1. Report No. FHWA/TX-09/0-5748-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WATER RETENTION TECHNIQUES FOR VEGETATION ESTABLISHMENT IN TXDOT WEST TEXAS DISTRICTS		5. Report Date April 2009 Published: March 2010
		6. Performing Organization Code
7. Author(s) Jett McFalls, William Rogers, Clay Robinson, Beverly Storey, B.A. Stewart, Ming-Han Li, James Schutt, Vipul Saxena, and Li Chi Wang		8. Performing Organization Report No. Report 0-5748-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. Project 0-5748
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080		13. Type of Report and Period Covered Technical Report: September 2007–February 2009
		14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Water Retention Techniques for Roadside Vegetation Establishment in Arid Regions of Texas

URL: http://tti.tamu.edu/documents/0-5748-1.pdf

16. Abstract

Water harvesting is the collection of runoff for its productive use and may aid in the germination and establishment of vegetation seeded in the roadside. This project is a synthesis study on the feasibility and implications of adapting water harvesting techniques to Texas roadsides in arid environments. The project uses a case-study approach via specific Texas Department of Transportation (TxDOT) roadway sites to investigate the potential application and impacts of adapting these techniques to roadside vegetation establishment and maintenance in a range of climate and soil conditions. The research seeks to develop alternative water harvesting techniques specifically adapted to the demanding environmental and safety requirements of the roadside. Recommendations for adoption are included along with guidelines, standard construction detail sheets, and specifications. A cost-benefit analysis for the various techniques and a recommendation for implementation of studies to field-verify the synthesis study is included in this report.

17. Key Words Water Harvesting, Water Retention, Vegetation Establishment in Arid Areas		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov	
19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 86	22. Price

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Published: March 2010

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permitting purposes. The researcher in charge of the project was James R. Schutt. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors would like to thank many individuals that were instrumental in the success of this project. Thanks to TxDOT Project Monitoring Committee (PMC) including John Blackman (Project Director), Randy Hopman (Project Coordinator), Dennis Markwardt (PMC member), Clyde Harper (PMC member), and Ann Finley (PMC member) for their continued support of this research.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Water harvesting is the general term used for techniques to collect stormwater runoff and rainfall for storage in the soil profile or other storage areas so that it can be used later for productive purposes. This report is a synthesis study on the feasibility and implications of adapting water harvesting techniques to Texas roadsides in arid environments. A case-study approach used specific TxDOT roadway sites to investigate the potential application and impacts of adapting these techniques to roadside vegetation establishment and maintenance in a range of climate and soil conditions. Recommendations for adoption are included along with guidelines, standard construction detail sheets, and proposed specifications. In addition, the study seeks to develop alternative water harvesting techniques specifically adapted to the demanding environmental and safety requirements of the roadside. A cost-benefit analysis is provided for the various techniques as well as a recommendation for implementation studies to field-verify the synthesis report.

Water harvesting in arid and semiarid regions has a long history, dating back at least 4000 years. In the southwest United States, various forms of water harvesting have been used and documented for centuries. Today, in view of increasing demands for agricultural products, decreasing groundwater supplies for irrigation, and shifts in regional rainfall patterns, water harvesting is becoming increasingly important. The methods applied depend on area conditions and include a wide variety of techniques and equipment (*1, 2*). Modern applications of water harvesting have been adopted recently in arid parts of the United States for use in landscapes and to encourage the replenishment of underground aquifers.

Water harvesting to improve vegetative cover to reduce erosion has unique potential for application in semiarid regions. Water harvesting management techniques can mitigate soil erosion, which will advance water quality goals. However, in many cases vegetation cover cannot become established in semiarid areas without supplemental water (*3*). While historic water harvesting applications have been used primarily for agricultural production, they also can be used for the following:

- to restore of the productivity of land,

- to increase productivity of rain-dependant farming,
- to decrease the risk of drought in regions prone to it, and
- to minimize the danger of desertification through decreasing runoff and increasing soil water content (*4*).

Fundamentally, water harvesting is used for the capturing, directing, and storage of rainwater for immediate or later beneficial use. Water harvesting has historically targeted two types of applications: 1) rangeland applications and the use of devices such as bunds (berms), dikes, and basins to slow or entrap floodwaters in fairly wide areas; and 2) harvesting water for crops, typically by channeling runoff into smaller basins, perhaps for a single fruit tree or cultivated row crops.

In general, the primary issues that must be addressed in the design of a water harvesting system are the likely available runoff and the nature of the soil. Each of these issues may be more specifically described with other distinctions such as rainfall frequency, seasonal patterns, intensity, duration, interval between events, size of events, soil texture, structure, depth, fertility, salinity, infiltration characteristics, antecedent soil moisture, available water capacity, construction properties, etc.

Additional site characteristics such as slope gradient, ground surface character, evapo-transpiration rates, watershed size, time and location of water concentration, existing vegetation cover, and adjacent vegetation cover all affect water harvesting mechanism designs. As straightforward as the concept of water harvesting is, the application of water harvesting techniques to existing and recently constructed roadsides to establish roadside vegetation offers unique challenges and is not well-studied.

Application of water harvesting to improve roadside vegetation in the semiarid and arid portions of Texas must make the best use of limited periodic and seasonal rainfall. West Texas is semiarid to arid with annual rainfall between 9.5 to 20 inches [250 to 500 mm] (*5*). However, very high, short-term rainfall events occur, causing high runoff flow from the road surface. The potential for infrequent, high precipitation events coupled with the potential for high winds and low humidity, increases the potential and severity of erosion.

Water harvesting, in these arid regions, may seem at odds with the general philosophy behind roadway drainage as highways are typically designed for the rapid removal of stormwater runoff. However, when considered as a whole, water harvesting offers potential benefits to the system overall in that it helps reduce the environmental impact of the system while helping improve the roadway's function. Implementation of water harvesting strategies must consider related TxDOT performance criteria or standards for:

- vegetation cover requirements,
- roadside safety,
- low maintenance,
- implementation using readily available or easily adapted equipment,
- life cycle cost effectiveness, and
- roadside stability performance.

An additional challenge faced by TxDOT is that road construction completion does not, in most cases, coincide with optimum vegetation establishment seasons and rainfall availability. Opportunities exist to expand the water harvesting concept to making the vegetation adapt to the rainfall events by selecting vegetation seeding strategies that will maximize the available rainfall. Other opportunities include the use of potential soil amendments that can alter soil temperatures to be more favorable for seed germination and vegetation establishment.

PROJECT GOALS AND OBJECTIVES

The purpose of this project is to assess and define water harvesting techniques applicable to the more arid west Texas districts and to make recommendations based on field evaluations at four sites located near: Childress, Canyon, El Paso, and San Angelo. These sites were analyzed to determine best management practices possible for maintaining vegetation along the roadsides. This project evaluates the integration of cost effective, site specific water harvesting strategies to improve roadside vegetation establishment through:

1) optimizing/maximizing water harvesting via physical options,
2) maximizing soil water retention or available water content (AWC) using soil amendments/techniques, and
3) identifying biological approaches that improve water availability to vegetation through both cool and warm soil amendments and seasonal seed mix and planting strategies.

CHAPTER 2: LITERATURE REVIEW

The literature review was based on the project evaluation criteria for roadsides in arid or semiarid regions in the state of Texas. In order to improve roadside vegetation establishment in the limited periodic and seasonal rainfall, these evaluation criteria focus on physical options that maximize water harvesting for vegetation requirement, soil amendments that improve soil water moisture, and biological approaches that supply water to plants via soil amendments, seasonal seed mix and planting strategies in cool and warm seasons.

OPTIMIZING/MAXIMIZING WATER HARVESTING VIA PHYSICAL OPTIONS

Water harvesting techniques that improve the collection, management, and use of water have been researched and applied consistently in several parts of the world (*1*). Physical approaches depend on the goals of the designer, the size and configuration of the site, rainfall patterns, and soil type and conditions. Cost will be relative to the degree and type of mechanization required and whether or not new structures are needed. Multiple techniques may be used on the same site or in conjunction with each other.

Micro-Catchment Water Harvesting

Micro-catchment is one of the physical methods used to collect surface stormwater runoff from a small catchment area into the root zone of an adjacent infiltration basin. This infiltration basin may be used for vegetation, crops or livestock (*1, 6*). Micro-catchment water harvesting techniques have been widely used for planting trees and shrubs in arid and semiarid regions of the world since the nineteenth century (*7, 8*). Simply put, micro-catchments are alterations of the topography to direct rainfall runoff to plants. They are simple, inexpensive, and provide many advantages over alternative irrigation schemes. Micro-catchment techniques are particularly effective on slopes not exceeding 7–8 percent. The optimal size of the micro-catchment depends on the site characteristics. There are several methods of micro-catchment water harvesting techniques (see Figure 1).

Figure 1. Berms Used to Concentrate Stormwater Runoff for Shrubs.

Contour Bunds/Berms

"Bund" is used throughout the international literature, but the analogous term used in the United States is "berm." Contour bunds are typically used in areas receiving 12 to 24 inches [300 to 600 mm] annual rainfall on slopes of 1 to 25 percent gradient with a catchment plot of approximately 60 to 120 yd^2 [50 to 100 m^2]. Contour bunds are commonly used for tree establishment (see Figure 2) (*9*). Hatibu and Mahoo (*10*) reported that contour bunds of stones or small brush embankments constructed along the contour lines trap the runoff flow behind the bunds, allowing water to infiltrate into the soil.

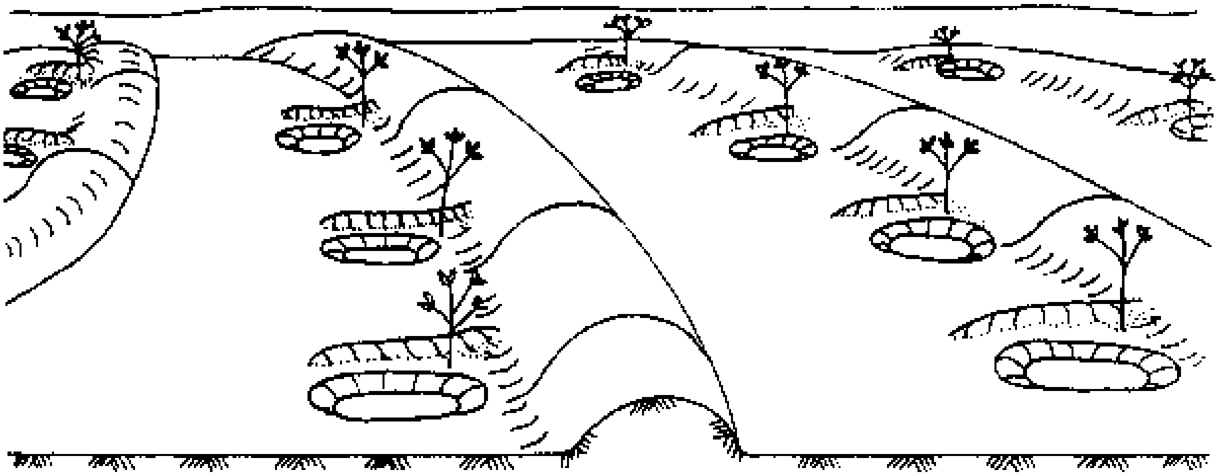

Figure 2. Contour Bunds for Tree Establishment (*10*).

Semi-Circular and Triangular Bunds and Berms

Semi-circular and triangular bunds are methods to physically modify the soil that are useful on slopes of 0.5 to 5 percent gradient in regions with more than 12 inches [300 mm] annual precipitation. The bund height of 1.6 ft [0.5 m] encloses a slight depression (*9*). Runoff flow is collected within the depression. Surplus water is drained around the tips and is intercepted by the second row and so on (Figure 3) (*10*). These physical techniques have advantages of quick and cheap water collection for livestock requirement, tree planting, and crop supply (*11*).

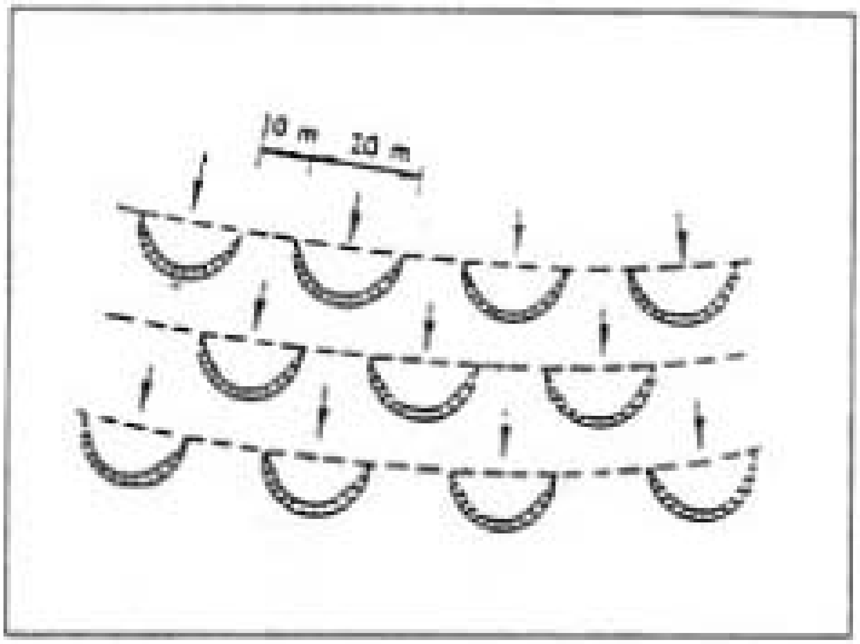

Figure 3. Semi-Circular Bunding (*10*).

Contour Bench Terraces

Contour bench terraces are built on slopes of 20 to 60 percent gradient in regions with 8 to 24 inches [200–600 mm] annual precipitation using natural slopes converted into a series of steps (*9*). Figure 4 shows different types of contour bench terraces. This technique is usually an adaptation of the large-scale techniques used for rangeland and cropland. Terracing of cropland today is a practice most familiar to many as ‘contour terracing’ and can be seen in many cultivated fields. This approach is also used in stormwater detention basins. Although typically intended to reduce downstream peak runoff flow, some basins incorporate porous bottoms to allow infiltration to the ground water.

