Water Conservation Best Management Practices (BMP) Guide for Agriculture in Texas

Based on the Agricultural BMPs contained in:

Texas Water Development Board
Report 362
Water Conservation Implementation Task Force

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FORWARD

The information contained in the publication was made available by the Texas Water Development Board and was first published in November of 2004 as Report No. 362. This publication contains only those Best Management Practices (BMPs) applicable to conservation of water used by agriculture, whereas Report No. 362 also contained BMPs applicable to municipal and industrial sectors. The language regarding Agricultural BMPs in this report is identical to that in Report No. 362. The information was reformatted to save printing cost and photographs were added to help identify the proposed practices. Credit for the source of each photograph is given in the photograph title.

Views expressed in this report are of the authors and do not necessarily reflect the views of the Texas Water Development Board, the Texas State Soil and Water Conservation Board, or any other entity.

Cover Photograph– Furrow Irrigated Cotton in West Texas *(Courtesy of El Paso County Water Improvement District No. 1).*

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1. Introduction

This document is the result of the work of the Texas Water Conservation Implementation Task Force, a volunteer group of Texas citizens with experience in and commitment to using Texas water more efficiently. The Task Force was created by the 78th Texas Legislature under Senate Bill 1094. The Legislature directed the Texas Water Development Board ("TWDB") to select members of the Water Conservation Implementation Task Force from applicants representing the following entities and interest groups:

- Texas Commission on Environmental Quality
- Department of Agriculture
- Parks and Wildlife Department
- State Soil and Water Conservation Board
- Texas Water Development Board
- Regional Water Planning Groups
- Federal Agencies
- Municipalities
- Groundwater Conservation Districts
- River Authorities
- Environmental Groups
- Irrigation Districts
- Industries
- Institutional Water Users
- Professional Organizations Focused on Water Conservation
- Higher Education

The legislature charged the Task Force with reviewing, evaluating, and recommending optimum levels of water use efficiency and conservation for the state. These Best Management Practices were prepared in partial fulfillment of this charge. This document was developed by GDS Associates, Inc., Chris Brown Consulting, Axiom-Blair Engineering, Inc. and Tony Gregg, P.E. through funding from the Texas Water Development Board's Research and Planning Fund.

1.1 Background

Municipal water conservation efforts in Texas have been motivated by diverse goals such as preventing land subsidence, addressing short-term or long-term water shortages, providing environmental protection, and avoiding or postponing the high costs of new water system improvements. Through implementation of water conservation programs across the state, experience has been gained in the effective delivery of programs and lessons learned in approaches which are not as effective.

Industrial water users have also made advances in water use efficiency over the past several decades. Inspired by increasing costs of resources, such as the water itself, energy needed to pump, treat, and heat water in industrial processes, and the challenges of drought, many Texas businesses have developed or adopted techniques to lower water use. One indication of the success of industrial efforts is actual water use recorded for the manufacturing sector in the year 2000. Actual use was 70 percent of water demand projections developed in the late 1990s.

Agricultural growers using groundwater from the Ogallala Aquifer have pioneered water efficiency in agricultural irrigation in the Texas panhandle region. As early as the 1970s, low-pressure center pivot irrigation systems were reducing water use by 30 percent to 50 percent from existing irrigation methods at the time. Since then, irrigation efficiency has increased both in the sophistication of low pressure irrigation methods as well as increased efficiency in other irrigation and water management methods in agricultural production.

While there are a number of successful conservation efforts in Texas, there is an opportunity for a more comprehensive effort by all sectors of the State. The legislation that created the Water Conservation Task Force was passed in order to further conservation efforts in the State. One of the objectives of the Task Force was to gather information about the elements of successful conservation programs, good cost estimates and reliable water savings estimates for use in water resource planning. In this guide, the Task Force uses the following working definition of conservation: Those practices, techniques, programs, and technologies that will protect water resources, reduce the consumption of water, reduce the loss or waste of water, improve the efficiency in the use of water, or increase the recycling and reuse of water so that a water supply is made available for future or alternative uses. As part of its work, the Task Force hopes to move the process of water conservation planning a significant step forward in Texas by the publication of Best Management Practice Guidelines based upon this current analysis.

1.2 Best Management Practices (BMPs)

Experience in water conservation program implementation over the decades has resulted in a body of knowledge in Texas, across the United States and around the world. Practitioners have shared these experiences and adopted the approach of the BMP. A BMP is structured for delivering a conservation measure or series of measures that is useful, proven, cost-effective, and generally accepted among conservation experts.

In Texas, conservation BMPs are designed to fit into the State’s water resource planning process as one alternative to meet future water needs. As a result, each BMP should be clearly defined in its schedule of implementation, expected water savings, and costs of implementation (based on Exhibit B Guidelines for Regional Water Plan Development).

Each BMP structure has several elements that describe the efficiency measures, implementation techniques, schedule of implementation, scope, water savings estimating procedures, cost effectiveness considerations, and references to assist end-users in implementation.

1.3 Development and Purpose of Best Management Practices Guide

The BMPs and the cost effectiveness tools in this Guide are offered to the state's regional water planning groups, water providers, and water users as a tool for planning and designing effective conservation programs. The Guide is organized into three sections, for municipal, industrial and agricultural water user groups ("WUG") with a total of fifty-five BMPs. At the end of each section is a chapter giving guidance on cost effectiveness evaluation for the specific BMPs in the section. Each BMP is organized to be of assistance in conservation planning, program development, implementation, and evaluation.

The BMPs can be evaluated for potential water savings and the cost effectiveness for consideration in the regional water planning process. Within each planning region, sufficient variation exists at the local water user level that more specific analysis should be done by a prospective end-user prior to adopting the BMP. Best-management practices contained in the BMP Guide are voluntary efficiency measures that save a quantifiable amount of water, either directly or indirectly, and can be implemented within a specified timeframe. The BMPs are not exclusive of other meaningful conservation techniques that an entity might use in formulating a state-required water conservation plan. At the discretion of each user, BMPs may be implemented individually, in whole or in part, or be combined with other BMPs or other water conservation techniques to form a comprehensive water conservation program. The adoption of any BMP is entirely voluntary, although it is recognized that once adopted, certain BMPs may have some regulatory aspects to them (e.g. implementation of a local city ordinance).

The Task Force unanimously agreed that the BMP Guide must be in accordance with the state's philosophy of region-based water planning. The Task Force firmly believes that applying a mandatory set of BMPs throughout Texas would **not** be appropriate. One size does not fit all in a state characterized by wide variations in climate, geography, municipal demographics, water utility and service profiles, and agricultural and industrial needs. State policies adopted to guide the implementation of water conservation in Texas must acknowledge the fundamental decision-making primacy and prerogative of regional planning groups, municipalities, industrial and agricultural water users, and water providers. Each BMP is organized into nine standardized sections (A-I), which are described in general terms below.

A. Applicability

The specific type of water user group that could potentially benefit from the BMP is described, as are the general goals for water efficiency that the BMP addresses.

B. Description

This section provides an explanation of the specifics of the conservation measure(s) included in the BMP. The best available technology that is proven and cost effective is recommended. Often a best available technology may not yet be cost effective to be implemented by all water users. Highly efficient water conservation measures that will produce cost-effective results are mentioned.

Example: The current standard for water efficient toilets is 1.6 gallon per flush ("gpf") models. Lower flush volume toilets exist such as dual flush toilets which flush 1.6 gpf for solid waste and 0.8 gpf for liquid waste, but their availability is not yet widespread in the United States. Since this technology is new and few models are available, costs are currently high but are expected to fall as additional models become available. As prices fall, this technology will become more cost effective.

C. Implementation

The basic steps to accomplish the BMP are described. If the description section includes more than one measure to complete the BMP, the implementation section will suggest necessary steps for achieving the water savings.

D. Schedule

In BMPs which have multiple implementation steps, a recommended schedule for implementation is included. In general, planning, data gathering and evaluation steps should be accomplished within 12 months of adoption of a specific BMP.

E. Scope

For simpler BMPs, the scope is complete when the steps described in the implementation section have been achieved. For more complicated BMPs, the scope indicates the level of implementation necessary to consider the BMP complete. Where different levels of implementation or constraints are present, these are described.

F. Documentation

To track the progress of a BMP, the water user should collect certain data to document progress implementing the BMP and evaluating actual water savings. This section identifies the recommended data.

G. Determination of Water Savings

This section specifies information necessary to calculate water savings from implementation of the BMP and may include statistical or mathematical formulas when appropriate.

H. Cost-Effectiveness Considerations

Basic costs of implementing the specific BMP are explained. Due to the wide variety in actual costs based upon size of program and location, ranges of costs are given where appropriate. In many cases, costs and expenses can be reduced or spread out when multiple BMPs are implemented by an entity. This section primarily serves to remind the users of costs to consider when performing a cost effectiveness analysis.

I. References for Additional Information

The BMP concludes with a listing of resources that can assist a water user in implementing the BMP.

1.4 Cost-Effectiveness Considerations

Each of the three sections of the BMP Guide, Municipal, Industrial, and Agricultural, has a dedicated chapter on cost-effectiveness analyses. Methods for determining the relationship between the value of water saved and the cost of BMP implementation are described and explained through examples. Users of the guide are encouraged to read and utilize any of the analytical tools found in these sections, if they find them to be appropriate.

1.5 Getting the Most Out of the Guide

The BMP Guide is designed for several uses and for a diverse audience of water resource planners and managers throughout the state. It has sufficient detail to be useful in the state water planning process, which is implemented at the regional level. The Regional Water Planning Groups are encouraged to review the BMPs and to consult with WUGs in their region that have an identified future need for water to determine which BMPs are appropriate and which BMPs the WUGs intend to utilize or are already using for conservation program planning and implementation. For planning purposes water conservation best management practices are not limited to those listed in this guide.

The Task Force acknowledges that the efficient use of water as a natural resource is an important planning objective and an economical means of operation and recommends that water user groups of all types evaluate the BMPs for use in their area. The first step for a municipal, agricultural or industrial water user is to review the Applicability section in a BMP to determine if the BMP is appropriate for their use. For those water users with stakeholders, a stakeholder involvement process is a valuable means of getting feedback on priority BMPs and on specific elements within a BMP which have broad support. In municipalities, stakeholders include customers and representative interest groups which have shown an interest in water issues in the community. Such groups may include representatives from neighborhood and business associations, technical groups, academics, environmentalists, and city departments. A number of the municipal BMPs recommend developing such stakeholder groups as a part of implementing the specific BMP. The Task Force also recognizes that stakeholder groups can be helpful in the initial selection of best management practices to be included in a Conservation Plan.

Industrial WUGs should consider employees from all affected departments, customers, suppliers, and regulators and impacted water users, including agricultural or municipal interests, as potential stakeholders. Depending upon the size of the business and the proposed BMPs, the process can be either formal or informal. The industrial WUG can also use the guidance included in the Employee Programs BMP as part of the process of selecting the appropriate BMPs. For those industrial WUGs that are already implementing an Environmental Management System the stakeholder process may be defined and can be used to help pick the appropriate BMPs. In the industrial setting, executive management support is essential for success and should be sought early in the planning process.

Agricultural WUGs at the farm level may include employees, suppliers and regulators among potential stakeholders. A valid input process may be an informal survey of individuals to solicit input for choosing the best BMPs. For political subdivisions of the State of Texas that deliver irrigation water to agricultural users, the stakeholder group may include representatives from agricultural and water conservation organizations, municipal, and rural water supply entities, and local, state, or federal governmental agencies.

In writing a Conservation Plan it is important for the WUG to follow state, local and, in some cases, federal guidelines which may include requirements for certain plan elements such as a utility profile and seasonal demand. Such requirements are often specific to the WUG, the type of water demand, and the political boundaries in which a WUG operates. Texas has numerous groundwater districts, river authorities, and irrigation districts all of which have specific authority and the potential for unique requirements within their area or operation. The BMPs are designed to be used as a resource in developing that part of a water conservation plan where specific measures, the schedule and scope of implementation, and the anticipated savings and costs are addressed.

Each BMP was prepared through research of literature and with the insight and experience of Task Force members, Board staff, and technical consultants to provide information based upon real world results of conservation program implementation. Because of the information accumulated in the development of the Guide, each BMP can serve as a program guide as well as a planning tool. Conservation program managers wishing to use the BMPs in program delivery should pay close attention to the Implementation, Schedule, Scope, and Documentation sections. Each of these sections contains information which can assist existing conservation programs as well as new conservation efforts to increase their effectiveness. Each BMP also includes a reference section with additional resources to assist conservation practitioners in delivering high quality programs with real water savings.

The BMP also has information that can assist managers, auditors and policy makers in evaluating the impact of conservation programs. The Documentation, Determination of Water Savings, and Cost Effectiveness Considerations sections are provided to assist in program evaluation. Each section of BMPs, municipal, industrial and agricultural, has a Cost-Effectiveness Chapter, which provides tools for doing cost-benefit analysis by each of the major types of WUGs.

The Task Force presents this Guide as a tool for advancing the practice and effectiveness of water conservation in Texas. The insights distilled in the enclosed BMPs come from years of conservation practice by the Task Force members. That same experience leads the Task Force to view this as a living document, with the recognition that further implementation of conservation practices will bring new insight, more study will provide new information, and new technology will improve savings. The Task Force members encourage conservation managers, planners, practitioners and policy makers to give feedback to the Texas Water Development Board about the BMP Guide in the hopes that it will be updated regularly over the years ahead.

2. BMPs for Agricultural Water Users

BMPs for agricultural water users are combinations of site-specific management, educational, and physical practices that have proven to be effective and are economical for conserving water. BMPs have been developed which focus on increasing the water use efficiency of water users such as producers of agricultural crops and of water suppliers such as irrigation districts. BMPs have been developed which focus on conserving rainwater, such as landowners managing and controlling brush species. BMPs provide a means of measuring the success of agricultural water conservation programs, their costs, and schedules of implementation. Good agricultural water conservation practices can provide benefits to wildlife resources.

Irrigation of crops accounts for the great majority of agricultural water use in Texas. The amount of water used in irrigation of a specific crop or in an agricultural practice varies with the location, climate, type of crops grown, local cropping practices, type of irrigation systems, and institutional constraints. Likewise, the amount of water conserved by implementing a BMP for such crop or practice will also vary.

