Description of drought management actions [Part 1. Components of drought planning. 1.3. Methodological component]

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Chapter 13. Description of drought management actions

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SUMMARY – This chapter presents a compendium of drought management actions related to agriculture and water supply systems together with a common conceptual framework based on the use of drought indicators for evaluating the levels of drought risk (pre-alarm, alarm, and emergency), that allow establishing linkages between science and policy. The rationale is that the actions relevant to all sectors are derived based in common institutional organization, legal framework, and are implemented by a unique decision making structure (defined in the organizational component of the Guidelines).

Key words: Long term actions, short term actions, demand, impact, supply.

General drought management components and impediments

Some countries have emergency drought provisions within their water-rights system, and others do not appear to have plans in place for managing water resources during droughts. In those countries where comprehensive water-management plans are established, they generally incorporate all of the basic concepts for effective drought management while some countries modify the rules for allocating water.

Droughts can be one of the major causes for reduced freshwater flows, and methods should be established to control or to minimize the causes of reduced freshwater flows.

Governmental role has generally been to provide financial assistance to citizens after the droughts have occurred, but, as water demands continue to grow, even minor droughts will become more serious, and countries will be compelled to develop water-management plans.

There are some general drought management components that should be taken into account independently from the affected system and as previous steps to defining drought-risk levels and the measures associated to each of these levels:

(i) Define the available resources: Water may be available from several sources to meet demands in time of drought.

(ii) Define the demand: The quantity, quality, and location requirements of all users must be defined.

(iii) Describe possible shortfalls in supply: Managing the resources to best accommodate the shortfall in meeting demand under a given drought event calls for sound preparation.

(iv) Describe the management measures for potential events: Define the adopted measures necessary in response to projected shortfalls for various drought events.

(v) User and public involvement: It has been repeatedly proven that the success of drought management depends most on the understanding and support of the users and the public.

(vi) Securing legislation agreements, rules, and procedures: Any water management under conditions of shortage usually calls for new authority, rules, and procedures; for example, new legislation and specific legal agreements.

(vii) Drought management plan: Any drought requires a specific set of management actions tailored to the specific event and a mechanism to forecast event dates (Frederiksen, 1992).

Just as many other phenomena there are some important impediments for planning for drought, varying from the perception of people, to political considerations or the lack of information to design an adequate drought management plan. The most common impediments are listed below:

(i) Repeating phenomena. People perceive drought as part of the normal climate (and it is). But also the randomness of drought induces the public to think that there is nothing to be done about it.

(ii) The tragedy of the commons. Droughts are a community problem having characteristics of Hardin's famous "Tragedy of the Commons" (Yevjevich *et al.* 1978). The self-interest of each individual using communal property is to maximize it for immediate gain. The net result can well be the destruction or deterioration of the communal property. In Hardin's example, the overgrazing and destruction of the common pastures occurred because each person sought to graze all the animals possible. The sum of the actions by each individual was not "best" for the sum of the individuals. This phenomenon makes the best policy infeasible unless the individuals reach a consensus themselves or are compelled to do so by a government.

(iii) Lack of information about the cost of droughts. The 1930's drought in USA had an effect on a whole generation of Americans, wherever they lived and however they made their living (Harrison, 1977). Even if the value of human life is ignored, the total economic losses from droughts can be staggering.

(iv) Political considerations. Water management of necessity, must be at the core of any program to mediate the effects of water shortages that occur during droughts, but political factors can substantially dampen the interest in managing water resources even during droughts.

Classification of drought management actions

For the selection of the most appropriate measures in each level of drought-risk, actions are classified in the following Table 1 attending to a number of criteria:

(i) Timeframe of action (long – short term measures). Depending on the timeframe of application or effect, there are long-term measures, taken before the initiation of a drought event aim to reduce the vulnerability to drought or improve drought preparedness. They are oriented to increase the reliability of water supply systems to meet future demands under drought conditions through a set of appropriate structural and institutional measures. The short-term measures try to mitigate the impacts of the particular drought event within the existing framework of infrastructures and management policies, on the basis of a plan developed in advance and adapted to the ongoing drought, if necessary.

(ii) Action strategy (demand, impact or supply management). Depending on the strategy selected actions can be oriented to act upon water demand, trying to decrease it before, during or after drought periods; upon water supply, increasing the availability of water to be used; or upon impacts, trying to minimize them.

(iii) Affected system. Actions can be oriented to different systems: Hydrological, supply, agricultural or institutional systems.

Table 1. Drought management actions

Strategy	System	Action
LONG TERM ACTIONS		
Demand management	Systems maintenance and management	Adopting demand delivery scheduling in pressurised systems
	Water saving practices and management	Water pricing Legislation and regulations Information and education Water recycling
	Water savings in agriculture	Crop resistance to water stress and water use efficiency Crop management Soil management Improving surface irrigation measures Improving sprinkler irrigation systems Microirrigation systems Irrigation scheduling Adopting water prices that induce farmers to irrigate by night Adopting water prices that induce farmers to save water Users and farmers information Involving farmers in decisions to change delivery schedules dictated by limited supply
Impact management	Contingency planning Emergency actions for drought impacts mitigation	Early warning systems development Insurance development
Supply management	Artificial recharge of all water bodies	Terracing Small dams (farm ponds) Runoff enhancement Runoff collection Water holes and ponds
	Emergency supply for drought mitigation	Develop conjunctive use Reinforcing the use of non-conventional waters Hydrological forecasting and drought watch systems
	Groundwater use and recharge	Groundwater recharge
	Improving reservoir operation	Upgrading monitoring of reservoirs Application of optimisation, risk, and decision models
	Reservoir management	Need for reservoirs Single large reservoir management
	Water conservation, systems maintenance and management	Improving conveyance and distribution systems Monitoring and metering the water supply and distribution system The use of information systems and modern technologies Maintenance of urban water supply systems Dual distribution networks for high quality and for treated reusable water Improved regulation and control

		Improved regulation and control Automation and remote control in canal management Adopting low-pressure pipe distributors Changing from supply oriented to demand oriented delivery schedules Intermediate storage Information systems Application of optimisation tools for water allocation and to schedule deliveries Effective systems maintenance Water metering Monitoring The assessment of the system performances Training of personnel in operation, maintenance and management Water conservation measures for drought preparedness
LONG/SHORT TERM ACTIONS		
Supply management	Use of non-conventional resources	Water transfers
SHORT TERM ACTIONS		
Demand management	Water saving practices and management	Incentives and penalties Campaign for imediate water saving Water use restrictions
Impact management	Compensations for income loss Public aid for crop insurance Tax reduction, payment redemptions Temporary reallocation of water	
Supply management	Alternative storage of water Control of water losses and non beneficial uses of water	Tanks Leak detection and repair Location of losses
	Emergency supply for drought mitigation	Transfer of water rights Use of low quality water and reuse of wastewater
	Groundwater use and recharge	Groundwater use/overexploitation
	Use of non-conventional resources	Water harvesting Reduction of waste of water Flood spreading Rainwater collection
	Water conservation, systems maintenance and management	Relaxing ecological or recreational use constraints
	Water harvesting	Reduction of evaporation Changing reservoir water release equipment Canal lining

The following descriptions of measures have been summarised from a document devoted to the compilation of water scarcity management measures elaborated by Pereira, Cordery and Iacovides for UNESCO in 2002.

