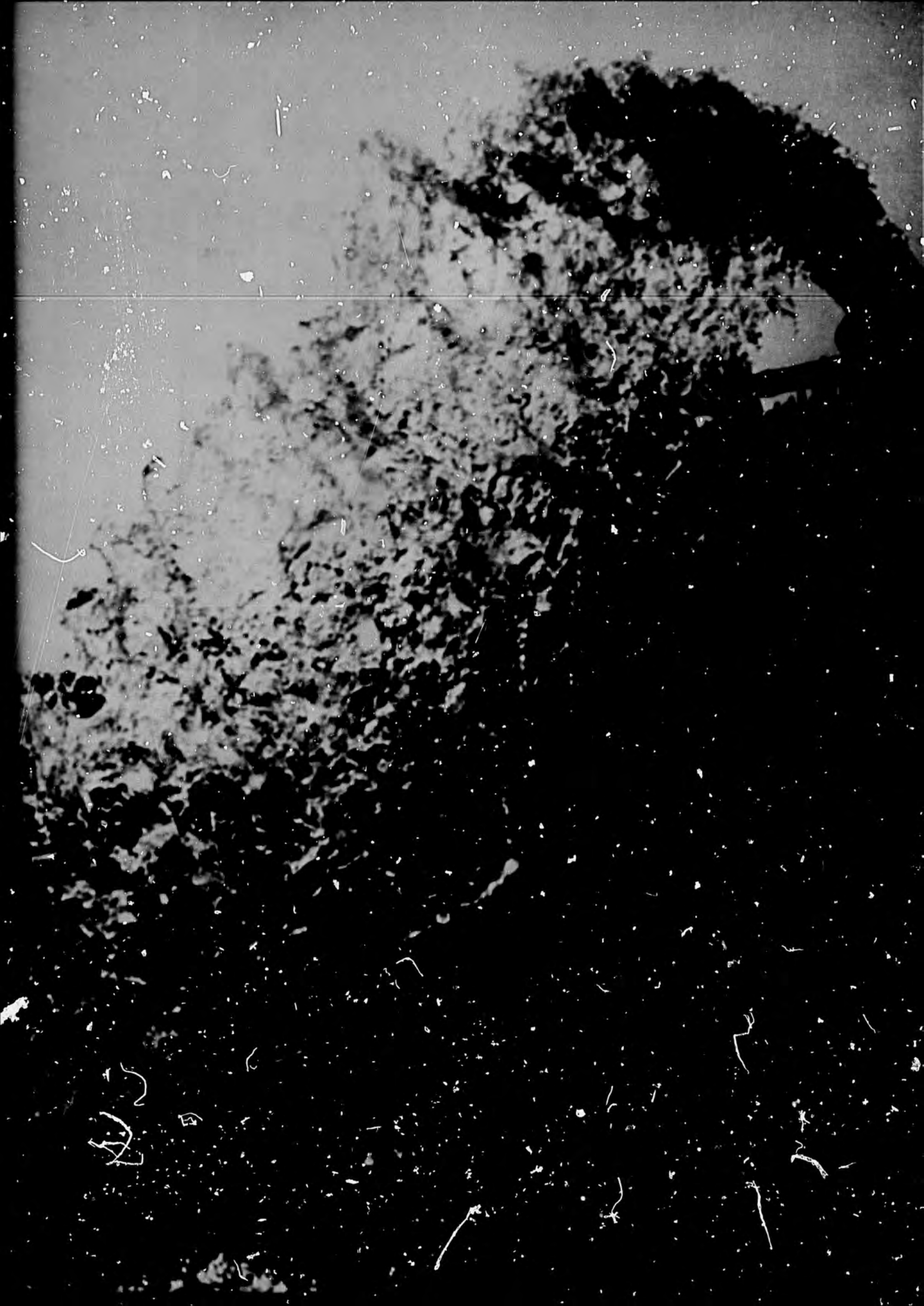
A Technical Guide to Water Management on Small Farms

Provided by the
United States Agency for International Development (A.I.D.)

Concern for man and his fate must always form the chief interest of all technical endeavors. Never forget this in the midst of your diagrams and equations.

-Albert Einstein



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Introduction

Man has been engaged in agriculture for the past 10,000 years, since farmers first learned to cultivate food crops. About 8000 B.C., men began to domesticate wild wheat and barley, and in so doing domesticated themselves. In increasing numbers, families gave up the nomadic life of the hunter and the gatherer and began to bend nature to their will.

The first farming began in, or near, the Fertile Crescent, that hilly arc of land curving north from the Arabian desert. Three or four thousand years later, farming was independently developed in northern China, Mexico, and Peru. The full-scale development of farming is known as the Neolithic Revolution, and it established man as the dominant form of animal life on the planet.

With the growth of agriculture, great civilizations were created, and large cities rose on once barren landscapes. However, the inability to exercise control over water sources often brought these civilizations and cities to ruin; removal of vegetation from hillsides brought about erosion and destroyed soil fertility. The story of agriculture in the alluvial plains of Mesopotamia is a story of people who lived and grew up under the threat of raids and invasions from grassland and desert tribes, and of the failure of irrigation canals that became loaded with silt. Scientists are finding that farmers face the same problems today in using water on their land; the same potential for disaster continues to exist.

Lessons Learned

Late in 1975, a team of water management specialists from the U.S. Agency for International Development met with farmers in a country struggling to increase its food production to discuss ways of improving the leaky watercourse that served their fields. The leading farmer in the area was anxious to mend the watercourse and make it more efficient, but he explained that a third of the shareholders belonged to another village, and they refused to cooperate with the others on a project designed to benefit the whole community. "My arms are open," he explained, "but my brotherhood is moribund."

A local extension officer, who understood how village rivalry can stand in the way of implementing practical measures for the common good, combined wisdom with grass-roots diplomacy to achieve the desired end. He first led all but the recalcitrant farmers along the watercourse, where he helped his countrymen understand how much of their water was being lost. He next chose the leading farmer and a man of religion to visit the neighboring villages, where they met after evening prayers to resolve their differences. In the end, all of the farmers agreed to put their weight behind the watercourse project.

A special training team went to work with topographical surveys, water supply and loss measurements, and other data-gathering activities necessary to the reconditioning of the watercourse. The farmers were kept informed of the team's progress. The results were sufficiently convincing to the farmers that they agreed among themselves to work on improving the watercourse during the holy season of Ramadan. They decided upon a workday from 6 a.m. until noon, or until each man completed his share; the length assigned to each farmer was in proportion to the land he owned in the watercourse command area.

The work continued harmoniously, interrupted only for wheat planting. Contractors agreed to a time-payment plan for building some of the needed watercourse structures, and in one case a supplier of precast panels charged the farmers 25 percent less than he had been charging government agencies. The farmers did most of the installation and canal improvement work themselves.

When the project was completed, the farmers could view the results (nearly 3500 meters of greatly improved watercourse at modest cost) with justifiable pride. The observable benefit was a 50 percent increase in the amount of water delivered to the fields.

The Challenge Now

Agriculture directly controls the economic and social life of 70 percent of the world's people. Although the state of agriculture is improving, it is improving so slowly that economic progress remains inhibited, improvement of rural life continues to be frustrated, and increasing numbers of people once wedded to the soil are fleeing to urban centers with often tragic consequences to themselves and to the community at large.

Strenuous efforts have been made in the past to rapidly increase agricultural production in food-deficient regions of the world, but overall performance has not reached expectations. Careful, if narrow, planning has been coupled with technical competence and large expenditures of money to increase yields. Although the gross yield has improved, the per capita yield has often remained the same or even declined in the face of rapid population growth.

The construction of new irrigation structures, for example, frequently has not been the action that produced the most rapid benefits. Perhaps the emphasis should be more profitably turned to improved water management practices on the farms themselves, where water can be better utilized for production of food and fiber.

Much has been learned—and much is yet to be learned—about helping farmers in the field. Several features of the process of technological transfer stand out. The farmer's own place in the structure of his own society and his habits of working the land must be considered. In proposing solutions to what might appear to be simple problems, the agricultural technician or extension agent must be aware that local institutions and relationships play no less a role than does the most sophisticated technology in reaching workable solutions.

Fieldwork in a number of countries has provided examples of what can be accomplished with farmer participation and with little capital outlay. When farmers were shown how to repair leaks in a watercourse, water losses were cut in half. When farmers complained, with justification, that factory-made siphon hoses were prohibitively expensive, efficient siphons were fabricated from junked tire casings at minimal cost. Not only were farmers able to distribute water where it was needed, but a new home industry was created to manufacture the new siphons. When a farmer complained that his crop yield did not meet his expectations, an examination of his field showed that the primary problem was the uneveness of the land. Once the problem was identified and the field leveled, crop yields jumped 50 percent over preceding years. Such low-cost improvements are relatively easy to implement and are highly visible to the farmer.

The philosophical premise at the heart of this presentation is that the farmer himself is the key to successful operation of any irrigation system and that he will react positively to new techniques that are sound and profitable, as well as compatible with his culture. Farmers want immediate, direct solutions to problems, once the problems have been identified; they will use a technology when they see it demonstrated on familiar land and are convinced it will work for them. Placing technologies on the farm where the benefits can be observed is crucial to the transfer process.

The following chapters serve as a guide to some of the technologies that are available for helping the farmer achieve maximum crop production with the best use of scarce water resources.

1

Crop Water Requirements

In 1975, an AID advisory team conducted surveys to probe farmers' knowledge of plant-soil-water relationships in order to help them improve crop production with savings in water. The findings can apply to any nation.

"When water is available," they asked, "how do you decide which crop needs irrigation?" To 40 percent of the farmers, the appearance of the soil was the most important factor in deciding which crop needed water the most; 31 percent replied that the last date of irrigation was the most important; 26 percent said the appearance of the plants was paramount; and a few said they had no idea or left it to the will of God.

The farmers were then asked how they determined when to irrigate. Seventy-nine percent replied that they timed it by the appearance of the crop, and 16 percent based their decision upon how the upper soil surface looked. Not one of the farmers surveyed indicated that he would check the subsoil for moisture content. Moreover, there was little evidence that the farmers knew the effective water-holding capacity of the soil profile or the depth water would penetrate from normal irrigation. When asked how far down the soil would be wetted if 125 millimeters were ponded on their fields, the answers ranged from 12 to 75 millimeters. Yet, tests showed that most soils in the area would wet down to 750 millimeters with a 125-millimeter irrigation. The farmers were even farther from the mark in guessing the depth of the root systems for their various crops.

During certain seasons, farmers were observed to be overirrigating crops by a factor of 2 to 3 times actual water requirements. This was to be expected, given the lack of information available to the farmers on soil moisture or the plants' ability to extract water from this moisture reservoir with their long and extensive root system.

Crops have differing water requirements for healthy growth

Studies of irrigation water requirements have been carried out for more than a hundred years, but in the last few decades these studies have been intensified and have become more scientific. A wealth of information is now available to help predict water requirements for crops. This information is vital for technicians engaged in helping farmers achieve real economies in water usage with increases in food output.

In irrigated agriculture, water supply can be the limiting factor, or availability of land can control how much food can be produced. Where water is scarce or expensive, irrigation should be scheduled for maximum crop production per unit of water. Conversely, where good land is more scarce than water, irrigation should be scheduled for maximum crop production per unit of planted area. In either case, farmers need guidance on how best to use the water available to them.

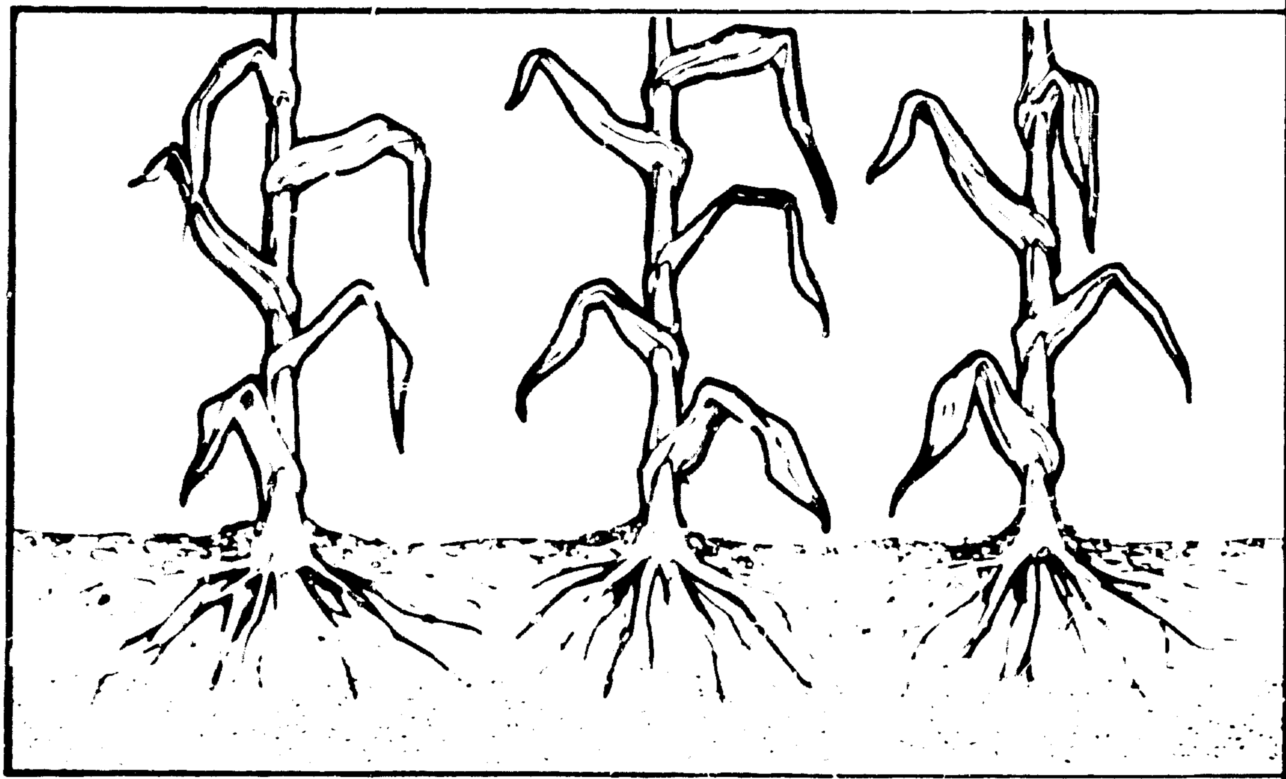
Evapotranspiration Methods

The amount of water taken up and transpired by growing vegetation, plus that unavoidable evaporation of moisture from the soil surface, is the consumptive use of the crop, described as evapotranspiration. The evapotranspiration rate is important; it establishes the rate at which an irrigation system must be able to supply water to the fields to ensure healthy plants and bountiful harvests.

The starting point for efficient irrigation is knowing how to estimate evapotranspiration with reasonable accuracy. Extreme accuracy is not possible except under the best scientific conditions, and this is not necessary because even under the best of circumstances, farmers cannot control the water reaching their fields with the precision that exact evapotranspiration figures would dictate. Fortunately, the determination of an evapotranspiration estimate to within ±10 percent of the actual need is accurate enough for the farmer's needs, and simple methods are now available to technicians to arrive at the necessary estimates.

Many factors bear upon crop evapotranspiration. Among them are variations in wind, temperature, and solar radiation. The size of the fields and the nature of the surroundings—altitude, soil water availability, salinity, irrigation methods, fertilizers, insect and disease infestation, and local methods of cultivation—also are important in varying degrees. In the face of these and other variables, farmers need to know approximately how many millimeters of water per day a particular crop will use and how much water should be applied at each irrigation.

Farmers need to understand effective water-holding capacities of soils and learn how deep irrigation water will penetrate into the root zone.



Evapotransporation pans, like the one seen at left, can help predict crop water requirements in most climates.

There are no fewer than 30 different estimating techniques available to provide the answers, and virtually all of them involve energy balance, mass transfer and combination equations, and all require complex instrumentation and highly skilled personnel to get accurate results. Fortunately, there is also a simple method that requires little scientific data to determine evaportranspiration.

The Pan Evapotranspiration method has much to recommend it because it provides a direct means of measuring evaporation in the field. It automatically integrates all those factors that affect evaporation and, when careful attention is given to pan environment, mean monthly evapotranspiration can be predicted to within ±10 percent or better for most climates.

The evaporation pan commonly used is the U.S. Weather Bureau Class A pan, 121 centimeters in diameter and 25.5 centimeters deep. The pans are made of 22-gauge galvanized iron or of 8-millimeter monel metal. Painted inside with a coat of aluminum paint, which should be renewed yearly, the pans are placed on a slatted wooden platform with the bottom 15 centimeters above ground level. The soil is built up to within 5 centimeters from the bottom of the pan, and water is added until the level is 5 centimeters below the rim; this water level should never be allowed to fall to more than 7.5 centimeters below the rim in order to avoid excess air turbulence when wind moves over the pan.

When properly installed and maintained, Class A pans provide an accurate measurement of the integrated effects of radiation,

$ET(crop) = kc \times ETo$

wind, temperature, and humidity on evaporation from an open water surface, reflecting the response crops have to the same climatic variables. However, an experienced technician knows there are factors that can produce dramatic differences in water loss between open surfaces and plants themselves. For instance, reflectivity of radiation from water surfaces seldom exceeds 8 percent, but most vegetation throws off as much as 25 percent of received solar radiation. Most crops lose about 95 percent of their water during daylight hours, but heat retention within the pan can cause almost equal distribution of evaporation during both daylight and darkness.

The immediate pan environment has a direct bearing upon the rate of evaporation, but coefficients have been worked out that take into consideration most variables, and simple tables and formulas enable differences to be reconciled. With proper siting and regular maintenance, Class A pans are highly recommended for predicting crop water requirements for periods of 10 days or longer.

Evapotranspiration Calculation

Whichever method is used to calculate evapotranspiration, there are elements common to the final steps of any procedure. Once the standard reference value of potential evapotranspiration has been determined, it must be multiplied by a crop coefficient to get the actual crop evapotranspiration figure. This value, ETo, has been defined as "the rate of evapotranspiration from an extended surface of 8- to 15-centimeter tall grass of uniform height, actively growing, completely shading the ground and not needing water."

To illustrate, using the pan evaporation method, a reference crop evapotranspiration, ETo, is calculated by the simple equation:

$$ETo \times Kp = E\ (pan)$$

where Kp is an empirically determined pan coefficient, and E (pan) is the measured pan evaporation in mm/day. Values of Kp depend on wind, humidity, and conditions of the area surrounding the pan. Kp values of 0.7 to 0.8 are common but can range from a low of 0.4 up to 0.85 for extreme conditions.

The predicted daily crop evapotranspiration, ET (crop), is determined by another simple equation using a crop coefficient:

$$ET\ (crop) = kc \times ETo$$

where kc is a crop coefficient that depends on the crop and its stage of growth at the time. Typically, kc values are small during the seeding state, e.g., 0.35, increasing as the crop reaches a maximum during the critical

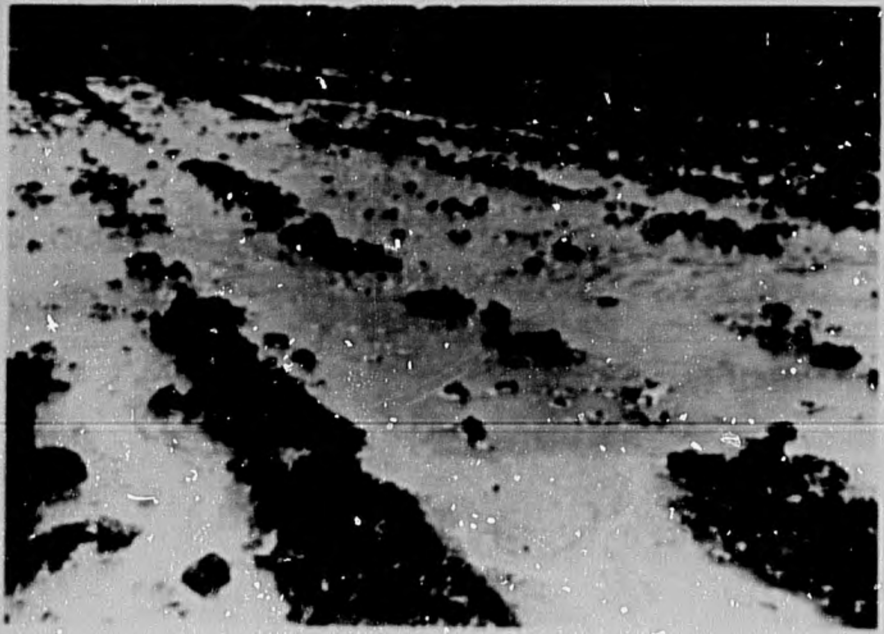
Evapotranspiration rates play a key role in determining how much irrigation is needed for specific crops. Transpiration can be cut down by enclosing crops within plastic tents, allowing transpired water to be collected and used again.

flowering and fruiting stage. Typical maximum values of kc for grain crops such as maize will be 1.0 or slightly higher.

Values of Kp for various climatic conditions and values for kc in selected crops are given in the 1975 publication, *Crop Water Requirements*, published by the Food and Agriculture Organization of the United Nations. Another useful and comprehensive report, *World Water for Agriculture*, has been prepared by Utah State University for AID. This report summarizes climatic records for weather stations throughout the world, taken from data gathered by the World Meteorological Organization. The data presented are important in assessing water availability for food production without irrigation and the irrigation needs for many locations in the 93 countries given coverage. From the data, technicians can immediately estimate likely water requirements in these places.

A Final Comment

It has been proved that water losses to vegetation along canals can be reduced by destroying unwanted phreatophytes, plants whose transpiration index is high. The widespread destruction of these phreatophytes remains controversial, however, because of possible disruption of the environment. Transpiration can also be reduced by building windbreaks to cut down air movement over crops and by enclosing crops within structures so that transpired water can be collected and reused. Research has shown that spraying certain crops with reflective materials reduces the absorption of solar energy, thus lowering leaf temperatures and subsequently slowing the transpiration rate. Chemical antitranspirants are highly effective in closing plant leaf



Too much irrigation is often worse than too little.

stomata and reducing transpiration, but the practice restricts the essential intake of carbon dioxide, threatening plant growth. These chemicals are expensive and are impractical for widespread use.

Knowledge of evapotranspiration is a necessary aid to water scheduling and savings and to increased crop yields. It is part of a broader program involving water management research, part of the effort to reach an understanding of local crop-weather interactions. However, until all the other problems related to water application on the farm are solved, ultimate precision in evapotranspiration has little value. The real question in the allocation of research funds concerns priorities and how these funds can best be utilized in the identification of serious water management problems at farm level.

Another factor to be considered is the common practice of delivering water on a rotational basis. Technicians can advise farmers when to irrigate to coincide with critical stages of plant growth, but this critical stage probably will not coincide with a particular turn at the water. Farmers often trade their turns, but

Tubewells can supply needed water, but timing and amount of water delivered to crops is critical.

this is an unreliable way of solving the problem; the practice of buying water from private tubewell owners is also an unsatisfactory solution. The problem of timing water delivery deserves serious attention on the part of government irrigation planners to avoid curtailment of food production.

When it comes to the design and operation of a new irrigation project, the need for information on crop water requirements is es-

sential. The ability to estimate evapotranspiration with reasonable accuracy is paramount in laying out irrigation channels to serve a patchwork of fields to be planted with a variety of crops during periods of peak use.

2

Land Grading for Water Control

Most irrigation is carried out by allowing water to flow over land surfaces, where it soaks into the soil. The surface of irrigated fields must be even and relatively flat so that water will be equally distributed over the cultivated portion of the land. Nature seldom provides such ideal field surfaces, and farmers generally have to grade their lands.

