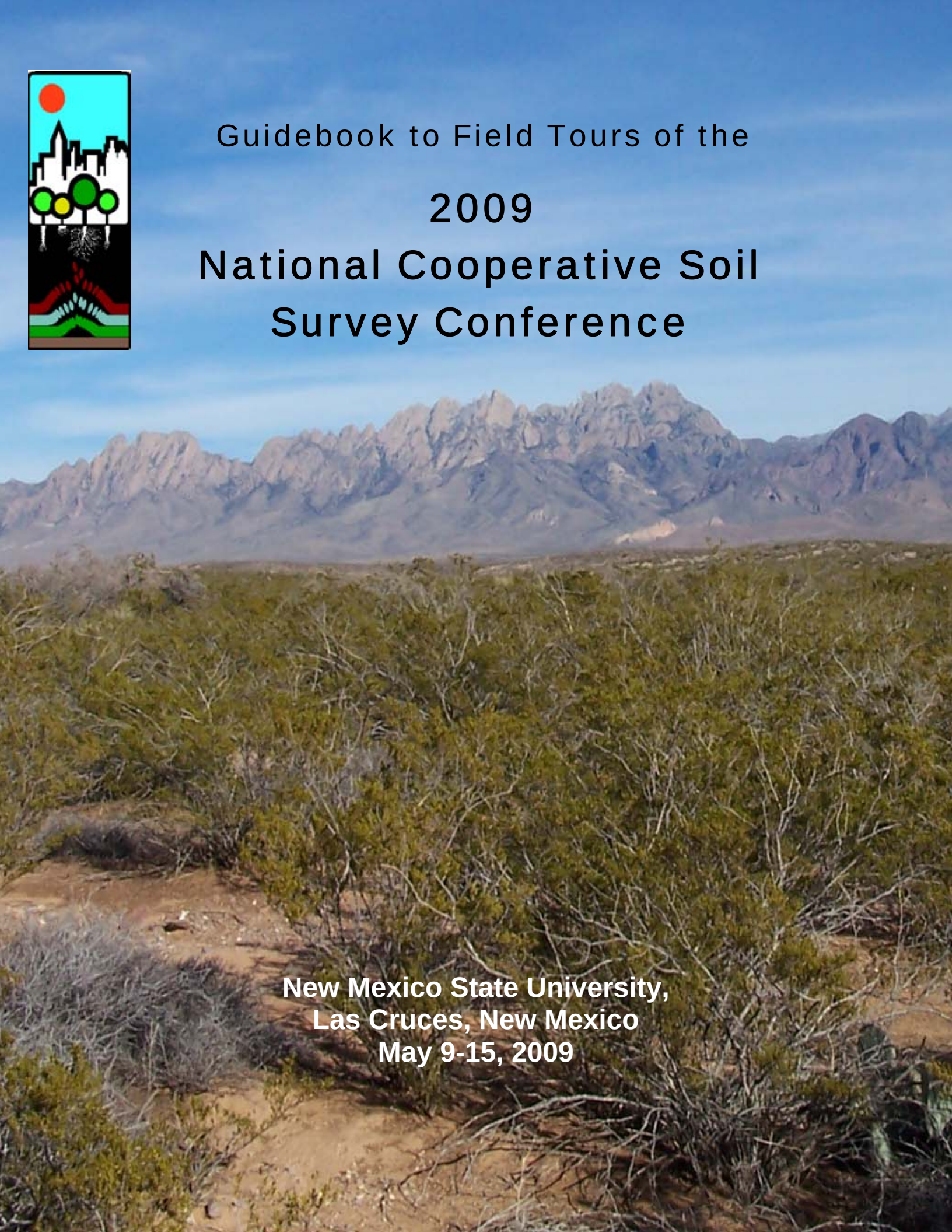
Guidebook to Field Tours of the

2009 National Cooperative Soil Survey Conference



New Mexico State University,
Las Cruces, New Mexico
May 9-15, 2009

Welcome To New Mexico

I am very pleased New Mexico was chosen to host the 2009 Conference of the National Cooperative Soil Survey in New Mexico.

The Soil Survey has always been an important tool in our efforts to conserve soil, water and other natural resources. New Mexico participated in the earliest days of the Soil Survey Program undertaking a survey of the Pecos Valley in 1898 - fourteen years before its statehood. Soil Surveys are important because it is upon the soil that we plant our crops, grow our livestock, and raise our families.

New Mexico truly is the *"Land of Enchantment"*. It is a state rich in diversity of landscapes, climate, natural resources, and people. We appreciate this chance to share a bit or our lives in the land we call home. During your stay here, please take the opportunity to visit some of the scenic beauty and cultural offerings of the state. If in a restaurant and asked the question, "Red or Green?" simply reply "Christmas". They will smile and know what you mean.

Cooperative partnerships are essential to success in resource management in New Mexico. Challenges posed by complex patterns of land ownership, limited water resources, and diverse cultures are best answered when we work together. The National Cooperative Soil Survey is one of our oldest and most dynamic cooperative efforts to help us protect and enhance our natural resources.

DENNIS L. ALEXANDER
STATE CONSERVATIONIST

Crescit Eundo – "It Grows As It Goes" – New Mexico

Contents

Overview of Tours

The 2009 NCSS Conference Tours 5

General Considerations and Precautions 6

Sunday, May 10, 2009 -7:30AM-5:30PM

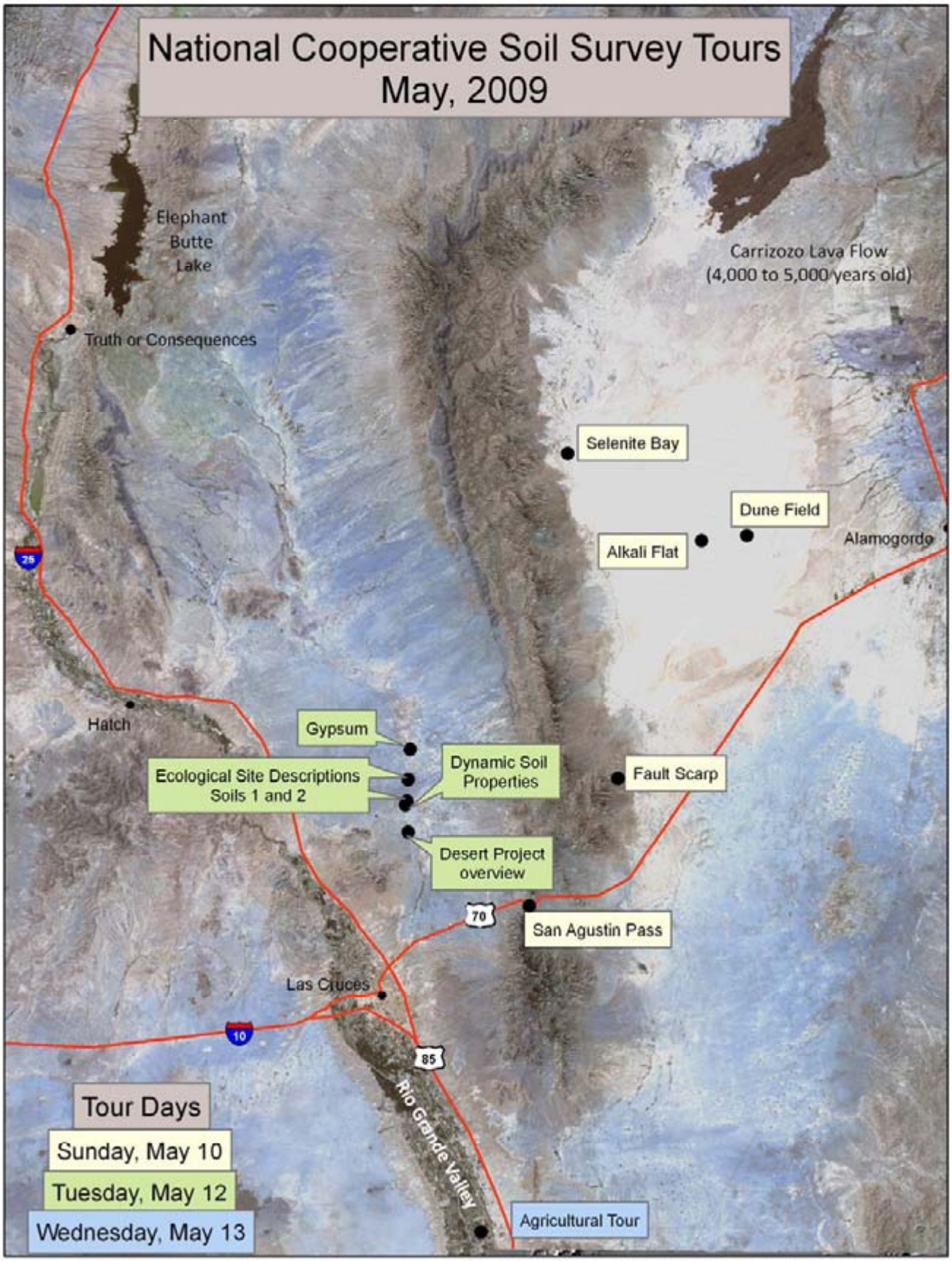
White Sands Missile Range 7
- Stop #1 – San Augustin Pass 8
- Stop #2 – Selenite Banks 8
- Stop #3 – Alkali Flat 9
- Stop #4 – Gypsum Dunes 9
- Stop #5 – Holocene Basin Fault 9

Tuesday, May 12, 2009 – 7:30AM-8:30PM

Jornada Long Term Experimental Research Station 55
- Workshop #1 – Desert Project/Gypsum 57
- Workshop #1 – Ecological Sites Description and S&T Models 75
- Workshop #3 – Dynamic Soil Properties 103

Wednesday, May 13, 2009 – 1:00PM-5:00PM

Agronomy Tour - Soil Quality and Health 119
- Station 1 - Soil Quality and Soil Health National Perspective 121
- Station 2 - Soil, Water, and Plant Analysis in Cons. Planning 131
- Station 3 - Soil Quality Test Kit Demonstration 147
- Station 4 - Irrigation Water Management 165


National Cooperative Soil Survey Tours
May, 2009
Elephant Butte Lake
Carrizozo Lava Flow (4,000 to 5,000 years old)
Truth or Consequences
Selenite Bay
Dune Field
Alkali Flat
Alamogordo
25
Hatch
Gypsum
Ecological Site Descriptions Soils 1 and 2
Dynamic Soil Properties
Fault Scarp
Desert Project overview
70
San Agustin Pass
Las Cruces
10
85
Rio Grande Valley
Agricultural Tour
Tour Days
Sunday, May 10
Tuesday, May 12
Wednesday, May 13

The 2009 NCSS Conference Tours

We are pleased to be able to schedule three tours for the 2009 National Cooperative Soil Survey Conference in Las Cruces, NM. The tours are designed to highlight the soil survey process from beginning to end emphasizing the contributions of partners in development of a complete product for the users.

The Sunday tour of the White Sands Missile Range begins with the broad view of the geologic, geomorphic and climatic setting in which soil surveys are conducted and soils products developed. We will be looking at the parent materials and the processes which have brought them to the land surface where soil forming processes have acted upon them over the millennia to shape and alter parent material into soils we map. We will look primarily at tectonic, geomorphic and hydrologic processes which redistribute the raw materials across the landscape and act to alter their composition.

The Tuesday tour of the Jornada Experimental Range and LTER consists of three mini-workshops. Workshop 1 will highlight soil-geomorphic relationships developed during Desert Soil-Geomorphology Project conducted from 1957-1972, but study continues today with additional research, synthesis of ideas, and extrapolation of concepts across additional landscapes and geologic settings using the latest analytical techniques and climate modeling. Workshop 2 will present the techniques of Ecological Site Description and State and Transition Model development developed through collaborative efforts of the USDA Jornada Experiment Station, New Mexico State University and other researchers to identify the stable plant communities in the Chihuahuan Desert, and the changes in state and the transition thresholds brought about by disturbance. Workshop 3 is a demonstration of multi-scale field methods to document the effects of management and disturbances on dynamic soil properties according to the newly released interagency Soil Change Guide: Procedures for Soil Survey and Resource Inventory.

The Wednesday afternoon Agronomy Tour at the Anthony Pecan Farm consists of four demonstration or discussion stations which emphasize management of soil health and long term sustainability. Processes used include the inventory for status of dynamic soil quality parameters; analysis of crops for nutrient uptake, analysis of irrigation water chemistry, and organic nutrient inputs for the development of management plans which optimize yields, maximize irrigation efficiency, and reduce deleterious impacts to water quality, and all the while maintaining soil health for long term sustainability. The stations include an overview of soil health, discussion of crop, soil, and water analysis, demonstration of the Soil Quality Test Kit, and discussion of maximizing irrigation efficiency through proper selection of irrigation systems, soil moisture monitoring, and irrigation water management.

General Precautions and Considerations

Exposure --You are in a desert!

The climate in the Chihuahuan Desert can be dangerous if you are not aware of or prepared for it. Your body may not be acclimated to the combination of altitude, low humidity, and high temperatures. You may not feel the effects of sun exposure, dehydration, and altitude until you are already in serious medical trouble. Please follow these easy safety tips to assure your continued enjoyment of New Mexico:

* Drink plenty of water – drink frequently and before you become thirsty - approximately 1 gallon per day in summer
* Minimize sun exposure on bare skin – wear a wide brimmed hat, long sleeve shirt, long pants, lightweight, loose fitting clothing, and durable protective footwear; use sunscreen lotions of SPF 30 or stronger
* Eat frequent light meals – avoid greasy and high protein foods
* Take a siesta – rest frequently, retreat to shade, and avoid strenuous activity in the heat of the day
* Avoid alcohol and caffeine which dehydrate the body
* Inform someone if you suddenly become dizzy or ill

Flora and Fauna

Many species of plant and animal in the desert utilize protective systems to deter predation, including thorns, spines, fangs, and stingers. Watch where you step and what you brush up against. Succulent plants and tender leaves are always protected by spines and thorns. Snakes, spiders, and stinging insects take protection in shady areas under rocks, limbs, and structures.

White Sands Missile Range- UXO and Photography

White Sands Missile Range is a secure military facility used for weapons testing since 1945. The weapons tested are designed to kill the enemy and destroy machinery and are very effective at both. Precautions have been take to avoid known ordinance testing areas, but accidents and misplaced explosives can be found anywhere on the range. Do not pick up, step on, or go near anything that looks suspicious. Report any sighting to the tour leader. Please watch the UXO briefing video at http://www.wsmr.army.mil/videos/uxo-brief.wmv .

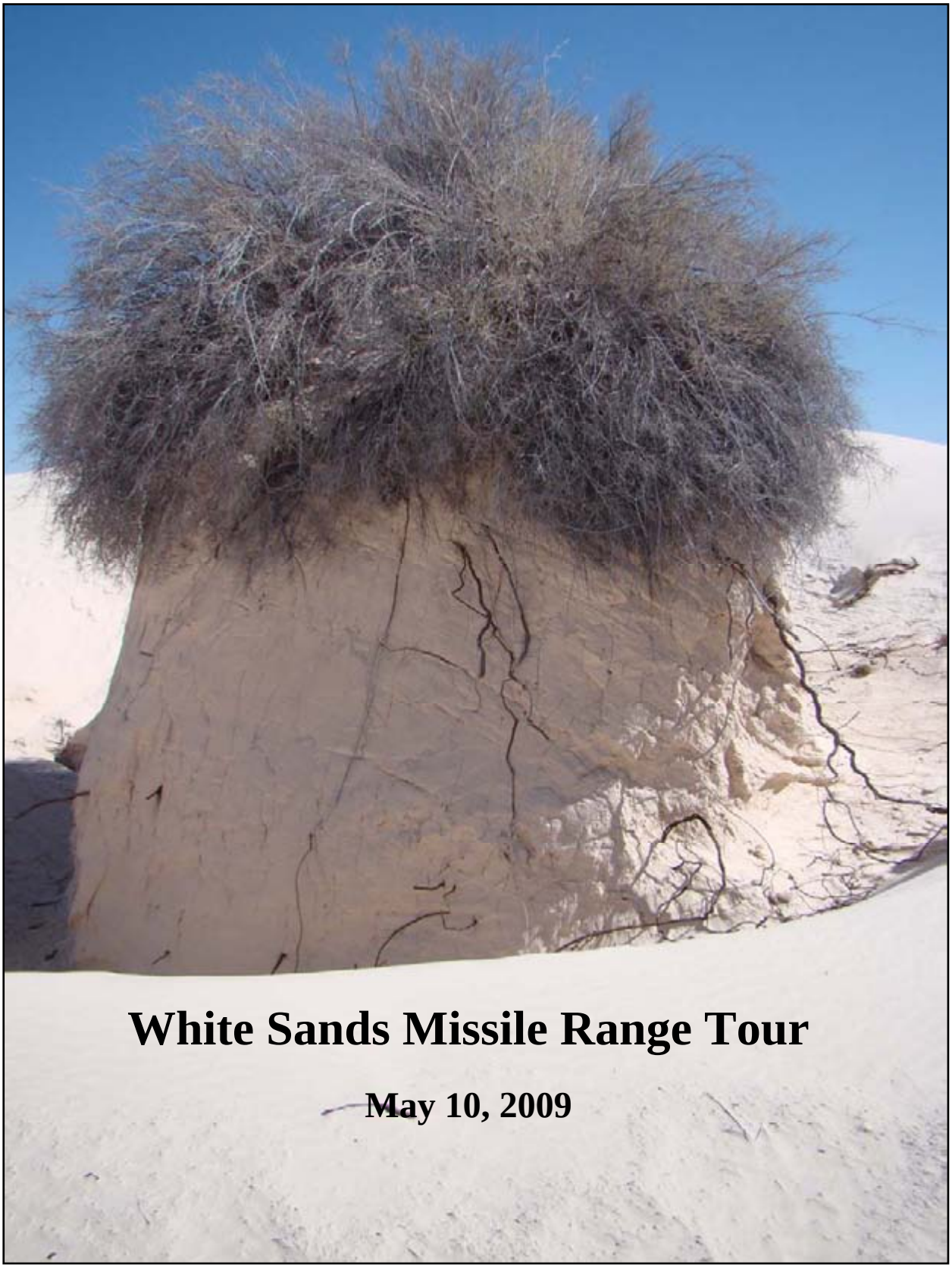
For the purposes of national security, no unauthorized photography is permitted. You risk seizure of equipment and imprisonment for violation. Even photos taken by authorized personnel are screened by military security personnel.

Jornada Experimental Range (JER)

The Jornada Experimental Range and Long Term Ecological Research Station is an active research facility with numerous experimental plots, sensor packs, data loggers, and livestock. Please be wary to avoid damage to experiments, and angering ruminate megafauna.

Agronomy Tour - Anthony Pecan Farm

The Diaz Family has graciously hosted numerous workshops, demonstrations, and training exercises for NRCS on their Anthony pecan farm. We value their friendship and support.



