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UNDERSTANDING SMALL-SCALE IRRIGATION SYSTEMS

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Patrice Matthews and Suzanne Brooks handling typesetting and layout,

and Margaret Crouch as senior editor and project manager. VITA Volunteer Dr. R. R. Ronkin, retired from the National Science Foundation, lent his invaluable perspective, as a volunteer, to the compilation of technical reviews, conversations with contributing writers, editing, and in a variety of other ways.

John Chapman is an agricultural engineer employed with a large irrigation equipment manufacturer. Claude Pair, retired after more than 40 years with the U.S. Department of Agriculture, is an expert on sprinkler irrigation with experience throughout Asia. Karl Klingelhofer is also an agricultural engineer with extensive experience in the Far East and Central America. All three have been VITA Volunteers for many years. Eng. Mohammad Sediq is the former President of Public Works for the government of Afghanistan and presently heads VITA's Agricultural Rehabilitation Program for that country.

VITA is a private, nonprofit organization that supports people working on technical problems in developing countries. VITA offers information and assistance aimed at helping individuals and groups to select and implement technologies appropriate to their situations. VITA maintains an international Inquiry Service, a specialized documentation center, and a computerized roster

of volunteer technical consultants; manages long-term field projects; and publishes a variety of technical manuals and papers.

UNDERSTANDING SMALL-SCALE IRRIGATION SYSTEMS

by VITA Volunteer John A. Chapman

1. THE IMPORTANCE OF IRRIGATION

Irrigation is the practice of supplying needed water to cropland to produce plant growth. It may be used to combat occasional drought or to make arid lands productive. Cropland may be irrigated before planting or as the crops are growing. Clearly, a decision to irrigate requires knowledge of the needs of crop plants and of local, natural conditions affecting water supply and loss.

Irrigation has been conducted for thousands of years. In some areas of the world, the only interruptions have been due to war or plague. Where irrigation was needed and not possible, land has become wasteland and irrigation systems have been abandoned. Some societies that depended heavily on irrigation did not survive poor irrigation system design. From these experiences it is clear that irrigated agriculture can be sustained and a properly designed irrigation system may be needed to support a society for a long period.

2. COMPONENTS OF AN IRRIGATION SYSTEM

The scope of irrigation is not limited to the application of water to the soil. In a larger sense, it deals with all aspects of water supply and use, from the watershed to the farms. It includes the design and construction of such works as dams, weirs, and water now regulators for storage or diversion of water, as well as subsoil drainage, soil reclamation, and the economics of the relationships among water, soil, and crop plants. This paper emphasizes practices of applying water to the soil.

Irrigation projects may be large or small, but scale does not affect the principles of operation. The important components or ingredients of an irrigation project are as follows: the characteristics of the soil, the kinds of crops to be grown, the water to be used, the kinds of irrigation methods, and project management.

The Soil

The design of an effective irrigation project requires an understanding of soil characteristics. The

soil is the main source of plant nutrients. Moreover, its structural features enable it to hold the plant roots in position and allow the plant to stand erect. The problems that occur with the soil are usually related to its chemical or structural features. In places where there are long periods of heavy rainfall (more than 100 cm per year), for example, soils are usually acidic. This happens because falling rain is slightly acidic and in passing through the soil dissolves some of the water-soluble nutrients, carrying (leaching) them below the root zone of the plants. Leaching of important nutrients is harmful to plant growth, but can be corrected by applying fertilizers to restore the soil to a more productive state.

Soils that have not been subjected to long periods of rainfall are often alkaline (basic). The reason is that the basic soil constituents have not been leached, so that the soil may retain high concentrations of the basic components of the rocks from which it is derived. A high concentration of sodium, for example, can seriously disrupt the chemical balance needed for plant growth. Minor chemical imbalances can sometimes be corrected by additions to the soil, but major imbalances may be repairable only at prohibitive cost.