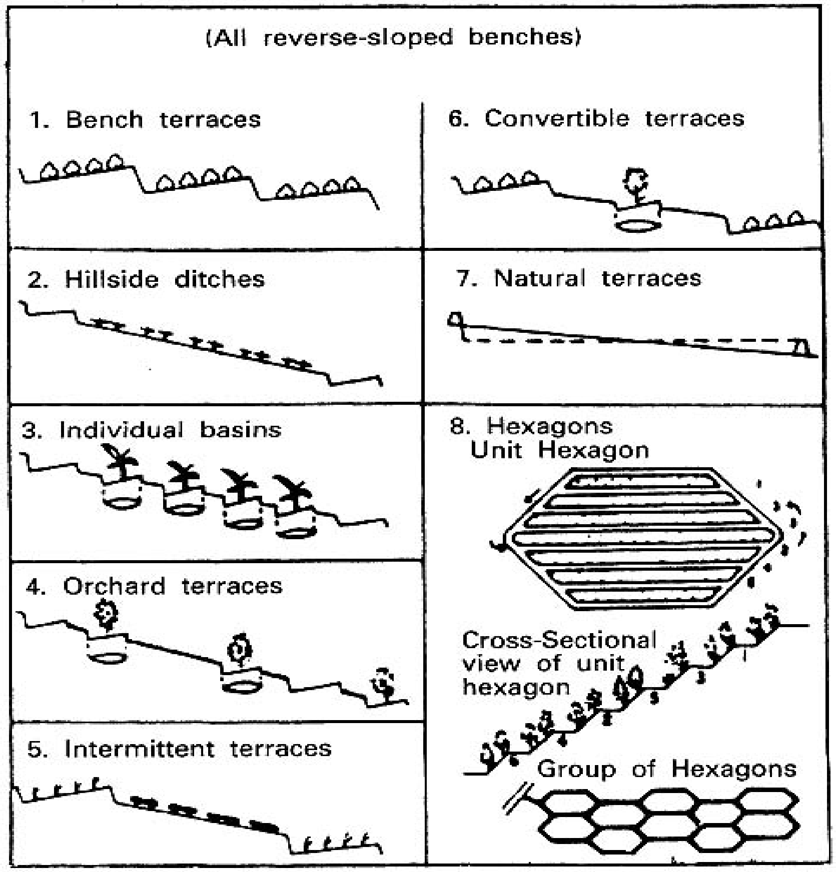

Figure 4. Contour Bench Terraces (*12*).

Conservation Bench Terrace Systems

The conservation bench terrace system developed at the U.S. Department of Agriculture's Agricultural Research Service Conservation and Production Laboratory (USDA-ARS) were designed with a 2:1 watershed-to-collection area. This system resulted in the collection area receiving about 30 to 50 percent more water from runoff from the watershed area. With impervious watersheds like road surfaces, the effective water in the collection areas can equal two or three times the annual precipitation, which allows a wider selection of possible plantings. Further, recently published research from West Virginia University (*13*) notes that stormwater runoff basins can be enhanced with vegetation to perform more like natural wetlands, and thereby improve runoff water quality. Broad terraces might (depending on slope, soil, and type of plants) create a stormwater runoff capture area that may improve water quality before it leaves the site as well as support a canopy of shrubs or trees.

Furrow Dikes

On relatively flat sections of ditches, shoulders and drainage areas, undulations of only a few inches can slow runoff over a wide area. To the eye these undulations would be imperceptible and to an errant vehicle they would be negligible. For example, USDA-ARS in Bushland, Texas, and other locations use furrow dikers, equipment that installs shallow basins 2 to 6 inches [50 to 150 mm] deep by about 20 inches [0.5 m] wide by 6 to 10 ft [1.8 to 3 m] long to decrease runoff and retain water on the soil surface, thereby increasing infiltration. This equipment could be adapted easily and used for parallel planting and seed bed preparation (i.e., mechanized micro-catchment). Clearly, soil type, roadside configuration, area, and safety issues are site-specific issues that need to be investigated. This approach would likely be very economical to install and would not pose an impediment to maintenance. One of the constraints in using micro-catchments is the lack of mechanized equipment to construct the catchments and the reliance on hand construction. Figures 5 and 6 provide a quick, non labor-intensive method to excavate micro-catchments that could easily be adapted to roadway ditches. The right side of Figure 5 shows stormwater detention for infiltration using the furrow dikes. The left side shows how the stormwater is not detained. Figure 6 shows a common furrow diker with tripping paddles.

Conditions conducive to positive crop responses to furrow diking on dry land are: 1) annual or intensive cropping, 2) large rainfall/runoff events occurring before or early in the growing season, and 3) limited growing season precipitation. Negative crop responses to furrow diking are usually due to poor weed control or retention of excessive water on the soil's surface that may cause aeration problems or restrict timely planting and tillage.

Figure 5. Furrow Dikes.

Figure 6. Typical Furrow Diker with Tripping Paddles.

Larger scale terracing and small basin may be suitable for use in establishment of woody vegetation in interchanges or other suitably large areas of roadside. Capturing the usually high runoff quantities found in interchanges might support ‘naturalized’ plant groupings. These plantings have been successfully installed in other TxDOT roadway landscape projects but have typically included piped irrigation systems.

Negarims

A negarim is a small diamond-shaped pond with low bunds. The runoff concentrates at the lowest point, where the trees are planted (see Figure 7). Most negarim micro-catchments are found on slopes of 1 to 5 percent gradient in regions with 4 to 16 inches [100–400 mm] annual precipitation (*9*). This physical method is often used to support single tree, bush, and crops in arid areas. The small basin is precise and neat, simple and cheap to construct. Negarims also collect runoff from small and low intensity storms within the catchment site (*11*).

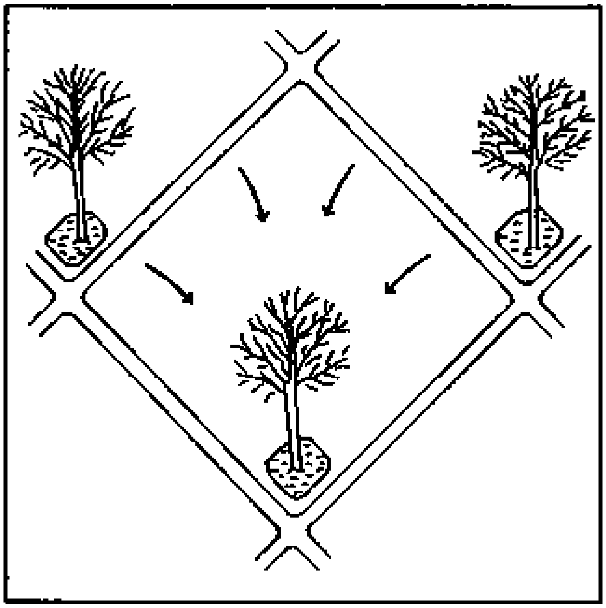

Figure 7. Negarim Micro-Catchments for Tree Irrigation (*11*).

Meskat Systems

Meskats are implemented on slopes of 2 to 15 percent gradient in regions with 8 to 16 inches [200 to 400 mm] of annual rainfall. The size of the meskat catchment is about 600 yd^2 [500 m^2] and surrounded by a 8 inches [200 mm] high bund with a spillway to concentrate runoff flow into the growing or crop area called the manka plots and drain surplus water (*9*). The site is divided into a distinct catchment part that is set above the crop site instead of cultivated areas and alternating catchments, as shown in Figure 8 (*10*).

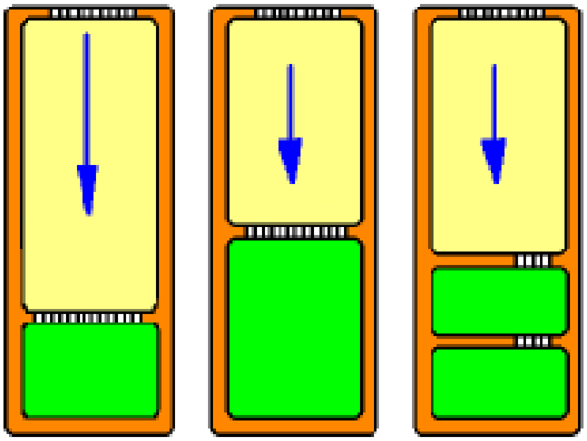

Figure 8. Meskat Type Bunding (*1*).

Infiltration Trenches

Infiltration trenches are typically several feet deep, in varying widths and employed to aid in groundwater recharge, peak discharge control, volume control, and streambank erosion control. Figure 9 illustrates a typical infiltration trench structure. Similar in concept to the smaller "French drains," trenches are rock-filled and designed to encourage rapid stormwater infiltration through the sides, ends, and bottom of the trench. Piping is sometimes included. This technique has not typically been applied to roadsides for vegetation enhancement, but the research team believes smaller versions may hold good promise. If the tops of narrower trenches are left even with existing grade, the recovery zone is kept clear for safety and maintenance access. The supportive capability of the drain is dependent on the type, sorting, and grading of the aggregate and how these relate to the existing soil. The questions of bearing capacity, depth, width, soil type, location, etc., will determine their potential. In areas that experience short-duration and yet sometimes high-intensity storms, a reduction in surface runoff may be very possible. If installed on a level gradient, it may be possible to use the system to distribute water over a large area, in effect creating an underground dike system.

Using this technique on roadsides may present problems. It would be difficult to implement on recently completed roadsides devoid of vegetation. Erosion would likely clog the trenches and render them ineffective. This technique would not work in roadways adjacent to cropped fields in areas prone to wind erosion. Again, erosion would cover the trenches and render them ineffective. The trenches will only work if the large pores in the gravel are open at the soil surface. So applying these on a level grade might prove to be a short-lived solution.

Trenches are soil-dependant in their suitability. Soils with a clay content of 30 percent are not typically recommended. Soils with a combined silt/clay percentage greater than 40 percent by weight may be prone to frost-heave and clearly not suited to some roadsides where this phenomenon occurs. Cost/benefit estimates have been found in the literature but are outdated and are based on large (6 ft × 6 ft [1.8 × 1.8 m]) trenches, so are not directly relatable to this research. However, the technique lends itself to fairly precise estimating so cost/benefit should be calculable.

Shallow Ripping

Shallow ripping is already a TxDOT-approved water harvesting technique; however, criteria for shallow ripping and optimum configuration have not been developed for arid regions. A variety of ripping equipment is readily available, and the practice is commonly used on arid upland rangelands to improve water harvesting and retention. Texas Agricultural Experiment Station researchers at San Angelo have demonstrated that ripping the soil about 8 inches [200 mm] deep perpendicular to the slope will support taller grasses and small shrubs, and contribute to the reclamation of degraded rangeland, even in drought periods. One concern, expressed by TxDOT engineers was the potential for surface disturbance by ripping and therefore potential safety implications. Ripping, using a press blade or rotary saw, may be more appropriate to reduce the excavation of large clods and surface crust monoliths.

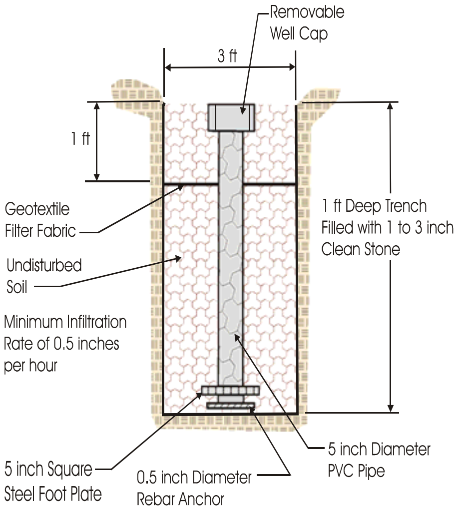

Figure 9. Typical Infiltration Trench (*14*).

Macro-Catchment Water Harvesting

Macro-catchment is the physical collection technique of runoff water in large catchment areas (see Figure 10). Macro-catchment size varies from 1200 yd^2 to 500 ac [1000 m^2 to 200 ha]. The type of catchment areas includes an overflow system or spillway and a catchment slope that varies from 5 to 50 percent. The water collected in these large catchment areas is normally used to irrigate crops located in terraces or in flat terrain (*11*).

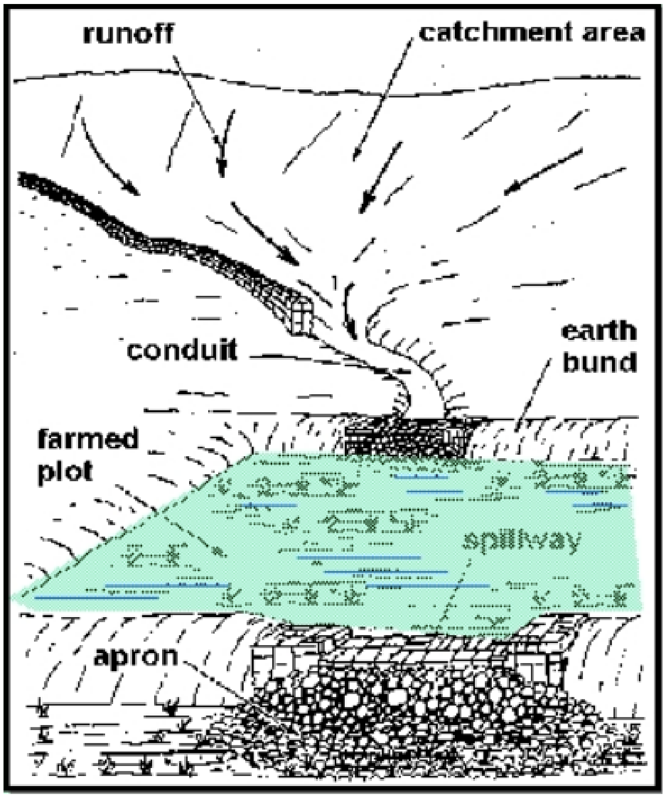

Figure 10. Macro-Catchment Technique (*15*).

Hillside Macro-Catchment

Hillside Macro-catchment is based on the capture of several runoff streams generated by groundwater or rainfall. The water captured is directed to a single channel and used to irrigate a specific area. Figure 11 illustrates the design and collection process of runoff.

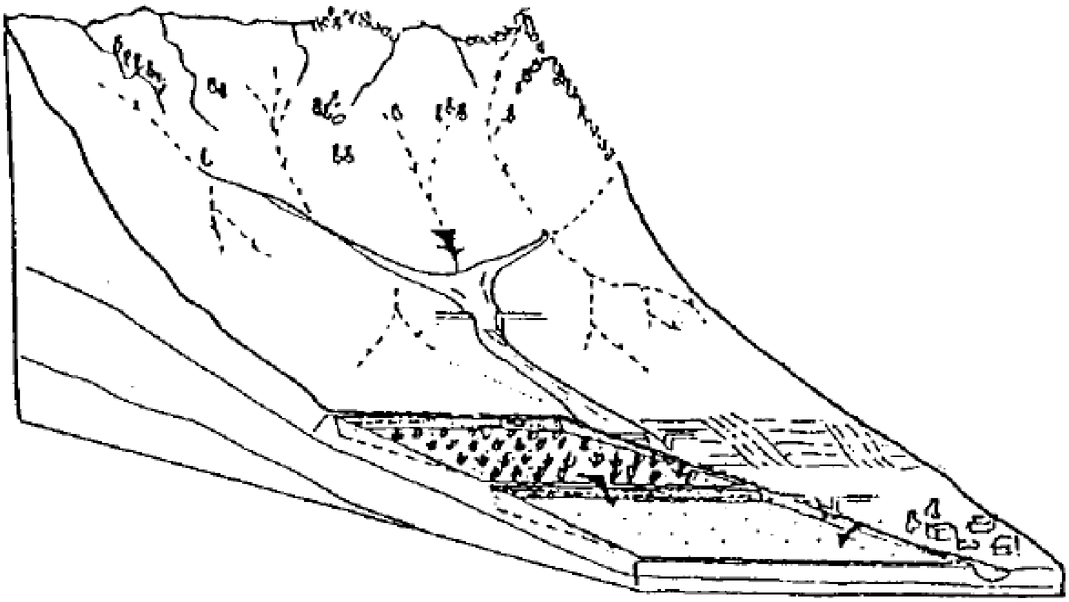

Figure 11. Macro-Catchment Hillside Conduit Technique (15).