White Sands Missile Range Tour

May 10, 2009

2009 NCSS National Conference
White Sands Missile Range Tour Itinerary
Sunday, May 10, 2009

Tour Departure

Location: Corbett Center, New Mexico State University

Estimated Time of Departure: 7:15 AM

Travel Time to First Stop: 7:15 – 7:55 AM

Purpose:

- Brief summary of day's events
- Photography restrictions
- Load NCSS tour group onto buses

Stop 1

Location: San Augustine Pass, Dona Ana County, NM

Estimated Time at Location: 7:55 – 9:00 AM

Travel Time to Second Stop: 9:00 – 10:15 AM

Purpose:

- Unexploded Ordinance and Photography briefing
- History of White Sands Missile Range
- Geologic History and Formation of the Tularosa Basin
- Soils, Temperature and Moisture Regimes and Ecological sites from pass to basin floor
- Landforms at Stop 1

Enter White Sands Missile Range at Small Missile Range gate at 9:20 AM

Stop 2

Location: Selenite Banks, Sierra County, NM, White Sands Missile Range

Estimated Time at Location: 10:15 AM – 11:25 PM

Travel Time to Third Stop: 11:25 – 12:00 PM

Purpose:

- Gypsum Parent Material Sources
- Formation of Selenite Crystals

- Display of pedogenic gypsum samples and other gypsum precipitates
- Soils and Ecosites of piedmont and northern Alkali Flat
- Landforms at Stop 2

Stop 3

Location: White Sands Missile Range Dune Field, Otero County, NM,

Estimated Time at Location: 12:00 – 1:30 PM

Travel Time to Fourth Stop: 1:30 – 1:40 PM

Purpose:

- Lunch
- Dune Types
- Water table influence on Dune Formation
- Soils and Ecosites of Dune Field
- Munsell White Page
- Landforms at Stop 3

Stop 4

Location: White Sands Missile Range Alkali Flat, Otero County, NM,

Estimated Time at Location: 1:40 – 2:40 PM

Travel Time to Fourth Stop: 2:40 – 3:40 PM

Purpose:

- Deflation Events on the Alkali Flat
- Ground Water and Salinity
- Gypsum Interps in Open and Closed Basins
- Soils and Ecosites of Alkali Flat
- Landforms at Stop 3

Stop 5

Location: Fault Scarp, Dona Ana County, NM,

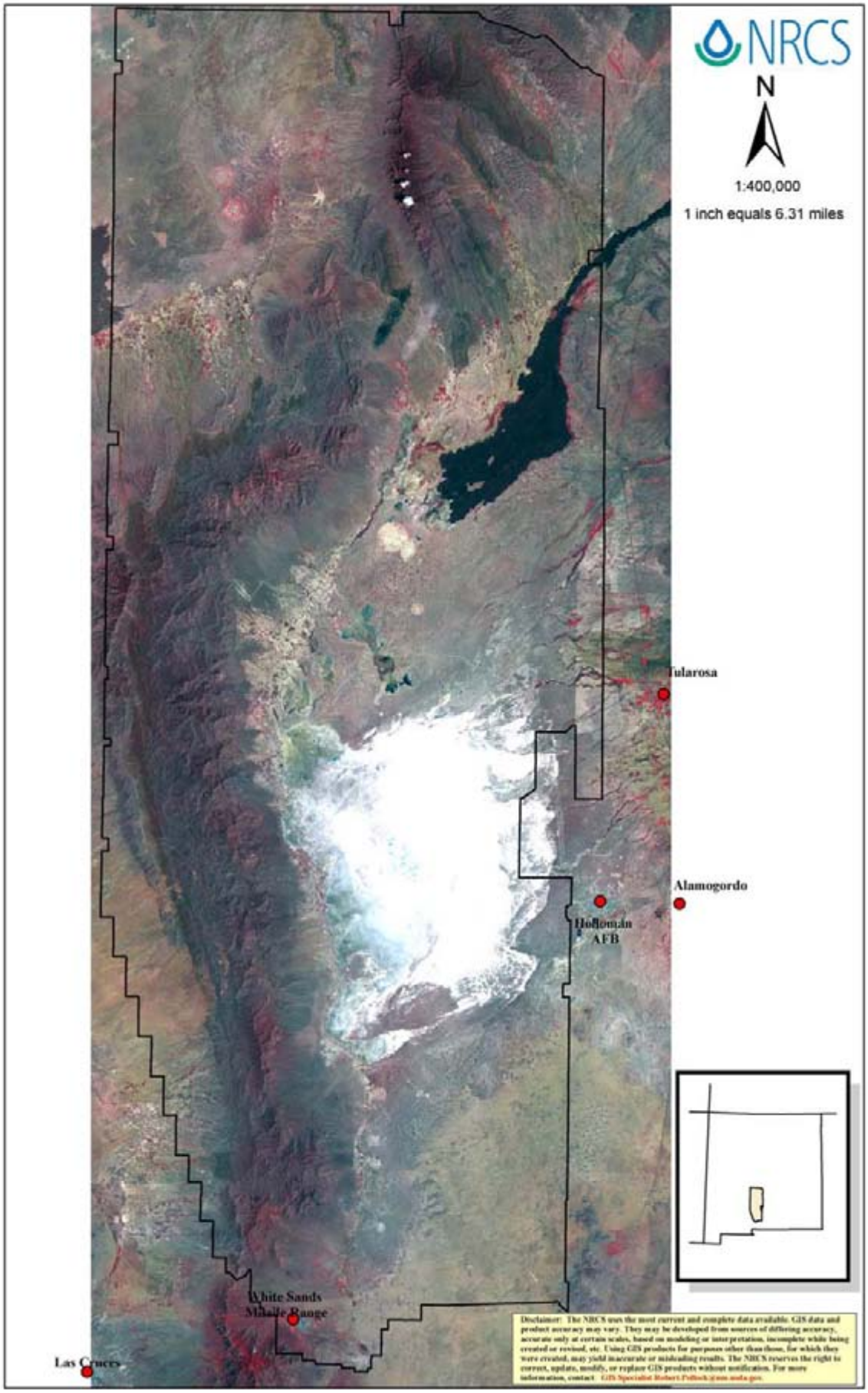
Estimated Time at Location: 3:40 – 4:40 PM

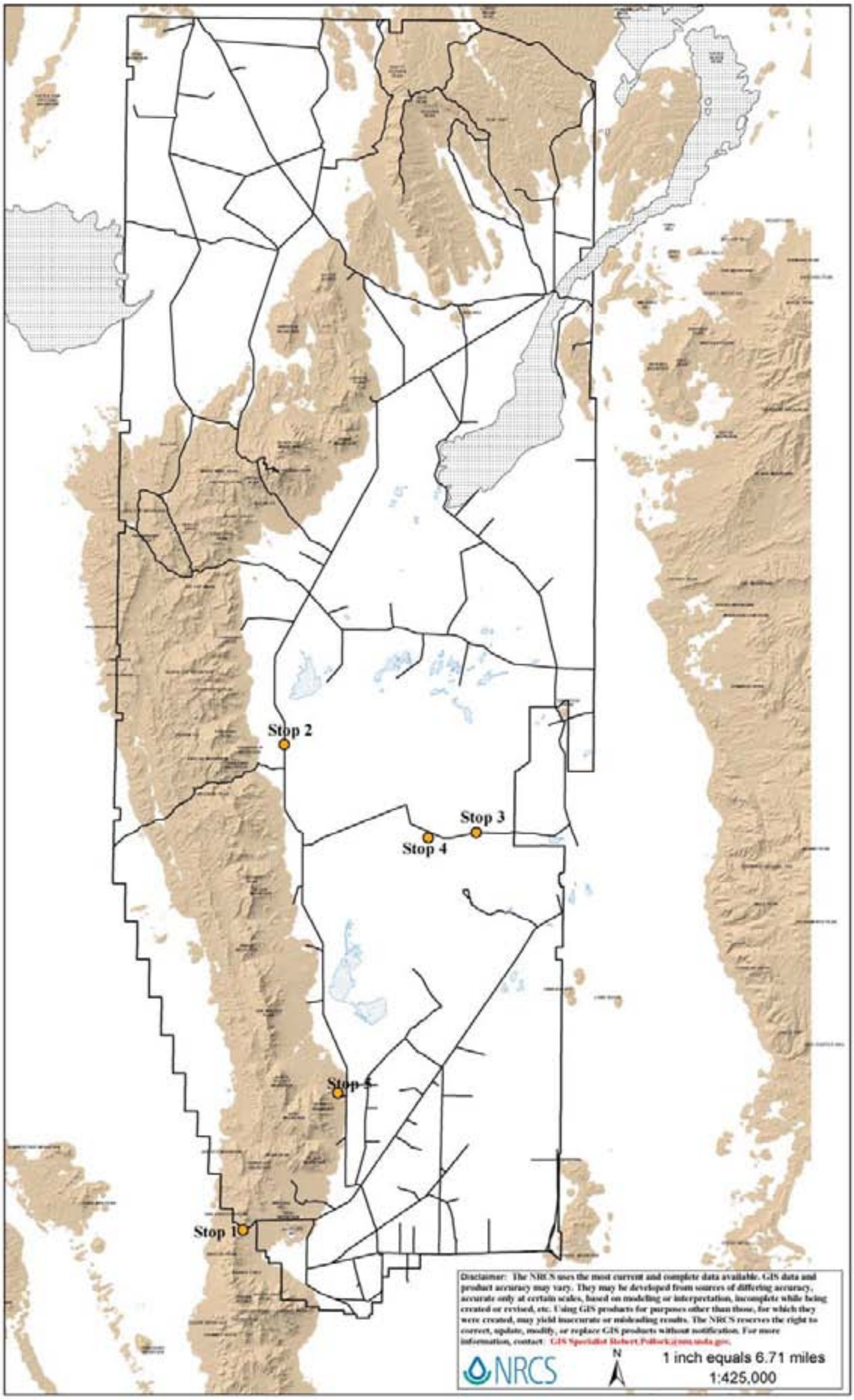
Travel Time to Corbett Center: 4:40 – 6:00 PM

Purpose:

- Discuss Fault Systems in Tularosa Basin
- Soils and Ecosites of Piedmont and Fault Scarps
- Landforms at Stop 5

Leave White Sands Missile Range at Small Missile Range gate at 5:10 PM


NRCS
N
1:400,000
1 inch equals 6.31 miles
Tularosa
Alamogordo
Holloman
AFB
White Sands
Missile Range
Las Cruces
Disclaimer: The NRCS uses the most current and complete data available. GIS data and product accuracy may vary. They may be developed from sources of differing accuracy, accurate only at certain scales, based on modeling or interpretation, incomplete while being created or revised, etc. Using GIS products for purposes other than those, for which they were created, may yield inaccurate or misleading results. The NRCS reserves the right to correct, update, modify, or replace GIS products without notification. For more information, contact: GIS Specialist Robert.Pollock@nm.usda.gov.


Stop 2
Stop 3
Stop 4
Stop 5
Stop 1
Disclaimer: The NRCS uses the most current and complete data available. GIS data and product accuracy may vary. They may be developed from sources of differing accuracy, accurate only at certain scales, based on modeling or interpretation, incomplete while being created or revised, etc. Using GIS products for purposes other than those, for which they were created, may yield inaccurate or misleading results. The NRCS reserves the right to correct, update, modify, or replace GIS products without notification. For more information, contact: GIS Specialist Robert.Pollock@nrcs.usda.gov.
NRCS
N
1 inch equals 6.71 miles
1:425,000

WSMR Unexploded Ordinance

Piedmont Vegetation

Creosote Bush (Larrea tridentata)

Honey Mesquite (Prosopis glandulosa)

Bush Muhly (Muhlenbergia porteri)

Four-Wing Saltbush (Atriplex canescens)

TULAROSA, OTERO COUNTY, NEW MEXICO

Weather station **TULAROSA** is at about 33.10°N 106.00°W. Height about 1388m / 4554 feet above sea level. **Source:** TULAROSA data derived from GHCN 1. 966 months between 1908 and 1989

Average Rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mm	12.9	12.3	11.3	9.2	12.0	18.5	40.8	43.4	37.6	22.7	12.9	16.3	250.5
inches	0.5	0.5	0.4	0.4	0.5	0.7	1.6	1.7	1.5	0.9	0.5	0.6	9.9

24-hr Average Temperature

Source: ***TULAROSA data derived from GHCN 1. 917 months between 1908 and 1987***

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	5.7	7.8	10.8	15.1	19.8	24.7	26.0	25.1	21.8	16.2	9.7	5.7	15.8
°F	42.3	46.0	51.4	59.2	67.6	76.5	78.8	77.2	71.2	61.2	49.5	42.3	60.4

CLOUDCROFT, OTERO COUNTY, NEW MEXICO

Weather station **CLOUDCROFT, OTERO COUNTY** is at about 32.95°N 105.73°W. Height about 2639m / 8658 feet above sea level. **Source:** CLOUDCROFT, OTERO COUNTY data derived from NCDC Cooperative Stations. 38 complete years between 1931 and 1987

Average Rainfall

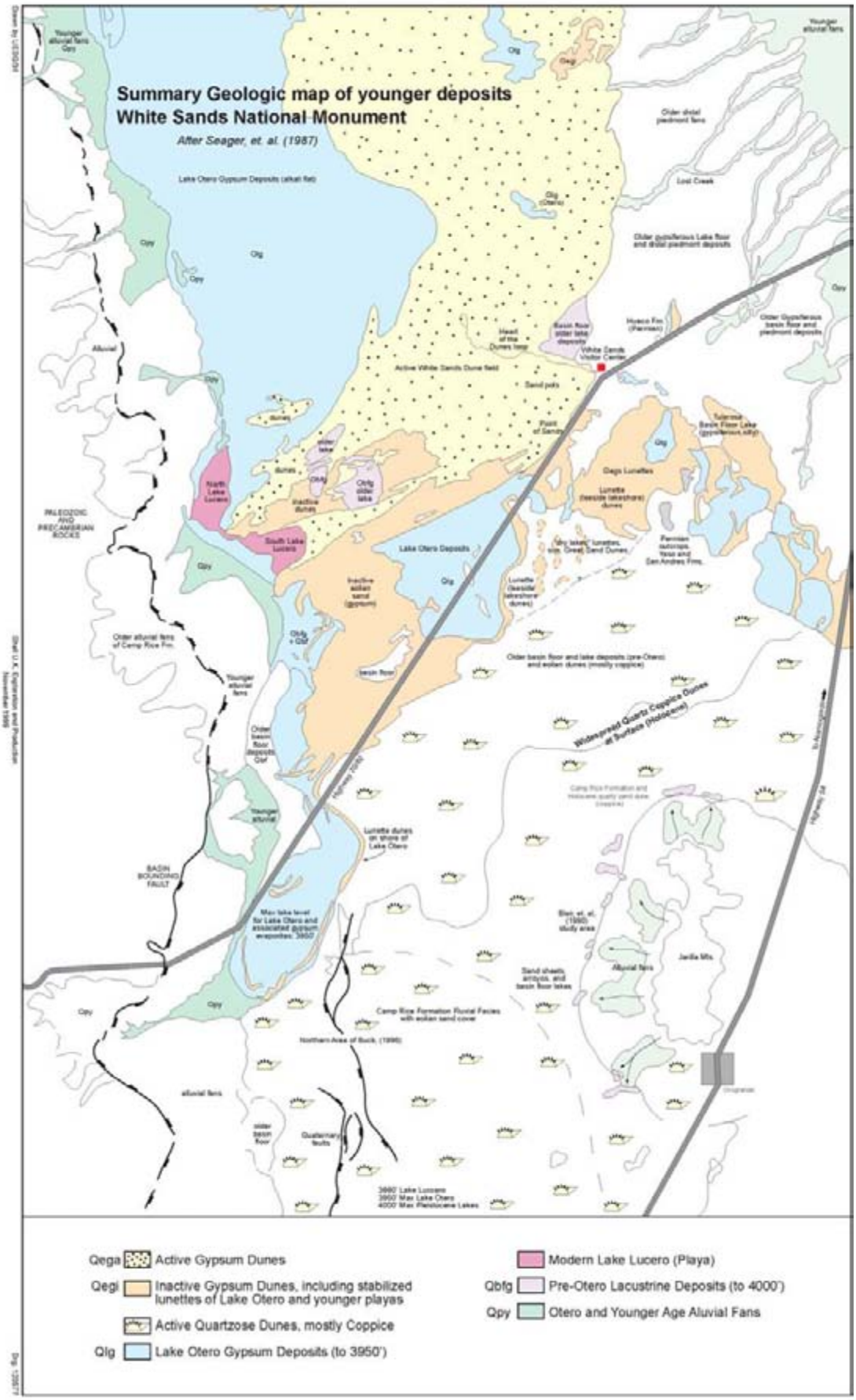
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
mm	43.7	44.6	42.5	19.2	26.4	50.4	142.9	136.1	74.3	46.0	30.5	46.8	704.3
inches	1.7	1.8	1.7	0.8	1.0	2.0	5.6	5.4	2.9	1.8	1.2	1.8	27.7

24-hr Average Temperature

Source: ***CLOUDCROFT, OTERO COUNTY data derived from NCDC TD 9641 Clim 81 1961-1990 Normals. 30 years between 1961 and 1990***

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
°C	-0.8	0.1	2.5	6.8	10.8	15.2	15.7	14.8	12.5	8.2	3.0	0.1	7.4
°F	30.6	32.2	36.5	44.2	51.4	59.4	60.3	58.6	54.5	46.8	37.4	32.2	45.3

© Copyright 1996-2008 Buttle and Tuttle Ltd. All Rights Reserved. Web Design and Programming by Robert Hoare.


Summary Geologic map of younger deposits
White Sands National Monument
After Seager, et. al. (1987)
Qegi Inactive Gypsum Dunes, including stabilized lunettes of Lake Otero and younger playas
Active Quartzose Dunes, mostly Coppice
Qlg Lake Otero Gypsum Deposits (to 3950')
Modern Lake Lucero (Playa)
Qbfg Pre-Otero Lacustrine Deposits (to 4000')
Qpy Otero and Younger Age Aluvial Fans

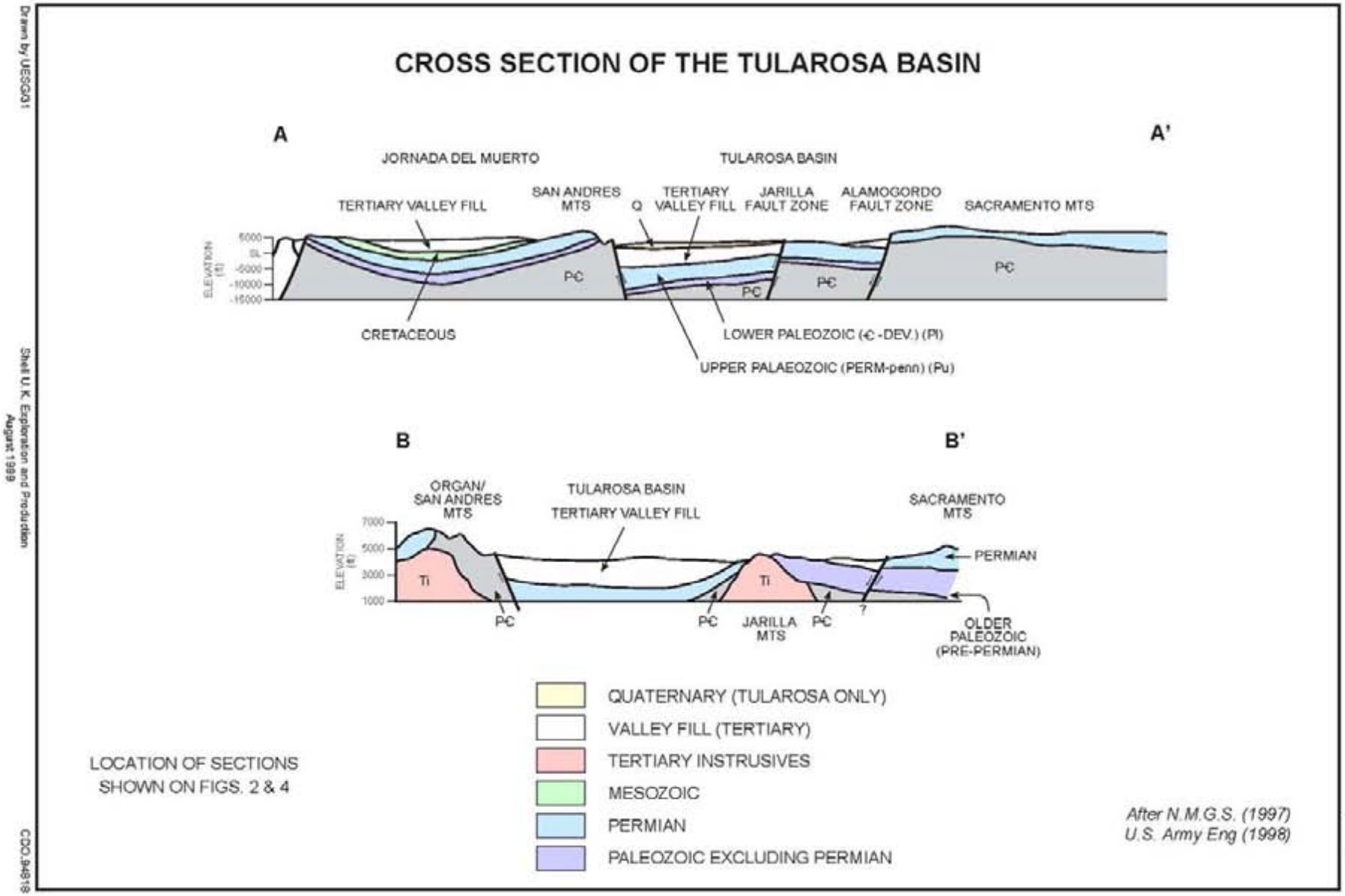

CROSS SECTION OF THE TULAROSA BASIN
A
A'
JORNADA DEL MUERTO
TULAROSA BASIN
TERTIARY VALLEY FILL
SAN ANDRES MTS
Q
TERTIARY VALLEY FILL
JARILLA FAULT ZONE
ALAMOGORDO FAULT ZONE
SACRAMENTO MTS
ELEVATION (ft)
5000
SL
-5000
-10000
-15000
P€
CRETACEOUS
LOWER PALEOZOIC (€ -DEV.) (Pl)
UPPER PALAEOZOIC (PERM-penn) (Pu)
B
B'
ORGAN/ SAN ANDRES MTS
TULAROSA BASIN
TERTIARY VALLEY FILL
SACRAMENTO MTS
7000
5000
3000
1000
Ti
PERMIAN
JARILLA MTS
?
OLDER PALEOZOIC (PRE-PERMIAN)
QUATERNARY (TULAROSA ONLY)
VALLEY FILL (TERTIARY)
TERTIARY INSTRUSIVES
MESOZOIC
PERMIAN
PALEOZOIC EXCLUDING PERMIAN
LOCATION OF SECTIONS SHOWN ON FIGS. 2 & 4
After N.M.G.S. (1997)
U.S. Army Eng (1998)
Drawn by UESG/01
Shell U.K. Exploration and Production
August 1999
CDO.94818

