DRAINAGE OF FARMLANDS

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Summary

The anthropogenic development of land in many areas is intimately connected with the discharge of excess water. The use of land for different purposes aggravates drainage problems due to leakage of water from pipes, irrigation, waterlogging induced by artificial ponds and water storage basins, road construction, and deforestation that reduces natural drainage capacity.

The design of drainage systems requires profound knowledge of topographic, soil, hydrologic, hydrogeologic, economic, and socioeconomic conditions. Special surveys are required to select the type of drainage system, character of water collectors, kinds of drains, and design parameters of the network. Special agromeliorative measures to accelerate runoff discharge and enhance the infiltration properties of soils are widely applied.

Calculation of the parameters of a drainage system should take into account the optimal drainage regime required for a particular type of land management. The design of drainage systems is supported by solid scientific knowledge, including mathematical models based on theoretical and half-empirical equations. Mathematical modeling is a

rapidly developing branch of land reclamation science.

Where capacious water collectors ensuring the self-flowing discharge of water from irrigated lands are not available, pumping stations and artificial levees embanking the drainage area are constructed. These systems are called polders. Regulation of river flows by straightening and deepening them has virtually stopped because of environmental damage. In areas with unstable precipitation regimes, drainage–irrigation systems are constructed to discharge excess water during wet periods, store water in ponds, and supply additional water during dry periods. Artificial ponds supply water for irrigation, improve wildlife habitats, and have recreational and aesthetic values.

Land drainage is generally accompanied by measures of land improvement, including the removal of shrubs, stumps, stones, and so on; land planing, and application of soil amendments and fertilizers. Drainage and soil amelioration techniques are fundamental to efficient agriculture and the preservation of biodiversity.

1. Introduction

Land drainage for agricultural and other purposes has a long history. The first works on land drainage, along with irrigation, were conducted about 4000–5000 years ago in the flood plain of the Nile in Ancient Egypt, and in ancient China. Extensive systems for the drainage of bogs and fens were constructed by the ancient Romans, and there is abundant evidence of their expertise in all forms of water control, including large-scale field drainage. This can be illustrated by the example of southeastern England, where the drainage of fens was started by Roman soldiers in order to provide the army with foodstuffs. There is little doubt that the Romans carried out the first reclamation works in areas like the Fens and Romney Marsh, and, although there is no evidence of piped field drainage, this reclamation must have included some form of infield water control.

After the Romans departed, the drainage works like their roads were allowed to fall into neglect, and it was not until after the Normans had established their rule in the eleventh century that interest in drainage was reawakened. During the twelfth century, Thomas à Becket continued the reclamation work started by the Romans. This was to have great significance in that Henry III confirmed the Charter of Romney Marsh (1252), which laid the basis for land drainage in various parts of the country for centuries to follow.

In the seventeenth century a leading figure was Cornelius Vermuden, a Dutch engineer who, having established his reputation by draining Hatfield Chase, in Yorkshire, was appointed Chief Engineer to the Fenland project. A notable achievement of his was the drainage of nearly 5000 square kilometers known as the Bedford Levels in 1636. This success, however, introduced a continuing Fen drainage problem: the combined effect of siltation in the channels, lowering of field levels due to shrinkage of the drained peat soil, and the resultant frequent flooding of the rivers. Drainage by gravity into the rivers became impossible, and hundreds of windmill pumps had to be built to raise water into embanked rivers.

By this time, the open field strip system of farming, which probably originated in Roman times, was widely practiced. The population was increasing and with it the demand for food. With encouragement from Church and State, drainage activity was renewed not only in lowland areas, but also on higher ground where agricultural production was being intensified.

By 1846, land drainage had become recognized as a national asset and, by Act of Parliament, the Government made available large sums of money for drainage improvement. The Act enabled companies such as the General Land Improvement Company to be formed to finance drainage works.

Open channels remained the main drainage method. Closed drains were built of fascines and stones until the early nineteenth century, when drains made of clay were developed. The revolution in drainage construction dates back to 1845, when Thomas Seragg invented an extruding machine that produced round clay pipes quickly, reducing cost. For the next century, ceramic (tile) pipes became the basic means of drainage in all countries.

The experience in land drainage gained in England deserves special study. Virtually all waterlogged land has been drained and is successfully used for crop growing. The thermal regime of drained land has also been improved, making it possible to grow up not only traditional but also heat-loving crops (sugar beet) and orchards. The creation of polder systems in the Netherlands and Germany is another amazing example of efficient drainage.

By the second half of the nineteenth century, the main works on land drainage were almost complete in Belgium, the Netherlands, Germany, Italy, Denmark, and a number of other countries. Virtually all waterlogged lands with agricultural potential had been drained. Since these achievements, for more than a century, the focus of attention has been upon reconstruction and modernization of drainage systems, which has been accompanied by evident changes in the whole landscape.