Jessour System

A jessour is an area between earthen check dam sited progressively down-slope to trap eroded material from the valley sides (*16*). This method is widespread in countries like Tunisia, in areas where precipitation is less than 10 inches [254 mm]. Jessours are used to grow trees and annual crops (*17*). Figure 12 shows a diagram of jessours from different perspectives.

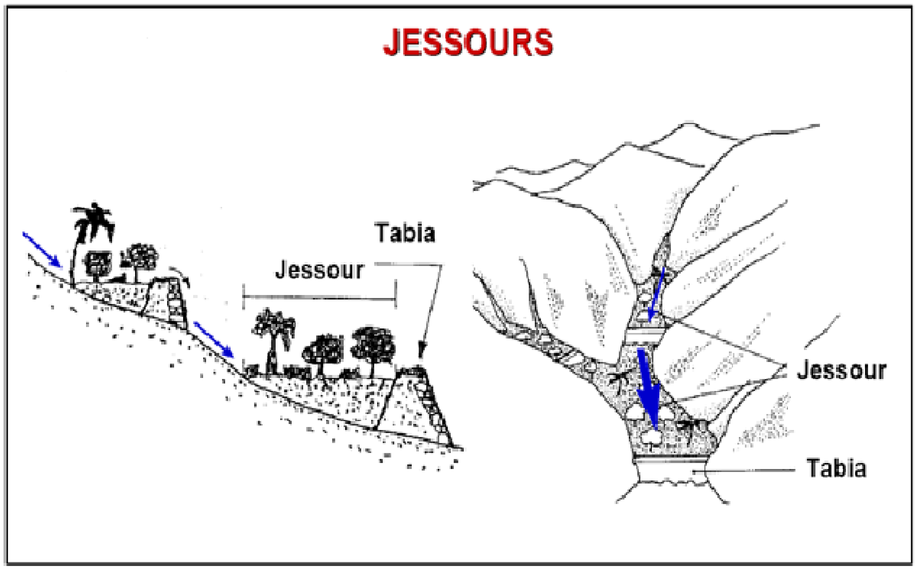

Figure 12. A Row of Jessours in Southern Tunisia (*18*).

Floodwater Harvesting System

Floodwater harvesting is implemented in dry areas and consists of catchments that are many square miles/kilometers in size. There are two major types: (1) floodwater harvesting within the streambed and (2) floodwater diversion (see Figure 13). The first type blocks the water flow so that it runs over the valley bottom of the entire flood plain. The second type forces water from the bed of an ephemeral stream to leave its natural course and conveys it to nearby sites suitable for cropping (*1*).

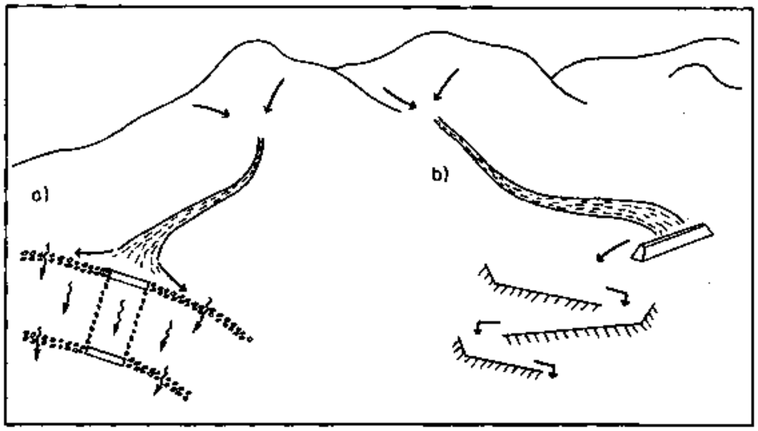

Figure 13. Floodwater Farming Systems: (a) Spreading within Channel Bed; (b) Diversion System (*11*).

Stormwater Best Management Practices (BMP)

There are other models found in the area of stormwater planning and management that can be effective in water harvesting. Some stormwater BMPs have been, or can be, adapted to water harvesting uses. Stormwater management manuals address flow attenuation or treatment.

Flow Attenuation

The primary focus of water harvesting techniques in rights-of-way should be on flow attenuation. Several published methods could accomplish this goal. Swales encourage slow, shallow flow (*19, 20*), and are often combined with vegetation in the swales to increase infiltration and filter the stormwater. Check dams may be used in conjunction with swales to enhance attenuation and infiltration (*20*). Check dams could be considered a type of infiltration berm designed to retain flow and encourage infiltration. Infiltration berms also may be used to direct flows. Retentive grading may be used in combination with berms to divert flows from channels toward shallow depressions that retain the flow or toward level spreaders (*20*).

Retention Basins

Another possible option practiced in some arid regions funnels water from the highway into a retention basin (sometimes the basin is an underground storage tank). The water in the retention basin can be used later in gravity flow drip irrigation systems to provide water to specific plantings downhill, such as tree groupings.

Wetlands

Wetland design and management is also a field that uses concepts of water harvesting. Using much of the same science as is found in the area of water quality, this field makes a more direct connection between plants and soil moisture.

INCREASING SOIL WATER HOLDING CAPACITY

These approaches focus on identifying biological treatments that increase soil moisture in the seedbed. These treatments include amendments that reduce or slow down the loss of soil moisture and alter the timing of seed germination to align with anticipated rainfall events. The use of soil amendments that may increase soil temperatures and retain available soil moisture to facilitate germination of warm season seed mixes in cool season can optimize the length of moist conditions for vegetation establishment.

Since roadside construction does not necessarily coincide with rainfall seasons, water retention is necessary to increase the germination rates on roadsides. Improving soil water retention requires consideration of the type and characteristics of the soil, infiltration and evaporation rates, and rainfall, among others. One of the terms used by the experts is available water content, defined as the "measure of the relative amount of water available in the upper levels of the soil strata, which is available for use by plants" (*21*).

Hydrogels and Polymers

New products have been created to improve water retention in soil. Hydrogel and superabsorbent polymers sometimes used to improve agricultural areas can absorb and store up to 400 times their own weight of water (*22*). On the other hand, these products must release the water absorbed from rainfall to plants until the next storm (*23*). These products have been tested in Spain (*24*) and Iran (*25*). This method increases the soil water holding capacity and improves germination rates. Hydrogels have been proven effective in different types of soils. The water retention of sandy soils may improve considerably, increasing the plant performance on those soils (*26*). On small scales, these products might be useful to enhance rainfall retention in the soil, especially on slopes that allow little runoff. The polymers absorb water as it infiltrates through the soil.

Soil Conditioning and Soil Amendments

Improvement of vegetation establishment depends on soil productivity and management of roadsides. Normally, roadside soils are residues from road construction and differ greatly from native soils where the road was constructed. These soils present challenges to promoting the germination of vegetation in roadsides (*27*). Furthermore, these soils are susceptible to erosion, which can eventually disturb road quality. Researchers at Virginia Tech University (*27*) evaluated different organic and inorganic compounds (amendments) to improve soil characteristics and vegetation establishment. Some of the amendments studied include compost, sewage sludge, paper mill sludge, and fertilizers, among others.

Mulching Technologies

Solar energy evaporates soil moisture brought to the surface by capillary action. Using mulch cover on bare soils in water harvesting ponds will reduce evaporation of soil moisture (*28*). The *Soil and Water Conservation Handbook* defined Mulch/Mulching as a natural or artificial material placed as a layer on the soil surface to help control erosion by water or wind or to improve soil water conservation. In many cases, mulch improves soil conditions, enhancing germination, plant establishment, and growth (*29*). Surface mulch, either organic or inorganic (besides holding the soil in place) lowers surface soil temperatures and prevents crusting. Crusting can occur when raindrop impact separates soil particles into very fine silt and clay particles that dry and settle over the surface as a thin layer. These tight layers can prevent water, air, and plant roots from entering the soil. Mulches absorb the energy of rainfall impact and prevent this soil separation.

Information on mulches can be found in TxDOT's *Guide to Roadside Vegetation Establishment* (*30*). Organic surface mulches include:

- hay and straw – agriculture residue,
- wood residue – chippings or residue from logging or clearing operations,
- hydro-mulching – a slurry of water and paper fiber to coat the soil, and
- fabrics and mats – organic materials such as wood shavings or woven papers in a mat fabric.

Mulching increases the time allowed for infiltration because it reduces runoff velocity, allowing more soil water storage. Mulch also decreases evaporation of soil water, extending the time water is available to plants. These characteristics improve vegetation establishment and growth.

Asphalt Emulsion

Asphalt emulsion may offer an opportunity to improve vegetation establishment. The emulsion may optimize both the establishment of vegetation as well as reduce soil erosion caused by high winds. A study conducted by the Colorado Agricultural Experiment Station (*31*) concluded asphalt improves the soil conditions and accelerates grass seed germination for the following reasons:

- The bitumen layer slows evaporation of water from the soil, making moisture available to the seedbed.
- The 'black' bitumen layer absorbs heat during the day creating enduring higher soil temperatures that encourage seed germination.
- The bitumen layer protects the seedbed from being displaced by wind, rain, and wildlife.

The study also examined the use of asphalt emulsion at coverage rates of 50 to 100 percent. Test plots of side-oats grama (Bouteloua curtipendula) and blue grama (Bouteloua gracilis) were drill seeded and sprayed with the two applications of asphalt emulsion on June 24. By June 30, six days after seeding, plants of both species had penetrated the asphalt cover while the untreated control plots did not produce any seedlings until late-July. By early August, less than 60 days after planting, many of the species treated with the asphalt emulsion were producing seed heads. The few plants in the control plots were small and spindly. During the following winter nearly all of the species planted in the control plots died. The species planted in the treated plots survived the winter and again produced seed heads the following spring.

The TxDOT Childress District has had success with using asphalt emulsions and has observed similar responses. The Childress District office is interested in optimum application rates and the potential for other less expensive surface amendments to improve soil germination temperatures.

Vegetation Establishment

Vegetation density improves soil water retention, decreasing the amount of runoff. As evidenced by the amount of effort and experience that has gone into the development of TxDOT's seed mix, plant selection is crucial to a successful vegetation establishment program. In many parts of the arid western United States, the dominant vegetation consists of low shrub vegetation and/or grassy vegetation. Shrubs have never been included as part of TxDOT's vegetation program, but populations of desert sage, four-wing salt bush, rabbitbrush, shin oak, etc., are native to Texas, although not to the extent found in New Mexico and Arizona. Certain water conservation initiatives would include the selective control and removal of plants and shrubs that use large amounts of water including mesquite, salt cedar, and ashe juniper.

Shrubs have a unique eco-function in desert environments. They provide shelter, allowing weaker plants to establish, and they help mitigate the effects of wind erosion by collecting windblown sand and silt at their base. Many water harvesting techniques are intended to concentrate runoff into a small area, sometimes as little as 1 yd^2 [1 m^2] to establish shrubs and trees. The research team determined that this synthesis study should look for unique vegetation alternatives that might be well suited to water harvesting.

When the USDA-Natural Resources Conservation Service (NRCS) initiated the Conservation Reserve Program to retire highly erodible cropland and plant permanent vegetation, researchers found that two seasons and a cover crop were essential to obtaining a good stand of grass in semiarid and arid regions. The most common practice involves planting a cool season cover crop such as wheat, triticale, or rye, in August or September, which will germinate with early fall moisture and establish a ground cover and root mass. In early spring, the cover crop breaks dormancy and is killed with glyphosate when it reaches a height of about

12 inches [0.3 m]. A permanent seed mix of warm and cool-season perennials is planted into the standing residues prior to the spring rains. The cover crop root mass improves the AWC of the soil, and the standing residues decrease evaporation, slow runoff, and increase infiltration. This practice is commonly used in semiarid and arid regions where there is a bimodal (early fall/early spring) rainfall pattern. In addition, the use of compost or other organic supplements can be used to improve the soil average water content; however, little information exists on the application rates, incorporation depth, and optimum application times for roadsides in semiarid and arid climates.

No matter which technique is used, in time the soil will revert to its former poor, closed condition, unless plant roots occupying the soil and compaction-causing conditions are removed or reduced. The key to maximum infiltration for the longest period of time is to establish grassy vegetation and promote management practices that prevent damage to the plants and to the soil.

Soil Organic Matter

Several TxDOT districts have developed innovative landscape development vegetation management techniques that seek to establish sustainable landscapes that require little if any supplemental water and utilize no chemical fertilizers. Techniques that utilize the environmental processes found in natural, self-sustaining and self-sufficient plant communities have been clearly demonstrated to minimize and restore development impacts on soil, reduce peak storm flows, and increase infiltration. These benefits are accomplished by utilizing the environmental processes that are the foundation for self-sustaining and self-sufficient plant communities found flourishing on their own outside the right of way. The Austin District first attempted this approach in 1993. Since then the Houston District has advanced this technique and greatly improved their success rate by experimenting with major soil modifications as part of the large-scale highway plantings and routine grass re-establishment on construction projects (*32*). One of the keys to this success is the incorporation of organic matter into the soil.

Over the centuries, soil organic matter has been considered by many as the most important soil characteristic. It is extremely important in all soil processes—biological, chemical, and physical. Of greatest importance here, however, is its effect on soil physical properties. It builds soil structure and increases the infiltration of water, which is a key to success in establishing vegetation on the roadside. In addition, the negative effects of compaction are reduced by increased amounts of soil organic matter. Perhaps even more important, soil organic matter tends to make very fine-textured soils behave like coarser-textured soils, and sandy soils behave like finer-textured soils. Also, capillary action is greatly enhanced by increasing soil organic matter content, particularly in sandy soils. Figure 14 shows the effect of increasing soil organic matter on the plant available water content of soils of varying amounts of sand, silt, and clay. This information is in agreement with Hudson (*33*) who reported that for each 1 percent increase in soil organic matter plant available water increased 3.7 percent by volume.