Agricultural Water Use Management BMPs may include Irrigation Scheduling to determine when to irrigate crops, Volumetric Measurement of Irrigation Water Use to provide information regarding the performance of irrigation systems, Crop Residue Management and Conservation Tillage to preserve soil moisture and On-Farm Irrigation Audits to increase water efficiency in irrigation.

Land Management Systems BMPs can include Furrow Dikes to reduce water runoff from agricultural row crops, Land Leveling to increase the uniformity with which water is applied to an irrigated field, Conversion of Supplemental Irrigated Farmland to Dry-Land Farmland which uses rainfall to irrigate agricultural lands, and/or Brush Control/Management to reduce evapotranspiration in order to improve water quality and water yield.

On-Farm Water Delivery Systems BMPs include lining of on-farm irrigation ditches and replacement of on-farm irrigation ditches with pipeline, Low Pressure Center Pivot Sprinkler Irrigation Systems for irrigation of land with flat to modest slopes, Drip-Micro Irrigation Systems for more efficient irrigation, use of Gated and Flexible Pipe for field water distribution, Surge Flow Irrigation to apply irrigation water to furrows to aid in reduction of deep percolation, and the use of Linear Move Sprinkler Systems for more efficient irrigation of certain shaped field and/or fields with elevation changes.

In Water District Delivery Systems, lining or replacement of the irrigation canals with pipeline improves efficiency and reduces or eliminates seepage, facilitating conveyance of water to a group of users.

Finally, other systems that aid in efficient use of water include Tailwater Recovery and Reuse Systems, which make use of the irrigation water that runs off the end of an irrigated field and Nursery Production Systems, which improve the efficiency of water use in the production of nursery crops.

The quantity of water and cost savings provided in each BMP are estimates, and actual values vary with location and site specific conditions.

Best-management practices contained in the BMP Guide are voluntary efficiency measures that save a quantifiable amount of water, either directly or indirectly, and can be implemented within a specified timeframe. The BMPs are not exclusive of other meaningful conservation techniques that an entity might use in formulating a state-required water conservation plan. At the discretion of each user, BMPs may be implemented individually, in whole or in part, or be combined with other BMPs or other water conservation techniques to form a comprehensive water conservation program. The adoption of any BMP is entirely voluntary, although it is recognized that once adopted, certain BMPs may have some regulatory aspects to them (e.g., implementation of a local city ordinance).

2.1 Agricultural Irrigation Water Use Management

2.1.1 IRRIGATION SCHEDULING

Photograph 2.1.1 – Automatic Weather Station (*Courtesy of Campbell Scientific*)

A. Applicability

This BMP is used to determine when to irrigate a crop and is intended for agricultural producers that have access to irrigation water in adequate quantities and at times required by the producer. Advanced irrigation scheduling methods are particularly applicable to nursery/floral irrigation systems that have an adequate water supply and delivery system.

B. Description

Irrigation scheduling is a generic term for the act of scheduling the time and amount of water applied to a crop based on the amount of water present in the crop root zone, the amount of water consumed by the crop since the last irrigation, and other management considerations such as salt leaching requirements, deficit irrigation, and crop yield relationships. Irrigation scheduling is a water management strategy that reduces the chance of too much or too little water being applied to an irrigated crop. Extensive publications exist regarding irrigation scheduling, many of which are documented in "Evapotranspiration and Irrigation Water Requirements" by the American Society of Civil Engineers, Manual No. 70. The most common irrigation scheduling methods are:

1) Direct measurement of soil moisture content, soil water potential, or crop stress including: soil sampling, tensiometers, gypsum blocks, infrared photography of crop canopy, time domain reflectrometry, plant leaf water potential, and other methods.

2) Soil Water Balance Equations: Irrigation methods based on soil water balance equations. These equations range from very simple "checkbook" accounting methods to complex computer models that require input of

climatic measurements such as temperature, humidity, solar radiation, and wind speed. The Texas Cooperative Extension Service maintains a network of weather stations that are used to determine the "Reference Evapotranspiration" in agricultural regions throughout the state.

C. Implementation

Each type of Irrigation Scheduling method has specific steps required for implementation. The manufacturers of soil moisture measurement equipment typically provide detailed instruction on how to operate their equipment. Soil Water Balance implementation information can be obtained from the Texas Cooperative Extension Services – Texas Evapotranspiration Network web site (texaset.tamu.edu) ET User's Guide for Growers. This guide has step-by-step instructions for using evapotranspiration for scheduling irrigations. Other evapotranspiration networks include North Plains ET Network and the South Plains ET Network.

D. Schedule

Irrigation scheduling can be implemented at any time during crop production, but normally an irrigation scheduling program is established prior to the first irrigation of the crop.

E. Scope

All agricultural producers, to one degree or another, schedule their irrigations. However, only a small percentage of producers use advanced irrigation scheduling methods. The producer has to balance when a crop is irrigated with both the demand by the crop for water and the amount of labor and water supply that the producer has available to irrigate. In many cases in western Texas where there is little rainfall, the producers have a limited water supply and limited capacity to deliver water to the field. Under these conditions the producer is continually using 100 percent of his water supply to irrigate, and most, if not all, of the producer's fields are under-irrigated (deficit irrigation). Another issue to many producers is the economics of scheduling. Yield and/or quality of many irrigated crops can be very dependent on adequate soil moisture at one or more critical periods in crop growth. Often, a producer will balance the cost of irrigation with the risk of reducing crop yield and/or quality if the irrigation is delayed or no water is applied. Depending on the producer's investment in the crop ($200 to $1,200 per acre) and the cost of water ($10 to $50 per acre per irrigation), the producer may choose to irrigate independently of any irrigation scheduling program.

F. Documentation

To document this BMP, the agricultural water user shall document and maintain one or more of the following records:

1) Records of the amount of rainfall, irrigation dates, and volumes of water applied during each irrigation and the method;

2) Records of the location and information collected from direct measurement of soil moisture; and/or

3) Copies of irrigation scheduling program reports or printouts.

G. Determination of Water Savings

The amount of water saved by implementing advanced irrigation scheduling is difficult to quantify, likely varies from year to year, and is strongly influenced by climatic variation, cropping practices, irrigation water quality, and total amount of water used to irrigate. The Pacific Northwest Laboratory (1994) attempted to verify estimates of reduction in the amount of irrigation water pumped in the Grand County Public Utility District resulting from the implementation of irrigation scheduling. The Public Utility District estimated savings of 0.3 to 0.5 acre-feet per acre, but actual savings could not be confirmed or disproved by the Pacific Northwest Laboratory's review.

H. Cost-Effectiveness Considerations

The cost for implementing advanced irrigation scheduling methods depends on the method of scheduling used and the number of fields scheduled, the type of scheduling program, and the cost for technical assistance.

I. References for Additional Information

1) *Evapotranspiration and Irrigation Water Requirements, Manuals and Reports on Engineering Practice No. 70*, 332 p., American Society of Civil Engineers, 1990

2) Texas Cooperative Extension Service, Irrigation and Water Management. http://farwest.tamu.edu/text/watermgt/et.html

3) Texas Evapotranspiration Network, Texas A&M University-College Station, Department of Biological and Agricultural Engineering. http://texaset.tamu.edu/

4) *Applicability and Limitation of Irrigation Scheduling Methods and Techniques*, Iteier, B. *et al.*, United Nations, Food and Agricultural Organization. http://www.fao.org/docrep/W4367E/w4367e04.htm

5) North Plains PET network: http://amarillo2.tamu.edu/nppet/whatpet.htm

2.1.2 VOLUMETRIC MEASUREMENT OF IRRIGATION WATER USE

Photograph 2.1.2– Irrigation well with a saddle mount propeller meter *(Courtesy of A. Blair)*

A. Applicability

This BMP is applicable to agricultural irrigation systems and agricultural producers that irrigate. The requirements and applicability of volumetric measurement of irrigation water use varies between specific geographic regions and political subdivisions in the State.

B. Description

The volumetric measurement of irrigation water use provides the water user with information needed to assess the performance of an irrigation system and better manage an irrigated crop. There are numerous types of volumetric measurement systems or methods that can be used to either directly measure the amount of irrigation water used or to estimate the amount of water from secondary information such as energy use, irrigation system design, or mechanical components of the irrigation system.

<u>Direct Measurement Methods</u>

Direct measurement methods usually require either the installation of a flow meter or the periodic manual measurements of flow. Several common direct measurement systems for closed conduits (pipelines) are:

- Propeller meters
- Orifice, venturi or differential pressure meters

- Magnetic flux meters (both insertion and flange mount)
- Ultrasonic (travel time method)

Several common methods for direct measurement of flow in open channels are:

- Various Types of Weirs and Flumes
- Stage Discharge Rating Tables
- Area/Point Velocity Measurements
- Ultrasonic (Doppler and travel time methods)

Indirect Measurement Methods

Indirect measurement methods estimate the volume of water used for irrigation from the amount of energy used, irrigation equipment operating or design information, irrigation water pressure, or other information. Indirect measurements require the correlation of energy use, water pressure, system design specifications, or other parameters to the amount of water used during the irrigation or to the flow rate of the irrigation system when irrigation is occurring.

Several common indirect measurements for irrigation systems are:

- Measurement of energy used by a pump supplying water to an irrigation system
- Measurement of end-pressure in a sprinkler irrigation system
- Change in the elevation of water stored in an irrigation water supply reservoir
- Measurement of time of irrigation and size of irrigation delivery system

Estimating irrigation water use from an indirect method can be as accurate as a direct measurement. For example, to estimate the volume of water pumped by a new electric powered irrigation pump based on kilowatt-hours of energy used during the billing period of the electric service provider, the following equation can be used:

$$\text{Acre-Feet per Billing Period} = \frac{(\text{Kilowatt Hours/Billing Period}) \times \text{Pumping Plant Efficiency (\%)}}{236.6 \times \text{Pump Pressure (psig)}}$$

Where the pump pressure is the total dynamic head (ft) of the pump converted to pressure, and Pumping Plant Efficiency (typically 55 percent to 75 percent) equals the pump efficiency (usually obtained from the pump manufacturers pump curves, typically

60 percent to 80 percent) multiplied by the motor efficiency (typically 90 percent-95 percent for 3 phase motors greater than 20 horsepower). The total dynamic head for a turbine pump installed in a water well includes the head required to lift the water from the well and head lost to friction.

C. Implementation

When implementing this BMP it is important to be aware that the installation of a flow meter or indirect measurement varies significantly with each site, type of measurement being made, desired accuracy of the measurement, and the volume or flow rate of the water being measured. Each type of direct measurement flow meter should be installed according to the recommendations of the manufacturer of the meter. Indirect measurement methods require the water user to determine the correlation between the indirect measurement (kilowatt hours, gallons, or ccf of fuel) and the volume of water used. Typically, the indirect measurement is correlated to the amount of water used by an engineer or technician using a portable flow meter or information from the irrigation system design. Both direct and indirect measurement methods should be periodically evaluated for the accuracy of volume or flow rate of the water being measured.

D. Schedule

For direct measurement systems, the time required to install a flow meter can vary from an hour or two for a saddle mount or insertion meter to several days for the construction of a metering vault and fabrication of associated piping or the construction of a weir, flume, or open channel metering station. For indirect measurement, once the indirect measurement (such as energy usage) is correlated to the volume of water used, no additional installation or construction is required. However, the indirect measurement correlation may need to be repeated periodically to verify pumping capabilities due to normal wear on irrigation equipment.

E. Scope

The methods for volumetric measurement of irrigation water and the associated scope vary from site to site, and each site and method may have unique limitations or requirements. The scope for volumetric measurement ranges from very simple (recording the amount of energy used per month from an energy bill), to complex (installation and management of a large open channel flow measurement station). Furthermore, metering requirements vary by geographic region and by political subdivision (River Authorities, Irrigation Districts, Water Improvement Districts, Groundwater Conservation District, etc.).

F. Documentation

The water user should record the total quantity of water used per site, field, or system on a periodic basis as determined by the water user to be necessary for implementing other

BMP practices. At a minimum, recording of the volume of irrigation water used should be done every year. Indirect measurements, such as energy use, are often documented by a monthly bill or statement from the supplier of the energy (i.e. the electric service provider), which becomes the record of the amount of water used during such billing period.

G. Determination of Water Savings

This BMP is used in coordination with other BMPs and in itself does not directly conserve any water. However, the information gained helps better inform the user of costs associated with water use and will assist the user in implementing voluntary conservation measures.

H. Cost-Effectiveness Considerations

Cost for volumetric measurement of irrigation water use varies greatly from application to application. Typical impeller meter installations for irrigation pipelines with diameters between 4 inch and 15 inch cost between $600 and $1,000 per meter. Cost for installation of a large open channel flow meter (flume, weir, or metering station) can be in the tens of thousands of dollars. Cost for indirect measurements, such as energy use, depends on the amount of time required to correlate the indirect measurement to the amount of water used and the time required to compile and record such information. The cost and the benefits of statewide implementation of this BMP are significant. The TWDB's 2001 *Survey of Irrigation in Texas* reported that there were approximately 6.4 million acres of land irrigated in 2000 in Texas and 115,857 irrigation wells. Most of these wells do not have flow meters, and the exact number of unmetered irrigation wells is unknown.

I. References for Additional Information

1) *Water Measurement Manual*, U.S. Bureau of Reclamation, 1997, U.S. Government Printing Office, Washington, D.C. 318 p.
2) *Techniques of Water Resource Investigation Reports, Book 3 Application of Hydraulics*, U.S. Geological Survey.
3) *Energy Use for Pumping*, Center for Irrigation Technology, California State University at Fresno. http://www.wateright.org/site2/advisories/energy.asp
4) *Buying an Energy-Efficient Motor*, Office of Industrial Technologies, U.S. Dept. of Energy, http://www.oit.doe.gov/bestpractices/motors/factsheets/mc-0382.pdf
5) *Survey of Irrigation in Texas*, Report 347, 102 p., Texas Water Development Board, August 2001.

2.1.3 CROP RESIDUE MANAGEMENT AND CONSERVATION TILLAGE

Photograph 2.1.3 – Planting of a field managed with conservation tillage *(Courtesy of USDA NRCS)*

A. Applicability

This BMP is applicable to irrigated crops and most agricultural producers using irrigation water. Conservation tillage in general is applicable to both irrigated and dryland farming and can be used to preserve soil moisture in areas where there is significant winter precipitation to allow conversion of irrigated land to dryland farming.

