DESERT RECLAMATION AND MANAGEMENT OF DRY LANDS: WATER ASPECTS

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Summary

Water is prerequisite to the growing of crops. Lack of precipitation in arid regions or unequally distributed precipitation throughout the year in semi-arid regions hampers soil productivity. All available water resources such as surface water from remote catchment

areas, local groundwater and water collected from local storms are suitable for crop growth. Simple surface water distribution or sophisticated sprinkler and micro-irrigation systems are used to provide water to crops. Efficient water use requires an optimal design based on crop water requirement, rooting depth, water application depth and time, and return period. Some irrigation water is lost as the result of conveyance losses and over-irrigation whether or not applied to limit soil salinity.

Water losses result in too high a groundwater table if no natural drainage occurs. Shallow water tables impede crop growth and cause salt accumulation in the soil. Drainage is required to prevent these harmful effects. Surface drainage evacuates storm and irrigation runoff. To avoid water stagnation in depressions, fields are shaped and field drains collect and convey the surface runoff through field laterals towards lower lying areas for irrigation or towards the main drainage system. Open ditches, underground drainpipes or tube well drainage are applied as subsurface drainage to lower the groundwater table. Subsurface drainage water is of inferior quality and direct evacuation to the disposal site involves high costs. Therefore, drainage water can be blended with better quality irrigation water or re-used for more salt-tolerant crops.

Domestic and agro-industrial wastewater can be very useful for irrigation in arid and semi-arid areas. However, the re-use of drainage water and wastewater requires sound planning, given the environmental, economic and social impact.

1. Introduction

Without water, no life. Many desert areas in the world are potentially fertile but lack of precipitation (< 250 mm/year) renders arid regions unproductive. Abundant but unequally distributed rainfall throughout the year may also limit the productivity of semi-arid regions. Both arid and semi-arid regions have a high evaporative demand. In the semi-arid regions, the rainy season with abundant rainfall may coincide with the highest temperature (savanna climate: e.g. Gambia, India, Pakistan), or the rainy season with moderate rainfall may occur during the winter with a typical hot and rainless summer (Mediterranean climate: e.g. along the shores of the Mediterranean sea, South Africa, California, Chile), or there may be a rainfall deficiency over the whole year (steppe climate: e.g. central and western part of North America, India, Australia, South Africa, Argentina).

High solar radiation favors high productivity if a plant’s need for water is satisfied. Therefore, provision of water is a prerequisite to make plant growth possible in arid regions with virtually no rainfall or to lengthen the growing season and to diversify cropping and crop rotation in semi-arid regions with rainfall deficiency during the growing season.

2. Water Resources

Water provision for crop growth requires the presence of water resources. In arid and semi-arid areas water resources can be of three different types: they can come from remote catchment areas that involve extensive and costly conveyance systems to bring the water to its destination; they can refer to local groundwater that requires the installation of pumping wells; or they can derive from special water harvesting techniques for collecting and optimizing the use of the limited rainfall.

2.1. Surface Water

The annual potential evapotranspiration in arid and semi-arid regions is significantly greater than annual rainfall. Precipitation can vary strongly from year to year and can either occur during well-defined seasons or be rather exceptional and irregular (extremely arid regions). Rainfall in arid and semi-arid regions occurs often under the form of heavy rainstorms, followed by intense surface runoff and large floods that last only a few hours or days. During the rest of the time, the riverbed is mostly dry.

Variations of stream flow are a major factor in the use pattern of the water, in particular in designing irrigation works. *Daily variations* are important in the design and operation of diversion works but not for storage reservoirs. *Seasonal variations* determine the possibility of utilizing natural flows for irrigation purposes. Seasonal variations may influence diversions to storage and irrigation. *Annual variations* and especially the sequences of dry years are critical periods in planning and designing irrigation projects. To adjust the natural stream flow as nearly as possible to the rate of water demand, reservoirs can be constructed to store the water and to release it when required.

