TECHNIQUES AND TECHNOLOGIES OF LAND DRAINAGE SYSTEMS

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Contents

Summary

Land drainage is performed through the construction of open channels and subsurface

plastic, ceramic, or tile drains. Land drainage projects are based on the results of topographic, soil, hydrologic, hydrogeologic, and other kinds of survey. The sizes of drainage channels and drainage parameters are calculated by special equations describing the hydraulic and filtration properties of soils. The main criteria used in these calculations are the desired drainage depth (the projected depth of the groundwater table), the drainage discharge rate, and the water-conductive capacity of drains. Water budget equations are used to determine optimum drainage parameters.

Envelope filter materials (sand, copra) are used to protect drains from silting; simultaneously, these filters increase the water intake capacity of drains and provide the hydraulic connection of drains with the plow layer in heavy-textured soils with low natural infiltration capacity. The deposition of iron oxides on drain walls (drain ochering) is another danger that decreases the efficiency of drainage. A system of preventive measures is required to minimize drain ochering.

Open channels are constructed with the use of heavy excavators. The construction of subsurface drainage is performed in trenches or without them, using flexible drain pipes and drain loaders. A crucial point in the construction of drainage systems is the driving of channels and drain pipes in strict accordance with the necessary slope angle. This is achieved with the help of laser-based equipment.

Special tillage operations—subsoiling, slitting, landforming, and land planing—are used to increase the efficiency of drainage. The removal of shrubs and stones from the surface, soil liming, and fertilization are also performed during the construction of drainage systems.

1. Introduction

Land drainage—the removal of excess water via open ditches, subsurface tile drains, vertical drains, or through the creation of dikes and pumping the water out from embanked areas—is widely used not only in agriculture but also in the forestry industry, municipal and industrial construction, the mining industry, the construction of sport facilities, and the organization of recreation zones.

Land drainage allows humans to bring low-productive areas (marshes, the sea bottom, inundated and waterlogged territories around water storage basins, etc.) into agricultural use and to raise the efficiency of farming. Land drainage has a long history: the first drainage systems were created in Ancient Egypt, China, and India as early as in the third millennium BC. Since that time drainage technology has improved considerably, in parallel with the general scientific and technical progress of our civilization.

Simulation methods are widely used for the scientific substantiation of modern drainage projects. A feasibility analysis of a drainage project should take into account not only economic but also environmental aspects of the problem. Modern drainage technologies apply the findings of many sciences, including physics, chemistry, mathematics, biology, ecology, soil science, and earth sciences.

Environmental protection should be studied thoroughly during the development of drainage projects. It is necessary to predict negative impacts of the future drainage system on the environment, including wildlife, and to suggest adequate mitigation measures. These measures should ensure the highest ecological security of drainage systems.

2. Drainage Techniques

As is shown in the article *Drainage of Farmlands*, open channels and subsurface drainage, as well as reclamation measures for agricultural land (soil profiling, mole plowing, furrows, etc.), are generally used to remove surface runoff and to lower the watertable. The main elements of a drainage system are considered below.

2.1. Channels and Subsurface Drainage

2.1.1. Open Channels

When measures are planned to accelerate the surface runoff and increase the filtering properties of soils, depending on the specific conditions, one should provide for:

(a) The covering, if possible, of abandoned channels, holes, quarries, and other excavations;
(b) The removal of liquidation from closed depressions by cutting artificial furrows for runoff discharge;
(c) The arrangement of channels to collect and remove the surface runoff;
(d) Thorough leveling of channel windrows and the establishment of discharge cones;
(e) Surface leveling by bulldozers or scrapers, with obligatory restoration of the humus horizon;
(f) High-quality planing of the surface by a long-base land leveler;
(g) The construction of percolation wells in combination with other measures;
(h) The construction of a thalweg system and subsurface collectors, if necessary.

To increase the filtering properties of fine-textured soils and to accumulate moisture in subsurface horizons, deep loosening is done perpendicularly to the regulating network with simultaneous liming or mole plowing, if necessary.

The discharge channels are 0.8–1.2 m deep. Their trapezoid cross-section has a bottom width of 0.4–0.5 m and 1:1 side slope ratio. The length of collectors depends on the size of plots with similar gradients; it is generally no more than 1–1.2 km. The least underwater gradient is 0.0005. The distance between collectors on clays and loams depend on the surface gradients and climatic conditions; they are generally no more than 60–120 m apart. Open collectors are not used for the drainage of plowland; the short channel spacings (50–100 m) interfere with machinery.

