The method is used to drain some of the organic soils of Florida. The mole drains remain effective for 3 to 5 years. Mole drains would fill with sediment within a year in other places. The practice has not been widely adopted.

Research workers have developed a method of pulling moles and lining the channels during the same operation with a U-shaped or round plastic lining. This practice has created wide interest. Field trials have been undertaken to test the practice under a wide range of conditions, varying from the fine-textured soils of the humid areas to the saline and alkali soils of the Western States.

If the practice proves economically feasible, it will open tremendous areas of clay soils to moling and to obtaining the benefits of subsurface drainage.

PUMPING for drainage has increased greatly. Among the advances is the development of drainage pumping installations to reclaim and improve lowland.

Pumping installations have reclaimed some half million acres of fertile bottom land soils near the Upper Mississippi and Illinois Rivers. These districts cover 3 thousand to 15 thousand acres, and are surrounded by dikes to prevent overflow. The drainage pumps lift the water usually 10 to 25 feet from the drainage ditches to the river level.

This type of installation may be adopted readily to reclamation of coastal marsh areas.

The development of small, efficient pumping units and the widespread installation of electric powerlines have made it feasible to install small units to drain low fields frequently less than a hundred acres in size. Such installations may be used instead of lowering outlet drainage ditches. Small pumping installations may lift water from an open farm ditch or a tile line into an outlet ditch or from a deep tile drain into a tile at higher elevation.

In areas where artesian pressures cause an upward movement of the ground water, deep-well pumps, 60 to more than 100 feet deep, are installed to drain the land by pumping from deep subsoil layers. Such installations are most economical where the pumped water is needed for irrigation.

Submerged propeller-type pumps, developed since 1940, are adapted easily to automatic operation. Floats or electrodes, which do not require constant attention of an operator, control them. When the water level rises to a predetermined level, a float activates an electric switch, and the pump operates until the water is lowered in the ditch or tile to a lower level also adjustable to site requirements. These installations provide controlled drainage where the ground water level is raised or lowered to meet needs of the growing plant.

Drainage pump systems in the West are most feasible where the pumped water can be used for irrigation.

More advances in drainage activities can be expected. Our increasing demand for water has led people to think of finding new uses for drainage water.

We have been engaged in developing ways to get rid of excess water. The development of techniques for the full utilization of these excess waters will come in the next decades.

Aids for Irrigation

Tyler H. Quackenbush and Marvin E. Jensen

FROM MODEST beginnings, irrigation agriculture has spread to nearly 35 million acres in the United States and has involved a capital investment of about 13.5 billion dollars.

Irrigation was practiced as early as 700 A.D., when Indians along the banks of the Gila River in Arizona dug canals to convey irrigation water.

While some irrigation systems were installed in Texas and California in the 17th century, modern irrigation was started by the Mormon pioneers who arrived in the Salt Lake Valley in Utah in 1847 and plowed a furrow from City Creek to a small tract of sagebrush land in order to moisten the soil and grow grain and potatoes.

Our great expansion in irrigated agriculture has been brought about by economics and scientific advances.

The development of water supplies under the multiple-purpose concept began in 1931, when the Hoover Dam, which towers 726 feet above its foundation, was built on the Colorado River. This multiple use of water opened the way for the large-scale development of water resources in the West.

The first irrigation projects usually comprised only a diversion dam, headworks, canals, and suitable turnouts. As the readily accessible land was developed and the simpler storage sites were utilized, projects of greater scope and complexity were required in order to make the best use of water.

Multiple-purpose projects, such as the Columbia Basin project, which supplies irrigation water to a million acres in Washington and includes the largest pumping plant in the world, provide for the production of power, control of floods and silt, navigation improvement, regulation of rivers, municipal water supplies, fish and wildlife, and recreation.

These additional benefits are becoming more and more important. Their addition to project plans has made possible the development of large areas of irrigated land that could not have been economically feasible as single-purpose projects. An example of these less tangible benefits is that in 1959 recreational use amounting to 19.5 million visitor-days was made of 163 irrigation storage reservoirs administered by the Bureau of Reclamation. The value of this use has been put at 31 million dollars.

The scope and complexity of these multiple-purpose projects have increased the engineering problems in their design and construction. Without the advances that have been made in the development and use of such basic construction materials as soil and concrete, many of them could not have been built.