B. Description

This BMP includes tillage methods such as no till, strip till, mulch tillage, and ridge till. Residue management and conservation tillage allow for the management of the amount, orientation and distribution of crop and other plant residue on the soil surface year-round on crops grown where the entire field surface is tilled prior to planting. Conservation tillage improves the ability of the soil to hold moisture, reduces the amount of water that runs off the field, and reduces evaporation of water from the soil surface.

C. Implementation

The number, sequence and timing of tillage and planting operations and the selection of ground-engaging components shall be managed to achieve the planned amount, distribution and orientation of the residue after planting or at other essential time periods. Loose residue shall be uniformly distributed on the soil surface. Tillage implements shall be equipped to operate through plant residues to maintain residue on or near the soil surface by undercutting or mixing. Planting devices shall be equipped to plant in the distributed residue on the soil surface or mixed in the tillage layer.

D. Schedule

Residue management and conservation tillage may be practiced continuously throughout the crop sequence or may be managed as part of a residue management system that includes other tillage methods such as no till.

E. Scope

For furrow irrigation, crop residue in furrows can impede the flow of water down the field and cause problems with irrigation uniformity and application efficiency. Conservation tillage is more appropriate with some types of irrigation systems than others. For example, conservation tillage works well with low-pressure center pivot irrigation and subsurface drip irrigation.

F. Documentation

Establishment and operation of this practice shall be prepared for each field and recorded using jobs sheet, narrative statements in the conservation plan or other acceptable documentation.

G. Determination of Water Savings

The amount of water saved by conservation tillage will vary by climate and irrigation method. Increased spring soil moisture content resulting from conservation tillage may allow a farmer to conserve one or more irrigation applications per year (typically 0.25 to 0.50 acre-feet per acre). Reduction in soil moisture loss during the irrigation season may save an additional 0.5 acre-foot per acre.

H. Cost-Effectiveness Considerations

The cost of conservation tillage depends on the type of field operation used to manage crop residues. Some conservation tillage programs are less expensive than conventional tillage.

I. References for Additional Information

1) *Conservation Practice Standard for Residue Management, No Till/Strip Till (Acre), Code 329A*, Natural Resources Conservation Service, March 1999.

2) *Conservation Practice Standard for Residue Management, Mulch Till (Acre), Code 329B*, Natural Resources Conservation Service, March 1999.

3) *Conservation Practice Standard for Residue Management, Ridge Till (Acre), Code 329C*, Natural Resources Conservation Service, November 2002.

2.1.4 On Farm Irrigation Audit

A. Applicability

This BMP is applicable to agricultural producers that currently use on-farm irrigation and should be thought of as the initial BMP for agricultural water users to increase water efficiency in irrigation. Under this BMP the water user will collect information about water that is used to irrigate farm crops.

Once an agricultural water user decides to adopt this BMP, the water user should follow the BMP process in order to achieve the maximum benefit from this BMP.

B. Description

Water audits are an effective method of accounting for all water usage for on-farm irrigation and to identify opportunities to improve water use efficiency. Benefits from implementation of this BMP may also include energy savings and reduced chemical costs.

On-farm irrigation audits include measurement of water entering the farm or withdrawn from an aquifer, the inventory and calculation of on-farm water uses, calculation of water-related costs, and identification of potential water efficiency measures. The information from the on-farm irrigation audit forms the basis for implementing measures to increase efficiency of current farming practices and the basis for deciding which additional BMPs to implement. The conservation program may consist of one or more projects in different areas of the agricultural operation.

The audit will consist of gathering information on the following (source: NRCS):

- Field size(s) and shape, obstructions, topography, flood vulnerability, water table, and access for operation and maintenance;
- Type of pump equipment and energy source and pumping efficiency, if any;
- Type of irrigation equipment, age and general state of repair;
- Records of previous and current crops and water use; and
- Human assets - Available technical ability and language skills of laborers. Time and skill level of management personnel.

C. Implementation

The agricultural water user should conduct an on-farm irrigation audit that generally follows the guidelines as outlined in this section. NRCS procedures for an on-farm irrigation audit will result in the same or similar results. References that provide more detailed audit procedures are listed in Section I below.

1) Preparation and information gathering

The material collected to implement this BMP will be useful for other BMPs as well. Information that should be collected before beginning the audit includes maps of the agricultural operation with field sizes and locations of main water supply, meters or measuring points, inventories of irrigation equipment, and irrigation schedules. Also, information about crop types, field slope, soil types and textures, and infiltration rates should be collected. Water use data for the past year should be collected. Additionally, any prior water use audits should be obtained and reviewed since these reports may include useful and relevant information to determine the most appropriate water saving measures to implement.

2) Conduct on-farm irrigation audit

The on-site physical examination and water use audit should identify and verify all equipment that uses water. Water usage for each major water use area should be determined. If possible during the audit, the performance of the irrigation equipment should be evaluated while it is being used to irrigate farmland.

3) Prepare a cost-effectiveness analysis

The cost-effectiveness analysis should determine the water efficiency opportunities that are cost-effective to implement. The analysis may also identify water efficiency opportunities that should be implemented even if not cost effective due to high visibility, ease of implementation, or general goodwill. After confirming the cost-effectiveness of the BMP, the action plan should then be prepared.

4) Prepare an action plan

The action plan should identify the conservation goals and recommend specific technology or actions that must be implemented by the agricultural producer to meet such goals. The plan should include estimates of the time required to implement the proposed technology or actions and list any governmental or non-governmental programs or services needed to implement the plan.

5) Preparation of an on-farm irrigation audit report

The data gathering and the on-site audit should be incorporated into an audit report that includes an updated set of field diagrams and water flow charts broken down by water use areas, a current list of all water using equipment including actual and manufacturer recommended flow rates, a current schedule of irrigation for all areas and equipment, an analysis of water costs by each field and for the entire farm, and calculations of the difference between water coming into the agricultural operation and a list of identified water uses throughout the operation. (Note: This is the amount of water that is potentially being lost by leaks and other losses.) The on-farm irrigation audit report should contain a proposed timetable to implement selected water efficiency measures.

D. Schedule

1) The audit will be completed in a timely manner.

2) The recommendations should be implemented within the first normal budget cycle following the conclusion of the audit. For most farms, this should be a reasonable time period to implement the recommendations. Major projects may take additional time for implementation.

3) If determined to be necessary for very large or complex agricultural operations or for more comprehensive conservation plans, the schedule can be extended. BMPs will be initiated in the second year and continued until the targeted efficiency is reached.

E. Scope

To accomplish this BMP:

1) Agricultural water users with one farm, or several farms with the same or very similar irrigation practices, should conduct a water audit following the schedule outlined in Section D above.

2) For agricultural water users with multiple farms sites, or multiple types of agricultural operations, a progressive implementation schedule should be followed, implementing the BMP at successive farms until all farms have been audited and conservation measures implemented.

F. Documentation

To track the progress of this BMP, the agricultural water user should gather and have available the following documentation:

1) The audit report;

2) Cost-effectiveness analysis;

3) The action plan;

4) Schedule for implementing the action plan;

5) Documentation of actual implementation of water efficiency measures contained in the action plan; and

6) Estimated water savings and actual water savings for each item implemented.

G. Determination of Water Savings

This BMP in and of itself does not save any water but helps identify other agricultural water conservation BMPs that may be implemented by the agricultural water user to save water.

H. Cost-Effectiveness Considerations

The cost of a farm audit varies from minimal to significant with the extent of the audit and if the audit is done internally, by a consultant, or using assistance from a governmental entity. The Texas State Soil and Water Conservation Board ("TSSWCB") prepares Water Quality Management Plans which often address water conservation measures for agricultural land, and the NRCS can assist agricultural water user in implementing conservation plans.

I. References for Additional Information

1) Edwards Aquifer Authority, Groundwater Conservation Plan, September 2000, Rev. January 2004, *Appendix F- Water Savings Assumptions*.

2) Texas State Soil and Water Conservation Board, *Water Quality Management Plans*, http://www.tsswcb.state.tx.us/programs/wqmp.html

3) Natural Resources Conservation Service, September 1997, Irrigation - Handbooks and Manuals - National Engineering Handbook Part 652 - Irrigation Guide, *Estimated Efficiency Improvements Expected from Irrigation System Improvements*, http://www.wcc.nrcs.usda.gov/nrcsirrig/irrig-handbooks-part652.html

4) Natural Resources Conservation Service, March 1999, *Irrigation Management*, National Conservation Practices Standards, Code 449, 2 p.

2.2 Land Management Systems

2.2.1 FURROW DIKES

Photograph 2.2.1 – Furrow Dike Holding Water (*Courtesy of Soil and Crop Sciences Dept., TAMU)*

A. *Applicability*

This BMP is used to reduce water runoff from agricultural row crops and is intended for use by agricultural producers that plant row crops.

B. *Description*

Furrow dikes are small earthen dams formed periodically between furrow ridges. Furrow dikes reduce runoff from the soil surface and increase infiltration of rain or water applied by sprinkler irrigation. Furrow dikes can be used on gently sloping land in arid and semiarid areas.

C. *Implementation*

Furrow dikes should be implemented in fields with row crops to capture rainfall, reduce runoff from fields, and improve uniformity of low pressure sprinkler irrigation applications.

D. Schedule

Furrow dikes are typically first installed in non-wheel traffic rows at the time the crop bedding is prepared and reinstalled or maintained as necessary during portions of the crop growing season with high irrigation demand or high probability of rainfall occurring.

E. Scope

Furrow dikes are installed using a tractor-drawn implement in non-wheel traffic rows and can be used in the following agricultural practices:

1) In conjunction with a conservation tillage practice, furrow dikes are installed in rows when the crop bedding is prepared to facilitate capture of rainwater or water from preplant low-pressure sprinkler irrigation and may remain in place during the entire growing season.

2) In conjunction with conventional tillage, furrow dikes can also be installed after the crop bed is prepared and prior to planting or after a crop is planted and prior to the crop height being such that the installation would damage the crop. The dikes must be removed prior to and replaced after mechanical cultivation of weeds.

3) Furrow dikes are typically removed when additional moisture from rainfall would be detrimental to production or harvest of the crop.

F. Documentation

To document this BMP, the agricultural water user shall document and maintain one or more of the following records:

1) Photographs of the furrow dikes installed;

2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project; and

3) Water measurement records from both the periods before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

The amount of water conserved using furrow dikes is difficult to estimate and is dependent on when the furrow dikes are installed, the amount of rainfall, rainfall intensity, the infiltration rate of the soil, the slope of the furrow, and the application rate of the sprinkler irrigation system. Measured data for a row crop field without furrow dikes in the High Plains Region of Texas showed that the quantity of runoff was equal to 12 percent of the gross quantity of water applied using sprinkler irrigation. The runoff was eliminated for the same field when the furrow dikes were installed.

H. Cost-Effectiveness Considerations

The cost for purchasing or constructing a furrow diking implement ranges from less than $2,000 to several thousand. Cost estimates per crop season per acre range from $5 to $30 per acre. The quantity of water saved by installation of such varies from field to field and season to season, but a conservative estimate would be three inches per season (0.25 acre-feet per acre).

I. References for Additional Information

1) *The Impact of Furrow Dike, Terracing, and Contour Cultivation on Water Conservation in Texas Agriculture*, Tucker, Kevin and Sam Feagley, 1998.

2) *Water management studies in the Rolling Plains*, TAES, B-1321. 19 p., Gerard, C.J., D.G. Bordovsky, and L.E. Clark, 1980.

3) *Furrow diking to conserve moisture,* J. of Soil Water Cons. 44: 271-273. Harris, B.L., and J.H. Krishna, 1989.

4) *Off-Season Manager Tips Pre-Plant Irrigation Management*, S5-02/03, Texas Agricultural Extension Service, 5 p., Porter, Dana, 2003.

2.2.2 LAND LEVELING

Photograph 2.2.2 – Laser controlled land leveling *(Courtesy of USDA–NRCS)*

A. Applicability

This BMP is applicable to agricultural producers that use furrow, border, or basin irrigating of agricultural crops.

B. Description

This BMP is used to increase the uniformity with which water is applied to an irrigated field. The term "Land Level" generally applies to mechanized grading of agricultural land based on a topographic survey. In only a few special situations does the final product of land leveling result in a level field. Most land leveling is done using a laser controlled scraper pulled by a tractor. The laser is set to predetermined cross and run slopes, and the scraper automatically adjusts the cut or filled land over the plane of the field as the tractor moves.

C. Implementation

All leveling work should be designed based on measurement of land elevations (topography). If more than one irrigation method or more than one kind of crop is planned, the land must be leveled to meet the requirements of the most restrictive irrigation method and crop. The leveling work must be designed within the slope limits of the water application method used, provide for removal of excess surface water and control erosion caused by rainfall.

D. Schedule

Land leveling work falls into two general categories: 1) large scale land shaping typical to newly irrigated land or land that has never been graded, and 2) land level or floating of a field prior to preparation of seed beds or borders. The time required per acre of land to grade a field depends on the size of the land grading equipment and the quantity and distance that soil must be moved. Typically, the time required to "touch-up" a field prior to planting is measured in hours per acre, whereas initial grading of a field may take one or more days per acre.

E. Scope

Land leveling is typically used on mildly sloping land. Contour farming is used to farm on modest slopes and terrace farming is used for steeply sloping land. Land leveling is primarily used by agricultural producers using surface methods (furrow, border, or basin) to irrigate their fields or by those wishing to improve surface drainage of their non-irrigated field.

F. Documentation

The documentation may consist of the following items:

- Copies of the topographic survey of the land prior to land leveling.
- Drawings that show the design slopes and field layout after the land leveling work is complete.
- Annual records of "touch-up" land leveling work by field.

G. Determination of Water Savings

The quantity of water that may be saved from land leveling is difficult to estimate. Land leveling is critically important to improving surface irrigation uniformity and application efficiencies.

H. Cost-Effectiveness Considerations

The cost of land leveling for new irrigation fields is usually estimated based on the soil type, the cut to fill ratio, and the total number of cubic yards which must be cut. Touch-up land leveling is usually based on a "per acre" or "per hour" rate. Cost per yard of cut varies from approximately $1.00 to $2.00 per cubic yard depending largely on diesel fuel costs. Initial costs per acre for land leveling can range from $50 to $400. Touch up land leveling usually costs less than $50 per acre and most commonly less than $25 per acre.