Long Term – Demand management measures

Systems management

Adopting demand delivery scheduling in pressurised systems

This is generally the most appropriate for the required flexibility to the farm use of sprinkler and micro-irrigation systems. As analysed above these systems may be managed for a variety of irrigation depths and frequency, thus for adopting water savings at farm too. When water supply is limited and restrictions to the demand have to be enforced the respective decisions should better involve the farmers.

Water saving practices and management

Water pricing

Historically, in most countries, water costs have largely been or still are subsidised. In others, water is supplied free. It is of importance to establish rate policies that emphasise greater user involvement in water conservation and saving. When users are charged appropriately for water services, the water use as well as the water waste tends to decrease. Water pricing can help to save water if the price structure meets some essential conditions:

(i) prices must reflect the actual costs of supply and delivery to the customers to ensure the sustainability of the water supply services and the maintenance of conduits and equipment;

(ii) the price rate should increase when the water use also increases to induce customers to adopt water saving and conservation;

(iii) different price rates should be practiced for diverse types of water use in municipal supply, e.g. differentiating domestic indoor uses from gardening water uses; when water is more scarce than usual, prices for less essential uses could be modified earlier;

(iv) differential increases in price must be large enough to encourage water savings;

(v) prices must reflect the quality of service, i.e. poor and non reliable service cannot be provided at high cost but costs must change as soon as service is improved; and

(vi) any change in pricing must be accompanied by information and education programs that support an increased awareness of the customers of the value of water and water supply services.

Water benefits are different for each type of user. In urban areas there are several types of water use: domestic, public, industrial, commercial, services, construction, and recreational. Each of these categories reacts differently to the same financial spur in charging for the service, so it is important for the rate structure to be properly designed (Arreguín, 1994). This involves knowledge on trends in costs and the respective price structure, on trends in the water market including its seasonal variations, and information on users' categories and their ability to pay. Other variables that affect decisions are the policies on subsidies and on fines and penalties for water misuse and abuse.

Legislation and regulations

Water laws give each country its general framework for water use and conservation, and are complemented by regulations, which establish the practical application of the legal water policies.

Regulations to improve water savings are often of a restrictive nature. In most cases, they are established for long-term application, but they may be applicable only during periods of limited water availability such as droughts. In that case they generally require very strict surveillance and should only be applied when they are really necessary.

Long term regulations concern questions such as the characteristics and standards for indoor plumbing fixtures, or maximum volumes per flush in toilets (e.g. 6 l/flush), or maximum discharge in showers (e.g. 10 l/min.). Regulations also include requirements to replace old type toilets, compulsory use of equipment for filtering, treating and recycling the water in swimming pools, etc. Temporary regulations may concern the prohibition of use of hoses to wash motor vehicles or sidewalks.

Information and education

Water saving programs need the users participation to be successful. Furthermore, information and education campaigns are required. The same requirements exist for successful implementation of legislation and regulations or to achieve water saving objectives in relation to the adoption of water metering and water pricing.

Information to the users may include leaflets sent out with bills, publicity campaigns in the press, radio and television, billboards on streets and public transport vehicles. Special campaigns for water saving may also include the free distribution of water-saving devices, assistance with the cost of investments required to renovate or upgrade household water systems, or allow tax deductions for specific water saving investments.

Education mainly concerns the introduction in primary and secondary school curricula of the essential aspects of the hydrological cycle and water sources. It should also cover limitations in water use, causes and other considerations related to water scarcity, the costs to mobilise and supply water, the main water uses and benefits, and, finally, how to properly use both water indoors and outdoors.

Water recycling

Recycled water (re-use water) results after the biological and physical treatment of the collected domestic wastewater. This water may be used for the irrigation of many crops and for the flashing of toilets. The treated recycled water can take two forms, the re-use water from biologically and physically treated wastewater that occurs in sewage treatment plants, which may include black and grey water effluents, and the re-cycled grey water (which includes only grey water from the wastewater, after a physical process that takes place in a small local grey-water treatment plant.

Water savings in agriculture

The role of farmers in reducing the demand of farm irrigation systems is limited both by the farm system constraints and by their capabilities to be in control of the discharge rate, duration and frequency of irrigation. These limitations are probably more important relative to deficit irrigation because farmers require some flexibility in the deliveries to decide the optimal irrigation timings and depths, as well as that deliveries be reliable, dependable along the irrigation season and equitable among upstream and tail end users. Therefore, the adoption of reduced demand strategies largely requires improved quality of supply management.

Crop resistance to water stress and water use efficiency

In dryland agriculture, crops and crop varieties are selected taking into consideration their tolerance to the water stress conditions that characterise the environments where they are cultivated. In general, these crops correspond to centuries of domestication of plants native to these environments, but new varieties have been introduced in the last decades following scientific plant breeding and improvement programmes. The most common food crops are wheat, barley and millet among cereals, and beans, cowpea and chickpea as legumes (pulses), as well as mustard and sunflower.

Crop management

Water conservation in dryland agriculture mainly refers to crop management techniques and to soil management practices. They relate to three main approaches: (i) Techniques to manage crop risk, which concern crop management; (ii) techniques designed to minimise the risks of crop failure; and (iii) techniques to increase the chances for beneficial crop yield using the available rainfall. They refer to:

(i) The selection of crop patterns taking into consideration the seasonal rainfall availability and the water productivity of the crops and crop varieties. Here the aim is to lower the water stress effects on crop development and, therefore, to reduce impacts on yields, including under drought conditions. This approach provides high effectiveness in coping with water scarcity.

(ii) The adoption of water stress resistant crop varieties instead of high productive but more sensitive ones particularly when there is the possibility of a drought.

(iii) The use of short cycle crops or crop varieties, thus having smaller crop water requirements than varieties or crops with longer growth seasons.

(iv) To adapt planting dates such as to plant after the onset of the rainy season to ensure more effective conditions for crop establishment.

(v) Early seeding to avoid terminal stress of the crop.

(vi) Early cutting of forage crops to avoid the degradation of the stressed crop.

(vii) Grazing drought damaged field crops to permit an alternative use of the biomass for livestock when the yield is lost due to drought damage.

(viii) To adopt supplemental irrigation of dryland crops at critical crop growth stages to avoid loosing the crop yield when a drought occurs. This can be a highly effective technique when water may not be enough to adequately irrigate a dry season crop.

Soil management

Soil management practices for water conservation refer to tillage and land-forming practices that favour rainfall infiltration into the soil, water storage in the soil zone explored by roots, capture of runoff to infiltrate the soil, control of evaporation losses from the soil and weeds, extraction of water by plant roots, and crop emergence and development.

