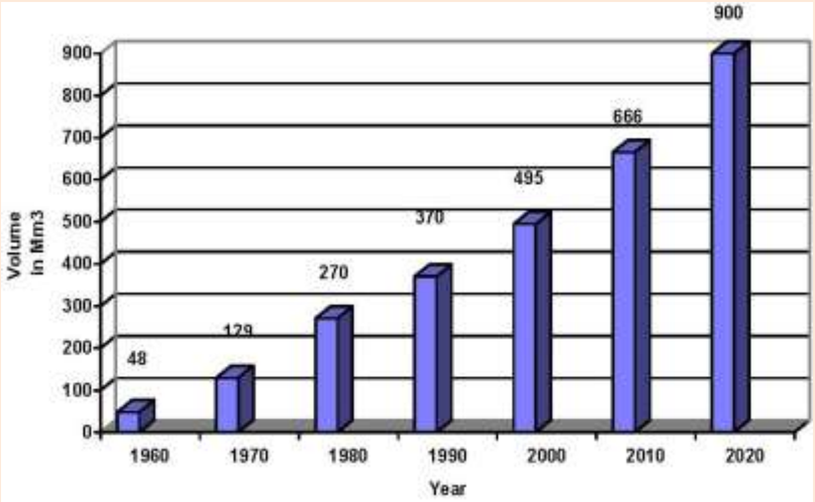

Figure A.V.4. The potential of wastewater in Morocco

(xi) Syria

Water shortage is becoming a major factor hindering economic development. The Syrian agricultural sector is the main sector using this limited resource. Agriculture plays an important role in the national economy. About 9 Mha of the land is arable. The Euphrates dam now covers 80 % of irrigation requirements. The soil salinity increases with distance from the river and becomes highest at the sub-terraces. The causes of salinity are irrigation methods, evaporation and quality of irrigation water. Insufficient irrigation with poor quality of water contributes to soil salinization. Ground water at the end of the cotton seasons was at 1.75 m causing salinity because of capillary rise in heavy textured soils. In uncultivated areas of the plateau, the ground water levels are 15-20 m deep (Al Haj and Al Saadi, 1971). The increasing salinity is related to presence of the sub terraces, parallel to Euphrates River at its southern edge (few meters to 10 km distance), irrigation methods and quality of ground water. Saline drainage water is used in different parts of this country.

(xii) The Lebanon

The total available water resource is about 2000 million cubic meters. The total need, in 2020, is estimated as 2450 million cubic meter. This imbalance will force the country to search for new non-conventional water resources. Wastewater is the only suitable source for additional water due to economic constraint. A master plan for secondary wastewater treatment is already elaborated for all Lebanon and funded at 70.47 % of total cost. Between 2005 and 2007, constructed plants are previewed to serve, until 2015, 88 % of the total Lebanese population. The possible collected wastewater for treatment, in 2020 is about 250 million cubic meter (Karaa et al., 2004).

Saline water is used in the Bekaa valley at small scale. The Bekaa Valley area demonstrates the water logging and salinity hazards. The Lebanon coast has a problem of seawater intrusion. The high water level of the Litani River during first part of the growing season makes the evacuation of the excess water more difficult. The soils in the northern Bekaa are in the rainfall zone of 200-300 mm. In the citrus growing area along the Lebanese coast, a number of walls have been dug down the depth exceeding in general sea level. Farmers put pressure on the government irrigation projects to supply good quality surface water. Despite farmers own investment for ground water use, they use it in limited cases with reservations.

(xiii) Tunisia

The total water resource is about 4.5 billion cubic meter of which 2.7 billion is surface water and 1.8billionis ground water. It is expected that by year 2020 the domestic and industrial demand will increase and the available water for agriculture will decrease. In order to overcome this problem and provide the different sectors with their needs, management, conservation of existing water resources and development of non-conventional water source have been developed in the field of water planning and management.

Water and soil salinity is a major constraint for Tunisian agricultural development. Salinity problems and saline irrigation practices and management have been intensively investigated since 1970. The experience gained helped in improving the water use efficiency and agricultural productivity under saline environment and setting up the guide lines and management techniques that need to be practiced in order to save and sustainably use saline water in irrigation. The saline Medjerda river water (annual average EC of 3.0 dS m) has been used to irrigate date palm, sorghum, barley, alfalfa, rye grass and artichoke. The soils of this region are calcareous heavy clays, which crack and shrinkage when dry.

(xiv) Turkey

Turkey (Anatolia or Asia Minor) have practiced irrigation since ancient times. Annual rainfall varies between 220 and 2400 mm. The north eastern coast receives maximum rainfall 2400 mm. The inland plateau receives minimum rainfall 220-459 mm. The total available water resource is about 108.66 billion m^3: about 95 billion m^3 is surface water and about 13.66 billion m^3 is ground water potential. The irrigated area is about 4.3 million hectare, 16.6 % of the total irrigable land. It is estimated that only 8.5 million hectare can be irrigated with the present water resources. When all irrigable lands are opened to irrigation, roughly 200 km^3 more water is going to be required. Therefore, the solution was to apply the deficit irrigation programs including supplemental irrigation and to manage the irrigation systems according to deficit irrigation approach and to find the new water resources. Non-conventional water such as brackish water (treated waste water, drainage water), shallow ground water and saline water must be used in near future (Kanber and Unlu, 2004).

The estimated waste water supply, both urban and industrial was about 6.7 billion m^3 in 2001. This will only make up a small part of the water deficiency. Diluted seawater seems to be the only way forward. Some experiments have been carried out using saline water for irrigation. Experiments showed that saline water decreases the yield and quality of all crops grown in the area. However, studies are on-going in an attempt to improve crop yield. The water logging and salinity is a problem in the low coastal plain and in closed basins of the central plateau. The effects of different levels of water salinity and fertilization on crop frouths and yields are investigated in the universities.

(xv) The United State of America

The United States of America has semi-arid to arid areas in the western and southwestern parts. The saline water has been successfully used for 85-110 years in the Arkansas River Valley of Colorado, the Salt River Valley of Arizona, the Rio Grande and Pecos River Valleys of New Mexico and West Texas. The composition of saline waters in use ranged in TDS from 1426 to 4850 mg/l, ECwi 2.3 to 7.5 dS/m, chloride 4.1 to 35.2 mmole/l, calcium 1.4 to 28.9 mmole/l, magnesium 2.3 to 21.2 mmole/l and SAR (mmole/l)½ 4.6 to 26.0. Though there is an exhaustive database on salinity guidelines available in USA, the information on relative salt tolerance of various crops at germination is given in Table A.V.11 (Mass, 1984).

In Pecos Valley of West Texas the rainfall is less than 300 mm. The major crops grown are cotton, sorghum, small grains and alfalfa. The soils are calcareous with low in organic matter (silty loam to silty clay) and infiltration rates average about 0.5 cm per hour. Water tables are below 3 m. Soils have the tendency on crust formation following rainfall. ECe of the major root zone is not more than 2-3 times that of the ECiw. Ground water has average TDS about 2500 mg/l, but ranges up to 6000 mg/l. Under these conditions, an area of about 81000 hectares has been successfully irrigated with saline ground (well) waters in sustainable way in this Valley of the USA.

Table A.V.11. Relative salt tolerance of various crops at germination.
(Source: Maas (1984), US salinity Laboratory, California)

Crop		50 % Emergence reduction (ECe in dS/m)
Barley	(Hordeum vulgare)	16 – 24
Cotton	(Gossypium hirsutum)	15.5
Sugardbeet	(Beta vulgaris)	6 – 12.5
Sorghum	(Sorghum bicolour)	13
Safflower	(Carthamus tinctorius)	12.3
Wheat	(Triticum aestivum)	14 – 16
Beet, red	(Beta vulgaris)	13.8
Alfalfa	(Medicago sativa)	8.2 – 13.4
Tomato	(Lycopersicon lycopersicum)	7.6
Rice	(Oryza sativa)	18
Cabbage	(Brassica oleracea capitata)	13
Muskmelon	(Cucumis melo)	10.4
Maize	(Zea mays)	21-24
Lettuce	(Lactuca sativa)	11.4
Onion	(Allium cepa)	5.6 – 7.5
Bean	(Phaselous vulgaris)	8.0

In Far West Texas, cotton has been grown successfully with well waters of EC up to 8 dS/m using alternate raw double row and furrow irrigation methods. In double row planting is more practiced in lettuce, onions and in some cases with cotton. Planting seed in the water furrow is advantageous because of lower levels of salinity, but as the soil in the furrow crusts badly and is colder, seedlings diseases and weed infections are worse. This method is therefore used in extreme saline soil conditions. Sprinkler irrigation is widely used for alfalfa and Forage crops in the Trans-Pecos region. However, in dry hot regions of Arizona, saline ground waters of EC 3 to 11 dS/m have been reported to be successfully used for cotton with one initial irrigation from low salinity water.

Intensive applied research is being done in the USA for long term safe use of saline/sodic water with the intention of obtaining optimum economic gains without harmful effects on the environment and ecosystem. The reuse of drainage water and wastewater is a greater challenge for sustainable environmental protection. The USA in fact has been a leading nation in saline/sodic water use and intensive research activities in the US Salinity Research Laboratory, California. The drainage water in San Joaquin valley California poses serious quality hazards. Table A.V.12 gives the water analysis. TDS varies up to 11 600 mg/l. Treatments are suggested, for which water quality objectives are kept as given in Table A.V.13.