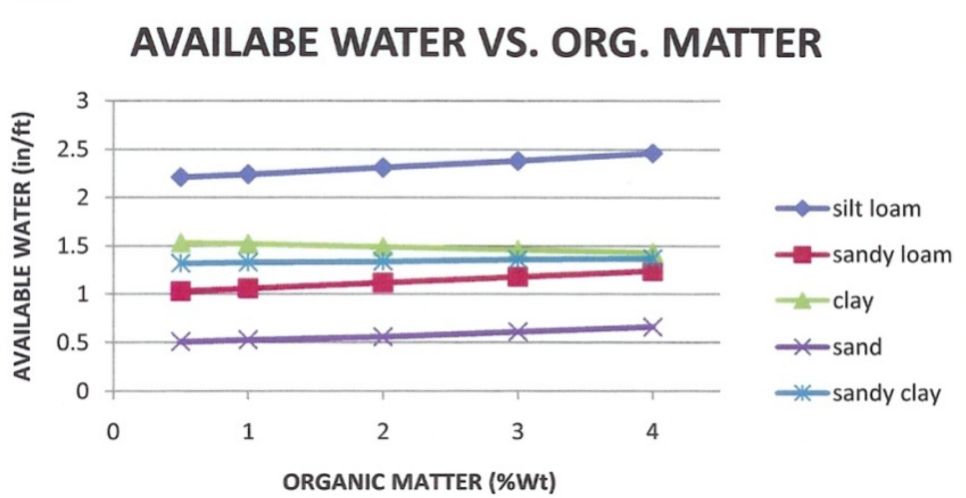

Figure 14. Effects of Increasing Soil Organic Matter.

Soil organic matter levels can be increased in a variety of ways, particularly in limited areas such as roadside rights of way. However, relatively large amounts of organic materials are required to have a significant effect. As a general guide, the top 6 inches [150 mm] of soil for 1 ac [0.4 ha] weighs approximately 1000 tons [907 metric tons]. Thus, a 1 percent increase in soil organic matter would mean an increase of about 20,000 lb [9071 kg] of soil organic matter. Soil organic matter is highly variable, but it is generally considered that the carbon compounds remaining in the soil after organic materials such as crop residues, manures, or composts have decomposed and are relatively stable. The carbon percentage of soil organic matter is approximately 60 percent, which means 12,000 lb [5443 kg] of "stable" carbon is required to raise the soil organic matter content of soil one percent. In contrast, crop residues contain about 40 percent carbon. Manures and composts are somewhat higher but usually still considerably lower than the 60 percent. Some compost may be as high as 55 percent carbon on a dry weight basis.

Adding these materials is the quickest way to increase the soil organic matter level, and since the materials in compost have been decomposed to the greatest extent, the carbon added with compost is the most stable. However, there will be additional carbon loss from compost after it is added to the soil before it reaches a more stable concentration of about 60 percent carbon (dry weight).

Figure 15 shows the significant effect that salinity can have on plant available water, so it is important that the salt content of compost be considered before large amounts are added to roadways. High sodium content in soils causes the soil particles to be forced apart chemically (deflocculation), which can result in surface sealing by reducing pore size, which in turn reduces infiltration and increases runoff.

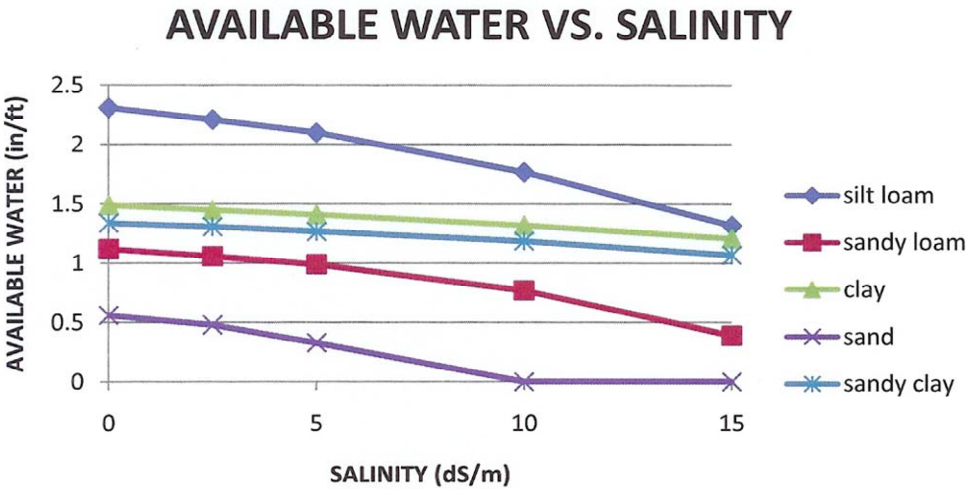

Figure 15. Effects of Increasing Salinity on the Amount of Plant Available Water in Soils of Varying Textures.

Based on this information and assuming water content of 40 percent, the addition of 20 tons [18 metric tons] of compost would add about 12 tons [11 metric tons] of dry matter, and if this is 50 percent carbon, this would add 12,000 lb [5443 kg] of carbon. However, over a period of a few months, some of the carbon will be lost as the compost is decomposed into a more stable soil organic matter. A conservative estimate is that 25 tons [22.6 metric tons] per acre of compost is required to raise the soil organic matter content of the top 6 inches [150 mm] of a soil by 1 percent. This is not to say that this much compost should be added, particularly in areas of low rainfall. The addition of large amounts of compost may add enough salt to the soil that many of the benefits of the added carbon will be negated by the salinity effect. The nitrogen in the compost may increase the growth of broadleaf, annual weeds, which germinate more rapidly and are more competitive than perennial grasses.

Figure 16 shows how the percentage of organic matter affects the bulk density of a soil. Soil bulk density measures total soil volume, which includes pore space. Soils that are loose, porous, or well aggregated will have lower bulk densities than soils that are compacted or non-aggregated.

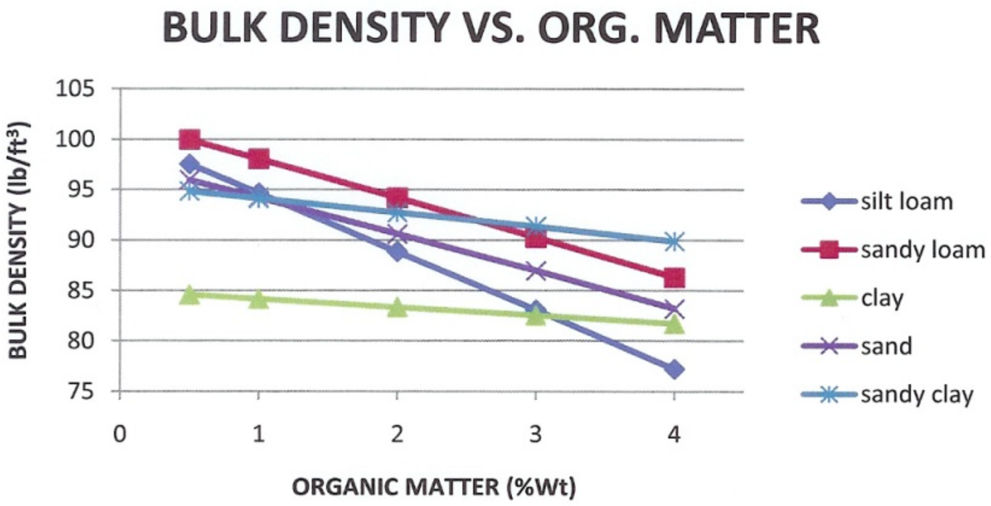

Figure 16. Effects of Increasing Amounts of Soil Organic Matter on the Dry Bulk Density Values with Varying Textures.

The above discussion shows the importance of soil organic matter but also shows the limitations. The use of compost or other organic materials on roadsides can aid establishment and maintenance of vegetation but will have a relatively small effect of harvesting or retaining water that runs off the paved surfaces. This is primarily because the water movement is simply too rapid for the soil to retain, even if it is relatively high in organic matter.

Capillary Movement in the Soil

Another benefit of increasing the soil organic matter content is that it significantly increases capillary movement of water. Capillary movement of water can aid in the wetting of roadway side-slopes whenever there is water at the bottom of the side-slope. Water rises more rapidly in sandy soils because the capillary conductivity of the larger pores is greater. Clay soil has small pores and attracts water more strongly than the sandy soil with large pores but transmits (drains) it more slowly. This means that clay soils will hold water longer than sand soils. When the soils are wet, water moves through the larger pores between the sand particles faster than it moves through the smaller pores in clay. However, water eventually rises higher in the clay soils because the pores are smaller and closer together due to forces of adhesion and cohesion. This is called capillary rise. Both the rate of water movement and the amount of water retention are related to soil pore sizes.

Water is almost always moving in soils. The two forces that affect the movement of water in soil are gravity and capillary action. When water is first applied to dry soil, it moves outward almost as far as it moves downward. However, as the soil becomes saturated, gravity becomes the dominant force moving the water downward. Capillary action refers to the attraction of water into soil pores by two types of attraction—adhesion and cohesion.

A possible strategy is to place small berms (bunds) in the channel at the bottom of the side-slopes to retain runoff water. Placing the berms perpendicular to the roadways would hold runoff water in the channels rather than diverting it away from the roads. Retaining this runoff water would allow infiltration to greatly improve vegetation in the channel and also would serve as a source of water to move by capillary action up the roadway side-slope to improve vegetation on the side-slope. The berms should be close enough together to retain the runoff water from a “somewhat typical” rainfall event, but they should be small enough that it would not greatly interfere with mowing and routine maintenance of the channels. They could be somewhat similar to “speed bumps.” The distance between them would depend on the slope of the channel area. For example, 1.5 ft [0.45 m] high berms would be required every 75 ft [22.8 m] in a channel with a slope of 2 percent. In the event of a large rainfall event, water would run over the berms and be diverted away from the roadway in the same manner as it would if there were no berms. The berms should be fairly stable once vegetation has been established, but there is always the possibility they could be destroyed if a large rainfall event occurs shortly after they are installed.

Supplemental Irrigation

Retaining soil moisture is extremely important for seed germination and appropriate development of plants. Supplemental irrigation is considered when climatic conditions hinder vegetation establishment. When rainfall is less than the annual average and a drier environment evaporates most of the rainwater (*34*), supplemental irrigation is beneficial, if available. As an example, the University of Florida established the following values: apply 0.25 to 1 inch [6 to 25 mm] per day for two to six weeks after sowing seeds, with the higher amounts and frequency in sandier soils. However, applying supplemental irrigation is probably not practical for large plantings (*35*).

INTEGRATED APPROACH

An integrated approach would combine and optimize/maximize water harvesting via physical options, maximize soil water retention or AWC using soil amendments, and identify both cool and warm season seed mixes and planting strategies. Each integrated approach must then pass TxDOT performance criteria including:

- vegetation cover requirements,
- roadside safety,
- low maintenance,
- implementation using readily available or easily adapted equipment,
- life cycle cost effectiveness, and
- roadside stability performance.

CHAPTER 3: CURRENT TXDOT PRACTICES

TxDOT has a detailed vegetation establishment process. This process is described in the *Guide to Roadside Vegetation Establishment* (*30*). The guide notes that "vegetative watering is intended to get you by until it rains" and "vegetation cannot be grown with a water truck." The guide goes on to note the importance of loosening the soil enough to provide a moisture reservoir.

Water is the essential ingredient for vegetation establishment and growth. Plants that manage to persist or thrive in arid environments have adapted to the scarcity of water but rarely to its complete absence. Establishing roadside vegetation in these areas must follow the dictates of the climate and soils—the source and the reservoir of water.

TxDOT currently employs three forms of water harvesting for plant growth. Although not large in scope, they are each designed to capture and/or conserve water in the soil. They include:

- vertical tracking of slopes to create micro-ridges that impedes runoff by allowing more time for infiltration;
- ripping of soils to create increased pore-space for infiltration, providing deeper water storage for plants;
- application of surface compost to prevent exposure to evaporation, impede runoff, and allow more time for water infiltration; and
- sedimentation ponds to collect eroded soil but also allow for infiltration, reducing the amount of water in the flow quantity.

Although some of these practices may have been developed with other goals in mind, their main goals are the control and use/direction of water. Most of these are associated with new construction and the need to meet the Environmental Protection Agency's requirements for water quality and erosion control (vegetation establishment). As noted in Figure 17 below, TxDOT constructed a series of berms (referred to as bunds in international literature) for the stormwater runoff to follow that effectively slowed down the water runoff, which contributed to the establishment of apparent vegetation.

Figure 17. TxDOT San Angelo District Construction Site.

CHAPTER 4: CASE STUDY SITES

METHODOLOGY

The research team used a case-study approach to identify the various constraints and issues found along the roadside based on the unique characteristics of location and off-site factors. Two roadway sites were selected for this project. The following format was used to identify and determine the two test sites:

1. The sites were selected based on their major classifications of soil/climate conditions. These sites include roadsides of differing configuration, size, and watershed properties such as runoff volumes, time of concentration, etc. Using existing base sheets provided by TxDOT, the team was able to accurately determine the size of the area selected.
2. All relevant factors within and adjacent to the sites were characterized.
3. An adaptation/design analysis of existing water harvesting techniques was conducted for each site. This process was not limited to known techniques found only in the literature, but new techniques were identified and investigated from fundamental technologies of water harvesting. The research team explored re-vegetation techniques currently used in roadside applications, as well as techniques used in agriculture and other international practices.
4. The techniques selected for investigation at each site were analyzed for their appropriateness and likelihood of benefit versus anticipated costs. Costs will be estimated from the scaled site plans using standard TxDOT estimating procedures for the specification items as listed in the Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges (36) in conjunction with the available Average Statewide and District bid price information.
5. The estimated cost of construction for the selected water harvesting techniques was discussed.
6. Suitable techniques were selected for the further development of guidelines for their usage, construction details, specifications, and standard sheets in a proposed implementation study.

BACKGROUND ON REGIONAL CLIMATE: TEXAS PANHANDLE

Figure 18 shows the long-term, mean precipitation for Amarillo, Texas, relative to the evapotranspiration (ET) and ½ ET. Note that during no week does the precipitation even approach half the ET requirement. For the year, the precipitation is approximately 0.2 to 0.25 percent of the ET requirement for the region. The majority of precipitation comes in the summer. At least 50 percent of the precipitation comes in the four summer months, June through September. If May and October are included, more than 70 percent of the precipitation is received in six months. Comparing Figures 19 and 20, Plainview has an earlier precipitation peak and more distinct later peak than Amarillo. This bimodal pattern is more pronounced at Childress. Figure 21 demonstrates that more than 75 percent of the years will have precipitation events exceeding 0.25 inches [6 mm], which are likely to cause some runoff. Figure 22 shows that most of the precipitation is received in events of 0.2 to 2.0 inches [0.0 to 51 mm], but events that exceed 2 inches [51 mm] are not uncommon.

