IRRIGATION SYSTEMS: MACHINERY AND TECHNOLOGY

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Summary

This article presents irrigation systems, their classifications by design features and types of water supply, range, and geomorphologic location, with characteristics of irrigation system components. System computation methods are given. Different designs of the irrigation system are considered: open, piped, and combined, as well as design methods. Design features of different irrigation methods for agricultural crops (surface, drop, subsoil, sprinkler, and mist irrigation) are presented, as well as rice systems and systems using wastewater and liquid manure. The questions of computer-based management and operation of irrigation systems are also considered.

1. Introduction

Irrigation is the supply of water to fields that lack moisture: it provides an optimal water regime within a root zone for the development of agricultural crops, and is one of the main methods of reclamation. It consists of a complex of engineering, agronomic, and organizational-economic activities based on hydraulic engineering techniques of rationed water supply to soil to provide soil moisture. Irrigation is required when there is a lack of natural moisture for crops, either for the whole vegetation period or at different stages of development. Without it the highly productive use of agricultural land is impossible. Because of irrigation, favorable moisture and other related soil regimes are established. These are necessary for enhancing fertility, obtaining a high and steady harvest, and the essential improvement of farming production quality. Irrigation makes it possible drastically to improve the soil conditions of dry zones and make them suitable for agricultural use, and to make more productive use of those regions that are adequately wetted. In the latter case irrigation is an indispensable prerequisite of the development of cotton and rice growing, grain production (with the creation of guaranteed grain harvesting zones), fodder crop and vegetable growing, horticulture and livestock breeding (the secondary sowing of fodder crops on irrigated land, and the creation of pastures and hay land). (See *Irrigation.)*

2. Irrigation Systems

An irrigation system consists of the hydraulic structures (water intake and pumping stations, canals and pipelines, and so on) and operational structures (roads, highways, bridges, and so on) within an area of land that provide irrigation to the area. There are systems for regular irrigation, basin irrigation, and irrigation impounding (impounding irrigation). The regular irrigation system consists of:

- a water source;
- a head water intake (that withdraws water from the water source and protects the irrigation system from silting, debris, and garbage);
- the irrigation network;
- a disposal network;
- a collector-drainage network (for drawdown of the groundwater table and disposal beyond the irrigated area);
- hydraulic structures;
- pumping stations;
- irrigation equipment;
- operational structures (roads, bridges, and so on); and
- instruments for monitoring reclamation and the state of the irrigated lands, communication lines, forest belts, and so on.

Irrigation systems can obtain their water supply from canals by gravity or mechanical lift (where water is supplied by a pumping station). The irrigation system efficiency is expressed as the ratio of water discharge supplied to the field (Q_{net}), to the volume withdrawn from the water source. (Q_{gross}).

The rational use of water resources requires an irrigation system efficiency of 0.8 to 0.9

for the inter-farm distributing canals; 0.85 to 0.95 for farm ditches; 0.9 to 0.95 for annual ditches (that is, ditches redug each year); and 0.95 to 0.98 for buried networks. With the aim of improving the irrigation system's efficiency and reducing seepage loss, use is made of lining materials and revetment (concreting and asphalt paving of bottom slopes, screens of polyethylene film, polymer-concrete and clay), sealing, solonetzification, and gleyzation of the canal bed. The irrigation system efficiency is much higher when buried pipelines are used.

There are three types of irrigation system design:

- open (commonly practiced) with earth ditches (lined or unlined) or flumes erected on supports of different height,
- buried irrigation systems (most advanced), where ditches are replaced with pipelines, and
- combined irrigation systems: these are combinations of open ditches and pipelines.

The large combined irrigation systems have open canals as main supply canals, whereas distributing and water application networks use buried pipelines; small irrigation systems have buried pipelines for the distribution network, while the water application network has annual ditches or connecting furrows. Water is supplied to pipelines by mechanical lift, pumping, or by gravity (owing to the natural slope). The choice of the irrigation system design is made on the basis of comparison of the engineering and economic alternatives for the particular irrigation area.

Irrigation systems are classified according to the following attributes (Table 1).