Table A.V.12. Drainage water analysis (San drain at Mendota in San joaquin valley, California). (Source: USA (Lee, 1988))

Constituent	Units	Average	Maximum
Sodium	mg/1	2230	2820
Potassium	mg/1	6	12
Calcium	mg/1	554	714
Magnesium	mg/1	270	326
Alkalinity (as CaCo3)	mg/1	196	213
Sulfate	mg/1	4730	6500
Chloride	mg/1	1480	2000
Nitrate/nitrite(as N)	mg/1	48	60
Silica	mg/1	37	48
TDS	mg/1	9820	11,600
Suspended solids	mg/1	11	20
Total organic carbon	mg/1	10	16
COD	mg/1	32	80
BOD	mg/1	3.2	5.8
Temperaturea*	ºC	19	29
pH	-	8.2	8.7
Boron	mg/1	14400	18000
Selenium	mg/1	325	420
Strontium	mg/1	6400	7200
Iron	mg/1	110	210
Aluminum	mg/1	<1	<1
Arsenic	mg/1	1	1
Cadmium	mg/1	<1	20
Chromium(total)	mg/1	19	30
Copper	mg/1	4	5
Lead	mg/1	3	6
Manganese	mg/1	25	50
Mercury	mg/1	<0.1	<0.2
Molybdenum	mg/1	88	120
Nickel	mg/1	14	26
Silver	mg/1	<1	<1
Zinc	mg/1	33	240

* Temperature varied from 23-25º C (summer) to 12-15º C (winter)

Table A.V.13. Water quality objectives for San Joaquin River, California (Source: USA (Lee, 1988))

Constituent	Objective
Selenium (wetland use)	2 mg/1
Selenium (in river)	5 mg/1
Electrical conductivity	1.0 dS/m
Boron	700 mg/1
Molybdenum	10 mg/1

Drip/micro irrigation became widespread in some areas of the U.S. by the mid–1970s. Drip/micro irrigation has steadily increased in popularity since the first large commercial installations of the early 1970s. The days of frequent and rapid introductions of completely new products slowed in the 1980s. But since the late1980s there have been steady improvements in product quality. In the very late 1990s there were many new innovations in this regards.

Appendix VI

A.VI Use of Wastewater in Irrigation

This Appendix presents the characteristics of wastewater, wastewater treatment systems, the socio-economic aspects of use of wastewater, guidelines for wastewater use in agriculture, the driving forces for use of wastewater in agriculture and the case study of Jordan.

A.VI.1 Introduction

The use of urban wastewater in agriculture is a century-old practice that is receiving renewed attention because of urban water demand and disposal lately. Irrigation with untreated wastewater can represent a major threat to public health, food safety and the environment as there are cases of chronic outbreaks of more acute gastrointestinal disease including cholera and typhoid. The complex challenges of managing wastewater require a proactive and forward-looking approach. Therefore, the use of wastewater in agriculture must be carefully managed requiring key thematic issue

(a) need to take a livelihood-based approach focused on farmers,
(b) need for public health guidelines and
(c) analysis of cost-effectiveness of treatment required to meet guidelines.

The use of wastewater in the irrigation sector particularly in arid and semi-arid regions are needs to maximize the potential benefits, while minimizing the potential costs. For this purpose, methodology framework for action is worked out need for a framework that provides a safe, sustainable and profitable use of wastewater in the irrigation sector.

Huibers et al. (2005) highlighted the concept of a water chain approach. This approach allows tracking down the stream of water from its origins as fresh household water to its ultimate destination as wastewater. The measures applied through a holistic approach would determine the final volume, quality and availability of wastewater for productive and sustainable use in agriculture. The potential and paybacks from such use are manifold: to release more freshwater resources for drinking water use, to reduce uncontrolled pollution of aquatic ecosystems and the environment, to reduce costs of wastewater treatment, to make use of nutrients in the effluent, thus reducing chemical fertilizer input and subsequently increasing farmers' income, to increase food production in urban areas as well as downstream and to provide employment for the urban community.

A.VI.2 Characteristics of Wastewater

Municipal wastewater is mainly comprised of water (99.9 %) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Table A.VI.1 shows the levels of the major constituents of strong (for arid and semi-arid countries), medium (for moderate climatic countries) and weak (for humid countries) domestic wastewaters.

Pathogenic viruses, bacteria, protozoa and helminthes may be present in raw municipal wastewater at the levels indicated in Table A.VI.2 and will survive in the environment for long periods, as summarized in Table A.VI.3. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as total coliforms/100 ml). Escherichia coli are the most widely adopted indicator of faecal pollution and they can also be isolated and identified fairly simply, with their numbers usually begin given in the form of faecal coliforms (FC)/100 ml of wastewater.

Table A.VI.1. Major Constituents of Typical Domestic Wastewater

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)[1]	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride[1]	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5[2]	300	200	100

1 The amounts of TDS and chloride should be increased by the concentrations of these constituents in the carriage water.

2 BOD_5 is the biochemical oxygen demand at 20°C over 5 days and is a measure of the biodegradable organic matter in the wastewater.

Source: UN Department of Technical Cooperation for Development (1985)

Table A.VI.2. Possible levels of Pathogens in wastewaters.

Type of pathogen	Survival times in days			
	In faeces, nightsoil and sludge	In fresh water and sewage	In the soil	On crops
Viruses				
Enteroviruses	<100 (<20)	<120 (<50)	<100 (<20)	<60 (<15)*
Bacteria				
Faecal Coliforms	<90 (<50)	<60 (<30)	<70 (<20)	<30 (<15)
Salmonella spp.	<60 (<30)	<60 (<30)	<70 (<20)	<30 (<15)
Shigella spp.	<30 (<10)	<30 (<10)	-	<10 (<5)
Vibrio cholerae	<30 (<5)	<30 (<10)	<20 (<10)	< 5 (<2)
Protozoa	<30 (<15)	<30 (<15)	<20 (<10)	<10 (< 2)
Entamoeba histolytica cysts	<30 (<15)	<30 (<15)	<20 (<10)	<10 (< 2)
Helminths *Ascaris lunbricoides eggs*	Many Months	Many Months	Many Months	<60 (<30)

* Figures in brackets show the usual survival time.

Source: Feachem *et al.* (1983)

Table A.VI.3. Survival of Excreted Pathogens (at 20-30˚C)

Type of pathogen		Possible concentration per litre in municipal wastewater[1]
Viruses:	*Enteroviruses*[2]	5000
Bacteria:	Pathogenic *E. coli*[3]	?
	Salmonella spp.	7000
	Shigella spp.	7000
	Vibrio cholerae	1000
Protozoa:	*Entamoeba histolytica*	4500
Helminths:	*Ascaris Lumbricoides*	600
	Hookworms[4]	32
	Schistosoma mansoni	1
	Taenia saginata	10
	Trichuris trichiura	120

? Uncertain
1 Based on 100 lpcd of municipal sewage and 90% inactivation of excreted pathogens
2 Includes polio-, echo- and coxsackieviruses
3 Includes enterotoxigenic, enteroinvasive and enteropathogenic *E. coli*
4 *Anglostoma duedenale* and *Necator americanus*

Source: Feachem *et al.* (1983)

A.VI.3 Wastewater and treatment systems

Definitions and concepts of wastewater are given in various reports and textbooks (Metcalf and Eddy, 1995; Pescod, 1995; Westcot, 1997; Asano and Levine, 1998; Martijn and Huibers, 2001. In this text, it is assumed that urban wastewater may be a combination of some, or all, of the following:

(a) Domestic effluent consisting of black water (excreta, urine and associated sludge) and grey water (kitchen and bathroom wastewater)
(b) Water from commercial establishments and institutions, including hospitals
(c) Industrial effluent
(d) Storm water and other urban runoff
(e) The above mix of water might pose a threat to sustainable agriculture and/or human health but can be used safely for irrigation provided certain precautions are followed.

A wastewater plant in most of the cities around the world, even in the industrial countries, are commonly centralized and require an extensive network of trunk sewers to convey the entire city’s wastewater to the wastewater treatment plant and sometimes involves pumping the wastewater from one drainage basin to another. A cheaper way would be decentralized wastewater treatment plants. In such case, each decentralized plant serves a single drainage basin or a small number of drainage sub-basins. Ideally, the treatment plants should be constructed close to agricultural fields where the treated water will be re-used.

The general set up of “Western Treatment” (Van Lier and Huibers, 2004) consists of:

(a) Primary treatment: screening, grit removal, solids sedimentation, resulting in 25-50 % Biological Oxygen Demand (BOD) removal.
(b) Secondary treatment: biological treatment (e.g. activated sludge, trickling filters), solid-liquid separation, resulting in effluent BOD of 20-30 mg /l
(c) Tertiary treatment: removal of colloidal matter and suspended solids (coagulation/ flocculation, membranes) and nutrients (N, P).
(d) Advanced treatment: disinfection (e.g. chlorination, UV, ozonation, reverse osmosis etc.).

The most applied technology in developed countries is the activated sludge system, which converts organic matter with oxygen (in air) to water and CO2. This technology requires high energy consumption. Less energy consuming systems are lagoons and pond systems. However, the areas which required for these systems are very big and could cause health problems to the nearby communities.

A.VI.4 Driving forces for the use of wastewater for irrigation

Most arid and semi-arid countries of the Mediterranean region, Middle East, USA, North of Africa, India and etc (FAO paper No 47, 1992) are characterized by severe water imbalances, now devising ways to optimize available water supplies and promote the use of non-conventional water resources with particular emphasis on wastewater reclamation (Shetty, 2004).

Urban development will give rise to greater quantities of municipal wastewater which could be a new water source especially in many arid and semi-arid countries. Treated wastewater can be used effectively for irrigation, industrial purposes, groundwater recharge and protection against salt intrusion in groundwater aquifers. The re-use of such marginal quality waters can contribute significantly to national water budgets, particularly when good quality water is limited or drought phenomenon occurred. The use of appropriate technologies, process for the development of this alternative source of water is essential. The water management policy should be directed to support preservation of higher quality, and unless there is a surplus of it, should not be used for a purpose that can tolerate a lower purity grade. Economic, social and environmental concerns must all be taken into account in the formulations of guidelines in accordance with the goal of sustainability in agriculture. It is important to strengthen the capacity of national and local hydrological research institutes to improve their links to environmental research as well as to institutes in the field of economic and social science, particularly in the field of urban studies and planning. The transfer of knowledge to local government decision-makers should be improved.

Properly planned use of municipal wastewater alleviates surface water pollution problems and not only conserves valuable water resources but also takes advantages of the nutrients contained in sewage to grow crops. The availability of this additional water near population centres will increase the choice of crops which farmers can grow. The nitrogen and phosphorus content of sewage might reduce or eliminate the requirements for commercial fertilizers. It is advantageous to consider effluent reuse at the same time as wastewater collection, treatment and disposal are planned so that sewerage system design can be optimized in terms of effluent transport and treatment methods. The cost of transmission of effluent from inappropriately sited sewage treatment plants to distant agricultural land is usually prohibitive. Additionally, sewage treatment techniques for effluent discharge to surface waters may not always be appropriate for agricultural use of the effluent.