Soil structure relates to the size of the soil particles that make up the soil

and the manner in which these particles are arranged. Coarse, sandy soils have low water-holding capacity (4 centimeters or less of water in a one-meter layer of soil) and need to be irrigated frequently to grow most crops.
A soil with a high clay content can be highly productive and may hold a considerable quantity of water that is available to the plant (16 cm or more per m of soil). This type of soil will require less frequent irrigation cycles and larger quantities of water can be applied at each irrigation.

Some soils tend to become compacted. Compaction reduces the pore space in the soil and makes it difficult for the plant roots to penetrate it. Compaction also retards penetration of water that is applied to the surface. It can usually be corrected by mechanical tillage, which may need to be repeated on a regular seasonal basis.

The Plants

The plant species that is to be grown may dictate the type of irrigation project that needs to be installed. Most plants have a variable water requirement during their life cycle. At the time of planting, the seed needs only enough moisture for germination. Initially, the amount needed may be only about twice the weight of the seed. However, as the seed starts putting out shoots and roots, the water demand increases. When the plant reaches its full flowering and fruiting stage, it usually has its highest water demand. It then requires less water until maturity. At fruit maturity, the plant may die (maize, wheat, etc.) and require no more water, or it may go dormant and only need enough water to sustain it until the next reproductive cycle (fruit trees).

The Water

Quantity and Quality of Water. The amount of water needed in the peak use periods varies with climatic and geographic conditions. An approximate rule is that the plant will extract 0.75 cm of water from the soil each day. That is, if the crop field is completely covered with plant growth, the entire field will have water extracted from it equivalent to a layer of water 0.75 cm deep. This estimate, along with others that are more exact, predicts the minimal water requirement that must be considered when the irrigation project is designed.

The quality of the water is also important. Some waters have such a large content of soluble saits that they cannot be used. Rough guidelines for estimating water quality are as follows: Rain water that falls directly on the soil is almost always good water. Water that has drained from a field

where it was previously used to irrigate another crop should be tested. The taste of water is not a reliable indication of quality; samples of the water should be analyzed at a competent water laboratory.

Naturally occurring water always contains some dissolved material. Water pumped from the ground or from drainage probably contains salts. When this is applied to the soil, it picks up additional soluble salts. The water is then extracted from the soil by the plant. The plant probably does not utilize much of the dissolved salts. but filters these out at the root. The clean water is then used by the plant to create new growth, or may be evaporated into the atmosphere. Salts remain behind in the soil. If they are not removed, they can accumulate to a level that renders the soil unfit for crop production.

Because of the prospect of salt accumulation, some experts recommend that soil that is to be irrigated must also be properly drained. For some projects, this recommendation is correct. However, management schemes that leach the salts to a level below the root zone are just as effective as drainage in keeping the salts under control. Such controlled leaching is usually applied with irrigation schemes employing sprinkler and drip-irrigation technologies.

Surface Water. The source of water should be reliable. Unfortunately, most sources of surface water are in greatest supply at early stages in the life of the crop plant. As the plant gets larger, it needs more water, but by that time the water supply is often diminished in flow or availability.

Water is transported from the source to the field by some form of conveyance structure. Structures may be open furrows (ditches, channels), closed conduits (pipes), or lined furrows. They are often expensive and and labor intensive to build. Some of them require labor-intensive maintenance.

Water supplied by a stream can often be delivered to a field using only the assistance of gravity. A common method is to construct a small diversion dam across the stream. Most of the water will flow over the dam and continue to flow downstream. A small part of the water will be diverted into a furrow where it flows in the same direction as the stream, but declines in elevation more slowly than the stream. After some distance, the stream level will be much lower than the water in the diversion furrow flowing in the same general direction. At that point, water from the diversion can be directed to the field for use. The structure and conveyance should be protected from floods, wild burrowing animals, and vegetation that may cause damage.

Ground Water. A reliable source of good-quality ground water may be useful for irrigation. Here are the questions that need to be answered: Does it provide enough water to meet the demand of the crop? Is the quality of the water suitable for the application? Are the costs of getting the water and maintaining the source affordable in the context of the project?