Precision land grading to provide conditions for efficient surface and subsurface irrigation can be counted as one of the greatest improvements in irrigation within the past century. Land grading programs, begun in earnest in the 1850's with the use of animal-drawn scrapers, have become increasingly sophisticated; an example of this sophistication is the technology now available using laser beams that pinpoint surface irregularities to be swept away with land leveling machines.

Worldwide research has shown that crop yields are adversely affected by uneven water application on poorly graded fields; invariably, some parts of the field receive too much water, and other parts receive too little. An AID-supported study of this problem involved 15 plots of land 6 × 6 meters square, where elevation differences between high and low spots averaged from 8 to 27 centimeters. The yield results of these fields, which were planted in cotton, showed a 50 percent reduction in yield in the grossly overirrigated low sections, compared to the yields produced in the mid and high elevations.

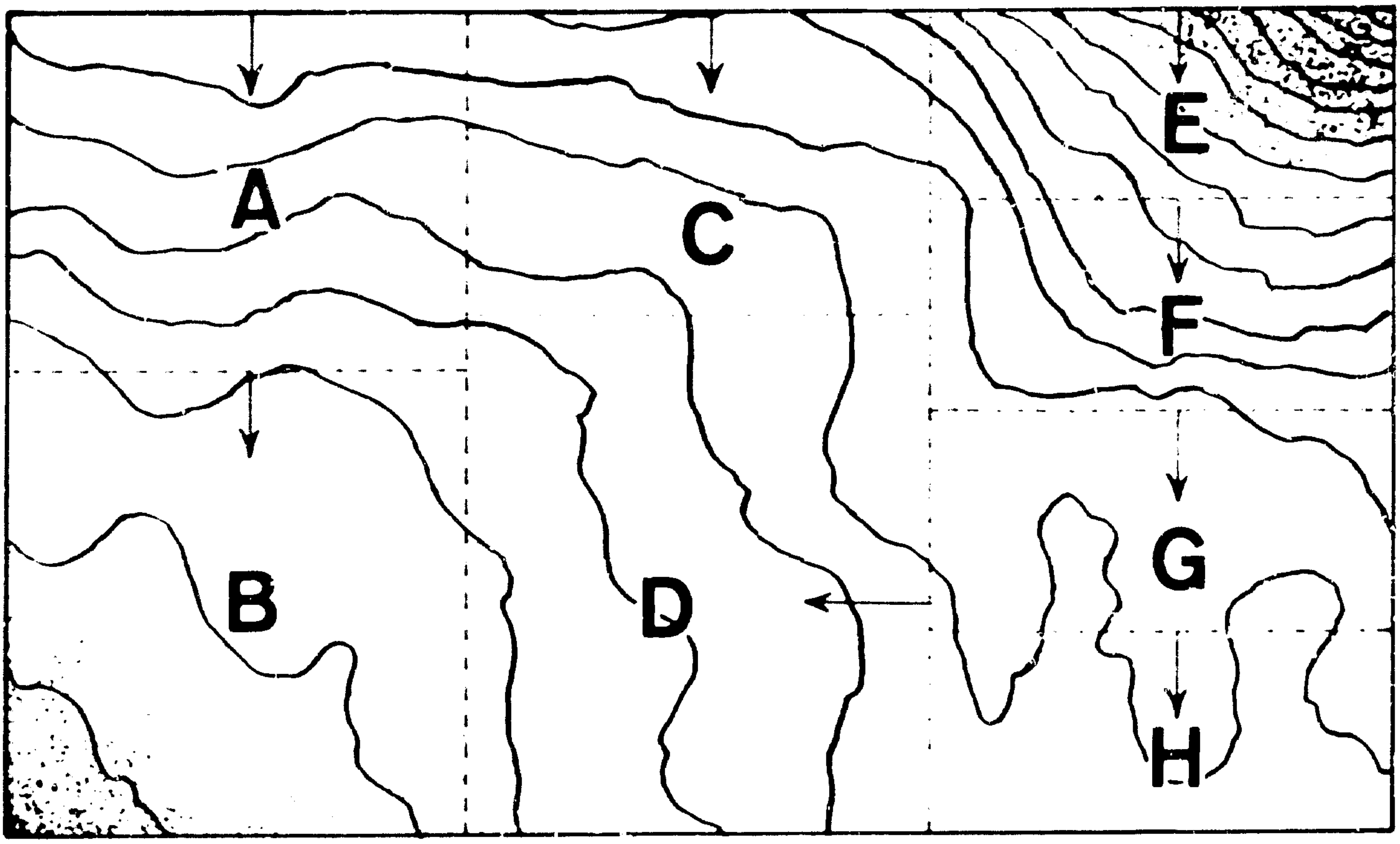
Precision land leveling is beneficial to any crop; however, not all sites are suitable for grading. Gravelly, sandy, and organic soils usually exhibit such high water intake rates that grading for surface irrigation might not be

worthwhile. If, after initial wetting, the soil absorbs water at a rate exceeding 75 millimeters per hour, surface irrigation will be so inefficient that water will be wasted. In addition, drainage and salinity problems might also develop. A higher limit of 100 millimeters per hour may be used if the individual plots to be irrigated are small and the irrigation stream is large. Further, there are some soils that have the right quality but are not deep enough to make grading practical. Sprinkler irrigation might be the answer in these instances.

If water intake and soil depth are satisfactory, farmers and their advisors must be sure there is enough water at hand to do the job once the field is graded. Where border or some kind of flooding are the chosen irrigation methods, the flow of water must be enough to spread across the field so that proper lateral surface distribution is obtained with a minimum of deep percolation.

Where row or furrow irrigation is used, there should be enough water available to set a number of furrows simultaneously. If only a small amount of water is available, the water provided by an overnight storage reservoir can be combined with the daytime supply to meet the farmer's total water needs. Otherwise, land grading will not be practical, and technicians might decide to recommend trickle or sprinkler irrigation, if feasible.

Land grading for rice dates back to prehistoric times, when early cultivators built low dikes around their plots and then used water leveling to remove surface irregularities. This was accomplished by loosening the surface soil, filling the plot with water, and dragging off the high spots. The system is still in use today, although "puddling" is generally thought of as a preparation for a seed bed instead of proper land grading; however, in some newly irrigated areas, three puddling



Precision land leveling begins with a survey of the field to provide a contour map showing elevation differences within a farmer's plot of land

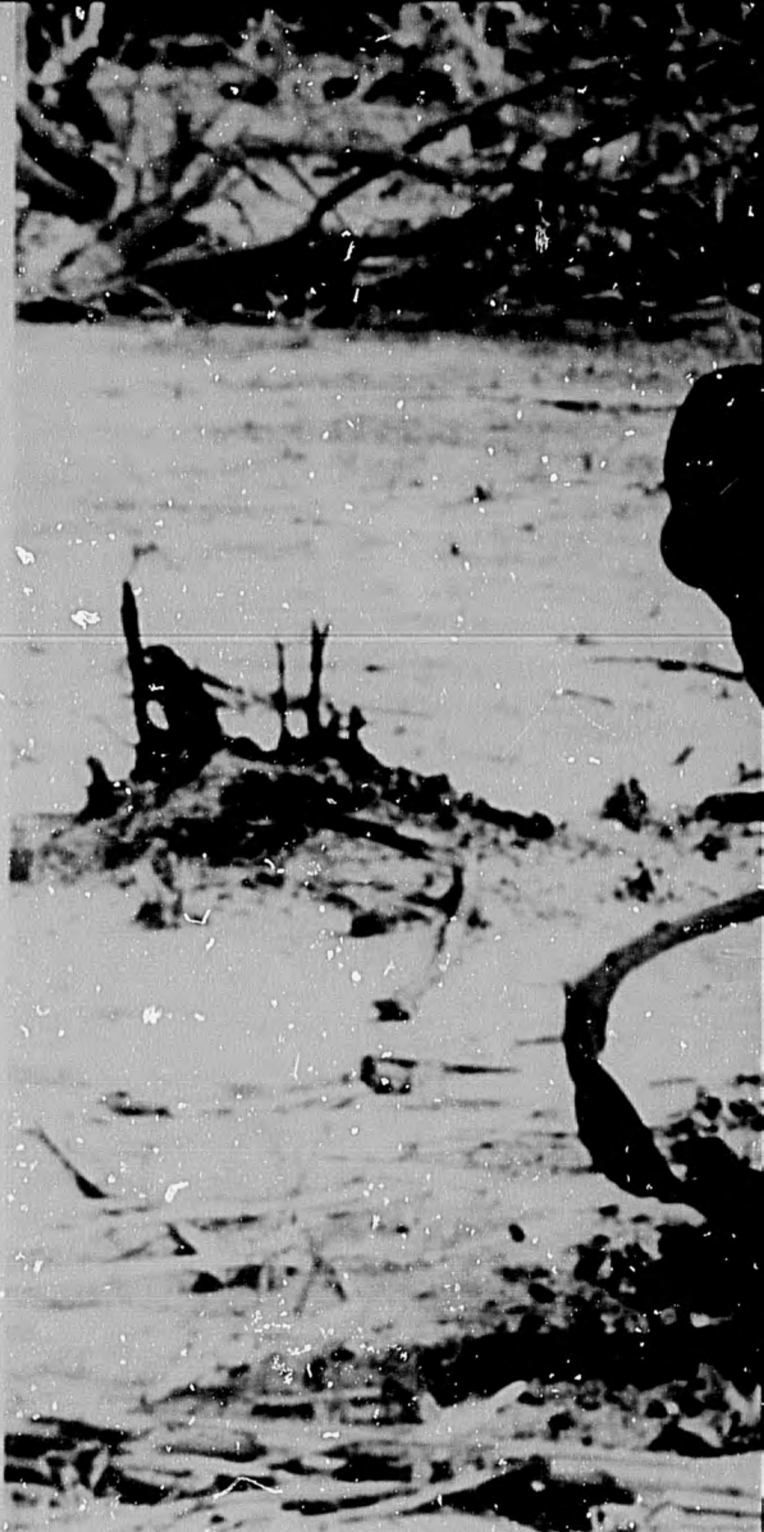
operations will usually level a field. Worldwide, more irrigation water is used for rice than any other crop, and millions of hectares of land have been treated in this manner to grow Asia's staple diet. Puddling has definite limitations; it destroys the soil structure, and it inhibits the growth of plants not adapted to wet environments.

When leveling dry land, the procedures are fairly straightforward. Native vegetation and the residue from past crops, which interfere with grading operations, are extracted from the earth with machines or by hand. The field is surveyed, staked, and topographically mapped by technicians from public agencies or by private engineers and land surveyors who provide the necessary calculations for cut-and-fill data. The soil is then loosened as the final step before grading operations begin.

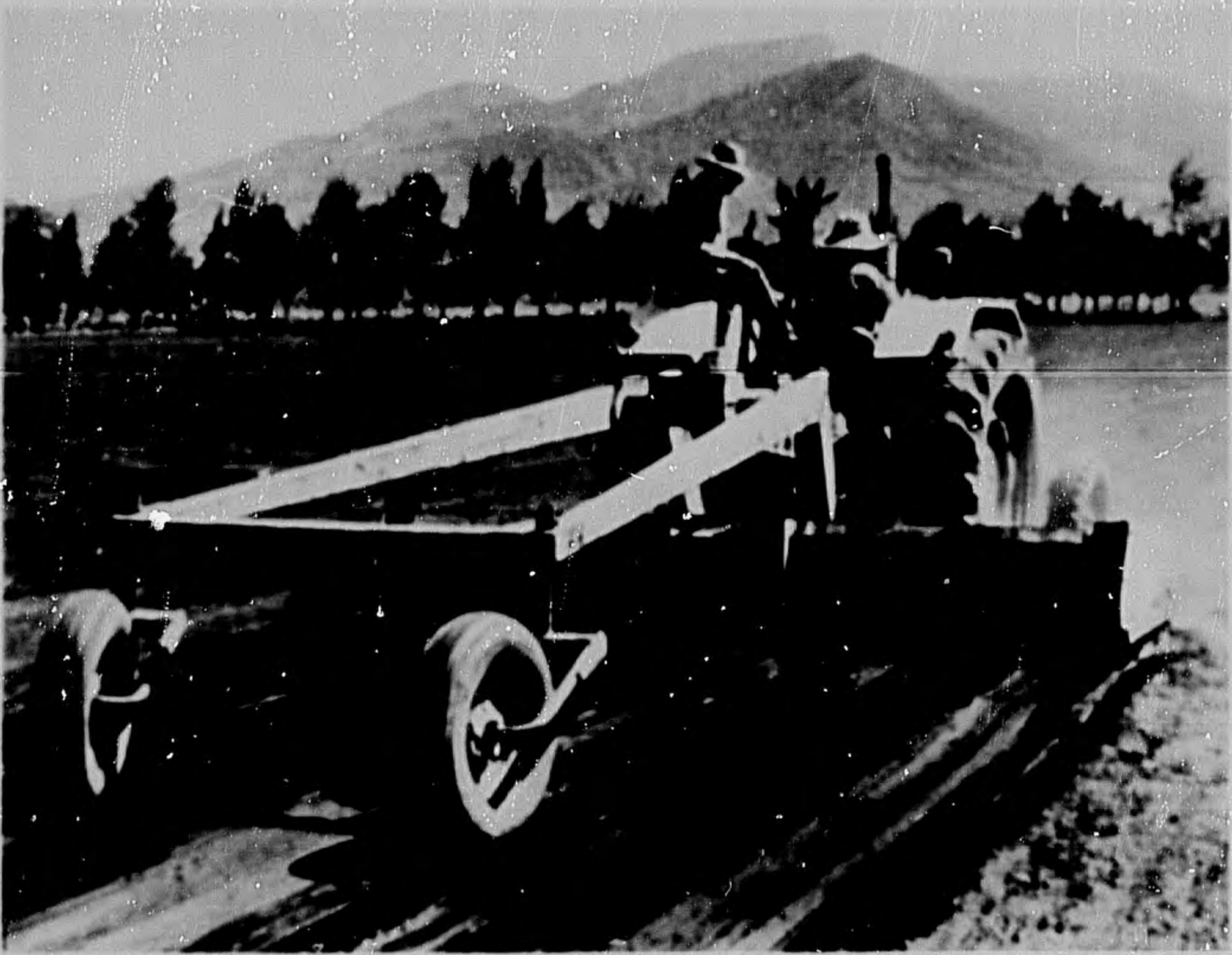
Grading can be carried out in a variety of ways. Not all of them require sophisticated and expensive equipment. The best time to carry out preliminary surveys—and certainly the best time to execute the grading operations themselves—is during the dry season. It is potentially injurious to soil to operate heavy earth-moving equipment during wet weather or across muddy ground.

Altough the farmer himself can attack the surface irregularities of his land using available hand tools, such methods are inefficient and seldom effective. Such manual eradication of smaller humps and hillocks is easier when the field is irrigated prior to planting. In many parts of the world, wooden scrapers with steel blades are harnessed to pairs of bullocks or donkeys for more efficient leveling, and although these methods cannot equal the job that can be done with mechanized equipment, it should be borne in mind that some grading is better than no grading at all. Savings in water and increased yields are related to the amount of grading that can be accomplished.

Except for the instances cited above, where farmers can grade small parcels of land



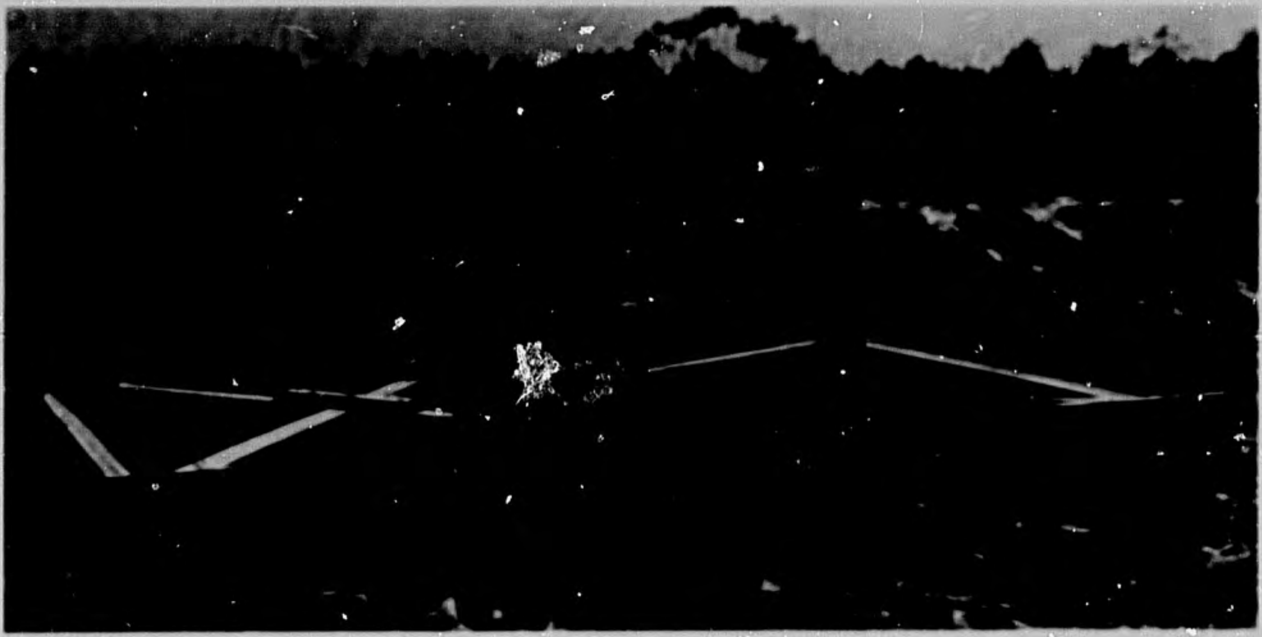
Where mechanized equipment is not available, a start at land leveling can be made with hand tools to clear away gross irregularities.



Tractors with land planes are ideal for smoothing nearly level land

using man or animal power, major earth-moving operations must be done by specialized mechanical equipment, at which time cost becomes a serious consideration. Most land grading in the main irrigated valleys of the world requires movement of 1,000 cubic meters of earth per hectare, or less. If a survey indicates shifting of 2,000 cubic meters per hectare is required to level the land, grading is usually not economically advisable; sprinkler irrigation might be an economic alternative.

It is practically impossible to level land precisely without a machine. The proper machine is called a soil scraper, which is capable of picking up small slices of surface soil and depositing them in similar layers in the low spots. Scrapers are usually powered by tractors, but animal-drawn scrapers have been used successfully. Rubber-tired tractors are becoming more popular than crawler tractors for agricultural land leveling because they are faster. Scrapers are available for tractors as small as 35 horsepower, which can effectively level



Wooden floats are easily made and can be dragged across fields by bullocks or donkeys.

Animal-drawn metal scrapers can be substituted for tractor-drawn land leveling machinery.

field units as small as half a hectare. In no case should bulldozers be used to level agricultural land; they are highly inefficient for such work, and it is impossible for them to carry out a precise land leveling job.

Where available, planing machines (land planes) should be used to smooth land once initial grading has been completed. Some of these planing machines are gigantic, measuring 30 meters long and 5 meters wide, but smaller units are available for small farm tractors. When pulled across a field, this equipment removes high spots and fills in depressions automatically. Final smoothing operations are executed by planing in three directions—once along each diagonal and once in the direction of the flow of irrigation.

Farmers should be encouraged to plant annual crops the first year in newly graded fields so that irrigation water or rainfall can settle the ground. Farmers who are introduced to precision land leveling for the first time should be made aware that the surface will be distributed from season to season by normal farming operations and that they must maintain the leveled field to protect their initial investment in time and equipment. Planing machines are excellent for this.

Land grading activities can be coordinated with watercourse improvements. Sometimes, government assistance in these important activities is available, and often they can be better done together. Watercourses may need to be relocated to improve their efficiency, and field sizes may need to be increased prior to conducting land grading operations.

Where land is level, irrigation is more efficient, crops more bountiful.

3

Irrigation Methods

The major building block of any agricultural irrigation system is the farmer himself, for he is the man who must make the system work. The constraints that farmers must deal with provide the basis for assessing those problems facing many countries where food production must be substantially increased.

Production difficulties in irrigated agriculture most often are related to unreliable irrigation supplies, inefficient water management, negligible water management extension services, and the persistent use of traditional irrigation and farming practices unsuited to modern agriculture. These constraints cannot be overcome by individual farmers or by groups of farmers alone; governments must step in and take action to help solve water management problems on the farm. Otherwise, irrigated agriculture will remain inefficient regardless of national investments in major works such as large dams and other costly structures.

Most farmers are willing to accept new technologies that are available when they understand how they will benefit from those technologies. But when the same technologies are presented to them without explanation or the opportunity to participate in the selection of those technologies, it will be considerably harder to gain the farmers' acceptance. More is known about the technological aspects of water management problems than is known about how to overcome habits, traditions, and customs that are detriments in getting the needed technology applied.

There are three primary irrigation methods, with variants. Farmers need sound guidance as to which one best suits their needs and capabilities. Surface, oversurface, and subsurface irrigation must satisfy at least four requirements:

- Ability to maintain a continuous supply of readily available moisture for the crop being grown
- Ability to maintain a healthy soil environment for the crop's root system
- Ability to function properly, given the characteristics of the soil, the topography, and other physical conditions
- Ability to provide a satisfactory net return to the farmer

Surface Irrigation

Surface irrigation includes many variants, but essentially they all provide for application of water directly onto the surface of the land, either to flow across a graded field or to be applied to specific points. Before selecting which method best suits the farmer's needs, variables must be taken into account that influence the uniformity of distribution. These variables include infiltration rate, topography, soil texture and structure, water holding properties, rates of movement within the soil, and cultivation requirements of the crop being grown.

One of the simplest ways to irrigate is to create a basin into which water is impounded and allowed to percolate into the soil. The farmer selects a level field and surrounds it with an earthen dike or levee to contain the irrigation water. Basin irrigation can be applied to areas as small as one square meter and, if a large irrigation stream is available, to areas as large as 5 hectares. The most important soil factor in contemplating basin irrigation is the infiltration rate. Soils with high infiltration rates require small sized basins; otherwise the water will simply soak in at the turnout and fail to spread evenly across the field. The use of basins is not recommended for crops whose stems are sensitive to wet soils or for annuals grown in soil that crusts badly when flooded.

Despite the attraction offered by basin irrigation's simplicity of construction, there are drawbacks inherent in this method of irrigation: dikes can interfere with moving farm machinery, and ponded water will become stagnant in low areas, reducing soil aeration and providing a breeding ground for mosquitoes.