Benefits that can be obtained from the re-use of wastewater are (Hamdy and Lacirignola, 2005):

(a) Prevention of surface water pollution, which could occur when wastewater is not used but is discharged in rivers and lakes. Planned reuse of wastewater for irrigation will greatly help in the elimination of several environmental pollution problems: dissolved oxygen depletion, eutrophication, foaming, fish deaths, etc. The quantification of the cost of the enormous damage those problems are already causing shows that the treatment and re-use of wastewater is now a must; the actual cost of wastewater treatment definitely being lower than the cost of the environmental damage caused by wastewater;

(b) Reduction of over-pumping and exploitation of groundwater, thus avoiding sea-water intrusion in coastal areas and the deterioration of ground water quality if the groundwater is the main source of drinking water supply;

(c) Rational use of the water resources with low quality water being used for irrigation purposes and good quality freshwater being used for potable water and other special uses;

(d) Use of treated wastewater serves also as a nutrient source; this reduces the use of artificial fertilizers with a reduction in energy expenditure and industrial pollution elsewhere.

Potential adverse impacts of the re-use of wastewater will largely depend on the wastewater characteristics, the degree of purification, the irrigation system and the management techniques. Soil, groundwater and surface water pollution are among the most important potential risks of wastewater reuse. However, through sound planning and a proper and effective management, and by using the existing knowledge and available technologies, it is possible to minimize these impacts to a level of insignificant environmental hazard. The real factor limiting the reuse of treated wastewater is our capability to bring health and environmental risks within acceptable levels, safeguarding public health and protecting the environment.

As an example, a city with a population of 500,000 and water consumption of 200 l/d per person would produce approximately 85,000 m^3/d (30 Mm^3/year) of wastewater, assuming 85 % inflow to the public sewerage system. If treated wastewater effluent is used in carefully controlled irrigation at an application rate of 5,000 m^3/ha.year, an area of some 6,000 ha could be irrigated. In addition to the economic benefit of the water, the fertilizer value of the effluent is of importance. With typical concentration of nutrients in treated wastewater effluent from conventional sewage treatment processes as follows:

- Nitrogen (N)=50 mg/l
- Phosphorus (P)=10 mg/l
- Potassium(K)=30 mg/l

and assuming an application rate of 5,000 m^3/ha. year, the fertilizer contribution of the effluent would be:

- N= 250 kg/ha.year
- P= 50 kg/ha.year
- K= 150 kg/ha.year

Thus, all of the nitrogen and much of the phosphorus and potassium normally required for agricultural crop production would be supplied by the effluent. In addition, other valuable micronutrients and the organic matter contained in the effluent will provide additional benefits.

A.VI.5 Wastewater Use in Irrigated Agriculture

To put wastewater use onto the international policy agenda there is a need to describe the importance of wastewater for integrated water resources management (IWRM), agricultural production and the livelihoods of poor urban, pre-urban and rural populations. Estimating the magnitude of wastewater use in agriculture is difficult, as no sound, verifiable data exist. There are different contradictory views concerning wastewater as an important irrigation water source. Some say wastewater is an insignificant source of water for agriculture because the amounts of water diverted to cities and later disposed as wastewater are small in relation to the amount of water needed for agriculture in most developing countries. Others claim that worldwide more than 20 million ha are irrigated with urban wastewater and that wastewater has an important impact on agricultural productivity and livelihoods. Clearly, there is a need to establish and apply a verifiable method for the prevalence of wastewater irrigation. This requires clear policy guidelines on how to optimize the benefits and minimize the risks of this practice. Such policies are generally lacking in most developing countries. Equally, a better estimate of the extent of wastewater irrigation is needed before the reality of its use can become an agenda item for policy and decision-makers.

A reality check of data on the extent of the area irrigated with urban wastewater can be obtained from a few typical scenarios that could apply to most countries. For example, assuming an annual rate of irrigation of 500 mm and a per capita sewerage production of 100 L/day, a city of one million people would produce enough wastewater to irrigate an area of 7000 ha using efficient irrigation methods (Strauss, 2001).

Farmer’s awareness and participation is the bottleneck governing the wastewater use and its perspective progress. To achieve general acceptance of re-use schemes, it is of fundamental importance to have farmer’s involvement. Social acceptance is pertinent. For instance, there may be deep-rooted socio cultural barriers to waste water re-use. However to overcome such obstacle, major efforts are to be carried out by the responsible agencies. Transparency concerning water and agricultural production quality is a very important feature, especially with regard to health hazard for farm workers and customers.

Confidence in the local management of the wastewater treatment utilities and the assurance that the re-use application will involve minimal health risks and minimal detrimental effects on the environment will greatly help in changing the opinion of the farmers from refusing to accept the re-use. The users must be provided with a clear understanding of the quality of treated wastewater and how it is to be used. Equally important is the continuous exchange of information between authorities and farmers representatives, to ensure that the adoption of a specific water reuse program will fulfill their real needs. Furthermore, the farmers should have special incentives for the re-use. Simultaneously, some hesitant users could be persuaded to re-use waste water as a supplementary source for irrigation. Their success would help in persuading the initial doubters to re-use the available wastewater.

There are limitations associated with using and managing wastewater. These are: nutrient management, choice of crops, irrigation methods and health risk. Water of poorer quality can be used to irrigate non-vegetable crops such as cotton or crops that will be cooked before consumption (e.g. potatoes). However, crop restriction may protect the health of consumers but not of farm workers and their families. Sprinkler irrigation has the highest potential to spread contamination on crop surfaces and affect nearby communities. If sprinkler irrigation is used with wastewater it is advisable to set up a buffer zone (e.g. 50 to 100 m from houses and roads). Farm workers and their families are also at the highest risk when flood or furrow irrigation techniques are used, especially when protective clothing is not worn and the soil is moved by hand. Drip irrigation (especially subsurface drip irrigation) offers farm workers the most health protection because the wastewater is applied directly to the plants; however, drippers can be clogged if the wastewater has suspended material in it and farm workers can still be exposed when cleaning the drippers. Discontinuation of irrigation for 1 to 2 weeks prior to harvest can be effective in reducing crop contamination. However, this may not be possible with vegetables as many vegetables need watering nearly until harvest to increase their market value (Carr, 2005).

Farmers expect regular supply of sound and sufficient irrigation water. They also expect regular information on the water quality and its nutrient contents in order to adapt fertilizer quantities applied to their crops. Farmers using wastewater do make more income because of savings in fertilizer and also because the reliable wastewater supply allows them to grow short-cycle cash crops. Although an increasing number of farmers have problems with the management of salinity and some heavy metals as well as with the marketing of crops irrigated by reclaimed wastewater. It is well recognized that the lower the financial costs, the more attractive is the technology. The ultimate goal should be full cost recovery although initially, this may need special financing schemes including subsidies. The latter may be necessary at the early stages of system implementation, particularly when the associated costs are very large. This would avoid any discouragement to treated wastewater users. Adopting an adequate policy for the pricing of water is of fundamental importance in the wastewater reuse. However, setting an appropriate mechanism for wastewater tariff is a very complex issue.

A.VI.6 Guidelines for the use of wastewater in agriculture

Guidelines for the safe use of wastewater in agriculture should have the primary objective of maximizing public health benefits while allowing for the beneficial use of scarce water. In many countries, wastewater used for irrigation is often inadequately treated. The median percentage of wastewater treated by effective treatment plants is estimated to be 35 % in Asia, 14 % in Latin America and 66 % in Europe (WHO/UNICEF, 2000).

It is extensively documented that the use of untreated, or inadequately treated, wastewater in agriculture has important health implications for produce consumers, farmers and their families, produce vendors and communities. Two sets of guidelines that aim to protect human health under conditions of planned reuse of treated wastewater are set out by the World Health Organization (WHO, 1989) and the United States Environmental Protection Agency (USEPA, 1973). In this regard, Fattal et al. (2004) estimated the annual risk of contracting infectious diseases including Typhoid fever, Rotavirus infection, Cholera and Hepatitis.

The International Water Association (IWA) published Water Quality: Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease. This publication outlines a harmonized framework for the development of guidelines and standards for water-related microbiological hazards (Bartram et al., 2001; Prüss and Havelaar, 2001). Developing and applying pragmatic guidelines based on managed risk or acceptable risk instead of no risk criteria must be the adopted approach (Scott et al., 2004).

In 1999, CSIRO published Australia's first comprehensive guideline for planning, designing and managing effluent-irrigated plantations entitled: Sustainable Effluent-Irrigated Plantations: an Australian Guideline. This book provides the background and tools required to design and manage sustainable effluent-irrigated plantations. Based on extensive scientific research, the guideline is written in an easy-reading style and is aimed at anyone with an interest in the productive and sustainable reuse of effluent as a resource. For any serious student of the subject, it provides a deep insight into the role of effluent-irrigated plantations, their potential benefits and risks as well as a comprehensive list of references to Australian literature on the subject. The guideline includes an economic evaluation model developed by the Australian Bureau of Agricultural and Resource Economics (Myers, Theiveyanathan 2000).

AVI.6.1 Guidelines for the use of wastewater in agriculture

In developing-country context, the use of wastewater is an unplanned activity and authorities tend to view the responsibility of regulating its use as a burden. In the absence of resources for treatment infrastructure and regulatory control, the guidelines proposed by WHO are often unachievable in case of unplanned use. Based on projected increases in urban wastewater supply, coupled with improved sewage collection resulting from sanitation programs, the volumes of wastewater released from developing-country cities will certainly increase and continue to grow, (Minhas,2008 The immediate priority should be to mitigate both chronic and acute risks while simultaneously addressing medium-and long-term constraints to integrated wastewater management. In the long term, changing societal demands for health and environmental protection must be the driving force behind compliance and enforcement of wastewater irrigation guidelines.

A.VI.6.2 WHO guidelines for the safe use of wastewater, excreta and grey water (WHO, 2006)

The regulation of water quality for irrigation is of national and international importance because trade in agricultural products grown with contaminated water may affect health both at local and international levels. Effective guidelines for health protection should include the following elements: evidence-based health risk assessment; guidance for managing risk and; strategies for guideline implementation. Those elements were the reasons for updating the WHO 1989 Guidelines and having the third edition of the WHO Guidelines for the Safe use of Wastewater, Excreta and Grey water (WHO, 2006).