2.2. Groundwater

Groundwater reservoirs or water-bearing layers (aquifers) are geologic formations where water is stored by natural or artificial means. Most aquifers are sand or gravel layers. Poorly cemented sandstones and permeable limestone and basalt may contain large amounts of water as well. Groundwater reservoirs contain water in volumes far greater than the largest surface reservoirs. Groundwater is, therefore, one of the most reliable water resources in arid and semi-arid regions.

The aquifer is not only a seasonal storage reservoir to overcome dry periods but also a long-term storage reservoir to smooth out large fluctuations in groundwater replenishment. If the average annual groundwater withdrawal is smaller than the average annual replenishment, safe groundwater exploitation is achieved. When it is greater, a new equilibrium will be established. However, continuously increasing withdrawal, exceeding the recharge or over-exploitation of the aquifer by excessive use of pumping wells, depletes the groundwater resource (e.g. the Hebei Plain, China).

Rational groundwater reservoir management involves a good understanding of the physical characteristics of the reservoir itself, sound economic planning, and exploitation based on an adequate legal framework. Efficient reservoir management requires that well withdrawals are so spaced in location, depth, and times and rates of pumping that good advantage is taken from the storage and flow characteristics of the aquifer under the given replenishment conditions.

Geologic studies are of prime importance in groundwater exploration to determine the extent, depth, thickness and continuity of the water flow as well as hydrologic parameters such as soil texture, porosity, permeability, and water quality. Several geophysical surface methods (electrical resistivity; seismic waves; density variation; magnetic properties) are used in groundwater exploration.

Most large wells are vertically drilled tubes ranging from ten to several hundreds of meters in depth. Drilling practice or the equipment to be installed will determine the well diameter. The collector type of well consists of a vertical shaft of large diameter extending to the water-bearing layer where horizontally drilled pipes collect the water from the aquifer. Smaller wells of a few meters deep and with a diameter of 1 m or more are frequently observed in rural areas and remote villages. They catch the water of shallow water-bearing gravel or sand layers. Ponds that intersect with such layers can also catch the groundwater.

2.3. Water Harvesting

Water harvesting deals with the collection of rainfall runoff and the water so gathered is of direct productive use to people, animals and plants, especially in drought-prone areas. Water harvesting is a rudimentary form of irrigation without any control over timing. Though no runoff can be collected in extremely dry years, water harvesting makes significant amounts of water available to crops in arid and semi-arid regions. In this respect it can considerably improve the reliability and sustainability of agricultural production systems. A productivity analysis in the hot arid tropics of India has indicated that the creation of farm ponds results in a substantial improvement in gross monetary returns to the farmers concerned.

Water harvesting is not new and various systems have been used throughout the centuries. The widespread droughts in Africa in the 1970s and 1980s regenerated interest in water harvesting systems for improved production, but the experiences gained in Israel, USA and Australia could not be transferred properly to the resource-poor areas in the semi-arid and arid regions of Africa and Asia where environmental degradation, drought and population pressure is more menacing.

There are different ways to harvest water. *Rainwater harvesting* is the runoff from roofs and ground surfaces. *Floodwater harvesting* is the collection of water from intermittent or ephemeral watercourses. Water harvesting techniques for plant growth can be grouped into three categories:

- *Micro-catchment systems* collect the overland flow from short slope lengths, usually 1-30 m long. The ratio of catchment to cultivated area ranges between 1 and 3. The collected runoff is stored in the soil and no provision against overflow is made. A rather even plant growth results from this way of water harvesting.
- *External catchment systems* collect overland or rill runoff water from catchments with a length of 30-200 m and have a ratio of 2-10 between the catchment and cultivated areas. The runoff is stored in the soil and a provision for overflow of excess water is made. The plant growth is rather uneven unless the land is leveled.
- *Floodwater farming* harvests water from channels that are spread within the channel bed or valley. The catchment area may have a length of several kilometers so that the ratio of catchment to cultivated area exceeds 10. The runoff is spread in the soil profile and a provision for overflow of excess water is made.