The total area of drained lands in the world is estimated at 1.8–2 million km^2 (180–200 million hectares); about two-thirds of these are in Europe and North America, including 0.6 million km^2 of drained lands in the United States. The area of drained lands in Asia is about 0.5 million km^2.

The twentieth century brought considerable changes to the technology of drainage works. Open channels and ceramic tubes have been replaced by plastic tubes with synthetic protective covers; water pumping is performed by electric pumps; combined drainage–irrigation systems are widely used; environmental protection issues are given special importance in the design of drainage projects.

Construction of a drainage or drainage–irrigation system redistributes water resources in drained areas and changes the intensity and direction of natural processes in the soil and the air above it. As a result, the whole ecosystem acquires new properties. Therefore, before drainage construction, we should find the answers to three important questions:

- How will drainage affect natural processes?
- What will be the future intensity of these processes? and

- What area will be affected by the drainage system?

The long-term forecast of drainage-induced changes in the environment presents certain difficulties; it is complicated by the need to assess these changes from the economic viewpoint.

The environmental impacts of a drainage system can be subdivided into direct and indirect effects. Direct impacts are related to the removal of excess water from the fields and intensification of agricultural production on them. Indirect impacts are related to changes in the environment within the drainage system and in neighboring territories. They may have both positive and negative aspects. Positive indirect impacts manifest themselves in changes in plant communities that increase biodiversity. Negative impacts result from the action of numerous factors that are often barely predictable and appear quite unexpectedly.

The main factors that change under the impact of drainage are: the discharge and water level in local streams, the total reserves of surface and ground water in the area, ground-water level, evapotranspiration, soil temperature regime, the character of pedogenesis (especially, during the drainage of peat bogs), and the species composition of local flora and fauna.

The drainage of bogs and waterlogged territories inevitably leads to a lowering of the groundwater level and considerable redistribution of water. This is the leading factor controlling all the other changes in drained areas.

Some factors change considerably; others remain relatively stable. The degree of changes depends on local environmental conditions. Thus, in humid regions, drainage systems cause significant changes in the temperature regime of soil and aboveground air. This factor is of primary importance for agricultural production. The character of changes also depends on the scale of the drainage system, in particular on the proportion of drained land in the total catchment area.

Both positive and negative consequences of drainage should be properly assessed in economic terms, in particular the repayment time of capital investments in the drainage system.

The goal of a drainage project is not just to ensure the maximum gain in yield at minimum expense but to take into account all possible adverse aftereffects of drainage and to suggest a system of preventive and control measures. This is a challenging task that must be solved by scientists specializing in land reclamation.

2. Needs for Drainage and Land Reclamation Resources

Lands with excess natural moisture content that are unsuited to agricultural production are widespread in humid parts of the world, including wet subtropical and tropical areas, where atmospheric precipitation exceeds evapotranspiration. Isolated areas of waterlogged lands can be found even in relatively dry climatic conditions of forest-steppe and steppe zones, where they are mainly confined to floodplains, the coasts of large water reservoirs constructed on the rivers, and to irrigation systems.

The need for drainage depends on the level of economic development reflected in the degree of intensification of agriculture and crop yields (see *Systems of Agriculture*).

The main drainage objects are river valleys and waterlogged mineral lands, as well as fen bogs. They all have a natural water regime unfavorable to farming: backwater, increased soil moisture content, and shallow groundwater.

Waterlogged lands are classified into two categories according to the duration of waterlogging: permanently waterlogged lands (bogs, flooded lands, low alluvial plains, coastal lowlands, etc.) and temporarily waterlogged lands. Permanently waterlogged lands are unsuitable for agriculture, although low yields of poor wild grasses can be obtained on them during some dry seasons. Temporarily waterlogged lands pose a risk for agricultural production, because crops cannot be grown or harvested in some wet seasons.

Permanently waterlogged lands are subdivided into peatlands, boggy soils, and mineral soils. The main criterion for their separation is the thickness of the peat layer (m) after drainage: peatlands have a layer of more than 0.3 m, while in boggy soils the layer is less than 0.30 m. In mineral waterlogged soils, there is no peat layer.

Bogs are subdivided by the topographic position and the kind of peat into low (eutrophic), transitional (mesotrophic), and high (oligotrophic) bogs.

Low-moor bogs and mineral soils are the main objects of agricultural amelioration.

Peats comprise soils with an ash content less than 50–75% of the dry matter weight; they can be subdivided into low-ash ($<$10%), medium-ash, and high-ash peats ($>$ 20%). The ash content in peat material depends on the species composition of peat-forming plants and the geochemical interrelations of a bog with adjacent territories. It has a zonal character, increasing in a meridional direction from north to south (in the northern hemisphere) in parallel to an increase in the erosion intensity and the salt content of the ground water. The high-ash peats have the highest value.