The approach followed in these guidelines is intended to support the establishment of national standards and regulations that can be readily implemented and enforced and are protective of public health. Each country should review its needs and capacities in developing a regulatory framework.

The guidelines set target values designed in such a way as to allow step by step implementation with greatest threats to health should be given the highest priority and addressed first. Over time, it should be possible to adjust risk management strategies to strive for the continual improvement in the context of national public health, environmental and socio-economic realities and international trade regulations.

Table A.VI.4. Summary of health risks associated with the use of wastewater in irrigation.

	Health threats		
Group exposed	Nematode infection	Bacteria/Viruses	Protozoa
Consumers	Significant risks of *Ascaris* infection for both adults and children with untreated wastewater; no excess risk when wastewater treated to <1 nematode egg/l except where conditions favour survival of eggs	Cholera, typhoid and shigellosis outbreaks reported from use of untreated wastewater; sero-positive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 FC/100 ml	Evidence of parasitic protozoa found on wastewater-irrigated vegetable surfaces but no direct evidence of disease transmission
Farm workers and their families	Significant risks of *Ascaris* infection for both adults and children with contact with untreated wastewater; risks remain, especially for children when wastewater treated to <1 nematode egg/l; increased risk of hookworm infection to workers	Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 FC/100ml; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated seroresponse to Norovirus in adults exposed to partially treated wastewater	Risk of *Giardia intestinalis* infection was insignificant for contact with both untreated and treated wastewater, Increased risk of amoebiasis observed from contact with untreated wastewater
Nearby communities	*Ascaris* transmission not studied for sprinkler irrigation but same as above for flood or furrow irrigation with heavy contact	Sprinkler irrigation with poor quality water 10^{6-8} TC/100 ml, and high aerosol exposure associated with increased rates of viral infection; use of partially treated water 10^{4-5} FC/100 ml or less in sprinkler irrigation not associated with increased viral infection rates	No data for transmission of protozoan infections during sprinkler irrigation with wastewater

Sources: Blumenthal and Peasey, 2002; Blumenthal et al., 2000; Armon et al., 2002
FC = Faecal coliforms; TC = total count

A.VI.7 Implementation of Guidelines

The incorporation of protocols for wastewater use into national water plans is important, especially under water scarcity situation to protect water quality but also to minimize treatment costs, safeguard public health and obtain the maximum possible agricultural benefit from the nutrients and organic matter contained in the wastes.

In most developing countries, untreated or insufficiently treated wastes are commonly used, thereby increasing health and environmental risks. This is the reality; banning the practice is unlikely to stop it but will make it more difficult to supervise and control and may also interfere with disease surveillance and health care among those most exposed to the risk of infection. The experience on the use of wastewater for irrigation suggest best approach is the one that provides support in improving existing practice. It will maximize health protection and increase productivity, as the major stakeholders are usually poor farmers.

However, this will not be sufficient to attain a sustainable and safe use of wastewater. Several essential parameters are still needed including the following:

(a) Legal Controls Regulations: For most countries further additional realistic and practical legal controls regulations are needed in the context in which they are to be applied in the presence of the institutions, staff and resources.

(b) Monitoring and Evaluation: Monitoring and evaluation of wastewater use programs and projects is a critical issue. Not performing monitoring regularly and correctly could result in serious negative impacts on health, water quality and environmental and ecological sustainability unfortunately, in many developing countries the monitoring and evaluation program aspects are not well developed, are ill defined and irregular mainly due to weak institutions, shortage of trained personnel, lack of monitoring equipment and the relatively high cost.

(c) Institutional Manageability: In most developing countries, existing sewage treatment plants rarely operate satisfactorily mostly due to lack of adequately trained technicians capable of operating such treatment plants. In this field all technologies require devoted and experienced operators and technicians who must be qualified through extensive education and training.

(d) Information (Tools, Techniques and Technologies): Development of information systems, management systems and skills are important priorities for many government systems and civil society organizations. Shared database systems, accessible via the Internet, are opening new opportunities to improve knowledge-based decision-making which will make exchange of information between the authorities and representatives of the public in adopting a specific water reuse program that meet the user’s needs and the community goals for health, safety and ecological concerns.

The selection of the best available technology requires comparative technical assessment of the different treatment processes for prolonged periods of time. The selection of technologies should be environmentally sustainable, appropriate to local conditions and acceptable to the users.

A.VI.8 Conclusion and Recommendations

Expansion of urban population and increased coverage of domestic water supply and sewage network will give rise to greater quantities of municipal wastewater. This wastewater can become a new water source. For many arid and semi-arid countries, re-use of wastewater may easily contribute more to the future water availability than any other means of increasing water supplies. Treated wastewater can be used effectively for irrigation, industrial purposes, groundwater recharge and protection against salt intrusion in groundwater aquifers. The re-use of such marginal quality waters can contribute significantly to national water budgets, particularly when good quality water is limited or drought phenomenon occurred. The use of appropriate technologies for the development of this alternative source of water is essential for solving the problem of water shortage, together with the improvements in efficiency of water use (water productivity) and adequate control to reduce water consumption.

The water management policy should be fundamentally directed to support “no higher quality, unless there is a surplus of it, should be used for a purpose that can tolerate a lower purity grade”. For this an inventory of water stocks should be made and the demand at local and regional level in quantitative and qualitative terms within the framework of national water strategy should be ascertained. Economic, social and environmental concerns must all be taken into account in accordance with the goal of sustainability in agriculture. It is important to strengthen the capacity of national and local hydrological research institutes to improve their links to environmental research as well as to institutes in the field of economic and social science, particularly in the field of urban studies and planning. The transfer of knowledge to local government decision-makers should be improved.

Wastewater treatment and the possible use of sewage effluents are a health and environmental concern. The re-use of municipal wastewater will require more complex management practices and stringent monitoring procedures then when good-quality water is used. Local governments should focus their policies on treating municipal wastewater to eliminate the rapid degradation in both surface and groundwater quality. In this regard, simple methods of wastewater treatment are to be recommended as realistic solutions; governments need to strengthen the capacity of both institutions and users.

Efforts concerning domestic sewage must centre on the promotion and further development of low cost, easy-to-handle treatment system. Special emphasis must be placed on minimizing the energy consumption of these technologies. The measures required to improve the efficiency of public administration at the local level include the allocation of responsibilities, improving environmental legislation, monitoring, reducing bureaucracy, decentralizing tasks to the lowest levels possible and enhancing the skills of the public administration employees. Cooperation between local governments and the non-governmental sector needs to be enhanced and improved. In this regard, the involvement of the Non-governmental Organizations, public participation and individual responsibility within the framework of urban water supply and wastewater treatment and use projects should be encouraged.

Finally, in order to achieve meaningful implementation and to secure the necessary funding from donors, further research and studies must be carried out to evaluate the feasibility and the cost effectiveness of waste water use in irrigated agriculture and to obtain better estimates of the economic value of wastewater use in urban and peri-urban agriculture.

A.VI.9 Examples of wastewater use

Many countries have included wastewater reuses as an important dimension of water resources planning. In the more arid areas of Australia and the USA wastewater is used in agriculture, releasing high quality water supplies for potable use. Some countries, for example the Hashemite Kingdom of Jordan and Kingdom of Saudi Arabia, have a national policy to reuse all treated wastewater effluent and have already made considerable progress towards this end. In China, sewage use in agriculture has developed rapidly since 1958 and now over 1.5 million hectares are irrigated with sewage effluent. It is generally accepted that wastewater use in agriculture is justified on agronomic and economic grounds but care must be taken to minimize adverse health and environmental impacts. Summary of health risks associated with the use of waste water in irrigation are given in table A.VI.4

A.VI.9.1 Case study of Florida, USA

Parsons et al. (1995) reviews the use of reclaimed water in the Water Conserv II project, the largest agricultural irrigation reclaimed water project of its type in the world. Located west of Orlando, Florida, Water Conserve II presently irrigates over 3000 hectares of citrus. Reclaimed water has been used successfully there for more than 7 years. Water from treatment facilities in Orlando and Orange County is pumped 25 km to a distribution center in an agricultural area in western Orange County and southeastern Lake County. A highly instrumented computerized system controls pumps and valves and monitors the operation of the system. From the distribution center, a system of pipes supplies reclaimed water at no cost to the grower to the edge of his property. Excess reclaimed water is disposed of in rapid infiltration basins (RIBs) which are areas of rapid percolation. Water quality standards were established at the beginning of the project, and continued extensive sampling to insure water of excellent quality for irrigation. Groves on reclaimed water generally appear to be in better condition than similar groves irrigated with well water. This reclaimed water is probably not an important source of nutrition for most elements, but does supply all the calcium, phosphorous, and boron required by the trees. No problems have developed as indicated by monitoring of soil and leaf mineral content in citrus groves over a period of 7 years. Landowners were initially skeptical about using reclaimed water, but are now eager to have its availability expanded. Reclaimed water, once considered to be a disposal problem, may become a limited resource.

From available literature and international experience the use of wastewater for irrigation was checked for small communities in Austria. The irrigable agricultural area in water scared regions depends mainly on the number of inhabitants (the amount of wastewater), the crop water requirement and the natural precipitation. As amount of well distributed annual rainfall is about 500 mm, irrigation is only an additional one. Because there is no demand during winter period, the purified wastewater has to be stored in a pond. A storage area of about 18 mm with an average depth of 3 m per inhabitant, an area of about 0.1 ha can be irrigated with 50 mm. The predominant irrigation systems in Austria are sprinklers and rain guns. This may cause some hygienically problems close to villages owing to the spread of aerosols if no disinfection is used. Surface or subsurface irrigation may also exclude such problems. For vegetables and raw eatable crops disinfection is absolutely necessary. Deep groundwater table and adsorption capacity of soils protect groundwater from pollution with trace elements. However, content of some salts in groundwater is high, and additional contaminant enrichment must be avoided. Without other measures salt concentration in the root zone will increase owing to substantial salt content in purified wastewater, despite dilution and small applied amounts in proportion to precipitation. In general the quality of purified wastewater of small communities is satisfactory, therefore it can be expected that no serious problems will occur, nevertheless each specific application case has to be investigated separately to take care for a sustainable use of resources soil and water.