I. References for Additional Information

1) *Irrigation Land Leveling*, Natural Resources Conservation Service, United States Department of Agriculture, National Conservation Practice Standards No. 464.

2.2.3 CONTOUR FARMING

Photograph 2.2.3 – Contour Farming *(Courtesy of USDA–NRCS)*

A. Applicability

This BMP applies to agricultural users where crops are irrigated on moderately sloping lands.

B. Description

Contour farming is the practice of tillage, planting and other farming operations performed on or near the contour of the field slope. This method is most effective on slopes between two (2) and ten (10) percent. Tillage and planting operation follows the contour line to promote positive row drainage and reduce ponding.

C. Implementation

The steps necessary for implementing contour farming are

1) Topographic survey of field.
2) Layout of a baseline contour with markers, an untilled crop row paralleling the contour, or other method of marking a baseline contour.
3) Prepare field borders to allow room for farm implements to turn.

4) Perform all farming activities parallel to baseline contour(s).

D. Schedule

Contour farming can be implemented at the time the field is being prepared for farming.

E. Scope

Minimum and maximum row grade, ridge height, slope lengths and stable outlets must be determined. Obstruction removal and changes in field boundaries and shape should be considered to improve the effectiveness of the practice and ease of farming operations. Agricultural operations with slopes exceeding 10 percent will find this practice less effective. Rolling topography having a high degree of slope irregularity is not well suited to contour farming.

F. Documentation

Specifications for this BMP shall be recorded using specification sheets, job sheets, narrative statements or other acceptable documentation.

G. Determination of Water Savings

The amount of water savings resulting from implementing contour farming is site specific and dependent on how the field was previously farmed and irrigated.

H. Cost-Effectiveness Considerations

The cost for preparing contour rows as compared to conventional rows is minimal. The primary cost per acre for contour farming is for the field layout and surveying of the contours. The cost for surveying varies from $1 to $3 per acre. Secondary costs for contour farming may include additional farming and harvesting costs for small row lengths in corners and ends of the field.

I. References for Additional Information

1) *Conservation Practice Standard, Contour Farming (Acre),* Natural Resources Conservation Service, February 2000, NRCS, NHCP Code 330.

2.2.4 CONVERSION OF SUPPLEMENTAL IRRIGATED FARMLAND TO DRY-LAND FARMLAND

A. Applicability

This BMP is applicable to agricultural producers that currently use ground or surface water as a supplement to rainfall to irrigate agricultural lands that are located in geographic areas where agricultural crops can be produced without irrigating. This BMP is not applicable to geographic areas of the state of Texas that have insufficient rainfall to produce an agricultural crop. This BMP is not applicable to the conversion of farmland to non-farmland.

B. Description

Dry-land farming produces agricultural crops using precipitation as the source of soil moisture. Many geographic parts of Texas receive sufficient precipitation to produce some types of crops. Typically the crop yields produced by dry-land farming are significantly lower than yields produced by irrigated farming. Crop yields from dry-land farming vary season to season depending on the amount and timing of precipitation.

Permanent pasture is the most common type of dry-land farming and is popular as a dry-land crop because pasture can survive longer periods of no rainfall compared to typical row crops such as milo, corn, or cotton. In the High Plains and Lower Rio Grande Valley regions of Texas, low water use crops such as cotton have been successfully grown without irrigation. However, irrigation of such crops in those regions reduces the risk of crop failure due to lack of soil moisture and increases crop yield.

Some crops such as sugar cane, rice, and many vegetable crops cannot be grown in Texas without irrigation regardless of the geographic location of the crop.

C. Implementation

The effect of conversion from irrigated farming to dry-land farming on crop yields, crop production costs including the costs of irrigation, and farm profits should be evaluated by comparing information from dry-land farming in the same geographic and climatologic area in which the irrigated land is located. After the agricultural water user has evaluated the increased risks associated with dry-land farming, the water user should then convert an amount of previously irrigated land to dry-land farming that is acceptable to the user based on the amount of increased risk.

D. Schedule

Conversion from supplemental irrigated farmland to dry-land farmland can be implemented at the beginning of the crop growing season on a field by field basis.

E. Scope

This BMP should be used with other BMPs that can improve the water use efficiency of dry-land farming such as conservation tillage and furrow diking.

F. Documentation

To track this BMP, the agricultural water user shall gather and maintain the following documentation:

1) Copies of records of crop yields and crop production expenses;
2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports documenting that specific fields were not irrigated; and
3) Irrigated water use and rainfall measurement records from the periods before conversion to dry-land farming.

G. Determination of Water Savings

The quantity of water saved by conversion from supplemental irrigated farmland to dry-land farmland can be estimated based on historical water use records for the crop type and geographic location where the crop was grown.

H. Cost-Effectiveness Considerations

The cost-effectiveness of conversion to dry-land farming requires complex economic and climate analysis. Dry-land farming can be significantly less costly than irrigated farming. However, since crop yields are often less, and the risk of crop failure may be significantly increased, the amount of profit per acre of dry-land is usually less than irrigated land. Texas Agricultural Extension Service estimated that crop yields grown in Bexar, Medina, and Uvalde Counties for dry-land farming are one-third to one-half less than for irrigated farming.

I. References for Additional Information

1) P. W. Unger, T. V. Sneed, W. R. Jordan, R. Jensen (eds.) *"Proc. Intl. Conf. on Dryland Farming, Challenges in dryland Agriculture - a Global Perspective"*, Aug. 1988, Amarillo/Bushland, Texas. TAES, p. 965.
2) Pena, Jose, 1997, *"Texas Crop Enterprise Budgets"*, Southwest Texas District, Texas Agricultural Extension Service, Uvalde, Texas.

2.2.5 BRUSH CONTROL/MANAGEMENT

Photograph 2.2.5– Mechanical Brush Control (*Courtesy of Tx State Soil & Water Conser. Board)*

A. Applicability

This BMP, where appropriately based on regional factors and site location characteristics, is a potential means of reducing evapotranspiration by brush species (such as ashe juniper, mesquite, and salt cedar) in order to improve soil conservation, water quality and water yield. It is intended for use by agricultural producers in riparian areas or on upland areas (rangeland, native or naturalized pasture, pasture, and hay lands) where sufficient rainfall or water exists as determined by a feasibility study prepared by the Natural Resource Conservation Service ("NRCS"), the Texas State Soil and Water Conservation Board ("TSSWCB"), or the project manager. This BMP is intended for use with governmental cost-share programs.

B. Description

Brush Control/Management includes the removal, reduction or manipulation of non-herbaceous plants by mechanical methods, chemical treatment, biological methods, prescribed burning, or combinations of these methods to achieve the desired plant community. Prescribed grazing shall be applied to ensure desired response from the above treatments. Chemical treatments should be applied in accordance with NRCS and

TSSWCB recommendations and in a manner consistent with the product label so as to protect water quality and non-target plant or animal species.

To be considered a water conservation BMP a Brush Control/Management project should:

1) Demonstrate water savings. The project should be able to provide probable and measurable water benefits, and the project manager should establish reasonable hydrologic goals considering local conditions before implementation.

2) Be cost-effective.

3) Be compatible with the natural soil profile and conditions. Excessive removal of brush or removal of brush in areas that have thin soil profiles or steep slopes can lead to severe erosion. This can negatively impact water quality downstream and remove important soil microorganisms from the site.

4) Be compatible with natural vegetation. Before removal of brush, a project manager should identify the vegetation appropriate for restoration of the area. A manager should assess whether or not the restoration can occur naturally or if it needs to be augmented with planting.

5) Maintain or promote affected wildlife. A properly designed brush management project can provide habitats for a variety of wildlife species, including endangered species.

6) Incorporate an effective maintenance plan. Maintenance of the brush management area is critical to ensure continuance of water production.

C. Implementation

A Brush Control/Management plan should be developed for each pasture, field, or management area where Brush Control/Management will be applied. The Brush Control/Management plan should include the following information:

1) Brush canopy or species count and percent canopy or number of target plants per acre.

2) Maps or drawings showing areas to be treated and areas to be left undisturbed.

3) For mechanical treatment methods:

    a. Types of equipment to be used

    b. Dates of treatment

c. Equipment operating instructions

d. Techniques or procedures to be followed

4) For chemical methods:

a. Herbicide name

b. Rate of application or spray volumes

c. Acceptable dates of application

d. Mixing instructions (if applicable)

e. Application techniques, timing considerations or other factors that must be considered to ensure safe, effective application, including available manufacturer's literature and/or instructions and NRCS or TSSWCD guidelines. The chemical will be used in a manner consistent with the product label so as to protect water quality and non-target plant or animal species.

5) For biological treatment methods:

a. Kind of biological agent or grazing animal to be used

b. Timing, duration and intensity of grazing or browsing

c. Desired degree of grazing or browsing used for control/management of the target species

d. Special precautions or requirements when using insects or plants as control/management agents

Brush Control/Management will be planned and applied in a manner to meet wildlife habitat requirements and consider wildlife concerns.

D. Schedule

Brush Control/Management projects are typically multi-year in scope to achieve initial removal levels and then require follow-up treatments every three to five years. A Brush Control/Management project can be scheduled over several years to reduce the cost of the project.

E. Scope

Brush Control/Management for water conservation is typically applicable to non-irrigated land in areas with sufficient rainfall, as determined by feasibility studies, for brush to become established and to present a problem or in riparian areas (land adjacent to water courses).

F. Documentation

To document this BMP, plans and specifications for each field scheduled for Brush Control/Management will be prepared and may include narratives, maps, and/or drawings. These documents may contain the following items:

1) Maps or aerial photographs of the field prior to brush treatment;
2) Maps or aerial photographs of the field one or more years after brush treatment;
3) Method used for Brush Control/Management and receipts for materials or contract work;
4) For chemical treatments, records should be kept of specific names and types of chemicals used, application rates, and total amounts used;
5) Estimates of the number of target plants per acre or percent canopy cover prior to treatment; and
6) Estimates of the number of target plants per acre or percent canopy cover one or more years after treatment.

G. Determination of Water Savings

Accurate determination of the quantity of water salvaged by Brush Control/Management requires expert analysis. In general, control/management of salt cedar in riparian areas has the potential to salvage significantly more water per acre treated than control/management of brush on uplands. However, there is significantly more land in Texas with brush infestation in upland areas as compared to riparian areas. The NRCS in cooperation with the Texas Agricultural Experiment Station through the TSSWCB reported that expected water yields for various levels of control/management of brush in upland areas range from 0.34 to 0.55 acre-feet per year per acre, net[1]. It was estimated that the annual amount of water salvaged from salt cedar control/management in riparian areas along the Pecos River in West Texas at 5 to 8 acre-feet per acre treated.[2]

H. Cost-Effectiveness Considerations

Texas A&M University at College Station, Department of Agricultural Economics, found that "present values of total upland brush control costs per acre range between $35.57 and $203.17" for a time period of ten years, and the cost of "added water" between $14.83 and $35.41 per acre-foot averaged for the same time period. The United States Natural

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[1] *Brush/Water Yield Feasibility Studies II"*, USDA Natural Resources Conservation Office, Texas Agricultural Experiment Station, USDA- Agricultural Research Service. Bednarz, S., *et al.*, no date.

[2] *The Pecos River Ecosystem Progress Report*, Texas Cooperative Extension Service, http://farwest.tamu.edu/rangemgt/Saltcedar/2002_Progress_Reports.pdf, Hart, Charles, 2002.

Resources Conservation Service Environmental Quality Incentives Program for Texas provides partial funding for eligible mechanical brush control and management projects at rates per acre based on the "established county average cost of the practice". The county average costs range from $150 to $200. It was reported that the cost for chemical treatment of salt cedars on the Pecos River in West Texas using aerial application of between $183 and $189 per acre and a resulting cost for the salvaged water of $7.90 to $8.22 per acre-foot using a conservative estimate of the effective life of the treatment of 3 years.[2] The cost of salvaged water per acre-foot in other locations may be significantly different.

I. References for Additional Information

1) *Brush/Water Yield Feasibility Studies II"*, USDA Natural Resources Conservation Office, Texas Agricultural Experiment Station, USDA-Agricultural Research Service. Bednarz, S., *et al.*, no date.

3) *The Pecos River Ecosystem Progress Report*, Texas Cooperative Extension Service, http://farwest.tamu.edu/rangemgt/Saltcedar/2002_Progress_Reports.pdf, Hart, Charles, 2002.

4) *Assessing the Economic Feasibility of Brush Control to Enhance Off-Site Water Yield*, Department of Agricultural Economics, Texas A&M University, College Station. Dumke, L, *et al.*, no date.

5) *Conservation Practice Standard, Brush Management*, Natural Resources Conservation Service, April 1995, Code 314.

6) *Brush Management, "Myths and Facts"*, Environmental Defense, 2003, 17 p. Ball, Laura and Melinda Taylor.

7) Technical Resources, USDA-NRCS, www.nrcs,usda.gov/technical, On-Farm Water Delivery Systems

2.2.6 LINING OF ON-FARM IRRIGATION DITCHES

Photograph 2.2.6 – Concrete lining of an irrigation lateral canal *(Courtesy of A.Blair)*

A. Applicability

This BMP is applicable to agricultural producers that use open channels to convey irrigation water to fields.

B. Description

This practice is accomplished by installing a fixed lining of impervious material in an existing or newly constructed irrigation field ditch. The three most commonly used impervious liners for irrigation canals in Texas are Ethylene-Propylene-Diene Monomer (EPDM), urethane, and concrete. Each type of liner has benefits and detriments specific to the liner. EPDM is the least expensive and concrete the most expensive. Reinforced concrete liners have the longest durability but may have the largest seepage rate. Urethane has low seepage rates but uses hazardous chemicals during installation. The U.S. Bureau of Reclamation report titled "Canal Lining Demonstration Project Year 7 Durability Report" provides a detailed description of these and other liners.