Soil characteristics determine runoff and hence, they are a significant parameter in water harvesting. Deep, non-saline or non-sodic, medium textured loamy soils are best suited, while sandy soils have a higher infiltration rate and form a serious limitation for water harvesting. Further detailed information on water harvesting possibilities and techniques can be found in Critchley and Siegert (1991).

3. Irrigation of Drylands

3.1. Irrigation Design Parameters

The water requirement, the application depth and time, and the irrigation frequency or return period constitute the basic parameters of an irrigation design. They depend on topographic, soil, crop and climatic conditions. Topography and soil determine the runoff and erosion hazard and will impose the application rate. The soil governs the water-holding capacity or water storage and thus the total amount of water that can be applied during an irrigation period if the rooting depth of the crop is known. The application time results from the application depth and rate. The climate dictates the crop water use and the return period or irrigation frequency results from the total amount of applied water and the crop water use.

3.1.1. Water Requirements

Evapotranspiration (ET) is an important parameter in estimating the water requirement for irrigation. It is the quantity of water that a cropped soil consumes both from the transpiration of crops and evaporation from the soil. To calculate the maximum water requirement for irrigation, the highest water demand or peak ET must be known. Peak rates range from 5-6 mm/d in moderately dry regions to 8-9 mm/d in hot dry regions.

To obtain the irrigation requirement, the rainfall, if any, should be subtracted from ET. Furthermore, water losses due to deep percolation and runoff should be considered. The water loss is generally given as a fraction or percentage of the total required amount of water. If F_l is the water loss fraction, then the total required irrigation water I_w (mm/d) can be obtained from:

$$I_\mathrm{w} = \frac{E_\mathrm{p} - R_\mathrm{e}}{1 - F_\mathrm{l}}, \qquad (1)$$

where E_p is the average daily ET rate (mm/d) and R_e the effective rainfall (mm/d).

3.1.2. Application Depth

The application depth is the volume of water applied at each irrigation. It depends on the amount of water stored in the soil over the rooting depth. The latter depends on the crop, the soil type and the presence of a water table or an impervious layer at shallow depth, as well on the fertility and salinity status of the soil. Average rooting depth for a number of common crops is given in Table 1.

Rooting depth (cm)	**Crop**
Shallow (60 cm)	Rice, Potato, Cauliflower, Cabbage, Lettuce, Onion,
Moderately deep (90 cm)	Wheat, Tobacco, Castor beans, Groundnut, Carrots, Pea, Bean, Chilies
Deep rooting (120 cm)	Maize, Cotton, Sorghum, Pearl millet, Soybean, Sugar beet, Tomato
Very deep rooting (180 cm)	Sugarcane, Citrus, Coffee, Apple, Grapevine, Safflower, Lucerne

Table 1. Effective root zone depth of some common crops

If irrigation maintains the soil moisture at a high level, roots generally develop more in the upper soil layer and decrease with depth. The soil moisture extraction pattern of average crops growing in deep uniform soils indicates that about 40% of the total moisture is extracted from the first quarter of the root zone, the second quarter counts for 30%, the third for 20% and only 10% is extracted from the last quarter.

The maximum application depth (or maximum amount that a soil can store for the consumptive use of the plant) is given by the difference in moisture content at field capacity and wilting point over a depth corresponding with the rooting depth, and is derived from the formula

$$d_{\mathrm{m}} = \frac{\theta_{\mathrm{fc}} - \theta_{\mathrm{wp}}}{100} \rho_{\mathrm{db}} H \,, \qquad (2)$$

where d_{m} is the maximum application depth (mm); θ_{fc} and θ_{wp} are the soil moisture content (% by weight) at field capacity and wilting point respectively; ρ_{db} the dry bulk density of the soil; and H the rooting depth of the crop (mm). Taking into account that 1 mm = 10 m^3/ha, d_{m} can also be expressed in m^3/ha. The moisture content at field capacity and wilting point and the water storage capacity of various soils is given in Table 2.

