Youth Education on Rainwater Harvesting and Agricultural Irrigation Training for Small Acreage Landowners

Final Project Report

For the Completion of
TWDB Contract No. 1003581100

by

Dr. Dana Porter, P.E.
Associate Professor & Extension Irrigation Engineer
Texas AgriLife Research
Lubbock, TX

Brent Clayton
Extension Program Specialist
Texas AgriLife Extension
Corpus Christi, TX

submitted to the

Texas Water Development Board

P.O. Box 13231, Capitol Station
Austin, Texas 78711-3231
April 2012

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1. Executive Summary

As population increases and water supplies decrease in Texas, the awareness of the importance of water is steadily rising. Managing water is a complex issue, as it involves many stakeholders, environmental conditions, policies, and laws. Though complex, one certainty remains true in all situations: water is essential for life. To ensure that adequate and safe water is provided to everyone in the present and future, rain and irrigation water must be properly managed.

According the 2007 State Water Plan, one of the most effective ways to manage water supplies is through conservation. For example, the 2007 State Water Plan estimates that in 2060 irrigation conservation strategies will account for 37% of all irrigation needs.

Because water conservation is usually performed by the end-user, in order for conservation to be a successful water management practice, education must be implemented. Areas where an effective conservation education program can be implemented are rainwater harvesting for youth, general public water awareness, and irrigation for small acreage landowners.

The goal of the Youth Education on Rainwater Harvesting and Irrigation Training for Small Acreage Landowners project was to promote water conservation through educational programs by targeting youth and small acreage landowners to change their water-use habits. In order to achieve the goal, three tasks were developed to target specific water-using audiences: 1) youth education; 2) public water awareness education; and 3) development of agricultural irrigation educational resources for small acreage landowners.

Youth education involved five program areas where youth were educated: school programs, a youth water camp, a youth range camp, Junior Master Gardener programs, and school teacher training events. The activities were a combination of hands-one activities and classroom presentations. In the youth education task, a total of 614 individuals were reached, which achieved a water savings of 34.4 acre-feet per year.

The public water awareness task included public festivals and Master Gardner/Master Naturalist education. At the public festivals, booths were set up and presentations were given on water conservation and rainwater harvesting. The Master Gardener/Master Naturalist education trained participants about water conservation and how they can conduct water conservation programs for youth. In total, programs from this task reached 134,298 individuals, which achieved a water savings of 6,961.6 acre-feet per year.

The irrigation training for small acreage landowners involved developing an Irrigation for Small Farms training manual and presentations with notes, posted on a publicly available “Water Management” website at watermgmt.tamu.edu. Most of the audiences addressed in the development of these materials included a range of farm sizes (large and small) throughout the Texas High Plains (primarily). Presentations were adapted to online format delivery for convenient use by Extension and other educators, as well as for independent study.

Overall, the project reached 135,822 individuals throughout Texas. The total estimated water savings from the project is approximately 34.4 + 6961.6 + 4,550 = 11,546 acre-feet per year. As programs continue under the direction of educators trained in this project, and after the Small Acreage Irrigation Curriculum is published and spin-off products are made available, the water conservation numbers are expected to continue to grow.

2. Introduction and Background

As population increases and water supplies decrease in Texas, the awareness of the importance of water is steadily rising. Managing water is a complex issue, as it involves many stakeholders, environmental conditions, policies, and laws. Though complex, one certainty remains true in all situations: water is essential for life. To ensure that adequate and safe water is provided to everyone in the present and future, rain and irrigation water must be properly managed.

As identified by the 2012 State Water Plan, one of the most effective ways to manage water supplies is through conservation. For example, the 2012 State Water Plan estimates that in 2060 irrigation conservation strategies will account for 34% of all irrigation needs. The 2012 State Water Plan can be accessed online at https://www.twdb.state.tx.us/wrpi/swp/swp.asp.

Because water conservation is usually performed by the end-user, in order for conservation to be a successful water management practice, education must be implemented. Areas where an effective conservation education program can be implemented are irrigation for small acreage landowners, rainwater harvesting for youth, and general public water awareness.

As the population of Texas continues to grow and land fragmentation continues, efficient management and conservation of water will become more critical, and the need for educational resources for the small acreage landowner audience will increase. The number of new landowners who manage small acreages in the state of Texas continues to grow. The 2007 Census of Agriculture contains data showing over 52% of all farms/ranches in Texas are less than 100 acres in size and almost 38% are less than 50 acres in size. Many of these current landowners did not grow up living on the land and lack management skills that larger agricultural producers possess. While they are generally well educated, these land managers lack specific knowledge about critical natural resource management. Current irrigation education is directed to large-scale agricultural irrigators. Development of an introductory irrigation training that is focused on the needs small acreage landowners will be an excellent resource for this growing market.

Education on various rainwater harvesting techniques directly benefit Texans by reducing demand on the water supply, and reducing urban and rural runoff, erosion, sedimentation and contamination of surface water. In the Texas Rainwater Harvesting Evaluation Committee's report to the 80th Legislature, Rainwater Harvesting Potential and Guidelines for Texas (2006), it was stated that if 10% of the roof surfaces in Texas collected their rainwater, it would accumulate to approximately 38 billion gallons or 116,618 acre-feet per year.

Rainwater harvesting protects surface water supplies through limiting contaminant transport off the land surface, reduces peak storm water flow rates through stream channels and conserves potable water supplies through landscape water conservation. Evaluation results from previous rainwater harvesting training programs have shown that in the process learning about rainwater harvesting, an understanding of water conservation and watershed processes are gained. The connection between rainfall, stormwater runoff, water quantity, and water quality are made apparent through learning the principles of harvesting rainwater.

Support of youth education and public water awareness displays with rainwater harvesting training/education sessions address the need for water conservation as identified by the 2007 State Water Plan. This was accomplished in this project by (1) support of youth education programs and (2) public water awareness education.

References

Texas Rainwater Harvesting Evaluation Committee. 2006. Rainwater Harvesting Potential and Guidelines for Texas. Report to the 80th Texas Legislature. Austin, TX: Texas Water Development Board.

3. Project Objectives

The goal of the Youth Education on Rainwater Harvesting and Irrigation Training for Small Acreage Landowners project was to promote water conservation through educational programs by targeting youth and small acreage landowners to change their water-use habits. In order to achieve this goal, there were three objectives that guided the project:

1. *Youth Education* – Educate youth of all ages on water conservation and management through the following means: support in school programs; a youth water camp; a youth range camp; Junior Master Gardener programs. In addition, train the educators of youth including school teacher and Master Gardener training.

2. *Public Water Awareness Education* – Educate the general public through presentations or informational booths set up at public festivals. This also includes educating Master Gardeners.

3. *Agricultural Irrigation Training for Small Acreage Landowners* – Educate small acreage landowners by developing an agricultural irrigation educational package and training manual.

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4. Tasks and Methodology

In order to achieve the goal and objectives of the project, three tasks were developed to target specific water-using audiences: 1) youth education; 2) public water awareness education; and 3) development of agricultural irrigation educational resources for small acreage landowners.

1. *Youth Education.* Because the present-day youth will be the decision makers and managers of tomorrow's water resources, it was deemed essential to target educational programs to the state's youth and their educators. The five program areas where youth were educated in this project were: school programs, a youth water camp, a youth range camp, Junior Master Gardener programs, and school teacher training events.

   In order to make education about water conservation and management fun and engaging for youth, a combination of hands-on and computer presentations were developed for this project. Many hands-on resources were developed through the *Master Gardener Rainwater Harvesting Specialist* course to educate youth on issues related to water conservation and management. Some of the activities that were conducted for youth education programs included the use of a rainfall simulator, a raindrop splash experiment, measurement of soil infiltration, a soil temperature experiment, and a plastic sheet watershed demonstration. These activities were compiled into a document titled *Rainwater Harvesting Activities for Youth Education*. This document was developed, printed, and distributed for teachers, Master Gardeners, and others who may educate youth on water conservation and management. A copy of this document is included in Appendix A.

   The computer presentations educated the youth more about water conservation to go beyond the hands-on activities. Information that they learned from these presentations included facts about water scarcity and water usage of common appliances.

   In addition to educating the youth directly, school teachers, Master Gardeners, and other educators were taught about water conservation and management through the same activities that the youth engaged in. The educators were also given additional information by computer presentation on critical water statistics and how to hold a successful water conservation program for youth.

   Because the setting of each youth education program varied, the activities given to youth varied. Some programs included most of the activities listed in the activities document. Others only included a PowerPoint presentation. One activity common to most of the programs was the rainfall simulator.

   The rainfall simulator is a device designed and built at Texas A&M to show what happens to rainfall when it lands on the earth's surface. The device, as shown later in Figure 7, uses trays of various land-cover samples to show the importance of vegetation in the infiltration of rainwater. The device has buckets to capture runoff and groundwater. These buckets show participants the negative effects of bare soil, as runoff from bare-soil trays is always turbid.

To calculate water savings from these educational activities, it is assumed that each individual participant represents a household that will save 50 gallons of water per day. This is based on the written responses in the evaluation surveys where both students and educators listed ways that they would conserve water. Because it is not anticipated that every participant will conserve, the following water savings estimates are minimum compared to the possible potential savings. This includes daily savings of 12 gallons saved on reduced shower time (this would be a reduction of shower time from 10 minutes to 5 minutes); 10 gallons saved on toilet water fixes/replacements (this can be accomplished by fixing a leaking toilet or replacing an old toilet using 5 gallons per flush with a high-efficiency model using 1.28 gallons per flush); 3 gallons saved by turning unused faucets off (this can be accomplished by turning the faucet off when brushing teeth and shaving); 25 gallons saved by using more efficient irrigation and/or water saving vegetation (this value can easily be achieved by reducing unnecessary irrigation or using native, adapted plants which require less water). This water savings estimate is assumed to begin after the completion of each specific program.

2. *Public Water Awareness Education.* The general public is a broad target audience, but an important audience nonetheless. In order to reach the greatest amount of people effectively, the program areas that this project targeted were public festivals and Master Gardener and Master Naturalist training events.

   At public festivals, water awareness education was conducted through presentations or informational booths. The environment of the festival determined whether there would be a booth, presentation, or both. The booth set up included a poster display that included several pictures and basic information on rainwater harvesting. The booths also included information free for distribution. This information included factsheets developed through this program and other available Texas AgriLife publications. A picture of the booth is shown in Figure 18.

   The presentation given depended on the festival and the audience. For more technical audiences, a presentation was given on the research done in rainwater harvesting. This PowerPoint presentation is included in this report. At more general festivals and general audiences, informal, impromptu presentations were given to small groups on how to make a rain barrel or general information about rainwater harvesting.

   In addition, there were onsite demonstrations. There were two onsite demonstrations used at public festivals. These included the rainwater harvesting simulator and the stream trailer (Figure 1). The rainwater harvesting simulator (different from the rainfall simulator) pumps water from a rain barrel to a small demonstration roof model, where the water is distributed across the roof surface and conveyed into gutters, downspout, and back into the barrel. The continuous-cycle demonstration shows the basic design setup for a rainwater harvesting system. The stream trailer uses a pump to convey water across a “watershed” where model homes, cars, livestock, etc. can be placed. The demonstration shows the effect of erosion and how water moves through a watershed.

Figure 1. Rainwater harvesting simulator (left) and stream trailer (right).

Master Gardeners and Master Naturalists were trained in a similar method as the school teachers in task 1. They were presented with information on water conservation, scarcity, and statistics and how to hold a successful youth education program by explaining the activities detailed in Appendix A. They then participated in these hands-on activities that the youth would participate in. The purpose of educating the Master Gardeners and Master Naturalists was to achieve a “multiplicative effect” where they would teach many more about water conservation and management than the project team members could on their own.

3. *Agricultural Irrigation Training for Small Acreage Landowners.* The number of landowners managing small acreages continues to grow in Texas. For many, managing their land is not their primary source of income and they have very limited time to educate themselves on proper land/irrigation management. Development of an agricultural irrigation educational package targeting this growing group will help to fill the current gap in available irrigation training material. The training materials allow for future incorporation of the training material into an online delivery format (not included in the scope of the proposal for this project). The manual is included as Appendix D.

   In the course of developing these materials and interacting with target audiences, additional emerging audiences were identified. In order to meet needs of these emerging audiences in the future, the products developed have been leveraged to secure funding for additional materials for these audiences.

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5. Results

In total the three main tasks of this project – Youth Education, Public Water Awareness, and Irrigation Training for Small Acreage Landowners – reached 135,822 individuals throughout Texas. This included 614 individuals reached through Youth Education, 134,298 individuals reached through Public Water Awareness, and 910 individuals reached through irrigation training. Based on the assumptions that individuals attending youth educational programs and public awareness programs will conserve 50 gallons per day and individuals attending irrigation training will conserve 0.1 acre-foot per acre of irrigated land (conservatively assuming only 50 acres per farm, as if all participants were small acreage landowners), the total water savings from the project in approximately 34.4 + 6961.6 + 4,550 = 11,546 acre-feet per year. As programs continue under the direction of educators trained in this project, and after the Small Acreage Irrigation Curriculum is published and spin-off products are made available, the water conservation numbers are expected to continue to grow.

5.1 Task 1: Youth Education

Throughout the duration of the project, there were 11 programs given to youth and 3 programs given to educators. In these programs, there were 566 youth participants and 48 educator participants, for a total of **614 participants**. These programs were given in 11 different counties. These counties include Refugio, San Patricio, Parker, Harris, Nueces, Webb, Kimble, Menard, Ector, Nacogdoches, and Wilson. Based on the assumption that each individual reached by these educational activities will conserve 50 gallons of water per day (this includes daily savings of 12 gallons saved on reduced shower time; 10 gallons saved on toilet water fixes/replacements; 3 gallons saved by turning unused faucets off; 25 gallons saved by using more efficient irrigation and/or water saving vegetation), the total water savings from this project is approximately 30,700 gallons per day or **34.4 acre-feet per year**.

The programs under youth education were divided into five subtasks which included school programs, youth water camp, youth range camp, Junior Master Gardeners, and school teach training. The results of each youth education program will be highlighted in their respective subtasks below. Because each program setting and age group was different, the evaluation surveys given were adapted to meet the specific audience. For example, the program in Corpus Christi on June 6, 2011 only had time allotted for the rainfall simulator. In response, the project team supplemented questions on the survey to apply only to the rainfall simulator. The template for the youth evaluation is included in Appendix B. The template for the educator and Master Gardener evaluation is included in Appendix C.

5.1.1 Task 1: Youth Education – School Programs

There were a total of eight school programs given during this project reaching 482 individuals.

A youth education program on rainwater harvesting was held in Poth, TX on April 28, 2011. There were 12 elementary-aged students participating. Because of the interest by students and teachers, the school is now currently planning to install a rainwater harvesting system to irrigate a sustainable garden and water a landscape feature.

A youth education program on rainwater harvesting was held in Corpus Christi, TX on June 6, 2011. There were 22 high school-aged youth at this program. This program featured the rainfall simulator, which demonstrated the effect of various local land uses on stormwater runoff. The participants to this event were enthusiastic and willing to assist the instructor in the demonstration. An evaluation survey was given to the youth to gauge knowledge gained and willingness to adopt water conservation practices. The results of this survey are summarized in Table 1.

Table 1. Evaluation survey from the youth education school program in Corpus Christi on June 6, 2011.

<table>
<tr><td colspan="2">Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = “a lot” learned; n=22)</td></tr>
<tr><th>Topics</th><th>Average</th></tr>
<tr><td>The importance of rainfall</td><td>2.8</td></tr>
<tr><td>Different types of land covers</td><td>2.5</td></tr>
<tr><td>How different land covers change water runoff</td><td>2.8</td></tr>
<tr><td>The importance of groundwater</td><td>2.4</td></tr>
<tr><td>What kinds of grass are best for groundwater</td><td>2.8</td></tr>
<tr><td>How grasses help to keep water clean</td><td>2.4</td></tr>
<tr><td>How rainwater harvesting helps</td><td>2.4</td></tr>
<tr><td>How a rain garden can help</td><td>2.8</td></tr>
<tr><td colspan="2">Question 2. How much participants learned overall (1 = very little and 5 = very much; n=22)

Average value = 4.4</td></tr>
<tr><td colspan="2">Question 3. Some ways participants plan to conserve water in the future (written responses)

• Catch water in a bucket
• Use a bucket to catch water when it rains
• Use less water
• To use a trash can to catch the water that falls off the house
• Shorter showers, don't leaving water running long
• Collect some rain
• Not cut my grass so short
• I can collect rain water and clean it to drink or water plants</td></tr>
</table>

A youth education program on rainwater harvesting was held in Sinton, TX on July 18, 2011. This program was part of the Wildlife Conservation Camp held at the Welder Wildlife Foundation. There were 28 high school-age youth that attended this program. This program featured the rainfall simulator that demonstrated the effect of various local land uses on stormwater runoff to the youth (Figure 2). There was also a demonstration called a “guzzler” built to show how to use rainwater harvesting for a wildlife water source (Figure 3). The results from the evaluation are summarized in Table 2.

Figure 2. School program featuring the rainfall simulator in Sinton, TX on July 18, 2011.

Figure 3. Wildlife “guzzler” featured at school program in Sinton, TX on July 18, 2011.

Table 2. Evaluation survey from the youth education school program in Sinton on July 18, 2011.

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=27)	
Topics	**Average**
The importance of rainfall	2.4
Different types of land covers	2.6
How different land covers change water runoff	2.8
The importance of groundwater	2.6
What kinds of grass are best for groundwater	2.6
How grasses help to keep water clean	2.5
How rainwater harvesting helps	2.6
How a rain garden can help	2.3

Question 2. How much participants learned overall (1 = very little and 5 = very much; n=27)

Average value = 4.3

Question 3. Some ways participants plan to conserve water in the future (written responses)

- I will take shorter showers
- Water the lawn in the mornings and evenings only
- Collect rain water
- Build water collectors and use the water to water plants
- Make a water garden and be mindful of chemicals in the grass
- Plant more native grass
- Learn more about water conservation
- Create a rain garden and use more rain barrels

A youth education program on rainwater harvesting and water conservation was held in Sinton, TX on July 18, 2011. This program was another, separate session during the Wildlife Conservation Camp. There were 28 youth that took part in the activities of this program, which rotated in four groups. The setting and quick rotations of the program did not allow for an evaluation to be given. Pictures of this program are included in Figures 4 and 5.

Figure 4. School program in Sinton, TX on July 18, 2011 where students learn how to calculate irrigation flow rate and understand water use of turf grass.

Figure 5. School program in Sinton, TX on July 18, 2011 where students learn how a watershed works by the using a plastic sheet to change direction of water flow.

A youth education program on rainwater water harvesting and water conservation water was held in Weatherford, TX on July 21, 2011. There were 17 youth that attended this program, ranging in age from 11 to 14 (grades 5-8). In this program, the youth learned about water resources through several activities which included making a bird bath, using a plastic sheet to demonstrate watersheds (Figure 6), the rain splash activity, and an indoor PowerPoint presentation (Figure 7). The results from evaluation survey are summarized in Table 3.

Figure 6. School program in Weatherford, TX on July 21, 2011 demonstrated how a watershed works through this plastic sheet activity.

Figure 7. School program in Weatherford, TX on July 21, 2011 where students learn about water issues by a PowerPoint presentation.

Table 3. Evaluation survey from the youth education school program in Weatherford, TX on July 21, 2011.

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = “a lot” learned; n=17)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	2.1
Soil infiltration – show water soaking into the ground through rings	2.2
Corrugated roof gutter – showing roof runoff using watering can	2.7
Plastic sheet watershed – showing how a watershed works	2.7
Rainfall simulator – showing the fate of rainfall	2.1
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=27) Average value = 4.0	
Question 3. Some ways participants plan to conserve water in the future (written responses) • Don't take long showers • Turn off water when brushing teeth • Make sure water is not dripping from the faucet • Save the water that runs off my gutter	

A youth education program on rainwater harvesting was held in Junction, TX on August 10, 2011. There were 70 participants in the middle-school age range. Because of the informal setting, evaluations were only provided to a few participants. Evaluation results are summarized in Table 4.

Table 4. Evaluation survey from the youth education school program in Junction, TX on August 10, 2011.

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = “a lot” learned; n=5)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	3
Soil temperature – measuring different soil temperatures	3
Soil infiltration – show water soaking into the ground through rings	3
Transpiration – showing plant transpiration using plastic bags on branches	3
Mist to heavy rain – showing rain drop size by spraying audience	3
Corrugated roof gutter – showing roof runoff using watering can	3
Plastic sheet watershed – showing how a watershed works	3
Rainfall simulator – showing the fate of rainfall	3
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=5) Average value = 5.0	
Question 3. Some ways participants plan to conserve water in the future (written responses) • Possibly use runoff barrel to collect water • Try to collect rain water and deep grass to help with topsoil • Think about taking shorting showers to save water • Be more conscious about water runoff • We would like to start a rainwater harvesting program at our school • Catch rain from our gutters, shorter showers, possibly use harvesting for our animals, yard, etc.	

A school program was held on November 18, 2011 at the Laredo Elementary School in Laredo, TX. This program was a “station” as part of their Agriculture Awareness Day. Groups of elementary children from grades K-6 rotated to watch the rainfall simulator and other water conservation activities. Due to the nature of the event, no evaluations were given. Pictures of the event are shown in Figure 8.

Figure 8. A school program on November 18, 2011 in Laredo, TX demonstrated fate of rainwater with this rainfall simulator.

A school program was held on January 13, 2012 at the Refugio Elementary School in Refugio, TX. The program was held during the science class period for six different classes. Each class lasted one hour. A total of 105 students, aged 5^{th} and 6^{th} grades, participated in the program. The students participated in several outdoor activities (Figures 9 and 10) and an indoor PowerPoint presentation. An evaluation survey was given to the students.

Figure 9. A school program on January 13, 2012 in Refugio, TX where students are learning about stormwater runoff with a rainfall simulator.

Figure 10. A school program on January 13, 2012 in Refugio, TX where students learn about rainfall with a rainfall splash activity.

5.1.2 Task 1: Youth Education – Youth Water Camp

The youth water camp was scheduled to take place in July 2011 in Monahans. However, due to low interest, the organizers of the event had to cancel it. Because the presenter, Billy Kniffen, planned to be in that region during that time, he organized a Junior Master Gardener program. The results from this program are discussed in section 5.1.4.

5.1.3 Task 1: Youth Education – Youth Range Camp

The youth range camp (Figure 11) was held at the Texas Tech Junction Campus in Junction, TX on June 19-24, 2011. The camp, organized by the Ecosystem Science and Management Department at Texas A&M, was attended by 39 high school-aged youth. Billy Kniffen conducted water resources training at the camp. Due to the setting of the program, an evaluation was not given for the water-specific presentation. However, evaluations were given for the entire camp. The evaluations were done as pre-course and post-course tests. The results from these tests showed that participants and an average knowledge improvement of over 84%.

Figure 11. Youth Range Camp in Junction, TX on June 19-24, 2011.

5.1.4 Task 1: Youth Education – Junior Master Gardener Programs

During the project period, there were a total of 2 Junior Master Gardener programs held, reaching a total of 45 individuals. There were 3 scheduled, but one in San Antonio had to be canceled due to low interest. To make up for the canceled class, an additional school program was held in Refugio, TX on January 13, 2012. The results from this program are shown in section 5.1.1.

A Junior Master Gardener program was held in Menard, TX in March 2011. There were 10 participants in attendance ranging in ages from grade 4 to grade 6. At this program, several of the water conservation activities for youth were done, including the rainfall simulator and the corrugated roof gutter. An evaluation survey was given to the participants to gage knowledge gained. Results from the survey are summarized in Table 5.

Table 5. Evaluation survey from the Junior Master Gardener program in Menard, TX, March 2011.

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=10)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	1.8
Soil temperature – measuring different soil temperatures	1.8
Soil infiltration – show water soaking into the ground through rings	2.7
Transpiration – showing plant transpiration using plastic bags on branches	2.9
Mist to heavy rain – showing rain drop size by spraying audience	2.7
Corrugated roof gutter – showing roof runoff using watering can	3
Rainfall simulator – showing the fate of rainfall	2
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=5) Average value = 4.4	
Question 3. Some ways participants plan to conserve water in the future (written responses) • Rain barrel • Rain barrel • rain bucket • use a rain barrel • not leaving the water on, get a rain bucket • get a rain bucket, not leaving the water on • take a small bath • pick up trash out of the water, get a rain barrel • not littering • get a water bucket	

A Junior Master Gardener program was held on July 12, 2011 in Odessa, TX. This program had a total of 35 youth that rotated in groups, which ranged in age from 5 to 12. Group one had 5 youth aged 5-7; group two had 11 youth aged 8-11; group three had 11 youth aged 9-11; group four had 8 youth aged 10-12. All of these groups participated in the various hands-on water conservation activities for youth. Because the rotations were done quickly, many of the evaluation surveys were given informally and some were incomplete. However, the results from each group are show in Table 6.

Table 6. Evaluation survey from the Junior Master Gardener program in Odessa, TX on July 12, 2011.

Table 6A. Group 1, 5-7 year-olds

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=10)	
Topics	**Average**
Corrugated roof gutter – showing roof runoff using watering can	3
Plastic sheet watershed – showing the fate of rainfall	3
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=5)	
Average value = 4.6	

Table 6B. Group 2, 8-11 year-olds

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=11)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	3
Soil infiltration – show water soaking into the ground through rings	2.6
Mist to heavy rain – showing rain drop size by spraying audience	3
Corrugated roof gutter – showing roof runoff using watering can	2.7
Plastic sheet watershed – showing the fate of rainfall	2.6
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=11)	
Average value = 5.0	

Table 6C. Group 3, 9-11 year-olds

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=11)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	2.7
Soil infiltration – show water soaking into the ground through rings	2.8
Mist to heavy rain – showing rain drop size by spraying audience	2.8
Corrugated roof gutter – showing roof runoff using watering can	2.9
Plastic sheet watershed – showing the fate of rainfall	2.9
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=11)	
Average value = 5.0	

Table 6D. ***Group 3, 10-12 year-olds***

Question 1. How much participants learned on each specific topic (0 = nothing learned and 3 = "a lot" learned; n=8)	
Topics	**Average**
Raindrop splash – showing how soil splashes during the rain	2.6
Soil infiltration – show water soaking into the ground through rings	3
Mist to heavy rain – showing rain drop size by spraying audience	2.8
Corrugated roof gutter – showing roof runoff using watering can	2.7
Plastic sheet watershed – showing the fate of rainfall	3
Question 2. How much participants learned overall (1 = very little and 5 = very much; n=8)	
Average value = 5.0	

5.1.5 Task 1: Youth Education – School Teacher Training

During the program year, there were three school teacher training events held. These three programs reached 48 individuals. An evaluation survey was given at each training event. A sample evaluation is included in Appendix B.

A school teacher program was held in November 2010 in Houston, TX. This training program was for Houston-area teachers. There were 10 individuals that participated from a variety of roles, including teachers of 5^{th}-8^{th} grades and a department head. An evaluation survey was given. A summary of the evaluation results is shown in Table 7.

Table 7. Evaluation survey from the school teacher training program in Houston, TX in November, 2010.