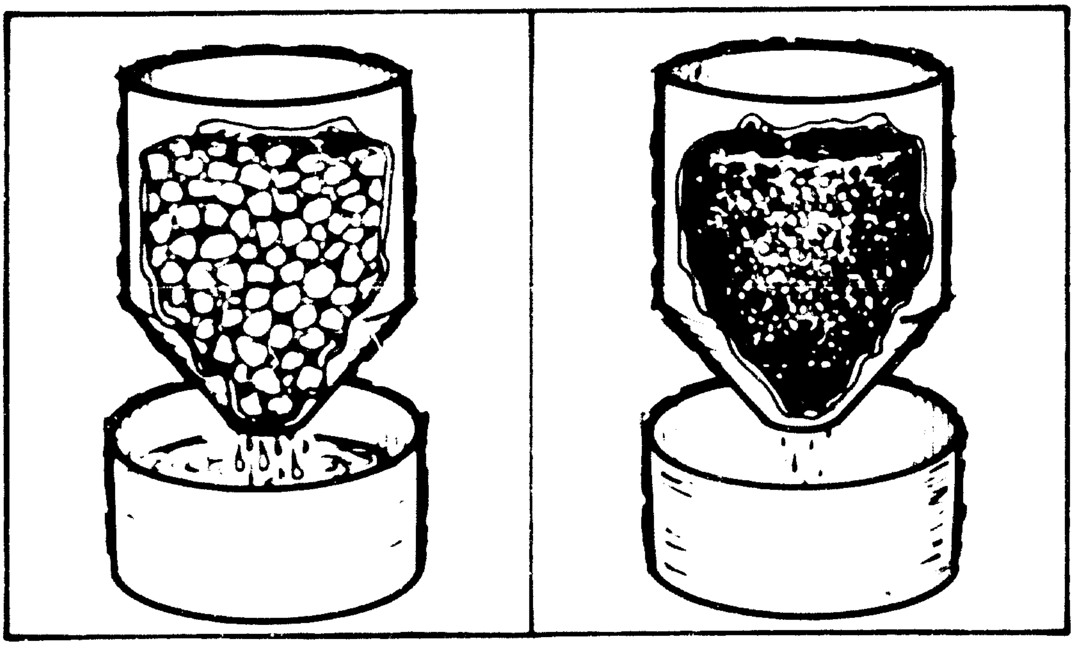
Graded border irrigation requires the formation of parallel earth ridges 3 to 50 meters apart. Between each ridge the farmer locates a graded strip where crops are planted. These strips vary in length from 100 to 1000 meters.

Border irrigation requires large water flows across land with a uniform, moderate slope in the direction of the flow, and the borders should be as level as possible cross-slope. Medium textured, deep permeable soils are ideally suited for border irrigation of both deep and shallow-rooted crops. The water infiltration rate is more critical with border irrigation than with basin irrigation, and the velocity with which the water moves down the strips must be regulated by the size of the irrigation stream so that the water covers each section for the time required to penetrate to the right depth.

Furrow irrigation is ideal for crops grown in rows, but water control is needed to avoid spillage from one furrow to another.

Tables are available to suggest the length and width of border strips, average desired water depth, unit flow of water per meter, width of border strips, and percent slope on different soil textures. Graded border irrigation is not suited for sandy soils with low water holding capacity, but it is suited for loam soils with moderate intake rates and average water holding capacities, as well as clay soils with slow intake rates and high water holding characteristics.

Furrow irrigation is best suited for crops grown in rows, such as cotton, maize, and vegetables, or for crops that can be damaged when water covers the stems or crowns of



The water infiltration rate is much higher in coarse soils (left) than in finely textured soils

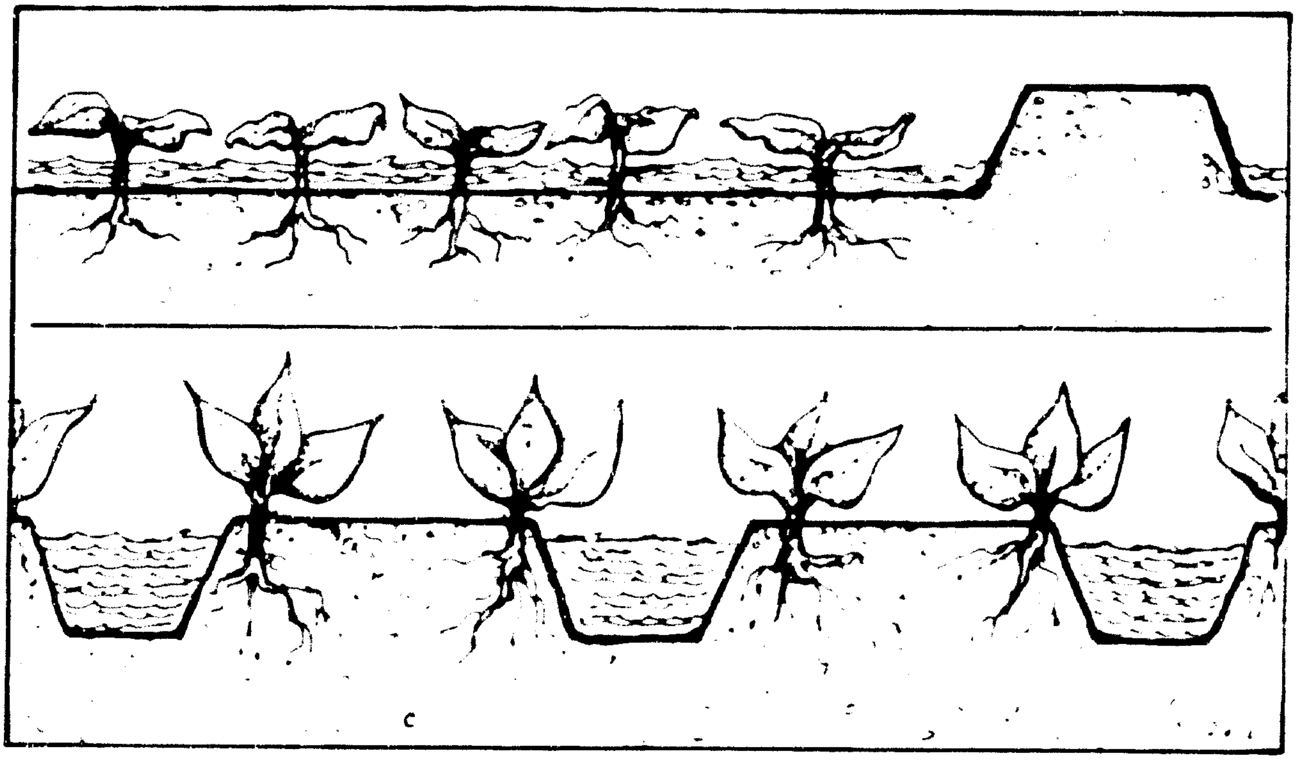
plants. This method involves running water down small channels between crop rows to wet the bottoms and sides of the furrows. Careful grading for uniform slopes is essential. Furrow spacing depends upon the crop, the kind of tillage equipment at hand, and the rate at which water will move laterally from the furrows into the beds. Some crops grow in single rows from 70 to 100 centimeters apart, and others are grown in double rows on beds with the furrows separated by at least one meter.

Furrow slopes should be uniform, and if steep lands are to be irrigated, the furrows should be installed on the contour so that the slope is lessened to avoid erosion, plant submersion, and soil deposition on flat spots.

Complete water control must be exercised; water spillage laterally from one furrow to another will cause serious erosion that will accelerate in moving downslope.

Water losses at field ends can be minimized by constructing a return flow system to collect water at the end of the field, carrying it to a small reservoir where it is pumped through a pipeline back to the head of the field, and then fed into a ditch or another pipeline with the original irrigation water.

Corrugation irrigation is similar to furrow irrigation, except the corrugations are smaller, usually about 10 centimeters deep and spaced 40 to 75 centimeters apart. It is usually used within borders. Corrugation is preferred for soils that crust easily after flooding and for areas that have not been graded for efficient irrigation. Corrugation irrigation should be considered only as an expedient and not a permanent solution for a non-graded field. Tables



Basin irrigation (at top) provides an entirely different plant environment than does bed and furrow irrigation.

are available to suggest furrow lengths, degree of slope, and average amounts of water to be applied to various soils.

Where water is abundant and the uniformity of distribution is not a major factor, contour flooding is an inexpensive means of irrigating close-growing crops planted on sloping land. Water is released down a gently graded contour supply ditch dug along the high edge of the field. Where it tends to concentrate, interceptor ditches should be dug at intervals downslope to distribute the water more evenly.

Contour ditches should be on gentle grades of 0.2 to 0.4 percent, and interceptor ditches should be sited at 30- to 60-meter intervals or at field elevation differences of 2 to 3 meters. They should have a grade that leads the flow away from the low points in the field to the highpoints which would otherwise remain unwetted. Turnouts are usually provided every 2 or 3 meters along the interceptor ditches — the same intervals used along the contour supply ditch at the upper side of the field. On large fields more than one contour supply ditch will be needed.

Considerable experience is needed to use contour flooding efficiently. Several trials may be needed to determine water release points along the contour and interceptor ditches so water can be spread more uniformly without causing erosion damage.

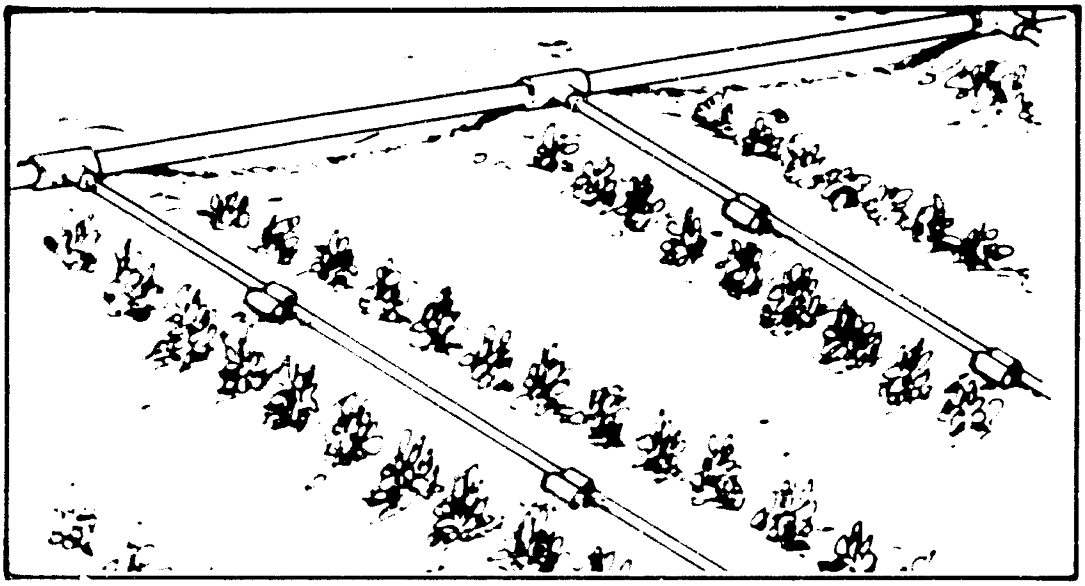
Subsurface Irrigation

Subsurface irrigation is practiced by manipulation of the water table, raising it over the natural table or creating one over a relatively large impermeable soil stratum. It is best adapted to large areas with the cooperative

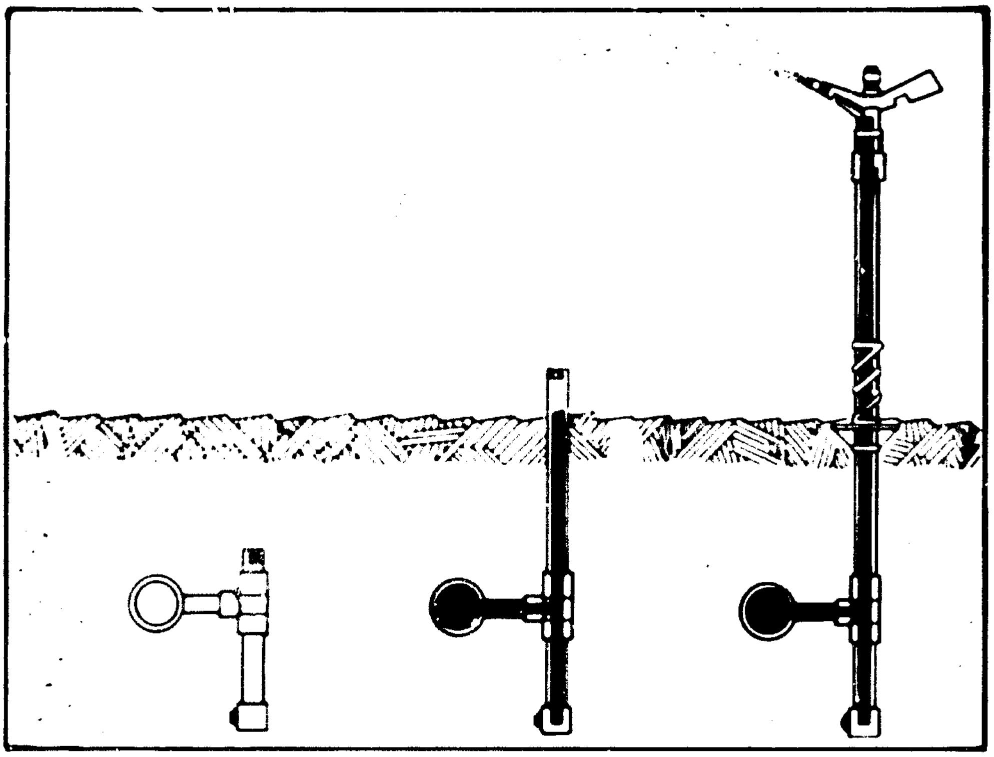
effort of a group of farmers working together. The natural water table or the impermeable stratum should be at a modest depth below the crop's normal root zone, and when the water table is raised to just beneath the root bottoms, the plants will be kept moist but not saturated. If the water table is allowed to rise above the roots, it must be lowered quickly, or the roots will die from oxygen starvation.

Fields where subsurface irrigation is to be practiced must possess an unusual combination of natural conditions; thus, its application is limited. Subsurface irrigation cannot be carried out without a high-capacity drainage system that will prevent the possibility of excessive rainfall raising the water table above the crop's normal root zone. A series of observation wells must be installed to monitor the rise and fall of the water table.

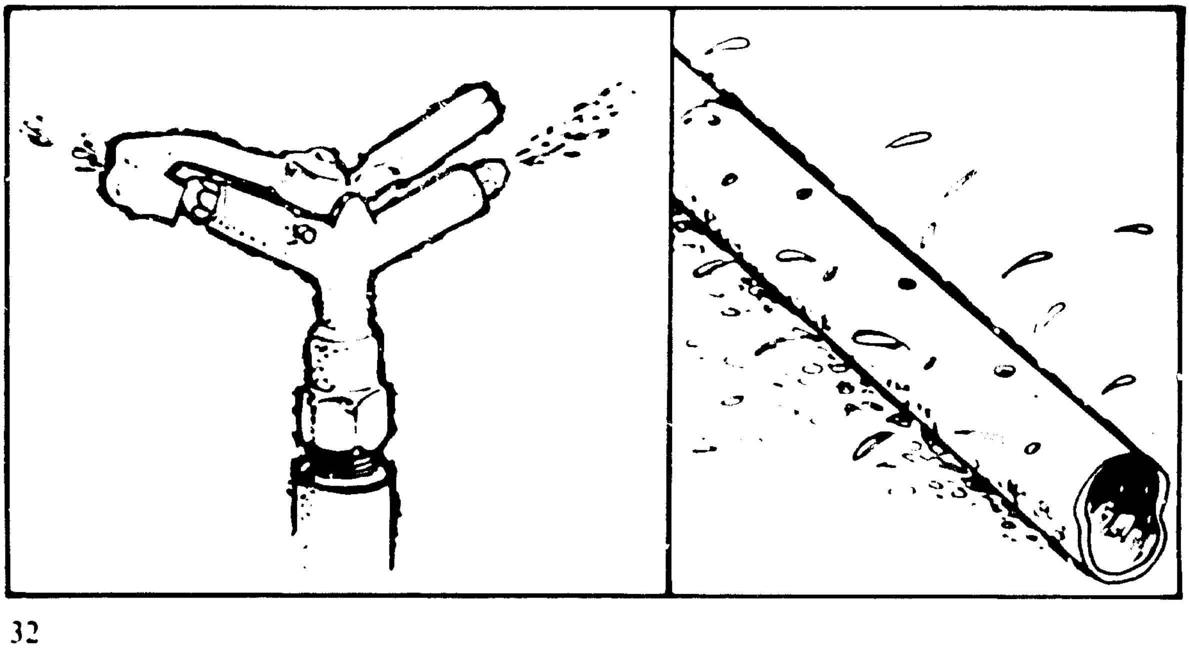
Surface irrigation is the least expensive method of applying water to fields, and can increase crop production significantly.



Sprinkler irrigation offers advantages in uneven, sandy soils.



Some sprinkler systems are permanently installed and require constant maintenance for continued efficiency.



Perforated pipe provides a simple sprinkler system for use on soils with high infiltration rates.

Sprinkler Irrigation

Sprinkler irrigation systems have a decided advantage on sites where the topography is hilly and uneven, where the soil is excessively sandy, and where contiguous fields exhibit varying water intake rates,especially where the intake rate exceeds 10 centimeters per hour. Although the application of water is never perfectly uniform, it is the best available system for many farms where surface or subsurface irrigation cannot be practiced. High winds will distort the sprinkle pattern, with a resultant decrease in irrigation efficiency.

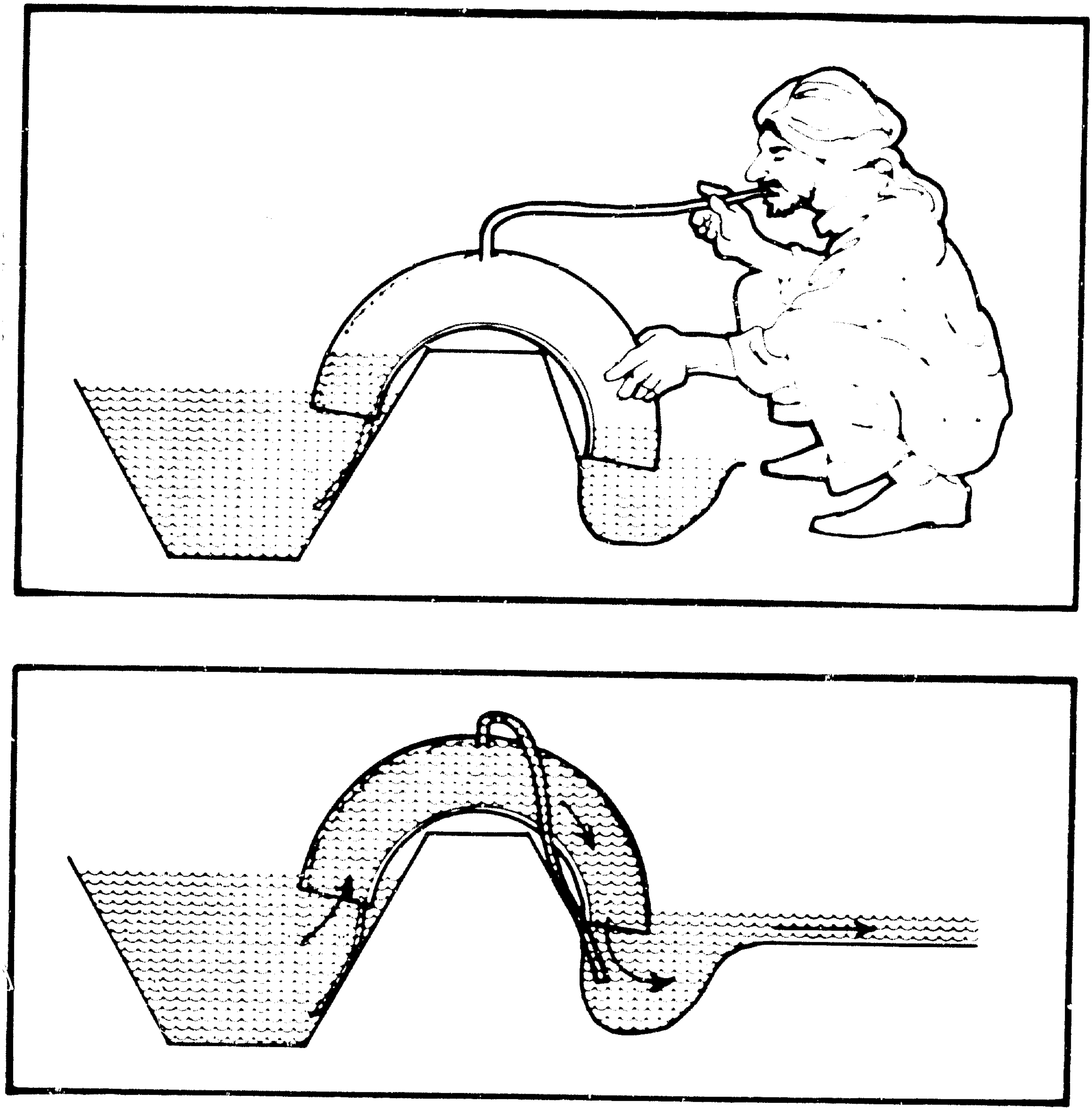
The major disadvantage of sprinkler irrigation is the cost. Necessary items include pumps, pipes, sprinkler nozzles, and fittings. Moreover, as fuel prices increase, the cost of running the pumps that provide pressure to the sprinklers may rise to unacceptable levels.

There are numerous types of sprinkler systems available, including non-rotating spray heads, perforated pipelines, reaction-rotated sprinklers, and impact-rotated sprinklers. All offer some advantages, and all suffer from drawbacks of one kind or another.

The simplest low-pressure sprinkler is the stationary spray head, which has no moving parts and is reliable and easy to use. The disadvantages of this type of sprinkler are that it wets only a small area, the holes in the head clog easily, and the rate of water application is relatively high.

Another simple system uses perforated pipe to spray water from small holes (about 1.6 millimeters in diameter) drilled along the top and sides of the pipe. The water sprayed from the holes produces a rainlike application that,in its rise and fall, breaks up into tiny droplets that are spread over the irrigated area by turbulence in the air. The width covered in this fashion ranges from 7 to 15 meters and increases with elevated pressures. This perforated pipe method can only be used on high-infiltration soils because application rates average 19 millimeters per hour and higher. Even with adequate filtration, the orifices tend to clog from debris picked up while transferring the pipe sections from one part of the field to another, from mineral deposits around the holes, and from corrosion inside the pipes. An advantage of this system is that the pipes can usually be manufactured locally.

Rotating sprinklers, driven by the reaction of the jet thrust when the water leaves the nozzle or by an impact device, are desirable for two reasons: because the entire water jet is concentrated in one or two directions, rather than being dispersed 360 degrees, a larger circle is wetted with any given discharge rate;



Workable siphons can be created from abandoned tire casings and scrap parts at little cost to the individual farmer.

secondly, the application rate is decreased because of the increase in the area that is wetted. Rotating sprinklers must be kept meticulously clean, for a grain of sand that finds its way inside the rotation collar will cause the sprinkler head to stop rotating.

Trickle Irrigation

Another over-surface irrigation method that has attracted attention in recent years is trickle, or drip, irrigation that uses a pipeline system with closely spaced emitters to apply water directly to each plant. The method is well known to greenhouse culture but is a relatively new practice in fields where vegetable, orchard, or other widely spaced crops are grown.

The use of trickle irrigation, a permanent system that can be maintained at relatively low cost, is expanding in the United States, Australia, South Africa,and Israel. Because water is applied to the soil almost continuously, there is a portion of the root zone that has a water content between saturation and field capacity. This is advantageous for many plants whose maximum yield depends upon maintenance of the soil at optimum water content. The water application rate is never as great as the infiltration rate; thus, there will be no surface runoff.

Despite the attractions offered by this system, trickle irrigation requires many components that need technical supervision. The complete system includes emitters, a water control station, meters, filters and screens, injectors for fertilizers and algaecides, pressure regulators, and special clock mechanisms to regulate water flow.

The cost per hectare to install trickle irrigation is high, and in countries that depend heavily upon imported fuel, the use of this system may well be prohibited by the expense factor alone. Trickle irrigation should be advised only to those farmers who are able to produce high-value crops.