These practices have long been known to have positive impacts on water conservation in dryland farming. However, results of any soil management technology depend upon the soil physical and chemical characteristics, the land-forms and geomorphology, the climate and the kind of implements used. All these factors interact, creating variable responses in terms of crop yields. When a technique is to be introduced in a given environment and it is substantially different from the traditional and well-proved practices adopted by local farmers, it is advisable to perform appropriate testing before it is widely adopted. However, the principles of soil management for water conservation are of general application, regardless of the size of the farm, the traction used, or the farming conditions.

Improving surface irrigation systems

Several surface irrigation methods are used in practice. The main ones are:

(i) Basin irrigation, which is the most commonly used irrigation system world-wide. Basin irrigation consists of applying water to levelled fields bounded by dikes, called basins.

(ii) Furrow irrigation: Water is applied to small and regular channels, called furrows, which serve firstly to direct the water across the field and secondly act as the surface through which infiltration occurs. There is a small discharge in each furrow to favour water infiltration while the water advances down the field. Furrow irrigation is primarily used for row crops.

(iii) Border irrigation: water is applied to short or long strips of land, diked on both sides and open at the downstream end. Water is applied at the upstream end and moves as a sheet down the border. Border irrigation is used primarily for close growing crops such as small grains, pastures, and fodder crops, and for orchards and vineyards. The method is best adapted to areas with low slopes, moderate soil infiltration rates, and large water supply rates.

Improving sprinkler irrigation systems

Main sprinkler systems are:

(i) Set systems: The sprinklers irrigate in a fixed position and can apply small to large water depths. Set systems include solid set or permanent systems as well as periodic-move systems, which are moved between irrigations, such as hand-move, wheel line laterals and hose-fed sprinklers. These systems are the least costly and the best adapted for small farms. A wide range of sprinklers can be selected for a variety of crops and soils as well as for environmental conditions.

(ii) Travelling guns: a high pressure sprinkler continuously travels when irrigating a rectangular field. The high application rates and the characteristics of the moving system make travelling guns unsuitable for applying very small or large depths, or to irrigate heavy soils and sensitive crops. In addition, these systems have a high energy requirement and may have low performances and high evaporation losses when operating under hot, arid and windy conditions.

(iii) Continuous move laterals: the sprinklers operate while the lateral is moving in either a circular or a straight path. Large laterals are used, equipped with sprinklers or sprayers.

Microirrigation systems

Microirrigation, also called trickle or drip irrigation, applies water to individual plants or small groups of plants. Application rates are usually low to avoid water ponding and minimise the size of distribution tubing. The microirrigation systems in common use today can be classified in two general categories:

(i) Drip irrigation, where water is slowly applied through small emitter openings from plastic tubing. Drip tubing and emitters may be laid on the soil surface, buried, or suspended from trellises.

(ii) Microspray irrigation, also known as micro-sprinkling, where water is sprayed over the soil surface. Microspray systems are mainly used for widely spaced plants such as fruit trees but in many places of the world they are used for closed space crops in small plots.

Irrigation scheduling

Research has provided a large variety of tools to support improved irrigation scheduling, i.e. the timeliness of irrigation and the adequateness of volumes applied.

Irrigation scheduling techniques may be used with diverse objectives in the practice of farmers. More commonly, farmers seek to avoid any crop stress and maximise crop yields.

When water is plenty, farmers tend to over-irrigate, both anticipating the timing of a need for irrigation and applying excessive water depths. Thus, the application of appropriate irrigation scheduling techniques permits them to optimise the timeliness and the volumes applied, thus controlling return flows, deep percolation, transport of fertilisers and agro-chemicals out of the root zone, and avoiding waterlogging in the parts of the field receiving excess water.

Adopting water prices that induce farmers to irrigate by night

Adopting water prices that induce farmers to irrigate by night is a policy particularly appropriate for pressurised systems but that can also be used for open canal systems when some kind of metering is adopted. It consists in differentiating the day-time and night-time water prices to induce night irrigation, which gives larger flexibility to the system operation, improves the service performance and reduces operational losses due to excess water flowing in the systems at night, when the demand is lower.

Adopting water prices that induce farmers to save water

Adopting water prices that induce farmers to save water may be an appropriate policy for pressurised systems where metering is available. It can also be used for open canal systems but its application is then quite difficult. It consists in water prices that vary in accordance with the water use, which increase after a given volume is diverted to the farm. The price structure ideally varies with the type of crop following policies on cropping patterns, and with the available supply, both affecting the minimum volume and the rate for increasing the prices. Water metering is essential for a fair application of this policy. Systems where water costs are associated with the land surface cropped may adopt alternative pricing policies differentiated by crop and water volume but its enforcement requires appropriate field surveys to check the areas declared by the farmers.

Users and farmers information

Users and farmers information is of paramount importance to increase the awareness of the value of the water and the importance of water savings. Information is required to involve farmers and other users in water saving and conservation programmes.

Involving farmers in decisions

Involving farmers in decisions to change delivery schedules dictated by limited supply. During periods of limited water supply the delivery schedules have to be modified in order to satisfy the priority uses and to enforce restrictions for other uses. When farmers are involved in the decision process that leads to modify the delivery schedules, or to fix the respective water quotas, the farmers may negotiate these emergency measures in order to adopt the best practices that accommodate with water constraints to be enforced. This involvement may be difficult in systems serving a large number of small farms but the involvement of farmers in this decision is important for the effective adoption of emergency water saving programmes.

Long Term – Impact management measures

Contingency planning

Early warning systems development

An early warning of drought is recognized as a key factor for a successful drought management effort. The effective response to drought events relies on monitoring system able to provide adequate information for an objective drought declaration and for avoiding severe water shortages through an effective water resources management under drought conditions.

Emergency actions for drought management mitigation

Insurance development

In all cases the operational risk management cannot guarantee full prevention of drought damage, and a risk level has to be adopted in the drought management plan. For example, in Spain, the drought insurance system (ENESA) has an operational drought insurance plan that establishes a risk level defined by the probability of suffering a reduction in crop yield below a pre-established threshold (acceptable risk). This threshold is defined for each crop and geographic areas and it is re-evaluated each season. Risk or insurance premium can be estimated by using statistical and risk evaluation models.

Long Term – Supply management measures

Artificial recharge of all water bodies

Terracing

Terracing can be used to collect water for two purposes. Firstly a horizontal surface reduces runoff and maximises the infiltration of water into the soil. If the soil surface is kept tilled and free of vegetation except for the desirable crop, almost all rain falling on the terrace will be used for crop growth. In regions of low rainfall, soil water can be stored over long periods provided the soil surface is kept tilled or mulched and vegetation free.

Small dams

In regions of high evaporation, small and shallow dams are usually a cause of high evaporation losses. However in groundwater recharge areas, small dams, or even low embankments across floodways, can be used to increase aquifer recharge. On grasslands used for grazing the encouragement of infiltration by low embankments which reduce flow velocities and hold water for a few hours after rain events can increase soil water and greatly increase the time after rain that water is available to vegetation roots. By this means it may be possible to double annual biomass production in semi arid regions.