If all of these questions are answered by "yes," then ground water may be the best source of supply. In an area where little is known about the water-bearing underground layer from which the water is to be pumped, it may be necessary to drill several test wells to locate the best site for a well. After the test well is installed, it should be test pumped for up to 24 hours to ensure that it will sustain an adequate flow.

The drilling or digging of a well should be done by someone who is familiar with constructing wells of the same size and capacity in the same area. Several techniques are used in making wells. Each is suited to a particular application. The equipment for well construction can be as simple as a shovel or as complex as a reverse rotary drilling rig. Try to secure locally available equipment that is suitable for the type of well needed.

2. IRRIGATION TECHNIQUES

The commonly used techniques for distributing irrigation water within a field are flood ("surface") and furrow irrigation, sprinkler irrigation, and low volume irrigation; each has its advantages.

Flood and Furrow Irrigation

This method is the oldest form of irrigation; it involves the direct discharge of water at low pressure from a conveyance structure (lateral furrow) to the land. The distribution of water over the soil is achieved by gravity. This technique is not generally as efficient as others because water percolates farthest into the soil at the point where it is first discharged to the land.

The efficiency can be increased with reuse pits and pumps, or surge irrigation. In every case a uniform and level or gently sloping field is required. Diversion dams on streams, diversion furrows, and flood distribution of water may be involved. Most fields require some earth work to make them level enough to be used. Once installed, these systems require. little capital investment. Their operation can be labor intensive, but labor costs can be reduced by methods described below. Knowledge of operation requires both experience and education.

Siphon tubes can be used to bring water into a lateral furrow and onto a field. The water first flows into a lateral furrow at the high end of the field. The water level is maintained fairly close to the top of the furrow. Small plastic or aluminum tubes that have been bent into a partial "U" shape have one end placed in the water. The other end is placed in a furrow that slopes downward across the field. Siphon action then moves the water from the upper furrow into the one below.
The tubes can be of various sizes; one common size is 2.5 cm. If more water is needed in a furrow, more tubes or a larger tube can be used.

<Figure 1>

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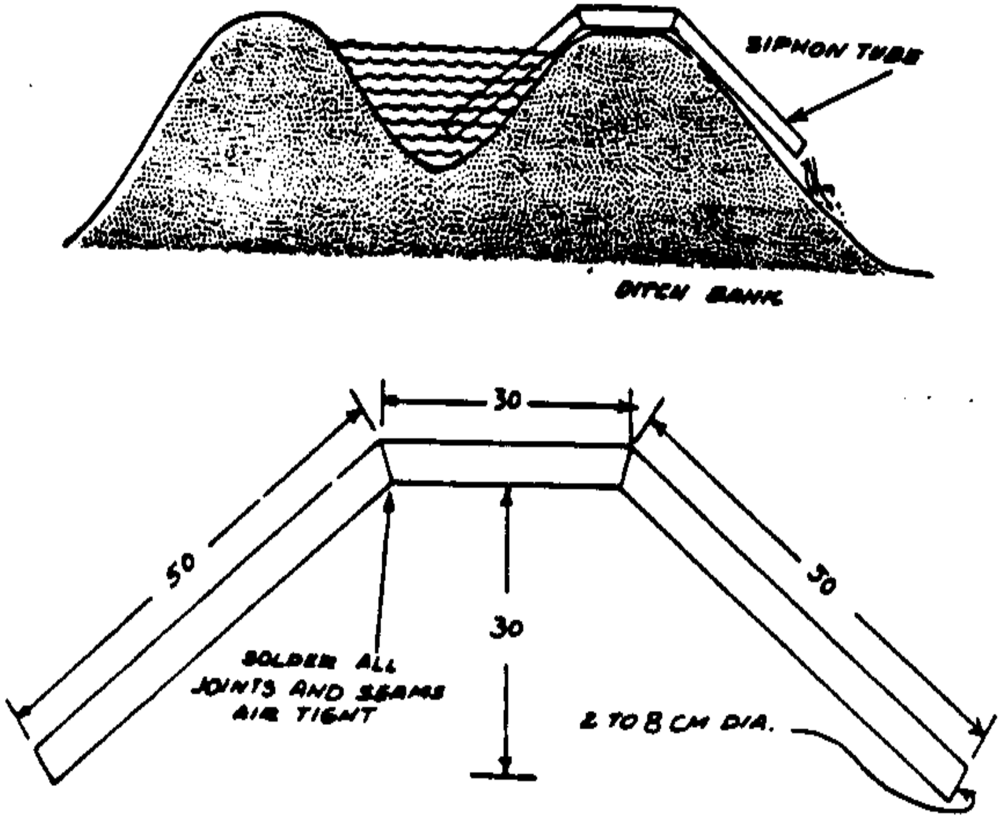