Thalweg channels 1.2–1.5 m in depth are used for draining narrow waterlogged areas between elevated relief elements. They are arranged in low relief elements. Discharge openings for surface water removal are established in windrows on either side of channels.

Channels (hollows) with very gentle slopes (1:8–1:10) and shallow depth (from 10 cm in the source to 40–45 cm in the mouth) which present no obstacles for agricultural vehicles are used to drain plains with surface waterlogging; tractor-drawn mowers and the like should be able to traverse the hollows freely in any direction. The cross-sections of hollows are trapezoid or triangular; they are made by hollow-makers or graders. The hollows are 400–800 m in length at an even topography. Where the water supply is from groundwater, channels find limited application in lowering the watertable. They are arranged in parallel (in a systematic network) across the groundwater flow at an acute angle with the horizontals (hydroisohypses), or along its lines in parallel with horizontals at low surface gradients.

The minimal slope of drainage ditches is 0.0005; their highest slope is not limited, because they are generally used in areas with low slopes. The length of drainage ditches is from 800 to 1500 m; they terminate in conductive channels at an angle of 60°–90° (or, more frequently, at a right angle).

Drainage ditches have trapezoid cross-sections with a bottom width of at least 0.4 m. Their depth is determined from the design watertable depth and the soil type; it varies from 1 to 1.5 m. The side slope ratio is 1:1 on shallow peatlands and deep grassy and mossy peats, and 1:1.5 on loams, sands, and other grounds.

The interditch spacing is determined from calculations or recommendations from expert organizations. An adequate watertable depth is generally provided for at a channel spacing of no more than 60–120 m.

A wide network of deep channels, sunk into sand by 0.3–0.5 m, is occasionally used on bogs with deep (1.5–3.0 m) peat beds, given a suitable economic and ecological foundation. The channel spacing is up to 500 m.

2.1.2. Subsurface Drainage

In this drainage technique, groundwater is collected and discharged into the conductive system through openings of a specified slope made in the subsoil layer. The opening walls and cavities can be paved or free. Therefore, drains are classified into the following groups: drains with paved walls and a free cavity (tile, plastic, wooden, etc.), drains with loose walls and a free cavity (mole and crevice), and drains with loose walls and a filled cavity (fascine, bat, and stone). Drains with paved walls or cavities (material drainage) are more stable and therefore preferable.

Subsurface drains are arranged in the traversal pattern, that is, at an acute angle to hydroisohypses. These drains are more effective in intercepting groundwater flows. A longitudinal pattern can be used only at low surface slopes (less than 0.001). In this case, drains should have an artificial gradient and their depth should vary from the source to the mouth.

Subsurface material drains are porous pipes laid on the trench bottom or special supports (stands), or pipes with interface gaps protected with a filter envelope from silting, and covered with soil to the soil surface. Supports are used where the ground is unstable, to increase the strength of pipes and preserve them from horizontal and vertical shifts. They are generally made of wooden or plastic laths.

Pipes can be classified in part according to the material of which they are made: ceramic, plastic, wooden, textolite, glass, and other types. The former two types are most widespread. The main pipe types are shown in Figure 1.

Patterns (c) and (d) are recommended for more uniform drainage on plains or gently sloping surfaces. Pattern (d) eliminates a serious problem: insufficient drainage in the drain-source areas and overdrainage in the drain-mouth areas, where the drains are deeper and the collector performs the drain function as well.

Tile tubes are fabricated from baked clay with admixtures. In the construction of a regulating system, 33 cm long tubes with an internal diameter of 50 mm (occasionally 75 or 100 mm) are used; gaps between the tubes in drains and headers should be no more than 1–2 mm.