The increased knowledge of the behavior of construction materials has reduced construction costs. An example is the discovery that the addition of air-entraining admixtures to concrete increases its durability and the workability of the mix and allows a reduction in cement and water content.

The knowledge that the introduction of fly ash, a finely divided residue resulting from the combustion of coal, makes possible the use of leaner concrete mixes and lowers the heat of hydration has been a major factor in the design of concrete dams for storing irrigation water. The Hungry Horse Dam in northwestern Montana, which contains 2.9 million cubic yards of concrete, was among the first major structures in which fly ash was used.

Standard laboratory tests for determining the physical and chemical properties of soils to be used as construction materials or in foundations have permitted an expansion in the use of soil as a construction material. New construction control techniques make it possible to build structures of materials and on foundations that formerly were considered inadequate. This increased knowledge of the behavior of soils has made it easier to build irrigation canals and storage reservoirs in places formerly considered unsuitable.

The development of earthmoving machinery, such as carryalls, bulldozers, and draglines, which have been designed to do specific jobs more efficiently, have made it economically feasible to move millions of yards of earth at costs that have increased very little during the recent period of rising installation costs for other construction materials.

Irrigation development by its very nature requires the movement of large quantities of earth in order to store, transport, and use water efficiently on the land. Land leveling on individual farms accounted for the movement of about 500 million cubic yards of earth on 2.5 million acres in 1953–1958.

Modern equipment also enabled us to construct many miles of canals and ditches to transport irrigation water long distances from the source of supply.

A problem in the use of canals is seepage losses, which often amount to more than half of the water diverted into them. As a result, the waterlogging of lower lands has created drainage problems, and accumulations of salt and alkali have made it necessary to abandon some formerly good agricultural land. To overcome this hazard, low-cost canal linings have been developed. They reduce greatly and often practically eliminate the seepage losses.

Control of seepage has been made economically feasible by the development of subgrade-guided slipforms to line small canals and laterals with portland cement concrete or asphaltic concrete, which previously had been prohibitive in cost. The development of ready-mix concrete and the perfection of the equipment used for transporting it has been a big factor in adapting the use of slipforms to the small ditches on the farm.

Shotcrete—pneumatically applied cement mortar—also has been used successfully for many miles of canal linings. It is particularly well adapted to the Southwest, where variations in temperature are not extreme. Other good lining materials are asphalt, bentonite, compacted earth, soil cement, plastic membranes, and butyl rubber membranes.

The manufacture of concrete pipe and installation techniques have developed to the point where it is generally feasible to transport irrigation water in buried pipelines. Concrete pipelines also are cast in place by the use of removable inner forms and slipform techniques. Other widely used types of pipelines are of steel, aluminum, asbestos cement, and plastics.

The use of plastics as plastic pipes and as protective coatings for steel lines has helped solve severe corrosion problems that once limited installations of pipelines in many places.

Aluminum pipe, light in weight and strong enough to withstand high pressures, has sparked a phenomenal growth of sprinkler irrigation.

WATER CONTROL structures are required in irrigation systems.

As irrigation water becomes more valuable and the labor needed to operate and maintain the irrigation systems becomes more critical, more efficient and more fully automatic gates, diversions, and head control structures are required.

An example of this type of structure is a gate, developed in France and widely used in this country, which can control automatically the discharge with a varying water level either above or below the structure. The gate rotates around a central pivot with radial arms and counterweights. It opens or closes as the water surface rises or drops. Gates of this type are expensive to install, but usually they pay for themselves in savings in water and labor.

Other types of water-control structures, which have automatic controls and use power to raise or lower the gates, provide higher operating efficiencies with less labor.

More pumps and wells have come into use. For example, the number of acres irrigated from wells in Nebraska increased 290 percent in 1955–1960; a total of 22 thousand wells were pumped. The number of irrigation wells in the High Plains of Texas increased from 8 thousand in 1948 to more than 45 thousand in 1958.

The Geological Survey estimated that approximately 33 million acre-feet of water was pumped for irrigation in the United States in 1955. That is more than the maximum capacity of Lake Mead above Hoover Dam in Arizona and Nevada or three times the capacity of Lake Roosevelt above Grand Coulee Dam in Washington.