4

Water Quality and Crop Production

Farmers who do not have expert knowledge of the chemical process going on in their soil and who are unable to see the salt dissolved in their irrigation water are understandably shocked when once fertile fields become barren. Such heartbreaking experiences are far from isolated. They occur in many parts of the world where salt accumulates in the soil from continued irrigation with poor water.

The original source of salts in irrigation water is the rock that forms part of the earth's crust; it is constantly subject to weathering, which releases salts to be carried away by water. When soil becomes truly saline, the visible surface evidence might be a white crust or dark, moist, oily looking patch. However, salt accumulation begins to affect crop yields long before visible signs of its presence appear. The leaves might look dark green with thick and succulent foliage even when affected by salt, but the plants will usually be stunted and the yield of fruit or grain sharply reduced.

Three principal irrigation problems arise from the quality of water delivered to fields. The first is salinity, which is directly related to the amount of salt dissolved in irrigation water. Almost all irrigation water contains potentially injurious salts, and none are removed by the evapotranspiration process. The salt balance must be maintained and controlled by leaching.

The second problem is one of maintaining soil permeability so that irrigation water can infiltrate and move freely through the soil. This problem develops when the soil structure is altered by the dispersion of aggregated soil particles. The cause can usually be traced to an excess of sodium in relation to the calcium and magnesium content in the water, an imbalance frequently referred to as an alkaline problem. There are also cases where permeability problems can result from water being too pure, i.e., lacking salt, but this situation is rarely found. Chemical treatment to correct problems of soil permeability can be accomplished by adding

Salt, seen here through an electron scanning microscope, is one of the farmer's greatest enemies when there is too much of it in water for irrigation.

measured amounts of gypsum to the soil to bring it into balance.

A third problem results from the existence of highly toxic substances in the water, such as boron or heavy metals. Boron is essential for plant growth, but it must be in low concentrations or it will become a toxic agent to plants.

There are other factors that can affect irrigation water quality, but the above three are those of most concern. Usually, irrigation waters are classed according to their total salt content and the relative amount of sodium as compared to calcium and magnesium. Boron content is noted because it is important that it remain below the toxic level.

The Salinity Problem

The level of salinity at which crops will be harmed depends on the particular crop. Values of salt tolerances for the world's major crops have been established. Many factors need to be considered when assessing salinity: amount of irrigation water applied, the crop, soil characteristics, and the amount of water leached annually through the soil, either from rainfall or from excess irrigation water percolating downward. Leaching water tends to carry excess salts with it; it is important that enough salts be leached out to avoid toxic buildup.

The salinity level of irrigation water can be determined directly by evaporating a known quantity of water and measuring the residue of dissolved salts that remain. The results are expressed in parts of salt per million parts of water (ppm). An indirect and more common method of determining salt content is to measure the electrical conductivity of the water—the greater the conductivity (EC), the greater the salt content. EC is expressed in millimhos per centimeter. Total dissolved salts in ppm is satisfactorily represented by the EC value times 640.

Testing for salinity levels in irrigation water is a necessary step in solving problems of water quality and failing crops.

Salinity adversely affects plants by reducing the water absorption rate. This will cause a marked production loss long before a plant is killed, and losses can be as high as 50 percent or more while the crop is still growing.

Leaching is the only practical way to remove salts but is effective only where there is adequate drainage, especially where there is an impermeable layer beneath the root zone. Merely flushing water over the surface is not enough. Leaching is best carried out by ponding water in a basin. The water must pass through the soil to dissolve salts, carrying them below the root zone in the leaching process.

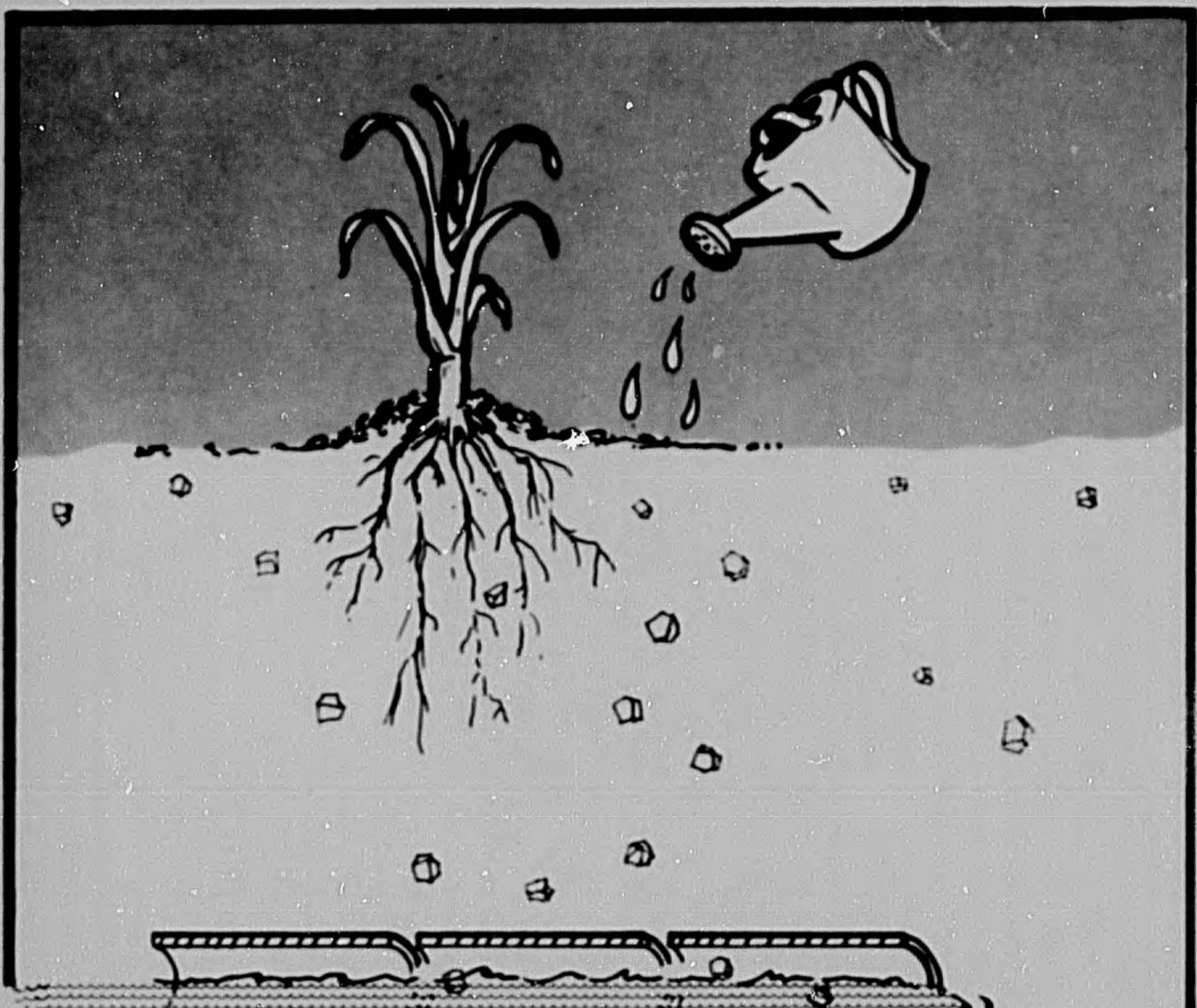
The Sodium (Alkali) Problem

Excess sodium in irrigation water—especially in relation to other cations such as calcium and magnesium—can damage fields. An unfavorable sodium-calcium ratio causes soil to lose its granulated texture, turning it instead to a clay-like consistency through which neither air nor water can freely move. In practice the problem has been overcome by applying a sulfur compound, e.g., gypsum, to the soil or irrigation water. Sulfur combines with sodium to render it soluble, thus leachable.

Powdered gypsum, to prevent sodicity (alkalinity), is seldom economically feasible, but it becomes practical when farmers can use "pit-run" gypsum, which may cost anywhere from one-third to one-half of the equivalent powdered weight. University scientists engaged in an AID project discovered that gypsum stones from 4 to 7 kilograms in weight, placed on watercourse beds, lost from 0.10 to 0.15 percent of their weight per hour of exposure to running water. Other experiments were conducted by placing gypsum blocks in fall boxes of tubewells and in concrete-lined watercourses.

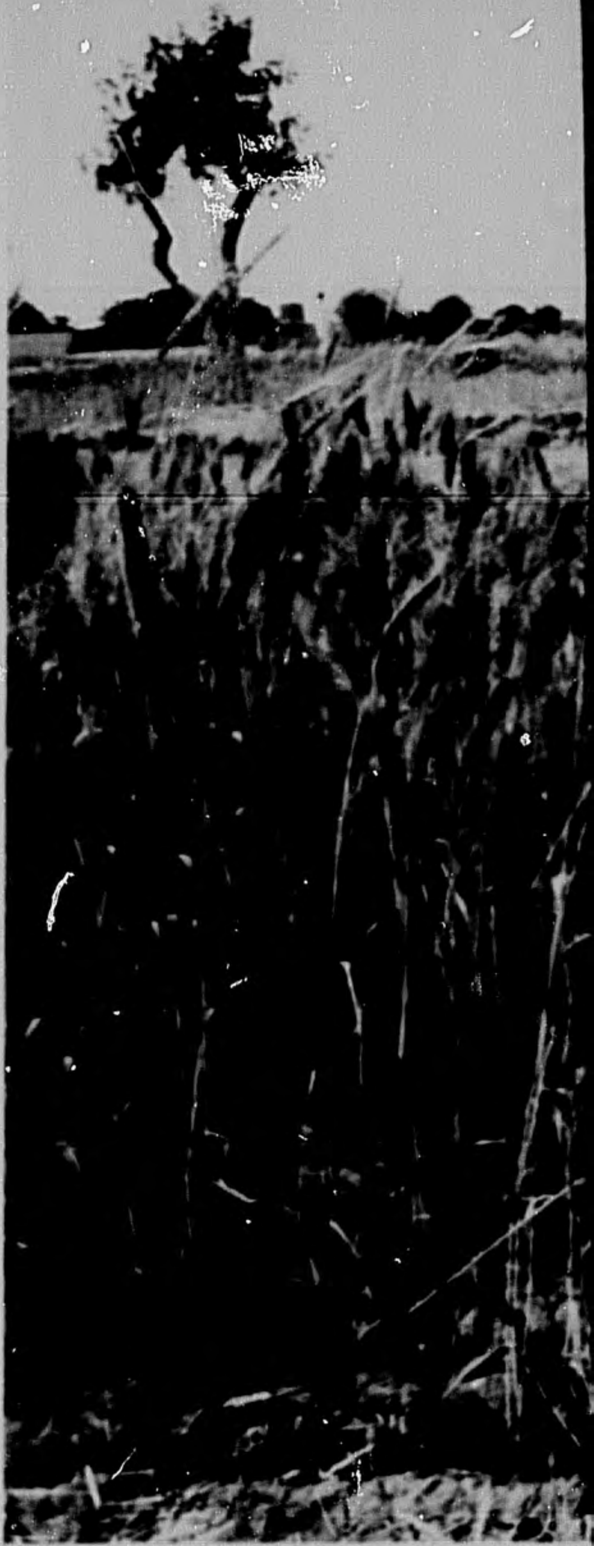
Chemical imbalances that threaten a farmer's soil can be rectified but only if there is a clear understanding of what is happening

Leaching is the only practical way of removing harmful salt deposits, but it requires a drainage system to carry away the toxic elements.



in the soil itself. Technicians must insist upon careful chemical analysis of both the soil and the irrigation water. An example from Latin America illustrates the point: farmers involved in an irrigation project believed they had a salinity problem because their crops were not doing well. However, leaching failed to bring about any improvement. Finally, a thorough chemical analysis of the soil disclosed that the primary problem was a micro-nutrient imbalance caused by an excess amount of heavy metals present in the soil.

Salinity and sodic problems are the cancers of soil, insidious in onset and recognized only after so much damage has been done that the farmer may be faced with but two alternatives: abandoning the land or spending as much or more to reclaim it than it is worth at current market value. Farmers must be aware of these problems so that remedial action can be taken in time to save land, crops, and income.



Farmers who understand the hazards posed by chemical elements in the soil are better able to maintain their lands to produce maximum crops.

5

Farm Drainage

Technicians and planners working with farmers to improve water management practices in the field should bear in mind that no new irrigation system should be inaugurated without considering the drainage problems that will inevitably arise. In humid areas, where land becomes waterlogged or the water table is near the surface, the need for drainage is readily apparent. The need for drainage of irrigated fields in arid regions—even in barren deserts—is less apparent, yet drainage in these regions is as critical to productive agriculture as it is in swamplands.

When irrigation water brings salt to the fields, that salt must eventually be removed lest it accumulate to the point of destroying the life of the fields. The only means by which the salt is removed is in drainage water that has passed through the soil profile, picking up the excess salts from the crop root zone. This leaching water might come from a periodic heavy irrigation, often before the crop is planted, or from the seasonal rains that occur in most areas. But the water must pass through the soil to wash away the salts, and it must be drained from below. If natural subsurface drainage is not there, man must provide it.

At first glance, it seems paradoxical that a desert with scarcely any water should require a subsurface drainage system when irrigation begins. Recently, large sums of money were invested in a program designed to bring new land under cultivation through a soundly engineered pumping system using water from a major river. The water application was efficient, and the cotton crops seemed to flourish. The simple, open-channel drainage system, however, proved to be disastrous. Salts accumulated in the soil until crops could no longer be produced on the land. The system failed because drainage was inadequate.

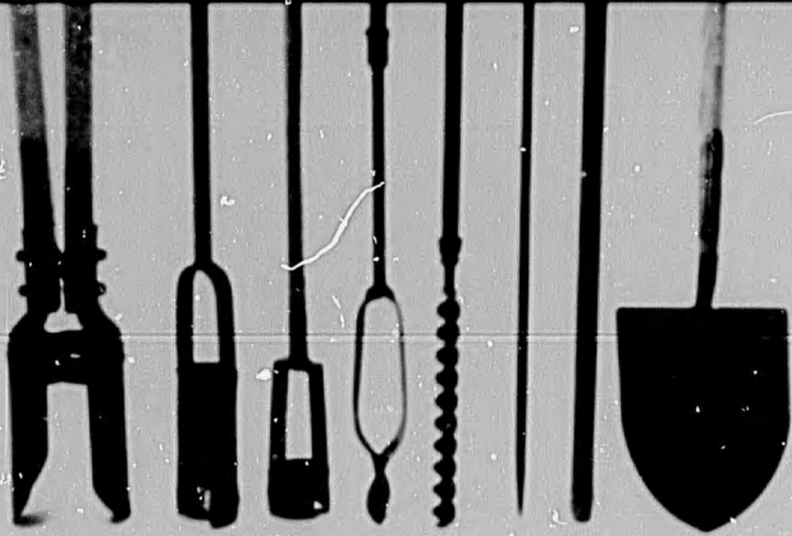
Faulty drainage causes a series of hazards and calamities to the farmer. Crops become

Adequate drainage is needed in dry areas as well as wet.

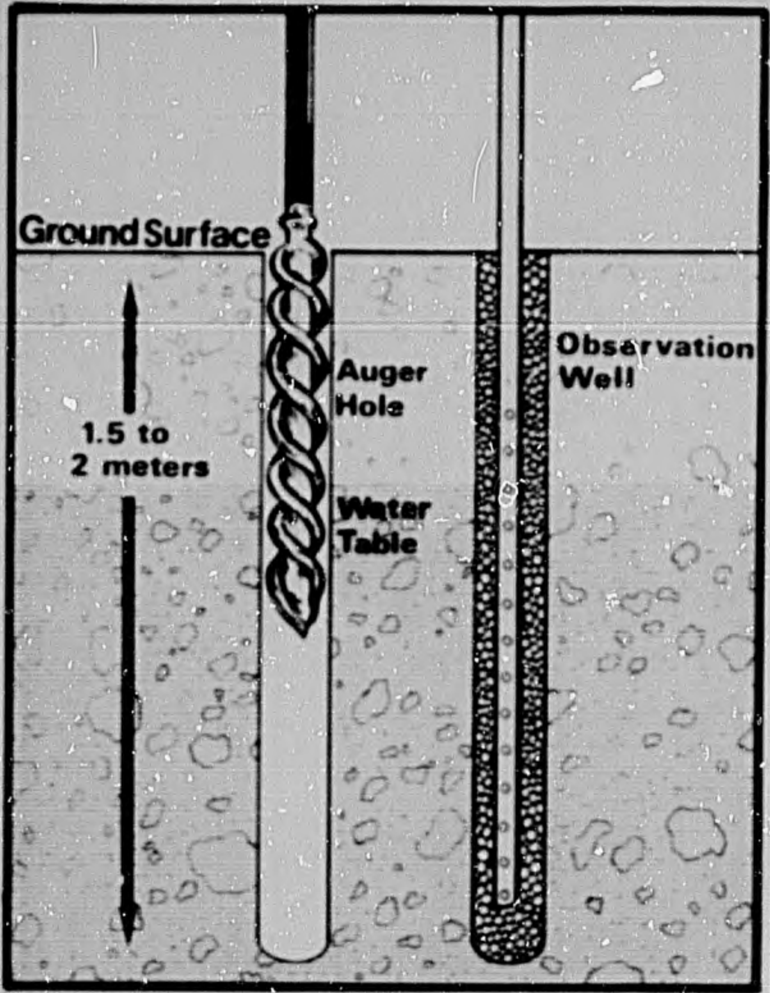
scalded from summer ponding, the same ponding that allows mosquitoes to breed and flourish. Soil becomes compacted and chokes off water penetration. Salts accumulate, and the crop root environment deteriorates. Plants are attacked by thriving fungi. Weeds and grasses proliferate and eventually take control of poorly drained areas.

Consider an example to illustrate the problem. If wheat is irrigated with water containing 2500 ppm salt, the crop will receive 25 metric tons of salt per hectare with each meter of applied water. If 50 centimeters of water are applied to the fields, the soil will absorb at least 12.5 metric tons of salt per hectare each year. At least 5 centimeters of water must be leached through the soil to maintain a satisfactory salt balance. If natural drainage does not provide this leaching, then man-made drainage must. If nothing is done, the field will soon die as a productive agricultural unit.

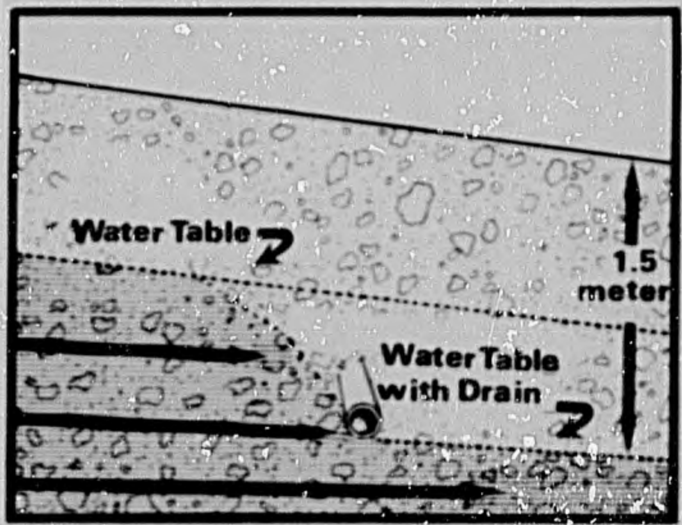
Local drainage problems can occur near the watercourse if the watercourse leaks, forcing the water table to the surface. Such water removed by drainage can have the same quality as the water in the canal and can be pumped back to irrigate the fields. The acceptability of this practice is totally dependent upon the quality of the water. As water moves through the irrigation system, to be used and reused, the quality will be constantly lessened because part of the water is evaporated and the salts it once carried in solution are left with the water that remains.



Auger holes provide information on soil texture, structure, relative permeability and water depth.



Auger holes can be turned into observation wells by packing gravel around pipe placed in hole. Such observation wells enable technicians to measure fluctuations in water tables. Buried drains can be used to keep the water table from rising too near the surface of the land.



Drainage Investigation

The first step in solving a drainage problem is the determination of the source, direction of movement, and amount of damaging water. Rainfall and runoff records must be studied to ascertain the amount and the intensity of water contributing to the problem. Topographic and aerial charts should be used by investigators to reveal ground slopes, channel locations, and areas subject to ponding and to indicate suitable sites for drain outlets. Well logs reveal local geology and can determine the presence of artesian water, as well as identify subsoil stratifications confining or perching water. Measurements taken in irrigation watercourses will indicate waste produced by seepage or water in excess of need. These samplings seldom lead the investigator to the heart of the problem, and more detailed work is usually called for in the field.

Affected plants should be examined, and probings should be made of the surrounding soil. An invaluable tool is the soil auger, ranging from about 5 to 10 centimeters in diameter, used to explore subsurface soil conditions and to bore observation wells. Auger holes should penetrate at least 1.5 times the expected depth of the drain, and the more holes drilled, the more pertinent information will be gathered. Auger holes provide information on soil texture, structure, relative permeability, and depth of the water table. These holes can be turned into observation wells by packing gravel around a perforated or plastic pipe slightly smaller in diameter than the auger hole. Such wells are essential for measurement of water table fluctuations and can help determine whether a rise in the level is from irrigation, rainfall, or from seepage from ditches or adjacent fields. Only after the cause and extent of the problem have been determined can technicians advise farmers how best to protect their crops and fields.

Drainage Methods

In general, where surface water is used for irrigation, the drainage problems are more severe. The problem can be solved by the installation of either interceptor or relief drains, the choice determined primarily by flow characteristics of excess water, by subsoil conditions, and by physiographic features of the stricken area.

The preferred tactic is to intercept damaging water before it can reach the cropping area, which is the function of an interceptor drain. Interceptor drains are used to remove overland surface water and subsurface water, such as seepage from a canal that invades a crop area by lateral flow above relatively impermeable soil. Interceptor drains should be laid as deep as possible to carry away the maximum amount of water flowing beneath the soil along the top of an impervious stratum. Some interceptor drains are merely open ditches; others are covered tile drains. Care must be exercised that backfill material over tile drain lines is porous and will provide enough inflow to guarantee that water will not bypass the drainage system.

Where interceptor drains cannot be used, relief drains can often solve the problem. Relief drains can be laid out in either a systematic or a random pattern within the affected field. Lateral lines are usually laid out in a grid or a herringbone pattern, with each lateral connected to a larger main line that discharges excess water into a central trunk drain that serves several farm systems. No drainage system, however, is better than its outlet. When water in trunk drains is higher than the water in the drainage ditch or tile line, the problem can only be solved by installing a sump and pumping plant to raise the water so that it can be discharged into the elevated trunk drain.

There are options open to farmers as to which type drain should be used to solve particular problems. Which option is chosen will be based upon economics, land factors, and prevailing customs.

Open drains are unsurpassed for quick removal of large amounts of water because water moving across the surface of the land can enter an open drain far more rapidly than it can flow into a covered drain. Open drains cost less to install and are efficient in intercepting runoff from hillsides or other elevated pieces of land prone to flooding during heavy rainfalls. The size of open ditches needed to carry given quantities of water is dictated by the slope and shape of the cross-section, which in turn is determined by the texture of the soil. Drains intended only to remove surface water or to intercept surface runoff can be designed to run full when runoff is at its maximum. Drains meant to lower the water table must be designed so that the water inside the drain is below the desired depth of the water table. However, accompanying the relative ease of construction and low installion cost of these open drains is the requirement for year-round maintenance.