Runoff enhancement

In places of water scarcity where the availability of water needs to be increased it is possible to enhance runoff from rainfall events by partially sealing the soil surface. This can be done by applying surface sealing materials or by compacting the soil surface.

Runoff collection

In undulating to flat terrain where runoff collects into large numbers of very small stream channels, the available water resource may be quite large, but its diversity makes it difficult to use. Under these circumstances it is often possible to capture part or all of the flow in a small channel and divert it to another channel. Diversion channels which run almost parallel to the contours can be used to carry this diverted flow to a different location.

Water holes and ponds

Natural water holes and ponds can be exploited for water supply purposes. There is a need to ascertain the source of the water. If the supply is from groundwater it may be possible to treat the pond as a well and increase the extractable water by making the pond deeper and increasing the hydraulic gradient towards the pond. If the water is supplied by surface flows in a stream bed there are several possible ways to increase the water availability.

Emergency supply for drought mitigation

Conjunctive use of surface and ground water

Develop conjunctive use of the surface waters that are mobilised through the existing water systems and the waters from emergency sources such as groundwater mining and non-conventional waters mentioned above. Adopting a conjunctive use approach provides for rational and sound water resources allocation.

Sound water resources development and management seeks to maximize the water resources availability at the least cost. This is even more important in arid and semi-arid climates and where droughts are quite frequent. In those regions and in areas with great fluctuation of demand, conjunctive use of surface and groundwater storage is often relied upon to offset deficits in the dry season and accommodate storage and recharge of excess water in the wet season. This is also the case for small to medium size islands, where the economic dimensions of dams is usually small, whilst the water supply demand in tourist areas increases disproportionately due to the seasonal character of tourism.

Use of non-conventional resources

Reinforcing the use of non-conventional waters such as rainfall harvesting for domestic uses –drinking water cisterns– and fog collection. These issues apply to areas where water collection systems are already available and in use since during drought they may not mobilise the required water quantities.

Whenever good quality water is scarce, water of inferior quality will have to be considered for use in agriculture, irrigation of lawns and gardens, washing of pavements, and other uses not requiring high quality water. Inferior quality water is also designated as non-conventional water or marginal quality water. Non-conventional water can be defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose (Pescod, 1992). Thus, the use of non-conventional water requires adoption of more complex management practices and more stringent monitoring procedures than when good quality water is used.

Non-conventional waters most commonly include saline water, brackish water, agricultural drainage water, water containing toxic elements and sediments, as well as treated or untreated wastewater effluents. All these are waters of inferior or marginal quality. Also included under the designation of non-conventional waters are the desalinated water and water obtained by fog capturing, weather modification, and rainwater harvesting.

Hydrological forecasting and drought watch systems

Hydrological forecasting and drought watch systems that allow for real time, or near real time prediction of reservoir inflows, evaporation and seepage, thus to better estimate the time evolution of storage that dictate the operation rules. These management tools may also be useful to estimate how the demand will evolve when appropriate feedback is developed with canal managers in case of irrigation uses. Then, the support by information systems is particularly useful.

Groundwater use and recharge

Under conditions of water scarcity diverse water sources need to be developed, such as surface and groundwater, including the development of deep groundwater, reuse of wastewater, desalination, and use of other non-conventional water sources. Intensive attention needs to be directed towards water management, including demand management.

Groundwater plays an important role in alleviating water scarcity problems due to its inherent physical and storage characteristics. Aquifers have some specific characteristics that distinguish them from other water sources and make them quite unique in their usefulness. As such, the aquifers can be extremely beneficial in supplementing other sources from which there may be diminished yield due to drought and dry spells and can constitute useful strategic reserves for coping with water scarcity. However, for groundwater to play such a key role under conditions of water scarcity an increased understanding of the aquifer system is required and its operation and management would demand greater attention than under normal circumstances taking into consideration that will never be enough abundant.

Groundwater may be found in areas where surface water is absent or difficult to transfer. In the case of temporal or seasonal scarcity of water, an aquifer can be operated as a seasonal water storage reservoir tapped during the dry season and recovered during the rainy season. Groundwater can be used as a supplementary source for blending with water from other non-conventional sources, and in conjunctive operation with other sources. Aquifers can be used for the storage and additional treatment of recycled water. Sediments in surface water are removed when water enters an aquifer and the quality of the water is improved. Aquifers often have a much larger storage capacity compared to surface reservoirs. In aquifers, the transport of water from the areas of recharge to the areas of extraction is natural and may involve very large distances. Groundwater reacts slowly to seasonal and medium term climate variations, acting as a buffer for such variations.

The main requirements for effective groundwater use under conditions of water scarcity include:

(i) Full assessment of the resource.

(ii) Development of proper operational and water allocation plans.

(iii) Awareness and consideration concerning groundwater quantity and quality protection, and enforcement of the necessary legal and institutional measures.

(iv) Application of integrated water resources management towards securing the sustainability of the source.

In arid and semi-arid regions, where water scarcity is endemic, groundwater plays an immense role in meeting domestic and irrigation demands. In these regions massive use of groundwater has been practiced for some time now for large cities and long-established irrigated agricultural developments.

Groundwater recharge

Where groundwater is an important source of water there can be considerable advantages in encouraging recharge of the aquifer. Care is needed to protect aquifer recharge areas from land use changes that can decrease the recharge. It is well established that increase in quality of vegetation, by reforestation, improvement of grazing vegetation or in some cases by introduction of cropping, generally increases infiltration, but also increases transpiration and therefore reduces recharge and runoff. Therefore care is needed to allow for the effects of such surface changes on the groundwater availability or to ensure that the vegetation characteristics of the recharge area are not changed. Change from native vegetation to cropping may lead to increased recharge because cropping involves leaving the soil fallow for part of the year. However the actual effects in any location will depend on the vegetation and crop types and rotations, the soils and the climate of the region.

Surface reservoirs can be used advantageously to increase recharge by holding water over a recharge area for some time, or by diverting water to spread it widely over a recharge area. However care is needed to ensure this does not encourage increased evaporation and a large net loss of water from the system. Precipitation is the source of all fresh water and in most situations the surface and groundwater resources are interdependent. Encouragement of recharge may mean a reduction in available surface water further downstream. Conversely impounding surface water may diminish recharge direct from the stream-bed downstream of the reservoir and hence may reduce the groundwater resource.

Under scarcity conditions, withdrawals during the dry season often by far exceed the safe yield of aquifers, resulting in the depletion of the reserves and occasionally, allowing water of inferior quality to intrude into the aquifers. As already analyzed, flash floods during the rainy season may not have sufficient opportunity to infiltrate the aquifers with the result that much needed water may not be utilized.

Among a number of management interventions that could help improve the situation is that of artificial groundwater recharge. This aims to increase the groundwater potential by artificially inducing increased quantities of surface water to infiltrate the ground and be later available at times of need. It could also help control or even reverse the sea-intrusion propagation in an aquifer caused by long-term or seasonal excessive pumping. This can be accomplished by creating positive groundwater levels through artificial groundwater recharge at selected strategic points in the aquifer. Furthermore, it could be used to improve the quality of pre-treated sewage water, and store it for subsequent development and reuse.