Question 1. Retrospective pre-post test knowledge gained by participants (n=10)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	19
Understanding of stormwater and its impact on the environment	19
Understanding of rangeland watersheds	42
Understanding of how landscaping affects water usage	13
Understanding of how rainwater can be used to water wildlife	16
Understanding of how rain gardens can be used to harvesting rainwater	29
Understanding of how to implement a youth education session	40
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=10)	
Topics	**Average**
Storm water:	4.78
Rangeland Watersheds:	4.44
Landscaping to save water:	4.56
Harvesting water for wildlife:	4.44
Rain gardens:	4.67
Youth Education on RWH:	4.67

A school teacher training program was in Nacogdoches, TX on January 21, 2011. This training event targeted AgriLife Extension Educators, including primarily 4-H faculty. This event was attended by 16 participants from the Texas AgriLife District 5 which surrounds the Nacogdoches area. During this program, participants learned the hands-on activities that they could use during their educational activities. An evaluation survey was given during this program. Results are summarized in Table 8.

Table 8. Evaluation survey from the educator training program in Nacogdoches, TX, January 21, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=16)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	51
Understanding of stormwater and its impact on the environment	36
Understanding of rangeland watersheds	38
Understanding of how landscaping affects water usage	40
Understanding of how rainwater can be used to water wildlife	44
Understanding of how rain gardens can be used to harvesting rainwater	50
Understanding of how to implement a youth education session	58
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=10)	
Topics	**Average**
Storm water:	4.00
Rangeland Watersheds:	3.85
Landscaping to save water:	4.46
Harvesting water for wildlife:	4.23
Rain gardens:	4.23
Youth Education on RWH:	4.15

A school teacher training program was held in Sinton, TX on June 16, 2011. This program was attended by 22 teachers from across Texas. In was part of the “Conservation across Boundaries” program held at the Welder Wildlife Foundation. Several hands-on activities were done to introduce teachers to water conservation activities that they could use for their own students. The summary of results from the evaluation is included in Table 9.

Table 9. Evaluation survey from the school teacher training program in Sinton, TX on June 16, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=16)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	48
Understanding of stormwater and its impact on the environment	46
Understanding of rangeland watersheds	49
Understanding of how landscaping affects water usage	38
Understanding of how rainwater can be used to water wildlife	42
Understanding of how rain gardens can be used to harvesting rainwater	72
Understanding of how to implement a youth education session	66
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=10)	
Topics	**Average**
Storm water:	4.36
Rangeland Watersheds:	4.41
Landscaping to save water:	4.45
Harvesting water for wildlife:	4.45
Rain gardens:	4.41
Youth Education on RWH:	4.57

5.2 Task 2: Public Water Awareness Education

Throughout the duration of the project, there were 12 programs targeting public water awareness education. These programs reached 124,298 individuals in 10 different counties. Based on the assumption that each individual reached by these educational activities will conserve 50 gallons of water per day, the total water savings from this project is approximately 6.2 million gallons per day or **6,961.6 acre-feet per year**.

The programs under public water awareness were divided into two subtasks, which included public festivals and Master Gardener/Master Naturalist education. The results of each public water awareness education program will be highlighted in their respective subtasks below.

Because each program setting was different, the evaluation surveys given were adapted to meet the specific audience. The template for the educator and Master Gardener evaluation is included in Appendix C. The results of program evaluations are included below.

5.2.1 Task 2: Public Water Awareness Education – Public Festivals

The team members of this project held booths and/or participated at 3 public festivals. The information at these festivals reached approximately 134,110 individuals.

An educational booth displaying a poster board and publications were displayed at the San Antonio Livestock Show and Rodeo in conjunction with the Bexar County Master Gardeners in February 2011. Multiple publications were given away to the attendees including: *Harvesting Rainwater for Wildlife* (200 copies distributed); *Rainwater Harvesting* (1000 copies distributed); *Making a Rain Barrel* (English) (200 copies distributed); *Making a Rain Barrel* (Spanish) (200 copies distributed); *Rainwater Harvesting Landscape Methods* (1000 copies distributed); and *Rainwater Harvesting in Texas* (5000 copies distributed). Viewership of this display is estimated to be over 130,000 individuals based on individuals counted entering the building. Pictures of the rainwater harvesting section of the festival are shown in Figures 12 and 13.

Figure 12. Public festival – Rainwater harvesting informational area at the San Antonio Stock Show and Rodeo in February 2011.

Figure 13. Public festival – *Making a Rain Barrel* publication available for attendees to the San Antonio Stock Show and Rodeo in February 2011.

An educational booth and rainwater harvesting demonstration were set up and displayed at the Landscape Irrigation Efficiency Expo that was hosted at the Dallas AgriLife Research and Extension Center on March 3, 2011. Multiple publications were given away to the attendees. These publications include: *Rain Gardens* (50 copies distributed); *Rainwater Harvesting* (50 copies distributed*); Making a Rain Barrel* (English)(50 copies distributed); *Making a Rain Barrel* (Spanish) (50 copies distributed); *Rainwater Harvesting Landscape Methods* (50 copies distributed); and *Harvesting Rainwater for Wildlife* (30 copies distributed). Approximately 60 individuals attended this exposition. Photos of the event, booth, and demonstration can be found in Figures 14 and 15.

Figure 14. Public festival – Educational booth at the Landscape Irrigation Expo in Dallas, TX on March 3, 2011 featuring a rainwater harvesting simulator (left) and a poster board display (right).

Figure 15. Public festival – Participants gathering information from the educational booth at the Landscape Irrigation Expo in Dallas, TX on March 3, 2011.

An educational booth and rainwater harvesting demonstration were set up and displayed at the Plano Live Green Expo held on April 15, 2011 in Plano, TX. Multiple publications were given away to the attendees. These publications included: *Rainwater Harvesting* (500 copies distributed); *Making a Rain Barrel* (English)(500 copies distributed); *Making a Rain Barrel* (Spanish) (50 copies distributed); and *Rainwater Harvesting in Texas* (500 copies distributed). Based on estimates, there were approximately 4,000 people that attended the Expo and viewed the rainwater harvesting booth. Photos of the event, booth, and demonstration are show in Figures 16 and 17.

Figure 16. Public Festival – The Plano Live Green Expo in Plano, TX on April 15, 2011. Exhibit features a rainwater harvesting simulator (left) and informational materials (right).

Figure 17. Public festival – A close-up view of the poster used at the Plano Live Green Expo in Plano, TX on April 15, 2011.

An educational booth and rainwater harvesting demonstration were set up and displayed at the Texas Irrigation Expo held on December 9-10, 2011 in McAllen, TX. This booth was set up in coordination with the Hidalgo County Master Gardeners. There were 50 individuals that participated in the event. Multiple publications were given away to the attendees. These publications included: *Rainwater Harvesting* (50 copies distributed); *Making a Rain Barrel* (English)(50 copies distributed); *Making a Rain Barrel* (Spanish) (50 copies distributed); *Rainwater Harvesting for Livestock* (50 copies distributed) and *Rainwater Harvesting in Texas* (50 copies distributed). A picture of the display is show below in Figure 18.

Figure 18. Public Festival - Display booth on rainwater harvesting at the Texas Irrigation Expo in McAllen, TX on December 9-10, 2011. Rainwater harvesting simulator is on the right.

5.2.2 Task 2: Public Water Awareness Education – Master Gardener and Master Naturalist Education

There were 9 Master Gardener and Master Naturalist Educational programs conducted in eight different counties. These programs reached 188 individuals.

A Master Gardener training was held in Montague, TX on November 5, 2010. The event was attended by 10 Master Gardeners. The evaluation results are summarized in Table 10.

Table 10. Evaluation survey from the Master Gardener training program in Montague, TX on November 5, 2010.

Question 1. Retrospective pre-post test knowledge gained by participants (n=10)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	118
Understanding of stormwater and its impact on the environment	96
Understanding of rangeland watersheds	124
Understanding of how landscaping affects water usage	61
Understanding of how rainwater can be used to water wildlife	100
Understanding of how rain gardens can be used to harvesting rainwater	117
Understanding of how to implement a youth education session	129
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=10)	
Topics	**Average**
Storm water:	4.5
Rangeland Watersheds:	4.3
Landscaping to save water:	4.7
Harvesting water for wildlife:	4.6
Rain gardens:	4.6
Youth Education on RWH:	4.6

A Master Gardener training event was held in San Angelo, TX on February 10, 2011. The event was attended by 19 Master Gardeners. The evaluation results are summarized in Table 11.

Table 11. Evaluation survey from the Master Gardener training program in San Angelo, TX on February 10, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=19)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	60
Understanding of stormwater and its impact on the environment	52
Understanding of rangeland watersheds	56
Understanding of how landscaping affects water usage	44
Understanding of how rainwater can be used to water wildlife	42
Understanding of how rain gardens can be used to harvesting rainwater	76
Understanding of how to implement a youth education session	78
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=19)	
Topics	**Average**
Storm water:	3.74
Rangeland Watersheds:	3.39
Landscaping to save water:	4.28
Harvesting water for wildlife:	3.89
Rain gardens:	4.35
Youth Education on RWH:	3.22

A Master Gardener training event was held at the annual Texas Master Gardener 2011 State Conference on April 27, 2011. In this event, 20 Master Gardeners were taught methods of educating youth about rainwater harvesting. There were no evaluations given at this event.

A training program for Master Gardeners and Master Naturalists about rainwater harvesting education for youth was held on March 15, 2011 in Kerrville, TX. There were 13 participants. Results of the evaluation survey are summarized in Table 12.

Table 12. Evaluation survey from the Master Gardener training program in Kerrville, TX on March 15, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=13)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	38
Understanding of stormwater and its impact on the environment	35
Understanding of rangeland watersheds	62
Understanding of how landscaping affects water usage	31
Understanding of how rainwater can be used to water wildlife	58
Understanding of how rain gardens can be used to harvesting rainwater	70
Understanding of how to implement a youth education session	81
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=13)	
Topics	**Average**
Storm water:	4.6
Rangeland Watersheds:	4.3
Landscaping to save water:	4.8
Harvesting water for wildlife:	4.8
Rain gardens:	4.7
Youth Education on RWH:	4.5

A training program for Master Gardeners and Master Naturalists about rainwater harvesting education for youth was held on April 13, 2011 in Bell County, TX. There were 35 participants. There were no evaluations given at this event.

A training program was held for Master Gardeners during the *Master Gardener Rainwater Harvesting* Specialist training on June 9-10, 2011 in Georgetown, TX. This program was attended by 23 master gardeners. The program included activities such are the rainfall simulator (Figure 19) and corrugated roof runoff (Figure 20). A summary of results from the evaluation are included in Table 13.

Figure 19. Master Gardener Training – Participants observe the rainfall simulator during the Master Gardener Rainwater Harvesting Specialist training in Georgetown, TX on June 9-10, 2011.

Figure 20. Master Gardener Training – Participants demonstrate how rainwater harvesting works with a simple corrugated roof at the Master Gardener Rainwater Harvesting Specialist training in Georgetown, TX on June 9-10, 2011.

Table 13. Evaluation survey from the Master Gardener training program in Georgetown, TX on June 9-10, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=23)	
Topics	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	21
Understanding of stormwater and its impact on the environment	24
Understanding of rangeland watersheds	44
Understanding of how landscaping affects water usage	30
Understanding of how rainwater can be used to water wildlife	38
Understanding of how rain gardens can be used to harvesting rainwater	38
Understanding of how to implement a youth education session	50
Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=23)	
Topics	**Average**
Storm water:	4.62
Rangeland Watersheds:	4.27
Landscaping to save water:	4.76
Harvesting water for wildlife:	4.55
Rain gardens:	4.77
Youth Education on RWH:	4.62

A training event was held for Master Gardeners during the *Master Gardener Rainwater Harvesting Specialist* training on July 13-14, 2011 in Granbury, TX. This program was attended by 10 Master Gardeners. The Master Gardeners learned and participated in the activities that could be used to educate youth (Figure 21). Evaluation results are summarized in Table 14.

Figure 21. Master Gardener Training – Participants learn how to harvesting rainwater on a simulator at the Master Gardner Rainwater Harvesting Specialist training in Granbury, TX on July 13-14, 2011.

Table 14. Evaluation survey from the Master Gardener training program in Granbury, TX on July 13-14 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=10) **Topics**	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	38
Understanding of stormwater and its impact on the environment	41
Understanding of rangeland watersheds	47
Understanding of how landscaping affects water usage	39
Understanding of how rainwater can be used to water wildlife	45
Understanding of how rain gardens can be used to harvesting rainwater	48
Understanding of how to implement a youth education session	61

Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=10) **Topics**	**Average**
Storm water:	4.3
Rangeland Watersheds:	4.2
Landscaping to save water:	4.6
Harvesting water for wildlife:	4.7
Rain gardens:	4.6
Youth Education on RWH:	4.4

A training program was held for the Williamson County Master Gardeners as a part of their training course on August 30, 2011 in Georgetown, TX. This program was attended by 35 participants. A summary of the results from the evaluation is included in Table 15.

Table 15. Evaluation survey from the Master Gardener training program in Georgetown, TX on August 30, 2011.

Question 1. Retrospective pre-post test knowledge gained by participants (n=35) **Topics**	**% Knowledge gain**
Understanding of how rainwater addresses water quality and quantity issues:	44
Understanding of stormwater and its impact on the environment	47
Understanding of rangeland watersheds	52
Understanding of how landscaping affects water usage	33
Understanding of how rainwater can be used to water wildlife	59
Understanding of how rain gardens can be used to harvesting rainwater	56
Understanding of how to implement a youth education session	72

Question 2. Participants ability to educate others on selected topics (1 = poor and 5 = excellent; n=35) **Topics**	**Average**
Storm water:	3.7
Rangeland Watersheds:	3.3
Landscaping to save water:	4.17
Harvesting water for wildlife:	3.87
Rain gardens:	3.9
Youth Education on RWH:	4.07

A training program was held for the Fort Bend County Master Gardeners as a part of their training course on October 26, 2011 in Rosenberg, TX. This program was attended by 23 participants. Though an evaluation was given for the entire course, there was no evaluation survey given for this individual class.

5.3 Task 3: Agricultural Irrigation Training for Small Acreage Landowners

As training materials were being developed, portions of the content were presented in meetings and conferences targeting agricultural audiences, representing small and large farm operations, county extension educators, and other interested stakeholders. Events in Salado (October 2010), Levelland (January 2011), Muncy (January 2011 and January 2012), Plainview (February 2011), Dimmit (August 2011), Lubbock (September 2011), Muleshoe (September 2011 and January 2012), and Seminole (December 2011) offered great opportunities to present materials on soil moisture management, irrigation best management practices, and irrigation technologies. Estimated combined audiences of 910 were in attendance at these events.

Technologies, best management practices and availability of resources were promoted through local radio and television outlets, including the Fox Talk “Ag Talk” show with an estimated audience of 77,000 (combined AM 950 Radio and 34.2 Television audiences, with additional uncounted internet audiences); and the AM 580 “Today’s Ag” show, with an audience of 5,000. Both of these are live call-in shows with diverse audiences.

Publication of the irrigation training manual and “spin-off” products for small acreage and emerging audiences will continue in multiple formats (electronic and hardcopy) after the completion of this project on funds secured through the USDA-ARS Ogallala Aquifer Program and other sources. The resource manual is included as Appendix F.

6. Conclusion

With populations increasing and water supplies decreasing in Texas, this project was a critical step towards ensuring a sustainable water supply for the future. The goal of this youth education and small acreage landowner irrigation training project was to promote water conservation through educational programs by targeting youth and small acreage landowners to change their water-use habits. This goal was achieved by saving an estimated 11,546 acre-feet of water per year through three main tasks: youth education, public water awareness, and irrigation training for small acreage landowners.

In youth education, a total of 614 individuals were reached through various educational programs. This included training programs for educators who will reach an even greater number of youth with similar water conservation programs. Assuming these individuals will use the information gained to make changes in their lives, an estimated 34.4 acre-feet will be saved per year.

In public water awareness, a total of 134,298 individuals were reached through festivals and Master Gardener training programs. Similar to the teacher training events in the youth education task, in this task, Master Gardeners and Master Naturalists were taught how to conduct water conservation programs for youth. Assuming every individual's household saved 50 gallons per day based on the information that they gained, an estimated 6,961.6 acre-feet will be saved per year.

In the irrigation training for small acreage landowners, a total of 910 individuals were reached through various meetings and programs. Additionally, up to 82,000 more individuals were reached through radio and television shows that featured this information.

Through this project, a total of 135,822 individuals were reached with information related to water conservation. An additional 82,000 were also reached via a radio/television broadcast. Though this project is technically completed, the effects of its impacts will continue. Those who change their water-use habits will undoubtedly influence the water use of others around them. This is especially true with youth. As they grow and become adults the importance of water will remain with them and affect the decisions they make.

Appendix A:
Document explaining water conservation activities for youth

AgriLIFE EXTENSION
Texas A&M System

Rainwater Harvesting Activities for Youth Education

Rainwater Harvesting

This document may be found on the TWDB Conservation Education page at:

http://www.twdb.texas.gov/conservation/education/

This booklet was created to helped educators

Developed by the Texas AgriLife Extension Service

Through a grant provided by the

Texas Water Development Board

For more information, please go to

http://rainwaterharvesting.tamu.edu/

Table of Contents

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Introduction

This booklet was created to help educators teach students about the importance of water management and conservation, with a focus on rainwater harvesting. The activities included in this document can be used for students ranging from grades K-12. It can also be used for 4-H or Junior Master Gardener education. Attachments A and B include two tables showing how these activities can achieve various Texas Essential Knowledge and Skills.

This document was developed by the Texas AgriLife Extension Service through a grant provided by the Texas Water Development Board

For more information about rainwater harvesting, please go to

http://rainwaterharvesting.tamu.edu/

Rainfall Simulator

Objective:

- Understand the movement of water through the water cycle
- Understand the concept of a watershed
- Understand the effects of land cover and management on the path of rainwater.
- Understand the practical implementation measures of rainwater harvesting for water storage in the soil, groundwater, and surface reservoirs.
- Understand the effect that increased impervious areas have on water movement in the watershed.
- Understand water and land management options that decrease runoff and promote infiltration.

Materials:

- Rainfall simulator frame
- 4 land cover trays (varying landscapes):
    - Urban landscape
    - Native grasses
    - Overgrazed land
    - Turfgrass
    - Rain garden
- 4 rain trays
- 8 catch containers
- 2 buckets for water
- Towels

Procedure:

Fill the rain trays with about 1-2 inches of water and watch to see where the rainfall goes. First explain the three reasons why Texas landscapes do not look like they did before European settlement: 1 – development; 2 – overgrazing; 3 – lack of fire. This caused a decreased in native grass prairies. Then discuss how the resulting land covers cause different patterns in water infiltration and runoff. Discuss how water movement and land management can affect water quality and what landowners can do to improve infiltration and the quality of water downstream.

After the rain has fallen for a few minutes, compare the water quantity and quality of the various catch containers. Discuss differences in water amounts between land covers and why some containers' water is turbid while other is clear. On the tray with an urban landscape, use small cups and a sponge (picture on bottom of previous page) to simulate rainwater harvesting.

Questions to Ask:

- What are three reasons why there are not abundant native grassland prairies in Texas?
- Where do you think there will be the most surface runoff?
- How does overgrazing negatively affect the land?
- How does development negatively affect the land?
- How does the lack of fire negatively affect the land?
- What are ways we can improve water infiltration?
- Why does water not infiltrate into the overgrazed land cover?

For more information on how to obtain or build a rainfall simulator please see Attachment C on page 18.

Rain Drop Splash

Objective:

- Understand that a falling raindrop has energy and can detach soil particles,
- Understand how ground cover affects the energy in the raindrop

Materials:

- 1- Sprinkler can or 5 gallon bucket with holes punched in the bottom
- 1- Poster board
- 1- Ruler or measuring tape

Procedure:

Rainfall is simulated by holding a sprinkler can or 5 gallon bucket with holes punched in the bottom about 4-5 feet above the ground (pictured on right). A measured amount of water is poured out on the soil. The splash is recorded using a poster board placed next to where the rainfall strikes the soil.

Measure and compare:

- **Height of the splashes**
- **Amount of soil splash (color of water splashed on the poster board)**
- **A separate test is then done on grass or vegetated area. Select 2 or 3 different soil or vegetation conditions.**

Questions to Ask:

- Which surface will have the most splashing soil?
- Why is there more splashing on bare soil?
- Why is this bad for the environment and the watershed?

Soil Temperature

Objective:

- Understand the relationship between air temperature and soil temperature.
- Understand how ground cover affects the soil temperature.

Materials:

- 2- Thermometers

Procedure:

Take the soil temperature reading in the afternoon because it is usually the hottest time of the day. An inexpensive thermometer that will register up to 120-130 degrees should be sufficient. The bulb of the thermometer should be placed about ½ inch below the soil surface on both the grassed and bare areas. The ½ inch depth is suggested because this is usually the depth of most seedling grass roots. Also take the air temperature at least 4 feet above the ground to avoid soil heat radiation.

Observations and Discussion:

Have the students record the temperatures of the grassed and bare soil areas and the air. Discuss the importance that vegetation has on moderation of temperature in the soil (because it helps hold in moisture). Discuss how the temperature in the soil and earth greatly impacts the temperature of the air. Explain how the hottest years in Texas were also the driest years when there were droughts (i.e. 2011).

Questions:

- Which soil surface do you think will have the greatest temperature?
- Why is the temperature in the bare soil greater?
- How does vegetation help to retain water?

Soil Infiltration Measurements with Rings

Infiltration rings will be used to demonstrate how fast soils will absorb moisture. These rings may be used to show differences between soils or to show the effect of range condition on rates of infiltration on similar soils.

Objectives:

- Understand the relationship between land health and infiltration.
- Understand that if the rainfall rate exceeds the infiltration rate, runoff will occur.

Materials:

- 1- Bucket with water
- 2- 6" sections of 4" metal or PVC pipe
- 1- Large hammer

Procedure:

Select two or more different soil or vegetation conditions for measurement. Hammer the rings into the ground one to three inches so that water cannot seep out from under them.

Fill rings with water to a depth of 2 inches. Pour the water in as fast as possible without disturbing the soil surface. Record the time it takes for the water to disappear. Repeat with another container of water if time allows.

Check to see how far the water infiltrated into the soil. This can be done by digging a hole until you strike dry soil or parent material and then measuring from the surface to the dry soil or parent material. The different soil condition measurements can then be graphed or charted.

Questions:

- Which land cover will have the greatest amount of infiltration?
- Why does vegetation allow for more water to infiltrate?

Transpiration

Objectives:

- Be able to define transpiration and describe its role in the water cycle.

Materials:

- 4- gallon sized plastic bags

Procedure:

Describe to the audience what transpiration is and its role in the water cycle. Select 4 different types of plants and seal the bag over as much of the plant as possible. Leave the bags alone and check them in 30 minutes. Compare the amount of water that was transpired by each type of plant.

Discuss which plants had the most transpiration and why. Explain how introduced or invasive plants may withdraw more water than native plants, leaving less water in the soil.

Questions:

- Which plant will have the most amount of transpiration?
- Why would that plant have the most transpiration?
- What other plants would have high levels of transpiration?
- What might be bad about transpiration?
- How can we control the amount of transpiration occurring on our land?

 

Mist to Heavy Rain

Objectives:

- Understand that rainfall rates differ during each rainfall event.

Materials:

- 1 spraying water bottle that allows you to change the flow from a fine mist to a heavy spray.

Procedure:

Describe to the students how rainfall rates affect the environment. Demonstrate this by spraying the water bottle in front of the audience and changing the flow to demonstrate the difference between a mist to a heavy rain. Discuss how these differences can affect erosion on the soil surface. Also discuss how the rate of rainfall can change the potential of water to infiltrate or become surface runoff.

Questions:

- What rate of rainfall will cause the most amount of erosion?
- What rate of rainfall will lead to more water infiltration?
- Why might heavy rain be important?

Corrugated Roof and Gutter

Objectives:

- Identify where rainfall goes if it falls on a roof with and without gutters.
- Understand the role and purpose that gutters serve on a roof.
- Show the basic principles of rainwater harvesting.

Materials:

- Short piece of corrugated plastic/tin/wood (2' x 2')
- Sprinkler can to simulate rain event
- Short piece of gutter to divert water
- Bucket or container to catch the water

Procedure:

Have 2 students hold the short piece of corrugated plastic/tin in their hands (one on each side) and a third student to use the sprinkling can and sprinkle water on to the small roof to simulate a rain. Discuss where this water is going - running off the roof, splashing on the ground and running off into a ditch, drain and down the watershed.

Then slip the piece of gutter under the roof and slope it to one end and have a container there to catch the water. Discuss how much water per square foot of surface you can catch (measure your roof to determine the area and amount of water). Example: 2' x 2' = 4 square feet of surface. You can capture approximately 0.6 gallons of water per square foot per 1" of rainfall; 4 ft^2 x 0.6 = 2.4 gallons of runoff.

Questions:

- Where is the water going when there are no gutters?
- Why are having no gutters a bad thing?
- How much water can we capture from this roof with an inch of rain?
- What can you use harvested rainwater for?

Plastic Sheet Watershed Activity

Objective:

- Understand what a watershed is and how human activities impact water quality.
- Understand that everyone in a watershed is responsible for protecting water quality.
- Understand the importance of managing all of the water that falls on a landscape.

Materials:

1. Clear plastic sheeting – heaver gage – 4 mil thickness or thicker (square or rectangle). Sizes can range from 8' x 8' to 10' by 20'.
    a. Cut a 4" diameter hole in the very center
2. Water hose with spray nozzle on the end if possible.
3. Water holding container like a 1 – 5 gallon container or bucket.
4. Open space, preferably outside.

Procedure:

1. Have students open up the sheeting and stretch it out at waist level and spread out uniformly or evenly spaced all the way around the sheeting (see picture above).
2. Discuss with the students that the sheeting represents their watershed and water flows from the highest point to the lowest. The sheet could represent their watershed, which includes their school and community and drains into the nearest creek, river, lake or ocean
3. Place about 2 gallons of water onto the sheeting and instruct students to move the water in a circle all the way around the sheeting without it going to the center and being lost in the center hole (leaving their watershed). Students learn to raise and lower their section to get it to move around. Instruct them to work slowly at first.
4. Once they have moved it in a circle 2-3 times (or after about 5 tries), let that water drain into the center hole to remove it.
5. Select a taller student and have him or her get into the center and raise it up as high as possible. Instruct all other students that it is going to rain on their new home and they can either be underneath it or on the outside.

6. Spray water up high over the sheeting to create a rainfall event (previous page on bottom).
7. Once you have allowed it to rain for a few minutes, ask the students where the water went.
8. Have the student in the center bring the sheet low. Select another student to hold the bucket under the center hole of the sheet.
9. Spray water up high for a minute and wave the nozzle from end to end.
10. Explain that all the water went into the bucket and this is the process of rainfall capture. Discuss that we can capture and save that water for dry days and use it for all types of purposes outside their home. With proper treatment, it can also be used inside the home.
11. Next repeat step 3 and have the students move the water than before.
12. Once they are successful (3-10 circles depending on time available) stop and discuss:
    a. Water is precious. World-wide children only have about 5 gallons of water per day to bathe, drink, cook and use. In the USA, there is abundant and safe water to use and play with.
    b. We want our children and their children to be able to have the same privileges and fun playing and using water as we have the fortune of doing. But it will take teamwork – just as it did to move the water around in a circle – for us to give that luxury to their children. We all live and play in our watershed and if we can work together to protect and conserve that water in our watershed we can continue to have the fun we do today.
13. Finally allow the students to shake the sheet dry. Have the students fold up the sheet or lay it out for the next group.