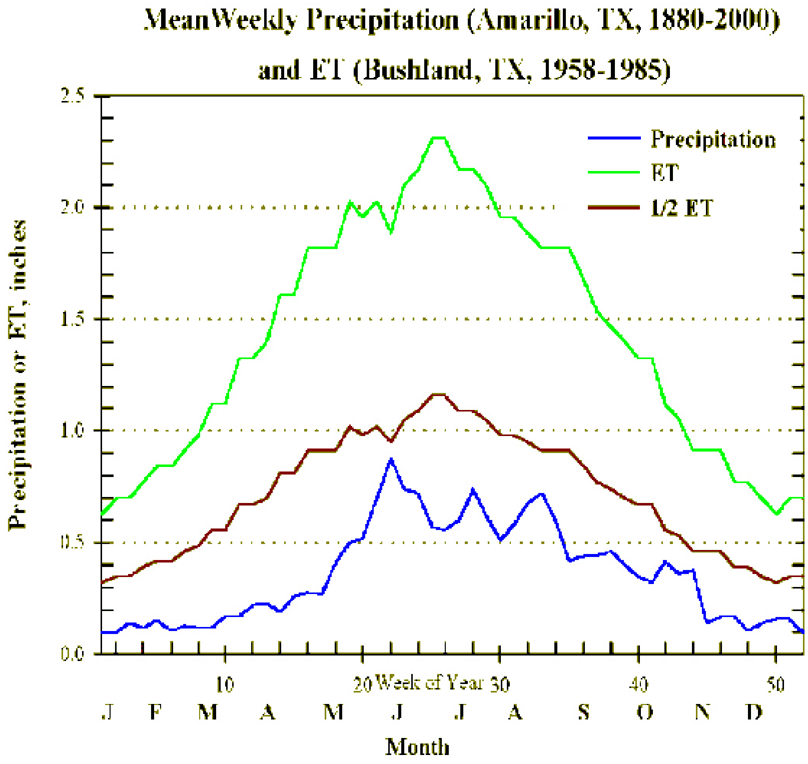

Figure 18. Mean Weekly Precipitation and Evapotranspiration for Amarillo, TX.

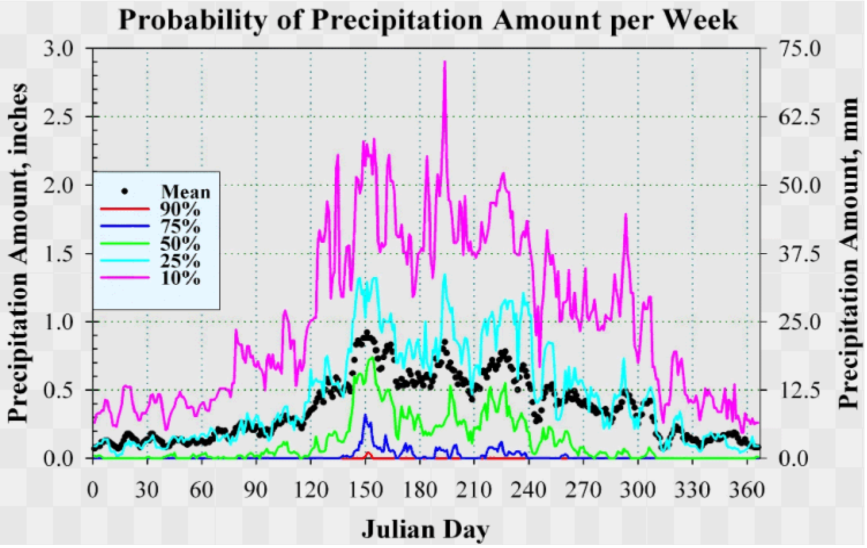

Figure 19. Probability of Precipitation Amount per Week in Amarillo, TX.

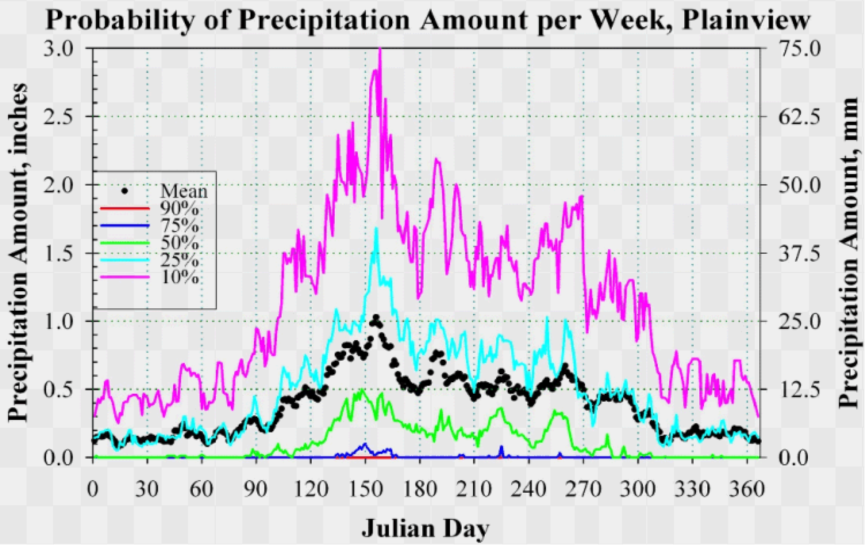

Figure 20. Probability of Precipitation Amount per Week in Plainview, TX.

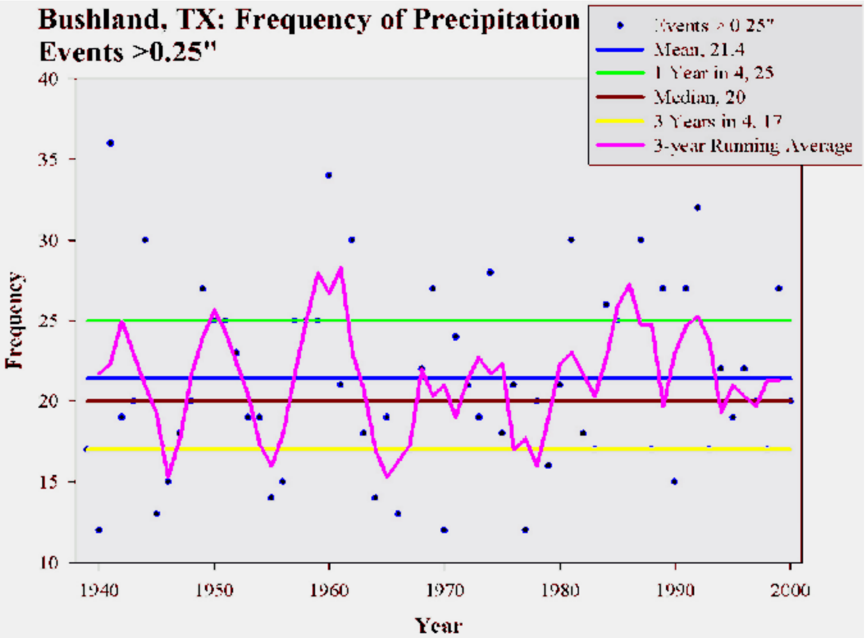

Figure 21. Frequency (Days) and Number of Precipitation Events of More than 0.25 inches in Bushland, TX.

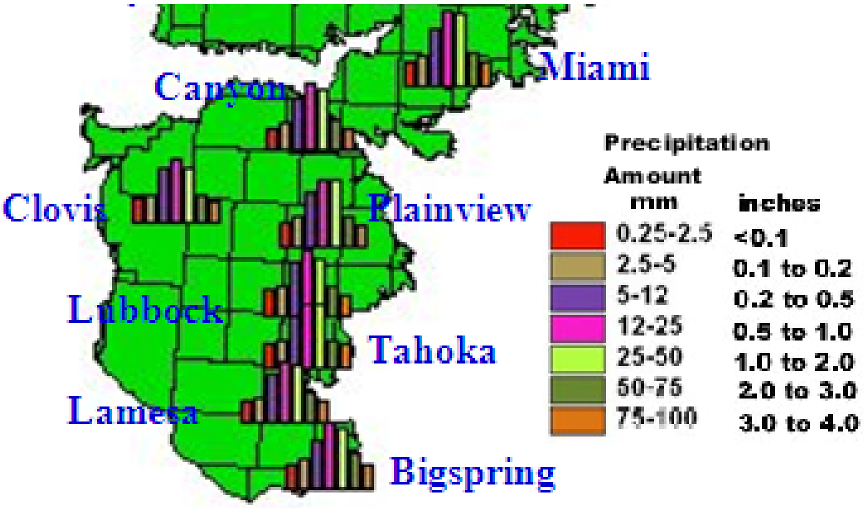

Figure 22. Precipitation Distribution by Event Amount Class.

STUDY AREA INFORMATION

The four sites investigated for use in this project were located in Childress, Canyon, El Paso (see Figure 23), and San Angelo. Based upon the site visits and analysis, two sites were chosen as case studies on water harvesting techniques: one in the Childress District and one in the Amarillo District (referred to as the Canyon site).

Figure 23. Possible El Paso Test Site.

Study Area #1: Childress, Texas

This area is located along US Highway 287 just west of Childress, Texas, and lies at the transition between the high plains and the rolling plains. The research team examined three separate sites within this area to ensure the site contained the right characteristics for data collection.

Childress District Area Engineers Interviews

Prior to collecting data at the site the research team met with Childress District engineers to discuss current water harvesting practices, successes, and difficulties, in order to gain a better understanding of the day-to-day difficulties in establishing vegetation in the northernmost part of Texas. These TxDOT engineers are challenged by having to address vegetation establishment in an area with low rainfall of 18 to 22 inches [0.46 to 0.56 m] per year that arrives in a bimodal period with the heaviest and most predictable rains falling in the early fall and early spring. Summers are typically very hot and dry. A summary of the soils, temperatures and rainfall can be found in Appendix A. The Childress District has a wide variety of soils to address from very sandy areas, heavy clays to rocky outcrops to the drainages that are characteristic to the rolling plains of Texas. After filing the Notice of Termination, TxDOT maintenance staff typically spends considerable resources in vegetation maintenance and final establishment to meet the

Texas Pollutant Discharge Elimination System (TPDES) Construction General Permit's requirements for a uniform (e.g., evenly distributed, without large bare areas) perennial vegetative cover with a density of 70 percent of the native background vegetative cover for the area on all construction sites.

The greatest challenge facing the district is the timing of rainfall and the seasonal temperatures. Rainfall occurs in the early fall at a time when it is too late to plant warm season grasses and returns in the early spring before the soil temperature has reached a level suitable for warm season grass seed germination. Once the soil temperatures have reached the seed germination temperature many of the rainfall events have passed, which allows only a short period of time for the warm season grass to establish and to develop a root system prior to the dry and hot summer months. Two options that offer great potential to biologically harvest water include:

- allowing seed germination earlier in the spring and
- taking advantage of the early rainfall events or options to store the early rainfall so that it can be used later in the growing season.

The district typically does not use truck watering and will do so only to take advantage of natural rainfall; for example, if a grass stand is beginning to establish and requires support until the next rainfall. It is never used to establish a stand. Truck water is used for establishment of trees and shrubs; however, at some sites it was evident that contractors had bermed around the trees to hold delivered water. These berms, if not bladed down, then direct water away from the trees. The Texas Panhandle is not heavily populated so access to water sources is also problematic, especially in view of the current transportation costs. Skilled contractors have the ability to deliver water to roadsides without causing additional problems of erosion and washout.

Field Data Collection and Observations

After visiting with the Childress staff, the research team from West Texas A&M University visited the Childress area (see Figure 24) and collected field data including location, elevation, and mean bulk density and infiltration, as shown in Table 1. Detailed information including grade, slope, vegetation, and data for each site is included in Appendix B.

Table 1. Location and Soil Characteristics of Childress, TX, Test Sites.

Location (WGS 84)		Elevation in feet	USDA Soil Texture (Surface)	Bulk Density g/cm^{-3}		Infiltration Inches/Hr
Latitude Degrees N	Longitude Degrees W			0-7.5 cm	7.5-15 cm	
34 26.757'	101 14.230'	1970	sandy loam	1.52	1.60	4.1
34 26.904'	101 15.998'	1961	sandy loam	1.32	1.55	5.9
34 26.269'	100 16.649'	1950	sandy loam	1.12	1.35	13.9

The USDA soil texture was consistent, ranging from 60 to 78 percent sand (mostly fine sand). The site lower on the landscape had 59 to 63 percent sand (mostly fine sand). Low bulk densities in the surface are due to presence of grass crowns/roots in the surface 3 inches [75 mm]. Site 1 had been recently graded and had less vegetation than Sites 2 and 3. Bulk density increased with depth at all sites, as would be expected, though the increase at Site 3 was less than expected. This result is probably due to macro-pores associated with the presence of Bermuda grass roots.

There was no infiltration limitation on these sites as noted by the 1 inch infiltration rates. The means exceeded 4 inches/hr [101 mm/hr] and only one measurement was less than 2 inches/hr [50 mm/hr]. The infiltration rates were highest on the soils with the lowest bulk densities and thick Bermuda grass vegetation. The level to slightly sloping areas were dominated by dense stands of Bermuda grass, and the areas with the greatest slope had scattered more drought resistant species, such as little bluestem and Old World bluestem. Another observation was that Bermuda grass occurred in the areas upgrade from the vertical road crossings, even in areas that would not typically support the Bermuda grass (>5 percent slope). This phenomenon was observed throughout the highway segment. One site was selected because it represented this characteristic. The site had a gravel median crossing with an elevation of 1.9 ft [.57 m]. The crossing had a culvert and was approximately 10 ft [3 m] wide with gradual sloping sides. It was evident that the crossing and the structure did not impair tractor mowing. Below the road crossing, the vegetation was dominated by clumps of bluestem. Above the road crossing was a healthy stand of Bermuda grass. The site was surveyed from the crossing to the extent of the Bermuda grass (see Table 2). It was noted that the 1.9 ft [.57 m] crossing or berm, even with a culvert, appeared to improve the grass stand for more than 625 ft [190 m] (elevation change equaled the berm elevation). Considering the infiltration rates, the apparent backwater effect of the road crossing had an apparent positive effect on vegetation establishment. It was observed that the effect of ponded water has a capillary effect on the ditches resulting in improved vegetative stand for approximately 1 to 1.5 ft [0.3 to 0.45 m] from the high water mark on the ditch sides.

Table 2. Media Survey above a 1.9 ft Elevation Road Crossing (Berm) in Childress District.

Bottom of Median Topographic Profile for Sites 2 and 3		
East to West in Meters	Elevation Change in Feet	Comments
0	1	Bluestem dominant
10	0.8	
20	0.4	
30	0	
40	0.6	
50	1.2	
60	1.6	
70	2.4	
80	3	
90	3.2	
100	**3.3**	
110	3.4	
120	3.4	
130	3.6	
140	**3.8***	
150	3.98	
160	4.15	scattered Bermuda grass begins
170	4.35	
180	4.6	
190	4.83	full Bermuda grass coverage
200	4.92	
210	5.1	
220	5.1	
230	5.14	

Table 2. Media Survey above a 1.9 ft Elevation Road Crossing (Berm) in Childress District (continued).