Figure 1: Siphon Tube for Flood and Furrow Irrigation

Gated pipe is used on some farms. With this system the water is pumped into a pipeline and conveyed
to the field. At the field there are pipes that have openings in them at intervals between the
rows of crops.

Perhaps the oldest form of water distribution is the small lateral furrow, opened and closed by the irrigator who uses a shovel to break down the wall of the furrow so the water can run onto the field. Although this primitive technology is rarely efficient, it works in certain locations.

Sprinkler Irrigation

When water is delivered to the field under pressure, it can be deposited on the land in many different ways. One of these ways is the automatic distribution by sprinklers. The water is discharged into the air and falls to the ground in a fine mist, similar to the fall of gentle rain. The discharge pressure at the nozzle of the sprinkler device is usually between 1.5 and 5 atmospheres (atm). This type of irrigation requires more energy than flood irrigation, but is more versatile since it can be used on steep slopes. Moreover, one can easily irrigate by frequent light applications. No more water should be supplied than the root zone of the plant can retain. The capital equipment costs are comparatively high, but are somewhat offset because the cost of land preparation (for example, levelling) is less compared to flood irrigation.

Large, mobile devices can be used to fully automate large land areas, among them central pivot, linear, and reel units. Central pivot units supply the water to the center of the field, at which point the water flows into a long pipeline supported above the ground at up to 50- to 60-meter intervals on mobile carts. The carts move the pipeline about the pivot point where the water is introduced. The pipeline moves like the minute hand of a clock around the field. These units are able to cover small fields of 4 to 5 hectares (ha) and large fields of over 200 ha. They traverse slopes of up to 25 or 30 percent. With proper design, the units can be almost fully automated; one properly trained person can easily irrigate over 1000 ha without help.

Rectangular fields of sufficient size are often irrigated with linear units. These are, in effect, made from the components of the central pivot unit. They travel back and forth and can irrigate the entire field as they move. They can irrigate fields with slopes of 5 percent and can be automated, but require about twice as much labor as the central pivot units.

<Figure 2>

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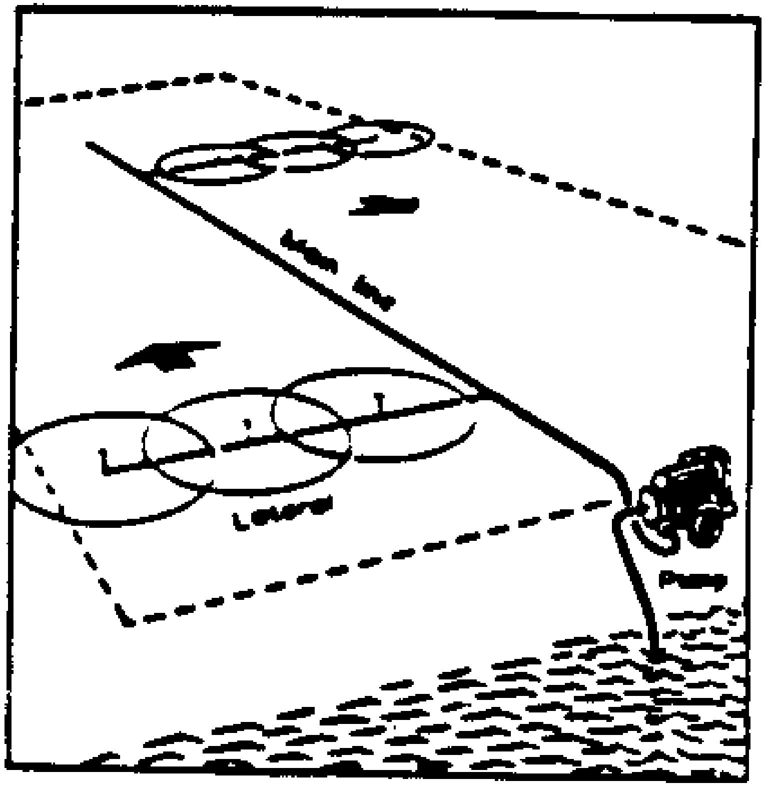