C. Implementation

The specific steps required to implement this BMP depend on the type of ditch liner used and the existing conditions of the ditch to be lined. Installation specifications, material specifications and detailed installation instructions for most types of ditch liners are available from liner manufacturers and governmental agencies. In general, most ditch lining projects require the following steps:

1) A site survey of the proposed ditch being lined which includes the length of ditch and one or more typical cross-sections of the ditch;
2) Development of a plan that details the installation and materials specifications;
3) Preparation of the ditch bed, including removal of any vegetation, bed compaction, and bed shaping;
4) Installation of liner; and
5) Finish work including inlets and outlets to lined ditch.

D. Schedule

The time required to line a farm irrigation ditch depends on the size of cross-sectional perimeter of the ditch, the amount of work needed to prepare the ditch for lining, and the type of liner used to line the ditch. EPDM liners are usually the easiest and quickest to install. For a typical farm ditch with a top width of five feet, between 500 and 1,000 feet of EPDM liner can be installed per day with a crew of five persons. Slip form concrete lining of the same ditch with the same number of workers can line between 200 and 500 feet per day.

E. Scope

Replacement of on-farm ditches with low-pressure pipelines is an alternative to lining the ditch. Typically, small ditches with flow capacities less than 5 cubic feet per second are candidates for replacement with a buried pipeline. Each type of liner has advantages and disadvantages. EPDM should not be used in a location where the ditch is subject to large animal or other traffic that might tear the liner. Concrete liners handle most traffic well, but are subject to crack formation due to soil heave, tree root pressure, or thermal expansion.

F. Documentation

To document this BMP, the agricultural water user shall gather and maintain the following documentation:

1) Copies of equipment invoices or other evidence of equipment purchase and installation;
2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project.

3) Water measurement records from the period both before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

The seepage rate of a farm ditch can be estimated by conducting a ponding test with a typical section of the ditch prior to the ditch being lined. A ponding test measures the rate at which the level of water ponded behind an earthen dam placed in the ditch drops over two to twenty-four hours. The amount of the ditch that is wetted by the pond behind the dam must be measured. The seepage rate can be calculated as acre-feet per mile of ditch per day. The total quantity of water lost to seepage from the ditch is estimated by multiplying the seepage rate times the number of days per year the ditch is used to convey water. For example, a small farm ditch with a wetted perimeter of 5 feet and a length of 1/2 mile is found to have a seepage rate of 1.0 acre-feet per mile per day, assuming the ditch is used to carry irrigation water 40 days per year. The total seepage from the ditch is 20 acre-feet per year (½ × 1.0 × 40). Lining the ditch with an EPDM liner would result in minimal or no seepage. Seepage loss from a concrete lining depends on how the liner was constructed and the amount of water that seeps through cracks and expansion joints in the concrete. A conservative estimate would be that concrete lining salvages 80 percent of the original seepage, or for the example, 16 acre-feet.

H. Cost-Effectiveness Considerations

U.S. Bureau of Reclamation in June of 2001 published “Construction Cost Tables – Canal Lining Demonstration Project.” The cost table included material and installation costs for approximately thirty-five different types of liners or coatings. The cost for an installed EPDM liner was approximately $0.85 per square foot and $1.43 per square foot for urethane. The cost for concrete lining ranges from $2.50 to $3.50 per square foot. For the example above the cost per acre-foot of water salvaged in the first year for the EPDM liner would be $11,220 ($561 per acre-foot), for urethane liner $18,876 ($944 per acre-foot) and for concrete $33,000 ($1,650 per acre-foot). Because each of these types of liner has a different life expectancy a present value analysis of cost should be performed. For example, while the concrete liner may have the most expensive installation cost, it also has the longest life expectancy.

I. References for Additional Information

1) *Conservation Practice Standard, Irrigation Water Conveyance, Flexible Membrane Ditch and Canal Lining,* 9 p. Natural Resources Conservation Service, October 1980.

2) *Canal Lining Demonstration Project Year 7 Durability Report,* 156 p. U.S. Bureau of Reclamation, Pacific Northwest Region, September 1999.

3) *Canal Lining Demonstration Project,- 2000 Supplemental*, 46 p. U.S. Bureau of Reclamation- Pacific Northwest Region, January 2000.

4) *Construction Cost Tables – Canal Lining Demonstration Project*, 5 p U.S. Bureau of Reclamation, Pacific Northwest Region, June 2001.

2.2.7 REPLACEMENT OF ON-FARM IRRIGATION DITCHES WITH PIPELINES

Photograph 2.2.7 – Trenching and installation of PVC irrigation pipe *(Courtesy of USDA–NRCS)*

A. Applicability

This BMP is applicable to irrigated farms that use an open ditch to convey irrigation water and as an alternative to lining the ditch. In general, pipelines are used to replace on-farm ditches with less than 2,000 gpm (4.5 cubic feet per second) capacity.

B. Description

This practice is the replacement of on-farm irrigation ditches with buried pipeline and appurtenances to convey water from the source (well, irrigation turnout, farm reservoir) to an irrigated field. On-farm pipelines can be used to replace most types of farm ditches. In general, on-farm pipelines are 24 inch in diameter or less, with 8 inch through 15 inch pipelines being common. Most farm pipelines use either PVC Plastic Irrigation Pipe (“PIP”) or Iron Pipe Size (“IPS”) PVC pipe. PIP is available in diameters from 6 inch to 27 inch with pressure ratings from 80 psi to 200 psi. IPS PVC pipe is available in diameters from 6 inch to 12 inch with pressure rates from 63 psi to 200 psi.

C. Implementation

Installation of any pipeline requires design and field engineering. The pipeline location must be surveyed and the size, installation procedures, pipe type, bedding and compaction details, and other engineering considerations should be addressed in engineering drawings and a design report. Planning considerations include working pressure, friction losses, flow velocities, and flow capacity. Systems shall be designed with appurtenances to deliver water from the pipe system to the irrigated field, check valves to manage backflow, and pressure relief stands to manage air entrapment and pressure issues.

D. Schedule

The time required to replace an open ditch with a buried PVC pipeline depends on the site conditions, depth of the pipeline trench, size of the pipeline, and number of outlets or connections in the pipeline, and the type of equipment used. Typical installation times range from 100 feet per day to more than 500 feet per day for a 6 inch to 12 inch diameter pipeline installed in a sandy loam soil with few or no rocks, using a four person crew with mechanical excavation of the pipe trench to a depth less than 4 feet, minimal site preparation, and mechanical backfill. Most on-farm pipeline projects are constructed during a time when no irrigation water is required for crops and are typically designed and installed during the winter or early spring.

E. Scope

The two primary limitations for replacement of a farm ditch with pipelines are cost and capacity. Construction of an unlined farm ditch can typically be done using farm equipment common to farming and at minimal cost. Installation of pipeline usually requires the farm to rent trenching or excavating equipment or contract for the installation of the pipeline at significant costs. In general, a farm ditch has the capacity to carry significantly more irrigation water than a farm pipeline. The decision to line a farm ditch or replace the ditch using a pipeline is often made based on how much water is conveyed in the ditch. The smaller the capacity of the ditch, the more likely it is a candidate for replacement using a pipeline.

F. Documentation

To document this BMP, the agricultural water user shall gather and maintain the following documentation:

1) Copies of equipment invoices or other evidence of equipment purchase and installation;
2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project.
3) Water measurement records from both the period before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

The seepage rate of ditch can be estimated by conducting one or more ponding tests with a typical section of the ditch prior to the ditch being lined. A ponding test measures the rate at which the level of water ponded behind an earthen dam placed in the ditch drops over two to twenty-four hours. The amount of the ditch that is wetted by the pond behind the dam must be measured. The seepage rate can be calculated as acre-feet per mile of ditch per day. The total quantity of water lost to seepage from the ditch is estimated by multiplying the seepage rate times the number of days per year the ditch is used to convey water. For example a small farm ditch with a wetted perimeter of 5 feet and a length of ½ mile is found to have a seepage rate of 1.0 acre-feet per mile per day. The ditch is used to carry irrigation water 40 days per year. The total seepage from the ditch is 20 acre-feet per year (1/2 x 1.0 x 40). Replacement of the ditch with a buried PVC pipeline would result in minimal or no seepage.

H. Cost-Effectiveness Considerations

The cost for low pressure PVC PIP or IPS pipe is dependant on the pipe diameter and the distance between the pipe factory and the installation site. PIP 80 psi PVC pipe with a 15 inch diameter costs approximately $5.00 delivered to most parts of Texas. The cost for pipeline design, site preparation, trenching, bedding materials, backfill, compaction, and finish work are is site and project specific.

I. References for Additional Information

1) *Conservation Practice Standard, Irrigation Water Conveyance, Low Pressure, Underground, Plastic Pipeline*, 5 p. Natural Resources Conservation Service, December 1988.

2.2.8 LOW PRESSURE CENTER PIVOT SPRINKLER IRRIGATION SYSTEMS

Photograph 2.2.8 – Low Pressure (15 psig) center pivot irrigation system *(Courtesy of A.Blair)*

A. Applicability

Low Pressure Center Pivot ("LPCP") Sprinkler Irrigation Systems are applicable to both arid and humid locations, most soil types, and land with flat to modest slopes and can be used for irrigating a wide variety of crops. LPCP systems are typically used in Texas by agricultural producers of cotton, alfalfa and other hays, pasture, chile, corn, silage, and other non-orchard crops.

B. Description

The four types of Center Pivot Sprinkler Irrigation Systems that are commonly considered to be low-pressure systems and BMPs are:

1) Low Energy Precision Application ("LEPA")
2) Low Pressure In-Canopy ("LPIC")
3) Low Elevation Spray Application ("LESA")
4) Medium Elevation Spray Application ("MESA")

All four systems are low-pressure sprinkler systems (with typical pressures at the outer end of the center pivot ranging from 10 to 25 psig) and use fixed sprinkler applicators or nozzles or drop tubes or a combination of both to apply water. Center Pivots equipped with high or medium pressure (greater than 25 psig) impact sprinkler heads have lower water application efficiencies than low-pressure systems. Care should be taken to match water application rates to soil intake rates to minimize water runoff. Each of these LPCP systems can be combined with cultural practices necessary to prevent runoff during irrigation or moderate rainfall events. LEPA systems combine the LPCP system BMP with the Furrow Dikes BMP and the practice of farming with the row direction perpendicular to the direction of travel of the center pivot (i.e. farming in a circle).

C. Implementation

Conversion of a high or medium pressure center pivot to a low-pressure system is relatively inexpensive and can be completed in one to five days. Installation of a new center pivot on land that was previously irrigated using surface irrigation can take several weeks to several months and has significant cost. Implementation should be completed within one growing season of commencement of the BMP in order to achieve the maximum water efficiency benefit.

D. Schedule

To accomplish this BMP, the agricultural water user should, within two years of the implementation date, install and maintain a low-pressure center pivot sprinkler irrigation system.

E. Scope

The scope for MESA, LESA, and LPIC systems is complete when the system is installed or the conversion from a high or medium pressure system to a low-pressure system is complete. LEPA systems require installation of additional conservation practices (such as farming in a circle and use of furrow dikes) before the scope of the BMP is complete.

F. Documentation

To document this BMP, the agricultural water user shall gather and maintain the following documentation:

1) Copies of equipment invoices or other evidence of equipment purchase and installation;
2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project.
3) Water measurement records from both the period before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

The amount of water saved from converting a conventional center pivot sprinkler irrigation system to a BMP center pivot sprinkler irrigation system (i.e. LPCP system) can be estimated using the following equation:

$$\text{Water Saved (acre-feet per year)} = A_1 \times (1 - E_1/E_2)$$

Where A_1 is the annual amount of water pumped or delivered to the inlet of the non-BMP center pivot sprinkler system, E_1 is the application efficiency of the non-BMP center pivot sprinkler system, and E_2 is the application efficiency of the BMP center pivot sprinkler system. E_1 and E_2 can be directly measured or obtained from the estimated values in the table below.

Estimated Application Efficiency Percent

System Type	New Condition	Fair Condition	Poor Condition
Non-BMP Systems			
Spray	78	60	40
Regular Angle Impact	65	50	30
Low Angle Impact	80	60	40
BMP Systems			
MESA	80	85	70
LESA	90	85	75
LPIC	90	85	75
LEPA (Drop Tube to Furrow Dike, concentric rows)	95	90	80

The amount of water saved is also affected by environmental conditions during irrigation, the amount of runoff that occurs during irrigation (soil slopes, soil texture, cropping practices), and the time of irrigation (i.e. pre-plant irrigation versus irrigation once the crop canopy is established).

H. Cost-Effectiveness Considerations

The cost for purchase and installation of center pivot systems is typically $300 to $500 per acre. The cost per acre-foot can be estimated by dividing the estimated quantity of water conserved (acre-feet per acre) by the cost per acre of the system ($ per acre-foot).

I. References for Additional Information

1) *LEPA Conversion and Management*, B-1691, Texas Agricultural Extension Service, New, Leon, and Guy Fipps.

2) *Comparison of Spray, LEPA, and Subsurface Drip Irrigated Cotton*, Texas Agricultural Experiment Station, Bordovsky, James.

3) *Optimal Performance from Center Pivot Sprinkler Systems*, B-797, Idaho Cooperative Extension System, King, Bradley and Dennis Kincaid.

4) *Comparison of SDI, LEPA, and Spray Irrigation Efficiency*, Paper No. 12019, American Society of Agricultural Engineering, 2001 International Meeting, Schneider, A.D., T.A. Howell, S.R. Evett, July 2001.

2.2.9 DRIP/MICRO-IRRIGATION SYSTEM

Photograph 2.2.9 – Subsurface drip irrigation header pipeline *(Courtesy of USDA–NRCS)*

A. Applicability

There are numerous variations of types of drip or micro-irrigation, and each type has its limitations in application to production of agriculture. In general, this BMP is applicable to agricultural producers of crops which have been proven to be irrigable using drip or micro-irrigation in the geographic region of the producer and when the producer has available a water supply of sufficient quality to make drip or micro-irrigation feasible.

B. Description

Drip or micro-irrigation is a generic term for a family of irrigation equipment that provides for distribution of water directly to the plant root zone by means of surface or sub-surface applicators or emitters. TWDB's 2001 "Surveys of Irrigation in Texas" reported approximately 77,000 acres of micro-irrigated land within Texas for 2000. This amounts to approximately 1.2 percent of the total of 6.4 million acres irrigated in 2000. The three most common types of micro-irrigation used in Texas are:

1) Micro-spray or bubblers
2) Sub-Surface (buried) Drip
3) Orchard Surface Drip or Microspray Irrigation

Micro-irrigation is typically used on high value crops (vegetables, orchard, and nursery). Recently, sub-surface drip irrigation has begun to be used on cotton, chile, and other row crops.