One Gallon Jug Watering Device

Objective:

- Understand the importance of water to wildlife.

Materials Needed:

1. 1 gallon water or milk jug
2. An adjustable drip emitter
3. A drill and 3/16" drill bit or punch to make hole for emitter
4. Spray paint for plastic
5. Markers or other paint
6. String or bungee cord to hang watering device

Procedure:

Making the watering jug:

1. **Clean out 1 gallon jug**
2. **Spray a base coat of paint over the jug to prevent UV degradation**
3. **Drill or punch a small in the bottom and opposite corner as the jug would hang**
4. **Have students paint or decorate the jug as desired**
5. **Insert the drip emitter into the hole**
6. **Attach a string or cord to the handle so it can hang in a tree or other support**

Steps to making the concrete base (Two methods)

<u>Method 1</u>

1. Mix concrete according to directions on bag
2. Pour the concrete in the plastic pie container or mold and spread it out (either use spackle tool or protective gloves)
3. Put a bowl in the middle and push down until it is about an inch away from the bottom
4. Let it sit for about 5 minutes
5. Decorate the concrete around the bowl with shells or other items (be sure that they are firmly in the concrete)
6. Take out the bowl and see if there is an indention there; if not keep the bowl in there a few more minutes.
7. Remove the bowl and decorate the center indention
8. Let it dry for approximately 24 hours or until completely set
9. Remove the concrete base from the mold or pie pan
10. Place under watering jug

<u>Method 2</u>

1. Mix cement according to directions – fast setting concrete is preferred
2. Lay a plastic sheet over the top of a table and cover with one inch of sand
3. Find a larger leaf – 2 to 4 inches in diameter and lay it on the sand
4. With a finger draw an outline of the leaf in the sand down to the plastic sheet
5. Place about 1 inch of cement over the leaf and into the trench outlining the leaf created by the child's finger
6. Have the students – *with protective gloves on – pat the cement until it is smooth over the top and beaten into the trench
7. Allow the cement to dry – about 1 hour
8. Have students roll the cement over and dig out the leaf
9. The imprint can be left the color of concrete or painted
10. Place under watering jug

Water Conservation Pledge

I promise to do my best to save water in my home.

I also promise to help others by telling them about ways to conserve water.

I will do my best to be a water conservation citizen.

AgriLIFE EXTENSION
Texas A&M System

____________________ Signed

____________________ Date

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Attachment A.

Texas Essential Knowledge and Skills (TEKS) for Science

Activity	TEKS for Science Addressed by Activity
Rainfall Simulator	Grade K, TEK 7 B; Grade K, TEK 9 B; Grade 1, TEK 7 B; Grade 2, TEK 7 B; Grade 2, TEK 8 C; Grade 3, TEK 9 C; Grade 3, TEK 10 A; Grade 4, TEK 3 C; Grade 4, TEK 7 A,B,C; Grade 4, TEK 8 B; Grade 5, TEK 8 B; Grade 7, TEK 8 A,B,C; Grade 7, TEK 10 B; Grade 8, TEK 10 B; HS Aquatic Science, TEK 7 A,B,C; HS Aquatic Science, TEK 11 A, B; HS Biology, TEK 12 F; HS Earth and Space Science, TEK 11 A,E; HS Earth and Space Science, TEK 12 A; HS Earth and Space Science, TEK 15 C; HS Environmental Sciences, TEK 4 B; HS Environmental Sciences, TEK 5 A,B,E; HS Environmental Sciences, TEK 9 A,E,F
Rain Drop Splash	Grade K, TEK 7 B; Grade 3, TEK 7 B; Grade 4, TEK 7 B; Grade 7, TEK 8 A,B,C; HS Earth and Space Science, TEK 11 A; HS Environmental Sciences, TEK 9 A; HS Physics, TEK 6 B
Soil Temperature	Grade 3, TEK 2 A; Grade 4, TEK 2 A; Grade 4, TEK 7 A
Soil Infiltration Measurements with Rings	Grade 3, TEK 2 A; Grade 4, TEK 2 A; Grade 4, TEK 7 A; Grade 5, TEK 2 D; Grade 7, TEK 8 C; HS Aquatic Science, TEK 7 B; HS Earth and Space Science, TEK 15 C
Transpiration	Grade K, TEK 9 B; Grade 1, TEK 10 B; Grade 2 TEK 10 B
Mist to Heavy Rain	Grade K, TEK 7 B
Corrugated Roof and Gutter	Grade K, TEK 7 C; Grade 1, TEK 7 C; HS Environmental Sciences, TEK 5 B
Plastic Sheet Watershed Activity	Grade 1, TEK 7 B; Grade 2, TEK 7 B; Grade 2, TEK 8 C; Grade 4, TEK 3 C; Grade 4, TEK 7 C; Grade 5, TEK 8 B; Grade 7, TEK 8 A,B,C; HS Aquatic Science, TEK 7 A,B,C; HS Earth and Space Science, TEK 15 C; HS Environmental Sciences, TEK 5 B; HS Environmental Sciences, TEK 9 A
One Gallon Jug Watering Device	Grade K, TEK 9 B; Grade 7, TEK 10 A

Attachment B.

Texas Essential Knowledge and Skills (TEKS) for Agriculture, Food, and Natural Resources

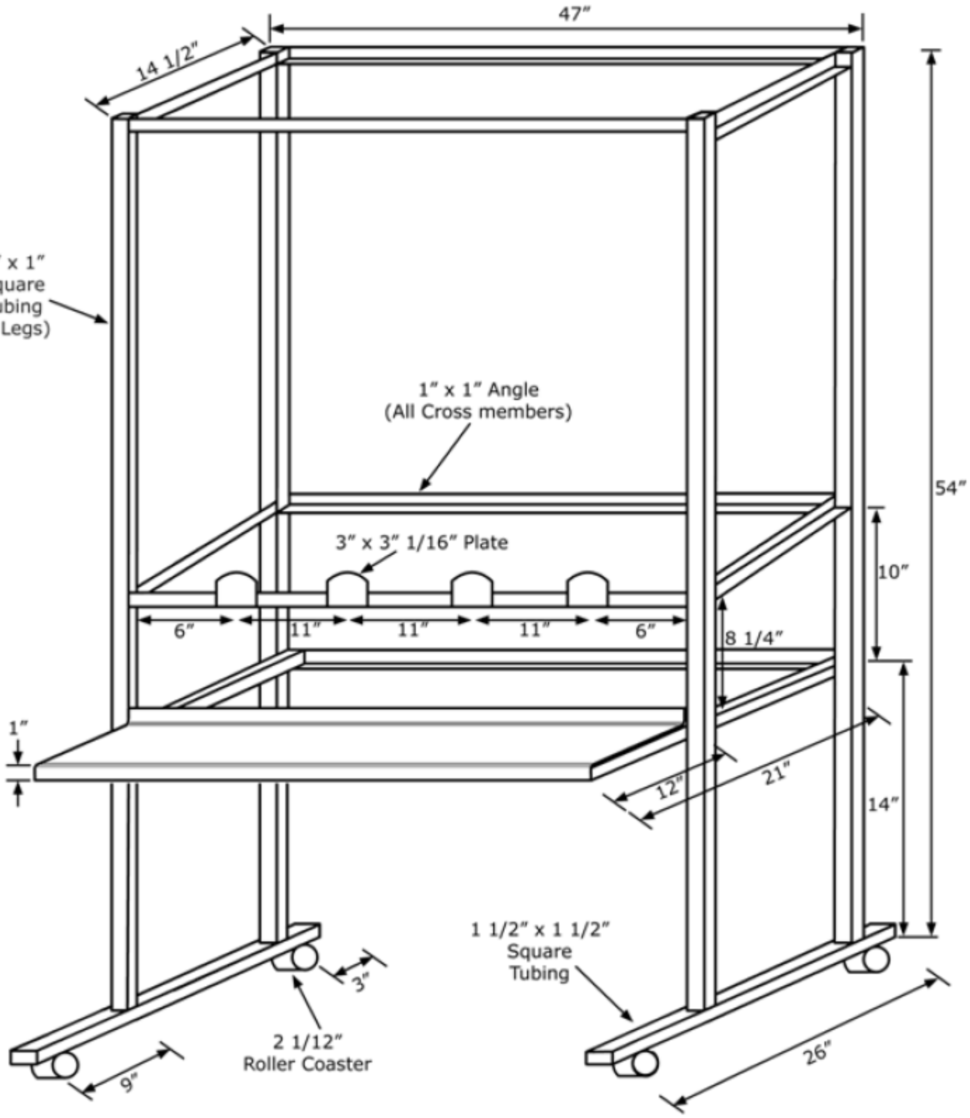
Activity	TEKS for Agriculture, Food, and Natural Resources Addressed by Activity
Rainfall Simulator	Principles of Agriculture, Food and Natural Resources, TEK 6 D; Principles of Agriculture, Food and Natural Resources, TEK 15 E; Energy and Natural Resources Technology, TEK 8 A,B,C,D,E,F; Advanced Environmental Technology, TEK 5 A,C,D,E,G,H; Advanced Environmental Technology, TEK 8 A,B,C,D Rangeland Ecology and Management, TEK 3 B; Rangeland Ecology and Management, TEK 4 B,E; Forestry and Woodland Ecosystems, TEK 2 H; Advanced Plant and Soil Science, TEK 8 B; Advanced Plant and Soil Science, TEK 9 A,B,C,D; Advanced Plant and Soil Science, TEK 11 A,B
Rain Drop Splash	
Soil Temperature	
Soil Infiltration Measurements with Rings	Mathematical Applications in Agriculture, Food, and Natural Resources, TEK 4 A; Rangeland Ecology and Management, TEK 3 B
Transpiration	
Mist to Heavy Rain	
Corrugated Roof and Gutter	Principles of Agriculture, Food and Natural Resources, TEK 15 E; Mathematical Applications in Agriculture, Food, and Natural Resources, TEK 1 F; Mathematical Applications in Agriculture, Food, and Natural Resources, TEK 4 A; Energy and Natural Resources Technology, TEK 8 A,F; Advanced Plant and Soil Science, TEK 8 B; Agricultural Mechanics and Metal Technologies, TEK 5 A,B,C
Plastic Sheet Watershed Activity	Energy and Natural Resources Technology, TEK 8 C,D,E,F; Advanced Environmental Technology, TEK 5 A,D,E; Wildlife, Fisheries, and Ecology Management, TEK 5 G; Forestry and Woodland Ecosystems, TEK 2 H; Advanced Plant and Soil Science, TEK 9 A,B,C,D; Advanced Plant and Soil Science, TEK 11 A,B
One Gallon Jug Watering Device	

Attachment C.

Obtaining or Building a Rainfall Simulator

The rainfall simulator as shown on page 2 is available for use for educational purposes from several AgriLife Extension offices throughout Texas. To find contact information for a local Extension office, go to http://agrilifeextension.tamu.edu/. Contact the county's Extension Agent to find out if they have a simulator available or where to find one. For more detailed teaching instruction, there are leader guides available for purchase online at agrilifebookstore.org. The title of the series is, "What is the Fate of Your Rainfall?"

The rainfall simulator can also be built with proper tools and supplies. Below are drawings and pictures for the currently-used rainfall simulator by the Texas AgriLife Extension Service. The construction of the frame requires welding. Be sure to follow all safety precautions when welding the simulator or hire a trained professional.



Drawing of the rainfall simulator frame.

The plant tray for the simulator is made from a 15”×11”×6” plastic storage (15 quart volume) container.

There are two drains in the tray: one for groundwater and one for surface water runoff. The groundwater drain is made from ½” PVC pipe. As show above, the pipe extends along the bottom of the tray to maximize the capture of groundwater. The surface water hole drilled into the tray is 1 ½” in diameter and the hole for the groundwater pipe is 7/8” in diameter.

Above are the groundwater pipe components which include ½" sizes of the following (starting at the bottom left and moving up and to the right): 90° elbow, 2" long pipe, male adapter, two rubber washers, threaded 90° elbow and slip, 7" long pipe, end cap. Also, there are four holes drilled in the section of pipe that will be in the container. The hole is 3/16". The rubber washers go on both sides of the plant tray when the groundwater pipe is assembled.

Above are the surface water pipe components which include 1" sizes of the following (starting at the bottom left and moving up and to the right): 4" long pipe, 90° elbow, 2 ¾" long pipe, male adapter. The male adapter threads into the surface water hole at the top of the tray.

Once the trays and piping have been assembled, they can be filled with "land uses." In this picture, there are (from left to right) land uses of native grasses, over-grazed land, turf grass, and urban landscape. Note that the water pipes in this example use 45° elbows, which is a viable option.

On the urban landscape tray, a small model house (i.e. birdhouse) can be used to represent roof surface. The impervious ground is a piece of plastic glued to the tray. Small containers can be used to simulate rainbarrels and a sponge can be used to simulate a rain garden. The gutters are made from ½" pipe cut in half.

The containers to collect the groundwater and surface runoff should be clear plastic containers. It is also important to label them (as seen above).

The rain trays are the same sized containers as the plant trays. They are drilled with 35 small holes (1/16") across the bottom for the water to simulate rainfall.

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Appendix B – Evaluation Survey Given to Youth
Youth Education: Rainwater Harvesting Evaluation

Name (optional) ___________________________________Current Grade: _______________________

1. What did you expect to learn this program? ____

____

2. Please rate how much you learned in each activity (0 = nothing, 1 = very little, 2 = Some, 3 is a lot):

	Nothing….A lot			
a. Raindrop splash – showing how soil splashes during the rain	0	1	2	3
b. Soil temperature – measuring different soil temperatures	0	1	2	3
c. Soil infiltration – showing water soaking into the ground through rings	0	1	2	3
d. Transpiration – showing plant transpiration using plastic bags on branches	0	1	2	3
e. Mist to heavy rain – showing rain drop size by spraying audience	0	1	2	3
f. Corrugated Roof Gutter – showing roof runoff using watering can	0	1	2	3
g. Plastic Sheet Watershed – showing how a watershed works	0	1	2	3
h. Rainfall Simulator – showing the fate of rainfall	0	1	2	3

3. How good were the instructors teaching about water?

   Poor……Excellent

   1 2 3 4 5

4. Please rate how much that you learned overall (1 is very little, 5 is very much):

   1 2 3 4 5

5. List some ways that you will conserve water in the future?

____

____

6. What ideas do you have to make the course better next time?

____

____

____

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Appendix C

Evaluation Survey Given to Teachers and Master Gardeners

Name (optional) ____________________________Your Job Title:___________________________________

1. What were your expectations for this program? ____

____

2. Please evaluate each topic regarding knowledge before and after the program:

BEFORE the Program	**Poor……Excellent**
a. Understanding of how rainwater harvesting addresses water issues:	1 2 3 4 5
b. Understanding of stormwater and its impact on the environment:	1 2 3 4 5
c. Understanding of rangeland watersheds:	1 2 3 4 5
d. Understanding of how landscaping affects water usage:	1 2 3 4 5
e. Understanding of how rainwater can be used to water wildlife:	1 2 3 4 5
f. Understanding of how raingardens can be used to harvest rainwater:	1 2 3 4 5
g. Understanding of how to implement a youth education session:	1 2 3 4 5

AFTER the Program	**Poor…...Excellent**
a. Understanding of how rainwater addresses water quality and quantity issues:	1 2 3 4 5
b. Understanding of stormwater and its impact on the environment:	1 2 3 4 5
c. Understanding of rangeland watersheds:	1 2 3 4 5
d. Understanding of how landscaping affects water usage:	1 2 3 4 5
e. Understanding of how rainwater can be used to water wildlife:	1 2 3 4 5
f. Understanding of how raingardens can be used to harvest rainwater:	1 2 3 4 5
g. Understanding of how to implement a RWH youth education session:	1 2 3 4 5

3. Please evaluate each topic in regard to increasing your ability to educate others about	**Poor…...Excellent**
a. Stormwater:	1 2 3 4 5
b. Rangeland Watersheds:	1 2 3 4 5
c. Landscaping to save water:	1 2 3 4 5
d. Harvesting water for wildlife:	1 2 3 4 5
e. Raingardens:	1 2 3 4 5
f. Youth Education on RWH:	1 2 3 4 5

4. Rate the presenters effectiveness	**Poor…...Excellent**
	1 2 3 4 5

5. Other comments: ____

____

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Appendix D

Presentations for Educators

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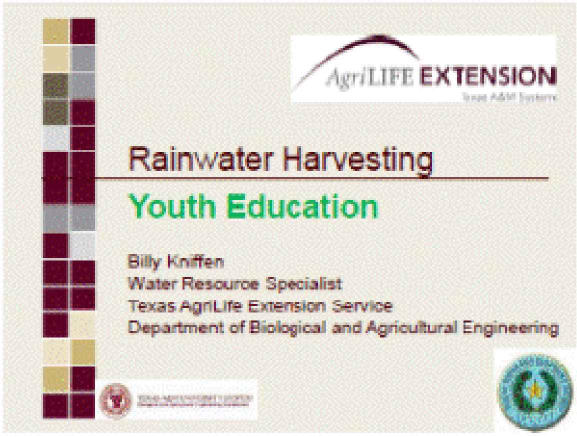
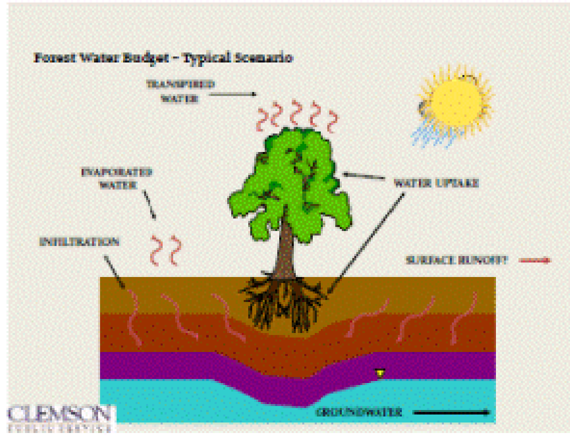
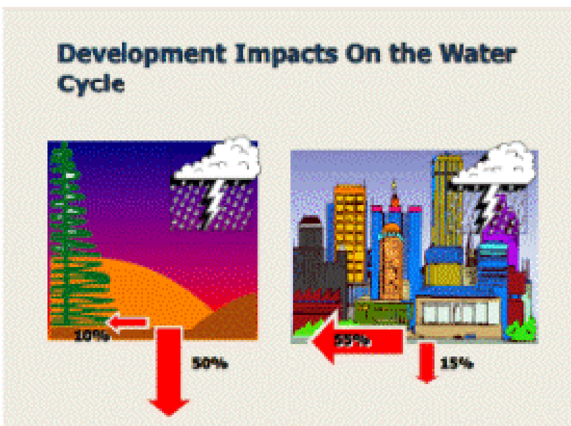


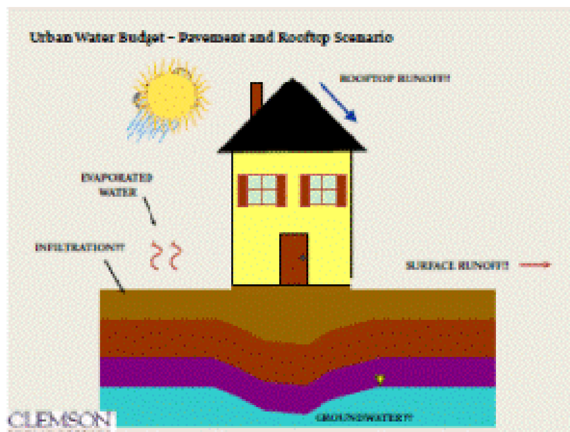
AgriLIFE EXTENSION
Rainwater Harvesting
Youth Education
Billy Kniffen
Water Resource Specialist
Texas AgriLife Extension Service
Department of Biological and Agricultural Engineering



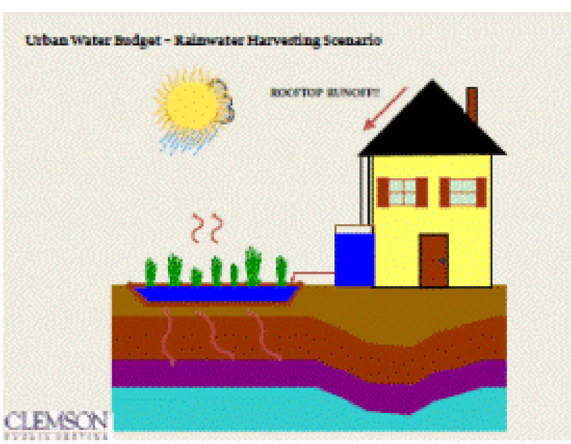
Forest Water Budget - Typical Scenario
TRANSPIRED WATER
EVAPORATED WATER
WATER UPTAKE
INFILTRATION
SURFACE RUNOFF?
GROUNDWATER
CLEMSON



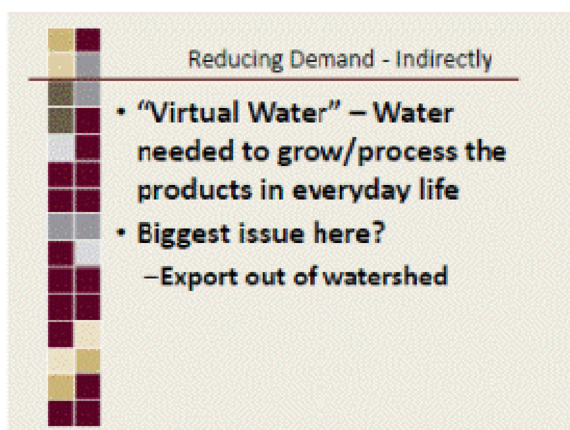
Development Impacts On the Water Cycle
10%
50%
55%
15%



Urban Water Budget - Pavement and Rooftop Scenario
ROOFTOP RUNOFF!!
EVAPORATED WATER
INFILTRATION??
SURFACE RUNOFF!!
GROUNDWATER??
CLEMSON



Urban Water Budget - Rainwater Harvesting Scenario
ROOFTOP RUNOFF!!
CLEMSON



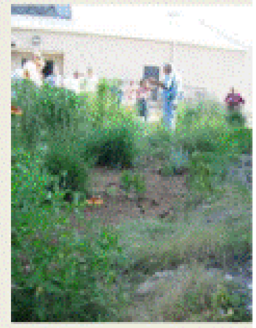
Reducing Demand - Indirectly
• "Virtual Water" – Water needed to grow/process the products in everyday life
• Biggest issue here?
–Export out of watershed

Virtual Water - Examples

Beef – 1,800 gal needed per 1 lb
Coffee – 37 gal for 1 mug
Cotton – 766 gal for 1 t-shirt
Bananas – 103 gal per 1 lb

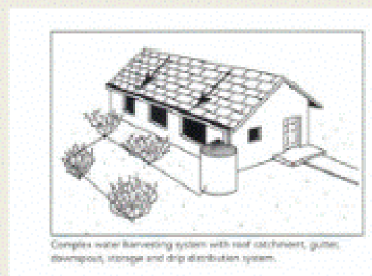
Passive Collection

- Raingardens
- Bog gardens
- Soil storage and infiltration systems
- Stock tanks/ponds
- Constructed wetlands
- Gabion baskets
- Water spreading
- Vegetated filter strips



Passive Collection: Rain Gardens

Complex /Active Rainwater Harvesting

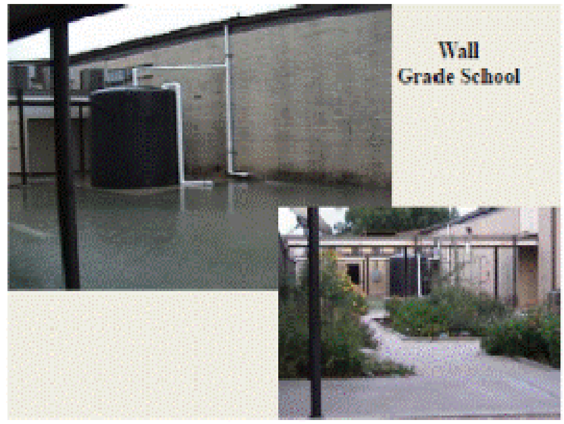


How to Collect Rainwater

- .6 gallons/square foot of roof/1" rainfall
- 2,000 sq.' X .6 gal. X 1" rain = 1,200 gal. water
- 1,200 gal. X 30" rainfall per year= 36,000 gal/yr

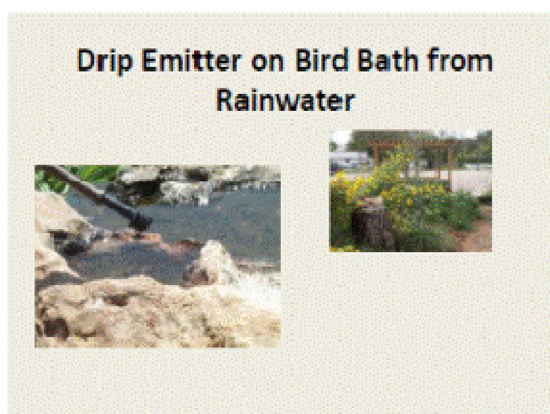
From Rain Barrels


Trash Can Waterer


Wall
Grade School


Monahans Rainwater Collection


School Wildscape and Water 1000 g. Collection


Drip Emitter on Bird Bath from Rainwater


Container Gardening with 5th Grade Using Drip & Rainwater


Installing Bird Feeder


Burn at High School and 10 months later


Rainfall Simulator

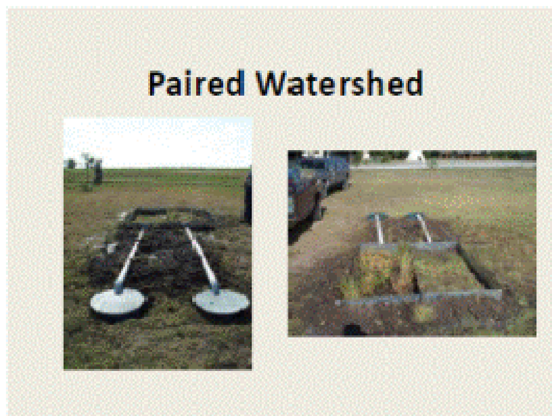

Rain Simulator Plans


Wildlife Water Guzzler


Raindrop
Splash


Water
Infiltration
Collar


Rainfall off the Roof, From a Gutter to a
Rain Barrel

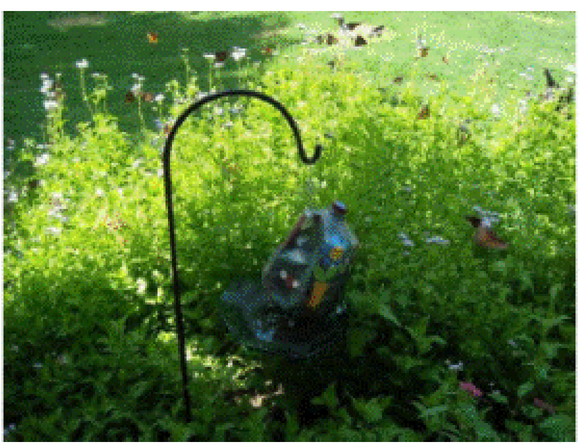

Paired Watershed


Youth Observing and Pouring
Water


Pouring and Watching Runoff

Outdoors Day
2003 - 20010
Menard 1st – 8th Grade

- Fishing
- Outdoor cooking
- Seining the river
- Exploring for fossils and artifacts
- Kayaking or canoeing
- Pressed flower bookmarks
- Wildlife tracks, skulls and hides
- Archery, Bike Safety

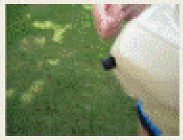


Materials

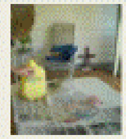
- 1 gallon plastic milk jug with lid
- Lighter Fuel
- Spray paint for plastic
- Assorted stickers- color and size
- Adjustable Dripper- flow rate 0-10 GPH
- Mod Podge- gloss luster
- Sponge brushes
- Concrete
- Plastic molds or pie pans
- Small bowl to make indention
- Shells or other decorations for concrete
- String

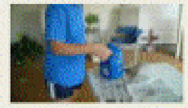
Steps for making a water jug dripper

1. Clean the jugs with hot soapy water
2. Remove labels with lighter fuel
3. Let dry completely
4. Spray milk jugs with paint for plastic materials (any color) example: Krylon Fusion
5. Let dry completely
6. Install adjustable dripper by pushing it in the bottom corner of the milk jug
7. Punch small hole in the lid to allow air flow



8. Put stickers for decoration on the jug
9. Paint the Mod Podge on the jug with the sponge brushes (the Mod Podge is white but will come out clear and shiny and is like glue)
10. Let dry completely approximately 24 hours
11. Attach string to handle of milk jug (which has been filled with water) for hanging to hook or tree





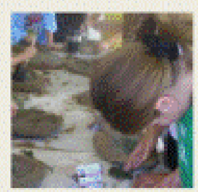
Steps to making the concrete base

1. Make concrete according to directions on bag
2. Pour the concrete in the plastic pie container or mold and spread out
3. Put a bowl in the middle and push down were it is about an inch away from the bottom
4. Let it sit for about 3 minutes
5. Decorate the concrete with shells or other things (make sure you push them down a little so they will stay on)

6. Take out the bowl and see if there is an indention there; if not keep the bowl in there a little longer so it can keep the shape, but not too long
7. Remove the bowl and decorate the center indention if you would like, but make sure you keep an indention in the middle so water can drip in to it
8. Let it dry for approximately 24 hours or until completely set
9. Remove the concrete base from the mold or pie pan

10. Hang the milk jug (which is filled with water) 1-2 feet above the concrete base; open the adjustable dripper slightly for one drop to come out at a time. Refill the jug when all the water drips out.
11. Enjoy watching the birds and butterflies drink the water!