In areas where there is seasonal variation of stream flow availability, water can be conserved through artificial groundwater recharge in the wet season for use during the dry season. Furthermore, control and recharge of water in wet years may help reduce the impact of droughts and to some degree alleviate man induced water shortage problems.

The artificial groundwater recharge schemes may be classified under two broad groups:

(i) The indirect methods through which increased recharge is achieved by locating means of groundwater abstraction as close as possible to areas where surface water is in contact with the aquifer or areas of natural water discharge. In such cases, the natural hydraulic gradient is affected so as to cause increased recharge.

(ii) The direct methods through which surface water is conveyed from lakes, reservoirs, waste water treatment plants or is being diverted from flowing streams to suitable areas of aquifers where it is made to infiltrate to the groundwater from basins, trenches, dry riverbeds, injection wells, pits, etc.

Indirect or induced artificial groundwater recharge consists of abstracting groundwater within a short distance from a flowing stream, lake or impoundment. The pumping lowers the piezometric surface to cause a steeper hydraulic gradient, thus inducing increased recharge. The same artificially developed conditions tend to reduce the outflow of local groundwater into streams and surface water storage. The groundwater abstraction facilities could consist of well fields, a gallery or a line of wells. Depending on the hydrogeologic parameters of the local aquifer, considerable amounts of surface water could be induced to infiltrate into the aquifer. Higher permeability favors larger quantities to be recovered through pumping wells.

Artificial recharge by spreading: Artificial recharge by spreading is usually carried out when the aquifer extends close to the ground surface. Recharge is accomplished by spreading water over the ground surface or by conveying the raw water to basins and ditches. Use of spreading grounds is the most common method for artificial recharge.

Artificial recharge by well injection: When the aquifer is located at some moderate depth below the ground surface, recharge may be accomplished by introducing water through pits and shafts and, in the case of the presence of overburden of a large thickness, water can be injected through wells or boreholes which reach the aquifer. This technique is also preferred where land is scarce, when environmental reasons oppose the use of large spreading grounds, when the local hydrogeologic conditions do not favor spreading, or wells and pits are already available for use for recharge. In areas where the pervious formations are at shallow depth, recharge can be accomplished by digging pits or shafts. Abandoned gravel pits could also serve as recharge sites. Injection wells are quite versatile in that they can be used on any type of aquifer.

Recharge with surface and subsurface dams. Other types of artificial recharge schemes refer to floodwater retention dams, especially on broad wadi floodplains. The purpose of these is to delay the flow of the water and provide the opportunity for recharge into the local aquifer. The structures consist usually of low dams, including earth walls and gabions built to be toppled by floods.

Improving reservoirs operation

Improving reservoirs operation for controlling water losses, mainly operational losses, and better allocate the available water. In few cases, measures may include changes in equipment that control releases but most of improvements concern management.

Upgrading monitoring of reservoir

Upgrading monitoring of reservoir inflows and releases to better support the adoption of information tools mentioned above.

Application of optimisation, risk, and decision models

Application of optimisation, risk, and decision models to reservoir operation, to define optimised system management rules and to decide the allocation of water resources among the different users – municipal, irrigation, industrial, recreational, energy and nature. A large panoply of such tools has been made available by research, many are in use, but their adoption under water extreme water scarcity still is low due to the difficulty in gathering the information required to optimise decisions.

Reservoir management

Need for reservoirs

Most water supply schemes need to incorporate reservoirs. These may be surface storages or sub-surface aquifers. The function of the storages is to smooth out the natural variability of the hydrological system to allow human activity to be supported by a constant, or a regular, seasonally varying supply. Where water is scarce it is most unlikely it will be possible to take water on demand from the natural system. In times of high flow (either surface or subsurface) it is often possible to extract whatever water is required. However in drier times the natural flow is likely to be significantly lower than the expected extraction rate. Hence surface or subsurface reservoirs serve as temporary storages, capturing high flows whose water can then be available for use during periods of low natural flow.

Operation of single and multiple reservoir systems

Here we should use the word reservoir in its broadest sense. That is we will include all water storages including surface reservoirs, natural lakes and groundwater aquifers. These reservoirs may be replenished naturally, or they may be pumped systems or even storages built up from desalting of brackish or sea water.

Without doubt the operation of several linked water sources, rather than a single reservoir system, offers the water manager many options and flexibilities with numerous opportunities to maximise the potential availability of water. This applies to all water resource situations, not just to regions where water is scarce. However the cost of this increased flexibility of management is a very large increase in the complexity of the operation of the system and a very much increased possibility of management of the system being sub-optimal. However there are very large advantages to be gained from multireservoir systems, particularly where the reservoirs within the system have different water sources. For example a system with a river-fed surface reservoir, whose storage level depends on recent precipitation and a groundwater system which varies only with long term variations in precipitation has many advantages. High rates of extraction can be obtained from the surface reservoir but only for limited periods, whereas the groundwater can provide a medium level of extraction for very long periods. Similar advantages can be obtained from inclusion of desalinated water, renovated waste water, or urban stormwater.

Surface water can often be supplied at low cost. Groundwater may involve larger costs for pumping. It may be efficient to design a system for surface water supply only, with highcost groundwater only to be used in emergencies, such as prolonged droughts, when the surface supply is exhausted.

Multiple reservoir systems also offer the advantages of redundancy. Provided there are multiple water delivery pathways the system will not be shut down by any single failure of a reservoir, a pipeline or a control valve, and therefore the security of supply can be very high.

Water conservation, systems maintenance and management

Systems maintenance and management are essential to cope with water scarcity. When these are adequate, they provide for controlling water wastes, seepage and water spills and provide for water saving. When maintenance and management are poor, not only system losses are high but the water service is poor, less reliable and non-dependable, tail end users receive the poorest service and incentives for the users to save water are lacking.

When water scarcity is due to drought, water conservation and saving requires policies and practices that are common with aridity. However, coping with drought requires a distinction between preparedness and reactive or mitigation measures, the first consisting in preparing for the application of the mitigation measures during drought.

Improving conveyance and distribution systems

Improving conveyance and distribution systems, which refers both to equipment and management software. An enormous amount of research has been recently devoted to these subjects and a very large number of papers and books refer to these matters, particularly for irrigation systems. Approaches that help coping with water scarcity are generally oriented to control seepage and operational losses, to provide for higher flexibility in water deliveries to irrigated farms, and to improve the levels of service by matching supply to demand, increasing the reliability of supplies and enhancing the dependability of deliveries along the operation season and the equity of the distribution in the areas served.

Monitoring and metering the water supply and distribution system

Metering is required at both the supply and distribution systems and at household connections. At the supply level, it concerns monitoring and measuring the water stored, being conveyed, and circulating in the distribution system. The resulting data produces information on the state of the system, and the respective variables. This information is vital for planning system developments and modernisation, for operation, maintenance and management of the systems in real time, and, in particular for planning and implementation of water conservation and water saving programmes. Metering at the household outlets is required for knowing the users consumption, for billing the customers in accordance with the respective water use, and for the support of measures to be enforced when water availability does not allow the supply to match the current demand.