C. Implementation

The system shall be designed to uniformly apply water directly to the plant root zone to maintain soil moisture without excessive water loss, erosion and reduction in water quality or salt accumulation. The depth of application shall be sufficient to replace water used by the plant in peak use periods without depleting soil moisture in the root zone and to maintain a steady state salt balance.

D. Schedule

Typical design and construction of a drip irrigation system takes approximately 3 to 6 months for large fields (40 acres or greater) and less time for small applications. Typically, it takes one year from planning to operation of a system.

E. Scope

Considerations must be made for situations where natural precipitation or stored soil water is not sufficient for germination and systems must have the ability to provide enough water to properly germinate the seed. The amount of dissolved salts, suspended solids, and particulate (typically sand from irrigation wells or surface water) in the irrigation water must be tested to determine whether a micro-irrigation system is feasible. The following maintenance and monitoring issues must be addressed by the system manager on a nearly daily basis:

1) Cleaning and backflushing of filters;
2) Flushing lateral lines;
3) Measurement of applicator discharge and replacement of applicators as necessary;
4) Monitoring of operating pressures;
5) Injection of chemicals to prevent biological growth; and
6) Injection of chemicals to prevent precipitation of salts.

F. Documentation

To document this BMP the agricultural water user shall document and maintain one or more of the following records

1) Copies of the design drawings and specifications for the irrigation system;
2) Photographs of micro-irrigation pumping and filtration plant; or
3) Receipts or other documentation of purchase and installation of system.

G. Determination of Water Savings

Micro-irrigation can be the most efficient form of irrigation and typically requires the most capital expense per acre of irrigated land. It is the preferred irrigation method for high value crops, including many nursery trees, small fruit trees, grapes, melons, and other vine plants. Determination of the water saved by conversion from surface irrigation to drip irrigation depends on many parameters. The primary reasons for converting from conventional irrigation to drip irrigation is for crop yield and crop quality reasons rather than reduction in water use.

H. Cost-Effectiveness Considerations

Micro-irrigation is typically the most capital expensive type of irrigation. Installation costs for subsurface drip irrigation range from $800 to $1,200 per acre. The operation and maintenance costs vary depending on the value of the crop being irrigated and the quality of the irrigation water supply. The high capital and operational cost for micro-irrigation is the primary reason that micro-irrigation is limited to only 1.2 percent of the irrigated land within Texas.

I. References for Additional Information

1) *Irrigation System, Micro Irrigation*, Natural Resources Conservation Service, United States Department of Agriculture, National Conservation Practice Standards No. 441.

2.2.10 GATED AND FLEXIBLE PIPE FOR FIELD WATER DISTRIBUTION SYSTEMS

Photograph 2.2.10 – Furrow irrigation using gated pipe *(Courtesy of A. Blair)*

A. Applicability

This BMP is applicable to agricultural producers that currently use unlined ditches to distribute water to furrow or border irrigated fields.

B. Description

Gated pipe or flexible pipe (commonly called poly-pipe) is used to convey and distribute water to the furrow and border irrigated fields. Gated pipe is made of aluminum or PVC and ranges in diameters from 6 inch to 12 inch and lengths of 20 or 30 feet. Ports or gates are installed in the side of the pipe at 20 inch, 30 inch, 36 inch, or 40 inch intervals. The flow rate out of each gate is controlled by the percent opening of the gate.

Flexible pipe is a very low pressure (less than 5 psi) thin wall (less than 25 mil) pipe that is unrolled and can have ports installed after the pipe is pressurized. Flexible pipe is available in 12 inch through 21 inch diameters in roll lengths of 1,320 feet. Flexible plastic pipe can also be used as a surface pipeline to convey water between fields and can improve the application efficiency of furrow irrigation by allowing the delivery of larger stream sizes of water per irrigated row.

C. Implementation

This BMP is often implemented simultaneously with the replacement of an on-farm ditch with a pipeline. The steps required to implement this BMP are:

1) Selection of the diameter of the gated pipe or flexible pipe to match the desired flow rate to the irrigated field, and

2) Purchase and installation of the gated or flexible pipe.

D. Schedule

This BMP can be implemented in one or two days if the on-farm water delivery system is adaptable to gated or flexible pipe.

E. Scope

Both gated pipe and flexible pipe are laid out after the rows or borders are prepared and removed after the last irrigation of the season. Gated pipe has a long life cycle (10 to 40 years), whereas flexible pipe is typically used only one or two seasons before it must be replaced. Both gated pipe and flexible pipe are easy to install and remove. Flexible pipe installs faster than gated pipe and can be purchased in larger diameters than gated pipe. The larger diameter pipe will deliver more water per acre to the field and can facilitate the farmer improving irrigation application efficiency. Both gated pipe and flexible pipe are typically connected to a buried pipe via a pipeline riser with a hydrant. The hydrants for gated pipe and flexible pipe are different and are not interchangeable. Typically gated pipe uses a "bonnet" type hydrant and flexible pipe uses a "duck's nest" type hydrant. Surge irrigation is commonly used in conjunctions with gated pipe.

F. Documentation

To document this BMP, the agricultural water user shall document and maintain one or more of the following records:

1) Photographs of the gated or flexible pipe installed; and

2) Receipts or other documentation.

G. Determination of Water Savings

The amount of water saved by switching from an unlined ditch to gated or flexible pipe can be estimated by the amount of water that was lost to seepage from the unlined ditch. Seepage rates vary with soil type and local conditions. The information in the Lining of On-Farm Irrigation Ditches BMP can be used to estimate the amount of water saved from seepage. Gated and flexible pipe can also increase the amount of water delivered to each row and reduce deep percolation of irrigation water near the head of the field. Estimation of the amount of water saved from increasing the irrigation application efficiency can be made by measuring the amount of water delivered to the field prior to installing gated or flexible pipe and comparing it to the amount of water delivered to the field using gated or flexible pipe. Under most situations, the water saved by increasing irrigation application efficiency will be significantly greater than water savings from reducing the amount of water lost to seepage.

H. Cost-Effectiveness Considerations

The cost for 12 inch diameter PVC gated pipe ranges from $2.00 to $2.50 per foot and flexible pipe between $0.15 and $0.20 per foot. For a field length of 1300 feet with a row spacing of thirty-six inches it takes approximately 34 feet of gated or flexible pipe per acre. Because the life cycle for gated pipe is significantly longer than that of flexible pipe, the annualized price of PVC gated pipe is similar to flexible pipe. Assuming that 0.25 acre-foot per acre per year of water is saved by using gated or flexible pipe, the annual cost per acre-foot of water saved ranges from $20 to $25.

I. References for Additional Information

1) *Irrigation Water Conveyance, Rigid Gated Pipe*, Natural Resources Conservation Service, United States Department of Agriculture, October 1985, National Conservation Practice Standards No. 430HH.

2.2.11 SURGE FLOW IRRIGATION FOR FIELD WATER DISTRIBUTION SYSTEMS

Photograph 2.2.11 – Surge flow irrigation controller *(Courtesy of Waterman Industries)*

A. Applicability

This BMP is applicable to agricultural producers that currently use gated pipe or flexible pipe to distribute water to furrow irrigated fields and who have soil types that swell and reduce infiltration rates in response to irrigation.

B. Description

A surge irrigation system applies water intermittently to furrows so as to create a series of on-off periods of either constant or variable time intervals. Surge flow can also increase the amount of water delivered to each row and reduce deep percolation of irrigation water near the head of the field. Surge irrigation is typically applicable to agricultural fields with medium soils. Surge irrigation may have limited applicability to fields with heavy clay soils or light sandy soil. If improperly used, surge irrigation can increase the volume of water that runs off the tail of a field during irrigation. Under this BMP, the agricultural water user will install and maintain a surge irrigation system. The system will, at a minimum, include butterfly valves or similar equipment that will provide equivalent alternating flows with adjustable time periods and a solar or battery-powered timer. The agricultural producer should consider field slope, soil type, texture, and infiltration rates to maximize effectiveness of the system. Surge flow has also been shown to reduce runoff in some fields by increasing the uniformity of infiltration and by reducing the duration of flow as the water reaches the end of the field.

C. Implementation

This BMP is often implemented simultaneously with replacement of an on-farm ditch with a gated pipeline. The steps required to implement this BMP are:

1) Selection of the timer and valve equipment for the system based upon the type of gated pipe and soil type;

2) Purchase, installation and use of the surge flow equipment; and

3) Use of soil probes and trial set times to determine optimal use for each field.

D. Schedule

This BMP can be implemented in one or two days if the on-farm water delivery system is adaptable to gated or flexible pipe. If the surge flow system is installed at the same time the gated or flexible pipe BMP is implemented, it should add less than one day to the installation time of the new irrigation system.

E. Scope

The surge flow system is integral to the gated pipe or flexible pipe systems which are laid out after the rows or borders are prepared and removed after the last irrigation of the season. Surge flow valves have a life cycle of between 5 and 15 years; this results in different life cycle costs based upon the use of gated versus poly pipe and should be considered when doing a cost-effectiveness analysis. Surge irrigation is commonly used with gated pipe rather than with flexible pipe.

F. Documentation

To document this BMP, the agricultural water user will maintain one or both of the following records:

1) Photographs of the surge flow system installed; and

2) Receipts or other documentation.

G. Determination of Water Savings

The amount of water saved by switching to surge flow is estimated to be between 10 percent and 40 percent and is dependent upon soil type and timing of operations. The savings from installing the surge flow at the same time as replacing an unlined ditch with gated or flexible pipe should be considered separately as a factor in implementing that BMP. Experience has shown that differences in soil texture and field slope have a significant impact on actual water savings. Estimation of the amount of water saved from increasing the irrigation application efficiency can be made by measuring the amount of water delivered to the field prior to installing surge flow and comparing it to the amount of water delivered to the field by using surge flow.

H. Cost-Effectiveness Considerations

Cost for a surge valve with an automated controller will range between $800 and $2,000 depending on the size of the valve and the controller options. If installed at the same time as gated pipe, the cost for those systems is outlined in the Gated or Flexible Pipe BMP. Assuming that 0.25 acre-foot per acre per year of water is saved by using a surge valve, the annual cost per acre-foot of water saved ranges from $20 to $25.

I. References for Additional Information

1) Irrigation Water Conveyance, Rigid Gated Pipe, Natural Resources Conservation Service, United States Department of Agriculture, October 1985, National Conservation Practice Standards No. 430HH.

2) Estimated Efficiency Improvements Expected from Irrigation System Improvements, Natural Resources Conservation Service, United States Department of Agriculture, September 1997, Natural Conservation Practice Standards No. 210-vi-NEH.

3) Surge Irrigation, Yonts, C.D., et al., Nebraska Cooperative Extension NF. 94-176, January 1994. http://ianrpubs.unl.edu/irrigation/nf176.htm

2.2.12 LINEAR MOVE SPRINKLER IRRIGATION SYSTEMS

Photograph 2.2.12 – Linear move sprinkler system *(Courtesy of Valmont Industries)*

A. Applicability

Linear Move Sprinkler Irrigation (linear move) Systems are an adaptation of center pivot sprinkler systems for use on fields which are not appropriate for center pivot systems due to shape or elevation changes (*See* Low Pressure Center Pivot Sprinkler Irrigation Systems BMP). Linear move systems are applicable for both arid and humid locations, for most soil types with flat to minimal slope, and for producing a wide variety of crops. Texas agricultural producers typically use linear move systems to irrigate cotton, alfalfa and other hays, pasture, chile, corn, silage, and other row type crops.

B. Description

The linear move sprinkler irrigation system is composed of a series of towers that suspend the irrigation system and move laterally in the direction of the rows. Water can be supplied to the towers from a open ditch adjacent to the 1st tower and parallel to the director of travel or by a flexible hose typically 100 to 200 feet in length. The flexible hose is supplied through risers connected to a buried pipeline. Use of a linear move system is normally limited to irrigating rectangular shaped fields. The four types of Linear Move Sprinkler Irrigation Systems that are addressed in the best management practices document and are commonly considered to be low-pressure system include:

1) Low Energy Precision Application (“LEPA”)
2) Low Pressure In-Canopy (“LPIC”)
3) Low Elevation Spray Application (“LESA”)
4) Medium Elevation Spray Application (“MESA”)

All four systems are low-pressure sprinkler systems (with typical pressures at the farthest end of the sprinkler from the water source ranging from 10 to 35 psi) and use fixed sprinkler applicators/nozzles or drop tubes or a combination of both to apply water. Linear Move Sprinklers equipped with high or medium pressure (greater than 35 psi) impact sprinkler heads have lower water application efficiencies than low-pressure systems. Each of these linear move systems can or must be combined with cultural practices necessary to prevent runoff during irrigation or moderate rainfall events. LEPA systems can be combined with the Linear Move Systems BMP and with the Furrow Dikes BMP (*See* Section 4.3.1).

C. Implementation

Conversion of a high or medium pressure linear move to a low-pressure system is relatively inexpensive and can be completed in one to five days. Installation of a new linear move system on land that was previously irrigated using surface irrigation can take several weeks to several months. Implementation should be completed within one growing season after commencement of this BMP in order to achieve the maximum water efficiency benefit.

D. Schedule

To accomplish this BMP, the agricultural water user should, within two years of the implementation date, install and maintain a low-pressure linear move sprinkler irrigation system in order to achieve the maximum water efficiency benefit.

E. Scope

The agricultural water user with multiple fields can implement the Linear Move Sprinkler BMP or other irrigation BMPs on each field in different years or growing seasons, if such timing is more cost-effective.

F. Documentation

To track this BMP, the agricultural water user shall gather and maintain the following documentation:

1) Copies of equipment invoices or other evidence of equipment purchase and installation;
2) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project; and

3) Water measurement records from the period both before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

The amount of water saved from converting from a conventional linear move sprinkler irrigation system to a BMP linear move sprinkler irrigation system can be estimated using the following equation:

Water Saved (acre-feet per year) = $A_1 \times (1 - E_1/E_2)$

Where A_1 is the annual amount of water pumped or delivered to the inlet of the non-BMP center pivot sprinkler system, E_1 is the application efficiency of the non-BMP linear move sprinkler system, and E_2 is the application efficiency of the BMP (linear move) sprinkler system. E_1 and E_2 can be directly measured or obtained from the estimated values in the table below.