Classification attribute	Types of irrigation system	Design features
Irrigation system design	Open (surface)	All components of irrigation network are open ditches or flumes
	Buried (subsurface)	All components of irrigation network are pressure or non-pressurized pipelines
	Combined	Combination of open ditches and buried pipelines

Type of water supply	Gravity	Water comes from the irrigation source by gravity
	Mechanical lift	Irrigation source is located below irrigated area and water is supplied by pumping station (pump irrigation)
	Gravity-pressure	Water is conveyed via buried pipelines by gravity down a natural slope
Extent of steadiness	Solid-set	Intake structures, pumping stations, irrigation network and water application facilities have a permanent location
	Semi-stationary	Intake structures, pumping stations and irrigation network have a permanent location while water application facilities move from one position to another
	Traveling	All components of the system—pumping stations, irrigation network (mountable) and water application facilities travel from one position to another
	Stationary-seasonal	A kind of stationary system in which all components are assembled in the field early growing period, and are removed after harvesting
Geomorphologic location	Foothills	Intake structure without dam. Main canals are located along or at a sharp angle to natural slope
	Valley	Intake structure without dam or with mechanical lift. Main canal grade is less than that of the river.
	Watershed plains and plateau	Intake structure with mechanical lift. Main canal runs through watershed with dual command.

Table 1. Classification of irrigation systems

Water intake structures: are hydraulic structures for water withdrawal from rivers and subsurface sources to irrigation systems. The intake structures are located in the head part of the system, and therefore they are often named headworks. In order to withdraw water from rivers, use is made of intake structures with dams and without dams. A water intake without a dam is an artificial bed (canal) that branches at an angle and takes a part of river water discharge. Intake structures without dams are built when river levels and discharges make it possible to withdraw by gravity into the main canal. The simplest type of intake structure without a dam is an open ditch dug from the river to the irrigation system, without a permanent structure at its head. With big river discharges, use is made of intake structures with dams that constitute part of the hydraulic structure. They are built with overfalls. Usually, the overfall height is determined according to the difference in elevation of the main canal entrance and the riverbed average. The water intake structures are arranged at the side of the dam or in the riverbed within the dam site. When water is to be supplied to higher elevations and for pump irrigation, there is a need for pumping stations. Groundwater withdrawal is achieved with the help of tapping, open wells, and drilled wells.

An irrigation network: consists of permanent and temporary canals, and pipelines that supply water from the irrigation water source to the irrigated area. The irrigation network, both permanent and temporary, consists of conveying and regulating networks with water meters, and is provided with apparatus to enable the raising of water level in canals, to regulate discharges (head regulators, sluice offtake regulators, escape-regulators, outlets), for inlet–outlet canal transitions (falls, drop structures), sediment detention (desilting basins, guiding systems), and so on. The conveying network of an open irrigation system consists of the main canal, inter-farm, farm, and in-farm distributing canals (ditches). The conveying network canals are operated during the growing season, permanently or during long cycles. The main canal supplies water from the water source into the inter-farm distributing ditches, which convey it to the farms, while in-farm distributing ditches supply water to the fields or irrigated area. In some cases the conveying network does not have a complete set of canals.

For the effective operation of canals and structures, the water volume needed at any point in time should be conveyed with the maximum efficiency of canal and land use and the minimum of construction and operation expenses. The indispensable conditions of an irrigation network functioning through gravity are that the main canal should command a water level difference (of 10–22 cm) over the irrigated area, and that senior-order canals should also have a water level difference over inferior-order canals.

The conveying network of buried irrigation systems consists of the main pipeline that supplies water from the irrigation source to the distributing pipelines. The regulating network of open irrigation systems consists of ditches (dug annually) and connecting furrows from which water is supplied to the water application network (furrows or strips) or is taken by sprinklers and other irrigation facilities. The open regulating network is dug annually before irrigation begins and is leveled after the season, or before every water application and during each after-irrigation cultivation.

An inter-farm irrigation network: serves to deliver (transport) water to the irrigated fields and to distribute it among the various irrigated areas and water users on the farms. The inter-farm network consists of main canals and pipelines, various hydraulic structures (command and water distribution units, field delivery points, proportional dividers, etc.).

An in-farm irrigation network: is a system of waterways—canals, buried and open water conduits, etc.—that serve the fields of a farm.