Tile drains are of two kinds: short sections of concrete or clay tile butted together to make a continuous line and longer lengths of perforated plastic pipe. When properly installed, such drains require little maintenance, and they do not interfere with routine,

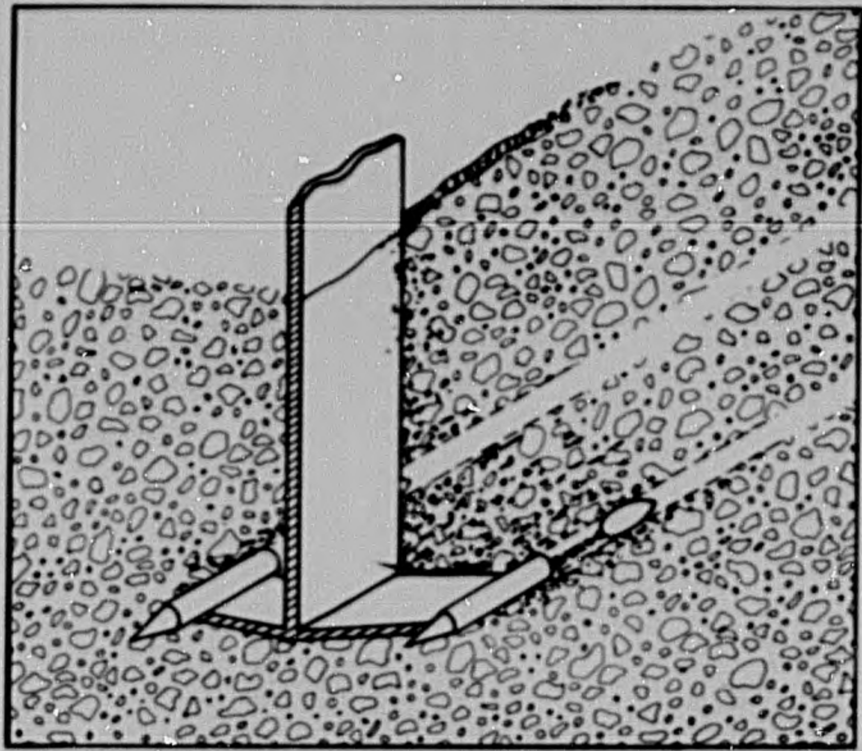
day-to-day farming operations. Where the water table is high and the salinity index is potentially threatening, tile drains should be placed fairly deep in the earth. The water table must be kept low enough so that capillary action cannot elevate water to the surface where it will evaporate, releasing salts.

Spacing between tile lines should be such that the water table midway between the lines provides sufficient unsaturated depth for the roots of the crop to be grown. The deeper the tile is buried, the greater the permissable spacing to keep the water table where it belongs.

Drains cannot lower the water table below the tile itself. Tile laid above the water table will not intercept water percolating downward, and no water will enter the tile until the table rises above tile level. Many formulas have been worked out for spacing of tile lines, but because movement of water into tile drains is chiefly dependent on soil texture and structure, these formulas can only provide estimates. In practice, fairly wide spacings should be tried. If experience shows that these spacings are not doing the job, more laterals can be laid down. If a farmer is working land containing silt or extremely fine sand, he will find the soil tending to liquefy when saturated with water. If this happens, he should be shown how to surround his tile drain with a gravel envelope from 5 to 10 centimeters thick. This envelope will keep the liquefied soil from flowing to the tile and plugging the openings.

Mole drains have been used in England since the 18th century and have been successful also in Australia and New Zealand. In 1970, AID began intensive studies to determine if mole drains could be successfully employed in

Double mole drains can be used only with certain soils and dug only under certain conditions.



other countries inasmuch as such drains are easy to install at relatively little initial cost.

Conventional moling equipment consists of a steel, sharp-nosed, torpedo-shaped object welded to a vertical steel blade; the unit is drawn through the earth by mechanized equipment. Most mole channels are dug between 45 and 60 centimeters below the surface. Experience with single-mole implements has shown that single channels have short lives. Deterioration is caused by runoff sediments falling inside the channel cut by the vertical blade, quickly filling up the drain itself.

The problem can be alleviated to a great extent by using a double-mole implement that cuts two channels during the same pull. Because the vertical blade is positioned midway between the two torpedoes, most of the sediment is trapped by this channel, and little filters into the drains.

Experience with double moles tends to prove that they can be effectively employed only in clay, in silty clay loams, and in fibrous, organic soils. The life of mole drains in any other kinds of soil is so short that they are not worth digging. When they are lined with plastic, their life expectancy is long enough to consider moles as a method of subsurface drainage. Tests conducted on unlined mole drains show that the higher the water application rate, the faster the drain will begin to deteriorate.

Heavy rainfall following construction of mole channels will bring about the collapse of the system, especially if hard rains fall while the soil is already saturated. The best soil condition for plowing mole channels is when the surface is dry enough to provide traction for haulage and when the subsoil is just moist enough to provide plasticity for molding smooth channel walls. Dry subsoil will cause shattering of the cavity lining when the torpedo makes its way underground, leaving the channel filled with loose particles of soil.

6

Water Measurement and Distribution Systems

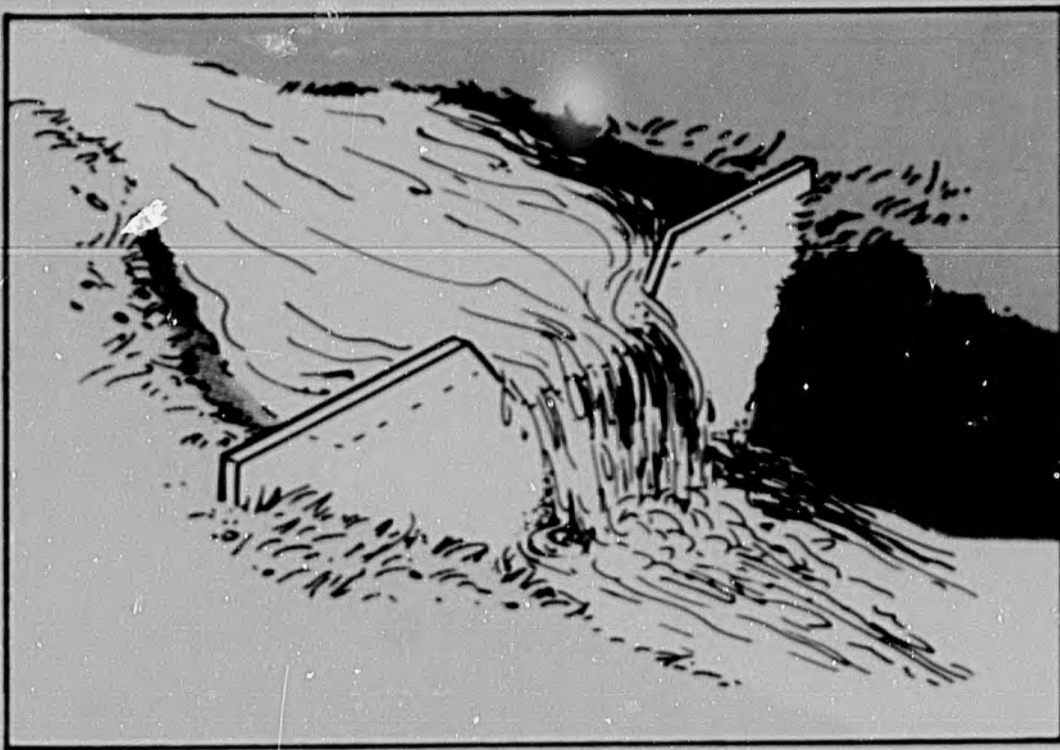
Technical advisors on irrigation need to measure water flow with accuracy to assess the efficiency of irrigation systems and to advise farmers how best to use the water put at their disposal. Farmers have no way of knowing how efficient their irrigation systems are without being able to measure water loss after it leaves the head and before it reaches the field. They also must know if crop water requirements are being met. Efficient management of irrigation water requires measurement of water flow at selected stages of the system.

Water Measurement

Flow measurement is needed both in main channels and as water discharges into the field. Volumetric measurement of small flows can be taken with the use of a calibrated container and a stopwatch to see how much time it takes the discharge to fill the container. Flow, in liters per second, is determined by dividing the volume of the catchment by the time, in seconds, required for the container to fill. Water flow is generally measured, however, with open-channel, flow measuring devices or with flumes.

One of the simplest devices for measuring flow in irrigation canals is a weir, a bulkhead placed across a channel with an opening of fixed dimensions. An opening is cut in the top edge of the bulkhead, V-shaped, trapezoidal, or rectangular. Tables and simple equations will quickly establish the flow through the weir based upon a single measurement—the upstream elevation of the water surface above the crest of the weir.

Weirs can be made of wood, metal, or concrete and are easy to construct and set in place, but they entail a considerable drop in water level (head loss) as the flow passes



Weirs are simple devices for measuring water flow.

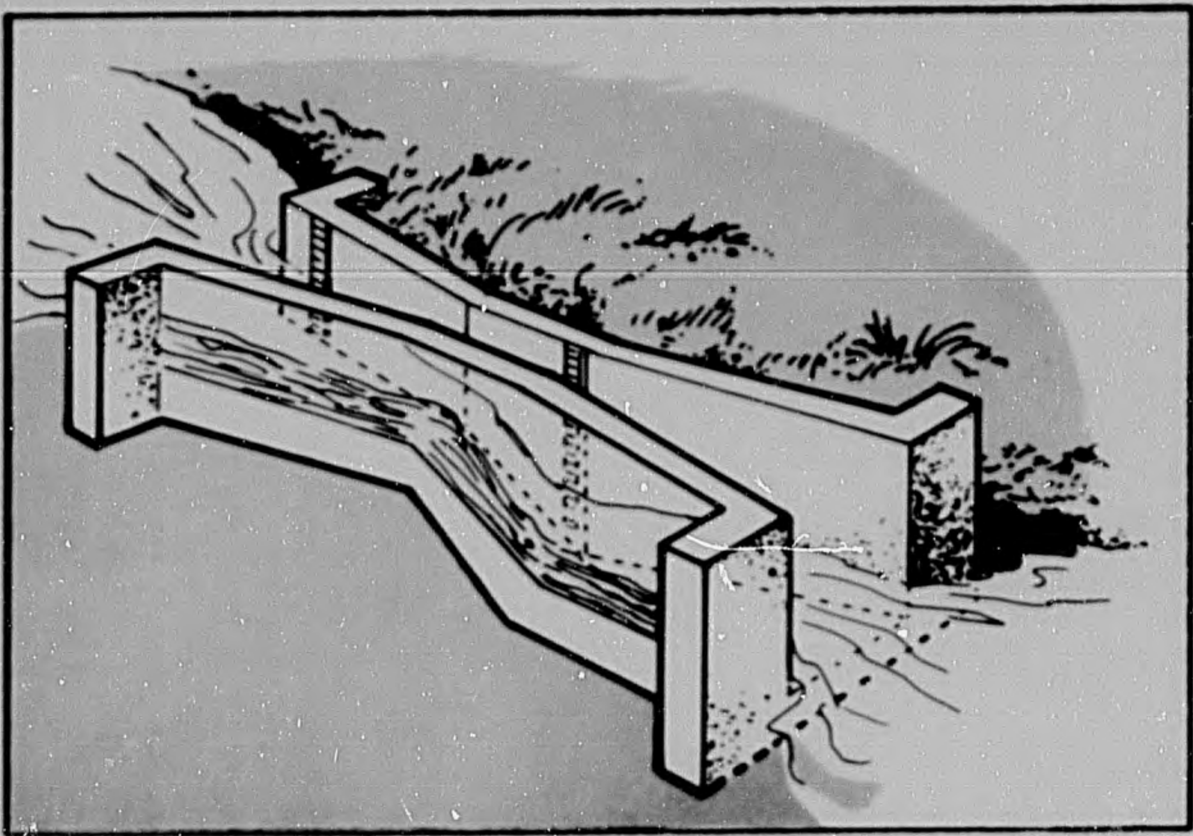
through the structure. The level of the water surface downstream should not reach the elevation of the crest of the weir if truly accurate measurements are to be made.

Where it is not possible to use flow measuring devices that require substantial head loss, flumes are suited to the purpose. The Parshall flume can be fabricated in a wide range of sizes and gives accurate measurements in small channels or in large canals. Flow through the flume is governed by flume dimensions and by the measurement of water surface elevation above the flume floor. The latter measurement is required at only one location in the flume, except where the downstream water surface elevation is fairly high in relation to the upstream water level. In this case, water surface elevation measurements are made at two points in the flume to gauge flow rate.

A variant of the Parshall is the cutthroat flume, which has been tested in the laboratory and in the field during the past 10 years. The cutthroat is relatively inexpensive to manufacture and easy to install. Moreover, the head loss required is minimal, which means that it can be placed in watercourses with little danger of forcing the flow to overtop either side of the channel.

The cutthroat flume differs from the Parshall in that its floor is flat, not inclined, making it simpler in design and easier to construct. The flat floor makes it possible to place the cutthroat flume directly on the channel bed. The flume can operate either as a free or a submerged flow structure, which increases its usefulness in the field.

The cutthroat flume will deliver accurate flow measurements only when properly installed. First, the flume must be placed in a straight section of the channel. If operating conditions require frequent changing of the water discharge, the flume can be sited near a diversion point or regulating gate—but not too near a gate because of a possible surging effect. Nor should this flume be located imme-



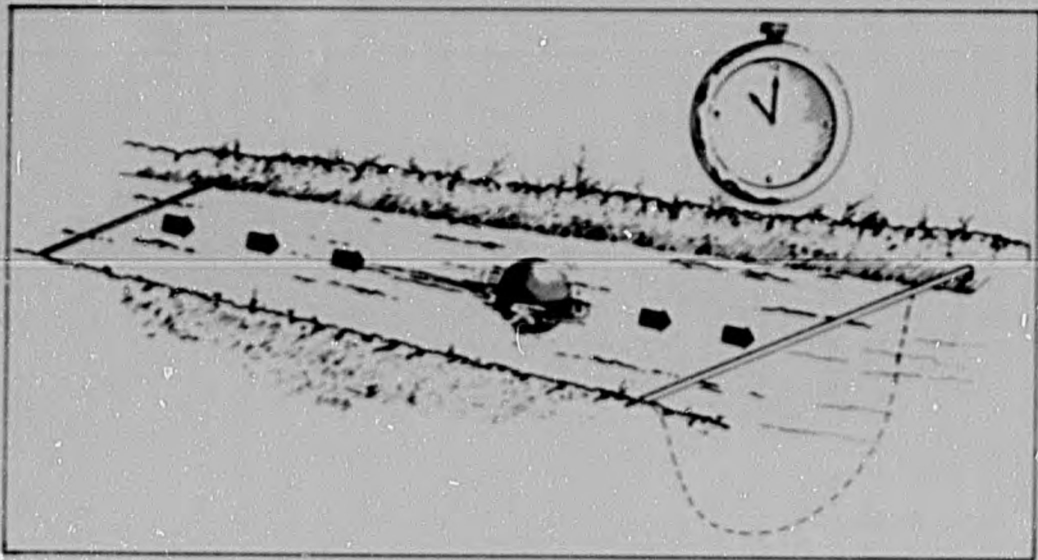
Flumes are easy to install and maintain in straight sections of watercourses.

diately downstream from a culvert or any other type of construction.

When placing a cutthroat flume in a watercourse, care must be taken to align the flume parallel with the sides of the channel and to bring it level on both axes. In time, these measuring devices have a tendency to shift position, usually dipping downward at the exit end. This is because the jetting action of the water in its passage through the flume erodes the channel immediately downstream.

A transition structure between the open channel and the cutthroat flume is not usually needed. Measurements can be made in a cutthroat flume with either staff gauges or stilling wells, which provide greater accuracy because these wells provide a calm water surface compared with the fluctuation and bounce of the surface water found inside flumes. Stilling wells are necessary if continuous recording instruments are put to use. It is always preferable to have flow measuring devices operating under free-flow conditions because only the upstream flow depth need be measured to determine the discharge. Although flow can be measured under submerged flow conditions, two stilling wells or staff gauges are required. The stilling wells can be placed adjacent to each other, permitting use of a double-head recording instrument to acquire a continuous record of upstream and downstream flow.

Maintenance of cutthroat flumes is simple and straightforward. When moss collects on the walls of the entrance section, it must be scraped off, and debris must be removed from the floor. Steel walls tend to encrustate over a period of time, but they can be easily cleaned with a steel wire brush and vigorous scrubbing. Once the walls are clean, it is a sound idea to retard the further buildup of encrustation by painting the walls with asphaltic paint, which will add to the life of the flume.



Where weirs or flumes are not available, the float-area method can be used to determine channel flow.

There will be times when technicians will need to determine channel flow but will have no weir or flume at hand. A simple solution to this problem is to use the float-area method, which requires a float, a stopwatch, and a wind-free day.

Assume a channel rectangular in shape and one meter wide. Measure off a 10-meter length along the top of the channel. Place the float in the center of the channel and clock its passage from release point until it passes the 10-meter mark. Repeat the procedure several times and find the average time of passage. If the average is 20 seconds, the flow velocity is 0.5 meters per second. But it must be remembered that flow velocity in the channel will be less than surface velocity, usually by a factor of 0.8. Thus: 0.5 × 0.8 = 0.4 meters per second.

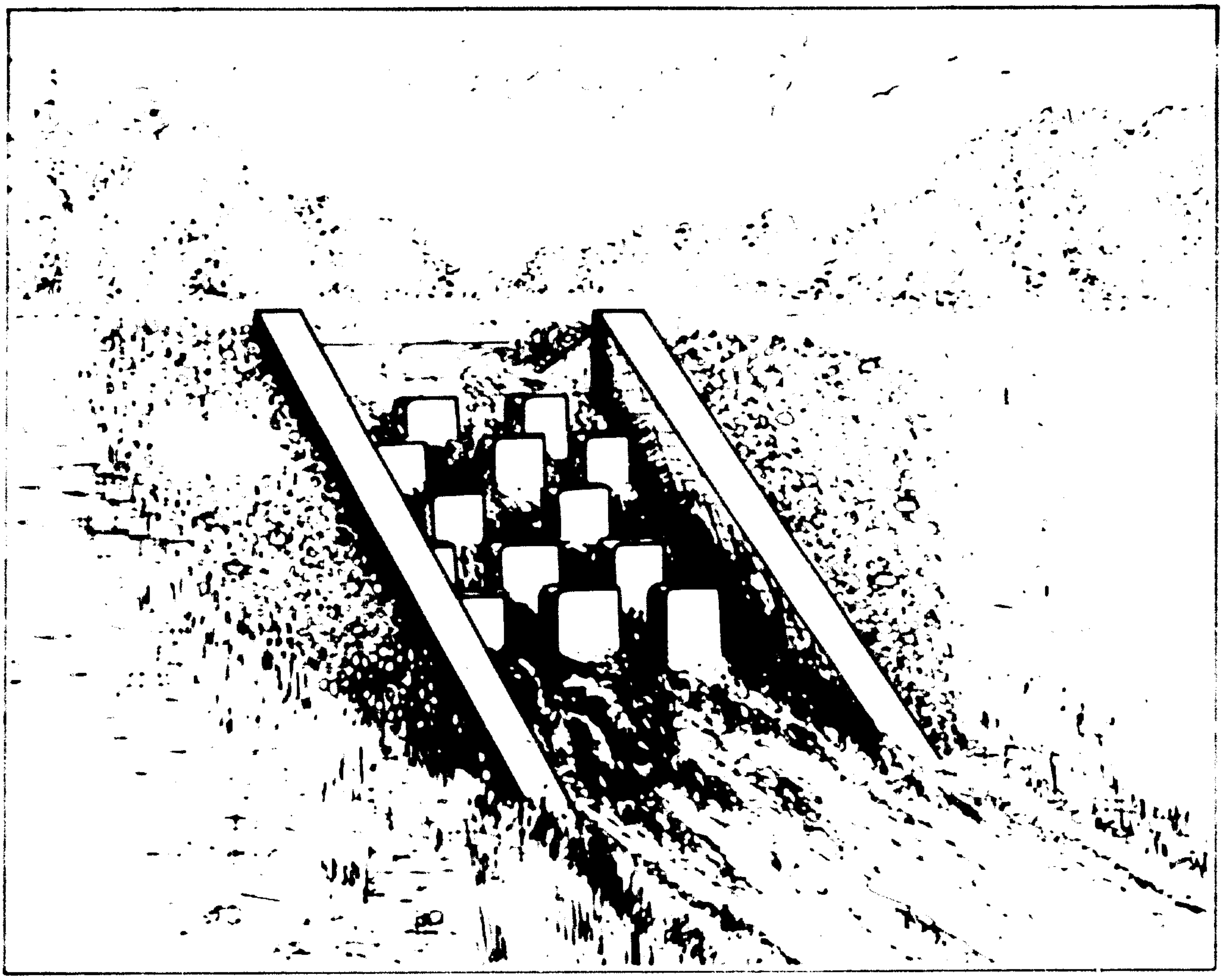
If the cross-channel area of the measured channel is 0.5 square meters, then the quantity of flow at this point is about 0.4 × 0.5 = 0.2 cubic meters per second. It follows that if the flow continues at the same rate for 1 hour (3600 seconds), the volume of flow past this point will be 3600 × 0.2 = 720 cubic meters. This amount of water applied uniformly to one hectare (10,000 square meters) of land will provide the farmer with an average depth of 17.2 centimeters.

The float-area method will give a fairly accurate measure of the flow in a watercourse, but it is not nearly precise enough to determine losses along the watercourse, and weirs or flumes are better employed for this purpose.

When technicians need to determine how much water is being lost from a canal through leaks and seepage but do not have the usual flow measuring devices at hand, the task can still be accomplished in the following manner.

A section of canal is temporarily blocked with earthen dams and filled to normal operating level. Lacking the normal flow, wastage will be from the ponded canal section where seepage and leakage will occur. Water loss is measured by installing a meter stick staff gauge and watching to see how much the water level drops each hour.

If the blocked section of canal is 100 meters long and averages 2 meters in width at the water surface and if the water level drops 5 centimeters per hour, then: 0.05 × 2 × 100 = 10 cubic meters per hour, which is equal to 0.0028 cubic meters per second. If the canal normally discharges 0.2 cubic meters per second at full capacity, this means that about 1.4 percent of the canal flow is being wasted every 100 meters



of the canal length, or 14 percent of the flow for a 1000-meter watercourse.

Watercourse Structures

In the design of any irrigation, drainage or soil conservation system, planners are confronted with the problem of controlling flow velocities so that erosion will be minimized. Often, energy dissipation to control such erosion can be accomplished with a hydraulic pump, usually in conjunction with some kind of structural check used to maintain or increase the flow level—i.e., water surface elevation in an open channel. These checks are designed so that the flow level needed downstream can pass over or through the structure while maintaining a constant depth upstream. Checks operate much like weirs, orifices, or a combination of the two.