- Another process for making the concrete watering device is to lay out 1" of sand and place a leaf on top of it. Mark around the leaf with your finger to create a depression about ¾-1" deep. Then pour about 1" slab of cement on top and pat it down.



Youth Education on Rainwater Harvesting

Funding provided by the
Texas Water Development Board

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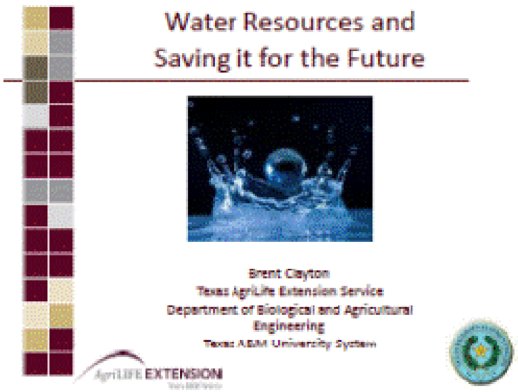
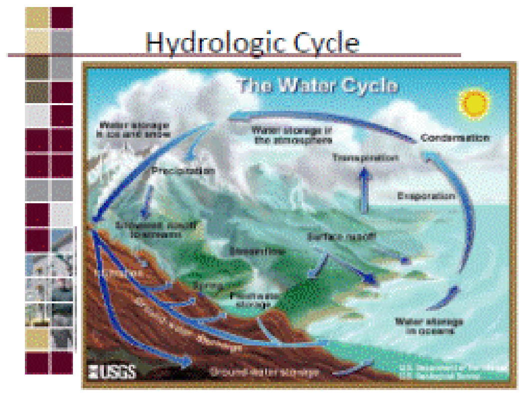
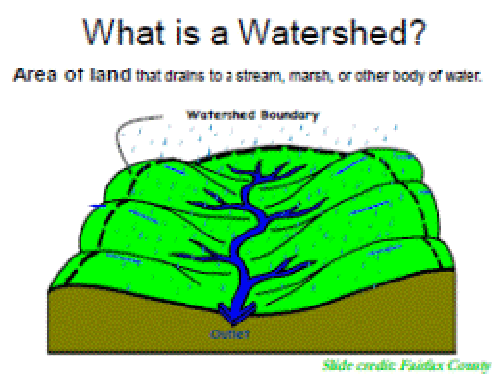
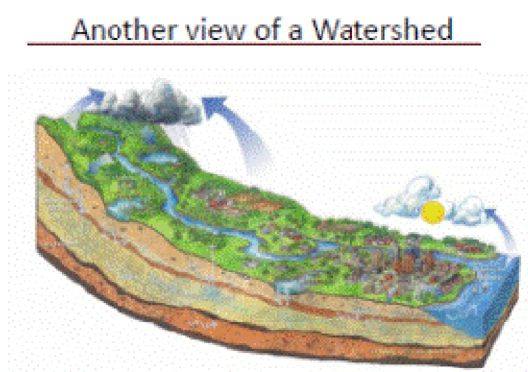
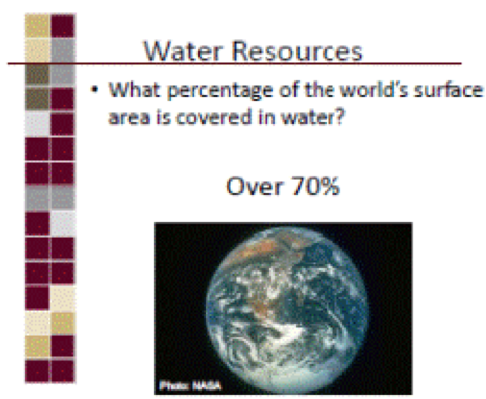
Appendix E - Presentations for Youth







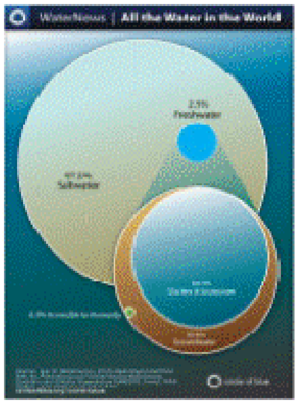




Water Resources

- What percentage of that water is fresh?

2.5-3%



Water Use – Some Facts

- United Nations recommends 13 gal/person/day to meet basic needs
- Average use per person per day in:

U.S. and Canada	United Kingdom	Kenya
150	30	3

Water Use – Some Facts

- Typical American flushes the toilet 5 times a day at home.
- Equals around 18.5 gallons everyday
- How much *per day* for whole country?

5,700,000,000 gallons

Water Use – Some Facts

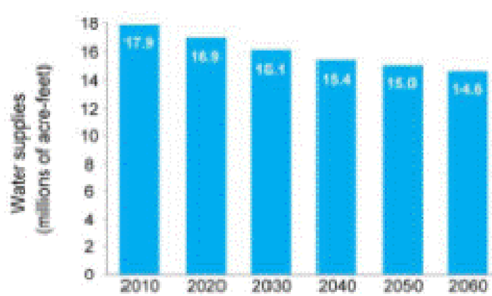
- Old infrastructure
- What percentage of water leaks from pipes before it reaches consumers?

United States	16%
United Kingdom	19%
France	26%

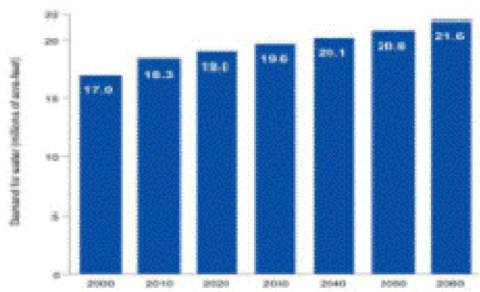
Water Quality – Some Facts

- Nearly 900 million people lack access to safe drinking water
- 2.5 billion people lack adequate sanitation
- Every 20 seconds, a child dies from a water-related disease

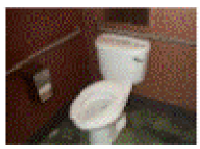
Projected Supply



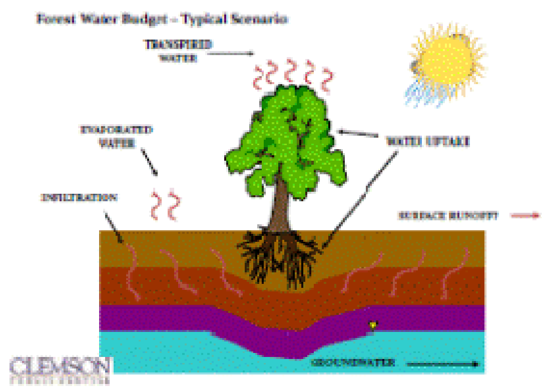
Projected Demand



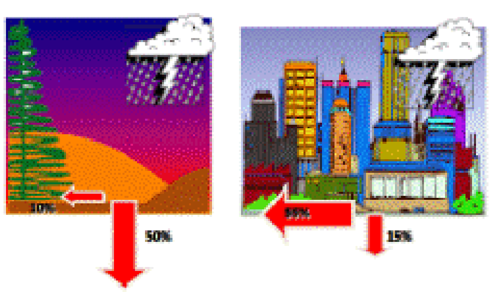
SO WHAT CAN WE DO TO PROTECT OUR WATER FOR THE FUTURE?

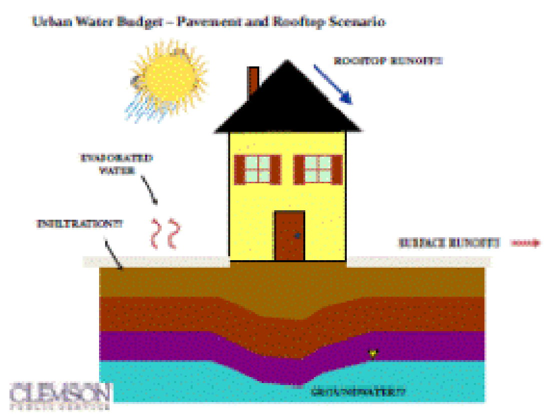


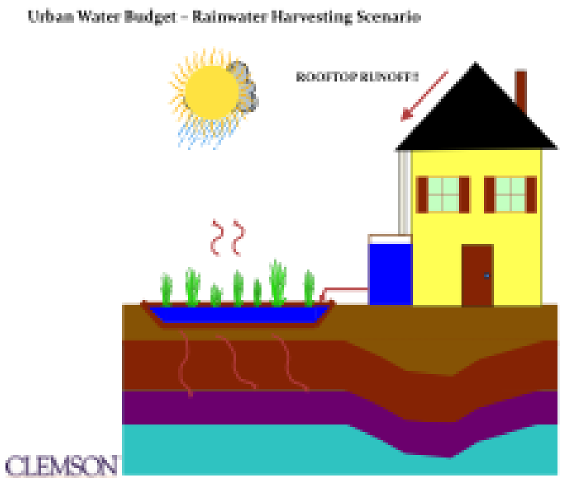
CONSERVATION



Development Impacts On the Water Cycle

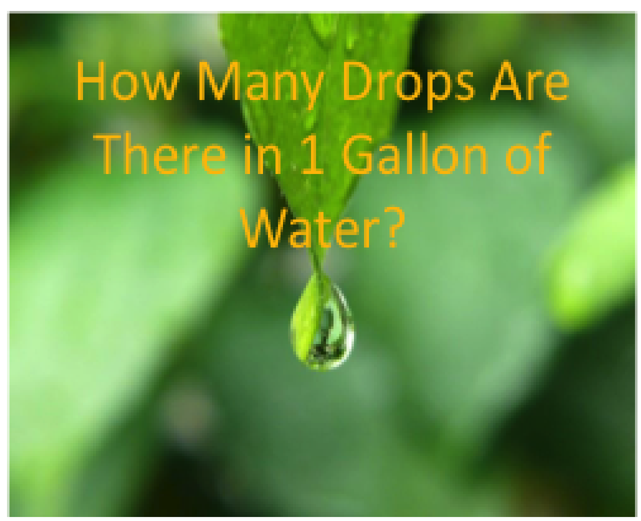


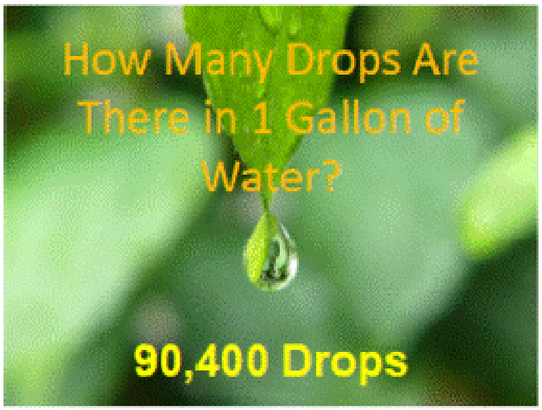



Urban Water Budget – Rainwater Harvesting Scenario
ROOFTOP RUNOFF!!
CLEMSON


Rainwater Harvesting


03/03/09 06:57 AM chipper


How Many Drops Are There in 1 Gallon of Water?



Youth Education on Rainwater Harvesting

Funding provided by the Texas Water Development Board

AgriLIFE EXTENSION

QUESTIONS?

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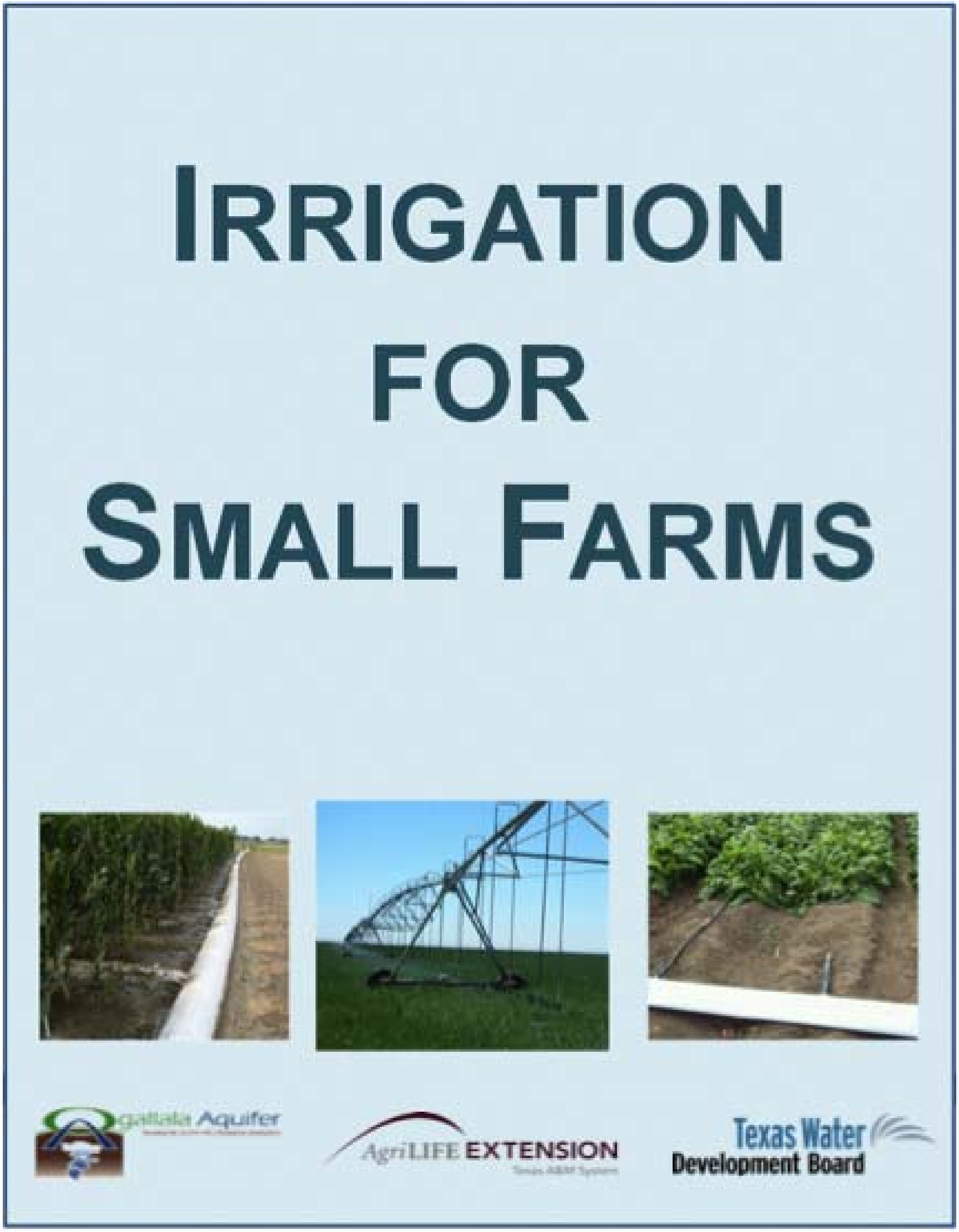
Appendix F

Irrigation for Small Farms Manual



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IRRIGATION FOR SMALL FARMS

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Contents

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1. INTRODUCTION

Water is often a limiting factor in crop production systems, where constraints may be primarily physical (water resource availability, capacity or quality); economic (costs of equipment and operation *vs*. economic benefit); or operational (management and labor capabilities). Where rainfall is insufficient to meet in-season crop water needs, irrigation is an important risk management tool, improving crop yields and quality.

Selection of irrigation technologies and management strategies involves considering suitability or adaptability of a technology or practice to a specific operation. This involves site-specific conditions (field shape and size, topography, soil conditions, crops grown, water source) and operational considerations (labor availability, management requirements, producer preferences).

Adoption of irrigation technologies and best management practices is supported through access to information and products. The irrigation industry offers a wide array of products and tools. Agricultural research programs have developed technology-specific and crop-specific recommendations for efficient irrigation management. There are many excellent educational and information resources available to support producers in irrigation decisions.

This manual provides an overview of crop water requirements, soil moisture management, irrigation water quality issues, and irrigation technologies. It also directs the reader to additional information resources that address specific subject matter in greater detail.

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2. IRRIGATION OPTIONS: TECHNOLOGIES AND METHODS

Introduction

Decisions of whether to invest in irrigation systems, which methods and technologies are applicable to a given operation; and how to manage these tools appropriately warrant careful consideration. The following overview of irrigation technologies and methods presents some more commonly used and commercially available options. Photos, images and mention of manufacturers or products are intended for information only, and not as an endorsement. All irrigation tools and technologies have advantages and disadvantages; most are not universally applicable, but warrant consideration of local (site, crop, soil, energy and water infrastructure, and other) conditions; labor and management capabilities; and cost/benefit factors.\\

Key Points:

1. Surface irrigation generally is less efficient than other irrigation methods, but careful system layout and management can improve irrigation efficiency and uniformity.
2. Sprinkler irrigation includes a range of technologies. High pressure systems require higher energy requirement and are often less efficient than low pressure systems. Portable systems require less capital investment, but more labor than permanent systems.
3. Low pressure center pivot irrigation systems include LEPA, LESA, MESA and LPIC irrigation. All of these can be very efficient with good management.
4. Microirrigation includes surface drip irrigation, subsurface drip irrigation and microspray irrigation. Microirrigation can deliver water very precisely to the target area

2.1. Surface Irrigation

Surface irrigation methods, including **level basin flooding** (figure 2.1) and **furrow irrigation** (figure 2.2) generally require the lowest capital investment, but can require significant manual labor for effective management. Surface irrigation generally is considered less efficient than other methods due to runoff, deep percolation, and evaporation losses. Practices and options that can improve surface irrigation include land leveling or land grading to improve the uniformity of application over the field; lining of irrigation ditches or use of pipelines to transmit water to the field to limit transmission losses; alternate furrow application to limit wetted surface area (and hence limit evaporation losses); use of berms to prevent runoff or use of tailwater reuse systems to catch and re-apply runoff water; use of shorter row length to reduce required set times and limit deep percolation losses; use of “cut-back” or surge irrigation strategies to limit runoff or deep percolation losses; and use of high volume ditch turn-outs to apply water more quickly and uniformly over the field. These practices are discussed in Rogers (1995) and Yonts (2007).

Figure 2.1. Flood irrigation can be conveyed to the field through irrigation district ditch networks (see far left image) or through underground pipelines. As the name infers, the field is flooded with overland flow, which is contained by borders or berms (see below).

Figure 2.2. Furrow irrigation is simple, portable and inexpensive. Labor requirement is high.

2.2. Sprinkler Irrigation

Sprinkler irrigation methods include a wide range of irrigation technologies and tools. They include fixed (solid set), portable, and self-propelled equipment. Some of the more widely used and commercially available options are described below in general terms.

Big gun, traveling gun and hose reel sprinkler systems (figure 2.3) often are used in pastures and turf (farms and sports fields), but they are readily applicable to a variety of crops, fields and operations. Big gun sprinklers use large capacity sprinkler heads and operate at high pressures (90 to 125 psi) to throw water over the field. The head is mounted on a wheeled cart and connected to a flexible or hard-hose wrapped on a trailer-mounted reel (Scherer, 2010). Before an irrigation set, the hose is extended; through the course of the irrigation set, the hose is retracted on the reel, pulling the applicator toward the reel. Many big gun systems have their own power units (or can work from another portable power source, such as a PTO from a tractor) and pumps; they are portable and applicable to irregularly shaped fields and over a range of field sizes. Operation of the big gun requires some hand labor for operation, and the high pressures and long "throw" of the water can make them less energy and water efficient than many other irrigation methods. Because big gun sprinklers use large nozzles, they are less susceptible to clogging than methods using smaller nozzles; hence they can be used to apply water with significant suspended solids (including wastewater) (Mukhtar, 2000). Because they can cover a large area with a single nozzle, they also are used for dust suppression (Mukhtar and Auvermann, 2009).

Figure 2.3. Traveling "big gun" hose reel system on an irrigated pasture.

Solid set and portable fixed-set sprinkler systems (figure 2.4) use sprinklers placed in a regular pattern over the irrigated area. All of the sprinklers may be operated at once, or the crop may be irrigated in zones (alternately irrigating groups of sprinklers connected with common laterals). Solid set sprinkler systems may be permanent, typical for applications in orchards, nurseries, horticultural crops, or lawn/landscape applications, or they may be placed for a season or for a partial season. Permanent systems are connected to permanent (buried) PVC pipelines; temporary systems may be connected to the water source by portable aluminum manifolds or permanent (buried) PVC manifolds (Smajstrla et al. 1997). With these systems, there can be a trade-off between investment cost and labor requirements. Permanent solid systems require design and more hardware (higher initial cost) but less labor than portable systems. Permanent systems also are used for frost protection and crop cooling for high value crops, such as orchards (Evans and Sneed, 1996).

Figure 2.4. Solid set sprinkler systems are often used for irrigating small fields. They may also be used for frost-control, dust suppression and other applications.

Side roll irrigation systems. Side roll (wheel line, wheel roll) systems (figure 2.5) are best suited to rectangular fields. These systems use moderate to high pressure (35-60 psi) impact sprinklers distributed along a 4-5 inch diameter lateral pipe that acts as an "axel" for the wheels. Wheels are available in a range of sizes, from 4 to 10 feet in diameter. Because the lateral line must be above the crop canopy, side-roll systems are not appropriate for tall crops. The lateral line is connected by flexible hose to hydrants located in the field. The lateral line is disconnected from the water source and drained between irrigation sets. Side roll systems are stationary during an irrigation set, but moving the system between irrigation sets is facilitated by a small gasoline or diesel power unit located in the center of the system, making it easier (requiring less labor) and faster to move than a hand-move system. They are less efficient and more labor intensive than center pivot or microirrigation systems. Operation and management of side roll system are addressed more thoroughly in Hill (2000) and Scherer (2010).

Figure 2.5. Side roll (wheel roll or wheel line) sprinkler irrigation.

Center pivot and linear move sprinkler irrigation systems (figures 2.7 and 2.8) are used widely throughout the High Plains, especially in the Texas High Plains where most of the systems are low pressure center pivot systems. Center pivot irrigation systems include a pipe lateral supported by motor-driven towers that travel around a center pivot point (figure 2.6.a). Water is delivered through nozzles placed along the length of the lateral (figure 2.9). Linear move systems operate very similarly, but travel in a straight line (figure 2.6.b), rather than in a circle. Small fields may be accommodated by using a limited number of lateral spans, but some irrigation manufacturers offer scaled-down mini-pivots specially suited to small farm applications (figures 2.10 and 2.11). It is worth noting that the per-acre capital investment tends to be higher for smaller farms. Still these systems are widely used, are easily automated, and require less labor than most other irrigation options. Ongoing improvements to center pivot and linear move sprinkler irrigation technologies continue to improve automation capabilities and expand applicability to a wider range of field layouts.

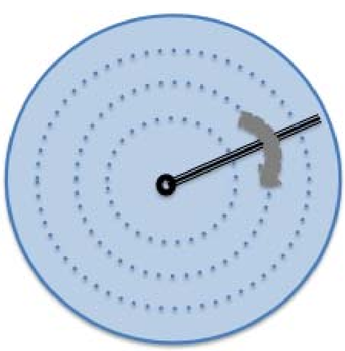

Figure 2.6.a. Center pivot systems move in a circular pattern. Water is supplied to the lateral at the pivot point.

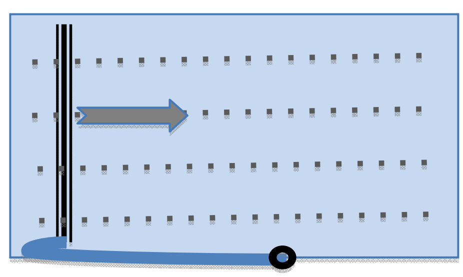

Figure 2.6.b. Linear move sprinkler systems move in a straight-line pattern. A flexible hose connects the lateral to the water source.

Figure 2.6. Travel of center pivot and linear move sprinkler irrigation systems. Arrows and dashed lines indicate travel patterns of wheeled towers.

Low pressure spray application options

Low pressure sprinkler systems are more efficient, requiring lower energy to operate and reducing evaporation losses compared to high pressure systems. Specific applications of low pressure center irrigation include Low Energy Precision Application (LEPA), Low Elevation Spray Application (LESA), Mid-Elevation Spray Application (MESA), and Low Pressure In-Canopy (LPIC).