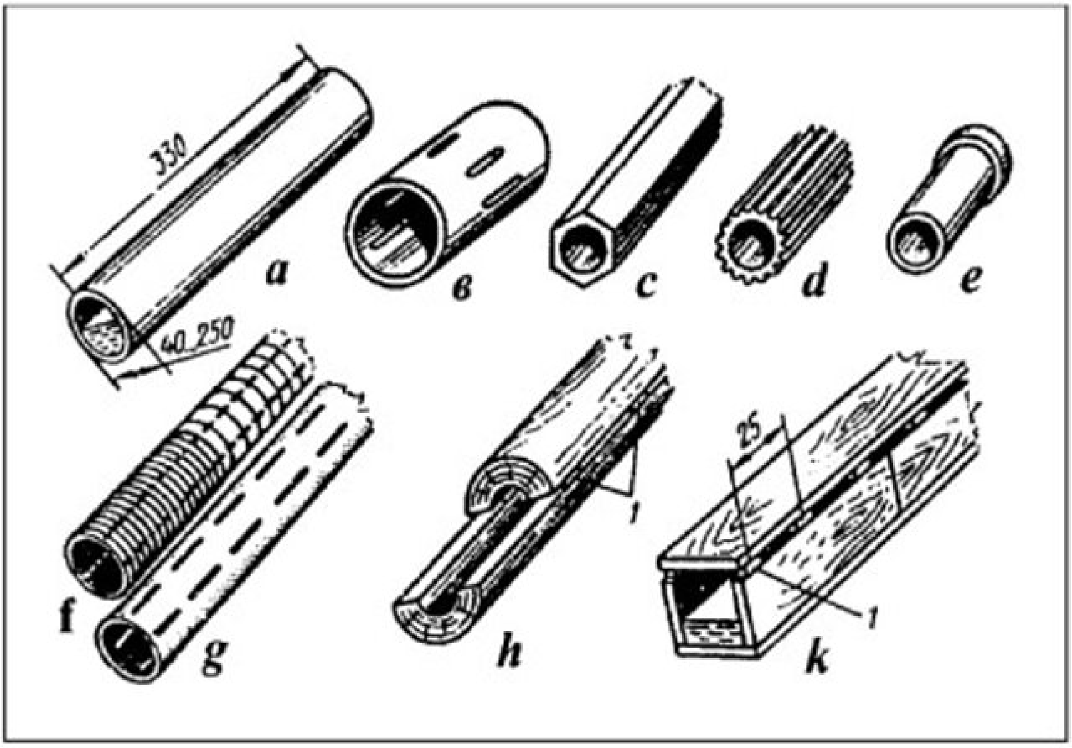

Figure 1. Construction of drainage tubes. Tile tubes: (a) round, (b) fissured, (c) hexahedral, (d) grooved, (e) bell-mouthed. Plastic tubes: (f) corrugated, (g) smooth-wall. Wooden tubes: (h) chase, (k) box-like. (*1*) Gaskets.

Tubes of larger diameters (75–250 mm) are used for collectors. The main sizes, and limiting deviations of ceramic drainage tubes from the nominal values, are specified in standards.

When drains are installed, the tubes are butt-joined. Water arrives in tile tubes through gaps in junctions that should not be more than 1–2 mm. The tubes are connected to a close collector. Connection sites are thoroughly covered with a protecting filter material (coconut fiber, sand, pebble, glass cloth, etc.), in a layer no less than 2 mm thick. For drains consisting of ceramic tubes, shaped elements (in ceramic or plastic) should be used: couplings, tee-joints, sleeves, plugs, outfall tubes, reducers, elbows, and so on.

Plastic tubes (corrugated and smooth wall) are made from high-density polyethylene (HDP) or polyvinyl chloride (PVC). Corrugated tubes are up to 100–200 m in length and are furnished in coils; smooth-wall tubes are furnished in full-length logs and seldom in coils.

The external diameter of tubes is 50–125 mm and more; the walls are 0.8–1.5 mm thick, and the perforated catch-water holes are 1.6 mm in diameter (the total perforation area is 8–20 cm^2 m^{-1}). The tube length in a coil is 60 to 200 m; the coil weight is 40–50 kg and more.

Plastic tubes have some advantages over ceramic tubes. They are light, elastic, and resistant, which ensures their transportability, complete mechanization of installation, and reliable functioning even in unstable ground. Plastic tube filters, made from perforated plastic tubes covered with a seamless filter jacket made out of fibrous-porous polyethylene or some other material, have found wide use. They are indispensable in the narrow-trench and no-trench constructions.