Figure 1-3

Figure 1-5

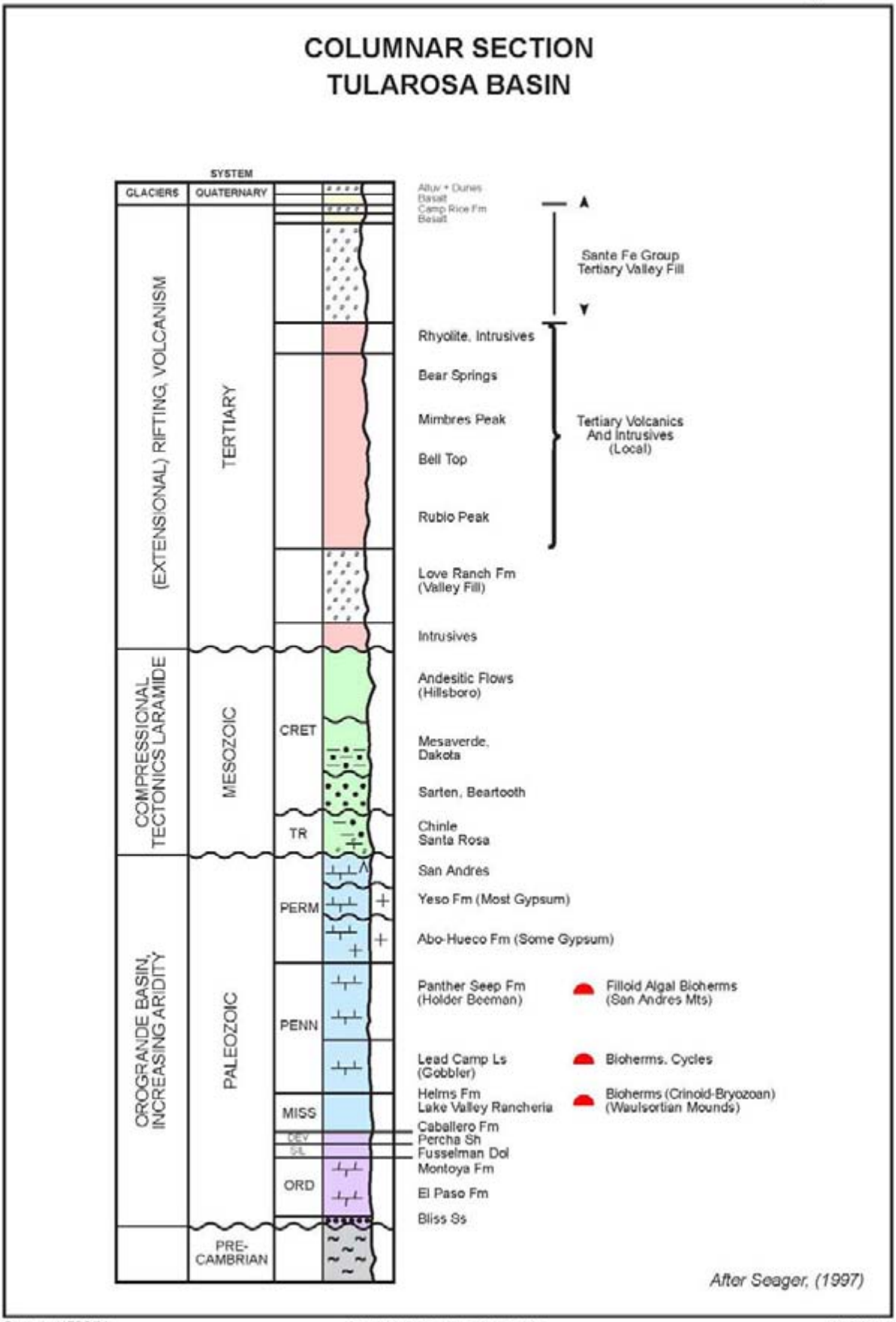

COLUMNAR SECTION
TULAROSA BASIN
SYSTEM
GLACIERS
QUATERNARY
(EXTENSIONAL) RIFTING, VOLCANISM
TERTIARY
COMPRESSIONAL TECTONICS LARAMIDE
MESOZOIC
CRET
TR
OROGRANDE BASIN, INCREASING ARIDITY
PALEOZOIC
PERM
PENN
MISS
DEV
SIL
ORD
PRE-CAMBRIAN
Alluv + Dunes
Basalt
Camp Rice Fm
Basalt
Sante Fe Group
Tertiary Valley Fill
Rhyolite, Intrusives
Bear Springs
Mimbres Peak
Bell Top
Rubio Peak
Tertiary Volcanics
And Intrusives
(Local)
Love Ranch Fm
(Valley Fill)
Intrusives
Andesitic Flows
(Hillsboro)
Mesaverde,
Dakota
Sarten, Beartooth
Chinle
Santa Rosa
San Andres
Yeso Fm (Most Gypsum)
Abo-Hueco Fm (Some Gypsum)
Panther Seep Fm
(Holder Beeman)
Filloid Algal Bioherms
(San Andres Mts)
Lead Camp Ls
(Gobbler)
Bioherms, Cycles
Helms Fm
Lake Valley Rancheria
Bioherms (Crinoid-Bryozoan)
(Waulsortian Mounds)
Caballero Fm
Percha Sh
Fusselman Dol
Montoya Fm
El Paso Fm
Bliss Ss
After Seager, (1997)
Drawn by UESG/31
Shell U.K. Exploration and Production
August 1999
CDO:94817

Figure 1-1

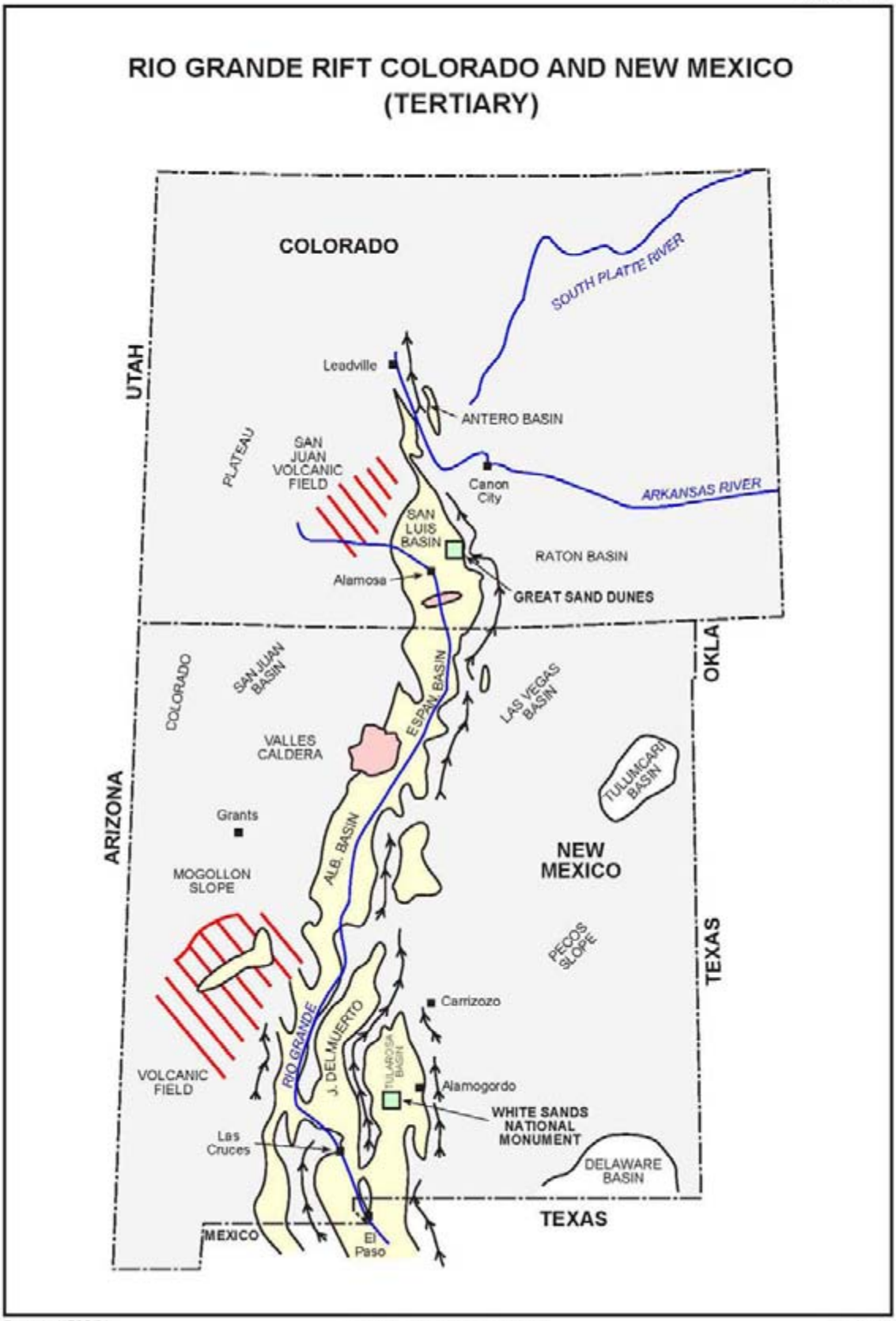
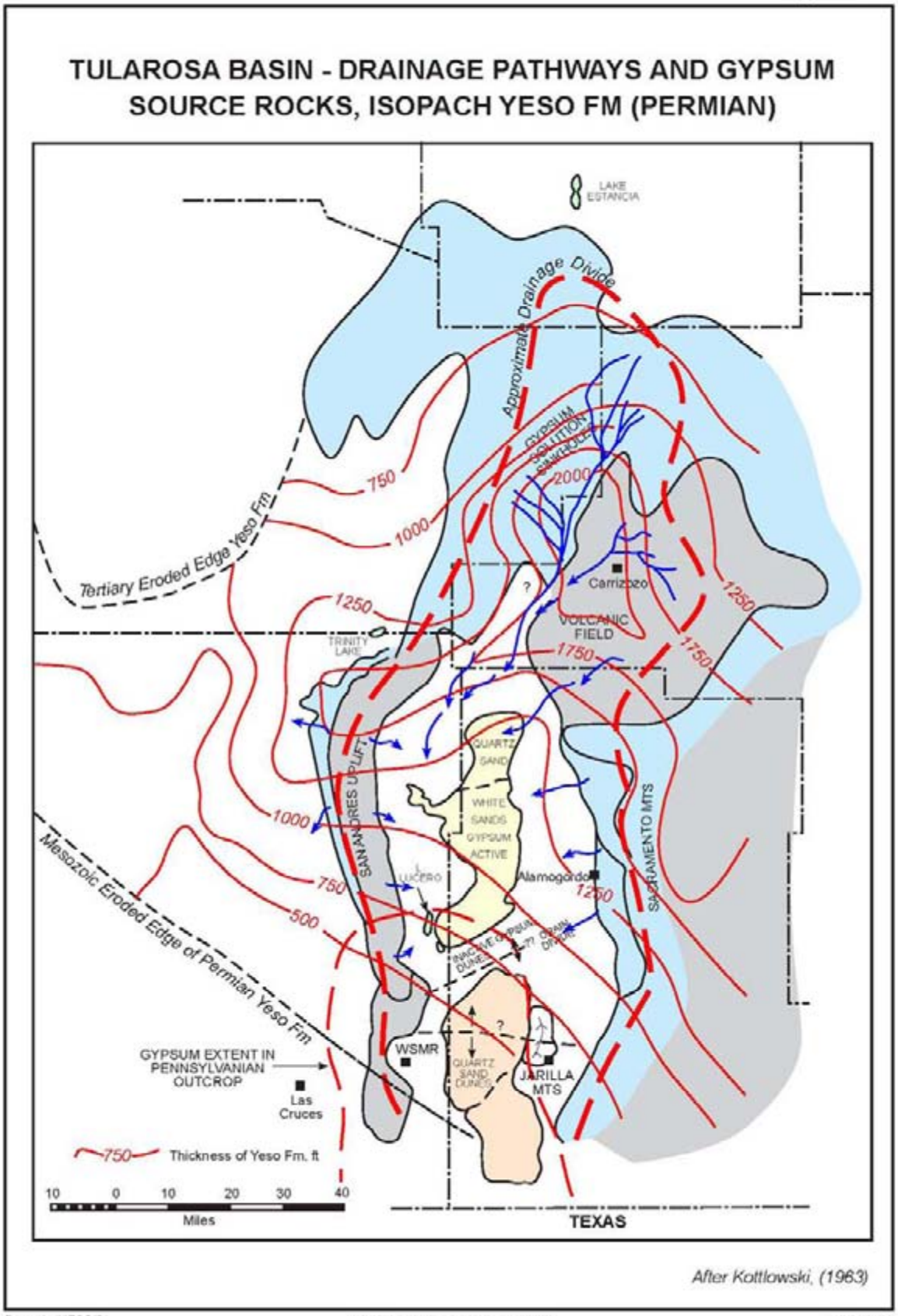
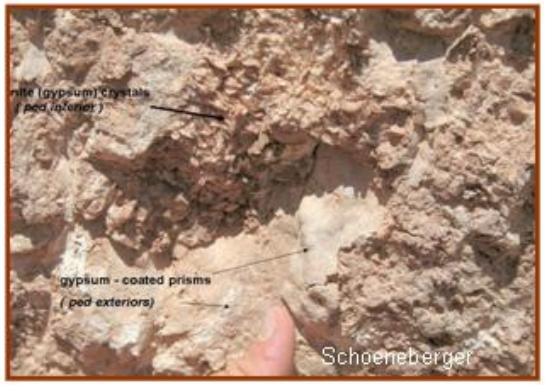

RIO GRANDE RIFT COLORADO AND NEW MEXICO
(TERTIARY)
COLORADO
SOUTH PLATTE RIVER
UTAH
Leadville
ANTERO BASIN
PLATEAU
SAN JUAN VOLCANIC FIELD
Canon City
ARKANSAS RIVER
SAN LUIS BASIN
RATON BASIN
Alamosa
GREAT SAND DUNES
OKLA
COLORADO
SAN JUAN BASIN
ESPAN. BASIN
LAS VEGAS BASIN
VALLES CALDERA
TULUMCARI BASIN
ARIZONA
Grants
ALB. BASIN
NEW MEXICO
MOGOLLON SLOPE
PECOS SLOPE
TEXAS
Carrizozo
RIO GRANDE
J. DEL MUERTO
TULAROSA BASIN
VOLCANIC FIELD
Alamogordo
WHITE SANDS NATIONAL MONUMENT
Las Cruces
DELAWARE BASIN
TEXAS
MEXICO
El Paso
Drawn by UESG/31
Shell U.K. Exploration and Production
August 1999
CDO 94813

Figure 1-13



Drawn by UESG/31 Shell U.K. Exploration and Production August 1999 CDO 94825

Gypsum Forms



Gypsum Coats and Selenite Crystals

Gypsum nodule/mass

Vertical laminar cap along prism faces

Gypsum nests

Gypsum Forms

Petrogypsic

Gypsified Rhizoliths

Vertical Needles (Satin Spar)

Selenite Crystals

Dune and Alkali Flat Vegetation

Iodine Bush (Allenrolfea occidentalis)

Alkali Sacaton (Sporobolus Airoides)

Gypsum Grama (Bouteloua breviseta)

Inland Saltgrass (Distichlis spicata)

Geology of White Sands

Chapter 4: Dune Systems

http://www.nps.gov/archive/whsa/Geology%20of%20White%20Sands/Chap04/Chap04%20Main.html

Introduction:

White Sands has many features in common with other dune fields around the world. In addition to a similarity of process and product due to the importance of wind in shaping the landscape, it also consists of a number of terrain types common to all eolian systems. The dune facies encompasses of all the myriad types of dunes found around the White Sands. The interdune sediments are deposited in the sheltered areas between dunes. Interdune sediments have very different sedimentary features than dunes, and process regimes are so different from those of nearby dunes, that they have been recognized separately by geologists; even though they evolve interdependently surrounding dunes. The third important eolian sediment group is sand sheets. These are widespread, flat-bedded deposits that are commonly found at the margins of many dunefields. The fourth sediment group, which is also found at White Sands is the eolian sabkha. Eolian sabkha deposits form when dry sand is blown across damp surfaces near water table, particularly in evaporitic settings such as White Sands. Sabkha deposits are common on the alkali flat and on the margins of Lake Lucero, and are also found in some open places within the dunefield. In addition there are important terrain types at the White Sands that are not formed by wind - for example the **playa** sediments of Lake Lucero and **fluviatile** sediments of streams that onto the playa and into the dune field. Additionally, there are striking erosional terrains around the monument that testify to the forward movement of dunes or even the removal of significant portions of the landscape by wind scour. Our method in the next series of chapters is to discuss these basic terrain types one by one, after reviewing certain basic aspects of sand and dune movement, and the gypsum sand. We hope to provide some facts about the origins and growth, internal architecture, sedimentary features and current process regimes of the various terrains of the White Sands.

Sand movement

Sand movement by wind is a complex process involving several styles of grain movement by wind that occur more or less simultaneously (Bagnold, 1941). The process most easily observed is saltation, the bouncing of sand grains near the sand surface, sometimes in streamers. A second component of the sand drift process is surface creep. Surface creep is the jerky forward movement of larger grains that are too heavy to be lofted by the wind, but are jolted forward when struck by smaller flying grains. The third manner in which smaller sizes of sand moves is by suspension. Suspended grains are so small that they are carried along without returning to the ground once they are thrown into the air by saltating grains or direct wind scour. Some of the suspension population is merely dust, which is carried far into the atmosphere and far away from the dunes. One of the reasons dune sand is so well sorted is the narrow size range of sand that wind can move under most conditions - usually grains up to .5 mm or so in size. Larger grains are too heavy to be moved by wind and are soon left behind, the silt and clay size fractions are either removed to the atmosphere or settle into sheltered places such interdunes.

Dune Growth and movement.

Dune growth and movement is a result of sand flow on and around a dune during periods when the wind is strong enough to move sand (for dry sand this threshold is about 15 mph). Dunes are constantly changing shape in response to changes in wind velocity or direction. Dunes grow when more sand drifts onto them from surrounding areas than is removed downwind. During storms, sand flows over all parts of the dune. Sand that flows over the center parts of the dune settles on the upper part of the slipface as grainfall deposits formed by settling in the lee of the dune. When the sand accumulates to a certain thickness or angle (the angle of repose: about 32 degrees) it becomes unstable and slides down the slipface. This process, known as avalanching is the basic mechanism of forward advance of most of the bedforms at the Monument. It is clear that some sand that drifts on to the dune from upwind can move past this dune and not become trapped in the slipface. Thus, this dune lives in a continual balance between sand loss at the arms and sand entrapment on the slipface.

One curious aspect of dune growth concerns the relationship of the slipface to the windward slope of the dune. T the highest point on the dune is not at the top of the slipface, but upwind, on the dune crest. Clearly, in this bedform, the dune crest deposits, which consist of ripple strata have grown higher than the slipface. Thus, part of the key to the upward growth of this bedform may lie in the ability of the ripples on the top of this dune to trap oncoming sand, as well as in the ability of the slipface to store it.

Origin and nature of the gypsum sand

White Sands is extraordinary in that most of the eolian deposits are composed almost entirely of gypsum sand. The geologic origins of this sand are discussed in Chapters 1 and 2, but it is useful to briefly review here the physical nature of the sand and it's proximal sources.

Generally speaking, average sand sizes grow finer from upwind (near lake Lucero) to downwind across the Monument. The fining of sand downwind reflects the breakdown of the gypsum crystals through weathering as well as rounding and breakage to smaller sizes through saltation impact.

Gypsum, with a specific gravity of 2.32 g/cm3 is slightly less dense that quartz, which has a specific gravity of 2.65 g/cm3. Despite this difference, which makes gypsum slightly easier than quartz for the wind to move, we could find no major difference between the behaviour of gypsum and quartz either in habit of transport by wind, or in the way in which dunes are formed. One significant difference does become evident after sand is deposited, however. Because gypsum is much more soluble in water than quartz, early cementation of the dune and other sands at White Sands is widespread. This occurs in two main ways; (1) solution by rainfall, followed by drying (light meniscus cement between grains) or precipitation due to evaporation at the top of the capillary fringe (heavy, pervasive cement) (Schenk and Fryberger, 1988). This may slow dune migration rates, or perhaps change the shapes of dunes slightly due to resistance to scour of windward slopes. It may also affect rates of eolian down cutting of source areas to feed new sand to the dunefield. However, the similarity between the eolian deposits and processes at White Sands and other dunefields formed mainly from quartz is quite striking, in the author's experience, while differences are subtle.

The present study as well as those of Almendinger (1971) and Almendinger and Titus (1973) indicates that the primary source of sand for the dune field both in past and present is re-cycling of gypsum crystals from deposits of Pleistocene Lake Otero. Secondary sources include recycling of sand from older dunes and much smaller quantities of freshly precipitated gypsum formed by precipitation from the shallow groundwater table.