This great increase in the use of ground water for irrigation is due largely to improvements in well drilling techniques, more efficient pumps and power units, and the general availability of power on the farm.

Diesel engines furnish cheap power for lifting large amounts of water great distances. More electricity on farms has eliminated many maintenance problems that were encountered when internal combustion engines were used. The irrigation farmer therefore has a more dependable source of power, which has increased his dividends from his investment in irrigation equipment.

New devices accurately measure water without changing greatly the cross section of canals. Water must be metered accurately when water from a project is distributed to many farmers and when specific amounts of water are applied to fields.

One method of water measurement consists of placing a wall across the ditch or canal with a notch for water to flow through. These notches are called weirs. Rectangular and trapezoidal weirs that use equations for converting the depth of flow to cubic feet per second were developed in the 19th century; they are still being used on many projects in 1960, but they are being replaced with measuring flumes because silt, sand, and gravel collecting above weirs cause inaccurate measurements. One such flume was developed in the early 1920's by R. L. Parshall in Colorado. This flume causes water to flow through a restricted opening in the channel.

Weirs also require more drop in the water level than Parshall flumes. A recent development is a trapezoidal flume whose sidewalls slope to correspond to the usual canal cross sections. It also has a flat bottom that is level with the canal bed. Other new measuring devices are flow meters installed in pipelines or pipe outlets. They permit direct reading in acre-feet or cubic feet of the amount of water that has passed through.

Many devices rely on the principles of submerged orifices, pipe orifices, weirs, reduced cross sections (as used by the venturi meter), and velocity meters. A pivoting flow vane can be installed in a channel with a uniform cross section. As the depth of flow and velocity increase, the vane is deflected more so that a direct indication of the rate of flow is obtained.

EQUIPMENT for regulating the flow of water from irrigation ditches to individual furrows or borders have improved the uniformity with which water is distributed and reduced the labor requirement.

Early irrigators cut ditch banks and then used a hand shovel to dig small channels to individual furrows—a laborious job that often did not apply water uniformly. Men have tried to improve the procedure. In Wisconsin in 1900, for example, a 36-inch strip of canvas was formed into a pipe with canvas outlets for individual furrows.

Similar devices used now have been improved considerably. Lightweight aluminum pipe, which has valves or other types of openings such as sliding stainless steel gates, commonly known as gated pipe, has come into use. Gated pipe is used to convey water along the upper end of the field and deliver it to individual furrows with a minimum of manual labor.

Other materials—improved canvas, butyl rubber, and nylon-reinforced neoprene—also are used to make gated pipe. Plastic, aluminum, and rubber siphons are used to distribute water from field ditches to furrows and border strips. Plastic, metal, and canvas dams in field ditches have reduced the labor once required when hand shoveled earth and sod dams were used.

Irrigation water is distributed in the field by surface or sprinkler methods. Early surface irrigation was done with furrows, corrugations, and contour ditches, because little leveling was required. Because the furrows sometimes ran down steep slopes, erosion was caused from irrigation water and runoff from rainfall.

Greater costs and more accurate leveling was required for surface systems that used border irrigation because uniform grade and minimum side slopes were required. Early irrigators often felt the cost was too great to justify extensive leveling with existing equipment. Also, with abundant water supplies, they felt that they did not need such systems for satisfactory irrigation. When water is allocated more sparingly, many irrigation farmers now spend 100 dollars an acre or more to modify surface irrigation systems for more efficient use of water.

Soil-moving equipment, such as rubber-tired scrapers that hold 5 to 11 cubic yards of soil and have chain and paddle loaders, allows the use of tractors for moving soil economically and rapidly from high places to low places. Large scrapers, drawn by crawler tractors, are used extensively. Landplanes up to 80 feet long and land levelers, which have automatic cut and fill devices, are used to finish the land smoothing, often to an inch of the desired grade.

Electronic grade control devices for trenching machines have been adapted for land leveling equipment.

Other equipment constructs and shapes border dikes without the use of hand labor. Fields can be made completely level in both directions. Sloping lands are shaped into level benches. Level irrigation systems provide efficient distribution of water, especially in places where large streams are available for irrigation. Rainfall is also held in level irrigation systems; that reduces the amount of irrigation water that is needed.