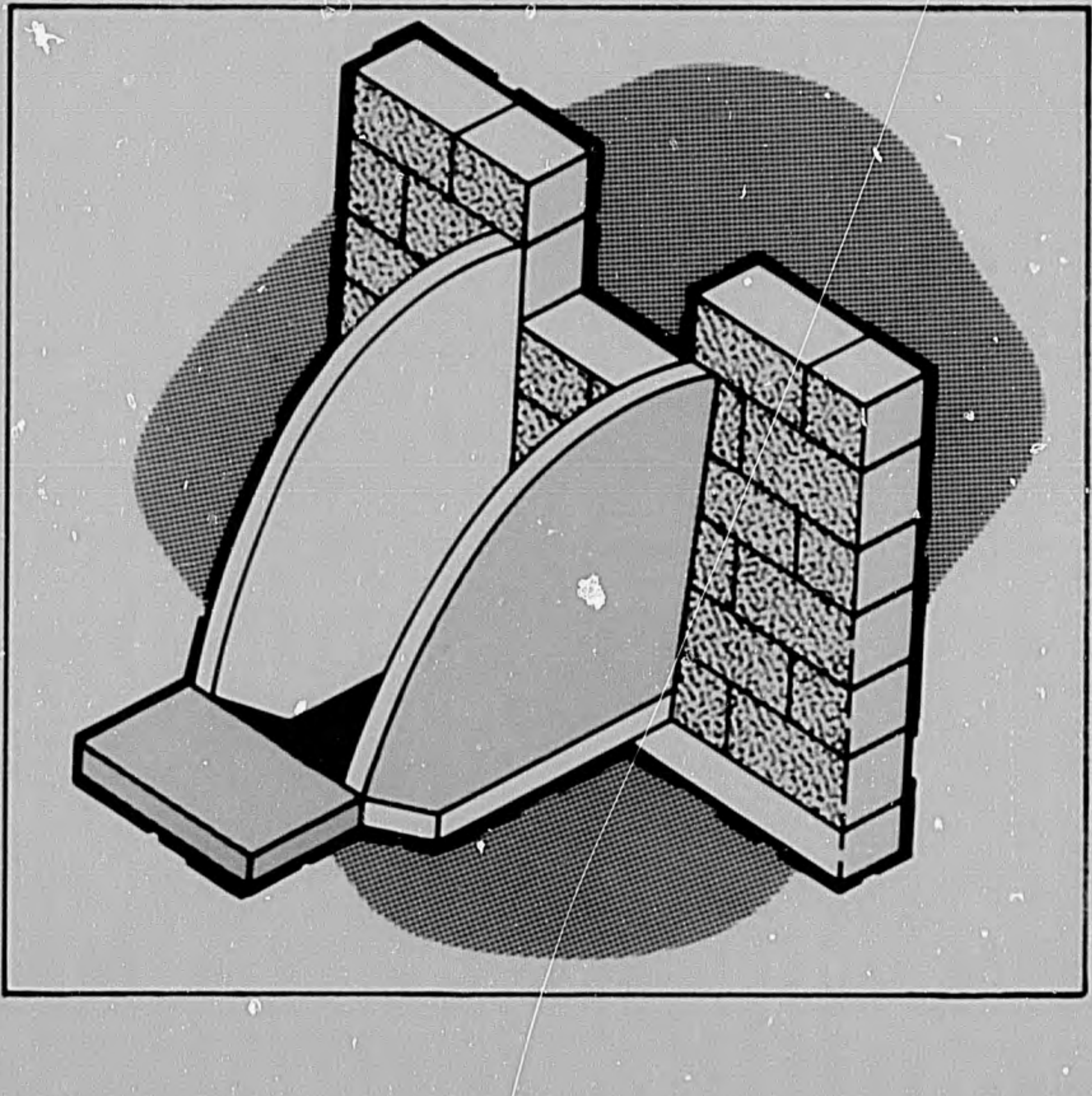
For earth-lined canals it is common to employ some kind of portable check dam prefabricated out of plastic, canvas, steel, cinder blocks, or concrete slabs. Where there is erosive soil, it will be necessary to provide the downstream side with an apron, wing-wall cutoff, or riprap. When dealing with concrete-lined canals, precast grooves can be used as gate guides. Portable steel gates held in place by hydrostatic pressure also make highly effective checks.

Drops are used for gully control and for lessening slope angles to prevent erosion where natural foliage will not grow. A drop will help to fill gullies by slowing the flow and allowing sediment to settle. Drops should be located upstream of erosion-prone areas, and checks are usually placed just above the drops so the water surface is raised sufficiently for distribution to the fields.

Problems can develop in the outlet channel of the energy dissipator structure as a result of wave action. Effects of such wave action can result in scouring the bank and in periodic overtopping. This problem is seldom anticipated, which means that corrective measures are usually applied after the structures are completed. Raft-type wave suppressors have been effective, and they provide an additional benefit by improving approach flow conditions when measuring devices are located a short distance downstream.

The accompanying illustrations provide an idea of the wide variety of check-drop energy dissipators available at reasonable cost for use in small farm irrigation systems. Designs for each structure are worked out in detail, and the necessary tables, graphs, and equations applicable to these structures are available to technicians as precise aids in improving on-farm water management.

Check and drop structures should be made of masonry and concrete for durability.



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Watercourse Management

Inefficiencies in water delivery systems for irrigation are common wherever agriculture is practiced. A survey of 22 irrigation projects in the United States revealed that the overall project use efficiency of water from dam to final irrigation process was 36 percent, and of the amount of water delivered to the farm, 42 percent was being lost through on-farm irrigation inefficiencies.

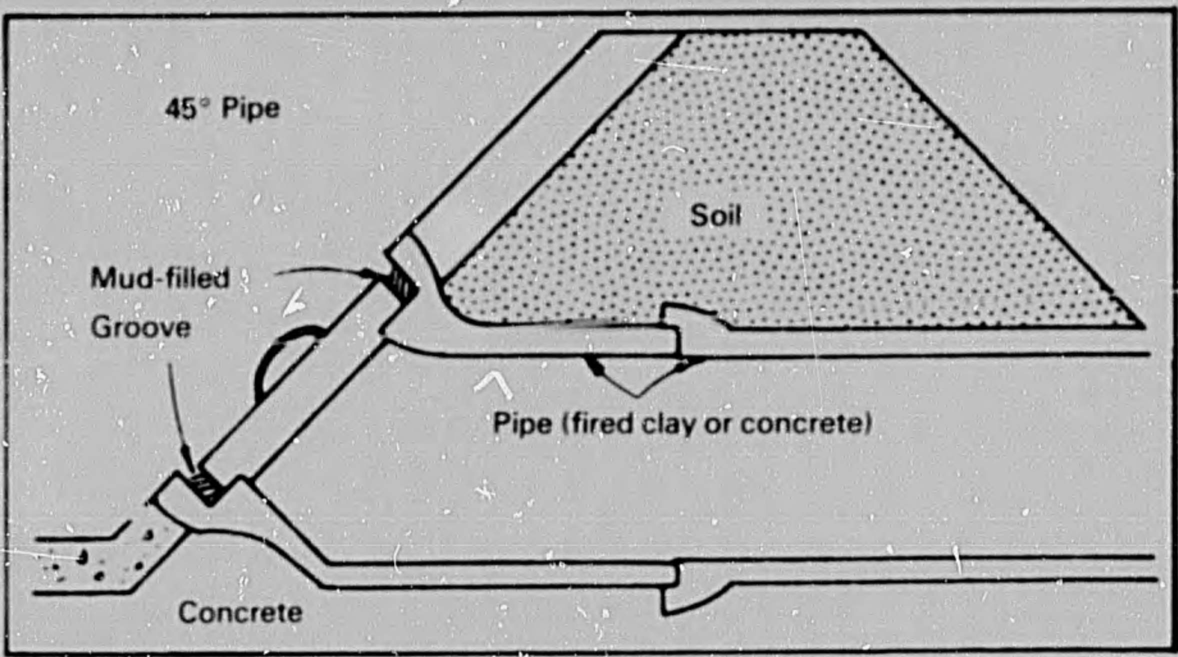
Thus, it is understandable that dedicated farmers are usually incredulous when technicians study their irrigation systems and point out they are losing unbelievable amounts of water before it reaches their plants. In one country where AID technicians helped survey a typical irrigation system, the findings were presented to 15 farmers gathered along the watercourse. One of the farmers commented, "It is no less than a lie that 50 percent of the water is being lost along the watercourse." When asked how much land he could irrigate, the farmer admitted that he could irrigate an acre per hour at the head of the watercourse, but only a half-acre at the tail. Convinced by his own answer, the farmer agreed to participate in a watercourse improvement program.

Water losses along the watercourse are caused by three factors:

- *Seepage* of water infiltrating from the channel cross-section down into the soil profile and eventually to the water table
- *Leakage* of water to ground surface by overtopping, slow seepage through the sides, and breakage of seals at turnouts or other weak areas
- *Evapotranspiration* of water consumed by useless vegetation growing in and along the watercourse

Water seeping from a watercourse is not lost from the delivery system in many instances; it goes to ground water, where it becomes available for reuse. But the water is lost to the farmer farther down the channel without a tubewell.

Trees, grass, and weeds growing within and along watercourses use significant quantities of water. The process of evapotranspiration also leaves behind residual salts, adding to



Neglected watercourse turnouts cause great losses of expensive irrigation water. Diagram above shows an ingenious concrete control structure.

the salinity problem. Roots penetrate the soil to the sides and below the channel, making the soil more permeable, which increases losses through seepage and leakage. Such vegetation also combines with sediment to roughen the channel, which reduces the amount of water that can be carried by the channel.

Another problem, especially with older watercourses, is the loss of water through rodent holes burrowed through the sides of the channel. Water funneled through these holes escapes to either side of the watercourse, often causing excessive irrigation of adjacent fields. It is virtually impossible to get rid of the

rodents themselves, and farmers must fill the holes with compacted earth.

Sediment poses a continuous and serious problem for all watercourses; this accumulation of silt and fine sand on canal bottoms has a clogging effect, reducing the quantity of the flow. A second problem arises when main canals branch off into smaller canals; the collective sediment transport capacity of the branch canals is almost always less than the transport capacity of the original, larger canal.

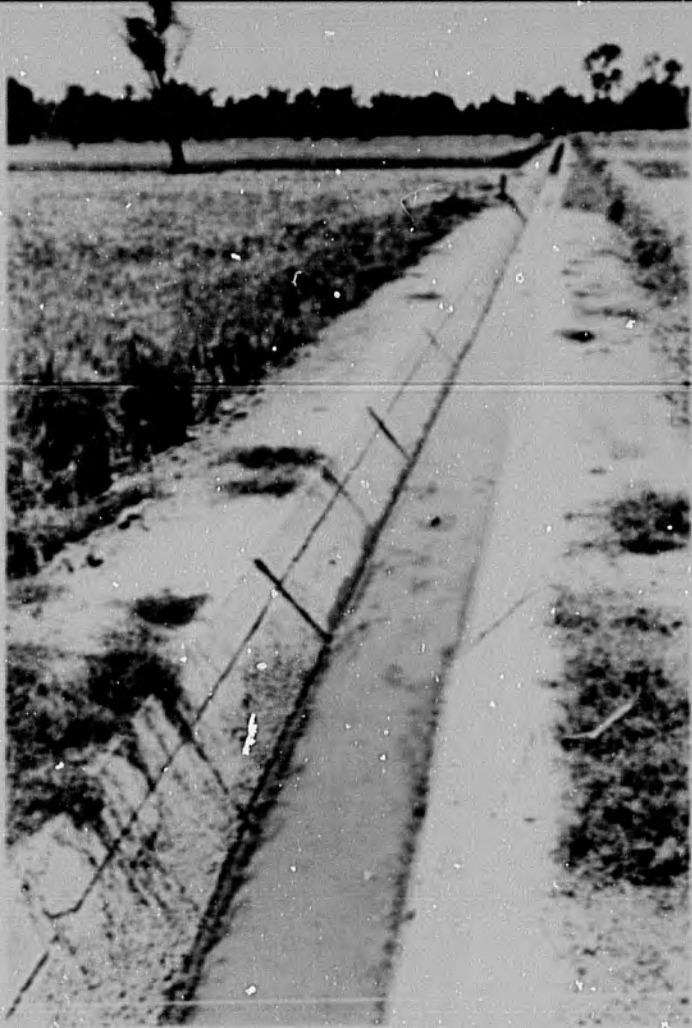
Obviously, this sediment must be removed, but this often extends the banks of the watercourse onto the land. Farmers either lose the use of that part of their land, or they may attempt to spread the sediment over the field, which will then need to be re-leveled. Experiments in the laboratory with hydraulic model studies continue in an effort to devise workable sediment ejection methods, but the currently available solution is the construction of sediment traps within the watercourse.

Sediment traps are sections of channel where the cross-channel area is enlarged by making the channel deeper and wider. The cross-sectional area of the sediment basin

should be large enough so that the velocity of the water is reduced to no more than one-half normal channel velocity. When the flow slows, sediment is deposited at this one location, where it can be removed. Sediment basins should be located near the upper end of the watercourse, a location convenient for sediment removal.

Under the guidance of AID advisors, farmers built one such sediment trap with excellent results. The basin, constructed in the first 45 meters of the watercourse, measured 1 × 2 meters and provided a cross-section of 1.7 meters^2. At a flow rate of 0.085 cubic meters per second, the average velocity in the basin itself was 0.05 meters per second; in the rest of the watercourse, the velocity of flow was at least 1.5 meters per second; thus, most of the sediment was forced to fall into the trap. In this particular watercourse, between 140 and 200 cubic meters of sediment were deposited each year, and the trap had to be cleaned from six to eight times annually.

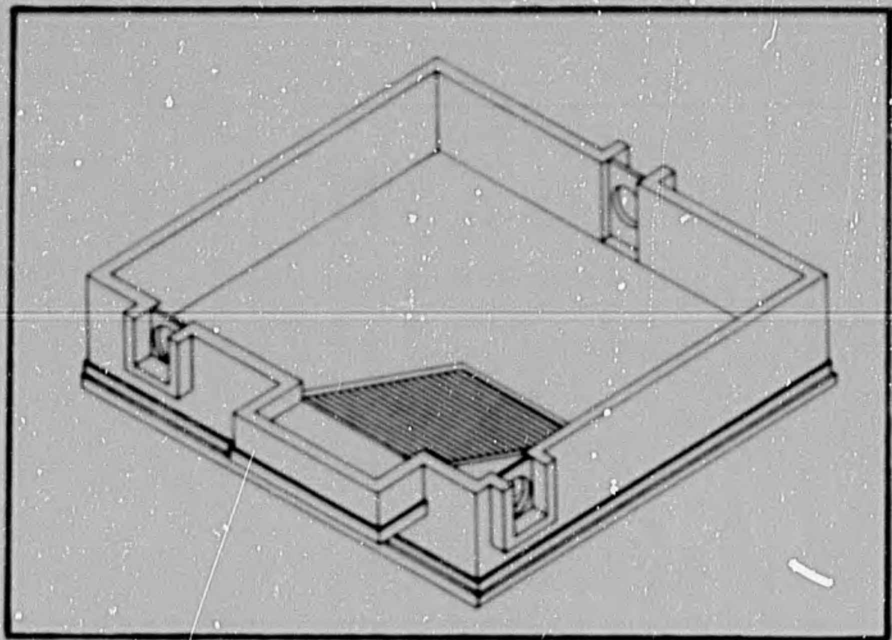
Before watercourse rehabilitation is started, water losses should be determined through accurate measurements of the flow. This is best carried out by installation of Parshall or cutthroat flumes placed 500 to 2000 meters apart, taking measurements after the water has been flowing in the channel for several hours. The percent delivery efficiency is the discharge of the downstream flume



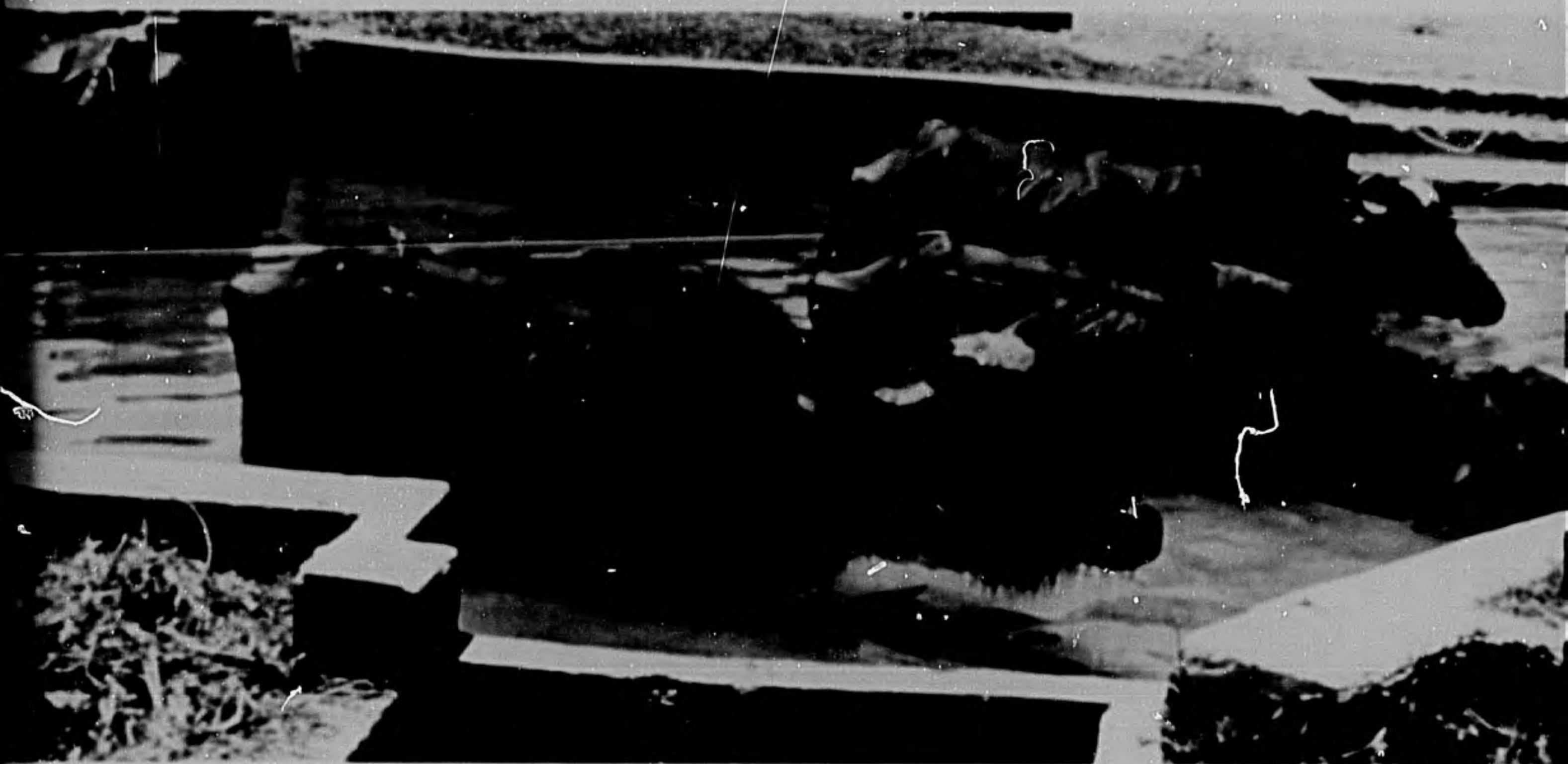
divided by the discharge of the upstream flume, with the ratio multiplied by 100. The loss between the two flumes can be expressed as actual water loss per 1000 meters or percent loss per 1000 meters.

Watercourse improvement will require shutting off the water supply long enough to pull weeds, compact the sides of the ditch, fill in rodent holes, and inspect the seals of the turnouts. This is all basic labor performed with hands and shovels. As the work progresses, technicians must provide surveys and check channel grades to be certain that proper dimensions and elevations along the channel are maintained.

If steel prices are high, cheaper control structures can be made of cement, and they work just as well. One such design includes concrete pipes inclined at a 45-degree angle, with a collar and lid flush with the bank. Where it proves difficult to get good compaction around the pipes, concrete cutoff walls on the inside of the watercourse will prevent washouts alongside these control structures. When wooden forms are used in the construction of concrete lids, a poor fit often results from warpage of the wet wood; steel forms avoid this problem. These structures are built with a special groove that can be packed with mud as a seal. Mud seals are effective but must be remade each time the lid is opened and closed.

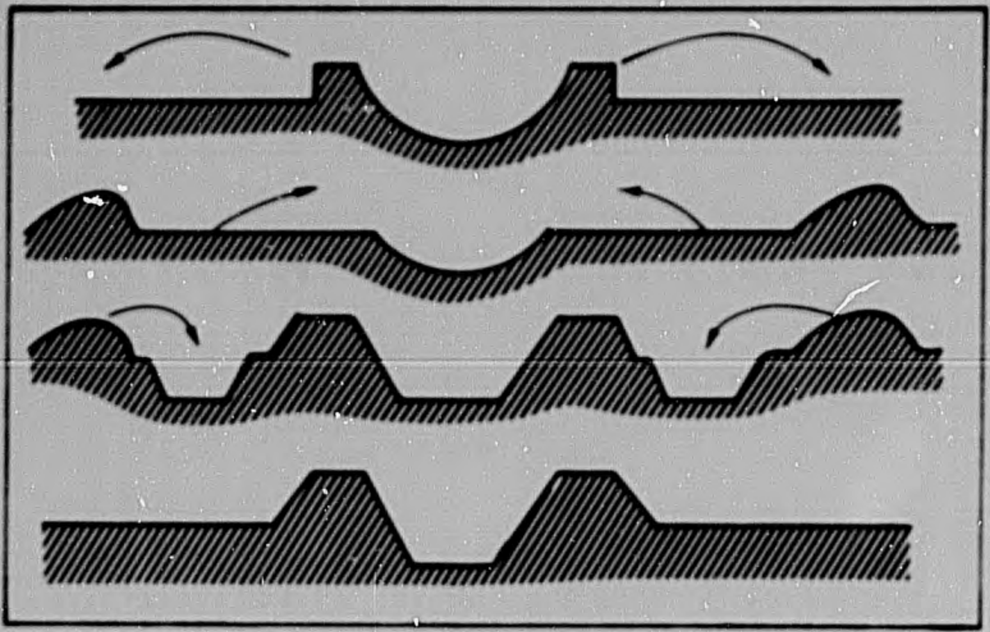


Social customs can be preserved and watercourse integrity maintained with addition of special structures, in this case, a buffalo bath of concrete.



One watercourse improvement project required the labor of 35 farmers working an 8500-meter watercourse serving a 900-acre area. The farmers worked along the channel at a rate averaging 190 meters per day for a total of 48 working days. Farmers put in 8800 hours of labor, and skilled workers and masons contributed another 4200 hours. The cost of this pilot project was about $1.20 per meter, but the refurbished watercourse delivered 50 percent more water to the fields.