In Hawaii (U.S.), reclaimed water has been used in agricultural irrigation and the irrigation of golf courses and other large landscaped areas. However, the Hawaii Department of Health's new "Guidelines for the Treatment and Use of Reclaimed Water" published in November 1993, limits uses of reclaimed water through overhead sprinkler irrigation systems. The subsurface drip irrigation concept provides a unique opportunity to effectively address the issues of reclaimed water management and disposal while providing for irrigation needs. Freddie (1995) discusses the design, implementation and management of two permanent subsurface drip irrigation projects in Hawaii using reclaimed water in accordance with the state's new reuse guidelines.

Reluctance on the part of the engineering design community to apply wastewater effluent in micro-irrigation is due primarily to limited full-scale operating experience and the lack of rational criteria for design and operation of the system. Design criteria have not been developed because very little information has been generated on the relationships between emitter performance and differing water qualities. The major disadvantage of micro irrigation is the potential for clogging. Clogging of even a small percentage of emitters can severely affect the uniformity of water application. Micro irrigation researchers and equipment manufacturers have chosen two approaches for solving the clogging problem. Hills and Tajrishi (1995) studied one of those approaches - improving the quality of water before it reaches the emitter. The objective of their investigation was to evaluate treatment criteria (filtration, chlorine injection, and ultraviolet light disinfection) for prevention of bio-fouling within a micro irrigation system when using secondary wastewater effluent. However, the successful operation of long-term micro irrigation systems requires that the interdependent effects of both water quality and emitter design be carefully considered before making water treatment recommendations.

A.VI.9.2 Case Study of Jordan

The use of reclaimed wastewater for irrigation has been progressively adopted by virtually all Mediterranean countries (Marecos do Monte et al., 1996). Today wastewater reclamation and re-use represent an important additional source of water for most developing countries in the region. Many countries have included treated wastewater re-use in their water planning. Policies have been formulated and most countries are working hard to implement them in their water management practices in terms of actions to deal with water pollution control and waste disposal.

In Jordan, one of the countries with the lowest available water volume/capita, wastewater represents 10 % of the total water supply (McCornick et al., 2004a). Groundwater recharge is one of the explicit uses of wastewater in Jordan, but only for aquifers that are not used for drinking water. Appropriately managed reclaimed water is viewed as a major component of the water resource supply to meet the needs of a growing economy. Given the severe scarcity of water supply and the high cost of chemical fertilizers, it becomes a high priority to dedicate considerable efforts to introduce new management and optimization techniques that include re-use of treated wastewater in irrigation.

The use of municipal wastewater in the agricultural sector is of vital importance to Jordan. It can provide the following advantages (McCornick et al., 2004b):

(a) Increase in agriculture production through expanding the irrigated area and thereby moving towards fulfilling the severe food gap the country is facing;
(b) Avoidance of environmental damages as compared with other disposal options;
(c) The conservation of the scarce freshwater resources which could be allocated to compensate the increasing water demand in the other sectors, particularly, municipal and industrial sectors; and
(d) The creation of new jobs and the enforcement of settlement opportunities in rural areas.

Indirect re-use of wastewater effluent has been occurring in Jordan for a number of years as a result of the historical practice of discharging wastewater to the Wadis where it is, generally, mixed with surface flow. Direct use of treated wastewater has been on the increase since 1985. To encourage re-use schemes, the government made it mandatory for all new sewage treatment plant projects to include a fully designed and feasible re-uses aspect. Legislation concerning the treatment of wastewater was introduced in January 1996 and relates to standards for control of the disposal of treated domestic wastewater. These measures reflect a further tightening of standard in response to continuing problems with pollution of water sources in some areas and genuine desire to harness this valuable and scarce commodity.

The Jordanian government, through its various ministries and the University of Jordan, has undertaken a number of study projects all over the country to investigate the re-use of treated wastewater on various plants, crops, trees and flowers. A brief list of the wastewater treatment plants (WWTPs) where re-use schemes are currently in operation is given in Table A.VI.5, together with the irrigated crops.

Table A.VI.5 Direct re-use in Jordan

WWTP	Planted area (ha)	Crops
As-samra	1000	Olive, forest, fodder
Aqaba	150	Forest, some olives trees and palm trees
Ramtha	50	Forest, barley, berseem, Sudan grass, alfalfa
Mafraq	25	Forest, fodder, crops and olive
Madaba	60	Forest, olive, fodder, Flowers
Maan	7	Forest, olives ornamental trees
Kufranjeh	7	Forest, olive sudan grass, alfalfa
Salt	6	Olive and citrus trees
Karak	50	Olives ornamental trees, forest
Fuhis	24	Forest, olive
Wadi Asir	15	Forest, olive

As appears from Table A.IV.5, As-Samra is the largest WWTP in Jordan. It was commissioned in May 1985 and by 1986 it was receiving approximately 57,000 m^3 day-1of domestic effluent from the urban area of Amman. At present, 35 % of the irrigated area around As-Samra is planted with Olives trees, which are reported as being very successful. The remaining 65 % are under forestry and fodder cropping. Since 1996 the land is rented to the private sector. The plant is currently treats a wastewater flow of around 150,000 m^3 day-1 in three series, each comprising two 3.2 ha anaerobic ponds, four 7.25 ha facultative ponds and four 6.25 ha maturation ponds. The total pond area is 181 ha. The plant discharges into the King Talal reservoir, which has the capacity of 78 Mm^3. This reservoir also receives some fresh water input as well as other treated wastewater. The contents of the reservoir are used for unrestricted irrigation in the Jordan Valley. Each year more than 70 million m^3 of reclaimed water, around 10 % of the total national water supply, is re-used either directly or indirectly (McCornick, 2001). The categories of use are:

(a) Planned direct water use is use within, or adjacent to, wastewater treatment plants: The direct use is generally under the jurisdiction of the water authority of Jordan (WAJ) which plans, builds, owns, operates and maintains the WWPTs. A number of these sites are pilot projects with some research and limited commercial viability, but more recent projects funded by USAID are aimed at developing more productive uses of the water resources while demonstrating public health and environmental protection.

(b) Unplanned water re-use in Wadis: Farmers, who have traditional water rights to the base flow, have continued to irrigate from the flow in the Wadis, which is mostly wastewater effluent. The Ministry of Health, in coordination with local authorities and the WAJ, recognizes that the microbiological quality of such water presents a serious health risk and jeopardizes wider export markets for crops. They have enforced the existing standard (JS 893/1995) where possible. The standard identifies the allowable limits for the discharge of treated wastewater to streams, Wadis, rivers, surface water and groundwater and for the re-use in the irrigation sector. With increasing population in the Amman Zarqa area in recent years, flow in the Wadis has increased and become more reliable, enabling the farmers to use larger volumes of water and irrigate larger areas of land.

(c) Indirect re-use of wastewater effluent: The majority of the reclaimed water in Jordan originates in the Amman-Zarqa Basin (Figure A.VI.1). Treated effluent for As-Samra WWTP is discharged to Zarqa Wadis. The Wadis flow into the King Talal Reservoir (KTR) and, blended with water from the King Abdullah Canal, when available, is used for irrigation in the southern part of the Jordan Valley (McCornick, 2001). From a Jordanian aspect, water downstream of the KTR, is no longer considered to be reclaimed water. From the practical perspective, however, the microbiological and chemical qualities of water are affected by the level of treatment at the WWTP and by non-point source contaminating surface run-off from the Amman-Zarqa catchment.

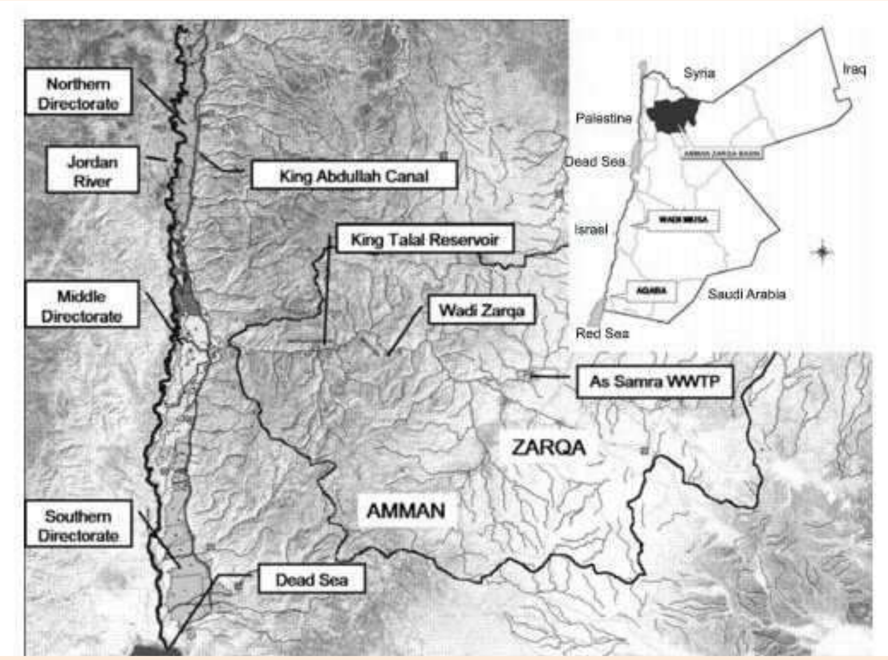

Figure A.VI.1. Schematic map of Jordan and the Amman-Zarqa Basin.

Since 1998, Jordan has been revising the strategy and policies used to manage its scarce national water resources. The national wastewater management policy (MWI, 1998) states that any use of reclaimed water must protect the public, conserve resources (water, soils/land, natural vegetation, etc.), comply with international treaties and ensure environmentally sound practices. Issues related to treated wastewater practices and management, knowledge of the problems faced by farmers and industry, the constraints faced by all parties using treated effluent, the potential impact of regulations on the export market of fresh fruit and vegetables and the possibility of restrictions placed by importing countries based on the poor microbiological quality of the irrigation water all were pressing strongly the Jordanian authorities, universities and scientific institutions to review the existing national treated wastewater standard JS/893/1995. The review process proved to be highly beneficial in bringing different opinions to close agreement on the content of the new standard. The standards have now been approved by the Jordanian Institution for Standard and

Meteorology (JISM, 2003) and were officially enacted (Table A.VI.6). It is expected that the new standards will provide Jordanian farmers with opportunities to comply, without losing any vested rights to retain water, and with much improved health and safety conditions for themselves, their children and their customers.