Metering and monitoring the supply system has many advantages (Arreguín, 1994), provides for an updated knowledge on the actual volumes stored and the discharges flowing in the water conveyance systems and in the distribution sectors, as well as water pressure and water levels at key nodes of the networks.

The use of information systems and modern technologies

The use of information systems and modern technologies such as remote sensing, GIS, and models that provide for the state variables relative to the reserves in storage and to the uses and demand. Information systems are essential to appropriately explore reservoir decision tools mentioned below and to create information relative to users decisions in agreement to the water availability.

Maintenance of urban water supply systems

Maintenance may be preventive and reactive. It plays a major role in water conservation. The main purpose of preventive maintenance is to ensure the proper functioning of the water supply system, from the upstream water sources to the customers. Consequently, it includes the network reservoirs and conduits and respective equipment, the pumping stations, the water treatment plants, and the metering system. For the latter, meter readings need to fall within a well-defined range of accuracy. A study in Mexico reported by Arreguín (1994) has shown that 23.4% of the meters over-recorded water use, 71.4% under-metered and only 5.2% measured accurately.

Each utility and sector should have its own program of maintenance. Computer programs may be helpful in establishing and controlling maintenance programmes. Reactive maintenance needs to occur as required. Reactive maintenance takes place in response to information provided by the field personnel, meter readers and users about system failures, equipment disrepair, and inaccurate meter readings.

Dual distribution networks for high quality and for treated reusable water

Diverse water uses in urban areas require different water quality. High quality water is definitely required for uses such as drinking, food preparation, or bathing. However the largest fraction of this water is not consumed but returned as effluent with degraded quality and is not reusable for the same purposes. On the other hand, uses such as toilet flushing, heating, floor washing, or irrigation of lawns and gardens do not need such high quality water and could use treated wastewater.

Originating from these different requirements, in urban areas where extreme water scarcity exists, a feasible but expensive solution is to duplicate the distribution network, mainly in the neighbourhoods or sectors where water users can manage with inferior quality water for uses other than human consumption (Okun, 2000). At the limit, different sewage systems may be built, separating the less contaminated and less charged effluents from the more degraded ones. The two effluents may require different treatments and may attain different quality levels, and therefore may have different uses. Urban drainage rainwater may also be treated and added to the higher quality treated urban effluents.

Improved regulation and control

Improved regulation and control of canal and pipeline systems, including local or centralised automation, generally permits higher delivery flexibility and improved conditions at farm level to adopt water saving irrigation practices. Adopting appropriate regulation and control provides for reduced operation losses and for easy maintenance since water levels vary much less during operation. In general, reliability, adequacy and equity of deliveries are enhanced, while dependability depends upon the policies for reservoir management. Increasing the levels of service give better opportunity to farmers to adopt improved farm irrigation, and to include practices that lead to water conservation and saving, as well as to control environmental impacts, specially in saline environments. Appropriate regulation and control is probably the most important issue for irrigation and multipurpose water systems. However, regulation and control systems may be expensive and require technological capabilities to be fully explored despite local control automation may be easy to adopt and apply.

Automation and remote control

Automation and remote control in canal management is a step further in technological advancement in regulation and control. Remote control allows a better operation of the system particularly to take into consideration the users demand in real time. The appropriateness of these technologies to cope with water scarcity relate to improved water service, more easy application of irrigation scheduling and the farmers ability to improve the water use leading to higher water productivity and water saving. Because high technology is required and the demand has to be known in real time, these technologies adapt better to systems serving large and commercial farms.

Adopting low-pressure pipe distributors

Adopting low-pressure pipe distributors in surface irrigation systems instead of open channels and ditches is an effective solution to reduce spills and leaks, to achieve higher flexibility and service performance, and to easily adopt water metering. The investment costs may be compensated by lower operational costs when compared with open channel distributors. Benefits at farm level are once again related with the flexibility in the deliveries. This technology has no particular technological requirements.

Changing from supply oriented to demand oriented delivery schedules

Changing from supply oriented to demand oriented delivery schedules is the desirable orientation of system management when regulation and control are enough reliable. In fact, demand oriented delivery schedules assume that managers give priority to satisfy the demand rather than optimising the supply service. Thus, it makes possible that farmers apply improved irrigation schedules to save water and increase water productivity. It requires that regulation and control be modernised and some kind of communication between farmers and managers is adopted. This communication may be performed through direct contact between farmers and canal operation personnel, by phone or via computer.

Intermediate storage

Intermediate storage in canal reaches, small reservoirs linked with selected canal nodes, or farm ponds are often used to increase the flexibility of the system to respond to variations in demand, to reduce operation losses during periods of reduced water use such as the night-time and holidays, and to permit the use of farm irrigation systems having discharge and duration requirements different of those provided by the delivery schedule practiced. The latter is the case of farms adopting micro-irrigation or sprinkling where distribution systems adopt delivery schedules designed for surface irrigation.

Information systems

Information systems may play an important role when decision models are used for systems operation or to help farmers selecting the respective management to cope with water scarcity. Information systems are particularly useful to identify the state variables of the system, inclusive in real time, thus providing for better matching deliveries to demand. Information systems are even more useful in multipurpose systems to support decisions on allocation of water by user sectors, especially when the management of the reservoir and the conveyance and distribution system are linked.

Application of optimisation tools

Application of optimisation tools for water allocation and to schedule deliveries is a technique that complement those modelling and decision tools mentioned before.

Difficulties in application are due to insufficient economic information to adequately perform optimisation, and to the required feed-back information from the users.

However, when it is possible to be applied, it may support achieving higher reliability, adequacy and equity in deliveries and the enforcement of water saving.

Effective systems maintenance

Effective systems maintenance, which is required not only to avoid seepage, water spills and leaks but for adequate operation of the hydraulic structures, regulation and control, and good service to users. Maintenance needs trained personnel and equipment as well as planning. Particular attention should be paid to periods when water supply is limited, when all available water is insufficient to meet the demand.

Water metering

Water metering –flow depth and discharges in surface systems and pressure and discharges in pressurised systems– is required to support operation and, at outlets and hydrants, for billing the users. Data from metering also provides basic data on system variables useful for management. The adoption of information and decision support tools mentioned above is not possible without metering at critical nodes of the system and, for more advanced technological levels, without metering the water deliveries to users.

Monitoring

Monitoring system functioning and system performances is required to identify the critical reaches of the conduits and canals and service areas and to provide the follow-up of maintenance programmes, improvements in equipment, implementation of upgraded management tools, as well as the quality of service provided.

Monitoring allows to quantify system losses, priority areas for improvement and to evaluate upgrading programmes. Data produced are an essential input to information systems and decision support tools in addition to metering. As for metering, monitoring do not produce water savings but is essential for their effective implementation.

The assessment of the system performances

The assessment of the system performances –physical, environmental, economic and service performances– provides for the evaluation of the actual functioning of the systems complementing monitoring and metering. Actual indicators are useful for planning modernisation, rehabilitation and improving of the systems and are generally useful to base decisions required for implementing such programmes, consequently for planning for water saving and conservation.