Wooden drainage can be made from boards (wooden box drainage) and rickers (trough drainage). Wooden box drains have a square, rectangular (with a clear size of 50 × 50, 55 × 45, and 75 × 75 mm), or triangular cross-section. Water arrives to wooden drains through 3–5 mm fissures between the ceiling and lateral boards. The fissures are filled with a sphagnum moss layer or glass material. The service life of drains in peat soils is up to 30 years.

Ceramic tubes are made of baked clay with admixtures. They are 33 cm long, with an internal diameter of 50 mm (sometimes 75 or 100 mm), and are used in the construction of the regulating network. Pipes with larger diameters (75–250 mm) are used for collectors.

The main sizes, and limit deviations of ceramic drainage pipes from the design values, are regulated by standards.

Water enters the pipes through interface gaps, which should be less than 1–2 mm. This stowing density ensures the optimal area of infiltration openings (perforation) that is no less than 4–10 square centimeters (up to 20–40 square centimeters) per running meter of the drainage pipe.

The ends of tile drainage pipes are plugged with ceramic or plastic stoppers, stones, or crushed tile pipes. Drains terminate in subsurface or (rarely) open collectors (see Figure 2). The attachment to the subsurface collector is the most crucial part of drains. Lap (rarely butt) drainage pipeline joints are used. Openings no less than 0.8 *d* in diameter (where *d* is the internal diameter of the attached pipe) are made in the joined pipes.

Fabricated plastic and ceramic connections are also used for these purposes. The pipe couplings are thoroughly covered with filter envelope and protected with crushed stone or a 30 cm layer of soil before pipeline burial.

Plastic drainage is made of plastic (PEH or unplasticized PVC) pipes. Corrugated or smooth-wall pipes can be used. Corrugated pipes have circular or sinusoidal corrugation profiles that make the rigid material of pipes more flexible and elastic. They are delivered in coils 100–200 m in length; the smooth-wall pipes are delivered in lengths and sometimes in coils.

Corrugated PEH pipes have external diameters of 50, 63, 75 mm and more. The thickness of pipe walls is 0.8–1.2 mm. The pipes are corrugated; the diameter of infiltration openings is 1.6 mm; there are 750–1000 openings, with the overall area of 9–20 square centimeters per running meter of pipeline. The smooth-wall pipes with an external diameter of 40–75 mm have walls 1.4–2 mm thick. Pipes of 40 mm diameter are delivered in coils 200 m long, and other pipes in 5 m lengths. The pipes are perforated with parallel fissures 0.8 mm wide, arranged in 6 rows with 60 mm spacing. There are 100 openings with the overall area of 14 square centimeters per running meter.