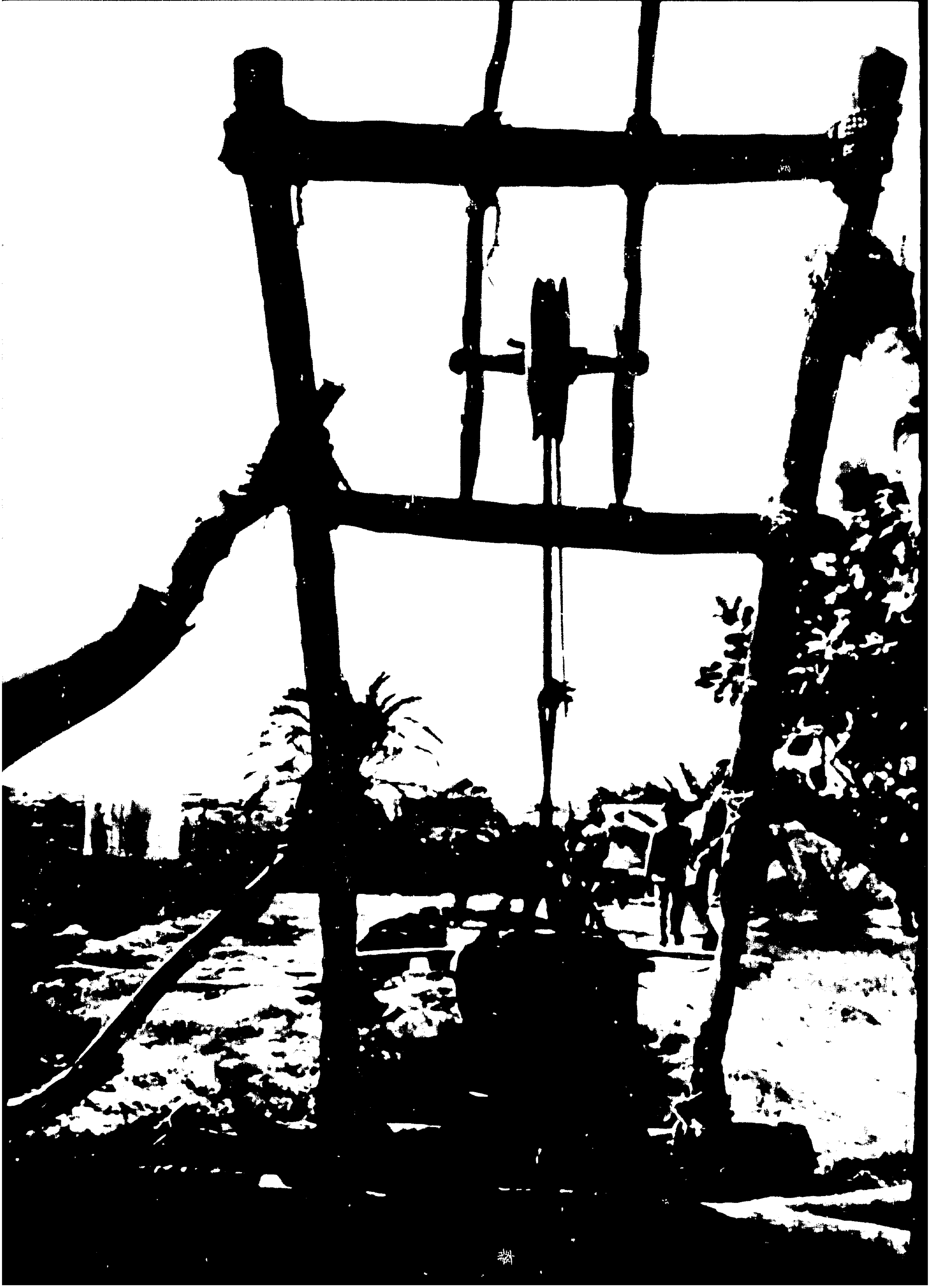
Watercourses will continue to pay back their costs in increased efficiency only if they are properly maintained by the farmers themselves. Experience shows that the hiring of full-time watercourse watchmen is a sound investment, whether they are paid in cash or in crops. Watchmen's duties involve the following areas of responsibility:



Watercourse designs include a variety of shapes. The important factor is regular maintenance by farmers themselves.

- *Leakage Reduction*: plugging holes, cracks and rodent burrows; packing mud inside turnout grooves
- *Seepage Reduction*: compacting cores in banks
- *Overtopping Prevention*: making sure there is a minimum of 15 centimeters of freeboard
- *Flow Restrictions:* elimination by removal of weeds, grasses, and other restrictions from watercourse channels
- *Regulation:* oversights of farmers' irrigation practices involving their portion of the watercourse
- *Flow Rise:* notification to local committee, when the water level reaches 5 centimeters above the designed full-supply level, that the watercourse is due for another thorough cleaning

Improvements in existing watercourses and careful maintenance thereafter are the most important steps any group of farmers can take as a joint venture to save their own water and to improve their own crop production.



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Water Supply for Irrigation

Irrigated crops depend upon ground water or surface water runoff. More often than not, surface water runoff occurs at times when farmers have no need to irrigate; this runoff, unpredictable in amount and unscheduled in appearance, is too precious to be wasted. Ways have been developed for its capture and storage until needed.

Surface Water: Reservoirs

Where terrain is suitable, surface reservoirs can be created in valleys across which dams have been built to form storage basins. Such reservoirs vary in size from those capable of storing enough water to irrigate thousands of hectares down to basins that retain only enough water to serve small holdings. There are problems to be faced when considering construction of such impoundments.

It is frequently the case that the only suitable dam sites are located great distances from the fields to be irrigated. This means heavy investments in time and labor to connect the fields to the reservoir via lengthy watercourses that will require perpetual maintenance if they are to remain efficient carriers. Under no circumstances should dams be constructed across valleys without thorough hydrological and geological investigations beforehand. Even if smaller dams can be built nearer irrigated fields, their construction should not be undertaken without engineering guidance.

Many sites offer such flat topography that dams are not practical. Even so, small storage reservoirs can be excavated on the land surface, with dikes built on three or four sides.

The dikes can be constructed with soil excavated from the basin. Such earthworks are feasible if not too ambitious in scale.

Small reservoirs of this type can be used to store water from wells whose capacity is too small to provide an adequate stream for surface irrigation. Enough water can be accumulated overnight in most cases for a limited amount of surface irrigation.

Ground Water: Skimming Wells

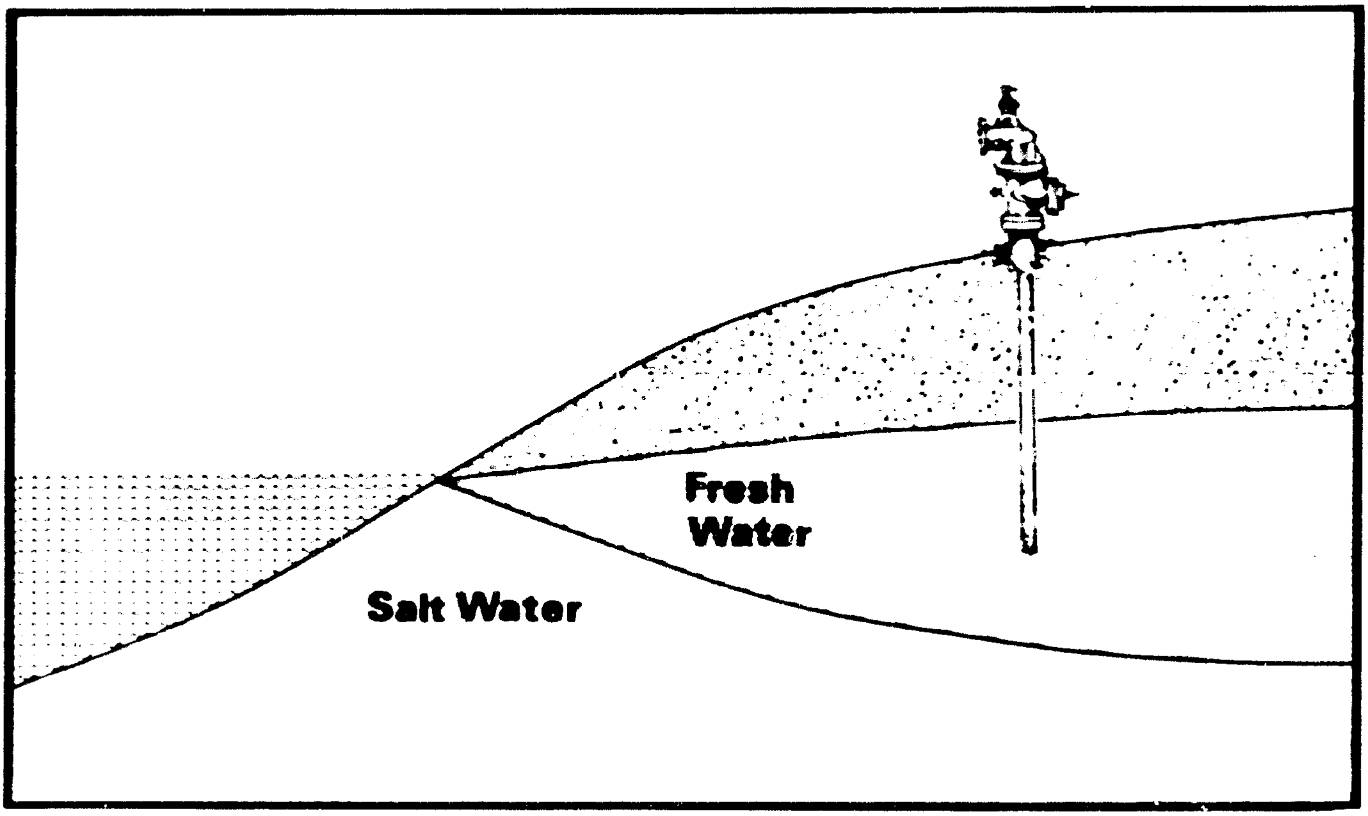
AID-supported research has shown that it is feasible to exploit ground water situations where fresh water suitable for irrigation and domestic use lies over an underlying layer of saline water. This situation is most often found on islands but can occur inland as well.

Methods have been developed to extract the fresh water from the upper surface through the use of skimming wells in such a way that mixing of fresh and saline waters in the

Traditional pumping of water from dug wells using animal labor may sometimes be more costly than the use of fuel-driven pumps.

acquifer is minimized. If the highly mineralized water is allowed to mix with fresh water during the pumping process, the water produced will be useless for irrigation.

First-time users of skimming wells are often puzzled when, after a long period of drawing high-quality water, water quality begins to deteriorate, and crops begin wilting from excess salinity. The usual explanation is not always easy to comprehend: the well has become the victim of upconing, a little understood pheonomena. What happens is that when pumping is started, the saline water rises in a cone in response to the pumping action; the apex of the cone will rise to a point directly beneath the well. Under steady-state conditions, the cone will keep rising until it reaches a certain height, the height dependent upon the drawdown of the well. If the drawdown exceeds a critical value, the cone will rise, and the well will pump salt water, despite the fact that the fresh water layer is far from exhausted. The salt water interface should



This cross-section of a skimming well shows how fresh water can be extracted over a layer of saline water.

never be allowed to rise above half the distance between the original interface position and the bottom of the well. If this distance is monitored and controlled within proper limits, the danger of upconing will be minimized.

Where wells have been drilled so deep that they begin pumping salt water, the problem can sometimes be corrected by plugging the well bottom with concrete. In effect, this will raise the bottom of the well above the zone where upconing occurs. In other cases, discharge from skimming wells can be reduced, which in turn will reduce the upconing rate to a safe level. This is explained by the fact that decreases in the pumping rate reduce the drawdown of fresh water, thus decreasing the upconing of saline water.

AID-supported field work on a small farm highlights procedures that can be used in solving skimming well problems: a small tubewell, drilled to a depth of 35 meters, began pumping water with the unacceptable salinity content of 2300 ppm, forcing its shutdown as an irrigation source. Technicians measured the salt content of the water flowing into the well at each level in the acquifer. They found a sudden increase in the salt content between the 28-meter depth and the bottom of the well, going from 1200 ppm to 3750.

On the basis of these field investigations, technicians blocked off the bottom 15 meters of the well with sand and a concrete plug. The pumping rate was reduced from about 25 liters per second to 8.5, but the quality of the water pumped showed an immediate improvement to 770 ppm, permitting the well water to be used once again to nourish crops.

Summary

One of the desirable and beneficial aspects of irrigated agriculture is the possibility of total water control, supplying plants with the water they need at the time they need it. In recent years, supplemental irrigation systems have been used in rain-fed agricultural areas when natural rainfall is deficient. This practice is economical in many areas because of increased production possible with a reliable source of soil water. Thus, even though the area of irrigated land is less than 15 percent of the world's total of cultivated land, the production from such irrigated land—especially when provided with supplemental irrigation systems—represents a significant food-producing potential.

The amount of water that actually reaches crops in a given area is usually only a small proportion of water delivered to the irrigation system. The reasons are many: seepage, evaporation losses, operational waste, spills from poorly maintained ditches, useless vegetation growing in and along channel distribution systems, and improperly designed and constructed farm fields. Each takes its toll. Rules and regulations under which farmers operate contribute to waste if the water is not available to the farmer when he needs it.

The physical irrigation system consists of a collection point for water (in some cases, a reservoir), a conveyance system to get the water from the source to the fields, and a method of applying water to crops. The complexity of the system varies according to the number of farmers to be served and the organizational structure that manages the system. Construction and maintenance of reservoirs, dams, large canals, and diversion structures are usually handled by a governmental agency and present no technical problems.

In most irrigation canal systems, especially those in developing countries where farms are not large, smaller channels carry the water from the main canal to individual farms. This subsystem is the portion with which the farmer works, and over which he has control.

The terminus of the irrigation system is where the crops are grown and where economic benefits of irrigation are realized; yet, it is to this portion of the system that developers and builders of irrigation systems often show the most neglect. Poor maintenance practices result in water wastage through leaks and overtopping.

Once irrigation water reaches a farm, additional ditch systems carry the water to individual fields. This system can be extensive because, even on small farms, individual fields tend to be rather small. The individual field itself becomes the last portion of the conveyance system that moves water from its source to the root zone of the crop. There are further losses from imprecise field leveling, over-irrigation and improper scheduling of water application.

Losses of irrigation water from the main canal to the root zone usually exceed those losses in the main canal itself. This is true of almost all systems in use throughout the world. It is not unusal for more than one-half of the water supplied by the canal to be lost along the way to a farmer's field, water thus not available for plant growth.

Water added to the soil, however pure, contains some dissolved salts. Continued application over a prolonged period results in a significant addition of salt to the soil unless proper management steps are taken. The preferred practice is to apply about 10 percent more water than is needed for plant growth so that salts are leached down into the soil profile below the root zone. But in many cases, so much water is applied that further problems are created, requiring the construction of drainage facilities to carry away excess sub-soil water. Flat topography requires extensive drainage works covering most of the irrigated land. Salinity, alkalinity, and waterlogging are problems peculiar to irrigation projects, and the severity of these problems is directly related to how the water is managed. Most of the water that is wasted finds its way to the body of water beneath the surface, causing it to rise and hastening the day when waterlogging and salinity cause the land to be abandoned.

There is a need for adequately trained personnel to manage irrigation systems. Attention must be given to training not only engineers and technicians but also those who work directly and indirectly with the farmer. Although agricultural experimentation stations exist, improvements to farms are usually limited because there are not enough trained farm-level advisors capable of transferring results of research directly to farmers. In many countries, the components of research and advisory services have never been brought together in a carefully planned relationship. Following are some major benefits that can be realized through successful implementation of improved irrigation water management practices:

- Irrigation water saved through proper management is perhaps the greatest source of water available to agriculture—it is already in the canal, ready for use.

- **Proper management increases production of land being irrigated, but more importantly, it provides more water for additional land.**
- If proper management of water on small farms can be accomplished by farmers working together, it will create a cooperative atmosphere among farmers themselves and between farmers and their governments. This can benefit other areas where similar cooperation and coordination is vital. A successful program can accelerate the diffusion of new technologies to larger farm systems.
- Equitable distribution of irrigation water can be accomplished, assuring that each farmer gets his share of the resource.

Note

This guide has been prepared in order to bring attention to some of the findings that have emerged from research sponsored by the United States Agency for International Development and conducted by agricultural scientists who have worked along with farmers and extension agents in the irrigation ditches and fields of small farms. The information in the guide is far from complete; a number of important concerns related to irrigated agriculture are not addressed, such as the control or prevention of water-borne diseases, the economic feasibility of irrigation programs, or the institution-building and training needs associated with the efficient planning and supervision of irrigation systems. The subject of rainfed agriculture has purposely been omitted from the guide because water management on small farms under these conditions properly requires fuller treatment than possible within the focus of this publication.

The editors and contributors to the Guide believe it will prove most valuable when it is used in conjunction with the services of professional irrigation engineers, agricultural scientists, and others who can work directly with farmers to help them identify their key problems and develop appropriate solutions. Some of those solutions are suggested in this guide.

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Glossary

ALKALI: a soil that contains sufficient sodium to interfere with water penetration and crop growth

BASIN IRRIGATION: application of water to small areas, usually level, which are surrounded by small dikes

BORDER IRRIGATION: the application of water to graded strips of land that are surrounded by small dikes to retain the water

CATIONS: the positively charged ions in chemical compounds that dissociate in water

CLASS A PAN: the U.S. Weather Bureau evaporation pan, a cylindrical container fabricated of galvanized iron or monel metal with a depth of 25.4 cm and a diameter of 122 cm

CONSUMPTIVE USE: rate at which water is transpired from a vegetal cover plus evaporation from the soil and from the wet surface of the vegetation, usually in mm/day

CORRUGATION IRRIGATION: a modified furrow irrigation method where the channels in the field are very small—usually only 6 to 10 centimeters deep and spaced one-half to one meter apart

CROP COEFFICIENT, Kc: ratio between crop evapotranspiration, ET (crop), and reference evapotranspiration, ETo, when both are in large fields under optimum growing conditions

DIVISION BOX: a structure to divide water in a watercourse so it can be distributed in two or more channels

DRAINAGE: removal of excess surface and ground water from the soil

DROP STRUCTURE: a structure to drop water in a watercourse to a lower level and dissipate its excess energy

ELECTRICAL CONDUCTIVITY: measure of salt content of irrigation water, usually given in millimhos per centimeter (Millimho is a unit of electrical conductivity.)

EVAPOTRANSPIRATION, ET: rate of transpiration from a vegetal cover plus evaporation from the soil and from the wet surface of the vegetation, usually in mm/day

FLUME: usually a device to measure flow of water in an open channel; sometimes an elevated open channel structure to carry water across low places

FURROW IRRIGATION: a method of applying irrigation water to fields in small furrows or ditches that traverse the field, usually between crop rows

HEAD: the total of fluid pressure head and elevation with respect to a specified datum—a measure of the energy of the water with respect to that datum

HEADGATE: the control mechanism at the entrance of a water supply works

INFILTRATION RATE: rate at which water will enter the soil when water is applied, usually in mm/hour (See intake rate.)

INTAKE RATE: rate at which water will enter the soil when water is applied, usually in mm/hour (See infiltration rate.)

INTERCEPTOR DRAINS: open or closed drains that intercept excess water that may create production problems in fields

IRRIGATION: application of water to fields by artificial means

LEACHING: removal of soluble salts by passage of water through soil

MILLIMHOS: a unit of measure for electrical conductivity in irrigation water, proportional to the dissolved salt in the water

MOLE DRAINS: a closed drain formed into an unlined conduit by pulling a torpedo-shaped cylinder through the soil below the surface

PAN COEFFICIENT, kp: ratio between crop evapotranspiration, ET (crop), and water loss by evaporation from an open water surface of a pan

PAN EVAPORATION, E (pan): rate of water loss by evaporation from an open water surface of the evaporation pan, usually in mm/day

PERMEABILITY: ease with which water can flow through the soil, usually the rate of water flow through a unit cross-section of the soil under a unit hydraulic gradient

PHREATOPHYTE: plants that use large quantities of water, usually along watercourses or where water is readily available

REFERENCE EVAPOTRANSPIRATION, ETo: the potential evapotranspiration, such as from an extended surface of 8- to 15-cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water, usually in mm per day

RELIEF DRAINS: drains that remove excess water from fields that can inhibit production

ROOT ZONE: soil depth from which roots extract most of the water needed for evapotranspiration, usually in centimeters

SALINITY: the amount of salts in the soil or in the water, often expressed in parts per million

SIPHON: a curved tube device to take irrigation water from the watercourse or ditches over the bank by siphoning action

SODICITY (sodic): a measure of the sodium in the soil—when in excess, it interferes with water penetration and crop growth.

SODIUM ABSORPTION RATIO: a measure of the amount of sodium in irrigation water relative to the amount of calcium and magnesium

SOIL AUGER: a device for sampling soil to depths of a few meters

SOIL INTAKE (INFILTRATION) RATE: rate at which water will enter the soil under given conditions, including soil water content, usually in mm/hr

SOIL PROFILE: a vertical section of the soil from the surface through all its sections (horizons) to the parent material below

SOIL STRUCTURE: Arrangement of individual soil particles onto secondary aggregates

SOIL TEXTURE: characterization of soil in respect to its particle sizes and distribution

STREAM SIZE: flow available for delivery to field inlet or irrigation area

SUBSOIL: that part of the soil under the well weathered topsoil

TRANSPIRATION: rate of water loss from the plant through the formation of water vapor in living cells, which is regulated by physical and physiological processes, usually in mm/day

TUBEWELLS: wells for irrigation water supply bored into the earth deep enough to penetrate the groundwater

TURNOUT: a structure to divert water from a watercourse to a farmer's ditch or field

WATERCOURSE: the water conveyance system that brings water from the main supply source or main canals to the farms

WATER TABLE: upper boundary of ground water where water pressure is equal to atmosphere, i.e., depth of water level in borehole when ground water can freely enter the borehole

WEIR: a device for measuring flow of water in an open channel

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Selected Annotated Bibliography of AID-Sponsored Research*

Durability of Double Mole Drains by Anan Sukwiwat. Report under AID Contract No. AID/csd-2167, 1970, Utah State University, 58 pages. AID Document Identification Symbol: PN-RAA-045.

Under certain circumstances, subsurface drainage using mole drains can be quite effective. The cost of mole drains is low, but the major disadvantage is the short life of the individual mole channel caused by collapse of the mole drain and sediment falling into the mole channels. An experimental double mole drain was tested under laboratory conditions in which a mole channel was formed on each side of the vertical slit made by the blade supporting the mole forming devices. The resulting double mole channels did not have a vertical slit above them from which sediment could crumble and fall into the channel. The durability tests of the double mole channel under conditions with four applications of water indicated the double mole channels were much more durable than a single mole channel.

Evaluating the Effects of Water Yield Management by Martin M. Fogel. Proceedings, Third International Seminar for Hydrology Professors on the Subject of Biological Effects in the Hydrological Cycle, July 18-30, 1971, pages 303-314. Prepared by University of Arizona under AID contract No. AID/csd-2457. AID Document Identification Symbol: PN-RAA-094.

The effects of watershed management on the water yield from a watershed is analyzed. The research reported concerns the effects of manipulation of watershed vegetation on the yield. The data is taken from research in Arizona. The results indicate that the prediction of the effect of a particular vegetative treatment is an uncertain process because of the lack of exactness in the science or surface hydrology. There is a potential for increase in watershed yield through vegetative management, but the trade-offs have to be carefully considered. One conclusion is that more reliable watershed models are needed before the vegetative manipulation procedures can be put in practice with confidence.

Installation and Field Use of Cutthroat Flumes for Water Management by Gaylord V. Skogerboe, Ray S. Bennett, and Wynn R. Walker. Water Management Technical Report No. 19 prepared under AID Contract No. AID/csd-2460, Colorado State University, March 1972, 131 pages. AID Document Identification Symbol: PN-AAA-174.

The cutthroat flume is an inexpensive and easy device to fabricate that can be used to measure flow in the irrigation channels. Data is presented on the use of the cutthroat flume for measurements in the irrigation channels under free flow and submerged flow conditions. The necessary tables for assessing the differences between free flow and submerged flow conditions are provided. Examples are given to illustrate the design procedure for determining cutthroat flume size, as well as obtaining free flow and submerged flow ratings. Proper installation and maintenance procedures for cutthroat flumes are described. Discharge ratings for cutthroat flumes of various dimensions are provided in both English units and metric units in the extensive appendices provided.

Irrigation Water Quality Evaluation by J. E. Christainsen, E. C. Olsen, and Lymon S. Willardson. Report under AID Contract No. AID/ta-c-1103, Utah State University, August 1975, 46 pages. AID Document Identification Symbol: PN-AAB-389.