Dune types at the Monument

Most of the freely moving dunes at the Monument are of the **barchanoid** type that develops a major slipface transverse to a single dominant wind direction and moves in that direction - which is from the southwest at White Sands. Barchanoid dunes are one of the several major classes of dune morphology known to exist generally. Two other important types are known as linear dunes (elongate dunes that form in parallel rows) and star dunes (star shaped in plan view) are not known to exist at White Sands. Linear dunes develop in bimodal wind regimes, and star dunes in complex, multidirectional wind regimes (Please see Schenk, 1990, for a very readable summary of dune forms and wind regime from a worldwide perspective, and Chapter 9 for summary of dune forms and wind regime). Although the wind regime at White Sands is not perfectly unimodal, the winds sufficiently dominated by the single southwest mode that barchanoid forms dominate the landscape.

Sand roses that summarize effective wind directions through the year for White Sands, based on wind data from Holloman Air Force Base located at the eastern boundary of the Monument. These roses illustrate that the strongest and most common winds are from the southwest, although there are significant flows from the north-northwest and southeast as well at various seasons of the year. There are a number of subtypes of the barchanoid family present at White Sands including barchans, barchanoid ridge and transverse ridge dunes (McKee, 1966). Barchan dunes have curved slipfaces and two horns extending downwind, with proportions in plan view much like a horseshoe. Barchanoid ridge dunes have a longer slipfaces that are sinusoidal in plan view, thus forming a more laterally continuous bedform. Transverse ridge dunes have slipfaces that are relatively straight and continuous. All these types migrate downwind through the erosion of the windward slope deposits and deposition on avalanche faces and lateral horns or extensions.

Another type of dune which has transverse affinities is the **dome dune**. Dome dunes, however, have no slipfaces most of the time. They have long been considered embryonic forms, that evolve downwind into barchanoid types with slipfaces; and indeed are found most commonly at the upwind margins of active dune field.

In addition to freely moving dunes, White Sands also has many tracts of dunes partially anchored by vegetation. **Parabolic dunes** have an actively migrating central mass and long arms that extend upwind, as opposed to shorter arms of the barchan that extend downwind. Also, there are much smaller dunes that do not move called **coppice dunes** that represent sand accumulating within and around small shrubs or grass. Usually, when the plant dies, the sand blows away and may or may not survive as a dune. Another unusual dune type at White Sands is the **lunette dune**, so named because of its shape when associated with small lakes. Lunette dunes form in the lee of lakes, and assume the shape of the shoreline, which is the immediate source of sand for construction of this immobile bedform. Of course, if the shoreline is not roughly circular in shape lunette dunes can grow quite elongate, however the shape is quite distinctive. They often in a semi-arid setting, and are commonly partially vegetated. Most

of the lunettes at White Sands appear to be older than the present active dune field, and have been somewhat reduced by weathering. However, they are easily visible on aerial photographs. These dunes seem to be non-migratory, perhaps due to stabilization by vegetation.

Sedimentary features of the dunes

The principal small-scale sedimentary features of the dunes include various kinds of primary and secondary laminations and bedding, as well as an internal structure reflecting growth, then partial erosion followed by renewed growth. The most common small-scale features are known as **primary stratification**. The two most common primary eolian stratification types are **avalanche** and **ripple** strata. Avalanche strata are formed when sand slides down the slipface of the dune after accumulating at the top and over-steepening past the natural angle of repose for dry sand. These strata are often an inch or more in thickness and rather massive, with drag structures that give evidence of shearing. Sometimes they are inversely graded due to rise of finer grains through the turbulent mass of sand that is sliding downhill. If the sand is damp at the time of avalanching, blocks of cohesive damp sand may be seen in trenches or on the slipface. Ripple strata are formed as one ripple migrates over another, preserving part of the ripple in front of it. Ripple strata are nearly always expressed as fine, thin laminations that are rather straight. Each thin ripple stratum is separated from the next by a thin layer of fines that accumulated in the trough of the ripple. These thin strata are known as pin-stripe laminations and are quite distinctive of eolian deposits.

The internal stratification of the dunes at White Sands was studied by McKee (1977) in a classic study that has been used worldwide by students of sand dunes. The light cementation typical of the gypsum dunes in the main dune mass made it possible for U.S Army, who helped McKee on this project, to bulldoze clean, flat cuts in several directions that revealed in extraordinarily complete detail the internal structure of the major dune types at White Sands Long, steep crossbeds typify the internal structure of barchanoid dunes with large slipfaces. Crossbedding and main bounding surfaces present in the main and cross trenches for barchan and transverse ridge dunes.

Rate of dune advance

Rates of dune advance at White Sands were measured by McKee and Douglass (1971) who measured dune advance rates using stakes in front of the dunes from 1962 to 1968, as summarized in Table 4-1.

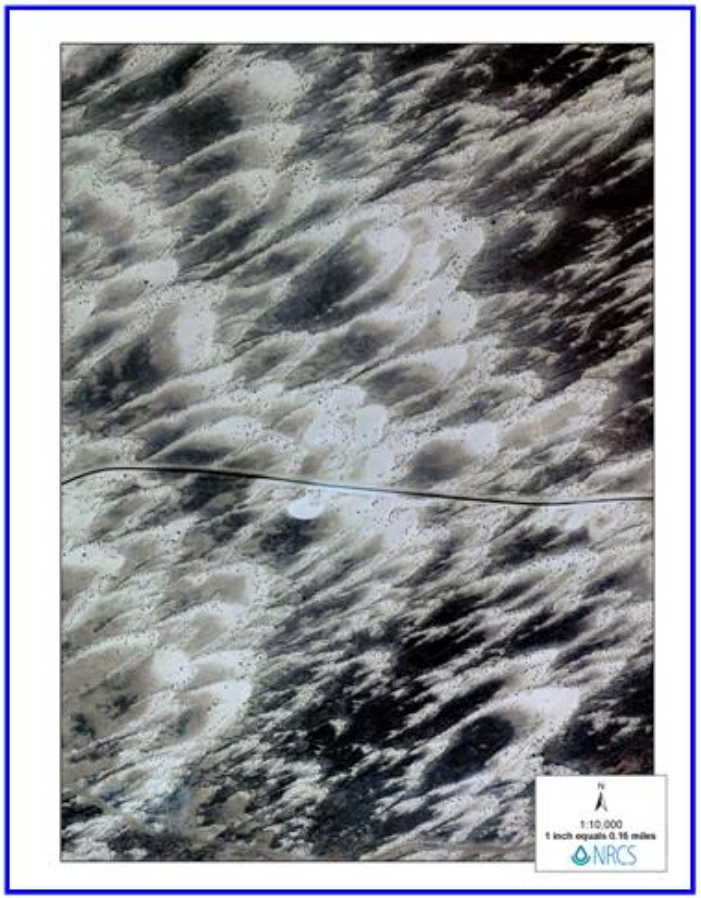
Table 4-1: Rates of movement determined by measurements of distances of aerial photographs

Type of dune	**Dune number**	**Average rate of movement** *ft/year*
Dome	2	24
	11	33
	11a	38
	12	36
Transverse/Barchanoid ridge	3	5
	4	4
	13	9
	14	12
Barchan	5	10
	6	9
	15	7
Parabolic	7	7
	8	2
Eastern margin Parabolics	16	0
	17	5

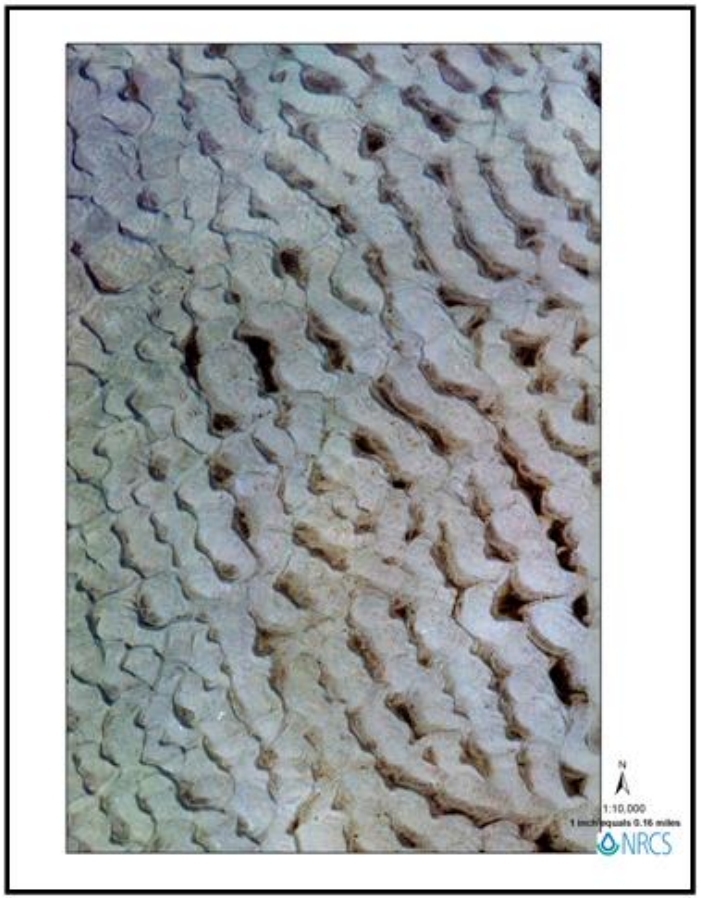
The data in Table 4-1 show that the dome dunes at the upwind end of the field are the fastest moving bedforms. As the field is crossed from upwind to downwind, rates of dune migration slow, partly because bedforms become larger, and vegetation becomes more abundant. Moreover, McKee (1966) felt that some the force of the wind diminished from southwest to northeast due to interference by the dunes themselves. Crabaugh, et. al (19__) also measured rates of barchanoid dune advance along two transects along the wilderness trail to the alkali flats. Average rate of dune advance on the transect at the edge of the Alkali flats was 7 feet per year (average of 3 dunes). Along the second transect located about ½ mile into the field dune advance rates were 4-5 feet per year (average of 8 dunes).

McKee and Douglass (1971) also documented the pace of sediment accumulation at the base of a barchan dune illustrating the episodic nature of eolian accumulation, with single avalanches intertonguing at weekly intervals with ripple deposits deposited more slowly by crosswinds.

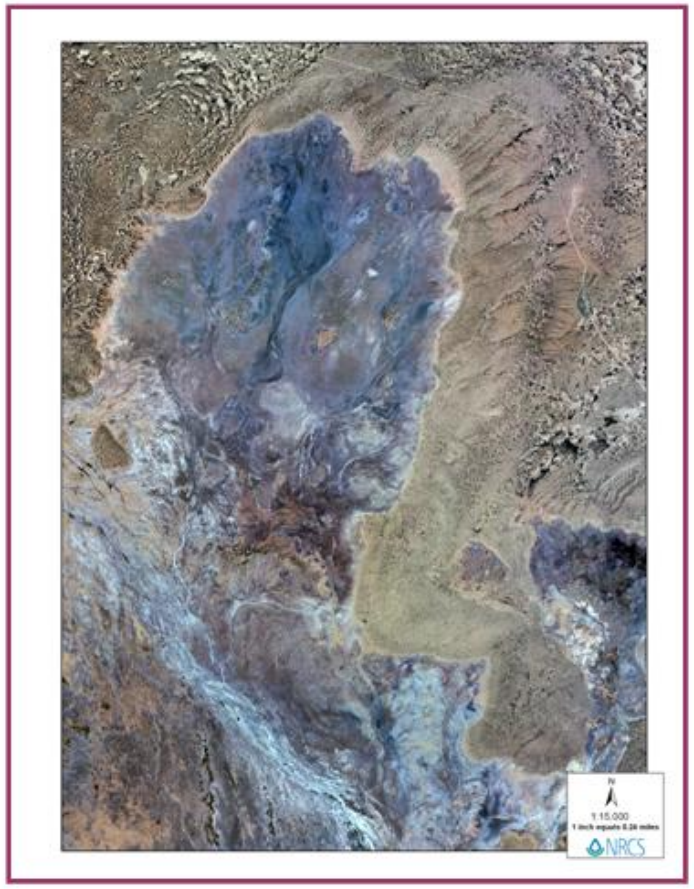
Dune Forms
Parabolic Dunes



Dune Forms
Transverse/Barchan



Dune Forms
Playa Dunes



Dune Forms
Lunettes

Geomorphology 105 (2009) 39–49

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Groundwater salinity as a control on development of eolian landscape: An example from the White Sands of New Mexico

Richard P. Langford [a,*], Jessica M. Rose [b], Diane E. White [c]

[a] Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968, United States
[b] Southwestern Energy Production Co., 2350 N Sam Houston Pkwy East, Houston, TX 77032, United States
[c] White Sands National Monument, Holloman AFB, NM 88330, United States

ARTICLE INFO

Article history:
Received 29 September 2006
Accepted 1 January 2008
Available online 19 June 2008

Keywords:
Parabolic dune
Groundwater
Water table
Holocene
Landscape stability
Sand transport

ABSTRACT

The White Sands of southern New Mexico form the largest field of gypsum dunes in the world. The juxtaposition of several different types of dunes within the field has long been recognized and has generally been attributed to changes in the rate of sand transport across the dune field. However, Steven Fryberger [Fryberger, S.G., 2003. Geology of White Sands National Monument, web page www2.nature.nps.gov/geology/parks/whsa/] recently hypothesized, however, that a primary control is groundwater salinity. The White Sands dune field is underlain by saline waters. Fryberger proposed that parabolic dunes could form in topographic highs that accumulated a lens of fresher water derived from precipitation. Water with lower salinity allowed vegetation to grow, and stabilized the sand except for the active noses of the parabolic dunes. This study is a test of that hypothesis. A study transect was established across the boundary between parabolic and barchan dunes. Groundwater and soil at six sites were sampled during December, 2004 and March, May, and June of 2005. Two sites were established in the parabolic field, two in the barchans, and two in the transition zone between them.

Groundwater was found to be three times more saline in the barchan area. Conductivity and chloride decreased across the transition zone. A GPS topographic survey revealed two abrupt topographic steps, one at the boundary between the barchans and the transition zone and a second at the edge of the parabolic field. A second, larger topographic step was found outside the study area defining a higher parabolic dune field. These data indicate that Fryberger's (2003) hypothesis is correct and groundwater is controlling the dune field morphology.

The dune field did not begin to form until the Mid-Holocene (6500 years ago). A compilation of dates shows that the parabolic dune field has probably been stable for the last 3500 years. In contrast, the barchan area has been recently deflated and exposed 2000 year old sediment near the surface.

© 2008 Elsevier B.V. All rights reserved.

1. Introduction

The White Sands form the largest field of gypsum dunes in the world (Talmadge, 1933; McKee, 1966; McKee and Douglass, 1971; McKee and Moiola, 1975; Schenk and Fryberger, 1988) (Fig. 1). The dunes cover over 400 km^2 of the Tularosa Basin of southern New Mexico where they are contained entirely within White Sands National Monument and White Sands Missile Range (McKee, 1966). McKee (1966) first described the variety of dunes within the White Sands, ranging from dome dunes along the upwind margin to barchan and complex barchanoid ridges in the center of the dune sea, to parabolic dunes along the downwind margin. He ascribed the transitions in types of dune to a decreasing rate of sand transport from west to east across the dune field. A recent hypothesis suggests groundwater chemistry influences the formation of different types of dunes (Fryberger, 2003). The theory suggests that vegetation forms on dunes only where precipitation creates a lens of fresh water within the sand. The vegetation stabilizes the landscape and forms the parabolic dune field at White Sands. Where the topography is lower and interdunes are just above the basinal saline groundwater, vegetation is restricted and greater rates of sand transport occur and barchan dunes develop. This study is a test of Fryberger's (2003) hypothesis. We combined a topographic survey with groundwater chemistry to assess if groundwater salinity increased with lower topography.

2. Setting

The White Sands cover the west-central portion of the Tularosa Basin, a north–south trending extensional basin within the Rio Grande Rift. The basin is topographically closed and has a restricted groundwater outlet. Groundwater discharges into the Hueco Basin to the south, however, rates of discharge are slow enough that the water

* Corresponding author. Tel.: +1 915 747 5968.
E-mail address: langford@utep.edu (R.P. Langford).

0169-555X/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.geomorph.2008.01.020

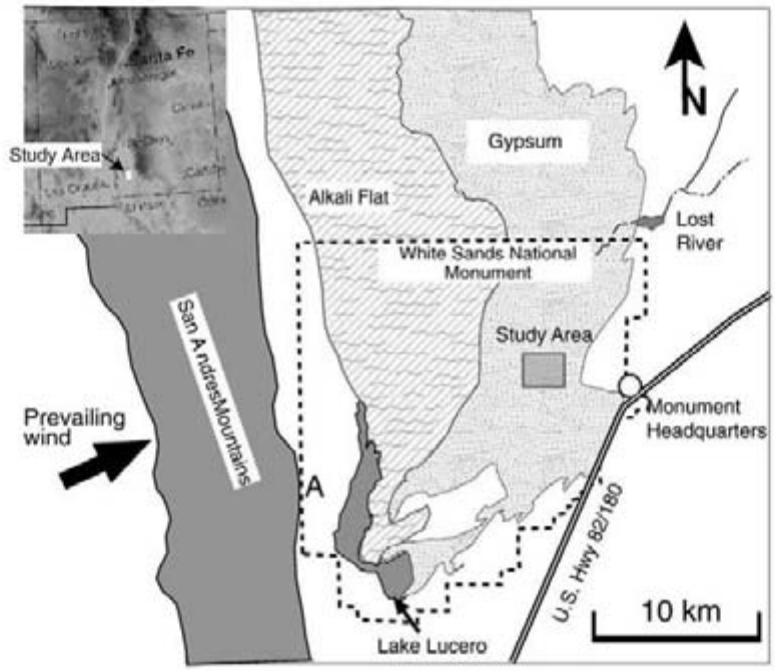


Fig. 1. Location of White Sands dune field. Rectangle shows the location of Fig. 2.

table is near the surface (McLean, 1975; Basabilvazo et al., 1994). Evaporation in a series of lakes and playa lakes during the Quaternary formed dense brines, and resulted in the deposition of evaporites (Allmendinger, 1971, 1972).

Important eolian studies have been conducted in the White Sands, beginning with the seminal work of McKee (1966). Numerous studies have focused on the sedimentary structures in the dunes (Talmadge, 1933; Gould, 1939; Jones, 1959; McKee and Douglass, 1971; McKee and Moiola, 1975; Simpson and Loope, 1985; Fryberger et al., 1988; Sweet and Kocurek, 1990; Frank, 1994; Frank and Kocurek, 1994, 1996). These studies documented largely unidirectional winds from the southwest that have transported the gypsum sand to the northeast, burying the basin floor. McKee (1966) documented rapid migration of the dunes along the upwind margin of the field and inferred that decreasing transport of sand resulted in the distribution of types of dunes. It has long been recognized that deflation of salt crystals from playa lakes and older evaporite beds has provided the sand for the dunes (Allmendinger, 1971, 1972).

More recently, the concept has been developed in which the dunes occupy a large deflation basin from which the dune sands have been excavated. Langford (2002, 2003) concluded that the dune field filled a shallow depression eroded into the floor of pluvial Lake Otero in the early Holocene. The dune field itself was inferred to have been formed almost entirely during the mid-Holocene. Furthermore, the sources of eolian sand were inferred to be a combination of active playa lakes and eroded Lake Otero gypsum beds that were exposed during Mid-Holocene deflation. Fryberger (2003) and Langford (2002, 2003) noted that the predominant sources of sand were along the upwind margin of the dune field. Fryberger (2003) provides a detailed map of the different types of dune at White Sands that illustrates the changes that occurred since the original 1965 McKee studies.

2.1. Groundwater and eolian morphology

Several researchers have discussed the importance of shallow groundwater as a factor in deposition at White Sands. McKee (1966) and Allmendinger (1971) described the interactions between gypsum crystallization on the playas and interdunes and inferred that the dunes were continuously nourished by gypsum that crystallized in flooded areas. Schenk and Fryberger (1988) noted the shallow water table in the dune field and described how moisture and cementation with salt reduced the availability of sand for transport by wind. Simpson (1983) and Simpson and Loope (1985) describe thin sets of eolian cross strata, preserved beneath interdunes in the barchan area, that have been preserved through episodic rise of the water table, which stabilized the sand in the capillary fringe.

More recently, Fryberger (2003) in his excellent online summary of the dune field, described how the shallow groundwater interacts with eolian morphology to shape the dune field. He presented data by Crabaugh (1994) that shows a correlation between the rate of evaporation and depth to the water table, with the water table dropping farther below the surface during the hot summer months. Kocurek et al. (2007) concluded that climatically influenced rises and falls in the water table determined whether accumulation, bypass, or deflation occurred within the dune field. In any case, deflation is slow because of cementation of the interdune, and the interdunes are not prolific sources of sand.

3. Geomorphology

Fig. 2 shows the morphology of the central White Sands erg and the locations of data collected for this paper. The types of eolian dunes were classified using field observations and aerial photographs. Thin, north–south trending lines show the inferred boundaries between different geomorphic regimes. Our interpretations generally follow those of Fryberger (2003) who shows barchans to the west and parabolic dunes to the east, with a gradational boundary. We have delineated a segment of that gradational boundary as the transition zone (Fig. 2).

