IRRIGATION

P.I. Kovalenko, Yu.A. Mikhaylov and **O.I. Zhovtonog**
Institute of Hydraulic Engineering and Land Reclamation of the Ukrainian Academy of Agrarian Science, Kiev, Ukraine.

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Contents

Summary

Irrigation is an essential factor in the intensification of agricultural production under conditions of dry climate. It involves the use of complex science and technology. As a scientific activity, irrigation needs to be inter-disciplinary, involving the following subjects: mathematics, physics, soil science, hydrology, hydrogeology, hydraulics, economics, hydro-techniques and others. Irrigation is the guarantee of food safety for billions of people.

1. A Demand for Irrigation

The level of civilization and quality of life in human societies are heavily influenced by the quantity and accessibility of the food resources available to them. Lack of food was a major hindrance to the development and evolution of our species. Civilization began when food reserves were sufficient to free human resources for the scientific-technical activity of increasing the production of high-quality food.

The process of humankind's settlement of the Earth has inevitably pushed separate groups of people to live under extreme conditions that were not amenable to extensive use of natural food resources. Agriculture became an obligatory element in the culture of the majority of contemporary nations. Different systems of agriculture came into being, with higher levels of scientific-technical sophistication in the more powerful economies.

The most fertile chernozem soils have arisen through the ecological interaction of mineral and biotic components in the Forest-Steppe and Steppe zones in regions of the planet with unreliable and insufficient natural moisture. Rice—one of the main food products for the major part of the Earth's population—is effectively grown only under conditions of prolonged flooding of the root system. Water in both these instances is the main limiting factor for the normal vital functions of plants used as agricultural crops, and watering is an obligatory requirement in such agriculture.

Within the regions of the planet with sufficient or excessive natural moisture the annual pattern of water requirement by crops is often at variance with the precipitation regime, resulting in significant reductions in yield. Watering of crops during the period of shortfall can prevent such reduction.

Irrigation can be considered as a method of adaptation of people to severe natural conditions. By making the microclimate of irrigated territories more favorable for plant growth, time that would otherwise be devoted to tending the crops can be devoted to other more valuable activity.

At first glance it would seem paradoxical that a vast expanse of land surrounded by oceans should suffer from shortage of freshwater. The fact is that their major source of moisture is the water which has evaporated from the surface of the oceans. This water condenses and falls as rain, some of it onto the land. Some of this water evaporates again, some is carried away to the oceans, and some percolates into the ground to accumulate in soil and groundwater.

Over the planet as a whole and over every part of the continents, the process of water-exchange is constantly proceeding, sustained by solar energy. The nature of water-exchange is as follows: it is formed from the separate relatively stable and powerful streams of moisture coinciding with the principal atmospheric flows. Very large territories are largely missed by these flows of moisture, or they are situated along their periphery, and consequently they receive very little precipitation.

The paths of the major moisture flows are changing constantly and, as a result, even regions of the Earth with high annual rainfall can be characterized by extremely uneven seasonal patterns. Besides the normal long-term fluctuations of annual and seasonal rainfall patterns, other changes now being observed suggest large-scale alteration of the character of global water transfer.

Surface evaporation is one of the major elements of water-exchange and is formed under the influence of two principal factors, namely: the amount of water available, and the temperature.

Evaporability, equating to surface evaporation, can be measured with special devices, and from this it is possible to calculate the maximum permissible evaporation, given unlimited water resources. Evaporation is related directly to the solar combined radiation, therefore latitude and seasonable variability is common to it, but each specific territory will have a relatively constant index.

The relationship between total evaporability and observed annual rates over a long period is called an aridity index, characterizing the climate of a given territory.

Precipitation also creates river water flow. The volume of river flow depends on a large number of natural factors, the main ones of which are as follows: the relationship between intensity of rainfall and evaporation over the seasons (current aridity index); territory relief, particularly the thickness and depth of its erosion and cracking, and surface slope.

The coefficient of river run-off, as ratio of run-off to total precipitation, increases with decline of dryness index and increase in average slope of river water-catchment. Relief by itself, as an influence on run-off, provides an explanation for waterlogging and soil salinization in catchments without run-off under conditions of low precipitation, as well as hydration of soils on steep slopes during heavy rain.

Water run-off partially proceeds by way of outcropping to the surface of an opened water-course. Ecological and hydro-geological conditions are of great importance in this process. Rocks and their sediments when adsorbing and containing precipitation can create steadier run-off through the year (i.e. flow with less amplitudinal variation).

The water exchange on a specified area of land is an obligatory term for the determination of irrigation needs. Water balance is a qualitative index for water-exchange, represented as a qualitative relationship between water-intake and expenditure on a certain territory and over a definite period of time.