Table A.VI.6. Revised standards for water re-use in Jordan (Government of Jordan, 2003).

Purposes of water use	Artificial ground water replenishment	Recreation grounds, courses and roadsides inside the cities	Roadsides outside the cities	Industrial crops	Discharge into valleys and torrential streams	
					Mechanical system	Natural system
	Operating specifications					
BOD (mg/l)	15	30	200	300	60	120
COD (mg/l)	100	100	500	500	150	300
DO (mg/l)	>2	>2	-	-	>1	>1
TSS (mg/l)	50	50	150	150	100	-
pH (unit)	6-9	6-9	6-9	6-9	6-9	6-9
Cl_2 residual	0.5-1.0	0.5-1.0	-	-	0.5-1.0	-
Turbidity (NTU)	2	10	-	-	-	-
NO_3 (mg/l)	45	45	70	70	45	45
NH_4 (mg/l)	5	10	-	-	-	-
T-N (mg/l)	20	45	45	45	45	45
	Environmental and health specifications					
E-coli MPN or CFU/100 ml	<2.2	100	1000	-	500	1000
intestinal helminthes eggs (egg/l)	≤1	≤1	≤1	≤1	≤1	≤1

BOD = Biochemical Oxygen demand TSS = Total Soluble Salts
COD = Chemical Oxygen demand NTU = Unit that measures turbidity
DO = Dissolved Oxygen of water using a typhilometer

Appendix VII

A.VII Desalination

[Appendix presents various aspects of desalination, including its costs, environmental aspects and the use of desalinated water in Agriculture]

A.VII.1 Introduction

Water desalination is a well-established technology mainly for drinking-water supply in water scarce regions such as the Near East. Among the options for augmenting freshwater resources is the desalination of salty groundwater, brackish drainage water and seawater. Distilling drinking-water from seawater has been studied over many centuries by Mediterranean and Near East civilizations. Large-scale solar pounding to serve as domestic drinking-water was practiced more than 100 years ago in Egypt (Abu Zeid, 2000). However, progress on modern desalination was made during the 1960s and plants have been developed since the 1970s, starting with some countries of the Persian Gulf because of their ready availability of energy and relevant scarcity of freshwater resources. Intensive research for large-scale commercial desalinating technologies began in the United States of America in the early 1960s (Buros, 1999).

Desalination increases the total amount of available water in the hydrological cycle and is a potential solution for enlarging the fresh water availability. However, with agriculture accounting for 69 percent of all water withdrawals compared to domestic use of about 10 percent and industry 21 percent, it is the main source of potable water in the Persian Gulf countries and in many islands around the world and it is also being used in certain countries to irrigate high-value crops. However, it has proven much less economic for agricultural application than the reuse of treated wastewater, even where the capital costs of the desalination plants are subsidized.

A.VII.2 Costs of desalination

The costs of desalination depend mainly on the type of desalination process used, the quality of the intake and product waters, the output capacity of the plant, and the available options for waste disposal. They include:

(a) investment costs (cost of land, equipment, civil works, etc.);
(b) operation and maintenance (O&M) costs (energy, chemicals, labour, etc.);
(c) environmental costs (water intake and environmental externalities, safe brine disposal, etc.);
(d) other indirect costs (insurance, etc.).

The primary operating cost of desalination plants is power, which typically accounts for 44 percent of the O&M costs of a seawater RO plant (considered less expensive than thermal distillation). Thermal distillation processes for desalinating very highly saline waters and seawater are relatively expensive because of high operating temperatures and high construction costs. In contrast, RO processes for desalinating brackish water are less expensive because they are modular in setup and simpler to operate. However, a reduction in the costs of high-capacity seawater desalination plants has been observed over time. The US Bureau of Reclamation (USBR, 1997) has surveyed detailed water desalination cost data in the United States of America. The costs of desalinated water are high enough that its major use is urban rather than in irrigated agriculture.

A.VII.3 Public–Private Partnerships in desalination

Desalination is the main source of potable water in the countries of the Persian Gulf Cooperation Council (PGCC), i.e., Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates. In these countries, desalination accounts for 40 percent of the water used for municipal and industrial uses. Kuwait and Qatar rely on desalinated water for 100 percent of their domestic and industrial needs.

The involvement of the private sector in providing freshwater is promising as it has the capability to provide the necessary capital, networks, technology, experience and human resources. Public–private partnerships (PPPs) have been much discussed at meetings worldwide on institutional and regulatory frameworks for private investment, market risk, off taker risk, tariff structure and desalinated water charging, construction/technical/operational risk, financing structure, credit enhancements, environmental risk, etc. The need for a market-based economy and an expanded role of regional banks has also been raised. Recently, many countries have turned to the private sector for additional funding in investment projects. The build own operate transfer project delivery method has become the preferred method for municipalities and public utilities worldwide as it allows cost-effective transfer to the private sector of the risks associated with the costs of desalinated water. Some of these risks include: predicting plant performance due to variable intake-water quality, permitting challenges, startup and commissioning, fast-changing membrane technology and equipment market, and limited public-sector experience with the operation of large seawater desalination facilities (Voutchkov, 2004).

However, there are infrastructure constraints on the application of PPPs. For example, desalination normally requires long-distance transport of desalinated water to its site of use. Furthermore, there are institutional constraints that need to be addressed in concert with PPPs, such as establishing a water pricing policy and incentives, investment in research and development, and integrated water resources management.

The State of California in the United States of America has the institutional experience of setting up of a water desalination task force. This task force has examined and reported on the opportunities and impediments of both brackish and seawater desalination, and the role of the State in furthering the use of this technology (Department of Water Resources, 2003a). A report from the California Coastal Commission (2003) has been released on the policy conformity of desalination to the Californian Coastal Act. Finally, environmental issues and plant permits are related institutional and legal issues, and a working draft of the California Water Plan Update was completed in 2003 (Department of Water Resources, 2003b).

Other constraints relate to the public perception of private-sector involvement in PPPs. Public concerns regard potential price increases, inappropriate business practices, and insufficient information dissemination. The effect of water quality on socio-economic growth has not been well quantified, and human resources and related organizations are still at a nascent stage. All the above issues pose current challenges to the sustainable application of desalination for supplying both potable water and irrigation water.

A.VII.4 Environmental Impact of Desalination

A major environmental problem of water desalination is the production of a flow of brine containing the salts removed from the intake water and that needs to be disposed. In addition, this brine may be polluted. This brine represents a significant fraction of the intake water flow. Seawater desalination typically yields a brine flow of 50–65 percent of the intake water flow, with about twice the initial concentration (FAO, 2003a). Brackish water desalination may result Process. Thus, brine production poses a significant problem of environmentally safe waste disposal. Even where plants are near the sea, brine disposal may affect the local marine ecosystem.

Environmentally safe disposal depends mainly on the site of the treatment plant. With plants situated near the sea or close to brackish environments, such as estuaries, brine disposal is comparatively easier than that from inland desalinating facilities. Where plants are not far from the sea, the construction of special collectors is an option. However, in this case, the additional environmental costs increase the total cost significantly. In inland plants, one option is to inject the brine into a confined aquifer through deep wells. This alternative has serious technical problems and high environmental risks.

A.VII.5 Use of desalination water in agriculture

In the past, the high cost of desalinating and the energy required have been major constraints on large-scale production of freshwater from brackish waters and seawater. However, desalinated water is becoming more competitive for urban uses because desalinating costs are declining and the costs of surface water and groundwater are increasing. In spite of this development, the costs of desalinated water are still too high for the full use of this resource in irrigated agriculture, with the exception of intensive horticulture for high-value cash crops, such as vegetables and flowers (mainly in greenhouses), grown in coastal areas (where safe disposal is easier than in inland areas). For agricultural uses, RO is the preferred desalination technology because of the cost reductions driven by improvements in membranes

Table A.VII.1 show recently desalination situation in the Mediterranean. Spain provides a significant example of the application of desalinated water in irrigation (AEDYR, 2008). Spain has more than 300 treatment plants (about 40 percent of the total number of existing plants) and 22.4 percent of the total desalinated water is used for agriculture. Most of these plants process brackish water (only 10 percent of the total desalinated water for agriculture originates from seawater) and are located in coastal areas or within 60 km of the sea (FAO, 2003b). In this country, small and medium-sized brackish-water desalination plants, with a capacity of less than 1000 m^3/d (11.6 litres/s), are common because they adapt better to individual farmer requirements and to the existing hydraulic structures. Figure A.VII.1 shows the desalinated water use situation in Spain in different sector during more than two decade.

Table A.VII.1 Desalination in the Mediterranean (Source: Wangnick, 2004)

Country	Number of plants	Largest plant (m^3 day-1)
Spain	287	165 000
Italy	132	36 000
Algeria	61	88 888
Egypt	55	11 732
Israel	33	395 000
Greece	29	14 500
France	24	140 000
Malta	14	27 600
Tunisia	13	22 500
Morocco	13	7 000
Jordan	9	145 344
Turkey	9	5 250
Cyprus	8	54 000
Lebanon	3	10 560
Syria	3	3 000
Palestine	3	2 000

The Persian Gulf Countries are the world's largest producers of desalinated water. All Persian Gulf Cooperation Council (PGCC) countries have supplied the bulk of municipal and industrial water from desalination of seawater for the past 20-30 years and reliance on this mode of water supply is expected to rise as the population grows. Right now, about two-thirds of the world's total desalination capacity is installed in the PGCC. Saudi Arabia alone accounts for one-quarter of world capacity in desalination, and the largest desalination centre in the world is located in Al-Jubail, in the eastern province of Saudi Arabia. One-third of the desalinated water in Saudi Arabia is produced at this plant. Saudi Arabia, Kuwait and the United Arab Emirates rate first, third, and fourth respectively in the world in desalination capacity, relying on large-scale plants capable of producing up to 500 million m^3 per year (UNU, 1997; WB 2005). The desalination industry, however, has several environmental impacts, which require proper mitigation. These include discharge to the near-shore marine environment of reject hot brine, residual chlorine, trace metals, volatile liquid hydrocarbons, anti-foaming and anti-scaling agents.