Bottom of Median Topographic Profile for Sites 2 and 3		
East to West in meters	Elevation Change in Feet	Comments
240	5.24	
250	5.25	
260	5.4	
270	5.43	
280	5.45	
290	5.45	
300	5.6	
310	5.65	
320	5.8	
330	3.9*	top of berm

*Berm elevation and elevation of ditch bottom up-gradient attaining the berm elevation

Study Area #2: Canyon, Texas

This area is located in the Amarillo District in Canyon, Texas. Five sites in the US60/87 interchange (see Figure 25) were evaluated. Three samples were collected at each site. Table 3 provides the location of the center evaluation in each site. The USDA soil texture was determined using the hydrometer method (*37*). Additional visual observations were made on the wetting front advance and observed preferential flow as the infiltrometers were removed from the soil. The surface soils had moderate to fine textures. The wetting front never reached the bottom of the infiltration cylinder by the time the water disappeared from the soil surface. Preferential flow was observed at some sites to the bottom of the soil in the infiltration cylinder.

Table 3. Location and Soil Characteristics of Canyon, TX, Site.

Location (WGS 84)		USDA Soil Texture (Surface)	Bulk Density g/cm^{-3}	Infiltration Inches hr^{-1}	Wetting Front (wf)	Preferential Flow (pf)
Latitude Degrees N	Longitude Degrees W					
34 59.241'	101 55.310'	sandy clay loam	1.26	13.1		
34 59.207'	101 55.311'	clay loam	1.29	4.8		
34 59.232'	101 55.299'	loam	1.34	7.2	<8 cm	8 cm
34 59.269'	101 55.190'	loam	1.42	5.9	<6 cm	n/a
34 59.327'	101 55.206'	sandy clay loam	1.30	2.8	<6 cm	8 cm

Figure 24. Childress Site at US 287.

Figure 25. Aerial Photo of Canyon, TX, Site.

The 1-inch infiltration rate was determined using a falling-head method. The bulk density was determined using 4.6 inch [117 mm] (inside diameter) × 3 inch [76 mm] cores. Visual estimates of the vegetative composition and cover were recorded. The surface (0–7.5 cm) bulk density ranged from 1.13 to 1.47 Mg m^{-3}. The infiltration rates ranged from 0.9 to 18.0 in/hr [23 to 457 mm/hr]. The subsurface bulk densities where collected were greater than the surface bulk densities, which was true of the Childress sites as well. However, the soils were very dry, as no measurable precipitation had been received for three months at the time of sampling. In these very dry soils, the wetting front seldom penetrated to the bottom depth of the ring within 30 minutes after all water had infiltrated.

Study Site Comparisons

As the subsurface bulk densities are higher than the surface, it is likely the subsurface bulk density is a controlling factor for initial infiltration. A correlation analysis used helped determine the relation of various factors to infiltration. At Canyon, the sand content was weakly, positively correlated ($r=0.31$), and the clay content was weakly, negatively correlated ($r=-0.25$) with infiltration rates. At Childress the surface silt content was positively correlated ($r=0.74$), and the surface clay content ($r=-0.71$), surface bulk density ($r=-0.51$), and subsurface bulk density ($r=-0.61$) were negatively correlated with infiltration rate. Figure 26 demonstrates predicting infiltration based on these properties would be difficult. Infiltration decreased slightly with increasing clay content, increasing bulk density.

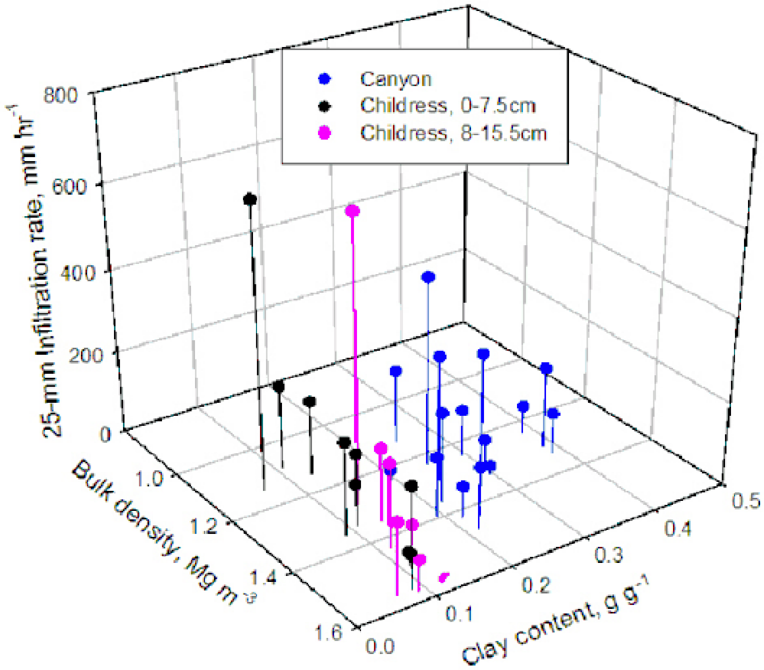

Figure 26. Comparison of Infiltration Rates and Bulk Density/Clay Content.

Even the lowest infiltration rate of approximately 1 inch [25 mm] hr^{-1} is not limiting to water harvesting techniques. Greater overland flows were caught in retention structures because of low infiltration. Once in those structures, infiltration would slowly occur. The US60/87 interchange offers many opportunities to implement water harvesting techniques that potentially would improve vegetation establishment and maintenance, and decrease runoff volume and sediment loads crossing roadways and entering waters of the United States. The ponded falling-head infiltration method used does not mimic natural precipitation conditions.

Table 4 combines the vegetative cover from both the Canyon and Childress sites. It suggests vegetation has an impact on infiltration rates. Though the number of observations was limited for the extremes, a pattern emerged. Sites with Bermuda grass cover had higher infiltration rates, followed by blue grama and bluestem cover, while buffalo grass cover had the lowest. The bare site had the lowest infiltration rate, but with only one observation, that conclusion is not reliable.

Table 4. Vegetation and Infiltration Rates.

Vegetation	Number of Observations	Infiltration, inches hr^{-1}
Western wheatgrass	1	18.0
Bermuda grass	4	12.2
Bluestems	6	7.1
Blue grama	3	7.2
Buffalo grass	9	4.5
Bare	1	<1.3

Though under ponded conditions, the initial (1 inch [25 mm]) infiltration rates appear adequate, during natural precipitation events, water will flow across the surface on these graded sites. None of the Canyon sites evaluated were in locations where water would pond. The elevation is highest along northbound US60 as the grade increases to cross over northbound US87. The natural elevation decreases from southwest to northeast toward Palo Duro Creek.

SUMMARY

As evidenced by centuries of success water harvesting is an effective method of intercepting stormwater runoff and putting it to beneficial use. Water harvesting typically offers a low cost, “passive” means of increasing the amount of water available to plantings. As shown in the preceding literature review, intercepted stormwater can be slowed down, retained, and collected by manipulating the surface of the ground by simply scarifying, ripping, or adding micro catchments and/or swales. The reason these techniques are successful is because they each accomplish one simple strategy: they increase soil infiltration rate by slowing down the runoff or improving soil characteristics.

The fact that highways and roadways are impervious results in large amounts of water runoff. In spite of surplus water, vegetation adjacent to these roadways is often lacking or suffering from severe water stress. This lack of water is particularly true in semiarid and arid regions. Even in these areas, however, there is sufficient runoff to support enough vegetation for roadside stabilization and aesthetic value if the runoff is harvested and retained. Harvesting is difficult because the water runs off quickly and the roadsides have significant slopes. Therefore, most of the water enters the channels and then in most cases drains to areas away from the roadways. Ideally, as much water as feasible should be retained on the slopes immediately adjacent to the roadway. Terraces or berms parallel to the roadway would be effective but are generally not acceptable because of safety concerns. Therefore, the best strategies slow water movement down the roadside to the extent feasible and increase the water holding capacity of the soil. This method should be complemented by trapping as much water as practical in the channel in the median or along the roadside. Trapping water in the channel would be beneficial for two reasons. First, it would wet the soil in the channel sufficiently to support vegetation in the channel. Second, it would hold water long enough so that significant amounts of water move up the roadside slope by capillary action. Treating the roadside soil to increase the water holding capacity of the soil is how this is done.

Substantial amounts of water could be harvested from roadways. However, there is considerable cost in designing and developing a satisfactory system. Such a system requires substantial management in order to effectively utilize the harvested water. Water harvesting should be utilized in special cases rather than for general use. Water could be harvested into a rather large basin where trees are growing. In such a system, an overflow would be required so that trees would not be subjected to flooding. In other cases, water could be retained in a large basin and then used as a supply for a drip or sprinkler irrigation system. The cost-benefit ratio would be difficult to establish because there are few guidelines on establishing the benefit derived from improved beauty associated with trees, shrubs, and other vegetation along highways and roadways.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Water harvesting offers potential benefits to the overall highway system in that it helps reduce the environmental impact of the system while helping to improve the roadway's function. The challenge in the arid portions of Texas is to maximize limited periodic and seasonal rainfall by developing cost effective, site specific, and integrated implementation strategies. Unfortunately, there is no single solution when it comes to solving water/irrigation problems in these difficult locations. However, there are several 'tried-and-true' methods available to the designer to encourage moisture availability to vegetation.

To determine the water harvesting techniques that will be most successful on a site, several characteristics must be evaluated. For obvious reasons rainfall characteristics, such as minimum annual rainfall, average annual rainfall, and peak rainfall intensity, must be determined. Site physiographic characteristics including existing vegetation, soil slope, and type are factors in determining which techniques will be most successful on a site. Based on the evaluation of site characteristics and interviews with key TxDOT personnel, the following ideas are recommended as water harvesting techniques in the two case study areas.

STUDY SITE #1 CHILDRESS

Asphalt Emulsions

The Childress District has had excellent success using asphalt or bitumen oil emulsions. One observation made by the staff was that when they applied emulsions early in the spring, the warm season grasses appeared to germinate earlier. The staff suggested that possibly the black emulsion was both absorbing heat during the day and retaining it during the night thereby increasing soil temperatures at a time when they receive the early season rainfall. Emulsion vendors, producers, and associations have stated that emulsion can aid in seed germination by increasing soil temperatures and preventing soil moisture loss by evaporation. The publications also state that the cover can reduce wildlife depredation on the seed bed and reduce loss of seed due to wind erosion. In discussions with the Childress District staff, the benefits have been observed, but they have not found quantitative data to support their observations. They would be interested in seeing additional work on these benefits.

Improved Infiltration

Options such as ripping may be effective in some areas but due to the compaction of the roadbeds and construction sites, ripping would compromise safety by yielding large soil crust fragments. The high clay content in some areas would also reduce the long-term effectiveness of the ripping.

Recommendations

After examining safety, cost, and maintenance, a practice of installing 1 to 2 ft [0.3 to 0.6 m] berms constructed in a manner similar to maintenance crossing with gravel cap with and without culverts is recommended. If constructed without culverts, the berms would need to include either rap or gravel caps to prevent erosion. According to local TxDOT engineers it was determined that the berms could be constructed with grades that would not interfere with safety, mowing, and maintenance. It was concluded that the berms, if included in the original design and construction, would not appreciably increase the project cost. Considering the difficulty that contractors have in establishing the required vegetation, it was decided that most contractors would be receptive to this application. Additional investigation is required to develop detailed cost-benefit data on the use of perpendicular low level berms, but the Childress site provides substantial observational support for berms to be considered as a water harvesting option. Based on estimates using the Childress site road profiles, water infiltration and vegetation establishment could be improved on up to 80 percent of the roadside establishment area.

STUDY SITE #2 CANYON

Application of appropriate stormwater best management practices would facilitate water harvesting while attenuating flow during storm events. The best candidates for this site include infiltration berms, retentive grading, and level spreaders (*19, 20*). An infiltration berm could be utilized to divert concentrated runoff from concentrated-flow channels to the landscaped area, which would serve as a level spreader. A variation would be to divert the water to a shallow depression to concentrate water infiltration for vegetation that requires more water.

Most of the trees are located within small, ringed berms, apparently constructed at planting time to allow truck watering. This practice now limits the amount of water available to the trees, since surface runoff is diverted around the trees. Small diversion channels could be constructed with a low (0.5 to 2 percent, or 200:1 to 50:1) grade to slowly redirect surface flow toward the landscaped area in the median. The frequency of these diversion channels would be a function of the overall grade, e.g., the frequency would be greater along the southeast as US60 grades to cross US87 than along northbound US60. Approximate graded lines were drawn on the satellite photo to illustrate the concept (see Figure 27). Since they are constructed along the grade, these diversion channels also would capture some lateral surface flow. Ideally, trees and shrubs would be planted at intervals along the diversion channels.

Figure 27. Conceptual Diversion Channels along Approximate Graded Contours at Canyon Site.

The lines east of US87 are drawn along approximate contours on a steep grade. The vegetation on this slope is minimal, and high intensity precipitation events erode soil through sheet and rill erosion, and deposit sediments on the roadway (US87N to US60W circle). Mini-terraces (retentive grading and infiltration berms) perpendicular to the slope at regular intervals would limit, or prevent, such erosion. Further, planting shrubs or ornamental grasses in the bottoms of the terraces would stabilize the slope while improving the aesthetics of the right of way.

For maximum effectiveness to provide water for vegetation in the right of way, these diversion channels should be designed to capture surface flow from a 24-hour precipitation accumulation, 10-year recurrence interval (*38*). Other design considerations include the soil hydrologic group and selection of the runoff coefficients for the rational method, Q = CiA (*38, 39*). Most Texas High Plains upland soils are in Hydrologic Soil Groups B and C, with the fine sandy loams and loams in Group B, and clay loams in Group C. The runoff coefficient selected should consider vegetation, as noted by the differences in mean infiltration by dominant vegetation. The runoff coefficients in standard tables range from approximately 0.2 for flat, native grass pastures to 0.8 for rights of way adjacent to pavement (*39, 40*).

DISCUSSION ON COST AND BENEFITS

As with any cost-benefit discussion, accurate cost analysis is made easier using regionally accurate, up-to-date records. Benefit analysis, on the other hand, often proves to be more difficult due to the fact that determining benefits is typically more subjective. Combine this subjectivity with rainfall predictions and it is easy to see the difficulty in applying this to water harvesting. However, there are predictors that can assist in making these decisions.

Cost will be relative to the degree and type of mechanization required and whether or not new structures are needed. In some cases multiple techniques may be used on the same site or in conjunction with each other. Considering the cost of emulsion at $11.00 per gallon [$2.90 per liter] and the TxDOT application rate the resulting cost is approximately $10,648.00/acre [$26,300 per hectare], its use would be restricted to the early spring planting to maximize soil temperatures to take advantage of the early spring rains in March and early April (25 percent of the annual rainfall occurs in March, April, and May) to increase soil temperature and to encourage early seed germination.