Water balance within a river catchment over the hydrological year is recognized as the most commonly used parameter, and it may be represented as the following equation:

$$X = E + Y + \Delta V , \qquad (1)$$

where X is precipitation; E is land evaporation; Y is surface and underground run-off; and ΔV is the change in water storage within a reservoir, being equal to the difference between its storage at the end and at the beginning of a year. The left-side elements of water-balance equation are called returnable and right-side elements are called expendable.

Land evaporation is composed of physical water evaporation from the land surface and water bodies, and from plants. The amount of evaporation depends on the temperature of the evaporating surface, moisture scarcity in a layer two meters thick over the land, moisture storage in the root layer, and the type and physiological state of the natural and cultivated vegetation. Under the most favorable conditions it may reach a definite maximum – E_o. River run-off does not directly act upon the vital functions of the plants.

Water-storage in the root layer of the water-catchment (ΔW) is a more important factor for them.

Taking account of the above and equation (1), irrigation is required when the coefficient of natural territory moistening calculated by the equation (by analogy with dryness index)

$$\rho = \frac{E_o + \Delta V}{X}, \qquad (2)$$

is more than unity.

To determine which lands require irrigation it is enough to perform the division of the territory on districts by the *p* coefficient. To estimate the quantity of water for irrigation we have to select the crops, determine their sowing areas and multiply these areas by the gross water-need. Other natural and economic conditions may prove to be limiting factors. It is necessary to take into account and integrate many often contradictory conditions in the interest of efficiency and ecological safety in irrigation.

Soils are an important factor limiting irrigation. The most fertile black-soil and chestnut soils in areas of water scarcity and being used as a base for irrigated agriculture were formed over very long periods with constant growth of steppe grass, occasional heavy showers, episodically heavy rains, and sharp changes of air and land surface temperature.

Irrigation radically changes the soil-creation process. Under alternative agricultural monocultures, changing almost annually, nutrients are irrevocably removed and humus development ceases. Often irrigation with water, sometimes of unsatisfactory quality, promotes salinization of soils, giving rise to leaching and washing out of humus. Even watering by weakly-mineralized water can lead to the washing out of salts, particularly calcium, from the soil profile, resulting in leaching of the soil.

Soil cover is subjected to the indirect influence of irrigation through the other natural factors. Relief (geomorphology) of land surface determines the intensity of water-soil erosion processes. Geological structure and hydro-geological conditions determine the natural drainability of the territory and the predominant depth of the groundwater level, exerting a strong influence over the water-salt regime of soil-creation. Water erosion is an inevitable factor in soil-creation. The destruction of rocks and minerals down to the size of soil particles, as well as transportation and distribution of organic substances, are both caused by water erosion. As a rule, under natural conditions a rather prolonged equilibrium is established between hydraulic deposition of soil and wash-out of soil, supported by the binding properties of plant root systems. Water flows above a threshold intensity destroy and wash out soils and even underlying material, so that gullies and ravines are formed. With irrigation, such phenomena occur more frequently due to the increase in water flow intensity and the poor soil-holding capacity of the crop root system.

There are two major types of water erosion: linear and plane. Both types occur under irrigation conditions. Erosion processes are inevitable where the irrigated land surface has a slope of more than 4 meters per mile, thus restricting the land which can safely be irrigated.

The geology and hydro-geology of the irrigated area determine the capacity and water-physical properties of the aeration zone. This is the zone lying between the surface and the top of the groundwater. The soil layer is located in the uppermost part of the aeration zone. With rare exceptions, the deeper the aeration zone, the better the conditions for irrigation.

The ground and soil in the aeration zone must have sufficient waterproof ability, characterized by least field moisture capacity. The higher the field moisture capacity the more water can be held in the aeration zone without draining into adjacent regions (horizons) under gravity. On the other hand a high field moisture capacity permits capillary rise from the groundwater. This favorable for irrigation under conditions of low mineralization and favorable chemical composition of groundwater, otherwise salinization occurs, unfortunately more often than most people realize.

The depth of the groundwater level is determined by interaction of field moisture capacity and surface water infiltration. If infiltration of surface water exceeds total losses, the level of the groundwater will rise. Conversely the level will fall if infiltration is less than the outputs. When groundwater rises into the aeration zone with ongoing evaporation, conditions are created for soil salinization. To avoid salinization, 70% of the flow of groundwater needs to be downwards, with a net downward flow in the aeration zone.

One of the necessary conditions for successful irrigation is that the land must be adequately drained.. Such conditions are relatively rare in nature, and they are in conflict with the geomorphologic requirement that the land has to be nearly flat. Minimal slopes are typically poorly drained lands. One solution to this problem is to install artificial drainage but this results in an increase in price.