Estimated Application Efficiency Percent

System Type	New Condition	Fair Condition	Poor Condition
Non-BMP Systems:			
Spray	78	60	40
Regular Angle Impact	65	50	30
Low Angle Impact	80	60	40
BMP Systems:			
MESA	85	80	70
LESA	90	85	75
LPIC	90	85	75
LEPA (Drop Tube to Furrow Dike)	95	90	80

The amount of water saved is also affected by environmental conditions during irrigation, the amount of runoff that occurs during irrigation (soil slopes, soil texture, cropping practices) and the time of irrigation (i.e. pre-plant irrigation versus irrigation once the crop canopy is established).

H. Cost-effectiveness Considerations

The cost for purchase and installation of linear move systems is typically $300 to $700 per acre. The cost per acre-foot can be estimate by dividing the estimated quantity of water conserved (acre-feet per acre) by the cost per acre of the system (dollars per acre-foot).

I. References for Additional Information

1) New, Leon, and Guy Fipps, *"LEPA Conversion and Management"*, B-1691, Texas Agricultural Extension Service.

2) Bordovsky, James, *"Comparison of Spray, LEPA, and Subsurface Drip Irrigated Cotton"*, Texas Agricultural Experiment Station.

3) King, Bradley and Dennis Kincaid, *"Optimal Performance from Center Pivot Sprinkler Systems"*, B-797, Idaho Cooperative Extension System.

4) Evans, R.O., et al., Center Pivot and Linear Move Sprinkler Systems, AG-553-3 North Carolina Cooperative Extension, 1997.

2.3 Water District Delivery Systems

2.3.1 LINING OF DISTRICT IRRIGATION CANALS

Photograph 2.3.1 – EPDM lining of a large irrigation canal *(Courtesy of A.Blair)*

A. Applicability

This BMP applies to any water district and serves as an integral part of the water distribution system designed to facilitate the conservation and efficient conveyance of water to a group of water users.

B. Description

A fixed lining of impervious material is installed in an existing or newly constructed irrigation canal or lateral canal. The three most commonly used impervious liners for irrigation canals in Texas are Ethylene-Propylene-Diene Monomer ("EPDM"), urethane, and concrete. Each type of liner has benefits and detriments specific to the liner. EPDM is least expensive and concrete the most. Reinforced concrete liners have the longest durability but may have the largest seepage rate. Urethane has low seepage rates but uses hazardous chemicals during the installation. The U.S. Bureau of Reclamation report titled "Canal Lining Demonstration Project Year 7 Durability Report" provides a detailed description of these and other liners.

C. Implementation

The canal considered for lining shall be of sufficient capacity to meet its requirement as part of a planned irrigation water conveyance system without overtopping, but with enough capacity to deliver the water needed to meet the peak consumptive use. The specific steps required to implement this BMP depend on the type of canal liner used and the existing conditions of the canal to be lined. Installation specifications, material specifications and detailed installation instructions for most types of canal liners are available from liner manufacturers and governmental agencies. In general, most canal lining projects require the following steps:

1) A site survey of the proposed canal being lined including length of canal and one or more typical cross-sections of the canal.
2) Development of a plan that details the installation and materials specifications.
3) Preparation of the canal bed, including removal of any vegetation, bed compaction, and bed shaping.
4) Installation of liner.
5) Finish work including inlets and outlets to lined canal.

D. Schedule

The time required to line a canal depends on the size of the cross-sectional perimeter of the canal, the amount of work needed to prepare the canal for lining, and the type of liner used to line the canal. EPDM liners are usually the easiest and quickest to install. For a small canal with a top width of 15 feet, between 500 and 1,000 feet of EPDM liner can be installed per day with a crew of eight persons.

E. Scope

Each type of liner has advantages and disadvantages. EPDM should not be used in a location where the canal is subject to large animal or other traffic that might tear the liner. Concrete liners handle most traffic well but are subject to crack formation due to soil heave, tree root pressure, or thermal expansion.

F. Documentation

To document this BMP, the water district shall document and maintain one or more of the following records:

1) As-built drawings or photographs of the lined canal; and
2) Water measurement records from both the period before and after conversion to the water efficient irrigation system.

3) Copies of equipment invoices or other evidence of equipment purchase and installation; and

4) Any USDA Farm Service Agency or other governmental agency evaluation and assistance reports that may relate to the project.

G. Determination of Water Savings

The seepage rate of a canal can be estimated by conducting a ponding test with a typical section of the canal prior to the canal being lined. A ponding test measures the rate at which the level of water ponded behind an earthen dam placed in the canal drops over two to twenty-four hours. The amount of the canal that is wetted by the pond behind the dam must be measured. The seepage rate can be calculated as acre-feet per mile of canal per day. The total quantity of water lost to seepage from the canal is estimated by multiplying the seepage rate times the number of days per year the canal is used to convey water. For example, a small farm canal with a wetted perimeter of 20 feet and a length of 1 mile is found to have a seepage rate of 1.5 acre-feet per mile per day assuming the canal is used to carry irrigation water for 270 days per year. The total seepage from the canal is 405 acre-feet per year (1 x 1.5 x 270). Lining the canal with an EPDM liner would result in minimal or no seepage. Seepage loss from a concrete lining depends on how the liner was constructed and the amount of water that seeps through cracks and expansion joints in the concrete.

H. Cost-Effectiveness Considerations

The U.S. Bureau of Reclamation in June of 2001 published "Construction Cost Tables – Canal Lining Demonstration Project." The cost table included material and installation cost for approximately thirty-five different types of liners or coatings. The cost for an installed EPDM liner was approximately $0.85 per square foot and $1.43 per square foot for urethane. The cost for concrete lining ranges from $2.50 to $3.50 per square foot. For the example above the cost per acre-foot of water salvaged in the first year for the EPDM liner would be $89,760 ($222 per acre-foot), for urethane liner $151,008 ($373 per acre-foot) and for concrete $316,800 ($782 per acre-foot). Because each of these types of liner has a different life expectancy a present value analysis of cost should be performed. For example, while the concrete liner may have the most expensive installation cost, it also has the longest life expectancy.

I. References for Additional Information

1) *Conservation Practice Standard, Irrigation Water Conveyance, Flexible Membrane Canal and Canal Lining*, 9 p. Natural Resources Conservation Service, October 1980.

2) *Canal Lining Demonstration Project Year 7 Durability Report*, 156 p. U.S. Bureau of Reclamation- Pacific Northwest Region, September 1999.

3) *Canal Lining Demonstration Project - 2000 Supplemental*, 46 p. U.S. Bureau of Reclamation- Pacific Northwest Region, January 2000.

4) *Construction Cost Tables – Canal Lining Demonstration Project*, 5 p. U.S. Bureau of Reclamation, Pacific Northwest Region, June 2001.

2.3.2 REPLACEMENT OF IRRIGATION DISTRICT CANALS AND LATERAL CANALS WITH PIPELINES

Photograph 2.3.2 – Installation of a 24" PVC irrigation pipeline *(Courtesy of A.Blair)*

A. Applicability

This BMP is applicable to Water Districts that use open canals and lateral canals to convey irrigation water and as an alternative to lining the canals or lateral canals. In general, pipelines are used to replace district canals or lateral canals with less than 44,900 gpm (100 cubic feet per second) capacity.

B. Description

This practice is the replacement of district irrigation canals or lateral canals with buried pipeline and appurtenances to convey water from the source (well, river, reservoir) to a farm or irrigation turnout. District irrigation pipelines can be used to replace most types of small canals or lateral canals. In general, district irrigation pipelines are 72 inch in diameter or less, with 12 inch through 48 inch diameter pipes being common. Most district irrigation pipelines use either PVC Plastic Irrigation Pipe ("PIP") or Reinforced Concrete Pipe ("RCP") with gasketed joints. PIP is available in diameters from 6 inch to 27 inch with pressure ratings from 80 psi to 200 psi. RCP is typically available in diameters between 24 inch and 72 inch. It is common practice in the irrigation districts in the Lower Rio Grande Valley to use PIP for 24 inch or less diameter pipe and RCP for pipe diameters greater than 24 inch. On a limited basis, 36 inch and 42 inch diameter PVC pressurized sewer pipe is being used to replace open canals.

C. Implementation

Installation of any pipeline requires design and field engineering. The pipeline location must be surveyed and the size, installation procedures, pipe type, bedding and compaction details, and other engineering considerations should be addressed in engineering drawings and a design report. Planning considerations include working pressure, friction losses, flow velocities, and flow capacity. Systems will be designed with appurtenances to deliver water from the pipe system to the farmer and open pipe stands to allow for air release and surge (water hammer) protection.

D. Schedule

The time required to replace an open canal with a buried PVC or RCP pipeline depends on the site conditions, depth of the pipeline trench, size of the pipeline, number of outlets or connections in the pipeline, and the type of equipment used. Most district pipeline projects are constructed during a time when no irrigation water is required for crops, which is typically during the winter or early spring.

E. Scope

The two primary limitations for replacement of canals with pipelines are cost and capacity. In many cases the length and engineering of existing canal systems will require a number of years to replace with pipeline. In such cases, a program for progressively replacing canals and lateral canals should be developed with a focus on replacing those canals and lateral canals with larger potential for water conservation. The decision to line a canal or replace the canal using a pipeline is often made based on how much water is conveyed in the canal. The smaller the capacity of the canal, the more likely it is a candidate for replacement using a pipeline.

F. Documentation

To document this BMP, the water district shall gather and maintain the following documentation:

1) Copies of equipment invoices or other evidence of equipment purchase and installation;
2) Any USDA, NRCS or other governmental agency evaluation and assistance reports that may relate to the project.
3) Water measurement records from both the period before and the period after the installation of the pipeline.

G. *Determination of Water Savings*

The seepage rate of a canal can be estimated by conducting a ponding test within a typical section of the canal or lateral canal prior to the canal and lateral canal being lined. A ponding test measures the rate at which the level of water ponded behind an earthen dam in a canal drops over two to twenty-four hours. The amount of the canal that is wetted by the pond behind the dam must be measured. The seepage rate can be calculated as acre-feet per mile of canal per day. The total quantity of water lost to seepage from the canal is estimated by multiplying the seepage rate times the number of days per year the canal is used to convey water. For example, a canal with a wetted perimeter of 50 feet and a length of 1 mile is found to have a seepage rate of 1.0 acre-foot per mile per day. The canal and lateral canal are used to carry irrigation water 270 days per year. The total seepage from the canal is 270 acre-feet per year per mile ($1.0 \times 1.0 \times 270$). Replacement of the canal with a buried PVC pipeline would result in minimal or no seepage.

H. *Cost-Effectiveness Considerations*

The cost for low-pressure PVC PIP pipe is based on the pipe diameter and the distance between the pipe factory and the installation site. PIP 80 psi PVC pipe with a 24 inch diameter costs between $15 and $21 delivered to most parts of Texas. Because of the heavy weight and associated transportation costs, reinforced concrete pipe is usually manufactured in the area in which the pipe is being installed. The cost for pipeline design, site preparation, trenching, bedding materials, backfill, compaction, and finish work are all site and project specific. The cost per acre-foot can be estimated by dividing the estimated quantity of water conserved (acre-feet per acre) by the cost per acre of the system ($ per acre-foot).

I. *References for Additional Information*

1) Natural Resources Conservation Service, December 1988, “Conservation Practice Standard, Irrigation Water Conveyance, Low Pressure, Underground, Plastic Pipeline”, 5 p. Code 430EE.

2.4 Miscellaneous Systems

2.4.1 TAILWATER RECOVERY AND REUSE SYSTEM

Photograph 2.4.1 – Tailwater reservoir and pump systems *(Courtesy of C. Robinson, WTAMU)*

A. Applicability

Tailwater recovery and reuse systems (tailwater systems) are applicable to any irrigated agricultural system (typically flood or furrow irrigation) in which significant quantity of irrigation water, as a result of the irrigation method, runs off the end of the irrigated field. Tailwater systems are typically implemented by agricultural producers that use flood or furrow irrigation.

B. Description

A Tailwater System consists of ditches or pipelines to collect tailwater and deliver water to a storage reservoir (typically below the grade of the irrigated land) and includes a pumping and pipeline system that conveys the water to irrigated fields for reuse. Most tailwater systems also collect rainfall that may run off of the irrigated field. Natural reservoirs, such as the playa lakes located in the High Plains region of Texas, may serve to both capture irrigation runoff and rainfall runoff and may be used as part of a tailwater system. Also, capture and reuse of tailwater can improve the water quality of downstream reaches of rivers, streams, or waterways. Conservation through reduction in field runoff may reduce agricultural drain flow and the amount of water in downstream reaches of rivers, streams, or waterways. In the irrigated agricultural areas of Texas supplied by groundwater, reduction or reuse of field runoff is a common practice and can provide secondary benefits such as an open water source for wildlife (tailwater ponds).

Also, capture and reuse of tailwater can improve the water quality of downstream reaches of rivers, streams, or waterways. Conservation through reduction in field runoff may reduce agricultural drain flow and the amount of water in downstream reaches of rivers, streams, or waterways.

C. Implementation

The steps required to implement a tailwater system are:

1) Construction of the tailwater collection system.
2) Construction of the storage reservoir.
3) Construction of the tailwater irrigation water delivery system.
4) Application of the tailwater for irrigation of crops or other uses.

D. Schedule

The time required to construct and install a tailwater system varies from several days to over a month.

E. Scope

The most common limitation on the installation of a tailwater system is the availability of land for construction of the storage reservoir such that the tailwater can be conveyed to the reservoir by gravity. Secondary concerns include water quality and disease problems that result from the reuse of irrigation water. Some agricultural users of tailwater systems have the systems designed so that reused irrigation water is kept separate from virgin irrigation water, and the reused water is applied to crops that are more resistant to the problems that may exist with use of tailwater for irrigation.