3.1. Barchan area

The barchan area, distinctive in its sparse vegetation and widely spaced, rapidly migrating barchan dunes (Figs. 2 and 3) that appear as isolated barchans and ridges of linked en echelon barchans. The

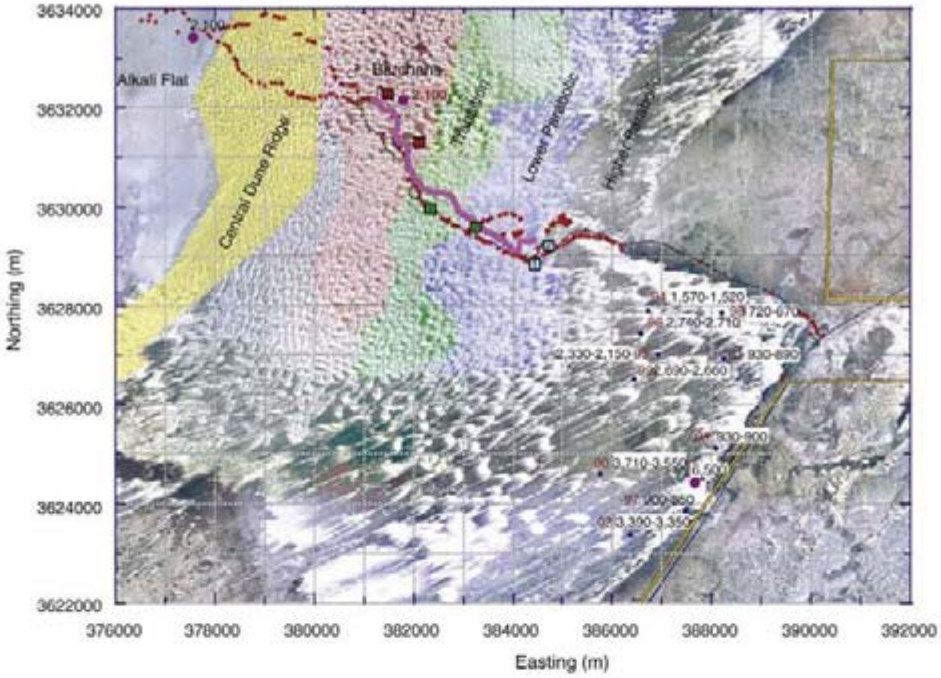


Fig. 2. Aerial photographic map showing the morphology of the central part of the White Sands. White areas are dunes and darker patches represent vegetation and moisture in the interdune areas. The colored regions show the extents of fields of different types of dunes. The more widely spaced crescentic barchans are found in the center. Well developed parabolic dunes are visible to the east. The transition zone separates barchan dunes from the parabolic dunes. The colored squares indicate the sample sites in each area and the numbers correspond to the site numbers in subsequent figures. The blue dots show the locations and one-sigma radiocarbon calendar year ranges of radiocarbon samples. The associated red numbers show the sample numbers, from Table 1. The purple dots show the locations of OSL dates. The red and pink dots show the locations of points along the GPS elevation survey shown in Fig. 11. This digital aerial photograph was provided by White Sands National Monument and constructed by EDAC, 1996.

barchan dunes migrate at annual rates of 1 to 4 m per year (McKee and Douglass, 1971; Crabaugh, 1994). Annual reactivation surfaces suggest that the recent average is approximately 1.5 m per year based on trenching and maps of dune migration (Kocurek et al., 2007). The dunes are devoid of vegetation. This has been ascribed to the rapid rates of erosion and deposition, which prevent the establishment of young plants. The dunes are spaced 50 to 100 m apart and are separated by flat interdune surfaces.

Two types of interdunes are common in the barchan areas; erosional interdunes and evaporitic interdunes. Erosional interdunes form where the cemented toes of dune foresets and adjacent interdune strata are eroded by the wind (Fryberger, 2003). Early cementation near the water table by gypsum cements these strata. After dune migration, the partially cemented strata are exposed to erosion (Fryberger, 2003). More common are the evaporitic interdunes that express salt crystallization at the surface and expose salt ridges and salt polygons (Fryberger, 2003). Salt crusts are formed within the upper 0.5 to 5 cm, consist of interlocked salt crystals, and create a hardened crust that can resist eolian erosion (Fig. 3). In areas of intense evaporation, growth of salt crystals creates a rough surface with shallow pans separated by irregular salt ridges (Fryberger, 2003). These salt crusts change with precipitation and evaporation and may at times be easily eroded. Salt crusts are ephemeral phenomena, related to the high rates of evaporation from a shallow water table. Below the salt crust, algae and lichen grow as part of a biotic soil crust (Shields et al., 1957).

The sparse vegetation largely consists of a variety of grasses, which include alkali Sacaton (*Sporobolus airoides*) and Little Blue Stem (*Schizachyrium scoparium*). Other plants include Ephedra (*Ephedra trifurca*), Soaptree yucca (*Yucca elata*), Squaw Bush (*Rhus trilobata*), Skeletonleaf Goldeneye (*Viguiera stenoloba*), and Sand Verbena (*Abronia angustifolia*).

3.2. Transition zone

East of the barchan dunes a transition zone contains dunes with both convex and concave slipfaces (Figs. 2 and 4). Patches of barchan dunes and parabolic dunes are found, as well as ridges with sinuous slipfaces. The transition zone is most easily differentiated from the barchan zone by the appearance of vegetation in the interdunes. The dunes also become more closely spaced (10 to 50 m apart).

Topography of the transition area is more irregular than the barchanoid area. A few remnants of stabilized dunes create an undulating topography across which the barchan dunes and the active noses of parabolic dunes migrate. The amount of vegetation on the active dunes varies, with isolated parabolic dunes being the most vegetated (Fig. 4). Vegetation on the dunes is dominated by large shrubs, predominantly squaw bush and yucca.

Vegetation occupying the interdunes is similar to the barchanoid area, although it is much more abundant. An increase occurs in the proportions of Soaptree yucca (*Y. elata*) and grasses. A fragile, efflorescent crust covers large portions of the interdunes (Figs. 3 and 4). Biotic soil crusts are minimal, forming thin, widely scattered patches. More of the interdunes are covered by mobile sand than in the barchan areas, where the interdunes are covered almost entirely with cemented sand or salt crusts.

3.3. Parabolic area

The topography of the parabolic dune area is the irregular surface of a vegetated dune field. Areas of mobile sand are restricted to isolated parabolic dunes and ridges consisting of laterally amalgamated parabolic dune noses. The entire surface is irregular on a variety of scales from 10 cm mounds to 2 m ridges formed by the arms of

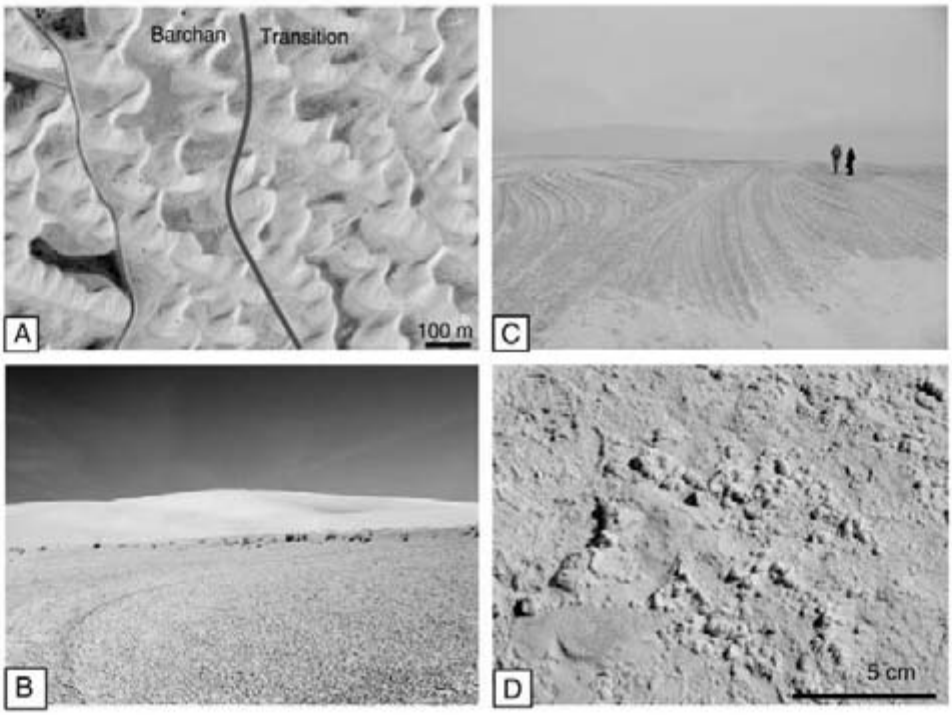


Fig. 3. Photos of the Barchan Area. Aerial photograph of the eastern margin of the barchan area showing geometries of dunes and interdunes. The more widely spaced dunes occur in the barchan area. Dark patches in the barchan area are moist sand in interdunes. Photo 1996 courtesy of White Sands National Monument. Photograph of interdune and dune at barchan site 1. Note the relative paucity of vegetation. The dune is approximately 30 m from the viewer and grasses are 60 cm tall. Erosional Interdune (after Fryberger, 2003) showing the corrugations left by migrating dunes. Ridges contain finer grained wind-ripple deposits. Photograph showing detail of salt efflorescence in the evaporite interdune at Barchan Site 1.

parabolic dunes (Fig. 5B). As parabolic dune noses migrate downwind, the flanks are stabilized, creating stabilized arms that extend to the point of origin of the dune.

The surfaces between the mobile parabolic noses are stabilized by vegetation and soil crusts. In contrast to salt crusts, biotic soil crusts are long lived features that are common to stabilized dunes and vegetated eolian sands in the southwestern United States (Shields et al., 1957; Johansen, 1993). At White Sands, biotic crusts form the upper 10 to 20 cm of the soil in parabolic interdunes. The surface of the crust is darkened and covered with micro-topography in the form of pinnacles composed of algae bound with lichen filaments (Shields et al., 1957). The organisms bind the surface of the sand, and mobile sand grains are largely absent.

Mobile sand consists of a few widely scatted 2 to 3 mm patches of sand on a thick biotic soil crust. Several authors have noted the decrease in the abundance of mobile sand. McKee (1966) and McKee and Douglass (1971) suggested that this dramatic decrease in mobile sand was responsible for the change from barchanoid to parabolic dune forms. Any moving sand between the dunes would be strikingly visible against the matted surface formed by the soil crusts. McKee (1966) noted that dunes migrate more slowly than in the barchan area (Fig. 5).

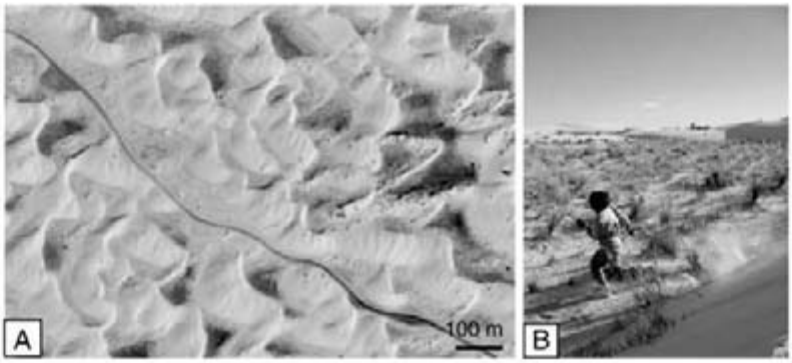


Fig. 4. Photos of the transition zone. Aerial photograph of the transition zone showing closely spaced barchan and parabolic dunes. A higher proportion of white unvegetated mobile sand occurs in the dunes compared to the barchan and parabolic areas in Figs. 3 and 5. Photo, 1996 courtesy of White Sands National Monument. Photograph showing the character of dunes and interdunes in the transition zone. The white sand between grass clumps in the interdune is mobile eolian sand.

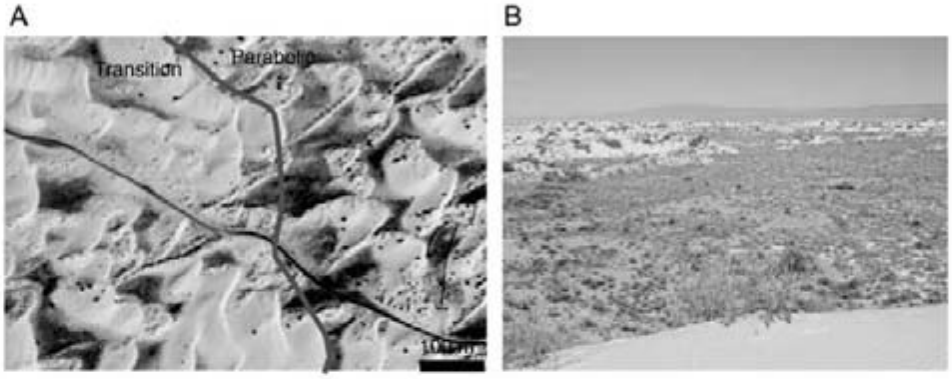


Fig. 5. Photos of the parabolic area. A. Aerial photograph of the upwind edge of the parabolic dune area and adjoining Transition Zone. The vegetation occurs on the parabolic dunes. Darker areas between dunes are vegetated interdunes. Photo, 1996 courtesy of White Sands National Monument. B. Photograph showing the character of dunes and interdunes in the parabolic zone. The white dune in the background is 150 m from the viewer and 4 m tall. Gray stabilized dunes in the middle ground are vegetated and have a well developed soil crust.

The parabolic area has a more diverse suite of vegetation than the barchan and transition areas. Here, Sagebrush (*Artemisia tridentata*), grasses,and Four-winged Saltbush (*Atriplex canescens*) work together to stabilize the wings of the parabolic dunes.

4. Methods

4.1. Study sites and sample collection

Six sites were established in interdunes along a 5 km long transect; two in the barchan, two in the parabolic and two in the transition zone. The sites were 2 m by 2 m plots in which borings were drilled to the water table during every visit. Each site was located in a topographic low in the interdunes to minimize boring depths, and the water table was shallower than 1.9 m at all sites. Because the hypothesis of a freshwater lens in the parabolic dunes requires a topographic high, two GPS transects were created in the dunes to define the topography. These transects occupied the same interdune lows and passed through at least one of the study sites in each type of dune.

Sediment and water samples were collected from 7.6 cm diameter auger borings at each of the six sites (Fig. 2). Samples were collected on December 23rd, 2004, March 23rd, 2005, May 2nd 2005, and June 31st, 2005. All samples were collected during a single day, to avoid temporal changes between measurements. Soil samples were collected using an impact hammer which collected 7.6 cm and 15.2 cm core intervals. Continuous samples were collected from each boring. Where loss from the sampling tube prevented collection of a continuous core, spaced samples were collected at 10 to 15 cm intervals. In some borings, liquefaction of the sand homogenized this interval and prevented sampling of the basal 10 to 30 cm. A total of 112 soil samples were collected: 27 in December, 26 in March; 31 in May; and 28 in June.

Once the water table was reached, a groundwater sample was collected using a bailer. Additional water samples were collected using a bailer from two 9 m deep observation wells in the barchan area during each sampling visit. This allowed comparison of the groundwater in the borings with the deeper groundwater. Water samples were tested on site for dissolved oxygen using a YSI 56 MPS temperature, pH, Conductivity Dissolved Oxygen Probe. The probe was calibrated prior to each sampling campaign, using Conductivity and PH standards. Testing of standards with the calibrated probe indicates precision of 0.1%. The results for dissolved oxygen were somewhat erratic and may have been influenced by agitation during the boring process (see Rose, 2006). These values however, did not impact the salinity and are not reported herein. The sample was then bottled for analysis of water chemistry.

4.2. Laboratory analysis

Damp soil samples were weighed and dried in an oven at 50 °C until weight loss ceased using the procedure of Porta (1998). It was assumed that the soluble salts in the moist samples had homogenized by the time the samples reached the lab, so only one sample was collected from each 10 to 15 cm core tube. The samples were then weighed again to obtain moisture content. Special attention was paid to the samples during drying. Too much heat too fast could dehydrate the gypsum crystals and change the density of the sample (Porta, 1998). Gravimetric moisture content was measured using the methods of Blake (1965).

Soil salinity was estimated by conductivity using the methods of Bowler and Wilcox (1965). Ten grams of dried sample were mixed with 100 ml of distilled water to extract soluble salts. The salt solution was filtered through Whatman 42 (2.4 μ) filter paper to remove contributions to salinity resulting from clay and other particulates suspended in the solution. Conductivity was measured on the filtered saline solution using the YSI meter.

The cationic and anionic chemistry of soil and groundwater samples were measured with a Dionex IC-600 ion chromatograph. Triplicate samples were run every five samples and blanks were run every five samples to document precision (1%). Calcium, sodium, magnesium, lithium, and potassium standards were used to calibrate cations. Sulfate, chloride, nitrate, and fluoride anions were measured. Concentrations of ions were recorded in mg/l. The amounts for the soil samples were then converted to mg of salt per kg of soil by dividing by the weight of the soil (10 g) used for the extract and multiplying by the volume of distilled water used to extract and dilute the salt prior to analysis. Triplicate samples and standards provided estimates of accuracy of 1–5 mg/l. Four sediment and three water analyses were lost because of malfunctioning of the ion chromatograph.

5. Results

5.1. Salinity

A dramatic decrease in salinity, as estimated by conductivity from the barchans to the transition zone occurred in all sampling periods (Fig. 6) The groundwater conductivity has a mean of 8.24 and 7.16 deciSiemens per meter (dS) in the barchan areas versus 4.18 dS in the adjacent transition area. The mean groundwater conductivity decreased to 2.71 dS and 2.49 dS in the parabolic sites (Fig. 6). Little change in salinity occurred from winter to summer at the sites (Fig. 7). The conductivity meter was calibrated using a TDS standard

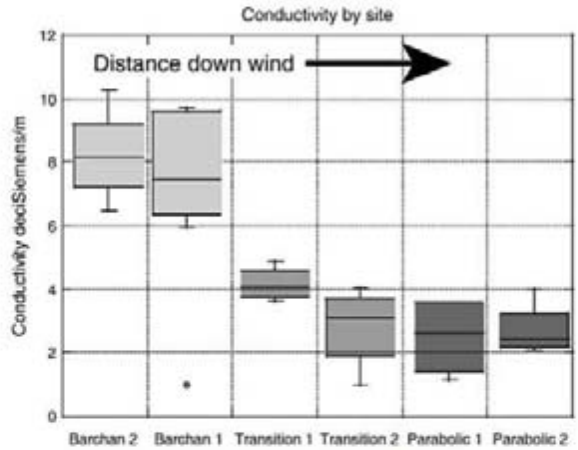


Fig. 6. Conductivity measurements were made on water samples from of the six study sites located in Fig. 2. The barchan sites show significantly higher conductivities than the transition and parabolic sites. The boxes show one standard deviation and the bars show the 95% confidence interval in the data. Black dots are measurements, in the order of the collection date, with the December samples on the left and June samples on the right.

(TDS mg/l = 0.701 + 0.26 EC μS/cm; r^2 = 0.98). This relationship provided TDS estimates of 5000 mg/l in the barchan area and 1600 mg/l in the parabolic area. Much of the change in salinity results from increases in chloride in the barchan area (Fig. 8). Chloride increased from a mean of 127 mg/l in the parabolic area to 640 mg/l in the Transition area to 1455 mg/l in the barchan area (Fig. 8).

5.2. Depth to groundwater

Groundwater was reached at shallow depths throughout the half-year of sampling in all areas (Fig. 9). The depth to the water table was measured by lowering a measuring stick until it reached the water visible in the bottom of each boring. The measured level is, therefore, the water table, and not a capillary fringe in the gypsum sand. Water depth increased by approximately a meter from winter to summer. Depth to water averaged about 53 cm throughout the sampling season within the barchan area (45 cm–80 cm). The water table within the transition area averaged 63 cm but fluctuated between 30 cm and 100 cm. In the parabolic area, the water table fluctuated between 80 cm and 180 cm and averaged 135 cm. Fryberger (2003) presented data by Crabaugh (1994) that shows similar trends. Mean annual precipitation is only 23 cm (Fryberger, 2003), with the greatest precipitation occurring in the late summer and early fall. Evaporation is much greater than precipitation with almost 25 cm of monthly evaporation in the summer (Crabaugh, 1994; Fryberger 2003). Depth to the water table is strongly correlated with evaporation, with the water table dropping during the hot dry summer months.

Light rainfall fell during the sampling period totaling only 6.35 cm. No precipitation fell within the two weeks prior to each site visit except for the May 2nd sampling when 0.76 cm accumulated during the week prior to the sampling (Fig. 10). The great majority of the precipitation (4.9 cm) fell between the December and March sampling trips. This period coincides with a rise of the water table by 5 to 50 cm at the barchan and the adjacent transition site (Fig. 9).