Low Energy Precision Application or **LEPA** irrigation (figure 2.12) applies as much to a management package as the actual hardware. LEPA irrigation applies water directly to the soil surface through drag hoses (primarily) or through "bubbler" type applicators. By definition, LEPA also involves farming in a circular pattern under center pivot irrigation systems or straight rows under linear irrigation systems. It also includes use of furrow dikes and/or residue management to hold water in place until it can infiltrate into the soil. LEPA irrigation typically is applied to alternate furrows; reducing overall wetted surface area, and hence reducing evaporation losses after an irrigation application. Because a relatively large amount of water is applied to a relatively small surface area, there is risk of runoff losses from LEPA, especially on clay soils and/or sloping fields. Furrow dikes and circular planting patterns help reduce the runoff risk. While very high application efficiencies are achievable with the system, LEPA is not universally applicable; some slopes are too steep for effective application of LEPA irrigation. Some commercially available LEPA applicators are easily adaptable to LESA “spray” mode for chemigation applications or for other spray applications.

Low Elevation Spray Application (**LESA), Low Pressure In-Canopy (LPIC)** and **Mid-Elevation Spray Application** (**MESA)** (figures 2.13 and 2.14) describe similar irrigation application systems that include the LEPA technology but do not meet one or more of the criteria to be called LEPA. Strictly interpreted, LESA systems have spray applicators within 18 inches of the ground (USDA-NRCS, 2003), while MESA systems apply water from between five and ten feet above the ground. LPIC systems apply water at a height less than seven feet above ground and discharge water within the crop canopy for a considerable portion during the crop season. Low pressure LESA, LPIC, and MESA spray systems are considered somewhat less efficient than LEPA, primarily due to increased evaporation from a larger wetted soil surface area and potential for evaporation of spray droplets during application.

Properly managed, LEPA, LESA, LPIC and MESA can be very efficient. LEPA allows for alternate furrow irrigation, in which alternate dry "traffic" furrows are more accessible for timely field applications. By limiting field operation traffic to the dry furrows, infiltration capacity of soil in the "wet" irrigated furrows is preserved. LEPA also allows for irrigation without foliar wetting. For some crops this can offer reduced foliar disease risk. If water quality (salinity) is an issue, LEPA can reduce risk of salt damage to foliage. In very coarse soils, there sometimes may be insufficient lateral soil water movement from alternate furrow LEPA applications. This is mainly a concern for seed germination, shallow rooted crops and crops (such as peanuts) that require a moist zone near the soil surface. Spray irrigation (LESA, LPIC, MESA) wet the soil surface more uniformly than LEPA. Commonly available nozzles are easily exchanged between LEPA and spray modes, making it possible to apply LESA for crop germination/establishment, then convert to LEPA to take advantage of the higher irrigation application efficiency in season, and convert back to spray applications for chemigation or for uniform wetting of the shallow root zone as needed.

Figure 2.7. Self-propelled linear move sprinkler irrigation system equipped with both LEPA drag hoses and LESA spray nozzles for research conducted at the USDA-ARS Conservation and Production Laboratory at Bushland, TX.

Figure 2.8. Center pivot irrigation system with the crop planted in a circular row pattern parallel with the direction of travel of the irrigation system.

Figure 2.9. Center pivot sprinkler irrigation system equipped with mid-elevation spray applicator nozzles. *Photo by Justin Mechell.*

Figure 2.10. Scaled down two-span mini-pivot sprinkler irrigation system. *Photo by Justin Mechell.*

Figure 2.11. Four-span mini-pivot sprinkler.

Figure 2.12. LEPA irrigation applies water directly to the soil surface in alternate furrows. Crop residue (photo above) or furrow dikes (top left photo) are used to impound the water until it infiltrates into the soil, thus preventing runoff.

Figure 2.13. Mid-Elevation Spray Application (MESA) applies water above the crop canopy.

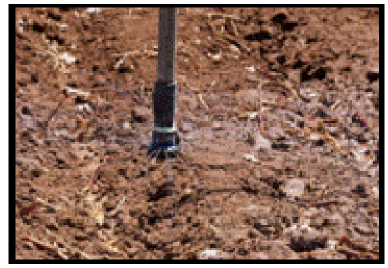

Figure 2.14. LESA irrigation applies water through low pressure sprinkler applicators within 18 inches of the soil surface. Large water droplet sizes and near surface application reduce evaporation losses.

2.3. Microirrigation (surface drip, subsurface drip and microspray irrigation)

Microirrigation systems are most often used for high value horticultural crops, nurseries, landscaping, vineyards and similar applications. Microirrigation is easily scalable for small acreages and specialty crops, and there is a wide range of products commercially available. Microirrigation systems typically work at relatively low pressures, so energy requirements are comparable to low pressure center pivot systems. Microirrigation can deliver water very precisely to the target area, and minimizes runoff and evaporation losses. They are easily automated, and they can consist of very simple designs and components (generally for temporary installations) or more elaborate systems for permanent and large-scale applications. Components of subsurface drip irrigation systems are discussed in Rogers et al (2003).

Surface Drip Irrigation (figure 2.15) can be used in permanent installations, as is often found in landscaping and vineyards. High quality materials are required to reduce risk of mechanical damage or ultraviolet light damage. Surface drip tape or very shallow subsurface drip tape (figure 2.16) frequently is covered by a mulch to reduce light exposure. Since precipitation of salts in the water is accelerated by high temperatures, mulching also helps reduce precipitate clogging of tape emitters. For temporary surface drip applications, less expensive materials (including thin wall tape products) are more often used.

Figure 2.15. Surface drip irrigation.

Subsurface Drip Irrigation

Subsurface drip irrigation (**SDI**) (figures 2.17 and 2.18) is gaining popularity in production of agronomic “row” crops, especially in areas of limited well capacities and/or small or irregularly shaped fields not well suited to center pivots. Initial cost of SDI is high, but a properly designed and maintained microirrigation system can last more than 20 years. A recommended maintenance program includes adequate filtration (figure 2.21) and maintenance (cleaning) of filters; flushing lines and manifolds; and injecting chemicals (chlorine and/or acid) as necessary to prevent emitter clogging. Specific maintenance requirements depend upon the irrigation system components and water quality; additional information on maintaining SDI systems is included in Enciso, et al. (2004) and Alam, et al. (2002). Frequently cited advantages of SDI include high efficiency and uniformity of water application; precise application of fertigation and chemigation; reduced labor requirement compared to other irrigation technologies; applicability to operations with large or small water capacities and over a range of field sizes, topographic and soil conditions; and ease of automation. Disadvantages include high initial cost; requirement of higher skill level for operation and management; potential problems with emitter clogging, root intrusion, rodent and insect damage to driplines; potential problems with germination of a crop; limited root zone and limited options for deep tillage and deep injection of chemicals that may be needed for pest and disease management.

Microspray or microbubbler irrigation uses a separate applicator, either inserted into the tape lateral or connected to the lateral with thin “spaghetti” tubing (Figure 2.20). Microspray irrigation is commonly used in greenhouses, nurseries, landscaping, and similar applications.

Figure 2.16. Shallow Subsurface Drip Irrigation under plastic mulch.

Figure 2.17. Excavation showing placement of Subsurface Drip Irrigation tape.


Figure 2.18. Shallow Subsurface Drip Irrigation under onions (left and below) and spinach (right).

Figure 2.19. Microirrigation on trellises in a vineyard.

Figure 2.20. Microspray or microbubblers are often used in landscaping and nursery applications.

 

Figure 2.21. Sand media filters (left); hydrocyclone and disk filters (right) remove particulate matter from water to reduce risk of tape or emitter plugging.

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3. CROP WATER REQUIREMENTS

Introduction

Effective water management provides sufficient moisture available to prevent drought stress in the crop, yet avoids over-watering that can negatively affect crop yield or quality. Some crops are more drought sensitive or drought tolerant than others. Specific irrigation guidelines are provided for some major crops grown in Texas; additional information resources are provided.

Key Points:

1. Crop water demand is determined by weather conditions, crop type and growth stage, and other local conditions.
2. Crop-specific irrigation recommendations address seasonal water demand, peak water demand, critical periods for drought stress, and water quality requirements.

3.1 How Plants Use Water

Plants need water for photosynthesis. They move water upward from the soil, through roots, xylem, leaf veins, leaf tissue, and eventually through the stomata (pores) on the leaves. This process is called *transpiration*. Water moves in response to water potential energy gradient. The energy level is higher in the water surrounding the roots and lower in the air space within the spongy parenchyma (porous tissue) of the leaf. *Evaporation* pulls water molecules away from the film of water coating air spaces within the leaf tissue, outward through the stomata into the atmosphere. Evaporation also results in cooling of the plant. *(In effect, the plant functions as its own built-in evaporative cooler.)*

Water molecules are bound to each other by hydrogen bonds. As water molecules evaporate from the air spaces in the leaf, water from surrounding cells and air spaces is pulled towards this area in response to the resulting suction. The suction is transmitted to water molecules lower in the plant. When water is moved from the soil into the plant, some dissolved nutrients and other elements are transported in the water (soil solution). This is how plants get nutrients from the soil. (It is also a pathway through which some harmful constituents, such as toxic elements or herbicides, enter the plant.)

During the day, plants photosynthesize using the solar energy, water, and carbon dioxide (CO_2) from the air to make oxygen and carbohydrate. Oxygen is released from plants' leaves through the stomata during the day. Plants also use some oxygen and release CO_2 into the air. This process is called respiration. When plants are stressed due to insufficient water availability or excessive evaporation, the guard cells around the stomata lose pressure and effectively restrict the stomatal opening, reducing transpiration water loss (and other gas exchange) through the stomata. A plant that is stressed generally will wilt. Reduced transpiration slows the process of water and nutrient uptake; reduced gas exchange slows photosynthesis. This, in turn of course reduces plant growth and crop yield.

3.2 Evapotranspiration

Evapotranspiration is a term that describes crop water demand by combining evaporation and transpiration components of crop water demand (figure 3.1). Evaporation is the process through which water is removed from moist soil and wet surfaces (such as dew on leaves). As previously stated, transpiration is the process through which water is drawn up through the plant. Evapotranspiration is affected by crop factors (crop type, growth stage, plant health) and environmental factors (air temperature, solar radiation, humidity, wind). Of course it is also limited to water that is made available to the plant (access to soil moisture in the root zone).

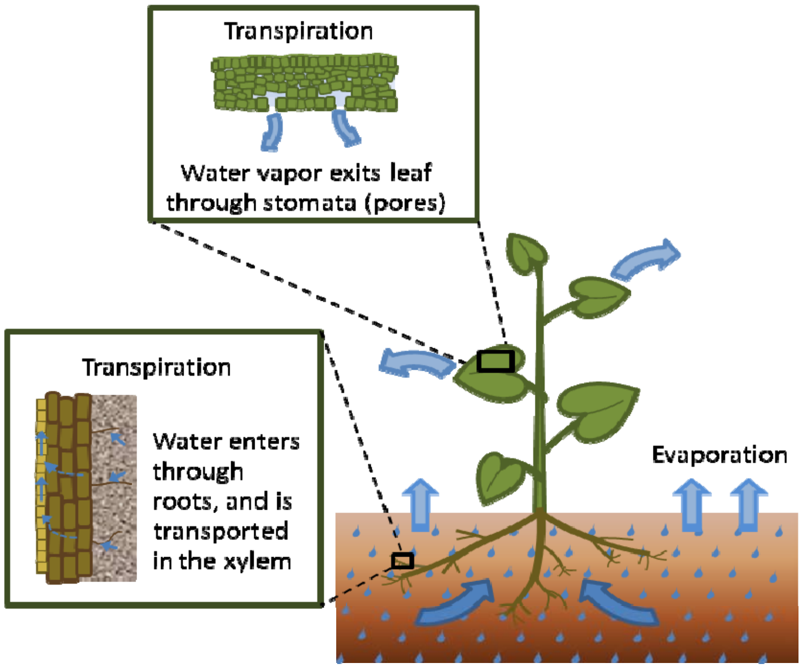

Figure 3.1. Evapotranspiration is crop water demand that encompasses evaporation from the soil and wet surfaces and transpiration of water through plants. (Graphic by Dana Porter)

Estimating Evapotranspiration (ET)

Reference crop evapotranspiration, ETo (formerly also referred to as Potential Evapotranspiration - PET), is an estimate of water requirement for a well watered reference crop. This reference crop (grass or alfalfa) is essentially an idealized crop used as a basis for the ET model. Reference ET is calculated by applying climate data (temperature, solar radiation, wind, humidity) in a model (equation). It is helpful to note that reference ET is only an estimate of the water demand for this idealized crop, based upon weather station data at a given location. ET Networks in Texas use an idealized grass reference crop.

How is Crop Evapotranspiration calculated?

Crop-specific ET is estimated by multiplying the Reference ET by a crop coefficient.

Crop ET = Reference ET x Crop Coefficient

The crop coefficient takes into account the crop's water use (at a given growth stage) compared with the reference crop. For instance, seedling corn does not use as much water as the idealized grass reference crop, but during silking the corn can use more water than the grass reference crop. The crop coefficient is understood to follow a pattern (curve) of the general shape shown below. Each crop (wheat, sorghum, etc.) has its own crop coefficient curve, based upon the crop's growth stage curve. Since crop development is often modeled as a function of number of days after planting or heat unit accumulation, crop coefficient curve models also use days after planting or heat unit accumulation to model growth stages for crop coefficient curves.

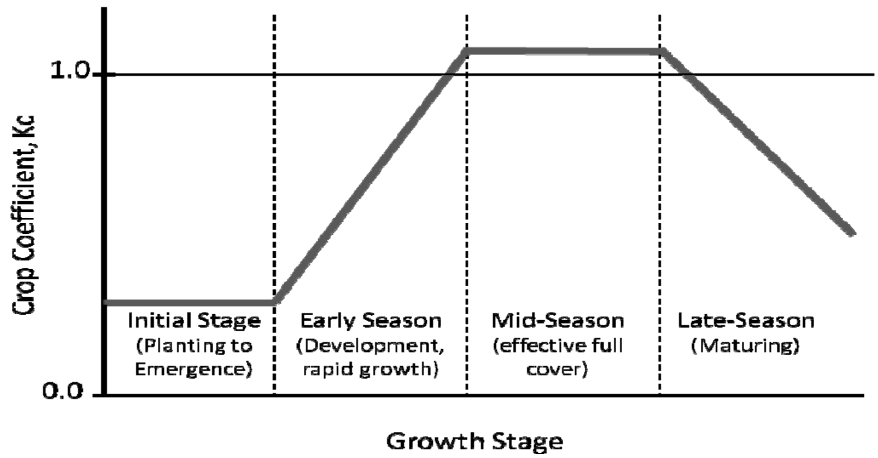

Figure 3.2. Generalized crop coefficient curve (after various sources, including Allen et al. 1998).

Reference crop ET model and the crop coefficient curves have been developed from long-term research at various locations. Actual crop water demand can be affected by many factors, including soil moisture available, health of the crop, and likely by plant populations and crop variety traits. These factors are not taken into account by the models. Hence, ET data provided by on-line networks are probably best used as guidelines for irrigation scheduling. The predicted growth stage and estimated water use should be verified with field observations. The actual crop water use likely will be less than the predicted value due to less than optimal field conditions.

How is estimated ET used to schedule irrigation?

There are a variety of irrigation scheduling methods, models and tools available. Many are essentially based upon a "checkbook" approach: water stored in the soil (in the crop's root zone) is withdrawn by evapotranspiration; water is deposited into the soil through precipitation and irrigation. When soil moisture storage falls below a desired threshold value, irrigation should be applied to restore the moisture. The threshold value may be determined by crop drought sensitivity, by irrigation system capabilities, or other farm-level criteria.

3.3 Irrigation Management for Selected Crops

Important considerations in managing irrigation are seasonal water requirement (how much total water does the crop need?); peak water demand (how much water is needed during the crop's highest water use period?); sensitivity to drought stress (or even waterlogging stress); critical growth stages during which the crop is most susceptible to drought stress; and water quality requirements (crop sensitivity to salinity or potentially toxic levels of salts or nutrients that may be in the water.) Much of this information is available in crop production guides available from Texas AgriLife Extension Service and from commodity organizations. Water management information for selected crops is summarized below. The reader is encouraged to consult with local crop production guides for more specific water management recommendations, as well as recommendations for nutrient management, Integrated Pest Management, variety selection, and other key production management decisions.

3.3.1 Irrigation Management for Corn Production

Corn is a relatively high water use and drought-sensitive crop. Seasonal water use for corn in the Texas High Plains is approximately 28 to 36 inches per season. Peak water use begins a few days before tasseling (concurrent with maximum leaf area index); water demand begins to decline about midway through the grain-fill period (dent stage). The most critical period during which water stress will have the greatest effect on yield corresponds with the maximum water demand period, approximately two weeks before and after silking. The general trend of crop water demand during the season is shown in Figure 3.3

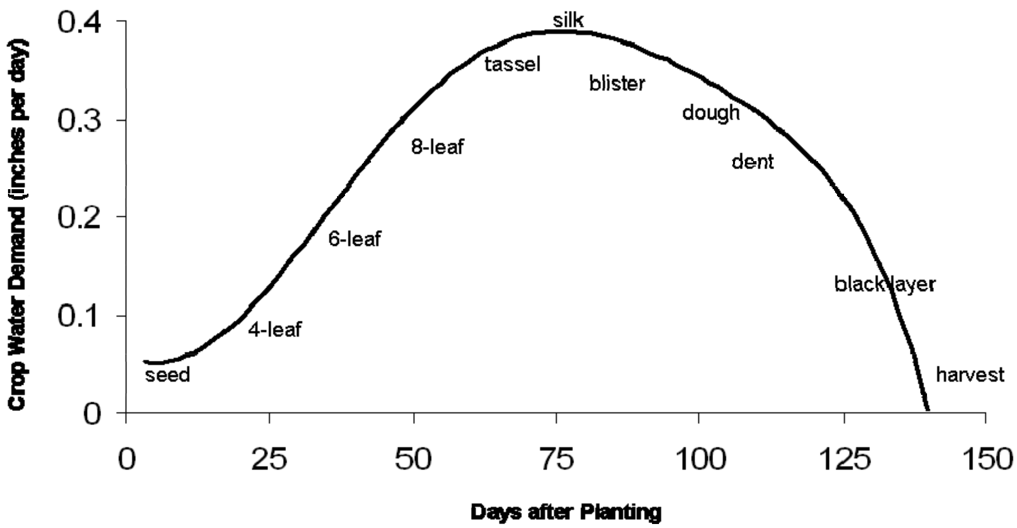

Figure 3.3. Approximate corn water demand in the Texas High Plains (Porter et al. 2005).

The **root zone** depth of corn typically ranges from 2.6 to 5.6 ft, depending upon soil conditions. Roots are generally developed early in the season, and will grow in moist (but not saturated or extremely dry) soil. Like most crops, corn will extract most (70% - 85%) of its water requirement from the top one to two feet of soil, and almost all of its water from the top 3 feet of soil, if water is available. Deep soil moisture is beneficial primarily when the shallow moisture is depleted in high water demand periods.

Irrigation capacity to meet peak water demand. Because corn is a drought sensitive crop, irrigation system capacity and soil moisture storage capacity should be considered - especially where rainfall is very limited - in planting and rotation decisions. Drought-stressed corn is more susceptible to some pest infestations (including spider mites) and quality (including aflatoxin) issues. Peak water demand for corn can exceed 0.35 inches per day (6.4 gallons per minute/acre) in some areas of the state. Because soil moisture storage (3 to 6 inches of water in the top 3 ft. of soil) can help meet water requirements during the high demand period, irrigation capacities of 5 to 6 gpm/acre are generally adequate for corn production, provided highly efficient irrigation equipment and management are used. Of course timely rainfall reduces drought stress risk and irrigation requirements.

Irrigation water quality: salinity. Corn is moderately sensitive to salinity in soil and irrigation water. Grain yield is adversely affected by irrigation water salinity above 1.1 dS/m electrical conductivity (EC), or soil salinity above 1.7 dS/m EC. A 50% yield reduction is expected with irrigation water EC of 3.9 dS/m. Corn is also moderately sensitive to foliar injury from sodium (tolerance between 230 and 460 ppm) and chloride (tolerance between 350 and 700 ppm) in irrigation water. Spray irrigation applications present a higher risk of foliar damage from marginal quality waters. Periodic excess applications of water (irrigation and/or precipitation) can facilitate leaching of accumulated salts from the root zone.

3.3.2 Irrigation Management for Cotton Production (*after: Sansone, et al. 2002.)*

Cotton is a relatively drought-tolerant and salt-tolerant crop that responds well to irrigation. Cotton can be produced over a range of irrigation levels, from rain-fed (dryland) to full irrigation. Often it is grown under a managed deficit irrigation strategy, wherein an irrigation level targeting less than full irrigation is applied. Cotton water use efficiency is generally higher under managed deficit irrigation than under full irrigation; however excessive water deficit or drought stress at critical growth stages can have a considerable negative impact on yield potential for the crop.

Seasonal water use for cotton in the Texas High Plains ranges from approximately 13 inches (dryland) to 27 inches (fully irrigated) per season, with seasonal crop ET demand of 24 to 28 inches. Deficit irrigation management (water applied less than full crop demand) is common practice, often due to limited irrigation water capacities. Peak water use occurs during flowering and boll development (figure 2.4). The most critical period during which water stress will have the greatest effect on yield is early in the season when drought stress can cause square shedding. Excessive irrigation with excess available nitrogen can support excessive vegetative growth, necessitating use of plant growth regulators. In the High Plains (where the crop season is limited in length), over-irrigation late in the season also has been associated with lower lint quality, due to higher numbers of immature “green” bolls at harvest.

Pre-Plant, Planting and Stand Establishment. Roots grow in moist soil (not in saturated or dry soil); hence good moisture conditions in the root zone are key to establishment of a good root system early in the season. An extensive root system improves the crop’s access to moisture and nutrients from a larger area of the soil profile. In West Texas, fields are often pre-irrigated because of limited rainfall in the winter and spring. The timing of pre-season irrigation depends on water availability, soil texture, irrigation system capacity and soil drainage. The amount of water applied depends on rooting depth, available moisture-holding capacity and current soil moisture. Because deep percolation and evaporation losses of pre-season applied irrigation can be high, it is recommended that pre-season irrigation be applied just prior to planting.

Emergence to First Bloom. From crop emergence to first bloom growth stage, water use increases from less than 1 inch per week at emergence to approximately 2 inches per week at first bloom. The goal is to avoid water stress early in the season and to have a full soil water profile as the plant reaches peak bloom (usually 3 weeks after first bloom).

First Bloom to First Open Boll. Water use increases dramatically from first bloom to open boll stages. Estimated crop evapotranspiration can be as high 0.4 inches per day or 2.8 inches per week, generally only for brief periods, depending upon local weather conditions. Soil moisture storage capacity and soil moisture management should be considered to offset temporary irrigation system capacity shortfalls. Once blooming starts, cotton responds better to frequent, low-volume applications of water than to large, less frequent amounts. This strategy also minimizes water stress between rain or irrigation events and increases fruit retention.

In West Texas, very few producers have the irrigation capacity to satisfy crop demands (0.3 to 0.4 inches per day). Highly efficient advanced irrigation technologies, including low pressure center pivot irrigation (LEPA-low energy precision application and LESA- low elevation spray application) and subsurface drip irrigation have proven to be excellent tools in these water-limited production systems. Research indicates that cotton responds very well to high-frequency deficit irrigations, even with amounts as low as 0.20 to 0.25 inch applied every 2 days. When irrigation capacities are above 0.2 inch per day, the frequency of irrigation is less critical.

First Open Boll to Harvest. At peak bloom, cotton requires about 0.3 inch of water per day. By harvest, the rate will drop considerably, to less than 0.1 inch per day. Ideally dryland fields will have a full profile of moisture at the third week of bloom, followed by timely rain showers. Late applications of excessive water can lead to many problems, including boll rot, late season re-growth, increase in late-season insect pests, added harvest aid input requirements and possible grade reductions from late-season re-growth. In West Texas, furrow irrigation should be terminated before September 1. Sprinkler or drip irrigation should be continued for 1 to 2 weeks after open boll or until 20 percent of the bolls are open. The goal is to provide adequate moisture for the last harvestable bolls to mature.

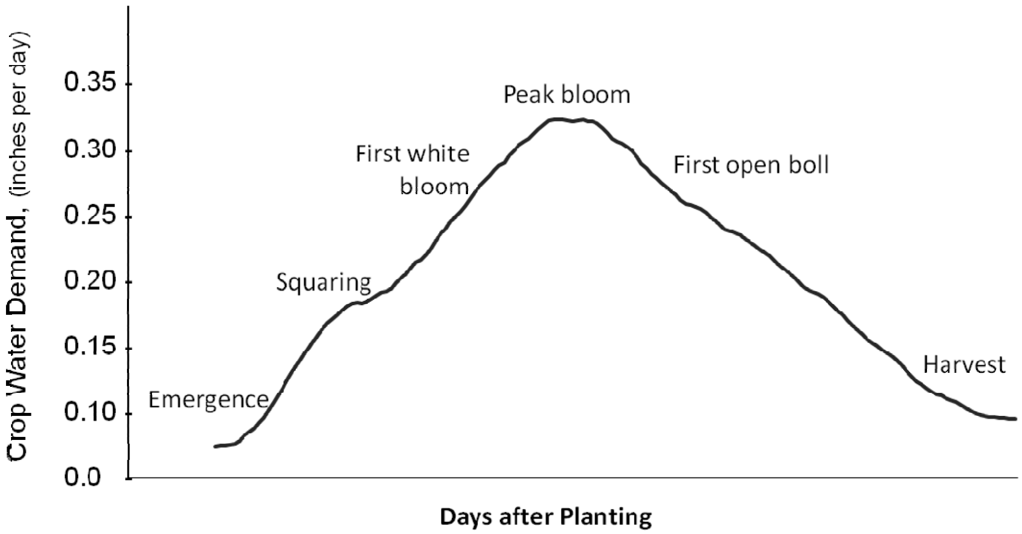

Figure 3.4. Approximate cotton water demand in the Texas High Plains. (Source: Texas High Plains ET Network.)

3.3.3 Irrigation Management for Sorghum Production

Sorghum is a relatively drought-tolerant crop that can be produced over a range of irrigation levels, from rain-fed (dryland) to deficit to full irrigation. It is often a feed grain of choice where irrigation capacity is limited. Seasonal water use for sorghum in the Texas High Plains is approximately 13 (dryland) to 28+ (fully irrigated) inches per season. Deficit irrigation management (water available is less than crop demand) is common practice, often due to limited irrigation water capacities. Peak water use occurs just before and during boot stage (figure 2.5).

Grain sorghum is a tropically adapted plant that can survive under drought and adverse conditions. Because of its ability to survive in unfavorable conditions, sorghum is often produced in poor soils and less intense management. However, profitable sorghum production requires sufficient water at critical points in the crop's development. Good crop management, including good irrigation management, is key to high yields and profitability.

Sorghum can produce an extensive fibrous root system as deep as 5-6 feet, but it generally extracts more than 75 percent of its water and nutrients from the top 3 feet of soil. As moisture is depleted from the top 3 feet, the crop will extract water (if available) from deeper in the root zone. Plants can use about 50 percent of the total available water (50% Management Allowable Depletion) without undergoing stress.