Figure 2: Simple Sprinkler Layout

A reel irrigator is mounted on a skid, or a trailer, that is attached to a hose that supplies the water.
As water is applied, the hose is coiled up on the hose reel; the hose and reel are
quite heavy and require a stable roadway. The units also may require water pressure between 5
and 10 atm. As a consequence of the pressure requirement, reel units are

generally considered
high consumers of energy.

Low-Volume Irrigation

Low-volume irrigation (also called "drip irrigation") is a relatively recent technique developed for
areas with low water supply. The water is delivered to the field under a pressure of 1 to 2 atm. It
is then distributed through small plastic tubes and is discharged to the soil through small holes
(emitters) very close to the plant, either above or below ground. The rate of discharge is low and
may be only a steady drip rather than a stream. This technique probably uses water more efficiently
than any other.

Drip irrigation equipment is fairly expensive to install. Its use usually requires filtered water lest
the emitters become clogged; algal growth also can plug them. The soil tends to become saline
where the wet and dry zones of the soil meet. Even with these problems, however. the advantages
of drip irrigation are evident, and the method is often preferred for tree crops.

<Figure 3>

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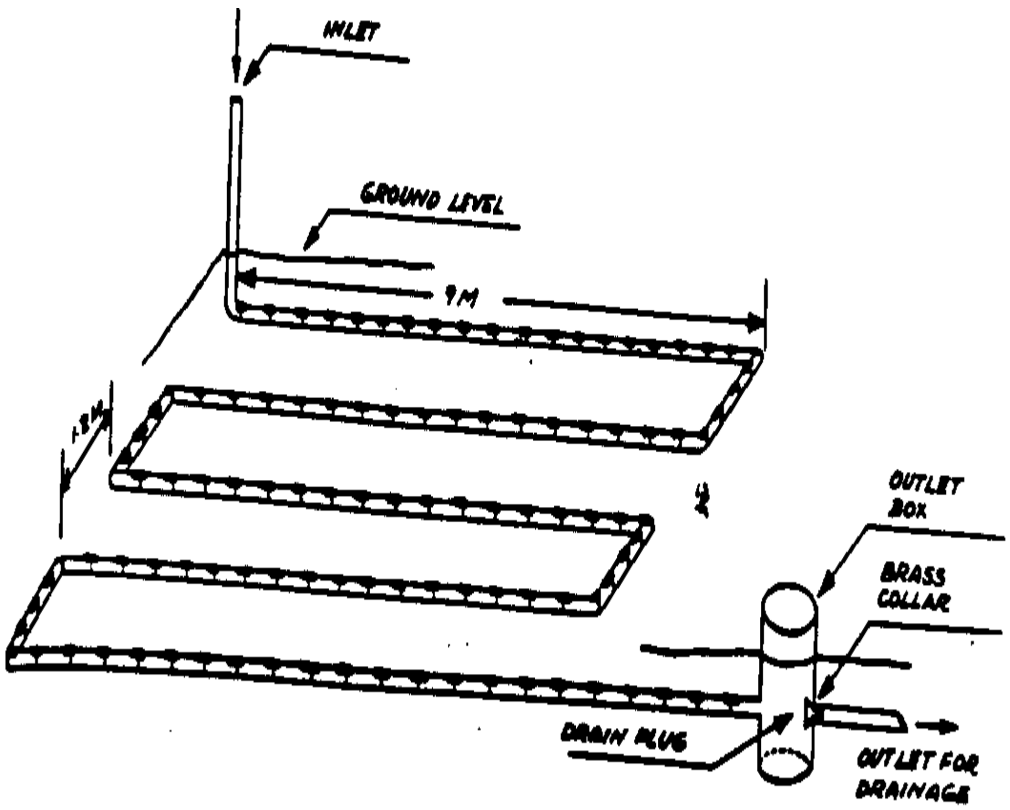