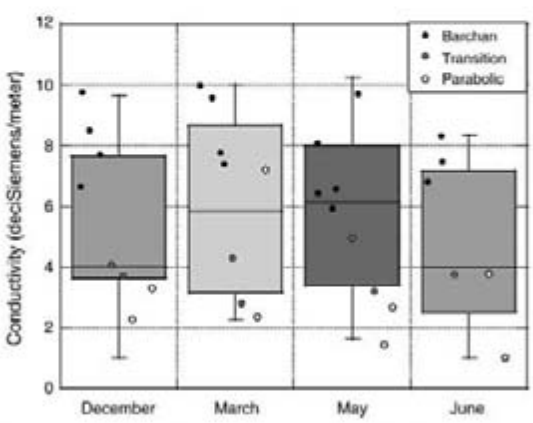


Fig. 7. Conductivity of groundwater samples grouped by collection date showing the lack of seasonal change. Note the segregation between parabolic and the other sites.

5.3. Elevation transects

5.3.1. Methods

A GPS survey was conducted using Trimble Pro-XR and 4000ssi GPS units to determine whether topographic changes might allow the formation of a freshwater lens. Data were differentially corrected using the White Sands Base station. The vertical precision of the Pro-XR was within 70 cm over most of the survey area. The survey quality 4000ssi instrument was used at more widely spaced points that were collected in a survey across the dune field that had 5–10 cm of vertical precision. Point samples were collected at 10 m intervals in the low precision survey and at approximately 100 m intervals in the high precision survey. The lowest points in each interdune were selectively occupied to help define this topography. Together, the surveys allowed us to define the lowest interdune surface within the study area (Fig. 11).

5.3.2. Results

The implication of Fryberger's (2003) theory is that the interdune surfaces within the parabolic dune areas should be topographically higher than those in the barchan dunes, thus allowing a perched fresh-water lens that supports vegetation and controls dune morphology.

The lowest elevations of the interdunes in the barchan area define a topographic flat with a slope of 0.0002 at approximately 1206 m elevation (Fig. 11). An abrupt 2 m topographic rise occurs at the boundary with the transition area and a second 2 m rise at the edge of

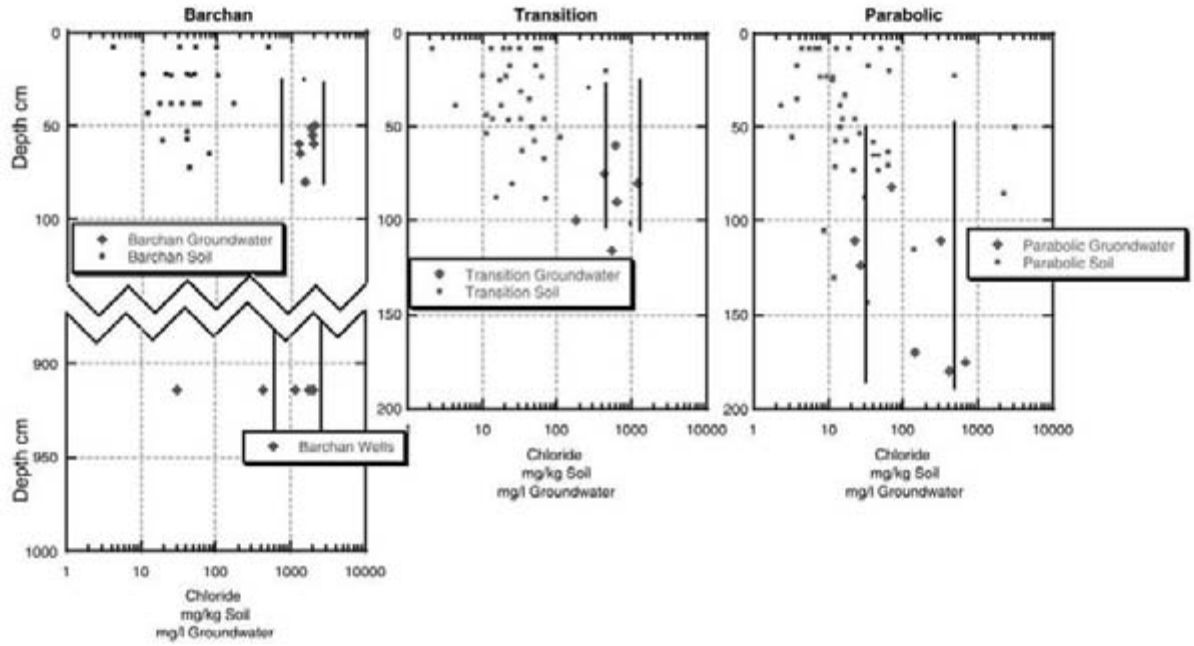


Fig. 8. Soil and groundwater chloride data collected throughout the sampling season on a logarithmic scale. Analyses were made approximately each 10 to 15 cm for each sample. Chloride concentrations are presented as mg of chloride per kg of soil or mg/L of groundwater. The vertical black lines are plus and minus one standard deviation from the means of the water samples.

the parabolic area. Therefore, the barchan area is 3.5 to 4 m lower than the lowest parts of the parabolic area.

The longer GPS transect defines the overall topography of the dune field. Connecting the lowest interdunes provides a slope to the east of 0.001. The landforms of the dune field are evident in the topographic profile. The Alkali Flat, to the west of the dune field, is an irregular surface with no detectable slope in our GPS measurements. The parts of the Alkali Flat nearest the dune field contain large areas of erosional interdunes, exposing relict dune foresets that are now being eroded (Fryberger, 2003). The western margin of the dune field is a topographic high that contains the largest dunes in the dune field. This large mound is termed the central dune ridge (Fryberger, 2003) and has been interpreted as an aggradational mound formed by deflation off the adjacent Alkali Flat (Langford, 2003). Dunes within the central ridge are closely spaced, and, therefore, interdunes in the central dune ridge are narrow. The interdunes are either erosional interdunes or dry interdunes covered in wind rippled, actively blowing sand. The lowest interdunes are topographically high. If the

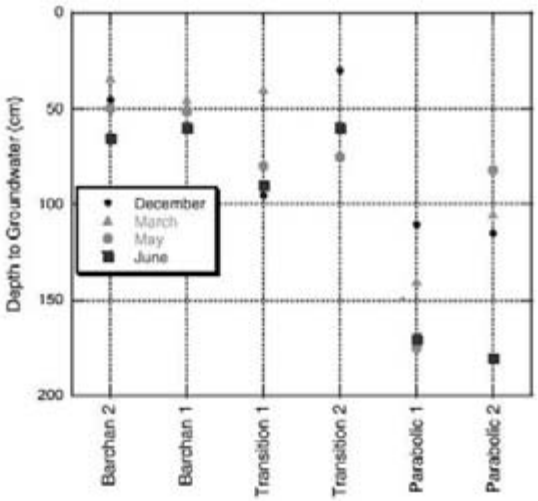


Fig. 9. Graph showing measured depths to the water table at the different study sites. The sites are organized along a west-to east transect, with Barchan 2 the farthest west and Parabolic 2 the farthest east.

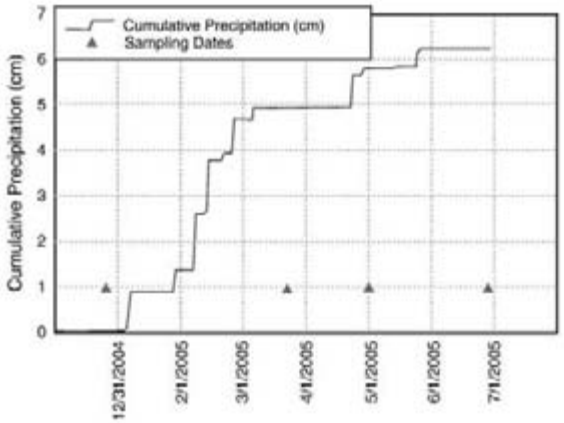


Fig. 10. Graph of cumulative precipitation recorded at White Sands Missile Range and sampling dates for this project.

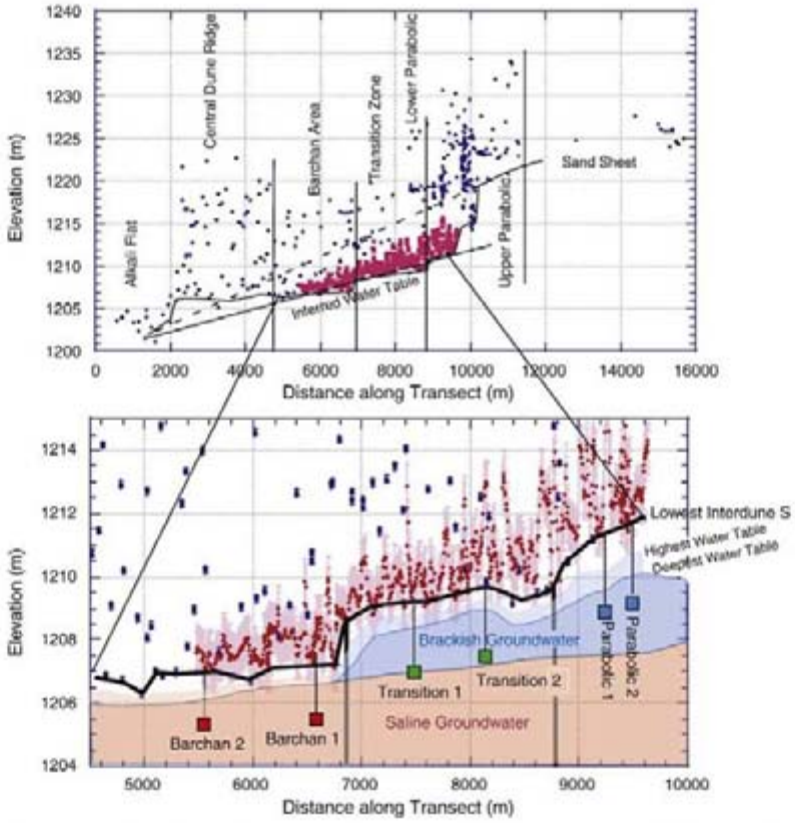


Fig. 11. GPS Transects located in Fig. 2. The longer transect with blue points illustrates the topography of the different regions in Fig. 2. The red points represent more closely spaced, but lower precision GPE elevations. The solid line shows the inferred water table with a slope of 0.001. The dashed line is the surface of the upper parabolic interdunes projected back across the dune field. The lower transect shows the topography within the study area. The points are GPS elevations, the error bars show vertical precisions. The higher points mark positions on dunes. The lower elevation points define interdune surfaces. The colored squares show the locations of sample sites and the vertical bars mark the boundaries between dune terrains as inferred from the aerial photograph and landscape observation as shown in Fig. 2. The lighter shaded stripe is an extrapolation of the measured depth to groundwater from the sample sites.

elevations of the water-table-influenced interdunes in the adjacent barchan and Alkali Flat are connected by a sloping line, the lowest interdunes in the ridge are 1 to 3 m higher (Fig. 11).

East of the central dune ridge lies the beginning of our study area. The widely spaced barchans lie in a topographic low between the central dune ridge and the parabolic dunes to the east. Within the study area, two abrupt 2-m elevation changes occur in the interdune surfaces within the transition areas and define the beginning of a topographic high that composes the parabolic dunes. An even larger, 4-m rise in the interdune surface is found just east of the study area. Beyond this the dune field continues to rise to its topographic high, along its eastern margin. A sand sheet slopes gently to the east away from the dunes. Examination of the topographic rise within the parabolic area shows that it separates a more active part of the parabolic dunes, in which we conducted our study from a higher, more stable portion, with more widely spaced parabolic dunes (Figs. 2 and 11).

6. Ages of surfaces

Recent dating provides estimates of the relative ages of the various surfaces in the dune field (Fig. 2). Optically Stimulated Luminescence (OSL) dates and radiocarbon dates are available from a variety of sources. OSL dates record the burial of sand, and provide ages of eolian migration or aggradation. Radiocarbon dates come from a variety of sources and date different features within the Monument.

One intriguing OSL date obtained by Steven Stokes, published by Fryberger (2003), provided an age of 6500 years BP for the leading edge of the dune field (Fig. 2). Additionally, a radiocarbon date from the north of the study area provides a minimum age for eolian accumulation of 5840 years BP (Langford, 2003). This date was from a lake that formed when a stream was dammed by the dune field. Together, these dates indicate that the dune field achieved its present size soon after its formation in the middle Holocene. The preserved lacustrine landscape, covered with scattered gypsum sand sheets east of the dune field, indicates that the location of the dune front has not changed substantially in the last 6000 years.

A suite of radiocarbon dates collected on prehistoric hearths by the Monument staff provide estimates of surface stability rather than dune mobility, and show two main regions of the parabolic dunes (Fig. 2). The samples were collected from hearths originally constructed on the tops of eolian dunes. The heat from the fires converted the gypsum sand of the dune into a hard plaster, forming an erosion-resistant surface. Migration of the dunes left the hearths as remnant tops of pedestals, capped by the plaster. Many pedestals have multiple hearths that were reoccupied at different times. These multiple hearths were not sampled so as to eliminate the possibility of mixing of carbon of different ages. Two to five gram samples were collected

Table 1
Radiocarbon ages from samples collected in the parabolic area

Beta analytic sample Number	Material	Conventional radiocarbon age (BP)	Calendar age 1 Range (BP)
Beta-179293	Charcoal from Hearth	970±40 BP	930–900
Beta-179294	Charcoal from Hearth	1650±40 BP	1570–1520
Beta-179295	Charcoal from Hearth	2210±40 BP	2320–2150
Beta-179296	Charcoal from Hearth	2540±40 BP	2740–2710
Beta-179297	Charcoal from Hearth	890±40 BP	900–850
Beta-179298	Charcoal from Hearth	780±40 BP	720–670
Beta-179299	Charcoal from Hearth	2420±40 BP	2,690–2660
Beta-179300	Charcoal from Hearth	3390±40 BP	3680–3580
Beta-179301	Charcoal from Hearth	960±40 BP	930–890
Beta-179302	Charcoal from Hearth	3150±40 BP	3390–3350

from ten hearths for radiocarbon dating (Table 1). The samples were sent to Beta Analytic for AMS radiocarbon dating. Samples were acid washed to remove dispersed carbonate and were analyzed using standard AMS Techniques.

The radiocarbon dated pedestals mark the locations of parabolic dunes within the stable parabolic field. In most cases, the active dunes can still be located by following the parabolic arms from the dated pedestal. The radiocarbon dates are, therefore, minimum dates for the stability of different parts of the parabolic area.

The leading edge of the dune field is a relatively active dune ridge. The hearths along the ridge provided dates approximately 1000 years old, whereas, dates on preserved surfaces within the higher parabolic surface provide dates as old as 3700 years BP. This suggests a minimum age of 3500 years BP for stabilization of the higher parabolic surface, just east of the study area.

Kocurek et al. (2007) has demonstrated at least episodic eolian aggradation through the Late Holocene. An OSL date from near the end of the Alkali Flat trail, reported by Fryberger (2003), and a date from the barchan area, reported by Kocurek et al. (2007) both provide ages of 2100 years BP at approximately 1 m below the surface. This indicates an accumulation of eolian sediment at a rate of 50 cm/1000 years over the last 2000 years.

6.1. Interpretation of dates

The higher parabolic surface, east of the study area, is a landscape at least 3500 years old. The parabolic landscape stabilized within the first three thousand years of the White Sands dune field. Because the traces of the parabolic noses associated with the older dates are clearly visible in the stabilized and vegetated landscape, this surface must be even older than the radiocarbon dates from the dunes. The barchan area is being actively reshaped today as is evidenced by the migrating dunes and erosional interdune landscape. The 2100 BP dates 1 m

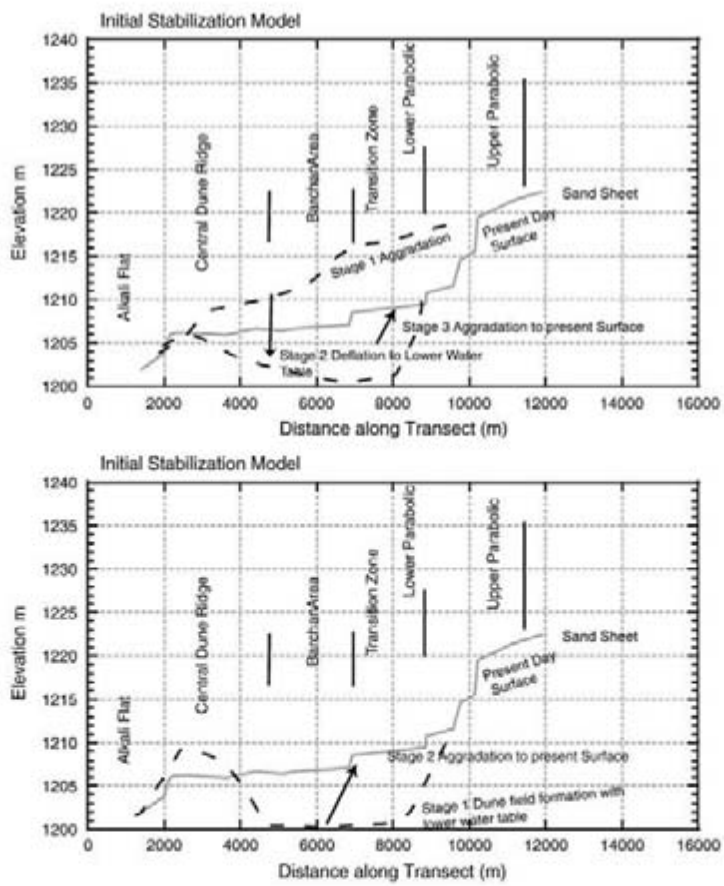


Fig. 12. Two models depict the development of the present day landscape at White Sands. The top diagram shows a model that supposes that the entire dune field was at one time vegetated. The parabolic field today is the remnant of a much larger topographic high. The second model supposes that the present day distribution of dunes is similar to that of the past, and the primary event has been the filling of the topographic low in the barchan area.

below the surface in these areas suggests deposition is at least an episodic process in this area and the surface has aggraded (Kocurek et al., 2007).

Two different interpretations of the history of the White Sands are possible given the existing data. One possible history is that the entire dune field was initially a topographic high with a surface that sloped to the west with a surface approximately following the dashed line in Fig. 11. In this model (Fig. 12), the barchan area fills a hollow that was created subsequently by deflation of the western part of the dune field. The very gently sloping water-table defined surface and abrupt topographic step at its downwind edge, suggest the level of at least the downwind edge of the barchan area may have been shaped by deflation. Projecting the lower interdune surfaces from the higher parabolic area traces a surface that lies about 3 m above the parabolic area and merges with the current interdune surfaces at the upwind edge of the dune field (dashed line in Fig. 11).

Some evidence, both regionally and locally, exists for this scenario (see Langford 2003, and Fryberger, 2003, for Quaternary environmental histories). The erosional shorelines that are west of the dune field document at two least major episodes of lowering of the water table associated with deflation of the playa floors (Langford, 2003). Similar erosion events in playa floors have been documented at 4000 and 2000 years BP in the Lake Estancia Basin to the North (Bachhuber, 1982; Smith and Anderson, 1982; Allen, 1991). Within the region, at least four major episodes of eolian activity and landscape instability have been documented. Episodes of eolian erosion and deposition are documented at approximately 2200 and 1100 years BP, as well as historically across the Tularosa Basin, including areas just south of the White Sands (Blair et al., 1990; Monger, 1995; Buck, 1996; Buck and Monger, 1999).

An alternative interpretation is that the topography of the dune field has been similar to that of the present day, with a barchan area lower than that of the adjoining dune ridge and parabolic areas. In this scenario, little change has occurred in the locations of the dune types over time and the barchans fill a depression that has gradually been filling throughout most of the history of the dune field.

Kocurek et al. (2007) provide data that constrain these models. They presented OSL dates from a core in the barchan area that were 5200 BP at 5 m and 6 m below the surface, and 2100 BP at 1 m below the surface. Kocurek et al. (2007) also present trenches in which they document the preservation of eroded eolian strata beneath upwind interdunes and succeeding dunes. They conclude that this documents bedform climb, in which dunes climb as they migrate relative to a base level. This indicates that the deflation event in the first scenario must have occurred either between 6500 BP and 5200 BP, or to shallower than 5 m below the present day surface between 5200 BP and 3400 BP.

7. Discussion and conclusions

From the beginnings of eolian studies, researchers have attempted to discern the controls on the occurrence of different types of eolian dunes within ergs. Several authors have noted the importance of wind regimes, with larger and more complex dunes forming in regions with more variable transporting winds (Fryberger and Dean, 1979; Lancaster, 1983,1989). Lancaster (1995) discussed the importance of dune or draa size as a factor, noting that small dunes are easily shaped by seasonal winds, whereas larger forms can have contributions from more complex, long-term wind patterns. Parabolic dunes in particular are shaped by the vegetation in and on the dunes (Wasson et al., 1983). At White Sands, several authors have pointed to changes in the rate of sand transport (McKee, 1966, McKee and Moiola, 1975). However, the role of groundwater in shaping morphology has not been explored, except as a limiting factor in the depth of erosion.