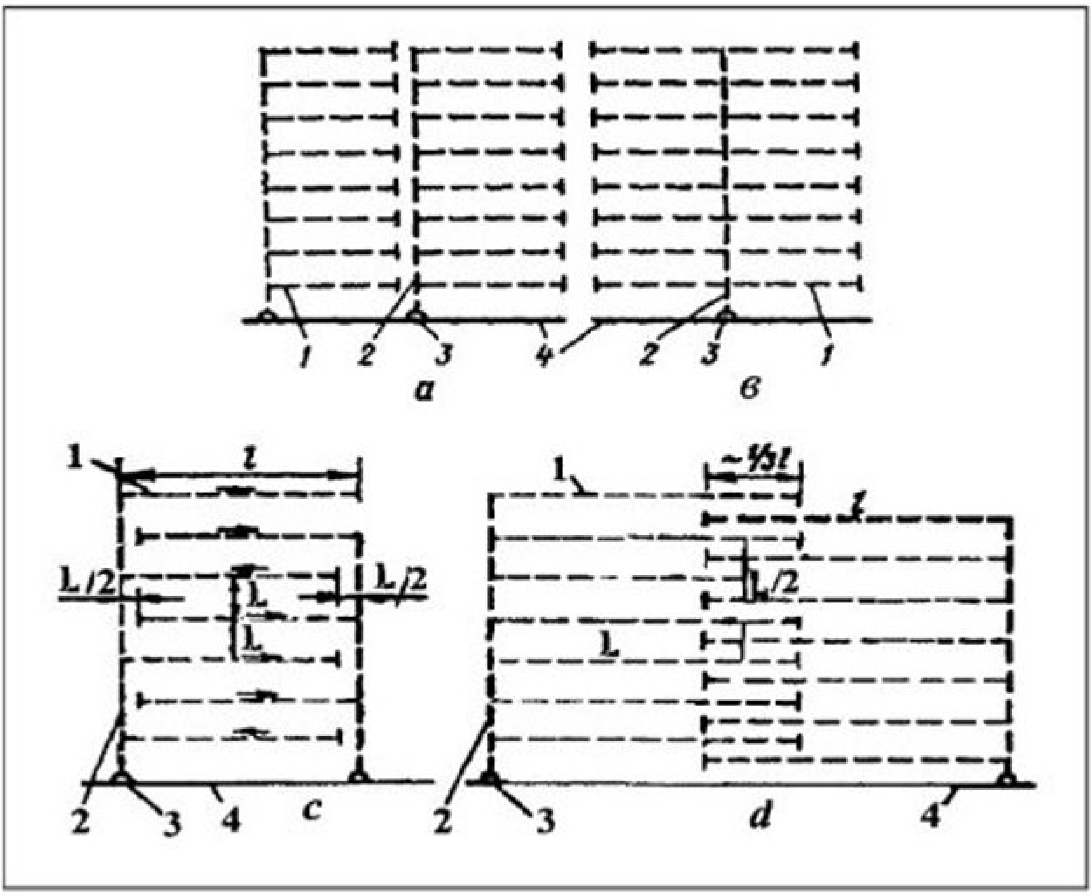

Figure 2. Drain arrangement patterns: (a) unilateral and (b) bilateral connection of drains to collectors; (c) alternate connection of drains to neighboring collectors; (d)

concentrated arrangement of source drain ends, connection "in comb." (*1*) Drain, (*2*) subsurface collector, (*3*) collector mouth, *(4)* main channel.

Plastic pipes have some advantages over tile pipes. They are light, elastic, and firm, which ensures their good portability and the all-around mechanization of construction works.

Wooden drainage can be made of boards (board drainage) or trees (wooden drainage). Board drains have square, rectangular (50 × 50, 55 × 45, or 75 × 75 mm in clear size), or triangular cross-sections. Water arrives in wooden drains through crevices 3–5 cm wide between the ceiling and lateral boards. The crevices are covered with a layer of sphagnum moss or glass material. The service life of drains in peatlands is about 30 years.

In drainage with loose walls, mole and crevice drains are used. Mole drainage is a system of underground loose cavities similar to mole burrows, with a preset slope at a specific depth. Mole drains 0.6–0.9 m in depth are established at the 5–10 m drain spacing. The length of mole drains is 100–170 m (rarely 200 m); their slope is 0.003–0.005, and their diameter is 6–22 cm (the highest size for peat). Mole drains are established using machines equipped with a passive tool, a mole plow, with a mole expander to create the required drain diameter.

Mole drains are arranged across the slope and terminate at the collectors at a right angle. The collector spacing is 350–400 m at the bilateral confluence of mole drains and 180–200 m at the unilateral confluence. Water arrives in mole drains through a knife fissure that retains increased water permeability, although it can become obstructed with soil over the whole drain service life. The mouth is the weakest element of a mole drain: it is destroyed under the impact of weathering and water flows much earlier than is the drain itself. In order to prevent deformation, the mouths of mole drains are fixed with ceramic or plastic pipes. Mole drainage is repeated every 2–6 years, depending on the soil resistance.

In distinction from mole drainage that operates as a regulating network, mole plowing is a land reclamation technique aimed at increasing the effectiveness of open or subsurface collectors. Mole plowing differs from mole drainage by the lower depth of molehill laying than of mole drains, and the absence of consistent slope along the full length. Mole plowing is performed to a depth of 35–60 cm, either simultaneously with plowing using a mole plow attached to a tractor plow base, or irrespectively of plowing (Figure 3).

Crevice drainage includes vertical fissures of different sizes in the soil to receive the groundwater and to drain it to channels. It is established in combination with the open channel network on stumpy and stump-free bogs where the degree of peat decomposition is no more than 45–50% and the depth no less than 1 m. Crevice drains are cut by specialized machines; they are triangular in shape, with a depth of about 80 cm and a bottom width of 18 cm. In order to prevent their filling with earth during soil plowing, they are covered to a depth of 35–40 cm.