Figure 3: Simple Drip Irrigation System

3. DESIGNING AND MANAGING THE PROJECT

Irrigation projects must be designed on a site-specific basis. Topography, soil type, soil depth, water supply, climatic conditions, and kinds of crops grown all differ from site to site. Here are

the factors to be considered in order to design a project:

*** the amount of water the soil holds in its root zone that can be available for the plant to use;**

*** the amount of water the plants need to produce crops; and**

*** the amount of water that is expected as rainfall during the growing season.**

*** water quality: the amounts of dissolved materials in the water in relation to the needs of the crop.**

*** respurces available to install and maintain the system.**

Assuming the soil to be saturated before planting the crop, then by adding the rainfall during the growing season, one predicts approximately how much water is available to grow the crop. Subtract this from the water needed by the crop to establish the approximate amount of water to be supplied by irrigation. Alternatively, an irrigation demand can be planned to supply all of the water needed by the crop. This will enable the plants to survive an infrequent drought.

After determining the amount of water needed by the crop, one then defines the source of water

and ensures that it is adequate to meet the demand.

The next step is to determine how to distribute the water on the fields. A rough topographic map should be made of each site to be irrigated. The elevation and location of the water supply relative to the site should be determined if it is not known. Soil and water analysis should be made to determine their suitability for irrigation. Finally, a competent irrigation designer should review any plans. This may seem rather restrictive or expensive, but decisions on irrigation are not trivial, short-term matters. They involve a major commitment of resources.

Starting with a careful design, one can often construct a complete irrigation project with local unskilled labor and locally available materials. For example, if the project is very small, a diversion dam can be built by placing rocks in a stream. Hand shovelling can construct a diversion canal, distribution laterals, or a field distribution system. The designer needs to know what materials and skills are available at the site.

It is essential to discuss the project early in the planning phase with those that must use and maintain it. Later, the users must be trained in its proper seasonal shut-down and maintenance.

Most irrigation systems are drained, repaired, and cleaned after the crop has been harvested. This is the opportunity to remove debris, repair leaks, and make improvements without affecting crop production. Most irrigation systems need off-season maintenance. Design of the project should include operation, the maintenance schedule, and training.

When the water conveyance system is used by several people, serious problems can arise in distributing the water on a timely basis to all of them. Those in control should ensure that priorities and rules are set forth that all or the users understand and which can be enforced.

REFERENCES

There are many good books for those who wish to review design techniques and have more detailed data. Some of these are used by engineers and soil scientists and may seem complex, but the principles are relatively simple. These books should aid in understanding terms used in this discussion and help to satisfy interests that go beyond it.

R. M. Hagan, H.R. House, and T. W. Edminster (eds.), Irrigation of Agricultural Lands. Madison, Wisconsin: American Society of Agronomy, 1967.

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Glenn O. Schwab et al. (eds.), Soil and Water Conservation Engineering, 2nd ed. New York: Wiley,
1981.

Peter Stern. Small Scale irrigation. London: Intermediate Technology Publications, 1979. This is
an excellent source of information for the non-expert for designing and installing small-scale
irrigation systems.

See also:

Village Technology Handbook, Margaret Crouch and Len Doak, eds., Arlington, Virginia: Volunteers
in Technical Assistance, 1988. The water and agriculture sections of this how-to guide contain
much valuable information on the construction of a variety of land-leveling implements,
water supply and diversion, and simple pumps.

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