The least costly method of capturing and using rainfall is to use it where it falls and avoid trying to move it someplace else. Compost cost, approximately $12 to $15/ton [$10.80 to $13.50/metric ton], is directly influenced by the haul distance and local delivery rates. The increased soil water retention of up to 20 percent could more than offset the cost over time. One problem has been the availability of compost meeting TxDOT specifications within a reasonable distance of the planned project. More TxDOT-approved vendors are needed throughout the area to provide sources in close proximity to TxDOT projects. Vendor education programs could be conducted to provide potential vendors with the TxDOT specifications as well as providing orientation to vendors on TxDOT's vendor approval procedures.

Using the Plan Profile diagrams provided by TxDOT and assuming a berm height of 2 ft [0.61 m] and an area of influence equal to the area rise and assuming no berms in depressions, the 3.18 mile [5.18 km] project would require from 25 to 30 berm structures for each ditch and median for a total of 75 to 90 berm structures. It is difficult to estimate the cost of the structures. Local materials would be used in the construction of the berms with the additional cost of adding gravel or other erosion features. Considering a berm width of approximately 30 ft [9.1 m] at the top, approximately 10 ft [3.04 m] wide with 6 inches [0.15 m] of gravel material cap, less than 16 cubic yards [12.2 m^3] of berm material and 5 cubic yards [3.8 m^3] of erosion cap would be required. Due to the low infiltration rates for scraped areas or recent construction areas, the dramatically improved infiltration rates on well vegetated areas, the low rainfall in the area and TxDOT's requirement to meet the Clean Water Act re-vegetation requirements the berms and optional features discussed above should be considered. Additional field studies are needed to verify the cost effectiveness of the berms and other recommended water harvesting options.

CHAPTER 6: IMPLEMENTATION

The results of this research have far-reaching applicability for TxDOT in maintaining regulatory environmental compliance. The research results directly impact the establishment of vegetation in arid areas which, in turn, affect the compliance of the Texas Commission on Environmental Quality Construction Stormwater General Permit.

Water harvesting (although an ancient and proven technology) has not been applied to the highway roadside for the use this project intends to accomplish. A site-based case study would provide a clear picture of the extent and implications on real sites and allow the research team to estimate both the added benefits and costs. An implementation study would provide the hard data needed to further accurately gauge benefits and costs. The study would also provide a demonstration example of the technology that can be used to explain the concepts and techniques to TxDOT personnel responsible for implementing them on future construction projects.

The research team recommends an implementation project using the findings of this synthesis research. The team proposes that active highway construction sites be identified and an appropriate water harvesting technique be installed on the project.

GUIDELINES FOR THE IMPLEMENTATION STUDY

1. The team and the research committee will select a set of construction projects that coincide with the timeframe allotted for the implementation study. The research team will conduct a review of each project and each site. The team will then design a water harvesting system for committee approval to be included in the project.
2. The costs for the installation phases may be paid with funding allowed in the implementation project budget, already allocated construction funds for earthwork, or other suitable pay items included as a change order or separately funded from other funds determined by the committee. Representatives of the research team will oversee the installation procedure.
3. A control area will be selected in each project against which the new technique will be compared. The sites will be compared using the following parameters:
    a. response of seeded vegetation,
    b. soil moisture content at varying depths and locations on the site,
    c. effects on runoff quantity, and
    d. installation costs.

These guidelines are preliminary and will be modified as necessary based on the approval of the committee.

Implementation Project Deliverables

The deliverables of the implementation project will include a report documenting the plan work, estimates, specifications, and costs.

Proposed Implementation Project Format and Testing Procedures

The ideal site should have the potential for improvement in infiltration rates, moisture retention, and optimizing warm season grass to take advantage of the early spring rainfall events under the following project completion scenarios. These scenarios are generic in design and may be implemented in most arid areas of Texas that are characterized by the ideal site description mentioned above. Actual implementation and procedures will be site specific and determined once implementation sites are identified.

Project Completion November 1–May 30

Install 2 ft [0.6 m] perpendicular berms (located at 2 ft [0.6 m] elevation drop points as designed), plant warm season permanent mix, soil preparation compost, or other organic material to improve soil water retention. Once seeding operation is completed, disc the soil per TxDOT specifications and apply emulsion (black bitumen) for early spring prior to April 15 and other less expensive additives to hold soils from wind and water erosion after that date.

Project Completion June 1–July 31

Install 2 ft [0.6 m] perpendicular berms (located at 2 ft [0.6 m] elevation drop points as designed), plant warm season temporary mix, soil preparation compost, or other organic material to improve soil water retention, disc the soil per TxDOT specifications. (Early June temporary plating—terminate warm season temporary and seed permanent warm season mix up through September 30). If warm season, temporary species is established no emulsion or soil stabilizers would be required.

Project Completion August 1–October 30

Install 2 ft [0.6 m] perpendicular berms (located at 2 ft [0.6 m] elevation drop points as designed), plant cool season mix, soil preparation—compost or other organic material to improve soil water retention, disc the soil per TxDOT specifications. Terminate cool season early April and no-till plant warm season permanent mix. No emulsion or soil stabilizers would be required.

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APPENDIX A:
SUMMARY OF SOIL, TEMPERATURE, AND RAINFALL FOR PROJECT TEST AREAS

High Plains, Llano Estacado, Staked Plain

A broad, flat, treeless, upland plain — essentially a huge mesa

- Elevation
    - N-S transects, east escarpment
        - 2600 to 3200 ft S of the Canadian River, decreasing to the south
        - 2800 to 3000 ft N of the Canadian River, decreasing to the north
    - N-S transects, west escarpment
        - 3000 to 4800 ft S of the Canadian River, decreasing to the south
        - 4200 to 5000 ft N of the Canadian River, increasing to the north
    - E-W transects
        - North escarpment, 5000 to 2800 ft, decreasing to the east
        - N rim, Canadian River, 4500 to 3000 ft, decreasing to the east
        - S rim, Canadian River, 4800 to 3200 ft, decreasing to the east
        - South escarpment, 3000 to 2600 ft, decreasing to the east

About 20,000 square miles [51,800 km^2] in the Texas and Oklahoma Panhandles, eastern New Mexico, and southeastern Colorado

- Cut off on the west and south by the Pecos River valley;
- Drained on the east by the headwaters of the Red, Colorado, and Brazos Rivers;
- Dissected in the middle (west to east) by the Canadian River;
- General slope is about 1 ft per mile to the southeast; and
- Since the landscape is young, there are few streams or rivers, and most water runs into local depression, basins called "playas," which range in size from less than an acre to a few sections. There are 15,000 to 20,000 playas in the High Plains. Playas are smaller and more frequent in the southern High Plains, and larger and less frequent in the north.

The climate is characterized by extremes.

- The annual rainfall ranges from about 14 inches [350 mm] in the west to about 20 inches [500 mm] in the east (increasing about 1 inch [25 mm] for each 25 miles), with dry winters and summer rainfall (50 percent of annual precipitation occurs in May–August, 13 percent from November–February).
- The maximum historical rainfall is about twice the mean, and the minimum is about half.
- Most precipitation comes in thunderstorms, which can dump >2 inches per hour. Some

town or area in the region usually receives 25 percent of the mean in one storm each year.

- The temperatures are mild in the winter and hot in the summer. Diurnal swings of 30°F [15.5°C] are not uncommon in the spring and fall. When a norther (continental polar cold front) comes in the winter, temperature changes of 60°F [32.5°C] may occur within an hour.

The evapotranspiration (ET) rate is among the highest for any inhabited region in the world. Measured values of 0.75 inch [18 mm] per day have been recorded in May. Winter ET averages 0.1 in d^{-1}, while average daily spring and fall ET usually exceed 0.2 inch [5 mm]. The daily average ET from about April 15 to September 15 exceeds 0.25 inch [6 mm], with the daily ET in June and July exceeding 0.30 inch [7.6 mm].

At least three factors contribute to the high evapotranspiration rate in the High Plains: clear, sunny days, low humidity, and constant winds. The average wind speed for the region is between 17 and 18 mph [27 to 29 k/h] (24/7/365). “The Windy City” of Chicago only has an average wind speed of about 15 mph [24 k/h]. Chinook winds dominate the spring weather patterns as hot, dry, downslope winds come from the southwest.

Palo Duro Canyon is the largest canyon system in Texas and the second largest in the USA. The most famous landmark in Palo Duro Canyon is the Lighthouse Rock formation. The canyon marks the eastern extent of the High Plains and the beginning of the Rolling Plains. The High Plains escarpment, or “Caprock,” rims the High Plains on all sides. The escarpment is formed by Ogallala caliche at the top of the Ogallala formation. This formation is covered with windblown sediments on the uplands to the west in which the soils formed.

Below the Ogallala sediments are sediments of the Dockum group (late Triassic), the Trujillo (red and green shales at the top and sandstones below) and Tecovas (about 200 ft [61 m] thick) formations. These formations contain many colorful (mostly Tecovas) sedimentary rocks of freshwater origin, mostly shales, siltstones, sandstones, and conglomerates. The top of these formations have a “caprock” of their own, the Trujillo sandstone, forming the mid-elevation mesas in the canyon and the Lighthouse Rock. The Tecovas siltstones and shales form the top of the Spanish Skirts.

Below this formation are marine sediments of the Quartermaster formation of Permian age that form the colorful Spanish Skirts, Devil’s Slide, and Catarina Caves. The red siltstones and shales (Permian Redbeds) are laced with veins of gypsum that give the Spanish Skirts their appearance.

General Characteristics of Texas Panhandle Soils

The soils formed under grassland vegetation. Soils dominated by coarser particles (sands) accumulate less organic matter and have less aggregation than in soils with finer particles. The sandy soils in this region have a reddish color and become more dominant south of Plainview. The soils dominated by finer particles (clays) accumulate more organic matter, are dark brown, and typically have a deeper surface horizon. These soils dominate from about Plainview to the Canadian River, and north of the Canadian River, east of Dalhart.

- Generally deep soils, 3 to 6.54 ft [1 to 2 m] or deeper;
- Except sands, generally test high in phosphorus and potassium;
- Except sands, pH is usually between 6.5 and 8.3;
- Free carbonates are usually present in the soil profile;
- Depth to carbonates increases with rainfall (west to east across Panhandle);
- A calcic horizon is often present, >15 percent pedogenic calcium carbonates;
- Often 1 to 2 percent organic carbon is in native soils;
- Organic carbon in cropped soils is about half of the original amount;
- Soils are generally fertile;
- Water is the most limiting factor to crop production;
- Soils have good water storage ability, 1.75 to 2 inches [44 to 51 mm] plant available water per foot; and
- This leads to the dryland practice of fallow to store water for use in growing a crop.

APPENDIX B: CHILDRESS, TEXAS, SITE DATA

Table B-1. Childress, Texas, Site Data.

Location WGS84					
	Latitude Degrees N	**Longitude Degrees W**	**Elevation (ft)**	**Slope (%)**	**Grade x:1**
Site 1			1917		
N. side				5.80%	17.1
Median N				10.00%	10
Median S				14.20%	7.1
Site 2	34 26.904'	100 15.998'	1961		
Median N				10.80%	9.2
Median S				12.50%	8
Site 3	34 26.929'	100 16.049'	1950		
Median N				12.90%	7.7
Median S				11.70%	8.6

Table B-2. Childress, Texas, Test Area Soil Data.

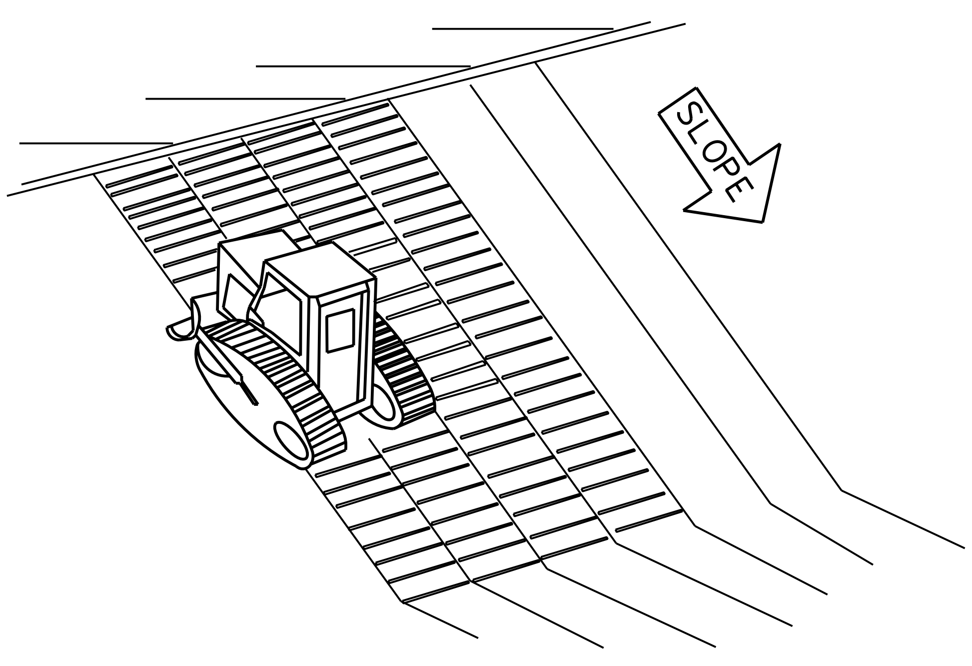
	Vegetation	Infiltration	Bulk Density g/cm^3		Texture	
		in/hr	0-7.5 cm	8-15.5 cm	0-7.5 cm	8-15.5 cm
Site 1						
East	Bare, roots below surface, recent construction, Johnson grass rhizomes	<2.0	1.24	1.35	Sandy loam	Sandy loam
Center	Little bluestem, Bermuda	3.1	1.23	1.37	Sandy loam	loamy Sand
West	Little bluestem, Old World bluestem	7.7	1.29	1.31	Sandy loam	Sandy loam
Site 2						
East	Little bluestem, Old World bluestem	8.9	1.09	1.38	Sandy loam	Sandy loam
Center	Little bluestem, Old World bluestem	2.1	1.02	1.2	Sandy loam	Sandy loam
West	Little bluestem, Old World bluestem	6.9	1.07	1.29	Sandy loam	Sandy loam
Site 3						
East	Bermuda grass	26.7	0.86	0.98	Sandy loam	Sandy loam
Center	Bermuda grass	8	0.83	1.16	Sandy loam	Sandy loam
West	Bermuda grass	7.1	0.87	1.12	Sandy loam	Sandy loam

Table B-3. Childress, Texas, Test Area Vegetation Data.