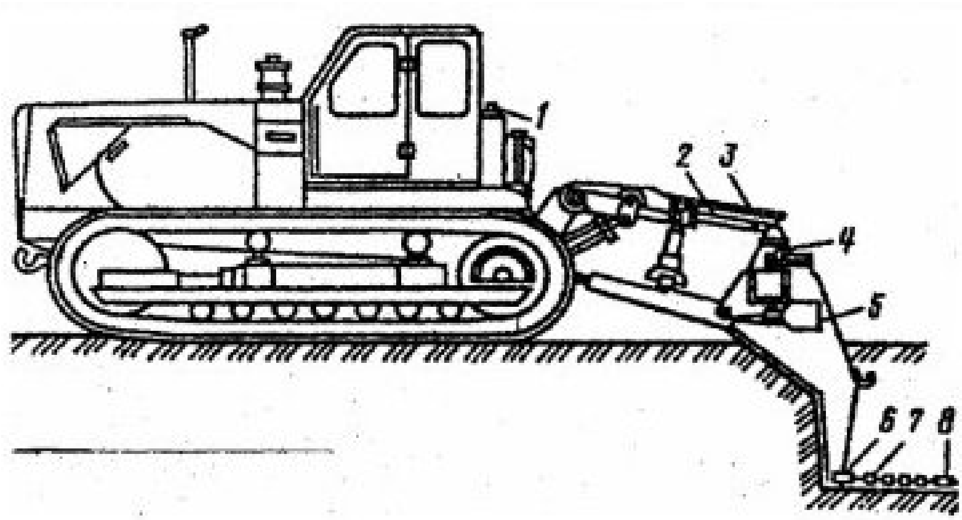

Figure 3. The design of a mole plow: (1) tractor, (2) hydraulic cylinder controlling the rotation of the working tool, (3) depth indicator, (4) frame, (5) blade, (6) steering cone-shaped mole, (7) chain, and (8) widening mole

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Biographical Sketches

B.S. Maslov was born in 1929. In 1954, he graduated from the Moscow Institute of Hydraulic Engineering and Water Management with a diploma of hydraulic engineer, as a specialist in hydromeliorative works. In 1965 he took training courses at the University of California. In 1976 he defended his doctoral dissertation; in 1979 received the title of professor; and in 1991 was elected Academician of the Russian Academy of Agricultural Sciences (RAAS).

He was the head of the Science Department of the Ministry of Melioration and Water Management of the USSR (1975–1985); Professor of the Moscow Institute of Hydromelioration, Director of the A.N. Kostyakov All-Union Research Institute of Hydraulic Engineering and Melioration (1985–1988); and Head of the Department of Melioration and Water Management of the RAAS (1991–1999). In 2000 he was appointed Senior Specialist of the Engineering and Production Center on Water Management, Melioration, and Ecology, Russia.

Professor Maslov is the author of more than 500 published works, including 40 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 Regulation* (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 has participated in the work of several international congresses and symposia organized by the International Commission on Irrigation and Drainage (ICID), International Peat Society (IPS), the Society of Agricultural Engineers, and other bodies. He is the Honored Worker of Science and Technology of the Russian Federation and Laureate of the AN. Kostyakov Gold Medal. His work in amelioration science was acknowledged by the jubilee diploma and medal of the ICID.

Yu.N. Nikolskii-Gavrilov was born in Moscow in 1941. In 1964 he graduated from Moscow Institute of Drainage and Soil Water Management with a diploma of hydraulic engineer. He defended his Doctor of Philosophy theses on Soil Water Management and Drainage in 1969; in 1989, he obtained a Doctor of Science Degree for his dissertation *Ecological Aspects and Optimization of Irrigation and Drainage.* In 1991 he received the title of professor. From 1964 to 1991, he worked as a research group leader at the Moscow Institute of Drainage and Soil Water Management (MGMI), Russia. From 1975 to 1976 he was visiting scientist of Unit of Soil Physics of Agriculture Research Council, Cambridge, England. Since 1992, he has been Professor Investigator at the Hydro Science Center of the Postgraduate College in Agricultural Science, Mexico. Professor Nikolskii-Gavrilov is the author of more then 100 publications on soil reclamation, plant-soil-water relationships, environmental impacts of irrigation and drainage. He has received several government honors including Achievement Award Medals from the Russian exhibition Centrum, and Presidium Award of the Academy of Agricultural Sciences of the USSR.