This study suggests that at White Sands the above factors are influenced not only the presence of a shallow groundwater table, but also its salinity. Accumulation of a topographic high composed of eolian sediments allows accumulation of precipitation, which in turn allows vegetation growth. Parabolic dunes form in the stabilized eolian sand above the freshwater lens, whereas barchan dunes form in areas deflated to the saline groundwater table. The positive feedback between eolian mobility and vegetation results in a setting with two equilibrium states; vegetated and active. The abrupt boundary between active and stabilized eolian settings observed at White Sands is consistent with a water salinity control on the eolian landscape.

Acknowledgements

We would like to first thank the staff of White Sands National Monument. They provided us the access to do our research and allowed us a key for sampling groundwater wells. Bill Conrad provided consistent support. We would also like to thank our laboratory assistant Meliza Cueto. We also thank Ben Drenth, Derek Folger for aid in data collection. Also thanks to Dave Tatum and Brandi Harkins for help with GPS collection and to Kathy Fernald for help with the GPR surveys. Thank you to Sonny Emmert for his help with the Ion Chromatograph. Dr. Gary Kocurek provided a very helpful editorial review.

References

Allen, B.D., 1991. Effect of climatic change on Estancia Valley, New Mexico: sedimentation and landscape evolution in a closed drainage basin. In: Julian, B., Zidek, J. (Eds.), Field Guide to Geologic Excursions in New Mexico and Adjacent Areas of Texas and Colorado. New Mexico Bureau of Mines and Mineral Resources Bulletin, vol. 137, pp. 166–171.

Allmendinger, R.J., 1971. Preliminary evaluation of the role of the hydrologic cycle in the development of the white sands, White Sands National Monument, New Mexico. Abstracts with Programs–Geological Society of America 3, 231–232.

Allmendinger, R.J., 1972. Hydrologic control over the origin of gypsum at Lake Lucero, White Sands National Monument, New Mexico. Master's Thesis, New Mexico Institute of Mining and Technology, Socorro, NM, United States, 182 pp.

Bachhuber, F.W., 1982. Quaternary history of the Estancia Valley, Central New Mexico. Albuquerque Country II: [Albuquerque, New Mexico], New Mexico Geological Society 33rd Field Conference Guidebook, 343–346 pp.

Basabilvazo, G.T., Myers, R.G., Nickerson, E.L., 1994. Geohydrology of the high energy laser system test facility site, White Sands Missile Range, Tularosa Basin, south-central New Mexico. US Geological Survey, Reston, VA, USA. 59 pp.

Blair, T.C., Clark, J.S., Wells, S.G., 1990. Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla piedmont and Tularosa Graben floor, White Sands Missile Range, New Mexico. Geological Society of America Bulletin 102, 749–759.

Blake, G.R., 1965. Bulk Density. In: Black, C.A. (Ed.), Methods of Soil Analysis. . Agronomy. American Society of Agronomy, Madison Wisconsin, pp. 374–390. Series Number 9.

Bowler, C.A., Wilcox, L.V., 1965. Soluble salts. In: Black, C.A. (Ed.), Methods of Soil Analysis. Agronomy. American Society of Agronomy, Madison Wisconsin, pp. 933–951. Series Number 9.

Buck, B.J., 1996. Late Quaternary landscape evolution, paleoclimate and geoarchaeology, southern New Mexico West Texas. Ph.D. Thesis, New Mexico State University, Las Cruces, 398 pp.

Buck, B.J., Monger, H.C., 1999. Stable isotopes and soil geomorphology as indicators of Holocene climate change, northern Chihuahuan Desert. Journal of Arid Environments 43 (4), 357–373.

Crabaugh, M.M., 1994. Controls on accumulation in modern and ancient wet eolian systems, Ph.D. Thesis, University of Texas at Austin, Austin, TX, 135 pp.

Frank, A.J., 1994. Models for airflow velocity profiles in natural settings; accounting for atmospheric conditions and secondary flow over eolian dunes. Ph.D. Thesis, University of Texas at Austin, Austin, TX, 140 pp.

Frank, A.J., Kocurek, G., 1994. Effects of atmospheric conditions on wind profiles and aeolian sand transport with an example from White Sands National Monument. Earth Surface Processes and Landforms 19 (8), 735–746.

Frank, A.J., Kocurek, G., 1996. Airflow up the stoss slope of sand dunes; limitations of current understanding. In: Lancaster, N. (Ed.), Response of Aeolian Processes to Global Change, vol. 17. Elsevier, Amsterdam, Netherlands, pp. 47–54.

Fryberger, S.G., 2003. Geology of White Sands National Monument, web page www2.nature.nps.gov/geology/parks/whsa/.

Fryberger, S.G., Dean, G., 1979. Dune forms and wind regime. In: McKee, E.D. (Ed.), A Study of Global Sand Seas, United States Department of the Interior, Professional Paper, vol. 1052. U.S. Geological Survey, pp. 137–169.

Fryberger, S.G., Schenk, C., Krystinik, L.F., 1988. Stokes surfaces and the effects of near-surface groundwater-table on aeolian deposition. Sedimentology 35 (1), 21–41.

Gould, C.N., 1939. The great White Sands [of New Mexico]. Mines Magazine 29, 379–381.

Johansen, J.R., 1993. Cryptogamic crusts of semiarid and arid lands of North America. Journal of Phycology vol. 29, 140–147.

Jones, B.R., 1959. Sedimentary study of dune sands, Lamb and Bailey Counties, Texas and White Sands National Monument, New Mexico. Master's thesis, Texas Tech University, Lubbock, 95 pp.

Kocurek, G., Carr, M., Ewing, R., Halvholm, K.G., Nagar, Y.C., Singvi, A.K., 2007. White Sands Dune Field, New Mexico, age dune dynamics and recent accumulations. Sedimentary Geology 197, 313–331.

Lancaster, N., 1983. Controls on dune morphology in the Namib Sand Sea. In: Brookfield, M.E., Ahlbrandt, T.S. (Eds.), Eolian Sediments and Landforms. Developments in Sedimentology, vol. 38. Elsevier, Amsterdam, pp. 261–290.

Lancaster, N., 1989. The Namib Sand Sea: Dune Forms, Processes and Sediments. Rotterdam, Balkema. 200 pp.

Lancaster, N., 1995. Geomorphology of Desert Dunes. Routledge, New York, p. 280.

Langford, R.P., 2002. Playa lake shorelines and the Holocene history of the White Sands dune field. In: Lueth, V.W., Giles, K.A., Lucas, S.G., Kues, B.S., Myers, R.G., Ulmer, S., Dana, S. (Eds.), Geology of White Sands. Guidebook—New Mexico Geological Society, vol. 53, pp. 45–47.

Langford, R.P., 2003. The Holocene history of the White Sands dune field and influences on eolian deflation and playa lakes. In: Lancaster, N., Tchakerian, V. (Eds.), Linkages Between Fluvial, Lacustrine and Aeolian Systems in Drylands. Quaternary International, vol. 104, pp. 31–39.

McLean, J.S., 1975. Saline ground water in the Tularosa Basin, New Mexico. Guidebook—New Mexico Geological Society. Guidebook of the Las Cruces country, vol. 26, pp. 237–238.

McKee, E.D., 1966. Structures of dunes at White Sands National Monument, New Mexico (and a comparison with structures of dunes from other selected areas). Sedimentology 7 (1), 1–69.

McKee, E.D., Douglass, J.R., 1971. Growth and movement of dunes at White Sands National Monument, New Mexico. United States Department of the Interior, U.S. Geological Survey, Professional Paper 0750-D, pp. 108–114.

McKee, E.D., Moiola, R.J., 1975. Geometry and growth of the White Sands dune field, New Mexico. United States Department of the Interior, U.S. Geological Survey, Journal of Research 3 (1), 59–66.

Monger, H.C., 1995. Chapter 1: Eolian evolution, Chapter 2: Paleoenvironmental changes in Eolian evolution and paleoenvironmental changes during the late Quaternary in the Fort Bliss Maneuver areas and vicinity. In: Monger, H.C., Buck, B.J. (Eds.), Historic and Natural Resource Report. Environmental Management Office, Directorate of Installation Support, Fort Bliss, TX.

Porta, J., 1998. Methodologies for the analysis and characterization of gypsum soils: a review. Geoderma 87, 31–46.

Rose, J.M., 2006. Differences in dune morphology related to changes in groundwater geochemistry, White Sands National Monument. Master's thesis/University of Texas at El Paso; no. 6229.

Schenk, C.J., Fryberger, S.G., 1988. Early diagenesis of eolian dune and interdune sands at White Sands, New Mexico. Sedimentary Geology 55 (3), 109–120.

Shields, L.M., Mitchell, C., Drouet, F., 1957. Alga- and lichen-stabilized surface crusts as soil nitrogen sources. American Journal of Botany 44 (6), 489–498.

Simpson, E.L., 1983. The geometry and structure of interdune deposits at White Sands National Monument, New Mexico. Master's Thesis, University of Nebraska, Lincoln, 83 pp.

Simpson, E.L., Loope, D.B., 1985. Amalgamated interdune deposits, White Sands, New Mexico. Journal of Sedimentary Petrology 55 (3), 361–365.

Smith, L.N., Anderson, R.Y., 1982. Pleistocene–Holocene climate of the Estancia Basin, central New Mexico. New Mexico Geological Society 33rd Annual Field Conference Guidebook, pp. 347–350.

Sweet, M.L., Kocurek, G., 1990. An empirical model of aeolian dune lee-face airflow. Sedimentology 37, 1023–1036.

Talmadge, S.B., 1933. Source and growth of the white sands of New Mexico. Pan-American Geologist 60, 304.

Wasson, R.J., Rajaguru, S.N., Misra, V.N., Agrawal, D.P., Dhir, R.P., Singhvi, A.K., Kameswara Rao, K., 1983. Geomorphology, late Quaternary stratigraphy and palaeoclimatology of the Thar dunefield. Zeitschrift für Geomorphologie Supplementbände 45, 117–151.

PERGAMON

Quaternary International 104 (2003) 31–39

The Holocene history of the White Sands dune field and influences on eolian deflation and playa lakes

Richard P. Langford*

Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968-0555, USA

Abstract

White Sands National Monument is the world's largest gypsum dune field. The dunes are downwind of a 20-m-deep, 19-km-wide deflation basin containing large playa lakes. Today, the gypsum sand is derived from the edge of the deflation basin, next to the dune field, rather than the alkali flat and playa lakes, where gypsum crystals are forming. Three erosional shorelines mark wetter episodes, when playa lakes formed in the deflation basin. Successively, younger shorelines formed within older ones as the basin deepened, but was not widened by deflation. The modern shoreline is forming around Lake Lucero Playa. The oldest shoreline, termed L1, is degraded and formed near the Pleistocene–Holocene transition. Deflation from the L1 to the L2 shoreline cut through Pleistocene bedded evaporites and probably marks initiation of the dune field. This event was before 5840 yr BP, based on radiocarbon dates. This reinforces an evolving consensus that episodes of deflation have characterized desert basins in the southwestern United States. Regional deflation events have been dated at 7000 and 4000 yr BP. The shorelines imply the White Sands dune field was created in short episodes and the modern dune field may not represent conditions during expansion of the dune sea.
© 2002 Elsevier Science Ltd and INQUA. All rights reserved.

1. Background and geological history

White Sands National Monument, in the southwestern United States, is the largest field of gypsum dunes in the world (Talmadge, 1933; McKee, 1966; McKee and Douglass, 1971; McKee and Moiola, 1975; Schenk and Fryberger, 1988) (Fig. 1). The dunes cover over 400 km^2 of the Tularosa Basin of southern New Mexico, where they are contained entirely within White Sands National Monument and White Sands Missile Range (McKee, 1966). The Tularosa Basin is a north south trending extensional basin that formed as part of the Rio Grande Rift. The basin is topographically closed and has a restricted groundwater outlet. Groundwater discharges into the Hueco Basin to the south of Lake Lucero, however, discharge rates are slow enough that the water table is near the surface at Lake Lucero (McLean, 1975; Basabilvazo et al., 1994), forming dense brines and resulting in the deposition of evaporites in a series of lakes and playa lakes during the Quaternary (Allmendinger, 1971, 1972). The gypsum has been reworked into a large field of white gypsum dunes.

For over 30 yr important results have come from studies of the White Sands, beginning with the seminal work of McKee (1966). Numerous studies have focused on the sedimentary structures in the dunes (Talmadge, 1933; Gould, 1939; Jones, 1959; McKee and Douglass, 1971; McKee and Moiola, 1975; Simpson and Loope, 1985; Fryberger et al., 1988; Sweet and Kocurek, 1990; Ahlbrandt et al., 1994; Frank, 1994; Frank and Kocurek, 1996). These studies documented a prevailing wind regime from the southwest that has transported the gypsum sand to the northeast, burying the basin floor. Various dune types are found within the White Sands. Dome dunes are found along the upwind margin of the dune field (McKee, 1966). Transverse and barchanoid forms form the core of the dune field, and are flanked to north, south and downwind by extensive fields of parabolic dunes. McKee (1966) documented rapid migration of the dunes along the upwind margin of the field and inferred that decreasing sand transport resulted in the distribution of dune types.

It has long been recognized that deflation of salt crystals from playa lakes and older evaporite beds has provided the sand for the dunes (Allmendinger, 1971, 1972). More recently, the concept has been developed in which the dunes occupy a large deflation basin, from which the dune sands have been excavated. Steve

*Tel.: + 1-915-747-5968; fax: + 1-915-747-5073.
E-mail address: langford@geo.utep.edu (R.P. Langford).

1040-6182/02/$ - see front matter © 2002 Elsevier Science Ltd and INQUA. All rights reserved.
PII: S1040-6182(02)00133-7

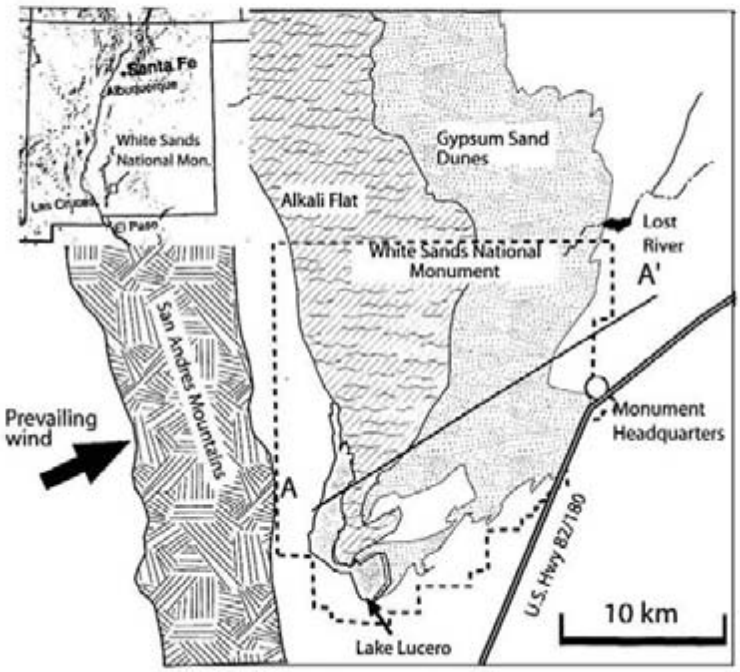


Fig. 1. Location map of White Sands National Monument showing the relationship of the gypsum sand dunes to Lake Lucero and the alkali flat. A to A′ shows the location of the topographic cross section in Fig. 4.

Fryberger has developed this concept and proposed it during discussions in the field (Fryberger, pers. comm., 2000). I observed what appeared to be relict shorelines surrounding the deflation basin, and these are the subject of this paper.

2. Geologic setting

Studies of the Tularosa Basin southeast of the White Sands have concentrated on the windblown sands, alluvial fans and associated soils (Blair et al., 1990; US Bureau of Land Management, 1990; Buck, 1996). This work has provided a general Quaternary environmental history of the Tularosa Basin. During the early- and mid-Pleistocene, the Rio Grande deposited sediment across the southern half of the basin. This deposition terminated early in the mid-Pleistocene, and a stable surface, known as the La Mesa surface, formed. Large parts of the basin floor have remained unmodified since the mid-Pleistocene (Buck, 1996). Faults have offset the La Mesa surface in several locations, and windblown sands have accumulated, burying this old soil (Buck, 1996).

2.1. Lake Otero

Only in the central part of the basin did significant deposition continue through the late-Pleistocene and Holocene (Seager et al., 1987; Herrick, 1904). Here pluvial Lake Otero extended across the width of the basin during the latest Pleistocene (Herrick, 1904; Kottlowski, 1958; Seager, 1980; Seager et al., 1987). A shoreline formed at 1216 m elevation during the latest Pleistocene (Seager et al., 1987). Additional shorelines formed at elevations of 1210 and 1207 m in isolated sub-basins of Lake Otero (Fig. 2). Better-preserved sedimentary structures in these lower-elevation shorelines suggest they are younger than the highest shoreline. These shorelines may be latest Pleistocene, based on age estimates described below for the erosional shorelines.

2.2. Holocene playas

At least 20 playa lakes fill basins that are incised into the sediments of Lake Otero. Lake Lucero, the largest of the playas, lies upwind of the dune field. Lake Lucero playa consists of three sub-basins in the shape of an L. The surface of the lake is a crust of white powdery gypsum with patches of halite. Below this crust are to 10-cm-thick beds of clay, gypsiferous clay, and coarse gypsum crystals. Several additional playa lakes with features similar to Lake Lucero are found to the north (Fig. 2). The playas are aligned with a topographic low that follows the most active basin-bounding normal fault along the western margin of the Tularosa Basin.

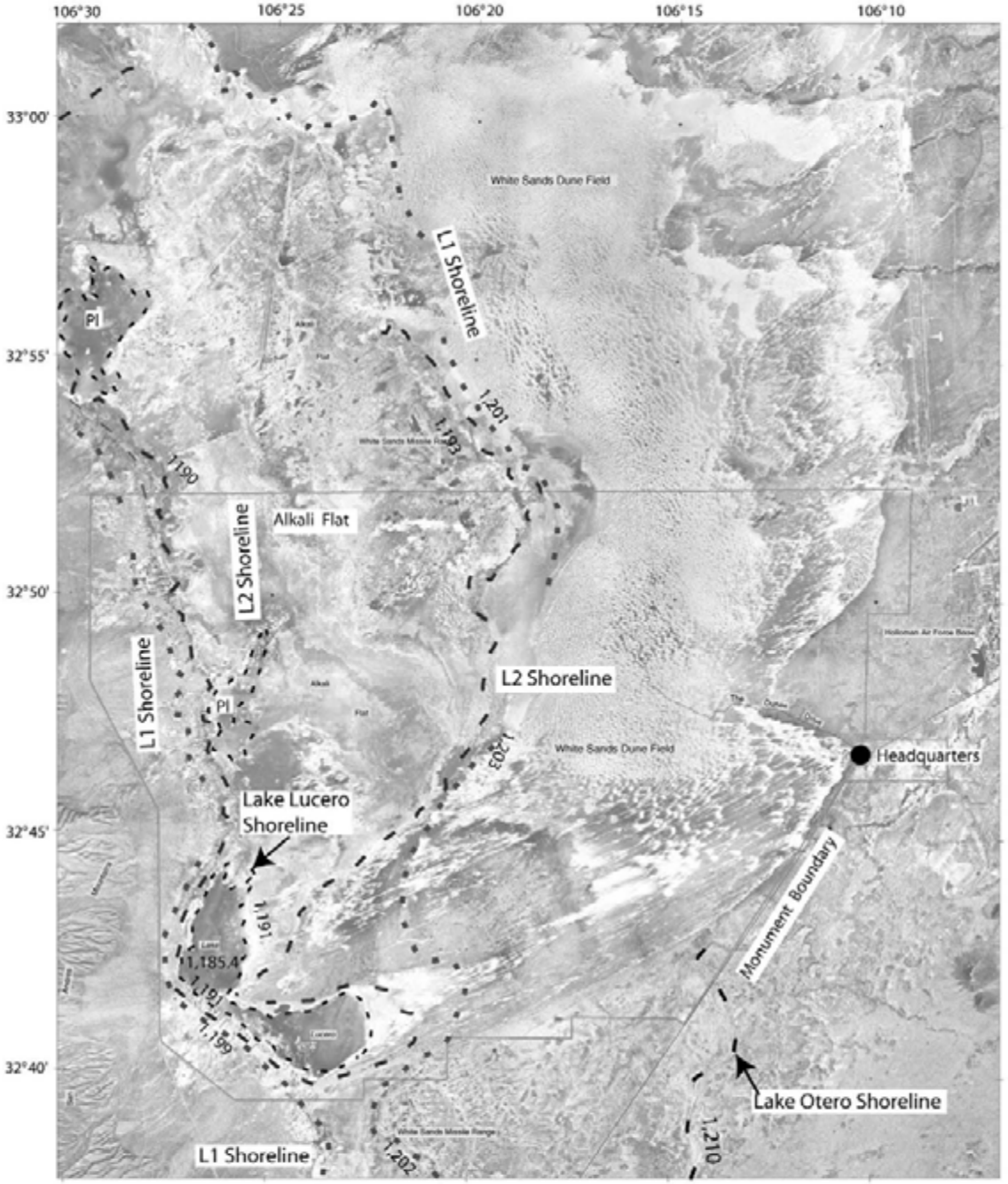


Fig. 2. Composite aerial photograph of Lake Lucero and the White Sands dune field. Dashed lines show erosional escarpments of the Lake Lucero, L2, and L1 shorelines. A short section of a depositional shoreline of Lake Otero is evident at the southeastern corner of the Monument. Elevations on the map mark locations of GPS measurements of shoreline elevation. This composite aerial photograph was supplied by White Sands National Monument and was prepared by ESRI in Albuquerque, NM.