Of a large number of factors affecting the feasibility of irrigation, one of the key determining points is the percolating capacity of the soils. The rate of percolation has to be close to the intensity of watering, otherwise surface water run-off erosion of soils may become a problem. On the other hand, percolation determines drainage load and high rates of irrigation become more expensive.

Soil, geomorphological, and hydrogeological conditions are spatially very variable, and often one or more of these will completely exclude the possibility of irrigation. Many problems could be solved by not installing irrigation systems over very large areas, but instead using appropriate irrigation works on small areas where the conditions are particularly favorable.

Irrigation is only viable for highly intensive agriculture. It requires complex technical constructions: reservoirs with dams, canals, water-outlets and catchments, pumping stations, machines and devices for irrigation, and a drainage system. Only technically and economically developed countries can afford such facilities. Irrigation is a great art requiring huge knowledge, experience and skill, and often intuition.

The greatest rise of irrigation in the world took place in the 1970s. But limited resources of land and water soon became exhausted, and large-scale reclamation construction requiring financial backing from the public sector nearly came to a halt in the 1980s. This continued only in USSR and a number of developing countries. At present we have no appropriate conditions for new large-scale irrigated agriculture projects, as further plowing of permanent grassland or other vegetation would lead to sharp deterioration of the ecological situation. Moreover a significant area of irrigated land is taken out of agriculture annually from the territory of the former Soviet Union because of salinization and alkalinization of the soils, deterioration of water quality in the irrigation sources, and the lack of resources for restoration of hydro-technical constructions. The state support system for irrigation has nearly ceased.

A special FAO Program on food support facilitates further development of irrigation, with the emphasis on efficiency, primarily with regard to reduction of water use per yield unit. The transition of bogharic lands into irrigated farmland should be carried out only after careful ecological evaluation.

Financial support for increasing technical sophistication of irrigation is limited by the state of the economy and the policy of the state, as well as the potential profitability of production based on irrigated agriculture. In general the limit of reasonable irrigation in developed countries has been reached, which is why the primary task for the next few decades must be the modernization of existing irrigation systems and watering equipment up to the world standard: the efficiency of water use in irrigation should be not less then 85%, and every thousand cubic meters of irrigation water should give no less then 40 food units per hectare.

Irrigation offers huge potential for increasing efficiency not only in crop production but in ecosystems in general. It allows the transformation of desert, semi-desert and steppe landscapes into forest-steppe and habitats generally favorable for human life. This is why ecosystems are currently considered as the main targets for irrigation management. The hierarchy of management levels has undergone some important changes. Cultural and natural biocenoses have been put in the forefront. The main task is provision of the physical medium—a biotope beneficial for the development of efficient biocenosis. Creation of favorable conditions for people is also an important factor.

Nowadays more than 250 million hectares or 17% of total cultivated land is under irrigation. Asia occupies first place (175.4 mha), followed by North America (30.1), Europe (22.5), Africa (12.3), and South America (9.8). Irrigated land yields more than 40% of world food production. Vegetables, food cultures and some grain cultures are grown in many countries under irrigation conditions yielding substantial addition to crop yields.

Land and water resources are the chief factors limiting irrigation. Further development of irrigation will be aimed at reduction of expenditure on water and energy, with simultaneous increase in ecological safety of irrigation agriculture, particularly where this involves plowing of old grassland or reclamation of other habitats.

2. Regime of Irrigation

In arid climates all plants, including agricultural crops, experience a water deficit equivalent to the difference of maximum possible gross evaporation and the quantity of fallen precipitation. The deficiency of water-consumption by irrigated crops forms the basis for the irrigation regime, namely: fixing of the terms and watering rates.

Water-need is a modern synonym for irrigation rate. It is necessary to distinguish the current net-water-need M_n, equal to the difference between precipitation and biologically optimal gross-water-consumption of the specific agricultural crop under specific climatic conditions, and the current gross-water-need M_b, which includes the inevitable losses of irrigation water for filtration and run-off during irrigation. The rate for net (gross)-water-need is taken as an average over many years, and is the basis for the definition of irrigation water-need.

The water-need depends on the type of irrigated crops and the climatic conditions in each region, and to characterize the need of each crop in each region, we can use the coefficient *p*. Table1 shows that rice crops have the highest rate of net-water-need, because of insignificant evaporation from the water surface. Of the so-called field crops, cotton comes first, followed by perennial grasses, vegetables, and corn

Long-term fluctuations in net-water-need, taking account of weather conditions, are obtained by ranking observed and calculated rows in ascending order with definition of the mathematical probability of exceeding the provision of water for every member of the row. Under this approach the drier the climatic conditions, the greater the net-water-need and hence greater provision of water, and a lower probability of exceeding the water-need in the wetter years. Table1 presents the difference between the rate of net-water-need on average, by water-provision year and in a dry year.