F. Documentation

To document this BMP, the agricultural water user shall gather and maintain one or more of the following:

1) Photographs of the installed storage reservoir and pump back system;
2) Reports or receipts that document the purchase and installation of reservoir and pump back system;
3) Any USDA, NRCS or FSA or other governmental agency evaluation and assistance reports that may relate to the project; or
4) Water measurement records from both the period before and after conversion to the water efficient irrigation system.

G. Determination of Water Savings

Both direct and indirect measurements of the volume of water captured and reused by the Tailwater System can be used to determine the annual volume of water saved. The amount of runoff from a surface irrigated field varies significantly from site to site, but it is not uncommon for runoff to be 15 percent or greater of the gross volume of water applied to the field. Typical tailwater systems can reuse 0.5 to 1.5 acre-feet per acre of irrigated crop per year.

H. Cost-Effectiveness Considerations

The cost of constructing a tailwater system varies significantly from site to site and with land costs. The cost to construct a small storage reservoir (assuming the water user owns the land) ranges from $800 to $2,000 per acre-foot. Construction of the tailwater collection system varies from little cost (adapting an existing surface drainage system) to as much as $15 per foot of installed pipe. The cost of the pump back system is also site specific and typically costs several thousands of dollars.

I. References for Additional Information

1) *Irrigation System, Tailwater Recovery*, Natural Resources Conservation Service, United States Department of Agriculture, National Conservation Practice Standards No. 447.

2.4.2 NURSERY PRODUCTION SYSTEMS

Photograph 2.4.2 – Commercial Greenhouses *(Courtesy of TAMU, Agronomy Department)*

A. Applicability

This BMP is applicable to irrigation of nursery crops and agricultural producers that grow nursery crops.

B. Description

This BMP considers the design of the irrigation system used for distribution and application of irrigation water to field, container, and greenhouse grown nursery plants. Improved efficiency of water use in the production of nursery crops includes the following practices:

1) Irrigation System Design and Management

a. Scheduling irrigation according to crop needs and growing-medium water depletion. Watering requirements will vary and should be adjusted based on time of year, weather, methods of storage and type and stage of the plant (e.g., dormancy). Plants need less water during cool, rainy weather than during hot, dry, windy weather.

b. Upgrading irrigation equipment to improve application efficiency. For example, a computerized irrigation scheduler using a drip system can reduce overwatering and excessive leaching compared to an overhead system.

c. Plugging sprinkler heads that are not watering plants, keeping sprinkler heads as low as possible to the plants, and use of the largest appropriate water droplet size to reduce irrigation time.

d. Use of drip tubes or spray tanks for each individual container, when reasonably practical.

e. When using programmable irrigation booms, travel rate and flow rates should be adjusted to specific crop needs.

f. Use of sub-irrigation systems where appropriate, using ebb and flood or capillary mat irrigation technologies with water capture and reuse systems.

2) Plant Media and Management

a. Grouping plants together that have the same water requirements (i.e., use hydrozoning).

b. When ball-and-burlapped stock and containerized stock are received, they should be kept out of the wind and sun. Ideally, balls should be covered with moisture-retaining materials such as sawdust or wood chips if stock will be stored for a long time.

c. Knowing characteristics of the application site, including soil type and depth to groundwater under the greenhouse or nursery.

d. Spacing containers under fixed overhead irrigation to maximize plant irrigation and reduce waste between containers.

e. Minimizing leaching from containers or pulse-irrigate containers. Many textbooks recommend leaching greenhouse and nursery crops to 10 percent excess. This rate can be reduced to close to zero by reducing fertilizer rates and closely monitoring the electrical conductivity or the root substrate.

C. Implementation

Many operational procedures and controls to improve water use efficiency of the nursery operations should be implemented simply as a matter of good practice. Implementation of this BMP consists of the following actions:

1) Perform a water efficiency audit of the nursery facility to identify areas of improvement for water savings and optimization of water use. The audit should review all aspects of operations including types of plants and

specific water requirements, growing medium characteristics, and the irrigation system.

2) Implement appropriate water efficiency practices, including:

- Design of the irrigation system such that water can be delivered to different zones at different application rates and for different durations.
- Upgrading or modernization of irrigation system.
- Organization of plants by water use.
- Programming of irrigation system controllers for optimal water use.

D. Schedule

The time required to implement one or more of the above practices depends on the size and extent of the nursery operation and which conservation practices are to be implemented. Implementation of some of the above practices can be done in less than a week (programming of irrigation controllers, replacement of sprinkler nozzles, scheduling irrigations, etc.) to several months (installation of a new irrigation system or water recovery and reuse system).

E. Scope

Nursery production systems vary in extent from small (less than 1 acre) operations to multi-acre farms and greenhouses. The applicability of each of the above practices must be customized for the specific requirements of each Nursery Production System. Some of the above practices may be not be cost effective for smaller operations. Larger operations may select to implement all of the above practices.

F. Documentation

The following information can be used to document implementation of this BMP:

- Description of irrigation techniques and water zones;
- Description of mulching practices and soil amendments used;
- Description of the irrigation and water recovery and reuse system; and
- Water use records for the periods both before and after implementation of water efficient practices.

G. Determination of Water Savings

Determination of the quantity of water saved by implementing this BMP must be determined specific to each nursery production system and is dependent on the amount of water used by the existing system and which conservation practices are currently implemented by the producer. Water use records prior to and after implementation of one or more of the above practices can be used to determine the amount of water saved.

H. Cost-Effectiveness Considerations

The cost-effectiveness of implementing one or more of the above practices must be analyzed for each nursery production system. The cost ranges from minimal (for reprogramming irrigation controllers, changing sprinkler heads, etc.) to significant (installation of water recovery and reuse system, upgrading or replacement of irrigation system, etc.). Some basic operational practices should be corrected without a cost-effectiveness analysis.

I. References for Additional Information

1) Colorado Springs Utilities, Water Conservation Program, *"Hydrozoning-Irrigation Definitions and Requirements"*, www.csu.org/files/general/2656.pdf, 2 p.

2) Southern Nursery Association, *"Production Practices for Nurseries, Greenhouses, and Growers"*, www.sna.org

3) Texas Nursery Landscape Association, www.txnla.org.

4) Department of Horticulture, Texas A&M University-College Station, Texas Greenhouse Management Book, www.aggie-horticulture.tamu.edu.

2.5 Cost Effectiveness for Agricultural Water Users

The table on the next page shows a simplified example that estimates the annual cost that an agricultural producer will incur to replace an earthen ditch used to convey water to an irrigated field with a buried PVC pipe. It lists the information and calculations needed to determine the annual cost per acre-foot of water saved from installing the proposed pipeline. Narrative information regarding each item in the table is included.

For this example the Net Annual Cost per Acre-Foot of Water Saved equals $11.51. The actual cost per acre-foot of water savings could be smaller or larger depending on actual cost information. Under conditions of high water loss in the existing ditch and/or high energy cost for well water, the Net Annual Cost per Acre-Foot of Water Savings could be a negative value (the cost of the proposed pipeline would both save water and increase the agricultural producers net revenue).

Cost Effectiveness Evaluation for Replacement of an Earthen Ditch with Buried PVC Pipeline

Item	Description		Units
1	Water Source:	Irrigation Well	
2	Typical Irrigated Crop:	Alfalfa	
3	Gross Water Application for Crop:	4.00	ac-ft/yr
4	Energy Cost per Acre-Foot of Water from Irrigation Well:	$20.00	$/ac-ft
5	Irrigated Area:	120	ac
6	Design Flow Rate for Pipeline:	800	gpm
7	Gross Annual Water Application:	480	ac-ft
8	Time Required to Apply Irrigation Water:	136	days/yr
9	PVC Pressurized Irrigation Pipe (Class 100) Pipe Diameter:	10	inches
10	Pipeline Length:	5,280	ft
11	Assumed Capital Recovery Period for Project:	20	yr
12	Assumed Interest Rate for Capital:	6.00%	%
13	Annual Water Savings:	136	ac-ft
14	Capital Cost for Pipeline:	$10.00	$/ft
15	Capital Cost for Pipeline:	$52,800	$
16	Annual Change in Maintenance Cost (Earthen Ditch to PVC Pipeline):	-$1,500	$/yr
17	Energy Cost for Pipeline Friction (@0.10 $/kwhr, and 70% Pumping Efficiency, 0.32 ft/100ft headloss):	$1,182	$/yr
18	Change in Annual Energy Cost for Well Water:	-$2,720	$/yr
19	Change in Annual Energy Cost (Earthen Ditch to PVC Pipeline):	-$1,538	$/yr
20	Total Change in Annual Energy and Maintenance Costs:	-$3,038	$/yr
21	Annual Capital Recovery Cost:	$4,603	$/yr
22	Net Annual Cost of Pipeline:	$1,565	$/yr
23	Net Annual Cost per Ac-Ft of Water Savings:	$11.51	$/yr

1) **Water Source.** The source of water for this example is from an irrigation well. The source of water is important in determining the amount of energy savings from reduced pumping requirements as a result of the water conservation effort.

2) **Typical Irrigated Crop.** The type of crop proposed to be grown on the irrigated area. Crop type can be used to estimate the annual irrigation water requirement.

3) **Gross Water Application for Crop** is the annual amount of water anticipated to be applied to the field per acre of irrigated area and includes any water that may run off the field or infiltrate past the crop root zone.

4) **Energy Cost per Acre-Foot of Water from Irrigation Well**. The energy cost per acre-foot of water pumped from the irrigation well can be estimated based on the total pumping depth, discharge pressure, energy loss in the pump column, pump efficiency, motor or engine efficiency, and fuel or energy cost. (*See* Texas Agricultural Extension Service Publication L-2218).

5) **Irrigated Area** is the irrigated acreage of the field for which water will be supplied by the proposed pipeline.

6) **Design Flow Rate for Pipeline**. The design flow rate of the pipe is typically matched to amount of water available from the supply source (in this case an irrigation well) and the requirements of the irrigation system. For this example the design flow rate was assumed to be 800 gpm.

7) **Gross Annual Water Application** is the product of the items 3 and 5.

8) **Application Time** is the amount of time required to delivery the Gross Annual Water Application (item 7) using the Design Flow Rate of the Pipeline (item 6).

9) **PVC Plastic Irrigation Pipe Diameter** is commonly calculated as the commercially available pipe diameter that results in a water velocity in the pipeline of approximately 3 feet per second for the Design Flow Rate (item 6).

10) **Pipeline Length** is the length of the earthen ditch being replaced with pipe.

11) **Capital Recovery Period for Project.** The Capital Recovery Period is assumed to be either the cost of borrowing money for the project or the value of the lost opportunity that might have been realized had the capital funds been invested.

12) **Interest Rate for Capital Investment** was assumed to be 6 percent per year.

13) **Annual Water Savings** equals the amount of water lost to evaporation and seepage in the earthen canal. Losses from a properly installed PVC pipeline are approximately zero. The earthen ditch in the example was assumed to lose water at 1 acre-foot per mile per day the ditch is used to convey water.

14) **Installed Capital Cost** (including valves, air release, and other items). The cost of installing the proposed pipeline per linear foot. The cost includes all mobilization, equipment, labor, material, and other construction costs.

15) **Project Capital Cost** (including valves, air release, and other items) equals the product of item 14 and item 10.

16) **Annual Change in Maintenance Cost** (Earthen Ditch to PVC Pipeline): Earthen ditch usually requires periodic maintenance to remove vegetation and wind blown sediments. Buried PVC pipe usually requires minimal maintenance but can require the occasional repair of leaks. The net decrease in cost was assumed.

17) **Energy Cost for Pipeline Friction**. Typically, there is minimal energy cost for using an open ditch to convey water. Energy loss in pipelines is proportional to the velocity of the water in the pipeline and the type of pipe material. Converting from an earthen ditch to a buried pipeline will increase the amount of energy needed to convey the water from the irrigation well to the field.

18) **Change in Energy Cost for Well Water.** The annual amount of water pumped by the irrigation well to be delivered to the field is reduced by the amount of water saved by installing the pipeline. The water savings results in a proportional reduction in energy cost for water supplied by the irrigation well.

19) **Change in Annual Energy Cost** (Earthen Ditch to PVC Pipeline) equals the sum of items 17 and 18.

20) **Total Change in Energy and Maintenance Costs** equals the total of items 16 and 19.

21) **Annual Capital Recovery Cost** equals the annual payment that would be required to service a loan for the amount of capital required to construct the proposed project (item 15).

22) **Net Annual Cost of Pipeline** equals the sum of items 20 and 21.

23) **Net Annual Cost per Ac-Ft of Water Savings** equals item 22 divided by item 13.

I. References for Additional Information

1) Texas Agricultural Extension Service, L-2218, “Pumping Plant Efficiency and Irrigation Costs.”

2) University of Tennessee, Agricultural Extension Service, “Irrigation Cost Analysis Handbook.”

Common Conversion Factors for Water Related Units

1 ft^3	7.4805195 gallons	62.3663 lb @ 60° F
1 acre-feet	43,560 ft^3	325,851 gallons.
1 MG	3.068883 acre-feet	133,681 ft^3
1 cfs for 24 hr	1.9835 acre-feet	0.6263 MG
1 MGD	1.547 cfs	1120.1 acre-feet/year
1 cms	35.3147 cfs	15,850 gpm
1 cfs	448.83 gpm	0.0283168 cms
1 hectare	2.4710538 acres	107,639 ft^2
1 mile	5,280 feet	1.61 km
1000 m^3	0.810714 acre-feet	0.26415 MG
1 hp	2542.48 BTU/hr	0.745700 kW
1 psi	2.307 ft of water	51.7 mmHg

Equations for Determining

Motor/engine horse power required for a water pump

$$hp = (gpm \times TDH) / (3960 \times e)$$

Acre-feet of water produced from an electric pump in a groundwater well estimated from the amount of electric power used to operate the pump

$$\text{Acre-feet} = (kWhr \times e) / (TDH \times 1.02)$$

Cost of per unit pressure loss

0.67 $/day = 1 psi of pressure loss @ 1 cfs of flow and 0.10 $/kWhr

Abbreviations

ft = feet
hp = horse power
cfs = cubic feet per second
BTU = British Thermal Unit
e = overall efficiency (fraction)
MGD = million gallons per day
psi = pounds per square inche
cms = cubic meters per second
hr = hour
TDH = total dynamic head (ft)
MG = million gallons
gpm = gallons per minute
m = meter
lb = pound
kWhr = kilo Watt hour