Considerable confusion frequently occurs relating to the meaning of the term "irrigation water quality". It sometimes refers only to total dissolved solids, often expressed quantitatively as milligrams per liter. Sometimes the quantity of solids (salts) in water is determined indirectly by measuring electrical conductivity and expressed as millimhos per centimeters. Such determinations give an incomplete picture of irrigation and water quality. This paper discusses water quality, the chemical constituents of importance in irrigation water quality, and other conditions that determine the suitability of a given water for irrigation. Parameters discussed include soil and plant factors. Water classification schemes are outlined considering the total salt in the water, the relative amounts of sodium compared to other cations, and the existence of toxic substances such as boron. Several tables are presented illustrating analyses of water of different quality.

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*An AID Document Identification symbol is given for each reference listed in this bibliography. These symbols are used in the Agency for International Development's catalog of *Research Literature for Development* and in the quarterly abstract journal, "A.I.D. Research and Development Abstracts" (ARDA). Microfiche or paper copies of documents listed in these publications can be purchased by writing to the address below for order forms and current pricing information. Institutions within the developing countries are entitled to selected titles from ARDA at no cost. To get on the mailing list to receive ARDA, interested institutions should request an "ARDA Questionnaire" from:

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Water Requirements Manual for Irrigated Crops and Rain-fed Agriculture **by George H. Hargreaves. Report under AID Contract No. AID/ta-c-1103, Utah State University, October 1975, 40 pages. AID Document Identification Symbol: PN-AAB-676.**

A review of methods for estimating crop evapotranspiration is given, along with a general discussion of leaching requirements, soil conditions for crop growth, and the effect of climatic factors. General information is also provided on irrigation efficiency, leaching requirements, soil conditions, and the effect of soil moisture deficitson crop yield. A generalized approach to irrigation scheduling is provided. The information provided will be most useful to central irrigation authorities or an irrigation advisory service (extension), rather than the individual farmer.

Physical and Socioeconomic Dynamics of A Watercourse in Pakistan's Punjab: System Constraints and Farmer's Responses **by Max Lowdermilk, Wayne Clyma, and Alan C. Early. Water Management Technical Report No. 42, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, December 1975, 106 pages. AID Document Identification Symbol: PN-AAB-672.**

A detailed survey of the majority of the farmers along a selected watercourse provides insight into the factors that designate the farmers' decision process concerning their farming operations. The sociological factors dominating in their decisions points to the need for better information advisory services (extension), so the decisions are based on the latest scientific and technical knowledge instead of long-standing beliefs. Major problems, such as excessive sediment in the watercourse, high watercourse losses, and the ill effect of either overirrigation or underirrigation, were not generally recognized by the farmers. The results of this detailed survey are consistent with other observations, indicating that the problems noted might apply in many different areas of the underdeveloped world.

Water User Organizations for Improving Irrigated Agriculture: Applicability to Pakistan **by George E. Radosevich. Water Management Technical Report No. 44, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, December 1975, 34 pages. AID Document Identification Symbol: PN-AAB-584.**

This report gives a brief analysis of water laws and the value of the laws providing for water user associations. Specific recommendations are given for Pakistan as pertain to the development and institutionalization of water user associations in Pakistan. The principles of such an association are given. This report is a condensed version of Water Management Technical Report No. 36 from Colorado State University (PN-AAB-671), except the analyses of water laws in other countries and the extensive appendices are omitted.

Organizational Alternatives to Improve On-Farm Water Management in Pakistan **by George E. Radosevich and Graig Kirkwood. Water Management Technical Report No. 36, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, June 1975, 258 pages. AID Document Identification Symbol: PN-AAB-671.**

The water laws of Pakistan and their provisions for water user organizations are described. In addition, selected water laws are also discussed. The value of having water user organizations is emphasized, with particular reference to Pakistan, considering the limitations of present laws. A set of principles is recommended for Pakistan based on information derived from the analysis of water laws in other countries. Extensive appendices provide examples of water laws from several of the countries studied.

Water Management Alternatives: A Tentative Appraisal **by Jerry Eckert, Niel Dimick, and Wayne Clyma. Water Management Technical Report No. 43, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, June 1975, 61 pages. AID Document Identification Symbol: PN-AAB-673.**

Various water management practices that can be undertaken to improve the potential benefit that might be received from irrigation water are discussed. Calculations are presented on the potential benefit of improving water management through watercourse lining, reconstructing earthen watercourses, precision land leveling, and implementing an effective irrigation advisory service (extenstion). Finally, a procedure is given for selecting the elements of a water management improvement program that are economically feasible and have the greatest potential benefit-cost ratio payoff. The hypothetical cases are representative of conditions existing in Pakistan.

Reference Climate Sites for Agricultural Technology Transfer **by R. H. Shaw and R. W. Hill. Report under AID Contract No. AID/csd-2459, Utah State University, July 1975, 15 pages. AID Document Identification Symbol: PN-AAB-363.**

A procedure for identifying reference climates according to their essential characteristics for food production is given. Also, the potential for transfer of agricultural technology, as affected by climate, is given. The hypothesis is proposed that if sufficient details on weather, soils, and crop data are presented, and if proper biological and physical models are developed, the transfer of most of the components of agricultural technology can be made. The topic of a systematic identification of major agricultural climatic zones in the world is presented. Finally, a rationale for eliminating the void in world climatic data, which can be used for transfer of agricultural technology with a minimum expenditure of funds and the shortest possible time, is identified.

World Water for Agriculture by George Hargreaves. Report under AID Contract No. AID/ta-c-1103, Utah State University, January 1977, 177 pages. AID Document Identification Symbol: PN-AAF-056.

The 30-year climatic records (1931-1960) of 644 climatic record stations, published by the World Meteorological Organization, are used to develop tables of precipitation probabilities, temperature, humidity, sunshine percentage, potential evapotranspiration, and potential evapotranspiration deficits based on the probability of precipitation at that location during the growing season. A classification of climate for agricultural purposes is proposed that is based on agricultural production and relative needs for irrigation and drainage. The data provided considers climate, and precipitation probabilities and adequacies for rain-fed agriculture at stations in 85 countries throughout the world.

A Research-Development Process for Improvement of On-Farm Water Management by Wayne Clyma, Max K. Lowdermilk, and Gilbert L. Corey. Water Management Technical Report No. 47, prepared under AID Contract No. AID/ta-c-1411, Colorado State University, June 1977, 58 pages. AID Document Identification Symbol: PN-AAF-544.

A systematic process is given for carefully focused research-development in developing countries for the improvement of water management and use on the farm. Four interrelated phases in the technology transfer process are identified as follows: priority problem identification, search for a problem solution, assessment of the possible solutions and, finally, program implementation. Problem identification involves farmer participation to help him achieve better understanding of water management system operation and to be sure the priority problems identified are ones that can be solved within the constraints that the farmer faces. Several phases for implementation of the process are identified, along with the necessary steps for their successful implementation. The process requires close cooperation between the trained technicians overseeing the process and the farmers who must completely understand all factors involved if the process is to be successful.

Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan by Max K. Lowdermilk, Alan C. Early, and David M. Freeman. Water Management Technical Report No. 48-A, prepared under AID Contract Nos. AID/ta-c-1100 and AID/ta-c-1411, Colorado State University, 6 volumes, summary volume 148 pages, September 1978. AID Document Identification Symbol: PN-AAG-347.

The six-volume study, summarized in volume 1, reports the results of field study to determine the constraints that prevent Pakistani farmers from improving their irrigation practices and achieving higher crop production. The study involved 287 farmers in 16 villages using 40 watercourses. Water losses along the watercourses were high, with from one-third to two-thirds of the water being lost along the watercourses between the irrigation supply canal and the outlet to the farmer's fields. On the average, about half the water was lost in the watercourses. The reports discuss in detail the things that need to be accomplished to improve water management and the constraints that must be overcome. Major factors identified include lack of an effective local organization to assist and discipline the farmers who fail to participate fairly in watercourse maintenance, lack of farmer knowledge of magnitude of water losses, and lack of technical knowledge necessary to improve watercourses.

Farm Irrigation System Evaluation: A Guide for Management (Third Edition) by John L. Merriam and Jack Keller. Report under AID Contract No. AID/csd-2459, Utah State University, 1978, 271 pages. AID Document Identification Symbol: PN-AAG-745.

This manual describes and explains detailed procedures for field evaluation of the performance of several types of sprinkle, surface, and trickle (drip) irrigation systems and of management practices. Most chapters include lists of equipment needed for performing these evaluations, give step-by-step instructions for gathering data in the field, show sample forms for recording and organizing this field data, and present sample studies that demonstrate the entire process. The book includes analyses and recommendations for a few actual case studies. The general concepts of uniformity, efficiency, and management that are used in evaluating each system are explained. Procedures for both full and simple evaluations of performance of irrigation systems are described.

Optimum Control of Irrigation Water Application by Martin M. Fogel, Lucien Duckstein, and Chester C. Kisiel. Automatica, Volume 10, pages 579-586, 1974. Prepared by University of Arizona under AID Contract No. AID/csd-247. AID Document Identification Symbol: PN-AAA-793.

The problem of controlling soil water within the root zone or irrigated crops to minimize the expected loss is examined. Control is accomplished by scheduling the amount of and timing irrigations to replenish the soil water reservoir depleted by the crop's water consumption. Actual evapotranspiration rates a function of the prevailing soil water level and the evaporative demand, which may be considered to be either deterministic or probabilistic. For crops grown on a particular soil, an optimum soil water level is defined as the lowest soil water level above which crops are not stressed. The reduced yield of a crop is related to its growth stage and to the amount and duration that the soil water content is below this optimum value. This report is based on theoretical considerations.

The Importance of Farm Water Management in Pakistan by Wayne Clyma and Gilbert L. Corey. Water Management Technical Report No. 38, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, March 1975, 28 pages. AID Document Identification Symbol: PN-AAA-806.

The history of recent studies in Pakistan, which preceded the Salinity Control and Reclamation Projects in Pakistan, are reviewed. These analyses generally assumed a much higher efficiency of farm irrigation than present measurements indicate. Field application efficiencies of nearly 20 percent appear more common than the earlier assumed values ranging from 50 to 85 percent. The conclusion is that improving on-farm water management will make more water available for producing food than any other similarly priced investment and reduce waterlogging and salinity as well. A proposed plan is presented to include the practices of field reshaping and leveling, watercourses rehabilitation (judged to be very important in Pakistan), irrigation scheduling, supply augmentation with tubewells, water storage on the watercourse, canal regulation to meet crop water demands, soil management for moisture control, precision planting, crop cultural practices, and maintenance of the irrigation system. The implementation of the plan must consider the physical system, the soil and water management practices, and the institutional structure for socioeconomic decisions.

Irrigation Practices and Application Efficiencies in Pakistan by Wayne Clyma, Arshad Ali, and Mein Mohammad Ashraf. Water Management Technical Report 39, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, March 1975, 36 pages. AID Document Identification Symbol: PN-AAB-720.

Field studies of farm water management practices in Pakistan indicate that overirrigation is a frequent occurrence. The reasons given for this are poorly leveled and improperly designed fields, inability to control when water is available according to need of the crop, and lack of adequate ways to measure water applied. Over 80 percent of the fields studied had irrigation application efficiencies less than 40 percent, with the most common application efficiency being about 20 percent. This is much less than the irrigation officials thought prior to the measurements, indicating the importance of field measurements to determine water application efficiency.

Village Organizational Factors Affecting Water Management Decision-Making Among Punjabi Farmers by Ashfaq H. Mirza, David M. Freeman, and Jerry B. Eckert. Water Management Technical Report No. 35, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, March 1975, 62 pages. AID Document Identification Symbol: PN-AAB-097.

The results of a study of 15 randomly selected Punjabi villages, as pertain to the sociological factors that lead to certain decisions about farm water management practices, are presented. Particular emphasis is given to decision-making regarding (1) cleaning and maintenance of watercourses, (2) changing the rotation system of irrigation turns practiced, and (3) interaction with irrigation authorities. Factors found to be important included the castes in the village, the extent of kinship among inhabitants of the village, land tennacy patterns, community leadership characteristics, and the nature of the bureaucracy. The authors present numerous conclusions and hypotheses resulting from their work, indicating the factors that appear to be important in the decision-making process.

Improving Farm Water Management in Pakistan by Gilbert L. Corey and Wayne Clyma. Water Management Technical Report No. 37, prepared under AID Contract No. AID/ta-c-1100, Colorardo State University, March 1975, 32 pages. AID Document Identification Symbol: PN-AAB-721.

The historical development of the extensive national irrigation system in Pakistan is given, and the components of the individual projects where the major water losses occur are evaluated. The need for more attention to improving the management of water in the branches of the watercourse near the farmers' fields and on the farms is stressed, and data is presented to show the enormous extent of the water loss that results. The need for governments to look at food production per unit of water, rather than simply the amount of water provided to the canals, is emphasized. Recommendations are given on steps to improve production per unit of water involving:

(1) Research on on-farm water management
(2) Conjunctive use of ground and surface waters
(3) A national program of precision land leveling
(4) Rehabilitation of watercourses
(5) Review of rules and procedures for water delivery to the farmer

Design of Irrigation Drop Structures by Soon-kuk Kwun. Water Management Technical Report No. 33, prepared under AID Contract No. AID/ta-c-1100, Colorado State University, March 1975, 123 pages.

Information is provided on the hydraulic design of drop structures for irrigation canals or other watercourses. These structures are necessary when the gradient in a channel is so great that scouring will occur if drop structures are not provided to dissipate the energy. The report provides sections on drop structure hydraulics and design of both vertical and inclined drop structures. Although the report focuses only on the hydraulic factors in drop structure design and not the structural design factors, an extensive bibliography on the subject is provided.

Irrigation Fundamentals by Glen E. Stringham. Report under AID Contract No. AID/csd-2459, 1972, Utah State University, 52 pages. AID Document Identification Symbol: PN-RAA-070.

This report provides a simple text on irrigation fundamentals developed for use in training programs in irrigation in South America. It concentrates on explaining soil characteristics, particularly the soil reservoir that stores the water used by growing crops. Information is given on how to manage this soil reservoir in terms of irrigation practices, considering the various soil characteristics. Extensive appendices provide eight different demonstrations that are helpful in teaching individuals various important principles about the soil and its function as a reservoir to store water for crop growth.

Irrigation Requirements in Latin American Countries by Jerald F. Christiansen and George Hargreaves. Report under AID Contract No. AID/csd-2167, Utah State University, 1972, 11 pages. AID Document Identification Symbol: PN-RAA-003.

The climatic records available in many locations in Latin America do not provide all the data desirable for estimating irrigation requirements. The data needed include good precipitation records of sufficient duration so the probability of dependable precipitation in a given month can be determined. Pan evaporation data is needed but reliable, well standardized measurements are often not available. In the paper, equations are given for calculating potential evapotranspiration when pan evaporation data is missing,but data is available for temperature, sunshine percentage, wind, and humidity. Using the equations and data from Venezuela, Ecuador, Colombia, and El Salvador, the procedures are used to develop tables that give the monthly evapotranspiration deficit for two locations in Venezuela that are typical of low rainfall regions and high rainfall regions. The dependable precipitation, which is based on precipitation probabilities in any month, is a very important factor in determining irrigation water requirements.

Irrigation System Evaluation and Improvement by John L. Merriam, Jack Keller, and Jose F. Alfaro. Report under AID Contract No. AID/csd-2459, Utah State University, September 1973, 176 pages. AID Document Identification Symbol: PN-AAA-439.

This manual on irrigation system evaluation contains detailed procedures for the field evaluation of sprinkler, surface, and trickle irrigation performance and management practices. Information on the equipment needed for the evaluation of irrigation systems and the step by step instructions for carrying out the field work are provided. Case studies are presented and the manual includes an analysis and recommendations for the actual case studies used. The sections on furrow and border irrigation evaluation contain a simple (short-cut) evaluation procedure, as well as a complete set of instructions for full evaluations. Several appendices are provided illustrating the procedures, as well as a glossary of terms used.

Practical Skimming Well Design by Farid-Uddin A. Zuberi and David B. McWhorter, Water Management Technical Report No. 27 prepared under AID Contract No. AID/css-2162, Colorado State University, November 1973, 61 pages. AID Document Identification Symbol: PN-AAA-535.

In some regions of the world, such as near the coastline and in basins with salty, deep groundwater subject to periodic percolation of fresh rainwater down to the groundwater, there exists a thin layer of good quality fresh water that "floats" on top of the salty groundwater. Such a condition exists in some areas of the Indus Plain of Pakistan. Ordinary, deep-penetrating wells, pumped at high rates, will yield salty water and can ruin the whole aquifer in terms of water quality. Skimming wells can be designed in which the depth of the well and the rate of pumping are carefully controlled to pump the fresh water off the top of the salty water without salt water entering the wells. Procedures based on theoretical formulas are given for the design of skimming wells. In cases where the yield from a single well is not adequate, batteries of skimming wells connected with a manifold arrangement can be used, and procedures for this are given. The report contains some cost data on skimming wells based on conditions in Pakistan. The theoretical equations presented are mathematically complex.

Groundwater Extraction and Water Balance by George H. Hargreaves. Report under AID Contract No. AID/csd-2167, 1973, Utah State University, 23 pages. AID Document Identification Symbol: PN-RAA-015.

Groundwater extraction and net use are related to groundwater depletion and the water balance. Potential evapotranspiration, actual crop and vegetative evapotranspiration, dependability precipitation, moisture deficits, and a moisture-available index are defined. A method is presented for estimating potential evapotranspiration and crop evapotranspiration from a minimum of climatic data. For most climates the only weather data required are mean temperature and mean humidity, but for arid areas only temperature is required. Crop factors are presented for a wide variety of crops. A water balance study for an essentially closed basin in Nicaragua is described to illustrate the relationship proposed.

Drainage and Salinity Problems in Irrigated Areas, How to Avoid or Minimize Them by J. E. Christiansen and E. C. Olsen. A report under AID Contract No. AID/ta-c-1103, Utah State University, April 1974, 64 pages. AID Document Identification Symbol: PN-RAB-202.

This paper provides a general description of the problems of drainage that are often associated with irrigated agriculture. The paper discusses the importance of water quality in determining the drainage requirements associated with irrigation. Soil characteristics and water quality characteristics are discussed. Various drainage methods suitable for irrigation agriculture are presented, along with reclamation procedures for lands that have deteriorated because of salt accumulation or excess sodium. The importance of evaluating drainage needs in planning irrigation projects is also covered. The paper provides an extensive glossary of terms relating to drainage and irrigation water management. This paper provides a useful general guide for those interested in developing irrigation projects.

Irrigated Corn Production in Chile: Increasing Yields Through Intensive Irrigation Management by R. Kern Stutler, Don C. Kidman, Juan Tossa, and Norbert Fritsch. Report Under AID Contract No. AID/csd-2167, Utah State University, December 1974, 27 pages. AID Document Identification Symbol: PN-AAB-090.

This report covers results from a 3-year program involving research and demonstration on modern concepts of irrigation management for corn, which was conducted in the Aconcagua Province in Chile. Irrigation, land management, fertility, corn variety, and plant population were emphasized. Results proved that yield potential of corn is well above the current level of production. By adopting the practices in this report, corn producers can increase yields at least 150 percent with the resources they currently have available. Although all of the research was conducted in the Aconcagua Province, the technology can be transferred to other provinces in the corn-producing area with only slight modification or adaptation.

Energy Inputs to Irrigation by J. C. Batty, Safa N. Hamad, and Jack Keller. Report under AID Contract No. AID/csd-2459, Utah State University, December 1974, 25 pages. AID Document Identification Symbol: PN-AAA-948.

Nine different types of irrigation systems are analyzed to calculate the energy required for providing water for irrigated crops using The systems illustrated include an open-ditch-supplied surface irrigation system without an irrigation runoff recovery system, a gated-pipe-supplied surface irrigation system with an irrigation runoff recovery system, several kinds of sprinkler systems, and a trickle system. Many of the systems illustrated are so expensive that they are of doubtful suitability for many developing countries. The analysis includes energy inputs to manufacture the components of the systems, install the system, and operate and maintain the system. The surface irrigation systems are the least expensive in cost and in energy required for their operation.

The Evaluation of Water Deficiencies by George H. Hargreaves. Report under AID Contract No. AID/csd-2167, Utah State University, 1982, 19 pages, AID Document Identification Symbol: PN-RAA-013.

This paper proposes concepts that further define both moisture need for crops and its availability. Potential evapotranspiration is used as an index of moisture need. Dependable precipitation, which is that precipitation equaled or exceeded 75 percent of the time, provides an index of dependable moisture supply. A moisture availability index is proposed as an index of moisture adequacy or deficiency. The percentage of occurence with respect to time is termed the adequacy percentage and is proposed to further define the adequacy of precipitation for crop production. Climatic data required to estimate the above indices are precipitation, temperature, relative humidity, wind velocity, and elevation. Equations are developed from these parameters based on a wide range of climatic conditions, including those encountered in various arid and semi-arid regions of the world.

A Suggested Program of Irrigation Research and Knowledge Transfer in Arid and Sub-Humid Areas by Allan D. LeBaron. Report under AID Contract No. AID/csd-2167, June, 1973, Utah State University, 21 pages. AID Document Identification Symbol: PN-RAA-057.

A simple procedure for organizing research in developing countries is presented. The suggested first step is to obtain crop yield response, considering moisture and fertility interactions under local conditions. The research should include tests of irrigation methods. Research sites in selected regions in the countries should be identified and tests conducted to determine on-farm irrigation cost data based on economic evaluations of irrigation practices under local conditions. Finally, procedures for transferring the knowledge obtained through knowledge transfer models should be identified. A conceptual model is given based on experience of several people, but no data, other than some generalized data relating to costs of research, is presented.

Irrigation Design and Management Related to Economics by Jack Keller, J. Paul Riley, and R. John Hawks. Report under AID Contract No. AID/csd-2459, Utah State University, September 1972, 17 pages. AID Document Identification Symbol: PN-RAA-069.

This report investigates the relationships between the hydrologic and economic systems in economic crop production under irrigation. Economic factors in the irrigation system include the fixed and operating costs of all kinds. Water costs are considered as are the physical factors that influence production of crops under irrigated conditions. Based on the relations between the various factors, a method is proposed for combining them into a procedure for optimizing the design and management of irrigation systems.

A Strategy for Optimizing Research on Agricultural Systems Involving Water Management by Jack Keller, Dean F. Peterson, and H. B. Peterson. Report under AID Contract No. AID/csd-2459, Utah State University, July 1973, 20 pages. AID Document Identification Symbol: PN-AAA-336.

The rationale for a model for optimizing agricultural systems through knowledge transfer is developed and presented. This conceptual model attempts to disaggregate the environment into significant components that are measurable. It uses crop production as the overall integrator of the agricultural system response to the husbandry program imposed at a specific site. The model should aid in organizing available crop data and investigations and provide a useful outline to guide thought processes involved in research program development and project analysis, as well as provide a framework for a data retrieval system. This paper presents a concept and does not include data on actual use of the model.

The Effect of Agricultural Use on Water Quality for Downstream Use for Irrigation by J. E. Christiansen. Report under AID Contract No. AID/csd-2167, Utah State University, July 1973, 35 pages. AID Document Identification Symbol: PN-RAA-002.

This paper provides an analysis of the effect of irrigation return flow to streams on the water quality for downstream irrigation use. Factors of importance in analyzing return-flow water quality include total salt, electrical conductance, concentration of major ions in water, sodium percentage, sodium absorption ratio, residual sodium carbonate, and several others. A classification of irrigation water quality is suggested that considers all of these parameters. To illustrate the procedure, changes in water quality that result from irrigation diversions are presented for three rivers in the United States.

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