	Vegetation %	Cover	Infiltration In/hr		Bulk density g/cm^{-3}	
			First	Second	0-7.5 cm	8-15.5 cm
Site 1						
East	w. wheatgrass	~15% bare	18	3.8	1.24	
Center	bluestem	~15% bare	14.1	1.7	1.4	
West	Bermuda grass	Dense 100%	7.1	1.8	1.13	
Site 2						
East	Buffalo grass	~70%	3.9		1.33	
	red-stemmed filaree	~20%				
Center	Buffalo grass	<90%	2.7		1.24	
West	Buffalo grass	<90%	7.8		1.31	
Site 3						
East	blue grama	~60%	1		1.24	1.35
	bluestem	~30%				
Center	blue grama	~60%	5.5		1.39	
	bluestem	~30%				
West	blue grama	~80%	15		1.4	
Site 4						
East	Buffalo grass	70%	3		1.42	1.61
	w. wheatgrass	20%				
	bare	10%				
Center	Buffalo grass	70%	6		1.47	
	w. wheatgrass	20%				
	bare	10%				
West	Buffalo grass	70%	8.6		1.36	
	w. wheatgrass	20%				
	bare	10%				
Site 5						
East	Buffalo grass	~70%	4.4		1.24	
	red-stemmed filaree	~20%				
Center	Buffalo grass	~70%	0.9		1.33	
	red-stemmed filaree	~20%				
West	Buffalo grass	~70%	3.1		1.31	
	red-stemmed filaree	~20%				

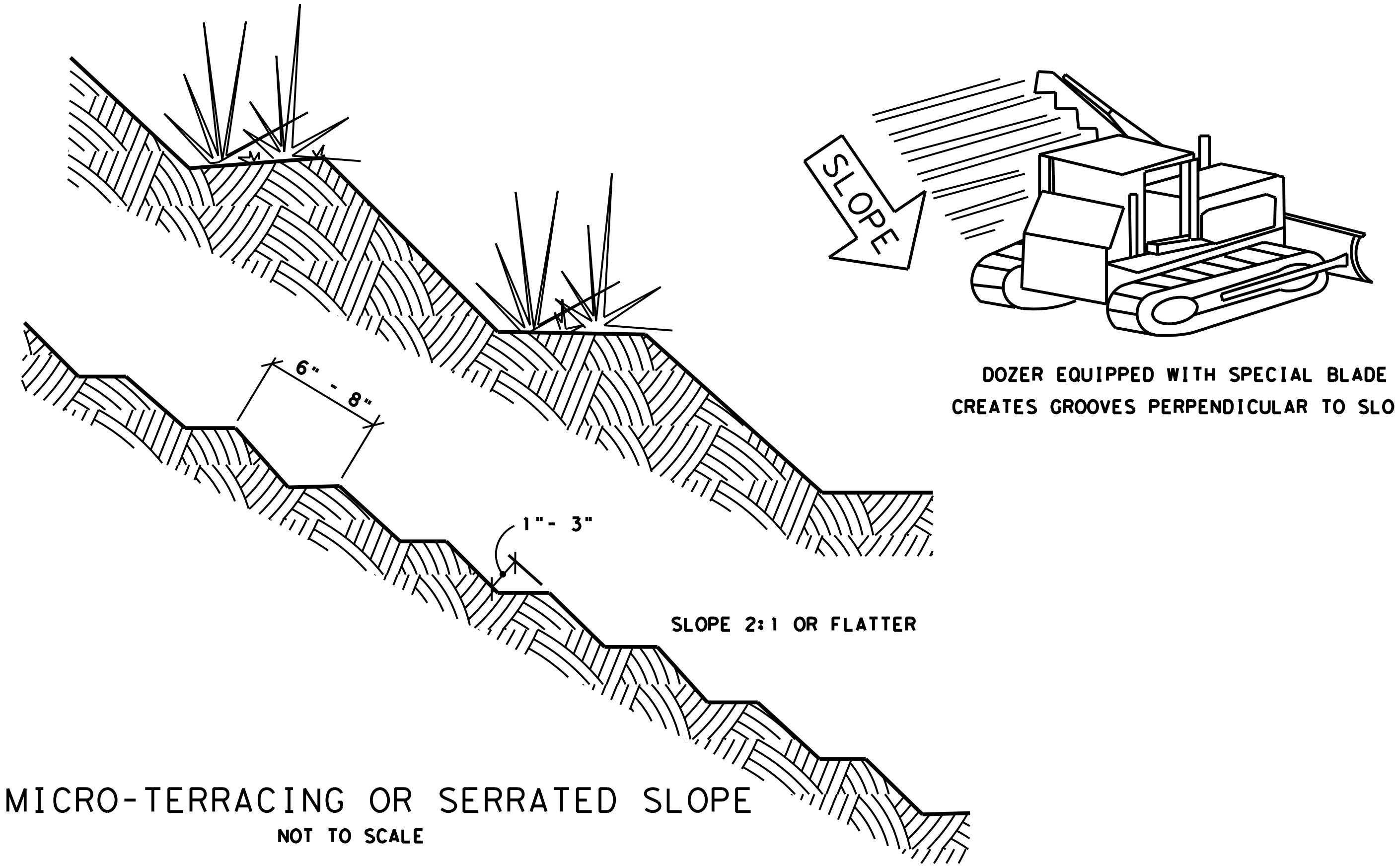
APPENDIX C: WATER HARVESTING STANDARD DETAIL SHEETS

DOZER TRACKS CREATE HORIZONTAL
GROVES PERPENDICULAR TO THE SLOPE



VEHICLE SLOPE TRACKING

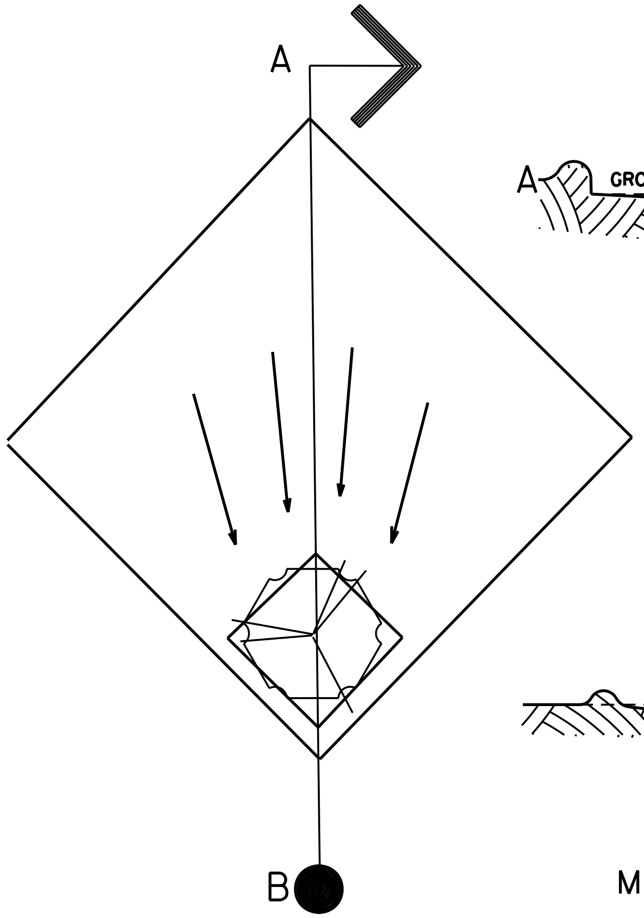
NOT TO SCALE



DOZER EQUIPPED WITH SPECIAL BLADE
CREATES GROOVES PERPENDICULAR TO SLOPE

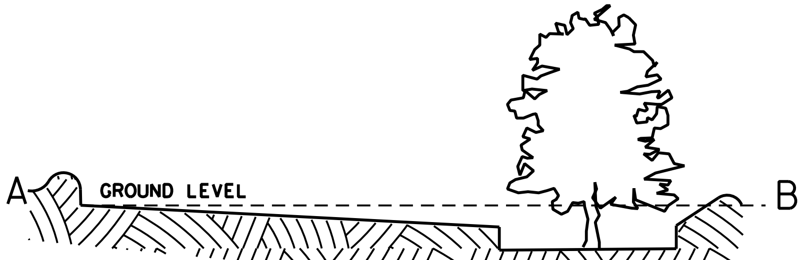
MICRO-TERRACING OR SERRATED SLOPE

NOT TO SCALE



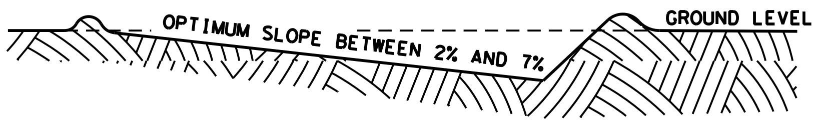
MICRO-CATCHMENT PLAN VIEW

NOT TO SCALE



MICRO-CATCHMENT CROSS SECTION WITH TREE PLANTING

NOT TO SCALE



MICRO-CATCHMENT CROSS SECTION

NOT TO SCALE

PRELIMINARY

SHEET 1 OF 2

Texas Department of Transportation
Houston District

WATER
RETENTION TECHNIQUES

(WRT)

FILE:	DN:	CK:	DW:	CK:
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	COUNTY	CONTROL	SECT	JOB	HIGHWAY

...\Water retention techniques.dgn 4/29/2009 9:31:20 AM

MICRO-CATCHMENT

DEFINITION
MICRO-CATCHMENTS ARE FORMED BY DIVIDING THE AREA INTO SMALLER PLOTS SURROUNDED BY SOIL BERMS 4 TO 8 INCHES HIGH AND 8 TO 14 INCHES WIDE. GRADIENT WITHIN THE CATCHMENT SHOULD BE BETWEEN 2 TO 7%. CATCHMENTS CAN BE MADE TO NATURAL SHAPES OR USE A RECTILINEAR CONFIGURATION.

PURPOSE
1. CONCENTRATE SURFACE RUNOFF AROUND THE PLANT OR TO AN AREA
2. TO REDUCE STORM WATER RUNOFF VELOCITY
3. TO INCREASE STORM WATER RUNOFF INFILTRATION
4. TO IMPROVE WATER RETENTION CAPABILITIES FOR VEGETATION ESTABLISHMENT

SOIL RIPPING

DEFINITION
SOIL RIPPING OR CONTOUR RIPPING IS THE MODIFICATION OF SOIL PHYSICAL PROPERTIES AND/OR PLANT COMMUNITIES WITH MECHANICAL TOOLS.

PURPOSE
1. FRACTURE COMPACTED SOIL LAYERS AND IMPROVE SOIL PERMEABILITY
2. REDUCTION OF COMPACTED SOIL LAYERS
3. REDUCTION OF STORM WATER RUNOFF
4. INCREASED STORM WATER RUNOFF INFILTRATION
5. MODIFICATION OF SOD-BOUND CONDITIONS TO INCREASE PLANT VIGOR
6. RENOVATION OF PLANT COMMUNITIES
7. REDUCTION OF NUTRIENT LOADS IN RUNOFF

CONDITIONS
THIS APPLICATION IS APPROPRIATE FOR AREAS WITH SLOPE 3:1 AND FLATTER.

EQUIPMENT CONSIDERATIONS
1. FRONT-END LOADER EQUIPPED WITH TEETH CAN RIP THE SOIL ACROSS THE SLOPE.
2. DOZER, EQUIPPED WITH A SPECIAL BLADE CONTAINING A SERIES OF SQUARE GROOVES AND POSITIONED AT THE SAME ANGLE AS THE CUT, CAN SERRATE THE SLOPE ALONG THE CONTOURS.

MICRO-TERRACING

DEFINITION
SHALLOW GROOVES CUT IN THE SOIL SURFACE PERPENDICULAR TO THE SLOPE

PURPOSE
1. TO REDUCE STORM WATER RUNOFF VELOCITY
2. TO INCREASE STORM WATER RUNOFF INFILTRATION
3. TO IMPROVE WATER RETENTION CAPABILITIES FOR VEGETATION ESTABLISHMENT
4. TO PROVIDE CATCHMENTS FOR SEED , MULCH AND FERTILIZER

CONDITIONS
THIS APPLICATION IS APPROPRIATE FOR AREAS WITH SLOPES 2:1 OR FLATTER.
SERRATIONS SHOULD BE BETWEEN 6 AND 8 INCHES APART; AND 1 TO 3 INCHES DEEP.

EQUIPMENT CONSIDERATIONS
DOZER, EQUIPPED WITH A SPECIAL BLADE CONTAINING A SERIES OF SQUARE GROOVES AND POSITIONED AT THE SAME ANGLE AS THE CUT, CAN SERRATE THE SLOPE ALONG THE CONTOURS.

VEHICLE SLOPE TRACKING

DEFINITION
VEHICLE SLOPE TRACKING OR SLOPE ROUGHENING CREATES HORIZONTAL GROOVES, FURROWS, DEPRESSIONS, OR STEPS RUNNING PARALLEL TO THE SLOPE CONTOUR OVER THE ENTIRE FACE OF A SLOPE.

PURPOSE
1. TO REDUCE STORM WATER RUNOFF VELOCITY
2. TO INCREASE STORM WATER RUNOFF INFILTRATION
3. TO IMPROVE WATER RETENTION CAPABILITIES FOR VEGETATION ESTABLISHMENT
4. TO REDUCE EROSION

CONDITIONS
THIS APPLICATION IS APPROPRIATE FOR AREAS WITH SLOPES FLATTER THAN 2:1

METHODS INCLUDE:
1. TRACKING (DRIVING A CRAWLER TRACTOR UP AND DOWN A SLOPE, LEAVING THE CLEAT IMPRINTS PERPENDICULAR TO THE SLOPE
2. STAIR-STEP GRADING
3. GROOVING (USING DISKS, SPRING HARROWS, OR TEETH ON A FRONT END LOADER)

SELECTION OF AN APPROPRIATE METHOD DEPENDS ON
1. GRADE OF THE SLOPE
2. MOWING REQUIREMENTS AFTER VEGETATIVE COVER IS ESTABLISHED
3. WHETHER SLOPE WAS FORMED BY CUTTING OR FILLING
4. TYPE OF EQUIPMENT AVAILABABLE

TYPICAL EQUIPMENT USED
1. FRONT-END LOADER EQUIPPED WITH DISKS, HARROWS, OR TEETH TO MAKE GROOVES ACROSS THE SLOPE
2. CRAWLER TRACTOR DRIVEN UP AND DOWN THE SLOPE TO MAKE CLEAT IMPRINTS PERPENDICULAR TO THE SLOPE
3. DOZER, EQUIPPED WITH A SPECIAL BLADE CONTAINING A SERIES OF SQUARE GROOVES AND POSITIONED AT THE SAME ANGLE AS THE CUT THAT CAN SERRATE THE SLOPE ALONG THE CONTOURS

PRELIMINARY

SHEET 2 OF 2

Texas Department of Transportation
Houston District

WATER
RETENTION TECHNIQUES

(WRT)

FILE:	DN:	CK:	DW:	CK:
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REVISIONS	HOU	6		
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