An inter-farm escape network: in an irrigation system consists of water-receiving escape and collector networks, and serves for the diversion of excess water from contour canals. It also comprises earth flow storage, and rain storm discharge channels with structures for catchment and diversion of the surface runoff (rainstorm or melt water) from the overlying sites as well as saline soil and flushing waters.

An in-farm diversion network: in an irrigation system is subdivided into "collector escape" and "collector drainage" networks, and serves to divert from the farm's irrigated area any wastewater and excess surface water resulting from irrigation, rainstorms, emergency accidents, flushings, emptying of canals (flumes, pipelines), and groundwater that lies too close to the surface.

An irrigation canal: supplies water to the irrigated land areas. There are main canals, inter-farm canals, in-farm ditches, and field ditches. Water is supplied to the irrigation canal either by gravity or by pumps. Canals may be in the form of earth ditches or may have a seepage-proof revetment (concrete, reinforced concrete, bituminous concrete, or polyethylene film). The cross-section of big canals is parabolic or rectangular, while that of small canals is trapezoidal.

Ameliorative canals: are artificial channels of regular form with unconfined water movement, dug in earth (as pit, embankment, or cut-and-fill) and designed for land reclamation.

Usually, a system of main distributing irrigation canals (ditches) and escape canals is built. Canals other than escape canals are as a rule traced along the highest elevations. In large irrigation systems the main canals can be several hundred kilometers long, and their discharge in the head part can be as much as 250–500 cu m s^{-1}. The ditch length ranges between 100 and 2000 m, and discharge is at 30–150 L s^{-1}. The shape of cross-section is dependent upon the canal designation, the construction properties of the soil, and earthwork conditions. The dimensions of cross-sections are determined by hydraulic calculations for the given water discharge and permissible velocities. The type of soil and canal dimensions dictates the slopes. The permissible flow velocities should range between maximum values that exclude possibilities of bed scouring and minimum ones that prevent silting and overgrowth. Lining of the bed (revetment) of the canal serves to prevent scours, reduce seepage losses and channel and slope roughness, and improve the carrying capacity. Among the different methods are colmatage (mudding), mechanical consolidation of the soil, and films of synthetic materials.

The main canal: in an irrigation system is the basic conveying channel that supplies the irrigated area with water. It consists of two parts: one conveys water from the water source to the first distributing canal, and the second (working) part branches water into distributing canals. The irrigation lateral takes water from the main canal to provide individual parts of the irrigation system, which are arranged according to farm layout, type of topography, or other attributes.

A water conduit: is a structure (canal, flume, tunnel, pipeline, etc.) that serves for the conveyance, distribution, and diversion of water.

Flumes: in the irrigation network are open irrigation canals made of prefabricated reinforced concrete parts of semi-spherical or parabolic shape installed on the surface, upon supports, or in trenches. They belong to the conduit network of the irrigation system. Owing to the flumes there are no seepage losses. Flume length varies from 6 to 8 m. Water is taken from flumes by siphons or outlet conduits.

An annual irrigation network: is the first link of the water distribution network over the irrigated field and consists of annual ditches, and distributing and irrigation furrows and strips restored every year. (See *The Economics of Irrigation Systems.*)

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Biographical Sketch

Kirill Vadimovitch Huber was born in 1937 and graduated from the Moscow Institute of Engineering of Water Management in 1960, with a specialty of engineering hydrotechnical systems and hydromelioration. He is a Doctor of Technical Science. He is currently VNIIGiM, Head of the Land Reclamation Section, A.N. Kostyakov All-Union Research Institute of Hydraulic Engineering and Land Reclamation, Russian Academy of Agricultural Sciences. He has published 140 papers, including 30 patents. His main publication are *Sprinkler Machines and their Application* (1975); *Movable Pump Stations, Construction and Operation* (1980); *Land Reclamation of the Nechernozem Region* (1980); *Melioratsiya I vodnoye khozyaistvo. Orosheniye* (1999); and *Reference Book on Land Reclamation* (1989). He has received several government honors including a medal from the Russian exhibition Centrum, and diplomas from the Russian Academy of Agricultural Sciences, Department of Melioration.