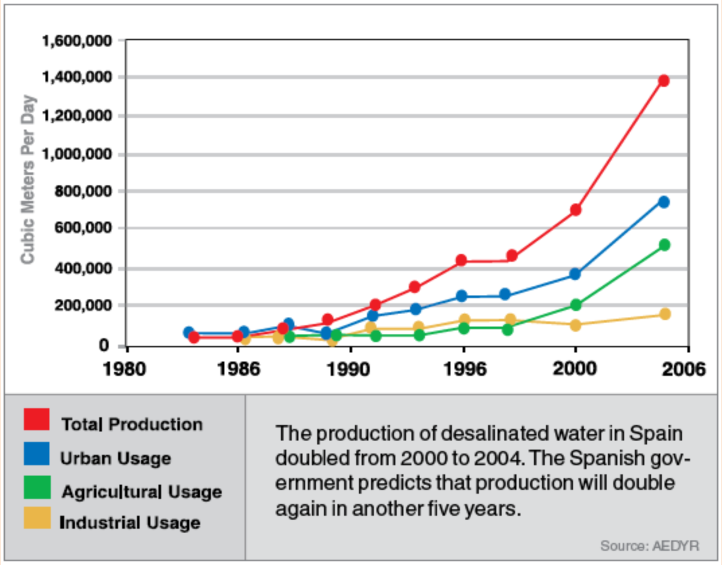

Figure A.VII.1. Desalinated water use in Spain in different sector during more than two decade.

According to the International Desalination Association, in June 2015, 18,426 desalination plants operated worldwide, producing 86.8 million cubic meters per day, providing water for 300 million people. This number increased from 78.4 million cubic meters in 2013, a 57% increase in just 5 years figure A.VII.2. The single largest desalination project is Ras Al-Khair in Saudi Arabia, which produced 1,025,000 cubic meters per day in 2014, [4] although this plant is expected to be surpassed by a plant in California. Israel produces a higher proportion of its water than any other country, totalling 40% of its water use.

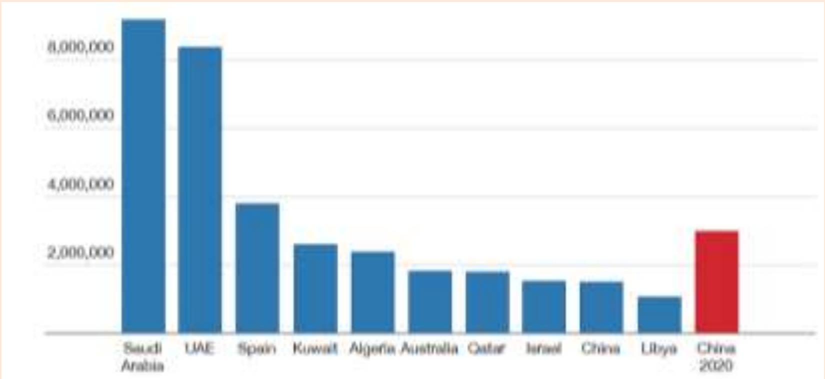

Figure A.VII.2. Commissioned sea water desalination capacity m^3/day in 2013

The multistage flash distillation process makes up the highest total production capacity of desalinated waters, followed closely by RO. Other processes are comparatively smaller in production capacity. Although thermal distillation plants make up about 21 percent of the total desalination facilities in the world, they produce more than half of the total desalinated waters because they are larger than RO facilities. RO is particularly appealing because recent advances in membrane technology allow modular construction of desalination facilities to meet small to large-volume desalination needs (FAO, 2003a).

Appendix VIII

A.VIII Policy Framework for Drought Management in South Africa

An assessment of the comprehensive policy framework influencing the formulation of drought management policy at both the international and the national levels needs to be made. In particular, international statutes and principles guide access to water, distribution of water among users, and risk management in the context of scarcity, which in turn informs national and local responses to issues such as drought and water scarcity.

At the national level in the South African context, it is predominantly the principles and guidelines imbedded in the Constitution that filters down to influence policy at the sectoral level. With this in mind, a drought evaluation policy cannot be detached from the constitutional and wider policy framework in which it is to be applied. Furthermore, since drought evaluation deals with issues such as access to and control over scarce water resources, it is imperative to imbed any policy framework in this regard into the wider policy framework that addresses these issues.

A VIII.1 The international context

Within the international policy framework, people in general and those that are vulnerable to the effects of natural and social issues in particular are protected. The Universal Declaration of Human Rights (1948), for example, provides such protection at the international level. International human rights principles accept that every human being is entitled to a range of rights protected under international law. Rights to equality, freedom of speech and political participation are referred to as first order rights. International human rights principles furthermore increasingly recognise that people are entitled to a set of socio-economic rights, also referred to as second order rights. The right to access of water is one of these rights. The relevance of these rights with regards to a drought evaluation policy becomes clear when this right needs to be protected in the face of scarcity, particularly as far as it affects those vulnerable to the effects of water scarcity.

There are few international human rights treaties that explicitly and directly recognise the right to water. Due to the close link between water and food rights, however, those treaties that protect the right to food are also interpreted to include the right to water. One of two treaties that directly recognise water rights is The Convention on the Elimination of All forms of Discrimination Against Women of 1979 (CEDAW) in which a duty is placed on states to ensure rural women's access to adequate living conditions, including water supply, and sanitation. A second treaty recognising water rights explicitly is The Convention of the Rights of the Child of 1989 (CRC). This Convention obligates states to implement children's right to health through, among others, the provision of clean drinking water (Liebenberg & Pillay 2000: 297).

A VIII.2 Policy formulation and implementation

Once the basic framework is in place, a process of policy formulation can develop. However, even if all elements are in place, there is no guarantee that the policies will be appropriate. It is important to ensure that all those interested, especially those defending the public interest, are able to play their roles. As a general rule, the more open the process of policy formulation, the more likely it will be that the policies will respond to the public interest and that their implementation will be successful. Policies defined in an arbitrary and authoritarian manner against the will of the population are destined for failure, even when they seem to be correct from a technical point of view (Carman, 2005).

The absence of adequate drought management planning and programmes could (and in many ways will) result in the following problems (National Department of Agriculture, 2003):

(a) More and extended hardship

(b) Increase in the disaster impact and consequences.
(c) Greater and avoidable financial strain and delay in economic recovery and urgent needed reconstruction.
(d) Avoidable additional loss of life, property and community infrastructures
(e) Greater possibility of epidemics
(f) Enhanced chance of political instability
(g) Potentially a prolonged disruption in essential services

A VIII.3 The South African policy framework

In the previous political dispensation, information for better policy making, as well as minor policy changes served little purpose, since it was not supported by a democratic political structure. Political reform encompassing a change to a participatory state in a constitutional democracy was instrumental to instituting drastic policy reform in the country (Backeberg 2003: 6). In the past decade, since the first democratic elections in 1994, South Africa has experienced unprecedented reform of the country's general policy framework. With the establishment of a democratic government and the adoption of a new constitution, virtually every sphere of society was, and still is, touched by policy reform. The water and agricultural sectors are no exceptions, both undergoing far-reaching policy transformation to bring these sectors in line with the spirit of equal access to and protection of rights for all South Africans. The institutionalisation and formalisation of basic human rights and the redress of past disparities by means of policy was first and foremost begun by the adoption of a new constitution for the country. In the Constitution, the basic first order rights or civil and political rights as well as second order socio-economic rights (social security, access to food, housing, health care etc.) are enshrined.

One socio-economic right in particular has significance here, namely the right to have access to sufficient food and water [Bill of Rights 27.1(b)]. This right is protected by among others, the National Water Act (no 36 of 1998), the Water Supply and Sanitation Policy and the Water Services Act (no 108 of 1997). The approval of the Water Supply and Sanitation Policy and the Water Services Act attests to the fact that priority is given to domestic water provision, particularly to communities without access to potable water and minimum sanitation (Backeberg 2003: 10). On the other hand, the National Water Policy recognises that agricultural water use is vital for rural economic growth and development. Current policy reform, however, ardently emphasises the provision and protection of individuals' socio-economic rights through policy.

Food security is a case in point. The Integrated Food Security Strategy for South Africa (2002) emphasises that food security is a priority objective in line with the Reconstruction and Development Plan. However, certain challenges to achieve food security are among others, inadequate safety nets and a weak disaster management system. Both aspects have particular relevance in the case of ensuring these rights for vulnerable households such as poverty stricken and rural households (see again paragraph 3.1). Especially with regard to agricultural based households, it is stated that there is a lack of a structured system to deal with food security disasters such as floods and droughts (National Department of Agriculture 2002).

Socio-economic rights and the remedy of past inequalities also receive attention in the transformation of agricultural policy. During 1996/ 1997, agricultural policy reform was undertaken, with particular emphasis on redressing inequalities by setting the overall objective of the policy reform as creating opportunities for smallholders and farmers who are resource-poor. In this reform process, provincial and national consultation workshops, involving both black subsistence farmers and white commercial farmers were undertaken, culminating in the drafting of a discussion document on agricultural policy in South Africa. (Backeberg 2003: 7). This discussion document deals with various aspects of agriculture in South Africa. Within this agricultural policy framework, new approaches to irrigation development and management with the aim of ensuring more efficient use of water in agriculture and a more equitable distribution is adopted (National Department of Agriculture 1998: 12). Irrigation policy is, according to the discussion document, intrinsically linked to Water Policy, therefore, a more in depth discussion of each is warranted.

A VIII.4 The National Water Act (no 36 of 1998)

Access to water is a key component of the National Water Act, but this right is also linked to food rights, rights to health, the right to equality and dignity and the right to a protected environment, all enshrined in the Constitution. The National Water Act recognises the linkages between water rights and other socio-economic rights. A central goal of the government's water policy is ensuring equitable access by all to the country's water resources, and ending discrimination in access to water on the basis of race, class or gender (Liebenberg & Pillay 2000: 295). This aim springs from the assumption that water is a national asset that must be utilised in such a way that the socio-economic needs of the country's people can be met within natural constraints (DWAF 2002: 3). This is particularly relevant in the context of drought and water scarcity, where demands from irrigated agriculture are often at odds with the demands from domestic users to supply basic needs.

With regards to water scarcity induced by droughts, the National Water Resource Strategy7 (DWAF 2002: 26) states that DWAF will co-operate with the National Department of Agriculture in developing prevention and mitigation measures for drought conditions. In the spirit of the National Water Act, water for meeting basic needs receives priority in allocations. Therefore, in periods of drought, water in storage dams is to be used judiciously and restrictions may be necessary – thus available water for irrigation is restricted first so that water can still be available for basic needs, thereby protecting people's right to access of water.