Training of personnel in operation

Training of personnel in operation, maintenance and management is required to enhance the quality of service, for technological upgrading of the systems and to carry out water saving programmes. Training is also necessary to develop skills required to contact with the public and for the communication with users.

Water conservation measures for drought preparedness

These include: (i) development and effective implementation of drought watch systems as a main component of the meteorological and hydrological information systems; (ii) storage and regulation reservoirs to mitigate the effects of the diminishing availability of the resource during drought; (iii) controlling and planning for larger groundwater withdrawals aiming at augmenting the water availability during drought periods; (iv) improved conditions for operation, maintenance, and management of water supply systems, mainly for controlling operational losses, and providing for flexibility in operation, and high service performances; (v) establishment of water allocation policies to be enforced under drought, which take into consideration the social, economic and environmental uses of the limited water resource; (vi) planning for the augmentation of available water resources during drought, including waste-water re-use and the use of non conventional water resources; however, note that water must be in accessible storage before the drought begins because it is unlikely any water will become available for capture until the drought ends; (vii) development of water technologies and practices to be adopted by the end users that help in reducing the demand and controlling the water wastes under conditions of diminished water availability; (viii) development of institutional conditions for drought preparedness and management, including for timely application of drought mitigation measures; (ix) establishing water pricing and financial incentives and penalties aiming at reducing water consumption and use and avoiding water wastage and misuse, including the control of water quality degradation by effluents and return flows; (x) encourage households to save funds in good times, to buy water from delivery tankers during drought; institutions need to have a backup reservoir and extraction equipment to provide water for carting to villages and households where local supply is totally exhausted; (xi) augmenting the public awareness on the economic, social and environmental value of the water, particularly oriented to produce a favourable attitude in regard to the adoption of drought mitigation measures.

When a drought occurs, water conservation for drought mitigation should be implemented. Then, measures and practices include: (i) exploring the drought watch system to monitor the drought onset, development and termination, as well as to produce information for decision makers and water users; (ii) implementing changes in reservoir and ground-water management rules; (iii) enforcing drought oriented water allocation and delivery policies; and (iv) adoption of farm water storage and soil water conservation practices, which cannot help during drought but must be in place before the drought starts.

Water conservation is particularly important in the preparedness for droughts but it must be complemented with water-saving programmes, which are essentially reactive. Water saving for drought mitigation concerns measures and practices common to those for coping with, such as items (i), (ii), (iii), and (v) enumerated above, and others that might be specific for drought conditions such as: (i) adoption of drought tolerant crops and drought oriented cropping patterns, (ii) reduction of the irrigated areas and/or adoption of deficit irrigation practices, (iii) extended use of inferior quality water for irrigation, (iv) adoption of water saving tools and practices for reducing domestic, urban, and recreational water uses, including the use of inferior quality water for irrigation of golf courses and gardens, (v) ceasing supply by pipe and implementing tanker delivery (this is a drastic move but in a desperate situation it greatly reduces water consumption); (vi) enforcing specific water price policies in relation to the used water volumes, the type of uses, and the efficiency of use, (vii) adopting incentives for reducing water demand and consumption and penalties for excessive water uses, for non authorised uses, as well as for degrading the available waters with low quality effluents and return flows, and (viii) developing campaigns for end-users to adopt drought oriented water saving tools and practices.

Long/Short Term – Supply management measures

Use of non-conventional resources

Water transfers

Water transfers are used as temporal measures during an extreme drought to satisfy water deficit. Scales can vary from local transfers among different supply systems, to regional among two different river basins or even international among distanced basins. They can also be planned as a temporal solution to a drought situation or as a permanent solution for basins or regions suffering from structural water scarcity.

Short Term – Demand management measures

Water saving practices and management

Incentives and penalties

Incentives and penalties of a financial nature are required as a complement of the water saving campaigns, and as the prime measure to enforce regulations.

Incentives are often required for urban water supply companies, municipal or private, mainly in less developed areas, to implement high cost water conservation technologies, which may require an expensive investment. Examples could be the full coverage of every customer with metering, the modernisation of the network in an area of low class population where reliability and equity are low, or the investments required to install separate supply and sewage systems.

Incentives to urban customers are required when the implementation of water savings implies investments in homes and buildings, in particular for low-income populations.

Campaign for immediate water saving

The main strategy is to save an amount of domestic water per year. This objective can be met by: (i) promoting demand for water-saving technology among consumers; (ii) stimulating water-saving technology markets; and (iii) training and informing professionals in this sector. Specific actions can be directed to: (i) professionals linked to domestic water use (i.e. manufacturers, distributors, retailers, plumbers); (ii) large-scale domestic users (i.e. hotels, restaurants, gymnasiums, etc.); (iii) young people; and (iv) the general public.

Water use restrictions

When drought affects supply systems with certain intensity, it might be useful to establish water use restrictions for the different uses. For this purpose it is essential to determine in the first place an order of priorities of use so that this rationale can be followed when defining the uses that have to be restricted first.

Short Term – Impact management measures

Compensations for income loss

This particular action can take several forms depending on national legislation or institutional organization, but the general idea is the provision of aid from the government to the user (money, special loans, free supplies) to compensate for the losses generated by drought.

Tax reduction, payment redemptions

As a result of drought and its associated effects, users might find themselves in the position of not being able to face fixed costs such as taxes, loans or social security payments.

Temporary reallocation of water

Water uses with a low level of priority might be restricted during drought periods in order to satisfy those with a higher level of priority. This is a temporal action during drought periods.

Short Term – Supply management measures

Alternative storage of water

Tanks

A tank means a constructed water container. It is usually fabricated from sheet steel, cement concrete or plastic. Such containers are expensive, relative to the volume of water they store, but they have an important set of advantages over larger, landscape-type storages. They are of particular importance where the resource is very limited and needs to be protected from evaporation and/or contamination. Constructed containers also offer easy prevention of contamination since access to the stored water can be controlled. This includes prevention of access by mosquitoes and other water sourced disease vectors.

Control of water losses and non beneficial uses of water

In regions of water scarcity there should be strong motivation to prevent waste of the precious resource. There are many ways in which water is wasted. Some of these are relatively easy to prevent. In particular losses that occur once water comes within the sphere of man's control should be preventable. Other losses, such as evaporation and removal of flowing water by infiltration into stream beds are, in general, very difficult to prevent.

Leak detection and repair

System losses in urban drinking water supply systems are mainly due to evaporation and seepage in storage and regulation reservoirs, and leaks in water treatment plants, in distribution networks and in home outlets. The used volumes not metered due to inaccurate or non-existent metering, the unauthorised outlets and the unrecorded volumes used by municipal services, such as for watering public gardens or used from fire hydrants, are often accounted as losses, despite the fact that they constitute beneficial uses. Also often accounted as losses are the leaks in households. However, reported leaks in the network are low, much below what is detected by careful monitoring, particularly in old systems. Leaks in the network are generally higher in systems that breakdown very often.