Techniques for stockpiling topsoil for replacement over areas that have deep cuts are used when benches are constructed on steeper slopes and topsoil is required to maintain yields.

Subirrigation, usually used in places where subsoils are permeable, permits water from parallel ditches to move laterally as crops use water. New porous pipes can be put close together in the soil for this purpose.

Among the many laborsaving devices are semiautomatic check gates, which open by various timing mechanisms, and are used when water is applied by surface systems.

The designing of modern, efficient irrigation systems requires experienced technicians and involves the consideration of the size of the available stream, intake rates of the soils, crops, water-holding capacities of the soils, and the peak and seasonal water requirements of the crop.

Irrigation guides have been developed to assist technicians in designing irrigation systems. Soil surveys also have provided information.

Reversible two-way plows mounted on tractors or tractor drawn have been developed for plowing surface-irrigated fields. The plows do not leave furrows in the middle of leveled fields. Tractor-mounted ditchers with hydraulic controls build field ditches with a minimum of labor.

Sprinkler systems have been improved greatly. They permit the irrigation of many fields unsuited for land leveling and also are used on soil that could be irrigated equally as well by surface methods.

Sprinkler systems have made possible the expansion of irrigation into areas that ordinarily require only one or two light irrigations to supplement rainfall. They are used also to protect orchards and vegetable crops against frost damage. Many types of quick couplers are used with lightweight aluminum pipe for rapid movement of laterals by hand.

Many types of sprinkler equipment are such that tractors can be used to move completely assembled lateral lines in one operation. Supplemental engines are mounted on some laterals for moving; the complete line is rolled on wheels.

Other self-propelled systems rely on water-actuated cylinders to propel a single pipe with sprinklers attached, mounted on wheels, and pivoted at one end in the center of the field. One such system can irrigate 40 acres to 160 acres in one revolution without the use of hand labor, except for servicing and adjustments.

Some systems use large booms; the sprinkler heads are mounted on movable trailers. Each setting of the boom will sprinkle 2 to 4 acres.

Another system uses a complete coverage of small-diameter aluminum pipe in the field. When the pump is started, only the first sprinkler on each lateral operates. When the pressure is reduced for a few minutes and increased again, the second sprinkler on each line begins to operate. Automatic valves at each sprinkler regulate the flow to individual sprinklers. Automatic controls start and operate the pump for given periods.

Pressure regulating devices permit more uniform distribution of water on sloping ground.

Instruments and equipment turn sprinklers on and off when the moisture in the soil reaches a predetermined level. A clock mechanism turns it on at specified times during the day. Automatic devices turn the sprinkler off when winds are too high for the uniform distribution of water.

Training and experience are needed to determine the best size of pipe and nozzles and the other factors.

Devices to measure soil moisture enable irrigators to determine when to irrigate for optimum yields. An example is the various types of blocks that are sensitive to changes in moisture and are buried in the soil. Wires leading from electrodes in the blocks to the surface are attached to a small meter, which indicates changes in resistance between electrodes. An indirect measure of soil moisture thus can be had.

In coarse-textured soils, such as sands and sandy loams, other instruments measure the suction force at which the soil holds water. The instruments consist of a porous cup at the end of a tube, which is placed in the soil to the desired depth. The tube, which may be of transparent plastic, is filled with water. A vacuum gage is attached to the upper end. The gage indicates the suction exerted by the soil.

The use of these and other instruments has provided valuable information on the water-holding capacities of soils, rates of water use by various crops during various stages of growth, the effective root zone of various crops, and the amount of leaching required to maintain a desirable salt balance in the soil. Continual use of water that contains some salts for irrigation requires occasional leaching to leach salts downward. Evaporation from the soil surface and transpiration of water by plants results in an increase in salt content unless leaching is provided.

Modifying Soil Profiles

R. M. Marshall and W. A. Raney

MAN CHANGES many things to suit his needs and wishes. He sometimes changes soils when he determines that such modification will enhance his use of the land. He often modifies the soil when natural forces—floods and erosion—and his use have produced a soil with undesirable properties.

Soil often is modified to improve the soil-water-plant relationships. This means improved infiltration, transmission, and retention of water for use by plants.

The anticipated increase in population and nonagricultural demand for land and water resources necessitates much more efficient use of those resources than currently exists.