Increasing water scarcity in South Africa has thus led to a major shift in policy from supply management to demand management, as is demonstrated above. This change in approach to water management in South Africa has already impacted on the distribution of water supplies between the competing sectors. It is projected that distribution patterns will continue to change especially to the advantage of the domestic users in order to realise the government's goal of providing safe water and sanitation to all its citizens within reasonable walking distance. As water resources in the country decrease in future, the competition between the various sectors over water allocations is likely to increase - a state of affairs that will pose serious challenges to the irrigated agricultural sector in South Africa.

The National Water Act also makes provision for the restructuring of the management and the conservation of water resources in the country, and requires a change in pricing structures to reflect the true environmental and social costs of water. In essence, the National Water Act seeks to achieve optimum, long-term, environmentally sustainable social and economic benefits for South African society from the use of the country's water resources (DEA&T, 1999: 9-10; Hamann and O'Riordan, 1999/2000; Fuggle and Rabie, 1999: 834).

A VIII.5 Policy for irrigated agriculture

The single biggest challenge to irrigated agriculture in South Africa is the changed governmental policy and legislation with regard to water resource management. Being the main consumer of water resources in the country (agriculture accounts for 51% of water consumption), the irrigated agriculture sector has become the prime target for governmental efforts to conserve water resources in order to meet increased demands from other users. Irrigation policy acts in conjunction with policy formulated in the water sector, namely the National Water Act and the National Water Policy. According to the National Department of Agriculture (1998: 66) there is little scope for increasing the land under irrigation due to the constraints of limited water availability and the competing demands of other economic and societal sectors. The focus is thus on better utilisation of existing infrastructure and more importantly on the improved efficiency in use of scarce water. To this effect, water pricing that more accurately reflects the cost of water and that promotes the more efficient use of irrigation water is being implemented.

Key components of the new water policy for irrigated agriculture include the abolition of water subsidies to established commercial irrigation farmers, the introduction of volumetric water pricing for all irrigation

[7] In the National Water Act (NWA) (no 36 of 1998) and the National Water Policy (NWP) (1997) provision was made for the establishment of the National Water Resource Strategy (NWRS). The NWRSs provides the implementation framework for the NWA and the NWP.

farmers regardless of the type of irrigation scheme, and the transfer of the annual operation and maintenance costs on government water schemes to water user associations (i.e. the irrigation farmers in the scheme). The National Department of Agriculture (1998: 66) states that policy related to irrigation is aimed towards the equitable and efficient utilisation of water with the objective of increasing agricultural productivity and maximising the sector's contribution to the reduction of income inequalities and national output growth. In keeping with the country's overall agricultural policy principles, irrigation also needs to be the responsibility of farmers instead of being government controlled practices.

Irrigation farmers are further charged with improving irrigation efficiency, either through irrigation scheduling or by changing to more efficient irrigation methods. If no action is taken by the irrigation farmer to improve efficiency on irrigated fields, a quantity of 10% of the total water use of the farmer will be added as a punitive measure. The SAAU successfully negotiated the phasing in of the new pricing and control system for irrigation over a period of five years. This period came to an end in March 2001 (DWAF, 1999: 32-37; DWAF, 2000: 1-20). The government's role is to aid in reducing inequalities inherent in irrigation distribution. To this end the National Water Resource Strategy makes provision for the fair and equal distribution of water through the water licensing process. Water licensing authorities are charged with identifying water users from marginalised or disadvantaged groups in calling for licence applications (Backeberg 2003: 8).

A VIII.6 The Policy on Disaster Management (1999)

A White Paper on Disaster Management was issued in 1999 which outlines the comprehensive terms of the government's new approach to disaster Management, followed by the Disaster Management Act, 2002 (no 57 of 2002). In this White Paper a broad policy and framework for a drought management programme is set out. A key component of the Disaster Management Policy is that disasters, including drought, should be managed on a continuous and pro-active basis to ensure proper mitigation and timely responses during periods of drought. A risk reduction approach to disaster management is advocated that includes reducing risk of loss of life, economic loss, vulnerability and environmental protection (Republic of South Africa, 1995; Department of Constitutional Development, 1997, Department of Agriculture 2003).

The government has, according to the Constitution, a responsibility to secure the well-being of the people of the country and in doing this give effect to the right to life, equality, human dignity, environment, property, health care, food, water and social security as contained in the Bill of Rights of the Constitution (Backeberg & Viljoen 2003: 8). In dealing with natural disasters, the White Paper on Disaster Management (1999) places the primary responsibility for dealing with natural disasters on the government. The focus of the Disaster Management Policy is on reducing risks, such as risk of loss of life, economic loss, and damage to property. Emphasis is placed on populations that are vulnerable to disasters due to poverty and lack of resources. Particularly with regards to drought, the White Paper recognises that drought not only affects macro-economic growth, but also the livelihoods of the poorer populations in rural areas (National Department of Agriculture 2003).

The Disaster Management Policy in turn led to the promulgation of the Disaster Management Act. The focus of this Act is on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness and rapid, effective response to disasters and post disaster recovery (Backeberg & Viljoen 2003: 10). In complying with this Act, the Department of Agriculture needed to develop a Disaster Management Plan for its sector, culminating in the Drought Management Strategy (see paragraph 4.2.4).

Risk management and proactively factoring in the possibility of drought by individual farmers is strongly emphasised both in the Disaster Management Policy, the Agricultural Policy as well as the Drought Management Strategy. This place the onus on farmers to manage risks associated with events such as droughts, as well as to insure against the impacts of natural disasters such as droughts.

Currently, an Agricultural Insurance Bill is being prepared to provide for a system of agricultural insurance (Backeberg and Viljoen 2003: 13). The Agricultural Insurance Bill specifically states that risk management programmes are to be put in place by government instead of providing direct disaster relief. Provision is made in the Bill for the establishment of an Insurance Fund by government and the importance of agricultural insurance as stated in the Strategic Plan for South African Agriculture.

A VIII.7 The Drought Management Strategy

Drought policy reform in South Africa forms part of wider policy reforms on the agricultural front in the context of the country's transition to a fully-fledged democracy. South Africa is characterized by both a developed and a developing component reflected in the agricultural sector by the divide between a sophisticated commercial farming sector and a subsistence farming sector. A comprehensive drought policy focusing on issues such as household food security and rural water supplies on the one hand, while promoting self-reliance, acceptance of drought as a normal environmental risk and risk management on the other hand is needed (O' Meagher et al. 1998: 243).

In recent years many countries plagued by frequent droughts have shifted emphasis towards proactive drought management strategies, focusing on early detection, warning and monitoring of droughts. A proactive approach, in which the productive use of water and the proactive management of water scarcity are given precedence, is thus emerging. Without effective management, the negative impacts of drought will increasingly surface, forcing countries to adopt crisis management approaches in drought periods (Nairizi 2003).

Policy on drought management in South Africa is closely linked to policy on disaster management and is essentially a component of the latter. Within the framework of the Policy on Disaster Management, a National Drought Management Strategy has to be formulated that is in line with the Disaster Management Act (no 57 of 2002). A key component of the National Drought Management Strategy is that drought management is not the responsibility of the national government, but should be an integrated effort of the National and Provincial Departments of Agriculture, local governments, the farming community, the private sector and civil society (National Department of Agriculture 2003: 8).

The government asserts that agriculture in South Africa is inherently risky due to low average rainfall and wide variability in rainfall. In the past farmers' reliance on government relief programmes to cope with risks such as droughts were the norm. Reliance on these programmes, however, have reduced farmers' willingness to adopt risk avoidance measures due to the costs associated with these measures and have encouraged the use of technologies unsuitable in drought prone areas in expectation of government support in the event of crop failure. A key component of the government's drought policy is that the farming community must accept the variability of rainfall patterns and adapt to it as a normal part of farm management (National Department of Agriculture 1998: 33).

Greater emphasis is therefore placed on the responsibility of farmers to reduce their own vulnerability to drought than was previously the case. Other options for reducing risk than reactive drought relief programmes are promoted instead (National Department of Agriculture 1998: 33). In the light of this, the government holds the view that it is the responsibility of the state to provide farmers with technical assistance to identify technologies suitable to variable conditions, to assist farmers in drought-prone areas to reduce their dependency on agriculture and to provide agro-meteorological information to farmers regarding weather forecasts and probabilities on the season ahead. Greater emphasis is also placed on risk reduction and prevention strategies through supporting risk management initiatives, research on risk reduction methods, information to farmers on markets and available insurance measures (National Department of Agriculture 2003). However, once the farmers make their decisions, they, according to agricultural policy, should live with the consequences of these decisions without state subsidies. Based on the Drought Management Strategy currently proposed, the commercial farming community can expect a drastic decline in governmental support during drought conditions in the future. The White Paper on Disaster Management (1999) further attests to the fact that the government's focus is shifting from reactive drought relief to greater responsibility expected from farmers. Therefore, the Drought Management Strategy needs to embody the government's policy on disaster management (National Department of Agriculture 2003).

The Strategy for Drought Management signifies a move away from a reactive approach in which the state had sole responsibility to a proactive approach in which the farmer's responsibility increases. There is a great emphasis in this strategy on good farming practice as the only proactive measure that can be employed to buffer the effects of disaster drought. The drought management strategy currently proposed aims towards developing an integrated management system that focuses on reducing risks caused by natural and human-induced disasters. A culture of preparedness and awareness to minimise the impact of drought on a daily basis is seen as a pivotal component of this strategy (National Department of Agriculture 2003). Reducing risk and managing drought is achieved through, among other strategic objectives, the setting up of a comprehensive drought plan in a system of information management, monitoring and evaluation that can assist in determining social and biophysical vulnerability to drought. In this regard the National Drought Strategy recognises the linkages between natural hazards and vulnerability. Vulnerability in turn arises from issues such as poverty and inequitable development (National Department of Agriculture 2003: 18).

A comprehensive approach to drought management is needed to counteract the major setbacks of drought impacts namely the direct loss of existing national assets and the diversion of national resources and effort from ongoing subsistence and development in an effort to achieve adequate recovery from drought. In developing a comprehensive approach there needs to be a balance between prevention, mitigation, preparedness, response, recovery and disaster-related development (National Department of Agriculture 2003: 18).

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