The distribution of bogs and boggy lands also has a zonal character: their area decreases from the northern agricultural boundary to the south. Climate is the main factor responsible for waterlogging: bogs develop in conditions of permanent or periodical dominance of atmospheric precipitation over evaporation.

Waterlogged mineral soils are characterized by the presence of reduced zones (gley features) at different depths (gleyed or gleyic soils).

The degree of soil waterlogging also depends on other factors: geological conditions (the soils of large tectonic depressions are more susceptible to waterlogging), relief conditions (the degree of ruggedness of the topography, slope degree, etc.), the character of parent rocks (water permeability and water yield capacity), hydrogeological conditions (the groundwater depth), natural drainage conditions (density and depth of the river system), and roughness of the soil surface, among other factors.

Soil waterlogging can also be caused by anthropogenic factors (the construction of reservoirs and land flooding, the elevation of groundwater table because of excessive water expenditure for irrigation, infiltration water losses from channels, etc.). The reasons for soil waterlogging should be determined clearly before the development of reclamation projects.

Land drainage and flood control works are performed on about 3 million km^2 (300 million hectares) around the world. These works generally affect the interests of various stakeholders. It is often necessary in drainage work for farmers to work together to accomplish their common goal: improved land drainage leading to sustainable farming. Drainage enterprise can be organized on the basis of voluntary or cooperative groups, legal organizations, drainage associations, informal drainage groups, and so on. Each of these has particular advantages and disadvantages; the choice of the most suitable form of drainage enterprise depends on local conditions. The majority of drainage works in European countries (the UK, Belgium, Germany, Italy, Russia, etc.) have been performed on the basis of drainage associations and legal drainage groups. State support of drainage works is primarily connected with control of the efficiency of drainage systems, the design of projects, and quality control.

3. Types of Soil Water Supply

The type of soil water supply determines the reasons for waterlogging and the main sources of excess moisture; it reflects climatic, geological, hydrogeological, geomorphic, soil, and other conditions (see *Organization and Management of Agriculture*).

Five main types of soil water supply can be distinguished: atmospheric, ground, ground-head, deluvial, and alluvial. There may be several types of water supply (or a mixed water supply) within a single area. In this case, the main type of water supply should be determined on the basis of water budget calculations for soil layers from the soil surface to either the lower boundary of the root layer, or the groundwater table, or the aquifuge. The main types of hydrogeological conditions in waterlogged areas are displayed in Figure 1.

Abundant water supply is characteristic of bogs developing in areas of groundwater discharge to the surface through head-water springs.

An equation for the groundwater balance or the water balance in the aeration zone (see *Agricultural Land Improvement*) can be used to determine the most important component of the water regime of a drained soil: the groundwater exchange rate and its recharge of the root layer. The value of water exchange between the groundwater and the aeration zone, *g*, changes at different seasons of the year: groundwater accumulates during periods of rains, whereas in dry periods groundwater recharges the root layer.

The water influx into the root zone is inversely proportional to the depth of groundwater. The main input element of the water budget in waterlogged soils is atmospheric precipitation, and the main output item is evaporation. The role of groundwater reaches its maximum in backswamps. To solve the water budget equation, data on precipitation and condensation (the latter is often negligible) obtained at meteorological stations, together with the results of hydrogeological (influx and deflux of groundwater), hydrological, and soil studies, are used.

Drainage procedures are mainly aimed at increasing the output items of the water budget, though it possible to regulate both input and output items of the water budget in order to maintain optimum moisture status in soils.