Water availability is most critical during the rapid growth stage and before the reproductive stage (figure 3.5). If plant maturity is delayed due to water stress, the crop may face frost damage in the event of an early freeze. Late-season water stress during grain filling can result in shriveled seeds, which reduces yield.

Grain sorghum's peak use begins at approximately initiation of the reproductive stage; this peak can be 0.3 inches per day (or temporarily higher in hot, dry weather conditions). Seasonal water demand for grain sorghum is 24-28 inches (from rainfall, stored soil moisture and irrigation). Grain sorghum has an extensive root system, and its drought tolerance makes it suitable for limited (deficit) irrigation.

Irrigation of grain sorghum on sandy soils requires more frequent and smaller irrigation applications than on soils with higher water holding capacity. Center pivot irrigation is an excellent option for irrigating in these conditions. Irrigation scheduling using evapotranspiration or by maintaining a given soil water depletion balance may be especially useful where soils with low water holding capacity and/or restricted root zones present challenges to irrigation management.

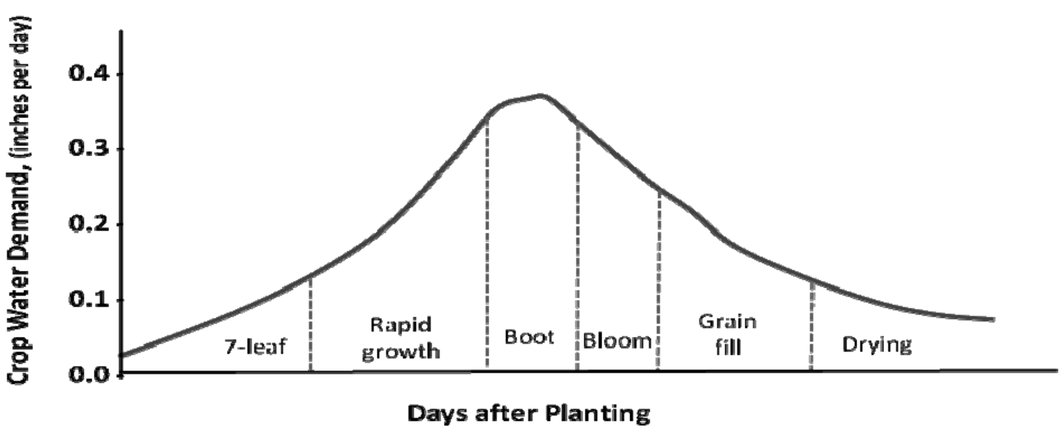

Figure 3.5. Approximate sorghum water demand in West Texas (after Warrick et al. 2002).

3.3.4 Irrigation Management for Hay and Forage Production

Forage crops include cool-season annuals (wheat, oats); warm-season annuals (corn, sorghum and hay grazers); and perennials (alfalfa and grass pastures). Irrigated pasture can be an important source of forage for beef cattle, sheep, horses and dairies.

Alfalfa

Alfalfa is well adapted to arid regions, but it requires more water for profitable production than most agricultural crops. Alfalfa can develop a very deep root system. It can tolerate periods of drought stress, but this stress will result in yield loss. Soil moisture monitoring and management to maintain at least 50% plant available soil moisture (50% MAD, addressed in Section 3.1) is recommended to minimize drought stress related yield and quality losses. Alfalfa can tolerate some salinity, but poor quality irrigation water will result in yield loss. Especially under deficit irrigation management, salt accumulation in the soil can be a concern. With efficient irrigation methods and management, alfalfa requires 5-7 acre-inches of water per ton of alfalfa produced. Peak water use can be 0.35" per day (and occasionally as high as 0.5"/day or more in hot, dry weather conditions) in the High Plains. Because of its high water use rate (approximate crop water use of 39 inches per year was measured by Evett, et al. 1998), it is often assumed that alfalfa yield is linearly related to water use: more water (from rainfall, stored soil moisture and irrigation) results in higher yield.

Irrigation scheduling in alfalfa (or other hay) production is complicated by the harvest schedule (typically about once per month). With the exception of subsurface drip irrigated fields, irrigation after each harvest must be delayed until after the hay bales are removed from the fields. (Some drying time may be required between swathing and baling; then the bales are removed.) Also, the soil should be dry before the next harvest. Hence irrigation timing in alfalfa often is determined more by harvest schedule than by soil moisture depletion (Hanson, et al, 2008).

Figure 3.6. Center pivot LESA irrigation on alfalfa. (photo by Dana Porter)

Annual and Perennial Grasses

Warm season annual grasses (such as Sudangrass) and perennial grasses (such as Bermudagrass) require adequate soil moisture for stand establishment. In arid or semi-arid areas, irrigation can increase yield and quality of hay or increase the stocking rate that can be supported on grazed pasture. Nutrient management is essential to high water use efficiency (yield response per water input), as adequate nitrogen fertility is necessary for the crop to fully utilize water to develop biomass.

3.3.5 Irrigation Management for Horticultural Crops

Vegetable production generally requires irrigation to ensure timely availability of water to support the plant, especially during critical growth stages, necessary for yield and quality. Where irrigation water is limited, planting should take into account the area (acreage) of the crop that can be adequately irrigated during peak water use times and during critical growth stages. Because many horticultural crops are sensitive to salinity in the soil and irrigation water, water quality merits special consideration. Irrigation water requirements and salinity tolerance information for many horticultural crops are summarized in Table 3.1. Additional crop-specific information is available from the Texas AgriLife Extension Service Aggie Horticulture website (http://aggie-horticulture.tamu.edu/); crop production guides for many small acreage and horticultural crops are available at: http://aggie-horticulture.tamu.edu/smallacreage/crops/, and http://aggie-horticulture.tamu.edu/commercial/veg_fruit_nut.html.

Table 3.1 Approximate seasonal water requirements, critical drought stress stages and relative salinity tolerance for selected vegetable crops.

	Water Requirement, Inches	Critical Stages for Drought Stress	Salinity Tolerance or Sensitivity
Asparagus	10 - 18	Plant development (bush) following harvest	Tolerant
Bean Green Pinto	 10 - 15 15 - 20	 Bloom and pod set Bloom and pod set	Sensitive
Beet, table	10 - 15	Establishment and early growth	Moderately Tolerant
Broccoli	20 - 25	Transplant and flower bud initiation, heading	Moderately Sensitive
Cabbage	20 - 25	Head development	Moderately Sensitive
Cantaloupe	15 - 20	Vining, pollination and fruit enlargement	Moderately Tolerant
Carrot		Root enlargement	Sensitive
Cauliflower	20 - 25	Transplant and curd development	Moderately Sensitive
Cowpea	10 - 20	Bloom, fruit set, pod development	Moderately Sensitive
Cucumber Pickling Slicing	 15 – 20 20 - 25	Fruit enlargement period	Moderately Sensitive
Eggplant	20 - 35	Flowering and fruit development	Moderately Sensitive
Lettuce	8 - 12	Establishment and head development	Moderately Sensitive
Onion	25 - 30	Bulb enlargement	Sensitive
Pepper	25 - 35	Vegetable growth (planting to fruit set)	Moderately Sensitive
Potato	20 - 40	Tuber set and tuber enlargement	Moderately Sensitive
Pumpkin	25 - 30	Establishment; 2-4 weeks after emergence; bloom-fruit set-fruit enlargement	Moderately Sensitive
Radish	5 - 6	Rapid growth and development; root enlargement	Moderately Sensitive
Spinach	10 -15	Throughout growing season	Moderately Sensitive
Squash Scallop Zucchini	15 - 20	Uniform throughout growth	Moderately Sensitive Moderately Tolerant
Sweet corn	20 - 35	Silking and tasseling, ear development	Moderately Sensitive
Tomato	20 - 25	Early flowering, fruit set and enlargement	Moderately Sensitive
Turnip	10 - 15	Root enlargement	Moderately Sensitive
Watermelon	10 - 15	Uniform until 10 - 14 days prior to harvest	Moderately Sensitive

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4. SOIL MOISTURE MANAGEMENT

Introduction

Soil moisture management is key to optimizing crop production. Plants extract water and nutrients from the soil through roots. A healthy and extensive root system affords the plant greater access to water and nutrients. Roots grow in moist soil; they can be limited by excessively wet or dry soil conditions. The goal of soil moisture management is to provide sufficient available water to prevent drought stress, yet avoid over-watering and hence promote high water use efficiency, crop yield and quality.

Key Points:

1. Soil permeability is affected by soil texture, structure, and moisture.
2. Plant available water in the root zone is that which can be stored in the soil between field capacity and permanent wilting point. Plant available water is soil-specific.
3. Water in soil is subjected to gravity, osmotic potential (suction), and matric (or capillary) potential (suction).
4. There are several methods available for measuring or estimating soil moisture. These include gravimetric (oven dry), soil feel and appearance, resistance (gypsum blocks or WaterMark™ sensors), tensiometry, capacitance, and other methods. Factors affecting selection of soil moisture monitoring method include costs, convenience, ease of use, precision and accuracy required, and personal preference of the operator.

4.1 Soil moisture storage capacity

Soil moisture characteristics: A soil's capacity for storing moisture is affected by soil structure and organic matter content, but it is determined primarily by soil texture. Figure 4.1 illustrates plant available soil moisture storage capacities by soil texture.

Field capacity is the soil water content after soil has been thoroughly wetted when the drainage rate due to gravity becomes negligible - when all the *gravitational water* has drained. Field capacity normally is attained 2-3 days after irrigation and is reached when the soil water tension is approximately 0.3 bars (30 kPa or 4.35 psi) in clay or loam soils, or 0.1 bar in sandy soils.

Permanent wilting point is the water content below which plants cannot readily obtain water and permanently wilt. This parameter may vary with plant species and soil type but generally is assumed to occur at a soil water tension of 10-20 bars. *Hygroscopic water* is held tightly on the soil particles (below permanent wilting point) and cannot be extracted by plant roots.

Plant available water is retained in the soil between field capacity and the permanent wilting point. It is often expressed as a volumetric percentage or in inches of water per foot of soil depth. Approximate plant available water storage capacities for various soil textures are illustrated in Figure 4.1.

Management Allowable Depletion is a management concept that represents a fraction of soil water depletion that will trigger an irrigation application before significant drought stress occurs. For many crops, 50% plant available water depletion (50% MAD) is recommended; for drought sensitive crops, the value will be less than 50% of the soil's plant available water holding capacity.

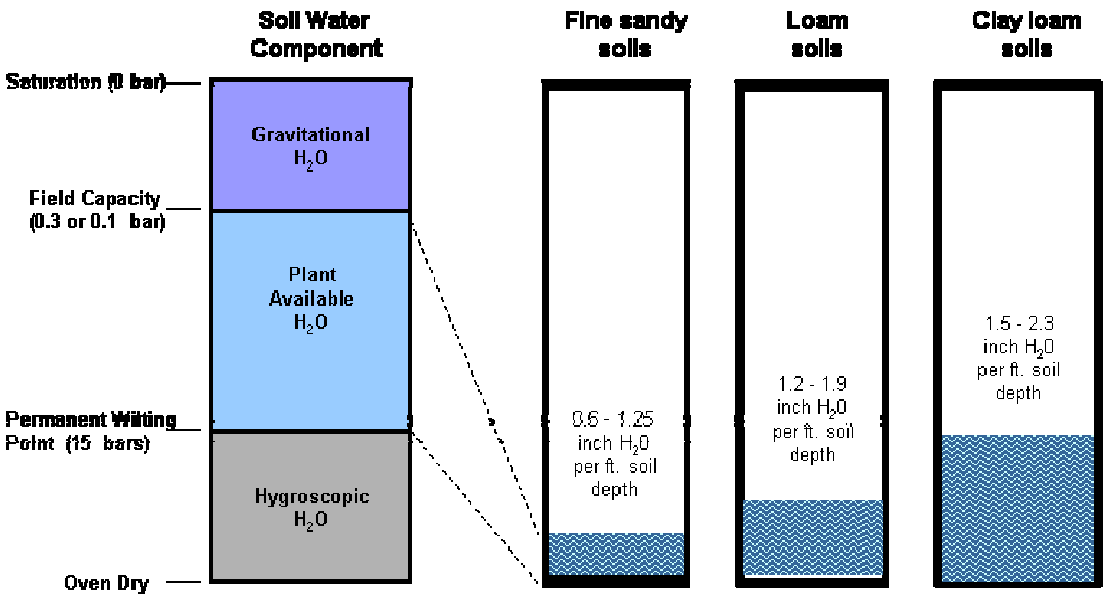

Figure 4.1 Available water storage by soil type. (Graphic by Dana Porter)

If the goal is to apply water to moisten the root zone to some target level (75% field capacity, for instance, depending upon local factors), it is essential to know how much water the soil will hold at field capacity, and how much water is already in the soil. Estimating soil moisture can be accomplished through direct methods (gravimetric soil moisture determination) or indirect methods. Soil moisture monitoring instruments, including gypsum blocks, tensiometers, and other sensors and tools commercially available provide the means to estimate soil moisture quickly and easily. Alternately, a soil's moisture condition can be assessed by observing its feel and appearance. A soil probe, auger, or spade may be used to extract a small soil sample within each foot of root zone depth. The sample is manually gently squeezed to determine whether the soil will form a ball or cast, and whether it leaves a film of water and/or soil in the hand. Pressing a portion of the sample between the thumb and forefinger allows one to observe whether the soil will form a ribbon. Results of the sample are compared with the guidelines summarized in Table 4.1.

Table 4.1. How soil feels and looks at various soil moisture levels

Soil moisture level	**Fine sand, loamy fine sand**	**Sandy loam, fine sandy loam**	**Sandy clay loam, loam, silt loam**	**Clay loam, clay, silty clay loam**
0 - 25% available soil moisture	Appears dry; will not retain shape when disturbed or squeezed in hand.	Appears dry; may make a cast when squeezed in hand but seldom holds together.	Appears dry. Aggregates crumble with applied pressure.	Appears dry. Soil aggregates separate easily, but clods are hard to crumble with applied pressure.
25 - 50% available soil moisture	Slightly moist appearance. Soil may stick together in very weak cast or ball.	Slightly moist. Soil forms weak ball or cast under pressure. Slight staining on finger.	Slightly moist. Forms a weak ball with rough surface. No water staining on fingers.	Slightly moist; forms weak ball when squeezed, but no water stains. Clods break with applied pressure.
50 - 75% available soil moisture	Appears and feels moist. Darkened color. May form weak cast or ball. Leaves wet outline or slight smear on hand.	Appears and feels moist. Color is dark. Forms cast or ball with finger marks. Will leave a smear or stain and leaves wet outline on hand.	Appears and feels moist and pliable. Color is dark. Forms ball and ribbons when squeezed.	Appears moist. Forms smooth ball with defined finger marks; ribbons when squeezed between thumb and forefinger.
75 - 100% available soil moisture	Appears and feels wet. Color is dark. May form weak cast or ball. Leaves wet outline or smear on hand.	Appears and feels wet. Color is dark. Forms cast or ball. Will smear or stain and leaves wet outline on hand; will make weak ribbon.	Appears and feels wet. Color is dark. Forms ball and ribbons when squeezed. Stains and smears. Leaves wet outline on hand.	Appears and feels wet; may feel sticky. Ribbons easily; smears and leaves wet outline on hand. Forms good ball.
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Root zone depth: Roots generally are developed early in the season, and will grow in moist (not saturated or extremely dry) soil. Soil compaction, caliche (calcium carbonate) layers, perched water tables, and other impeding conditions limit the effective rooting depth. **Most crops will extract most (70% - 85%) of their water requirement from the top one to two feet of soil, and almost all of their water from the top 3 feet of soil, if water is available**. Deep soil moisture is beneficial primarily when the shallow moisture is depleted to a water stress level. Commonly reported effective root zone depths by crop are listed in Table 4.2.

Permeability is the ability of the soil to take in water through infiltration. A soil with low permeability cannot take in water as fast as a soil with high permeability; permeability therefore affects the risk for runoff loss of applied water. Permeability is affected by soil texture, structure, and surface condition. Generally speaking, fine textured soils (clays, clay loams) have lower permeability than coarse soils (sand). Surface sealing, compaction, and poor structure (particularly at or near the surface) limit permeability.

Table 4.2. Root zone depths reported for various crops.*

Crop	Approximate Effective Rooting Depth (feet)
Alfalfa	3.3 – 6.6+
Beans	~ 2.5
Corn	2.6 – 5.6
Cotton	2.6 – 5.6
Peanut	1.6 – 3.3
Sorghum	3.3 – 6.6
Soybeans	3 – 4
Wheat	3 – 6+
Perennial pasture/turf	~ 1-2.5
Orchards	~ 6
Vegetable crops	1 - 3
Root crops (potato, beets)	~ 2-3
Grapes	~ 3+

** Active root zone depths, compiled from various sources. These values represent the majority of feeder roots. Actual root depth will be affected by local soil conditions (texture, structure, moisture).*

4.2 Using soil moisture information to improve irrigation efficiency

Deep percolation losses are often overlooked, but they can be significant. Water applied in excess of the soil's moisture storage capacity can drain below the crop's effective root zone. In some cases, periodic deep leaching is desirable to remove accumulated salts from the root zone. In most cases, however, deep percolation losses can have a significant negative impact on overall water use efficiency - even under otherwise efficient irrigation practices such as low energy precision application (LEPA) and subsurface drip (SDI) irrigation. Furrow irrigation poses risk of increased deep percolation losses at upper and lower ends of excessively long runs. Surge irrigation can improve irrigation distribution uniformity, and hence reduce deep percolation losses. Coarse soils are particularly vulnerable to deep percolation losses due to their low water holding capacity. Other soils may exhibit preferential flow deep percolation along cracks and in other channels formed under various soil structural and wetting pattern scenarios.

Runoff losses occur when water application rate (from irrigation or rainfall) exceeds soil permeability. Sloping fields with low permeability soils are at greatest risk for runoff losses. Vegetative cover, surface conditioning (including furrow dikes), and grade management (land leveling, contouring, or terracing) can reduce runoff losses. Irrigation equipment selection (nozzle packages) and management can also help to minimize runoff losses.

4.3 Soil moisture measurement

Methods used to measure soil water are classified as *direct* and *indirect*. The direct method refers to the gravimetric method in which a soil sample is collected, weighed, oven-dried and weighed again to determine the sample's water content on a mass percent basis. The gravimetric method is the standard against which the indirect methods are calibrated. Some commonly used indirect methods include electrical resistance, capacitance and tensiometry.

Electrical resistance methods include gypsum blocks or granular matrix sensors (more durable and more expensive than gypsum blocks) that are used to measure electrical resistance in a porous medium. Electrical resistance increases as soil moisture decreases. Sensors are placed in the soil root zone, and a meter is connected to lead wires extending above the ground surface for each reading. For most on-farm applications, small portable handheld meters are used; automated readings and controls may be achieved through use of dataloggers.

Capacitance sensors measure changes in the *dielectric constant* of the soil with a capacitor, which consists of two plates of a conductor material separated by a short distance (less than 3⁄8 of an inch). A voltage is applied at one extreme of the plate, and the material that is between the two plates stores some voltage. A meter reads the voltage conducted between the plates. If the plates are separated only by air, the capacitor measures 1 (the dielectric constant of air). Most solid soil components (soil particles), have a dielectric constant between 2 and 4. Water has a much higher dielectric constant of 78. Hence, higher water contents in a capacitance sensor are indicated by higher measured dielectric constants. Changes in the dielectric constant provide an indication of soil water content. Sensors are often left in place in the root zone, and they can be connected to a datalogger for monitoring over time.

Tensiometers measure tension of water in the soil (soil suction). A tensiometer consists of a sealed water-filled tube equipped with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. As the soil dries, soil water tension (suction) increases; in response to this increased suction, water is moved from the tensiometer through the porous ceramic tip, creating a vacuum in the sealed tensiometer tube. Water can also move from the soil into the tensiometer during or following irrigation. Most tensiometers have a vacuum gauge graduated from 0 to 100 (centibars, cb, or kilopascals, kPa). A reading of 0 indicates a saturated soil. As the soil dries, the reading on the gauge increases. The useful limit of the tensiometer is about 80 cb. Above this tension, air enters through the ceramic cup and causes the instrument to lose suction. Therefore, these instruments are most useful in sandy soils and with drought-sensitive crops because they have a relatively narrow soil moisture range.

Soil water monitoring methods have advantages and limitations. They vary in cost, accuracy, ease of use, and applicability to local conditions (soils, moisture ranges, etc.) Most require calibration for accurate moisture measurement. Proficiency of use and in interpreting information results from practice and experience under given field conditions.

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5. Water Sources and Water Quality

Introduction

Primary sources of irrigation water include surface water and groundwater. Each water resource has its own water quality concerns, and recommendations to protect water quality depend upon the nature of the water resource and upon the potential sources and pathways of contamination. The water used for irrigation is a potential source of salts and pathogens that can affect or contaminate a crop.

Municipal water, wastewater and harvested rainwater are considered alternative water sources for irrigation. Municipal water irrigation use is generally limited to landscaping, turf, and horticultural (nurseries, greenhouses, gardening) applications. Because it is treated to drinking water standards, municipal water poses very little risk as a source of contamination, but special care is necessary to avoid potential contamination of the source through backflow. Harvested rainwater is essentially surface water, so water quality concerns are the same as for other surface water sources. Special precautions are necessary in using wastewater sources due to higher water quality concerns.

Key Points:

1. Irrigation water sources include surface water, groundwater and alternative water sources. Water quality considerations depend upon the source and local factors.
2. Water quality considerations for irrigation include protection of water quality, managing salinity, and special concerns to avoid contamination of crops.

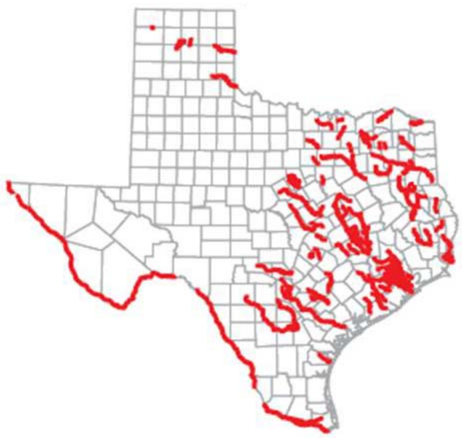
5.1 Water Sources

5.1.1 Surface water

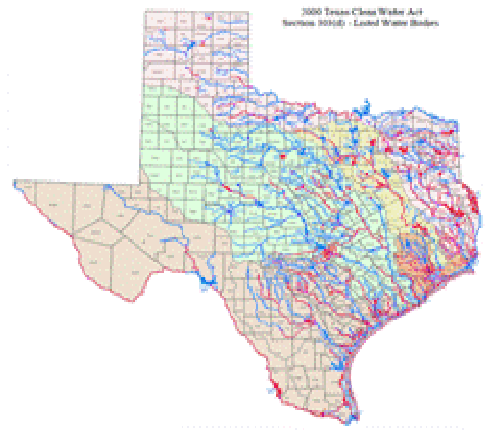
Surface water is the primary source of irrigation water in the United States. It is also the most likely source of water to be contaminated. The leading cause of pollution in surface water is storm water runoff. Storm water runoff from agricultural and urban landscapes can transport nutrients, sediments, pathogens, pesticides and other dissolved and suspended materials to surface water.

A good first step in determining the risk of contamination is to look at the site as a whole and consider all activity in the watershed. A watershed is defined as the land area contributing surface runoff and pollutants to a given point on a stream (ASABE, 2007). Observing activities and land uses in the watershed and how water flows within the watershed can indicate potential contamination sources and risks. To reduce contamination of surface water, land managers can adopt best management practices (BMPs) to control runoff and reduce pollution. Examples of BMPs to protect surface water quality include 1) using terraces and/or filter strips to reduce runoff and remove sediment from runoff water; 2) providing off-stream water and keeping livestock out of streams to reduce sediment, nutrient and potential pathogen load in the stream; and 3) storing, applying and disposing of fuels, agricultural chemicals, and wastes properly.

Runoff management is even more critical where activities are concentrated, such as in concentrated animal feeding operations (CAFOs), construction/development sites, areas with large populations of wildlife. Poor management practices can have detrimental effects on quality of surface water and groundwater. Figure 5.1 shows Texas surface water resources affected by bacterial contamination or other impairments.



a.



b.

Figure 5.1. a. Bacterial contamination in Texas water bodies, and b. impaired water bodies listed according to Clean Water Act Section 303d. (Source: Texas Commission on Environmental Quality, http://www.tceq.texas.gov/assets/public/gis/docs/303d.pdf)

Sampling and analysis of water for all potential contaminants can be very expensive and generally is not necessary. An efficient and cost-effective option for monitoring water quality is through use of indicator tests. For instance, a sample can be analyzed for a specific microorganism, and the results can be used to estimate the populations of other microbes in the water. Common indicator microorganism tests are those for generic *E. coli*, total coliform, and fecal coliform. These bacteria are easy to test for and are good indicators of the likely presence of other pathogens in the water. Other indicator tests can include nutrients (primarily nitrogen and phosphorus), salts (either EC or TDS) and other contaminants, as deemed appropriate for the given watershed, local sources of contamination and intended use of the water. From the results of these tests, it may be determined whether more extensive testing is warranted.

5.1.2. Groundwater

Groundwater makes up about 42 percent of the irrigation water used for U.S. agriculture. Groundwater is less likely to be contaminated than surface water. However, groundwater can still be contaminated if it interacts with other contaminated groundwater or surface water. Risks of groundwater contamination are related to depth of the water table and local hydrogeological conditions. Best management practices (BMPs) can reduce risk of groundwater contamination.

Common groundwater contaminants include sediment, dissolved consitituents (including salts) and biological contaminants. **Sediment** is mostly naturally occurring or it can be increased due to well construction. Sediment is a special concern in microirrigation as it can cause blockage of emitters and tubing, but this risk can be minimized through filtration. Excessive sediment can cause rapid wear on pumps and other irrigation system components. **Dissolved constituents, including salts** can be naturally occurring or introduced through contamination. Some crops are more tolerant of salts than others. Some salt constituents are more likely to be toxic or cause other problems than others. **Biological contaminants** may be naturally occurring or introduced; some are mainly nuisances, and others can present health hazards.

Wells should be properly maintained and inspected annually to identify and correct problems that can increase risk of contamination. Best management practices (BMPs) to protect groundwater from contamination include:

- Direct surface runoff away from wellheads.
- Ensure well casings are watertight. A damaged well casing can allow surface runoff to pollute groundwater.
- Observe water well setback distances stipulated by the Texas Administrative Code. Drill water wells away from potential sources of contamination, such as an onsite wastewater treatment (septic) system. An improperly functioning onsite wastewater system can introduce pathogens into groundwater (fig. 5.2).
- To prevent contamination risks associated with chemical handling, spills and leaks, store chemicals and waste products according to label instructions and away from the wellhead.
- Prevent back-siphoning; use adequate backflow protection devices in mixing chemicals and filling tanks. Use backflow protection valves (chemigation check valves) in chemigation operations.
- Properly close abandoned wells.