Soil type	**Moisture content (% by weight)**		**Water storage capacity (mm/m of soil)**
	Field capacity	**Wilting point**	
Clay	45	30	135
Clay loam	40	25	150
Sandy loam	28	18	120
Fine sand	15	8	80
Sand	8	4	55

Source: Withers and Vipond, 1980.

Table 2. Moisture content (% by weight) of various soils at field capacity and wilting point, and their corresponding water storage capacity.

In practice, irrigation is applied before the moisture content of the soil reaches wilting point. The depletion of the soil moisture depends on the crop. A depletion of 50% is accepted for grassland and fodder crops and 30% for most other crops, while for grains and vegetables only 20% is admitted. Consequently the practical application depth d_p (mm) or the water that will be stored in the soil for consumptive use of the plant results from:

$$d_\mathrm{p} = \frac{\theta_\mathrm{fc} - \theta_\mathrm{dp}}{100} \rho_\mathrm{db} H \,, \qquad (3)$$

where θ_dp is the moisture content of the soil (% by weight) at the accepted depletion point.

The actual application depth d_a should consider the water losses (F_l = 10-25%) due to deep percolation, runoff and evaporation, thus:

$$d_\mathrm{a} = \frac{d_\mathrm{p}}{1 - F_\mathrm{l}} \,. \qquad (4)$$

The ratio of the amount of irrigation water stored in the root zone to the supplied amount at field level is the irrigation efficiency I_e. It is expressed by the formula

$$I_\mathrm{e} = 1 - F_\mathrm{l} = \frac{d_\mathrm{p}}{d_\mathrm{a}} \,. \qquad (5)$$

The irrigation efficiency depends for a large extent on the irrigation system and may be 90% for sprinkler irrigation and 50% for surface irrigation.

3.1.3. Application Time

The actual application depth and the infiltration rate of the soil i_r (mm/s) for surface irrigation or the intensity of sprinkler irrigation i_s (mm/s) determine the application time t, thus:

$$t = \frac{d_\mathrm{a}}{i_\mathrm{r}} \text{ or } t = \frac{d_\mathrm{a}}{i_\mathrm{s}} \,. \qquad (6)$$

3.1.4. Irrigation Return Period

The irrigation return period results from the actual application depth d_a or the water that must be applied to replenish the root zone taking into account the water losses, divided by the daily required irrigation water I_w:

$$T = \frac{d_\mathrm{a}}{I_\mathrm{w}} \qquad (7)$$

or, taking into account Eqs. (1) and (4):

$$T = \frac{d_p}{E_p - R_e}, \qquad (8)$$

where T is the irrigation return period (d). Normally, the return period will be calculated for the highest consumption rate. Depending on the development stage of the plant and the climate, the daily consumption rate may differ from one period to another. A smaller E_p or I_w results in a longer return period. Usually the return period will be kept constant and the application depth adapted so that the irrigation schedule can be maintained.

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Biographical Sketch

Willy Dierickx is a senior research officer of the Institute for Agricultural and Fisheries Research, Technology and Food Unit, Agricultural Engineering, of the Ministry of the Flemish Community, Merelbeke, Belgium. He holds an M.Sc. in Agricultural Engineering, with specialization in Drainage and Irrigation Engineering, from the University of Ghent (1966), and a Ph.D. in Agricultural Science from the University of Wageningen, The Netherlands (1980).

He has been active for more than thirty years in agricultural water management research. His research topics were the hydraulics of drainage materials and geotextiles, both in the laboratory and in the field. He participated in many international conferences taking responsibilities as session chairman or keynote lecturer. He is author/co-author of numerous scientific papers, and co-author of an FAO Drainage and Irrigation paper on subsurface drainage materials and an ILRI-book on subsurface drainage envelopes. As a scientist, he carried out several scientific and technical advisory missions (Egypt; Pakistan, India and Suriname) by order of the Dutch government, UNDP and development companies.