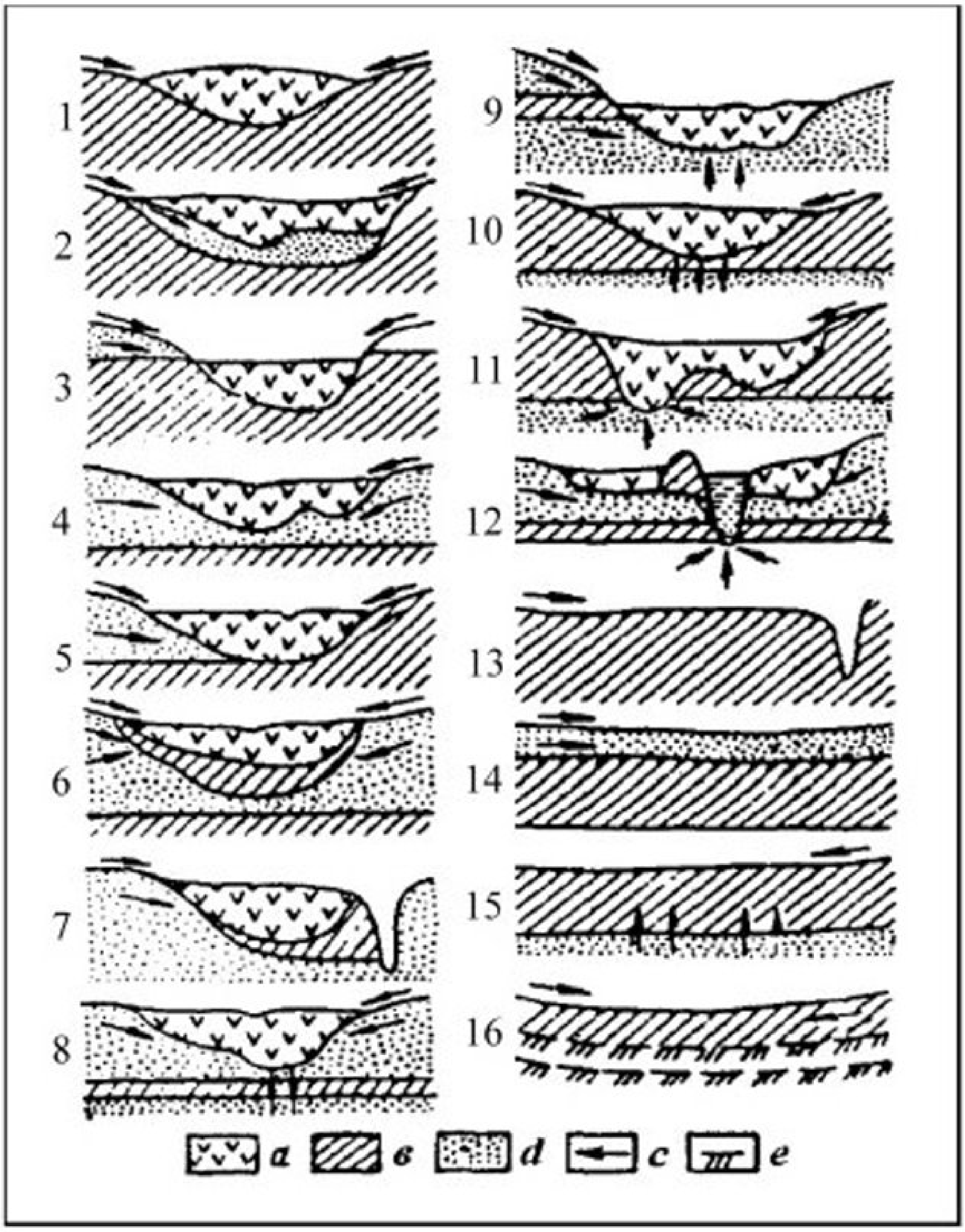

Figure 1. The main types of hydrogeological conditions in waterlogged areas

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Biographical Sketch

Boris Stepanovich Maslov was born in 1929 in Moscow oblast (Russia). He is a Doctor of Technical Sciences (1976), Professor (1979), Academician of the Russian Academy of Agricultural Sciences (1991), Honored Worker of Science and Technology of the Russian Federation (1994), Prize Winner of Council of Ministers of the USSR (1981), and Laureate of the A. N. Kostyakov Gold Medal (1993). His work in amelioration science was acknowledged by the jubilee diploma and medal of the ICID.

In 1954 he graduated from the Moscow Institute of Hydraulic Engineering and Water Management with a diploma in hydraulic engineering, specializing in hydromeliorative works. In 1965, he took training courses at the University of California.

He was the head of the Science Department of the Ministry of Melioration and Water Management of the USSR (1975–85); professor of the Moscow Institute of Hydromelioration, director of the A. N. Kostyakov All-Union Research Institute of Hydraulic Engineering and Melioration (1985–8); and the head of the Department of Melioration and Water Management of the RAAS (1991–9). In 2000, he was appointed the Senior Specialist of the Engineering and Production Center on Water Management, Melioration, and Ecology (Baumanskaya ul. 43/1, Moscow, 107005 Russia).

Professor Maslov's scientific interests encompass various aspects of land drainage and irrigation, reclamation hydrogeology, environmental conservation aspects of land reclamation, and the history of soil amelioration. He is the author of more than 500 published works, including forty monographs, on soil reclamation, meliorative hydrogeology, environmental protection issues related to land reclamation works, and the history of amelioration science. The main titles are: "*The Regime of Groundwater in Waterlogged Areas and Its Regulatio*n" (1970), "*Agricultural Amelioration: Textbook*" (1984), "*Amelioration and Scientific and Technological Progress*" (1986), "*Essays on the History of Land Amelioration in Russia*" (1999), "*Drainage Systems in the Twenty-first Century*" (1999), and "*Amelioration of Water and Land Areas*" (2000).

He participated in the work of several international congresses and symposia organized by the International Commission on Irrigation and Drainage (ICID), International Peat Society (IPS), and the Society of Agricultural Engineers, among others.