Abandoned or improperly maintained wells provide a potential pathway to contaminate groundwater. Abandoned wells should always be properly sealed and plugged to preserve aquifer quality. Wells not in use for 6 months are considered abandoned. According to Texas law, the landowner is responsible for capping and plugging abandoned wells and is liable for any water contamination or injury. If a local well is at risk of contamination, seek advice from the local groundwater conservation district, a local licensed water well driller, or the Water Well Drillers Program of the Texas Department of Licensing and Regulation. Local city ordinances or groundwater conservation district rules will have further specifications and regulations for wells, including required distances from potential contaminant sources such as cemeteries, stockyards, sewage collection facilities, property lines, etc. Additional information is available on the Abandoned Well Plugging website < http://abandonedwell.tamu.edu/>.

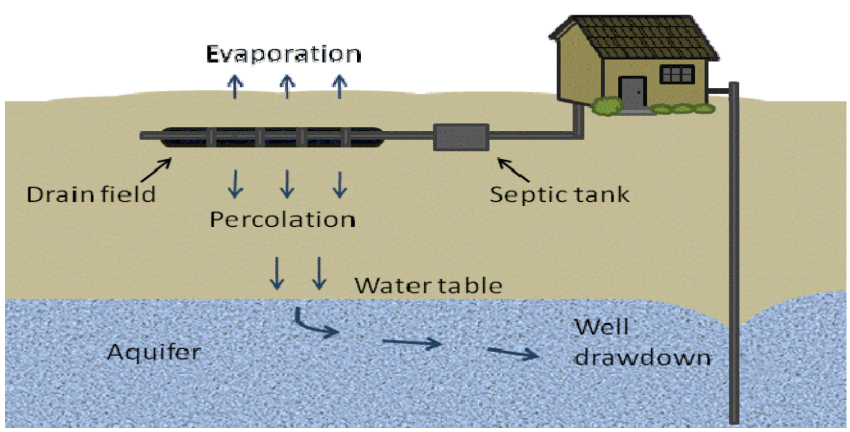


Figure 5.2. Effluent from an onsite wastewater treatment (septic) system can interact with groundwater, leading to contamination of a well.

5.1.3. Alternative Water Resources

Alternative water sources include municipal water, harvested rainwater, graywater or wastewater with appropriate treatment. Municipal water sources (and other similar community water systems) are typically potable quality, and pose little risk for irrigation. The main concern is that municipal sources must be properly protected from contamination due to backflow. This is generally accomplished through properly installed backflow prevention valves. Local ordinances address these requirements.

Harvesting rainwater for supplemental irrigation of landscapes is becoming more popular, and rainwater harvesting is addressed more completely in other references (including Persyn, et al, 2004; rainwaterharvesting.tamu.edu). Because untreated harvested rainwater is not potable, it is important to label the system with signs conveying that the water is non-potable.

Black water includes domestic wastewater generated from toilets, urinals, or food preparation sinks; and graywater includes other water from domestic usage such as the washing machine or showers. Homes can separate black water from graywater and use the graywater to irrigate non-food crops, sending only the black water to the wastewater treatment system (http://ossf.tamu.edu). If a homeowner chooses to re-route graywater from an onsite wastewater treatment system, he or she should consult an onsite wastewater professional to determine potential effects on the onsite wastewater treatment system. To reuse graywater, the homeowner first must decide which graywater sources to collect, as some sources are more likely to present contamination risks. Common graywater system components include (1) collection from residential wastewater from plumbing fixtures and appliances; (2) temporary storage in holding tanks not for treatment; (3) treatment through septic tanks; and (4) dispersal via gravity flow or subsurface irrigation. Additional information on graywater and onsite wastewater treatment options is available on the Texas AgriLife Extension Service Onsite Wastewater Treatment and Reuse website http://ossf.tamu.edu.

In systems built before Jan. 6, 2005, graywater from residential clothes washing machines may be discharged onto the ground through a gravity flow system. Graywater should be diverted through settling tanks and pump tanks for treatment and distribution. Generally, graywater should be stored for less than 1 day, especially is if it is to be dispersed onto the ground surface. Texas graywater rules also require that graywater be collected in an approved tank that: is labeled clearly as “non-potable water”, restricts access especially to children, eliminates habitats for mosquitoes and other vectors, can be cleaned, and meets the structural requirements of the current American Water Works Association http://www.awwa.org/ standards.

Graywater should be applied underground to minimize potential health risks and odors. Spraying graywater is forbidden. Guidelines can help protect human and environmental health include:

- Do not irrigate edible root crops, fruit or vegetables with graywater.
- Use graywater for well-established plants rather than for seedlings.
- Graywater usually is slightly alkaline, so it may affect soil pH or micronutrient availability.
- To prevent salt accumulation, distribute graywater over a large surface area and rotate distribution from one field to another.
- Select reuse applications appropriate for the amount of water to be generated in the system.

Additional information on graywater reuse systems is available in Texas AgriLife Extension Service publications B-6176, *Onsite Wastewater Treatment Systems: Graywater,* and L-5480, *Onsite Wastewater Treatment Systems: Graywater Safety* available on the Texas AgriLife Extension Service Onsite Wastewater Treatment and Reuse website <http://ossf.tamu.edu/>.

5.2. Water Quality Implications of Salts

One of the most common water quality concerns for irrigated agriculture is salinity. All major irrigation water sources contain dissolved salts. These salts include a variety of natural occurring dissolved minerals, which can vary with location, time, and water source. Many of these mineral salts are micronutrients, having beneficial effects. However, excessive total salt concentration or excessive levels of some potentially toxic elements can have detrimental effects on plant health, crop yield, and/or soil conditions. The term “salinity” is used to describe the concentration of (ionic) salt species, generally including calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}), sulfate (SO_4^{2-}), and others (Table 4.1). Types and concentrations of salts vary with water source and location.

Table 5.1. Salts normally found in irrigation waters. (after: Longenecker and Lyerly, 1994; Fipps, 2003)

Chemical name	**Chemical symbol**
Sodium chloride	NaCl
Sodium sulfate	Na_2SO_4
Calcium chloride	$CaCl_2$
Calcium sulfate (gypsum)	$CaSO_4$ $2H_2O$
Magnesium chloride	$MgCl_2$
Magnesium sulfate	$MgSO_4$
Potassium chloride	KCl
Potassium sulfate	K_2SO_4
Sodium bicarbonate	$NaHCO_3$
Calcium carbonate	$CaCO_3$
Sodium carbonate	Na_2CO_3
Nitrate	NO_3^{-}

5.2.1. Salinity Hazards and Analysis

High salinity in water (or soil solution) causes a high osmotic potential. In simple terms, the salts in solution and in the soil “compete” with the plant for available water. Some salts can have a toxic effect on the plant or can “burn” plant roots and/or foliage. Excessive levels of some minerals may interfere with relative availability and plant uptake of other micronutrients. Soil pH, cation exchange capacity (CEC) and other properties also influence these interactions. High concentrations of sodium in soil can lead to the dispersion of soil aggregates, thereby damaging soil structure and interfering with soil permeability. Hence special consideration of the sodium level or “sodicity” in soils is warranted.

Figure 5.3. Foliar damage on peanut due to salinity in irrigation water applied through spray irrigation (right) compared to LEPA irrigation (left) that minimizes leaf wetting.

Figure 5.4. Accumulation of salts at the soil surface under irrigated cotton.

Water and soil testing are essential to determining whether salinity will present a problem for a particular field situation. If wastewater or manure is applied to a field, or if the irrigation water source varies in quality, soil salinity should be monitored regularly for accumulation of salts. Water quality and soil chemical analyses determine which salts are present and the concentrations of these salts. Salinity is expressed in terms of electrical conductivity (EC), in units of millimhos per centimeter (mmhos/cm), micromhos per centimeter (umhos/cm), or deciSiemens per meter (dS/m). The electrical conductivity of a water sample is proportional to the concentration of the dissolved ions in the sample; hence EC is a simple indicator of total salt concentration. Total Dissolved Solids (TDS) is another term frequently used in describing water quality and is a measure of the mass concentration of dissolved constituents in water. TDS is generally reported in units of milligrams per liter (mg/l) or parts per million (ppm). Specific salts reported on a laboratory analysis report are often expressed in terms of mg/l or ppm; these represent mass concentrations of each component in the water sample. Another term used to express mass concentration is *normality*; units of normality are milligram equivalents per liter (meq/l). Standard laboratory analyses include total salinity reported as electrical conductivity (EC) or as Total Dissolved Solids (TDS). Tables 5.2 and 5.3 include commonly used terms, units, and useful conversion information for understanding water quality analysis reports.

Table 5.2. Terms, units, and useful conversions for understanding water quality analysis reports (after: Fipps, 2003; Rogers, et al. 2003).

Water Quality Indicator	Units	General Interpretation
Total Salinity		
Electrical Conductivity, EC	mmhos/cm, µmhos/cm or dS/m 1 dS/m = 1 mmhos/cm = 1000 µmhos/cm	< 0.25 dS/m excellent 0.25 – 0.75 dS/m good 0.75 – 2.0 dS/m permissible 2.0 - 3.0 dS/m caution[1] >3.0 dS/m unsuitable[2]
Total Dissolved Solids, TDS	mg/l = ppm	< 175 mg/l excellent 175-525 mg/l good 525 – 1,400 mg/l permissible 1,400 – 2,100 mg/l caution[1] >2,100 mg/l unsuitable[2]
Approximate conversions between EC and TDS For EC < 5 dS/m: TDS (mg/L) = EC (dS/m) x 640 For EC > 5 dS/m: TDS (mg/L) = EC (dS/m) x 800 mg/L = milligrams per liter ppm = parts per million dS/m = deci Siemens per meter at 25°C		
Sodium Hazard		
Sodium Absorption Ratio, SAR	Calculated ratio of sodium to calcium and magnesium (combined) concentrations	1-9 low risk 10-17 medium risk[3] 18 – 25 high risk[4] > 25 very high risk[5]
Exchangeable Sodium Percentage, ESP	**%** saturation by sodium of the soil exchange capacity (exchangeable sodium / CEC)	Plant tolerance to ESP levels 2-10 very sensitive 10-20 sensitive 20-40 moderately tolerant 40 – 60 tolerant 60+ very tolerant

[1] Careful management is warranted to avoid excessive salt accumulation in the soil. Leaching is recommended.
[2] Good management (leaching and drainage) is necessary. Avoid using on sensitive plants.
[3] Amendments (such as gypsum) and leaching should be used to prevent excess sodium accumulation.
[4] Generally unsuitable for continuous irrigation use.
[5] Generally unsuitable for irrigation.

Table 5.3. Water quality (salinity) constituents, conversions and toxicity risks (after: Fipps, 2003; Rogers, et al. 2003; Tanji, et al. 2007).

Constituents	Atomic weight	Convert ppm to meq/l multiply by	Convert meq/l to ppm multiply by
Cations			
Calcium, Ca^{2+}	40.1	0.050	20
Magnesium, Mg^{2+}	24.3	0.083	12
Sodium, Na^{+}	23.0	0.043	23
Potassium, K^{+}	39.1	0.026	39
Anions			
Bicarbonate, HCO_3^-	61.0	0.016	61
Sulphate, SO_4^{2-}	96.1	0.021	48
Chloride, Cl^-	35.5	0.029	35.5
Carbonate, CO_3^{2-}	60.0	0.033	30
Nitrate, NO_3^-	62.0	0.016	62

Potential toxicity concerns	General Risk of Toxicity[6] low	medium	high
Boron – mg/l	< 0.7	0.7 – 2.0	> 2
Chloride – meq/l Chloride - mg/l	< 4 < 140	4 – 10 142 - 350	> 10 > 350
Sodium (adjusted SAR) Sodium – mg/l	< 3 < 70	3 – 9 > 70	> 9 - -

[6] Relative risk of toxicity depends upon the plant sensitivity and growth stage; method of irrigation; and other factors.

Additional information from soil and water analysis, including concentrations of specific salt components, indicates the relative risk of sodicity and toxicity. High sodium can present a risk of toxicity to plants. It can also indicate a risk of soil aggregate dispersion, which can result in a breakdown of soil structure, and hence reduce the soil's permeability. Relative risk of soil damage due to sodicity is indicated by the Sodium Adsorption Ratio (SAR), which relates to the relative concentrations of sodium (Na+) compared to the combined concentrations of calcium (Ca^{++}) and magnesium (Mg^{++}). Private soil and water testing laboratories and the Texas AgriLife Extension Service Soil, Water and Forage Testing Laboratory (http://soiltesting.tamu.edu.) can analyze samples for salinity and salinity components (sodium, etc.) for a reasonable fee.

Salinity and irrigation

Salinity indicates the potential risk of damage to plants. Generally, electrical conductivity (measure of salt content) of a water source should be below 2.0 dS/m for irrigation. Sprinkler irrigation with water of high electrical conductivity (high salinity) will most likely result in foliar damage to crops. General crop tolerances to salinity of irrigation water and soil are listed in Table 5.4. These values should be considered only as guidelines, since crop management, site specific conditions, and crop growth stage can affect salinity tolerance.

Table 5.4. Tolerance* of selected crops to salinity in irrigation water and soil (Porter and Marek, 2003).

Crop	Threshold **EC in irrigation water** in mmhos/cm or dS/m		Threshold **EC in soil** (saturated soil extract) in mmhos/cm or dS/m	
	0% yield reduction	50% yield reduction	0% yield reduction	50% yield reduction
Alfalfa	1.3	5.9	2.0	8.8
Barley	5.0	12.0	8.0	18.0
Bermudagrass	4.6	9.8	6.9	14.7
Corn	1.1	3.9	1.7	5.9
Cotton	5.1	12.0	7.7	17.0
Sorghum	2.7	7.2	6.8	11.0
Soybean	3.3	5.0	5.0	7.5
Wheat	4.0	8.7	6.0	13.0
*After Rhoades, et. al. (1992); Fipps (2003) and various sources				

5.2.2. Salinity Management

Minimize Application of Salts

An obvious, if not simple, option to minimize effects of salinity is to minimize irrigation application and the resultant accumulation of salts in the field. This can be accomplished through converting to a rain-fed (dry-land) production system; maximizing effectiveness of precipitation to reduce the amount of irrigation required; adopting highly efficient irrigation and tillage practices to reduce irrigation applications required; and/or using a higher quality irrigation water source (if available). Since some salts are added through fertilizers or as components (or contaminants) of other soil additives, soil fertility testing is warranted to refine nutrient management programs.

Crop Selection

Some crops and varieties are more tolerant of salinity than others. For instance barley, cotton, rye, and bermudagrass are classified as salt tolerant (a relative term). Wheat, oats, sorghum, and soybean are classified as moderately salt tolerant. Corn, alfalfa, many clovers, and most vegetables are moderately sensitive to salt. Some relatively salt tolerant crops (such as barley and sugarbeet) are more sensitive at emergence and early growth stages than in their later growth stages. Crop breeding programs are working to address salt tolerance for several crops, including small grains and forages.

Some field crops are particularly susceptible to particular salts or specific elements or to foliar injury if saline water is applied through sprinkler irrigation methods. Elements of particular concern include sodium (Na), chlorine (Cl), and boron (B). More crop-specific information related to tolerances to salinity Na, Cl, and B are available in Fipps (2003), Rhoades, et al (1992), and other sources.

Leaching

Leaching is a classical solution to salinity management in the field and is done through flushing accumulated salts below the root zone. This is often accomplished by occasional excessive irrigation applications to dissolve, dilute, and transport the salts. The amount of excess irrigation application required (often referred to as the “leaching fraction”) depends upon the concentrations of salts within the soil and in the water applied to accomplish the leaching. A commonly used equation to estimate leaching fraction requirement (expressed as a percent of irrigation requirement) is:

Leaching fraction = EC of irrigation water/ permissible EC in the soil x 100%

Where the irrigation water quantity is limited, sufficient water for leaching may not be available. The combined problem of limited water volume and poor water quality can be particularly difficult to manage.

Soil additives and field drainage can be used to facilitate the leaching process. Site specific issues (including soil and water chemistry, soil characteristics, and field layout) should be considered in determining the best approach to accomplish effective leaching. For instance, gypsum, sulfur, sulfuric acid, and other sulfur containing compounds, as well as calcium and calcium salts may be used to increase the availability of calcium in soil solution to “displace” sodium adsorbed to soil particles and hence facilitate sodium leaching for remediation of sodic soils. In soils with insufficient internal drainage for salt leaching and removal, mechanical drainage (subsurface drain tiles, ditches, etc.) may be necessary. Local Texas AgriLife Extension Service office or USDA-NRCS field office staff are good resources that should be familiar with specific local soils and salt issues.

Irrigation Method

Where foliar damage by salts in irrigation water is a concern, irrigation methods that do not wet plant leaves can be very beneficial. Furrow irrigation, low energy precision application (LEPA) irrigation, surface drip irrigation and subsurface drip irrigation (SDI) methods can be very effective in applying irrigation without leaf wetting. Of course, more advanced irrigation technologies (such as LEPA or SDI) also offer greater achievable irrigation application efficiency and distribution uniformity. Further filtration and/or acid injection may be necessary in order to prevent clogging of microirrigation systems due to salts precipitating out of solution.

Wetting patterns by different irrigation methods affect patterns of salt accumulation in the seedbed and in the root zone. Evaporation and root uptake of water also affect the salt accumulation patterns. Often the pattern of salt accumulation can be detected by a visible white residue along the side of a furrow, in the bottom of a dry furrow, or on the top of a row. Additional salt accumulations may be located at or near the outer/lower perimeter (outer wetting front) of the irrigated zone in the soil profile.

Seedbed and Field Management Strategies

In some operations, seed placement can be adapted to avoid planting directly into areas of highest salt accumulation. Row spacing and water movement within the soil can affect the amount of water available for seedlings as well as the amount of water required and available for the dilution of salts.

Irrigation Frequency and Timing

Light, frequent irrigation applications can result in a limited wetted zone and limited capacity for dilution or leaching of salts. When salt deposits accumulate near the soil surface (due to small irrigation amounts combined with evaporation from the soil surface), crop germination problems and seedling damage are more likely. In arid and semi-arid conditions a smaller wetted zone generally results in a smaller effective root zone; hence the crop is more vulnerable to salt damage and to drought stress injury.

Although excessive deep percolation losses of irrigation are discouraged for their obvious reduction in irrigation efficiency and for their potential to contribute to groundwater contamination, occasional large irrigation applications may be required for leaching of salts. Managing irrigation schedules (amounts and timing) to support an extensive root zone helps to keep salt accumulations dispersed and away from plant roots, provides for better root uptake of nutrients, and offers improved protection from short-term drought conditions.

Residue Management/ Organic Matter

Organic matter offers chemical and physical benefits to mitigate effects of salts. Organic matter can contribute to a higher cation exchange capacity (CEC) and therefore lower the exchangeable sodium percentage, thereby helping to mitigate negative effects of sodium. By improving and preserving soil structure and permeability, organic matter helps to support ready movement of water through the soil and maintain higher water holding capacity of the soil. Where feasible, organic or other mulches also can reduce evaporation from the soil surface, thereby increasing water use efficiency (and possibly lowering irrigation demand). Because some organic mulch materials can contain appreciable salts, sampling and analysis for salt content of these products is recommended. To find out more information about soil sampling contact a local Texas AgriLife Extension Service office or the Soil, Water and Forage Testing Laboratory. Instructions for using this service can be found at http://soiltesting.tamu.edu.

Water Quality Implications- Bacteria/Pathogens

Water used for irrigation is a potential source of pathogens that can contaminate produce on a farm. Risks of pathogen contamination of water depend on the water source and local potential sources of contamination. Surface water resources are most likely to be contaminated by pathogens, due to natural contamination from wildlife and runoff from other land uses and activities in the watershed. Best management practices to reduce risk include exclusion fences around creeks and providing an off-stream supply of water for livestock or wildlife to reduce fecal contamination in the creek that could end up in irrigation water and proper maintenance of septic systems.

Methods and timing of irrigation can help manage risk of contaminating crops. For instance, furrow irrigation and drip irrigation pose less risk of contaminating foliage or fruit than overhead spray irrigation. Timing of irrigation with respect to crop growth stage (especially as harvest approaches) affects risk of contamination of products, as well.

Water treatment options

The type of treatment used on the water depends on the constituents to be removed and the final water quality desired. Three basic treatment methods used to improve water quality include filtration, adsorption, and disinfection.
Filtration removes suspended solids from the water. Depending on the filtration method used, this process may remove microorganisms, clays, silts, iron, manganese, natural organic matter, and by-products from other treatment processes. This process clarifies water and makes UV disinfection more effective.

Through **adsorption** organic contaminants in water are attracted to the surface of a material such as activated carbon. Activated carbon filters with more surface area can capture more contaminants. For producing potable water, the activated carbon filter should be certified by the

American National Standards Institute and NSF International (ANSI/NSF certified). A disadvantage of adsorption filters is that they are not primary sanitation devices; use them only in addition to other treatment devices.

Disinfection destroys or inactivates harmful organisms in the water. It is often the last step in a multi-stage water treatment system. Of the many methods of disinfection available, the three most common are chlorination, ozonation, and ultraviolet light. Selection of disinfection method depends upon site-specific water characteristics. Additional information on disinfection of water is available from the Texas AgriLife Extension Service On-Site Sewage Facilities website at: http://ossf.tamu.edu/disinfection/ and in TWDB (2005).

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6. IRRIGATION BEST MANAGEMENT PRACTICES

Irrigation technologies, especially advanced irrigation technologies such as low pressure center pivot and microirrigation systems can be excellent tools for applying water efficiently. The benefits of these systems, however, can only be realized with good management.

Irrigation system planning and design

The decision to adopt a specific technology or to invest in irrigation equipment should take into consideration site-specific conditions, including size and shape of the field; crop(s) to be grown; water source, capacity and quality; labor availability and management capability; access to utilities necessary to operate the system; initial and operating costs, and other factors. A good design by a qualified professional (professional engineer or Certified Irrigation Designer) is especially important for permanent systems such as center pivot or linear move systems or subsurface drip irrigation systems; even relatively simple systems merit design consideration of components (pumps, motors, pipelines, etc.). A good design will include all necessary components, and take into account site-specific conditions, maintenance and operator considerations.

Irrigation equipment and system maintenance

Proficiency in installation and diligence in maintenance of equipment are very important. A good maintenance program is necessary to avoid costly in-season down time and application inefficiency. Recommendations include monitoring of system pressure and flow, checking sprinkler or LEPA nozzle packages to maximize water distribution uniformity, and using pressure regulators on center pivot or linear irrigation systems applying to sloping fields.

Information available to support irrigation management decisions

Knowledge of crop water requirements, root zone and soil moisture holding characteristics, water quality and other factors are critical for efficient water management. Goals of soil moisture management are to promote an extensive effective root zone and optimize benefit of precipitation; provide adequate moisture to avoid drought stress without over-watering; take advantage of the soil's moisture storage capacity to help meet crop water demand during peak water use periods; and schedule limited water resources for the times when they will be most beneficial to the crop.

Roots grow in moist soil. Effective root zone depth for many crops may be deeper, but most water uptake occurs in the top 1-3 feet of soil. Caliche layers, dry soil, or other barriers can further limit the effective root zone. Use knowledge of soil water holding capacity and soil moisture monitoring to plan irrigation applications. Frequent light irrigation applications may result in excessive evaporation losses. Irrigation applications that exceed the soil's water holding capacity can result in runoff losses and/or deep percolation losses. In-season soil moisture monitoring is key to optimizing irrigation management.

Crop water demand estimates provided by Evapotranspiration Networks are especially useful in scheduling irrigation to meet in-season crop water requirements. Crop production guides available from Texas AgriLife Extension Service (and Extension services in other states) and other sources address crop-specific water requirements, including seasonal water use, peak water use, critical growth stages (when the crop is more sensitive to drought stress), and water quality considerations.

Soil moisture monitoring, using a simple “feel and appearance” method or one of a range of commercially available soil moisture sensors or systems, is fundamental to managing moisture in the root zone. Sensors also are available to monitor plant or crop water stress indicators (canopy temperature, plant water potential).

Conservation practices

Irrigation is just one source of water for the crop; rainfall stored during the off-season and fully utilized during the crop season improves the overall water use efficiency of the crop. Residue management, mulches, land forming (furrow diking, grading, leveling, terracing), can help to reduce evaporation or runoff losses. Maintaining residue on the soil surface increases water infiltration, reduces erosion, increases organic matter, reduces weed pressure, saves and reduces costs.

Integrated crop production management to optimize results within farm-level constraints

It is especially worth noting that while water often is the most limiting factor in crop production, especially in arid and semi-arid areas, an integrated cropping system approach addresses nutrient management, crop variety, and Integrated Pest Management, as well as water management. Where irrigation water capacities are limited, selection of drought-tolerant crops or varieties can help mitigate drought-related losses; adjusting planted acres/rotations to match crop water requirements to irrigation capacity, minimizing drought-related risk. Since water is not always the most limiting factor, Integrated Pest Management (IPM) approaches to address insect, weed and disease issues that can negatively impact yield, and effective nutrient (fertilizer) management programs are essential to optimize crop (yield and quality) response.

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APPENDIX G -
IRRIGATION FOR SMALL FARMS PRESENTATIONS

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IRRIGATION FOR SMALL FARMS:

IRRIGATION TECHNOLOGIES

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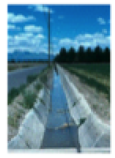
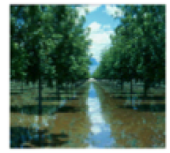
Surface (Flood) Irrigation

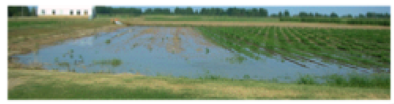


Lined irrigation ditch (left) to convey water from a surface water source to the field.

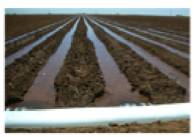
Water stands in a laser-leveled, flood irrigated pecan orchard (right).

Water is delivered from an underground pipeline to a field (below); berms contain the water until it percolates into the soil.

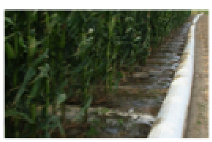




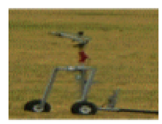
Surface (Furrow) Irrigation



Furrow irrigation is simple, portable and inexpensive. Labor requirement is relatively high compared to other methods. Gated aluminum of PVC pipe or flexible polyethylene pipe are commonly used to deliver water to furrows for row crop production.