Location of losses

When it is thought that significant volumes of water are being lost unaccountably from a system it is worthwhile making some effort to determine exactly where the losses are occurring. This requires some means of measurement of flows at a number of locations within the system.

Evaporation can be estimated by operating an evaporation pan adjacent to the storage, and making allowance for the higher loss from the pan than from the lake due to differences in energy transfer within the lake and through the sides and base of the pan.

Conveyance and distribution systems are often the source of large wastage of water, but some of it can be prevented.

Water use practices are a major source of wastage. Factory production processes and cooling systems which do not recycle can be very wasteful of water.

There are many opportunities to save water by changing irrigation practices. Similarly sprinkler irrigation can be very wasteful if used in windy daytime conditions in hot and dry climates.

Emergency supply for drought mitigation

Additional emergency supply for drought mitigation, which concern the exceptional use of waters during periods when the normal sources for the storage, conveyance and distribution are insufficient to meet the demand. These periods are limited in time such as the duration of a drought, but the operation of these additional sources has to be planned in advance to be effective and to prevent negative impacts on health and on the environment.

New sources of surface water, including the use of the dead storage in reservoirs and short distance water transfers from nearby systems and or sub-systems, generally associated with negotiations of water rights among farmers and non-agricultural users, including for nature, recreation, municipal and industrial uses. Since most of surface water sources in water scarce areas are already developed and water rights assigned, the use of additional waters requires appropriate planning and institutional framework.

Transfer of water rights

Transfer of water rights between users, where those having the right for a given fraction of stored volumes sell temporarily these rights to other users. This applies to societies where individual water rights are well recognised by law, thus being of difficult application in other societies.

Use of low quality water and use of waste water

Use of low quality water and reuse of wastewater for irrigation of agricultural crops, and landscape, including lawns and gulf courses, in addition or in alternative to water of good quality.

Groundwater use and recharge

Increased groundwater pumping

Changing from the exploration of the perennial yield to the mining yield. A continuous mining of the groundwater is not sustainable but a controlled use of the mining groundwater yield during periods of water scarcity is sustainable when appropriate planning, management and monitoring are adopted.

Use of non-conventional resources

Water harvesting

Water harvesting refers to methods used to collect water (i) from sources where the water is widely dispersed and quickly changes location or form and becomes unavailable, or (ii) that is occurring in quantities and at locations where it is unusable unless some intervention is practiced to gather the water to locations where it can provide benefits.

Reduction of waste of water

In regions of water scarcity, reduction of wastage of water should be part of the thinking and awareness of every individual. It needs to be taught in families to small children and in all formal education systems. In many societies the connection between simple traditional activities and waste of a precious resource is not realised. There is a need for continuous education programs to ensure everyone believes the loss of a single drop of water is a cause for sadness and concern.

Flood spreading

Flood flows are a feature of all landscapes, including regions of water scarcity. A very large part of the annual flows may occur in one or two floods, but the flow is often so large that the water passes through the region and can not be used where rain fell. Some advantage can be gained from these large flows by encouraging them to spread across flat areas. If water can be retained on flat surfaces for a day or two the upper soil layers may be saturated or water may percolate downwards to replenish the local aquifer. In both these circumstances the water thus "harvested" is available for later use, in the first case for growth of crops or to support grazing and in the second case for whatever purpose groundwater is used (Prinz, 1996; Missaoui, 1996).

Rainwater collection

Rainwater can provide a considerable water resource, not only in humid regions but also in semi arid and arid regions. Large volumes of water flow from roofs. In many regions roof water has not been collected because traditional roofing materials did not permit easy collection, and storage of collected water was difficult and expensive. However in recent years the ready availability of some form of roof sheeting and innovative ideas for water storage have made roof water a serious water resource consideration. There is a great need to encourage its use and to teach simple, low-cost means of collecting water from roofs, and constructing suitable storage facilities.

Water conservation, systems maintenance and management

Reduction of evaporation

There is no effective economic way to reduce evaporation from large water bodies. At the planning stage reservoir locations need to be chosen to minimise evaporation – by ensuring the volume to surface area ratio for the reservoir is a maximum.

Evaporation can be reduced from small, vertical sided reservoirs by providing a roof to shield the reservoir from solar radiation or by covering its surface by light coloured floating blocks.

The most effective means of evaporation reduction is to minimise the water surface exposed to the atmosphere and to the sun. Deep storages are to be preferred. Subsurface storage can be very effective for evaporation reduction. However with subsurface storage there will always be seepage losses and so these must be weighed against the gains from evaporation reduction.

Changes in reservoir water release equipment

Changes in reservoir water release equipment for more accurate control of volumes supplied, easy adjustment of discharges in the course of the time, and adopting automation when decision models are effectively operating in real time.

However, adopting rigid schedules in pressurised systems generally do not lead to easy adoption of savings at farm level.

Canal lining

Canal lining to avoid seepage losses. However, canal lining is only fully effective when canal management is improved, maintenance is carefully and timely performed, and other canal structures are also improved for enhanced conveyance and distribution service. Otherwise, investment costs may not be justified and resulting water costs may be excessive for farmers if the water service remains at low performance levels.

References

Arreguín-Cortés, F.I. (1994). Efficient use of water in cities and industry. In: H. Garduño and F. Arreguín-Cortés (eds) *Efficient Water Use*. UNESCO Regional Office, Montevideo, Uruguay.

Frederiksen, H.D. (1992). *Drought Planning and Water Efficiency Implications in Water Resources Management*. Technical Paper, No. 185. Washington, D.C.: World Bank.

Harrison, Robert (1977). *Response to droughts: Water Spectrum*, v. 9, No. 3.

Missaoui, H. (1996). Soil and water conservation in Tunisia. In: L.S. Pereira, R.A. Feddes, J.R. Gilley and B. Lesaffre (eds) *Sustainability of Irrigated Agriculture*. Kluwer Acad. Publ., Dordrecht.

Okun, D.A. (2000). The conservation of water through wastewater reclamation and urban nonpotable reuse. In: M.F.A. Goosen and W.H. Shayya, (eds) 2000. *Water Management, Purification & Conservation in Arid Climates*. Technomics Publ. Co., Lancaster, Pennsylvania.

Pereira, L., Cordery, I. and Iacovides, I. (2002). C*oping with water scarcity.* Technical Documents in Hydrology, No. 58. UNESCO, Paris.

Pescod, M.B. (1992). *Wastewater Treatment and Use in Agriculture*. FAO Irrigation and Drainage Paper 47, FAO, Rome.

Prinz, D. (1996). Water harvesting-past and future. In: L.S. Pereira, R.A. Feddes, J.R. Gilley and B. Lesaffre (eds), *Sustainability of Irrigated Agriculture.* Kluwer Acad. Publ., Dordrecht.

Yevjevich, V., Hall, W.A. and Salas, J.D. (eds), (1978). Drought research needs. In: *Conference on drought research needs*, Colorado State University, Fort Collins, Colo., December 12-15, 1977, Proceedings: Fort Collins, Colo., Water Resources Publications, 288 p.