Natural climatic zones	Beneficial water use, thousand m^3/ hectare										
	Cotton	Wheat			Maize			Vegetables			Rice
	95%	50%	75%	95%	50%	75%	95%	50%	75%	95%	95%
Desert	12.5	-	-	7.4	-	-	6.3	-	-	16.8	24.0
Semi-desert	9.5	2.6	2.7	3.3	4.3	4.8	5.3	4.9	5.9	6.2	16.0
Steppe	-	1.9	2.5	3.2	2.6	3.2	3.9	3.9	4.1	5.1	10.0
Forest-Steppe	-	1.4	2.0	2.7	1.3	1.9	2.5	2.1	2.8	3.7	-

Table 1. Beneficial water use of the main irrigable crops

Inevitable losses of water during irrigation are estimated when determining the net-water-need rates. Figure 1 shows the classification of the losses and their possible amounts. Coefficient α_o characterizes losses of water during irrigation in relation to the total volume of water fed for these purposes. The amount and the nature of losses are different for separate technological irrigation cycles. The more complicated the irrigation technology, the bigger α_o.

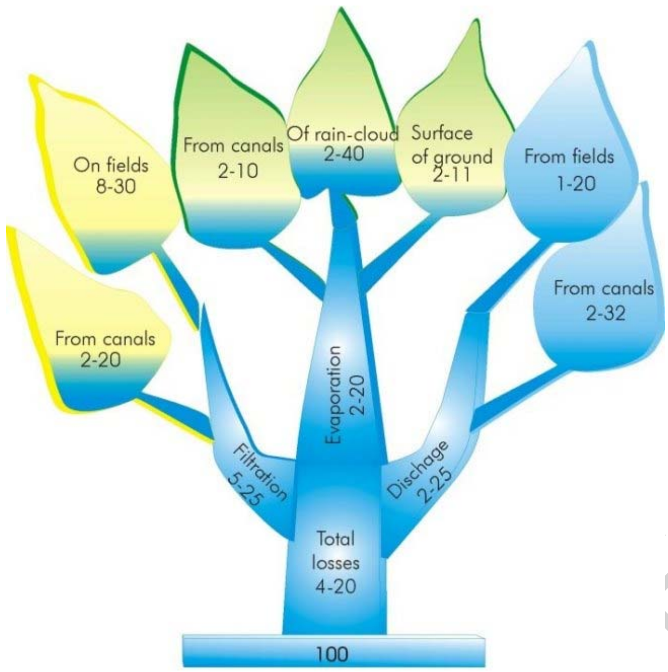

Figure 1. The tree of water losses in irrigation

As a rule the following are present in irrigation technology: distribution of water between irrigation systems with the help of main canals; distribution of water between farms (users); intra-farm distribution of water between fields and watering techniques, canals and pipelines, and finally the watering of agricultural crops. If the coefficient of losses in each of the above-mentioned stages is designated as α_1, α_2, α_3 and α_4, we have:

$$\alpha_o = \alpha_1 \alpha_2 \alpha_3 \alpha_4 , \qquad (3)$$

$$M_b = \frac{M_n}{1-\alpha_o} . \qquad (4)$$

Each irrigation regime depends on the specific local climatic conditions of the watering season and is a rather changeable value. Section 9.1 describes the technology for qualitative irrigation management.

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Biographical Sketches

Peter Kovalenko is Doctor of technical science form 1974, Professor, academician, Academician-Secretary of the Ukrainian Academy of Agrarian Science, Director of the Institute of Hydraulic Engineering and Land Reclamation, He was awarded the title of Honored Science and Technique Worker of Ukraine. Education: In 1962 he graduated from the Institute of the Engineers of Water Economy (State Technical University, Rivne). Specialty: engineer-hydro-technician. Specialization: automation of management by the technological processes on reclamation systems.

Yurij Mikhaylov Ph.D, is Head of the Scientific- technology Center (Irrigation) of the Institute of Hydraulic Engineering and Land Reclamation. Education. In 1973 he graduated form the Voronezhsky State University. Specialty: Engineer-hydrologist. Specialization: rational management of water-resources in irrigation.

Olga Zhovtonog Ph.D is Head of the Irrigated Land Use Department of the Institute of Hydraulic Engineering and Land Reclamation. Education. In 1978 he graduated from the Institute of the Engineers of Water Economy (State Technical University, Rivne). Specialty: engineer-hydro-technician. Specialization: efficient use of irrigated lands.