Sprinkler Irrigation:
Big gun, traveling gun and hose reel sprinkler systems

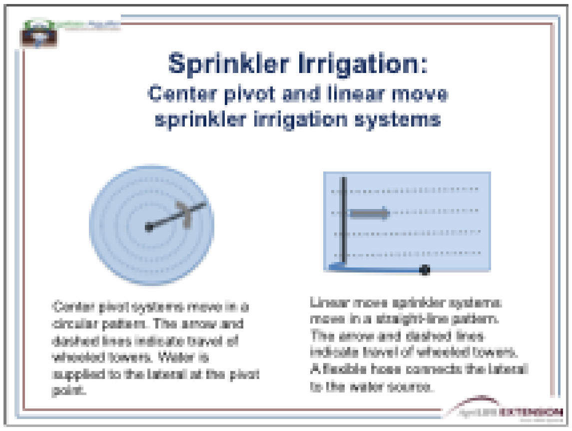


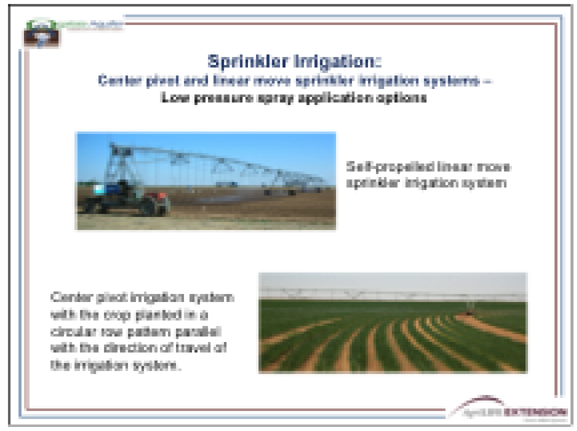
The head of this hose reel sprinkler is mounted on a wheeled cart (left) and connected to a flexible or hard-hose wrapped on a trailer-mounted reel (below). Before an irrigation set, the hose is extended; through the course of the irrigation set, the hose is retracted on the reel, pulling the applicator toward the reel.

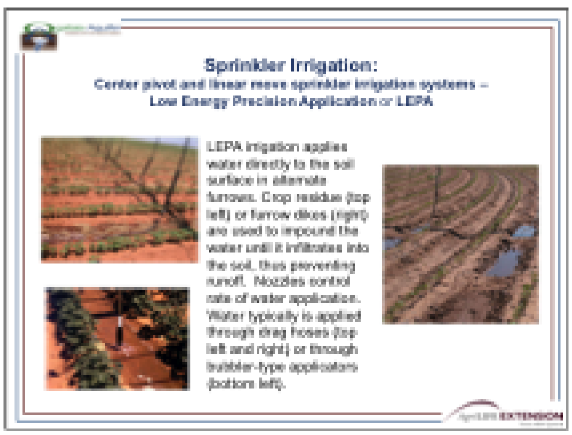
Sprinkler Irrigation:
Solid set and portable fixed-set sprinkler systems

Solid set sprinkler systems are often used for irrigating small fields. They may also be used for frost-control, dust suppression and other applications.

Sprinkler Irrigation:
Side Roll (Wheel Line or Wheel Roll) Systems

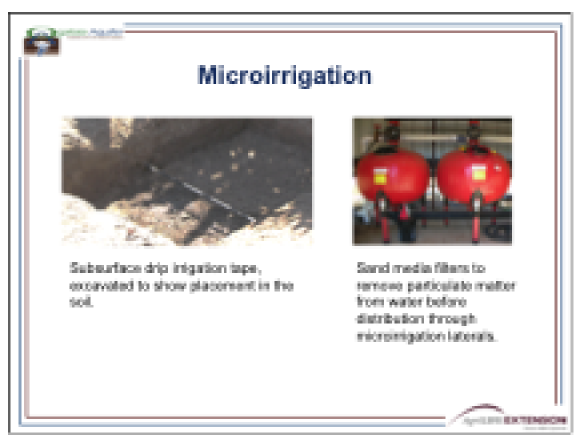

Sprinkler Irrigation:
Center pivot and linear move sprinkler irrigation systems
Center pivot systems move in a circular pattern. The arrow and dashed lines indicate travel of wheeled towers. Water is supplied to the lateral at the pivot point.
Linear move sprinkler systems move in a straight-line pattern. The arrow and dashed lines indicate travel of wheeled towers. A flexible hose connects the lateral to the water source.
EXTENSION

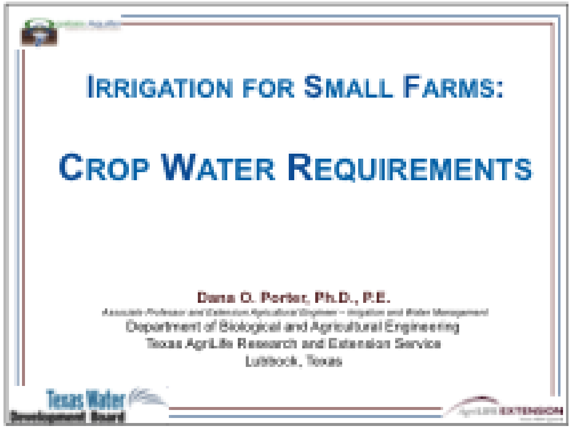

Sprinkler Irrigation:
Center pivot and linear move sprinkler irrigation systems – Low pressure spray application options
Self-propelled linear move sprinkler irrigation system
Center pivot irrigation system with the crop planted in a circular row pattern parallel with the direction of travel of the irrigation system.
EXTENSION


Sprinkler Irrigation:
Center pivot and linear move sprinkler irrigation systems – Low Energy Precision Application or LEPA
LEPA irrigation applies water directly to the soil surface in alternate furrows. Crop residue (top left) or furrow dikes (right) are used to impound the water until it infiltrates into the soil, thus preventing runoff. Nozzles control rate of water application. Water typically is applied through drag hoses (top left and right) or through bubbler-type applicators (bottom left).
EXTENSION


Sprinkler Irrigation:
Low Pressure Sprinkler Irrigation
LESA irrigation applies water through low pressure sprinkler applicators within 18 inches of the soil surface. Large water droplet sizes and near surface application reduce evaporation losses.
Mid-Elevation Spray Application (MESA) applies water above the crop canopy.
EXTENSION


Microirrigation
Surface drip irrigation.
Shallow subsurface drip irrigation under plastic mulch.
Microirrigation on trellises in a vineyard.
EXTENSION


Microirrigation
Subsurface drip irrigation tape, excavated to show placement in the soil.
Sand media filters to remove particulate matter from water before distribution through microirrigation laterals.
EXTENSION


IRRIGATION FOR SMALL FARMS:
CROP WATER REQUIREMENTS
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Department of Biological and Agricultural Engineering
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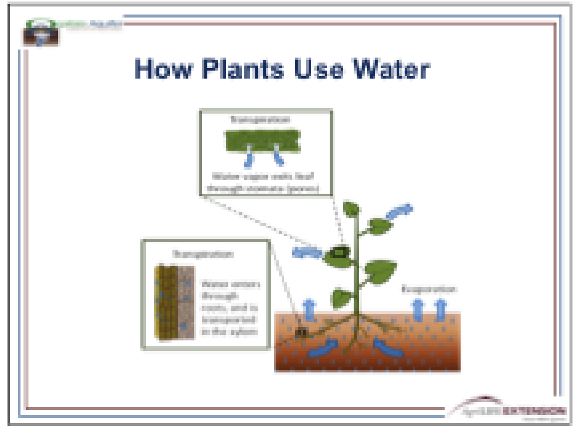
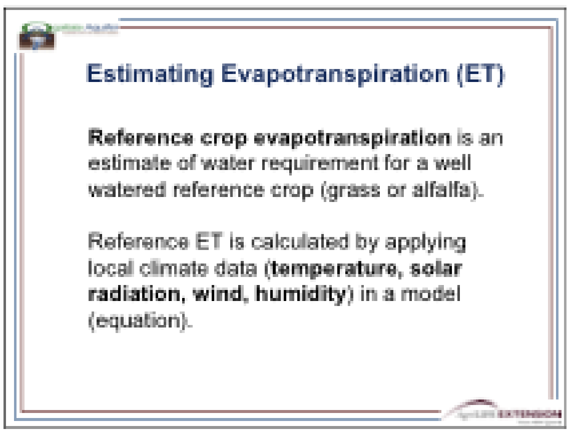
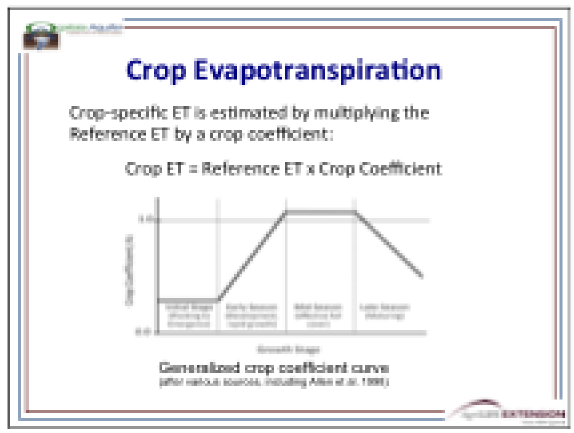
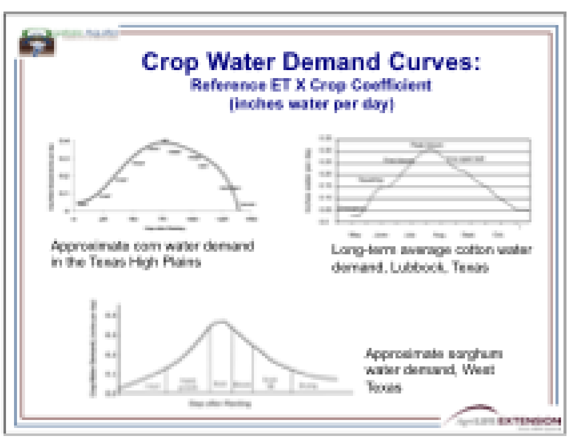
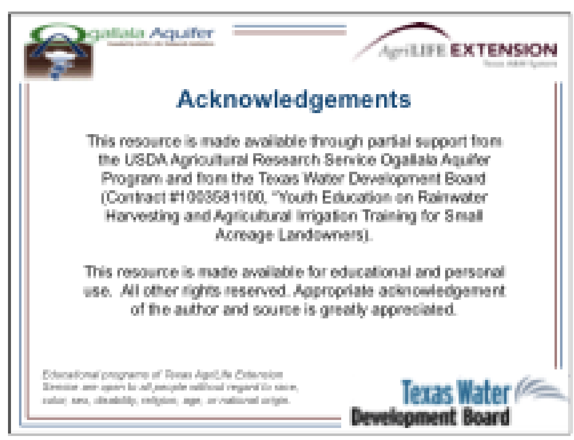
Lubbock, Texas
Texas Water Development Board
AgriLIFE EXTENSION


How Plants Use Water
Transpiration
Evaporation
AgriLIFE EXTENSION


Estimating Evapotranspiration (ET)
Reference crop evapotranspiration is an estimate of water requirement for a well watered reference crop (grass or alfalfa).
Reference ET is calculated by applying local climate data (temperature, solar radiation, wind, humidity) in a model (equation).
AgriLIFE EXTENSION


Crop Evapotranspiration
Crop-specific ET is estimated by multiplying the Reference ET by a crop coefficient:
Crop ET = Reference ET x Crop Coefficient
Growth Stage
Generalized crop coefficient curve
AgriLIFE EXTENSION


Crop Water Demand Curves:
Reference ET X Crop Coefficient
(inches water per day)
Approximate corn water demand in the Texas High Plains
Long-term average cotton water demand, Lubbock, Texas
Approximate sorghum water demand, West Texas
AgriLIFE EXTENSION


Ogallala Aquifer
AgriLIFE EXTENSION
Acknowledgements
This resource is made available through partial support from the USDA Agricultural Research Service Ogallala Aquifer Program and from the Texas Water Development Board (Contract #1003581100, "Youth Education on Rainwater Harvesting and Agricultural Irrigation Training for Small Acreage Landowners).
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Texas Water Development Board

Irrigation for Small Farms:

Soil Moisture Management

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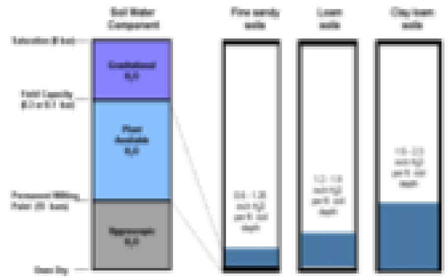
Soil Moisture Characteristics



How soil feels and looks at various soil moisture levels

Soil moisture level	Fine sand, loamy fine sand	Sandy loam, fine sandy loam	Sandy clay loam, loam, silt loam	Clay loam, clay, silty clay loam
0 - 25% available soil moisture	Appears dry; will not retain shape when disturbed or squeezed in hand.	Appears dry; may make a cast when squeezed in hand but seldom holds together.	Appears dry. Aggregates crumble with applied pressure.	Appears dry. Soil aggregates separate easily, but clods are hard to crumble with applied pressure.
25 - 50% available soil moisture	Slightly moist appearance. Soil may stick together in very weak cast or ball.	Slightly moist. Soil forms weak ball or cast under pressure. Slight staining on fingers.	Slightly moist. Forms a weak ball with rough surface. No water staining on fingers.	Slightly moist; forms weak ball when squeezed, but no water stains. Clods break with applied pressure.
50 - 75% available soil moisture	Appears and feels moist. Darkened color. May form weak cast or ball. Leaves wet outline or slight smear on hand.	Appears and feels moist. Color is dark. Forms cast or ball with finger marks. Will leave smear or stain and leaves wet outline on hand.	Appears and feels moist and pliable. Color is dark. Forms ball and ribbons when squeezed.	Appears moist. Forms smooth ball with defined finger marks; ribbons when squeezed between thumb and forefinger.
75 - 100% available soil moisture	Appears and feels wet. Color is dark. May form weak cast or ball. Leaves wet outline or smear on hand.	Appears and feels wet. Color is dark. Forms cast or ball. Will smear or stain and leaves wet outline on hand; will make weak ribbon.	Appears and feels wet. Color is dark. Forms ball and ribbons when squeezed. Stains and smears. Leaves wet outline on hand.	Appears and feels wet; may feel sticky. Ribbons easily; smears and leaves wet outline on hand. Forms good ball.

Source: USDA-NRCS. Estimating Soil Moisture by Feel and Appearance. 1998. United States Department of Agriculture – Natural Resources Conservation Service. Available at: [illegible]

Effective Root Zone Depth

Crop	Approximate Effective Rooting Depth (feet)
Alfalfa	3.3 – 6.6+
Beans	~ 2.5
Corn	2.6 – 5.6
Cotton	2.6 – 5.6
Peanut	1.6 – 3.3
Sorghum	3.3 – 6.6
Soybeans	3 – 4
Wheat	3 – 6+
Perennial pasture/turf	~ 1-2.5
Orchards	~ 6
Vegetable crops	1 - 3
Root crops (potato, beets)	~ 2-3
Grapes	~ 3+

* Active root zone depths, compiled from various sources. These values represent the majority of feeder roots. Actual root depth will be affected by local soil conditions (texture, structure, moisture).

Using Soil Moisture Information to Improve Irrigation Efficiency

Understanding and monitoring of soil moisture can help to improve irrigation efficiency by reducing **deep percolation (leaching) losses** of water below the root zone and/or **surface runoff losses**.

Minimizing these losses also reduces risks of groundwater and surface water contamination.

Acknowledgements

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Irrigation for Small Farms:

Water Sources and Water Quality

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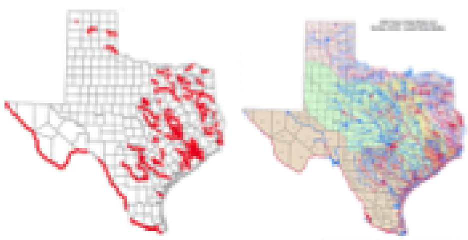
Special Thanks

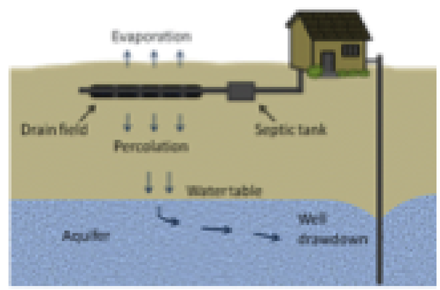
Special thanks are extended to
Justin Mechell, M.S., E.I.T.,
former Extension Program Specialist,
Department of Biological and Agricultural Engineering, for his significant contributions of information and material toward the development of this resource.

Surface Water Quality

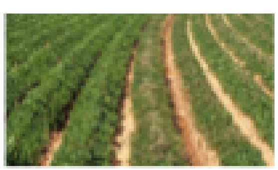


Bacterial contamination in Texas water bodies (left), and impaired water bodies listed according to Clean Water Act Section 303d (right). (Source: Texas Commission on Environmental Quality, http://www.tceq.texas.gov/assets/public/gis/docs/303d.pdf)

Protecting Groundwater Quality



Salinity



Foliar damage on peanut due to salinity in irrigation water applied through spray irrigation (right) compared to LEPA irrigation (left) that minimizes leaf wetting.

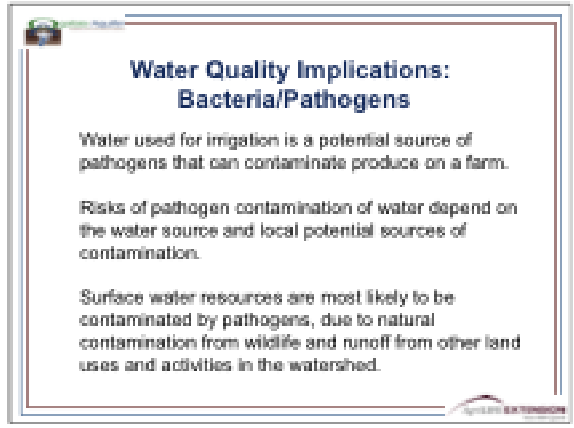
Accumulation of salts at the soil surface under irrigated cotton.

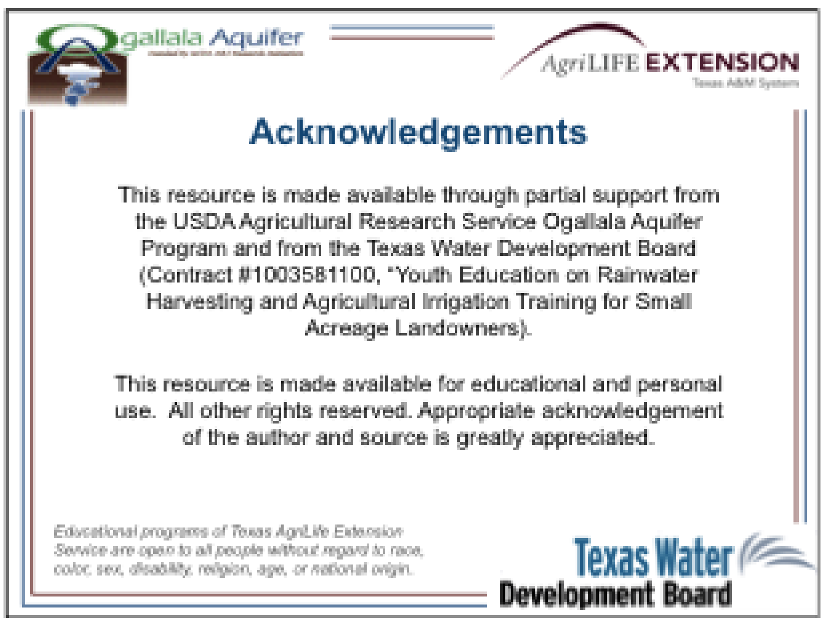
Salinity Tolerance of Crops

Crop	Threshold **EC in irrigation water** in mmhos/cm or dS/m		Threshold **EC in soil** (saturated soil extract) in mmhos/cm or dS/m	
	0% yield reduction	50% yield reduction	0% yield reduction	50% yield reduction
Alfalfa	1.3	5.9	2.0	8.8
Barley	5.0	12.0	8.0	18.0
Bermudagrass	4.6	9.8	6.9	14.7
Corn	1.1	3.9	1.7	5.9
Cotton	5.1	12.0	7.7	17.0
Sorghum	2.7	7.2	6.8	11.0
Soybean	3.3	5.0	5.0	7.5
Wheat	4.0	8.7	6.0	13.0

* Source: Porter and Marek, 2003; after Rhoades, et. al. (1992); Fipps (2003) and various sources.


Salinity Management Strategies
Minimize application of salts
Crop selection
Leaching alone or in combination with soil additives
Irrigation method
Seedbed and field management strategies
Irrigation frequency and timing
Residue management


Water Quality Implications: Bacteria/Pathogens
Water used for irrigation is a potential source of pathogens that can contaminate produce on a farm.
Risks of pathogen contamination of water depend on the water source and local potential sources of contamination.
Surface water resources are most likely to be contaminated by pathogens, due to natural contamination from wildlife and runoff from other land uses and activities in the watershed.


Ogallala Aquifer
AgriLIFE EXTENSION
Texas A&M System
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Texas Water Development Board

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Appendix F –
Comments from TWDB Executive Administrator on Draft Final Report

Attachment I: 1003581100 – Draft Report Comments – 03/23/12

Please provide an electronic copy of all educational materials and training manuals that were developed through this grant contract. Please make this report an accessible PDF format that will be available for easy posting and download. Please provide an unlocked Word version of the appendices documents for future edits.

Please reference, throughout the report, where the free educational materials (those that were developed through this project) may be found online and also where more information about the other materials may be found or where they may be purchased.

Page 3, Second paragraph – Please update the reference to the 2012 State Water Plan and provide a link to it in the report https://www.twdb.state.tx.us/wrpi/swp/swp.asp

Page 3, Fifth paragraph – Provide the estimated volume of rainwater harvesting potential in billions of gallons and (acre-feet).

Page 4, Last paragraph – Please provide an electronic copy of all "hands-on and computer presentations that were developed for this project."

Page 5, First paragraph – Please provide an electronic copy of the *Rainwater Harvesting Activities for Youth Education* that is included as Appendix A.

Page 5, Third paragraph – Please provide the power point presentation referred to in this section.

Page 5, Fifth paragraph – Please reference the source for the assumed water savings from educational activities. Could the results of the survey questions about ,"List some ways you will conserve water in the future?" be used to develop an estimate of water savings?

Page 5, Sixth paragraph – Please expand upon the water savings estimation, provide an estimate of total water savings for the duration of the project (include an estimated volume of water before the activity, efficiency gained through the activity, and resulting water savings calculation).

Page 6, First paragraph – Please provide the presentation information referred to in this section.

Page 6, Second paragraph – Please provide a photo and/or diagrams of the rainwater harvesting simulator and stream trailer used for the demonstrations.

Page 6, Third paragraph – Please provide the information on "how to hold a successful youth education program" which was used in the educator training. Is there a separate AgriLife publication for this topic? What was included in this segment of the training? Please expand.

Page 6, Last paragraph – Please expand upon the water savings estimation, provide an estimate of total water savings for the duration of the project (include an estimated volume of water before the activity, efficiency gained through the activity, and resulting water savings calculation).

Page 7, Second paragraph – Please expand upon the water savings estimation, provide an estimate of total water savings for the duration of the project (include an estimated volume of water before the activity, efficiency gained through the activity, and resulting water savings calculation).

Page 7, Second paragraph – Please provide a list of counties reached in Task 1.

Pages 8, 10, 13, 14, 18, 19 – Please explain the reasons for the difference in the questions on the survey evaluations and the youth survey in Appendix B page 1? Please provide any additional surveys that were used in the program along with the one in Appendix B.

Tables 1, 2, 3, 4, 5, and 6 – Please provide an additional table with the aggregated data from all six surveys to show the overall results.

Tables 7, 8, 9, 11, 12, 13, 14, 15, and 16 – Please explain the difference in the questions on the survey evaluations and the Master Gardener survey in Appendix C. Include any other survey questionnaires in the appendix. Please provide an additional table with the aggregated data from the nine different tables.

Table 10 is missing! Please renumber the tables appropriately.

Page 15 – Please provide an electronic copy of the presentation that is referenced (PowerPoint or PDF).

Page 32, Last paragraph – Please expand upon the Conclusions section to include a sum total of water savings that was realized for the duration of the project for all activities/tasks (include an estimated volume of water before the activities, efficiency gained through the activities, and resulting water savings calculation). Also, add what ideas were gathered in order to improve future training (survey question).

Appendix A – Add TWDB logo to this cover page. Also include a link to where the document may be found on TWDB Conservation Education page at http://www.twdb.texas.gov/conservation/education/

Appendix A – Add a Table of Contents page. Please also provide an electronic copy of this as a stand-alone document along with any educational materials/presentations/workshop activities that were developed through this project.

Appendix A – Please add a table of Texas Essential Knowledge and Skills (TEKS) for Science addressed in each activity (http://ritter.tea.state.tx.us/rules/tac/chapter112/ch112a.html).

For example, for grade 4, TEK 7 A, B:

7) Earth and space. The students know that Earth consists of useful resources and its surface is constantly changing. The student is expected to:

(A) Examine properties of soils, including color and texture, capacity to retain water, and ability to support the growth of plants;

(B) Observe and identify slow changes to Earth's surface caused by weathering, erosion, and deposition from water, wind, and ice; and

For grade 8, TEK 8 C:

8) Earth and space. The student knows that natural events and human activity can impact Earth systems. The student is expected to:

(C) Model the effects of human activity on groundwater and surface water in a watershed.

For Principals of Agriculture within Career and Technical Education- http://ritter.tea.state.tx.us/rules/tac/chapter130/ch130a.html

TEK 15 A, C, and E:

(15) The student explains the relationship between agriculture and safety, health, and the environment. The student is expected to:

(A) Determine the effects of agriculture, food, and natural resources upon safety, health, and the environment;

(C) Describe methods to maintain and improve safety, health, and environmental systems in agriculture, food, and natural resources;
(E) Evaluate energy and water conservation methods;

It is acceptable to use the abbreviated notation such as Grade 4, TEK 7 AB.

Appendix A, Page 2 – Please correct the typo in the first line "This booklet was created to helped educators…"

Appendix A, Page 4 – Is this a typo in Procedure section, "Rainfall is simulated by holing [sp.] a sprinkler can…"?

Appendix A – Please add an activity that describes how to build and use the Rainwater Harvesting Simulator referred to and photographed in Figure 13 on page 24.

Appendix A (all activities) – Please include diagrams showing how the key demonstration resources (rainwater simulator, rainwater harvesting simulator) are assembled and expand instructions for how to construct these resources.

Appendix A, page 3 – Please provide instructions for this activity rather than sending the reader to the AgriLife bookstore. These publications do not have online PDF versions available.

Appendix A, Page 15 – Please add the TWDB logo to this certificate (the Contract Manager will provide the appropriate/preferred logo for use here and elsewhere throughout the report).

Appendix A, (all activities), Please include more of the discussion items with students in the description of the procedures. For example, in "Mist to Heavy Rain" (page 8), what questions does the instructor use in the demonstration? In "Soil Infiltration Measurement with Rings" (pg 6), what questions does the instructor use in the demonstration to help the students understand the relationship between land health and infiltration?

Appendix D – Include a glossary of common terms for the unfamiliar/new agricultural producer. Include page numbers throughout and listed in the table of contents. Please also provide an electronic copy of this as a stand-alone document. Include a link to TWDB Conservation Education page where this may be found http://www.twdb.texas.gov/conservation/education/

Appendix D, Chapter 2 – Please provide an average return on investment for each of the technologies discussed.

Appendix D, Chapter 6 – Please expand upon the BMP section to include resources/references where the reader may find more detailed information and/or technical assistance (AgriLife Extension County offices, local Soil & Water Conservation district offices, NRCS, TWDB, etc.). Include the following links to NRCS BMP practices and TWDB BMP guide:

www.nrcs.usda.gov/technical/Standards/nhcp.html

http://www.savetexaswater.org/bmp/