Surface waters apparently do not contribute much dissolved salt to Lake Lucero (Allmendinger, 1971, 1972; LeMone, 1987). Instead, ground-water brines leaching from bedded evaporites around the basin margin are likely to be important sources. These conclusions are supported by several studies in Lake Lucero and other areas south and east of the White Sands (McLean, 1970a, b; Allmendinger, 1972; McLean, 1975; Myers, 1983; Cruz, 1985; Myers and Pinckley, 1987; Sutton et al., 1988; Myers and Sharp, 1989, 1992; Basabilvazo et al., 1994).

The gypsum crystals do not generally form through evaporation of surface water (Allmendinger, 1971). Instead, evaporation at the surface drives wicking of saline water from the shallow water table, 1–3 m below the surface (Allmendinger, 1972). Gypsum crystallizes as a fine efflorescence and small crystals at, and below the surface, but above the water table (Allmendinger, 1972).

2.3. Alkali Flat

Between the dunes and the playa lakes lies the Alkali Flat, an extensive, desolate, and largely unvegetated expanse. Patches of blowing gypsum sand lie within salt flats (sabkhas), and areas of scattered Mesquite (*Prosopsis*) and Salt Brush (*Atriplex*). Soils and vegetation are best developed on the eastern side of the Alkali Flat and salt pans are concentrated to west, near the playa lakes. Near the White Sands Monument, the flat is restricted to elevations below 1200 m elevation. The alkali flat is not developed near Lake Lucero, where parabolic gypsum dunes bury a topographic high almost adjacent to Lake Lucero (Fig. 1).

3. Erosional shorelines

An erosional shoreline surrounds modern Lake Lucero Playa (Fig. 3A). This shoreline is partially buried beneath aggrading playa muds and salts, but forms a well-defined escarpment except at the northern end of the playa. The base of this erosional shoreline escarpment is the playa surface, and is almost horizontal. The escarpment's irregular height results from differences in how deeply the playa has eroded into the adjacent hillsides. Depositional features associated with the shoreline are rare. Poorly defined gravel lags form one- to two-clast-thick stripes extending parallel to the shoreline escarpment near the mouths of some alluvial fans. Topographic profiles were made across the shorelines using a hand-level, tape, and staff. Over 50 measurements were taken across each of the shorelines and generally show a smooth, steeply sloping segment that may overlie a more gently inclined toe-slope. The profiles on the Lake Lucero Shoreline have maximum slopes that range up to 30–40° in poorly consolidated Lake Otero sediments. Higher slopes are associated with resistant limestone and evaporite beds.

Erosional shorelines are created by the erosive activity of waves when the playa is flooded. In many playa lakes this eroded material is reworked to form depositional shores. However, in Lake Lucero almost all of this material is either reworked into the lake interior or deflated away by the wind. The base of the erosional shoreline marks the level of flooding of the playa.

Two similar erosional shorelines are evident on the hillslopes above the modern playa (Fig. 2). The elevations of all three playas were measured using a survey quality Trimble 3100 GPS unit with an elevation accuracy of approximately 10 cm. Elevations were converted to NAD 83 datum to match the topographic maps of the area. The lowest of the shorelines occurs at an elevation of approximately 1191 m, some 5.5 m above the surface of Lake Lucero. A second shoreline is located at approximately 1200 m elevation, 14.5 m above the surface of Lake Lucero. These shorelines can be correlated at approximately the same elevation around almost the entirety of the present Alkali Flat (Fig. 2). These higher shorelines define either relict playas, marking stages in deflation of the Alkali Flat, or shorelines marking lake-level high stands associated with the modern Lake Lucero. The evidence described below indicates that the first interpretation is correct, and that the shorelines mark playas that formed between stages of deflation that eroded the Alkali Flat and Lake Lucero to their present elevations.

The lower erosional shoreline (1191 m) is marked as the L2 shoreline and the upper shoreline (1200 m), the L1 shoreline on Fig. 2. The L2 shoreline is almost identical in morphology to the shoreline surrounding Lake Lucero. Both of the shorelines have escarpment heights ranging up to 2.5 m and slopes in Otero sediment that range from 30° to 40°. The upper, L1 shoreline is a subtler feature, with slopes of 6–10° in Otero lake sediments. The escarpment is also much more gullied and eroded. Based on morphology, it appears that the L1 shoreline is older, whereas the L2 and Lake Lucero shorelines are similar in age. Dating of the shorelines are difficult, because they are largely erosional and few deposits that might contain datable material are preserved.

Erosion exposes older lacustrine sediments of Lake Otero in all of these shorelines (Fig. 3). Lake Otero sediments include laminated clays and silts, laminated gypsiferous marls, limestones, and massive silts containing large gypsum crystals. These sediments are exposed in gullies at elevations below 1215 m. Similar sediments are found at higher elevations and must represent deposits of pre-Lake Otero Pleistocene lakes. The lamination and prevalence of evaporites indicates deposition on the floor of a permanent or semi-permanent saline lake.

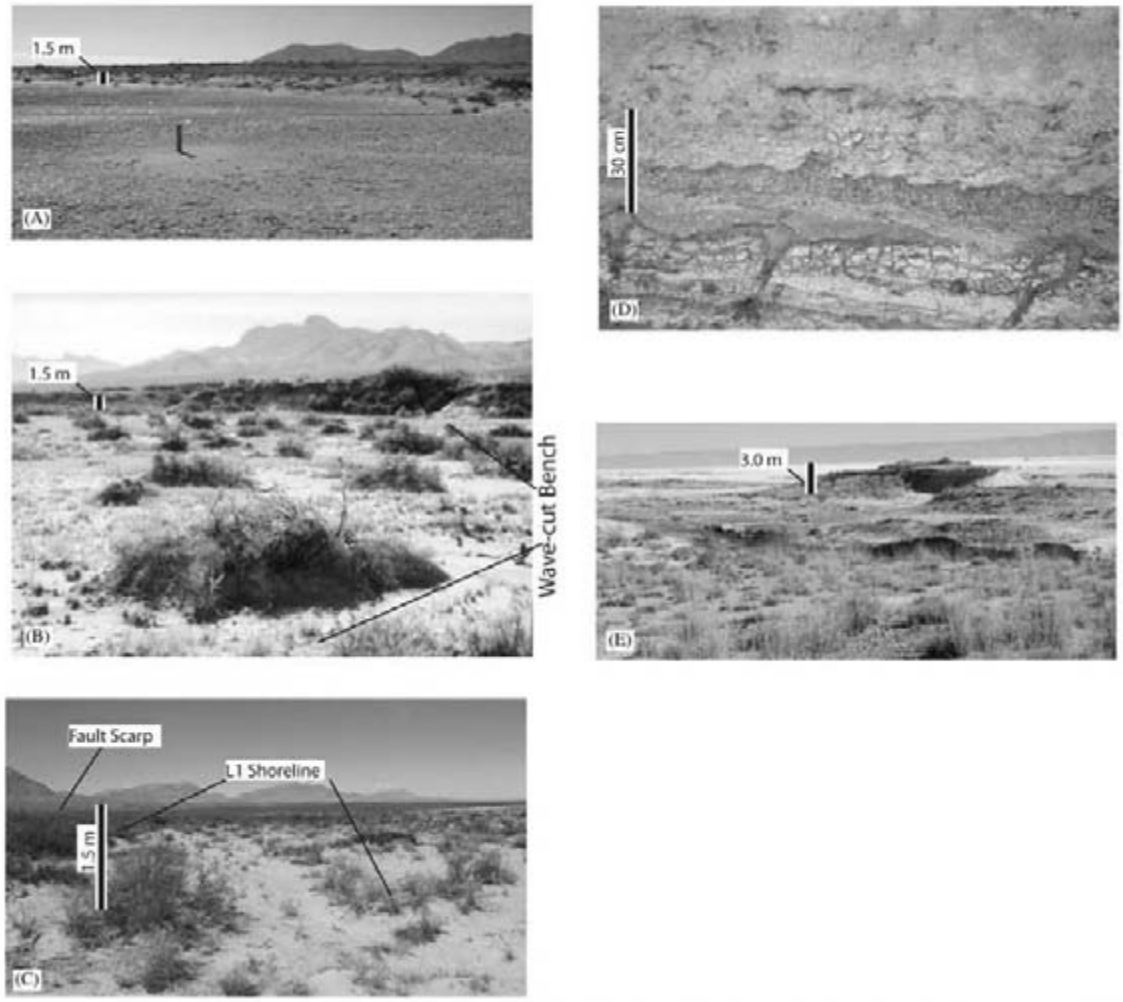


Fig. 3. Photographs illustrating shorelines and associated features: (A) The shoreline of Lake Lucero showing the erosional escarpment, which is approximately 1.5 m high at this location. Standpipe in the foreground is an observation well. Gypsum crystals eroded from Lake Otero sediments in the shoreline glint in the sun; (B) the L2 escarpment, 7 m above Lake Lucero. Note the similarity in appearance and the flat, wave-cut bench in the foreground; (C) the L1 shoreline escarpment shows up as the eroded foreground continues at this elevation as a light streak extending sinuously to the background on the right-hand side. At the left, just below the bedrock of the San Andreas Mountains is a prominent fault scarp; (D) Lake Otero sediments: silts, sands, and limestones exposed near the L1 escarpment. Mud cracks and soft sediment deformation are evident along with dark gypsum crystals in the massive upper bed; (E) eroded Lake Otero sediments showing the horizontal bedding and the lateral extent of these deposits. Lake Lucero is shown in the background.

A vertically exaggerated topographic profile across Lake Lucero and the White Sands dune field shows the extent of deflation. Logged wells within the White Sands Dune field indicate that the base of the eolian gypsum sand lies below the Lake Otero shoreline and slopes gently to the west (Fig. 4). At the western edge of the dune field, the eroded, older lake muds are exposed, just above the L1 shoreline (Figs. 2 and 4). The L1 and L2 shorelines define an extensive, 20-m-deep deflation basin, with relatively steep sides.

4. Interpretations

The horizontal beds of lacustrine Lake Otero sediments are key features in understanding the history of the White Sands because they define a relatively low-relief Pleistocene lake floor. The photographs in Fig. 3D and E illustrate the bedding in these sediments and show relict islands of this older sediment preserved within the deflation basin. Thus, the topography of the basin below the Lake Otero Shorelines is largely a product of

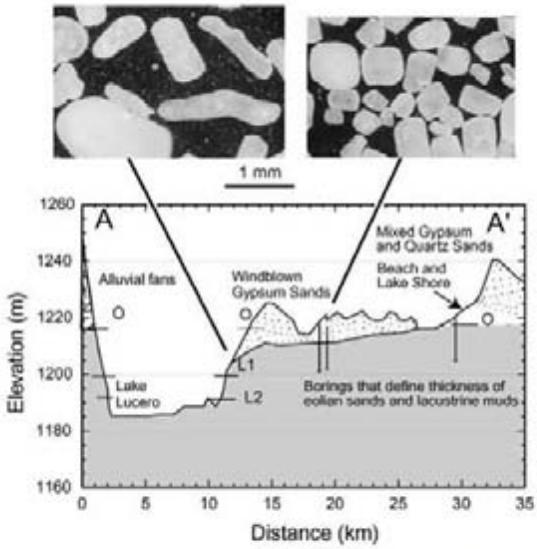


Fig. 4. Cross section from A to A′ (location shown on Fig. 1) showing the elevations of the Lake Lucero, the L1 and L2 shorelines and the Lake Otero shoreline. Also shown is the contact between the windblown gypsum sand and Otero lacustrine sediments, as determined from outcrop and well descriptions. The photographs are reflected light photo-micrographs of gypsum sand from the samples near each end of the transect shown in Fig. 5. Note bladed, twinned and poorly frosted crystals in the upwind (left) sample as opposed to the blocky frosted grains in the downwind sample.

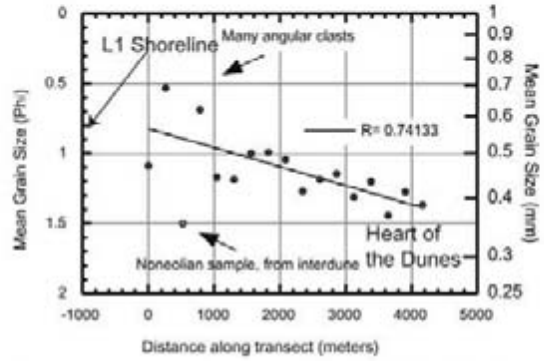


Fig. 5. Graph of mean grain size plotted against distance from the L1 shoreline.

Post-Otero Erosion. The L1 and L2 erosional shorelines mark times when playa lakes formed during this deflationary process. Because the L1 shoreline is largely preserved, deflation has deepened the Alkali Flats, but not widened it.

Most previous authors have noted that there are two sources of gypsum sand, deflation of the Alkali Flat and Lake Lucero (Allmendinger, 1971; LeMone, 1987, 1994). Allmendinger (1971) noted that the water table lies below the surface of Lake Lucero, and stated that as evaporation proceeds, water is wicked up and evaporated near the lake surface to precipitate salts, which are deflated to produce dunes downwind of the playa. Allmendinger (1972) also described a gypsum crystal-bearing layer that extends 9 m above the surface of Lake Lucero and indicated that deflation of this Pleistocene Lake sediment produced most of the White Sand Dunes. LeMone (1987) concurred and emphasized the importance of this gypsum layer. Both the potential sources described by Allmendinger (1972) can be associated with active dunes (Fig. 2). Several patches of parabolic dunes extend downwind from Lake Lucero, partially burying the L1 and L2 shorelines. However, the main mass of the White Sands dune field begins abruptly near the L1 shoreline (Figs. 2 and 4). The top of the gypsum bed described by Allmendinger (1972) lies between the L1 and L2 shorelines and within 1.5 km of the edge of the dune field.

Samples of eolian sand collected along transect A-A′ from the edge of the dune field show that the source of the White Sands dunes is probably the margin of the deflation basins along the L1 shoreline (Figs. 4 and 5). This is consistent with deflation of the gypsum unit described by Allmendinger (1972). The sand samples were collected from active wind ripples on the windward sides of dunes, 1 m above the elevation of the adjacent interdune. Mean grain size decreases downwind over a distance of 4 km (Fig. 5). In addition to the grain size decrease, there is a change from unfrosted angular gypsum blades at the upwind edge of the dunes to rounded and frosted grains (Fig. 4). The irregular gypsum blades must have experienced little transport. While some gypsum may be derived from distant parts of the Alkali Flat, both the grain size and juvenile forms suggest that the primary source is near the L1 shoreline.

5. Timing and significance of the L1 and L2 shorelines

The relationship of the L1 shoreline to the White Sands provides important information about the genesis of the White Sands dunes. Previous workers have described deflation of the White Sands as a continuous process (Allmendinger, 1971, 1972; LeMone, 1987). However, the deflationary events bounded by the L1, L2, and Lake Lucero shorelines indicate episodes of much more rapid deflation than is occurring today. Dating the L1 and L2 shorelines will constrain the history of the White Sands dune field.

Because the gypsum-bearing interval lies below the L1 shoreline, it is unlikely that a large dune field had formed until the deflation event between the L1 and L2 shorelines. No datable materials have been found so far on the L1 shoreline. Thus, archeology was used to

estimate the age of the shoreline. A search of the archeological database at White Sands National Monument shows Folsom culture sites just above the elevation of the L1 shoreline, but not within the L1 deflation basin (Eidenbach, pers. comm., 2000. Department of Archeology, New Mexican State University at Alamogorado, New Mexico). This suggests that the L1 shoreline can be dated to younger than the 9800–10,800 yr BP range of Folsom activity (Haynes et al., 1992; Ingbar, 1992). Local Folsom sites are widely scattered and the absence of a site below the L1 shoreline may be due to other factors. The L1 deflation basin, however, lies within an area containing several Folsom localities and a Latest Pleistocene/earliest Holocene age for the L1 Shoreline matches its degradation and stratigraphic position below the penultimate Lake Otero Shorelines. This suggests there was a deflationary event, near the Pleistocene–Holocene transition, that carved the deflation basin in which the dune field is located.

Deflation of the L2 and Lake Lucero basins must have occurred after the establishment of a Playa Lake at the L1 level. The only dates available come from Lost River Playa in the northeast corner of the Monument (Fig. 1). Radiocarbon dates collected from the sediments below Lost River Playa have provided dates of (1750 and 5840 yr BP) (Monger and Gallegos, 1997). The Lost River Playa filled a deflation basin when the advancing dune field dammed the stream flowing on the bottom of the basin. Lost River Playa has erosional shorelines similar in slope to the L2 and Lake Lucero. This suggests that the growth of the White Sands dune field, and incision to the L2 shoreline may have occurred before 6000 yr BP. This matches existing dates from the region.

Several studies have linked playa deflation to hydrologic changes associated with increased aridity (Jacobson, 1988; Rosen, 1994; Dutkiewicz et al., 2000). Playas generate dense brines that sink below them. When water evaporates faster than the rate of surface and groundwater influx, the brines sink faster than they form and the water table below the playa lowers, in these conditions, playas can deflate until they reach the moist zone above the water table (Jacobson, 1988; Rosen, 1994).

Climatic events are increasingly identified with playa basin deflation and eolian sand generation in the region. Recent work in the Lake Estancia Basin, north of the Tularosa Basin has identified two episodes of deflation in the mid-Holocene which created that playa (Bachhuber, 1982; Smith and Anderson, 1982; Allen, 1991; Rowe et al., 1995). The oldest was approximately 7000 yr ago, and the second event was approximately 4000 yr ago. Each deflation event resulted in excavation of a deflation basin, and the two events are separated by an erosional shoreline. Lunettes formed downwind of the playa during deflation. South of the White Sands, the Tularosa Basin also records episodes of eolian transport and deposition between 7000 and 4000 yr ago (Buck, 1996). These deposits are correlated to times of increased aridity recorded in soil carbonate isotopes (Buck and Monger, 1995).

Hydrologic and isotope studies indicate that playa deflation is linked to arid climatic events (Jacobson, 1988; Rosen, 1994). It is tempting to correlate incision of the L2 deflation basin to the 7000 yr BP arid climate event and the 4000 yr BP event to deflation of the Lake Lucero Basin. However, it premature to assume this specific correlation given the lack of dates. The L1 to L2 event and growth of the White Sands dune field can be ascribed to the mid-Holocene, based on the radiocarbon dates from Lost River Playa. However, the incision of the Lake Lucero Basin has not yet been dated and may have occurred anytime within the last 7000 yr.

Because the sand within the dunes is derived from the margin of the Alkali Flat, it is evident that only slow deflation of the Alkali flats is occurring today. During deflationary episodes, for example, deflation from the L1 to the L2 shorelines, the gypsum sand supply must have been greatly enhanced. The shoreline history described above implies that, while today the dune field is actively migrating and is receiving a limited sand supply from the Alkali Flat, the majority of the growth of the White Sands dune field must have occurred during short-lived more arid climatic events when the deflation basin was being deepened. We can now identify three of these events. One probably predated the dune field and occurred at the end of the Pleistocene resulting in deflation to the L1 shoreline. Two more events, the earliest ca. 7000 yr BP, formed the dune field and deflated to the L2 and Lake Lucero shorelines.

Acknowledgements

Steve Fryberger provided the impetus for this paper through his observation that the White Sands dune field is associated with a deep deflation basin. The park staff at White Sands National Monument has been unfailingly helpful in arranging permits and accompanying me in the field. I particularly want to acknowledge Dennis Vasquez and Bill Conrod for help and advice about the project. The environmental and security staff at White Sands Missile Range were gracious in allowing access to Lake Lucero and the Salt Flat area. David Loope and Jeff Lee provided thorough and very helpful reviews that significantly improved the manuscript.

References

Ahlbrandt, T.S., Gautier, D.L., Bader, T.A., 1994. Low-angle eolian deposits in coastal settings: significant Rocky Mountain exploration targets. The Mountain Geologist 31, 95–114.

Allen, B.D., 1991. Effect of climatic change on Estancia Valley, New Mexico: sedimentation and landscape evolution in a closed-drainage basin. In: Julian, B., Zidek, J. (Eds.), Field Guide to Geologic Excursions in New Mexico and Adjacent Areas of Texas and Colorado, New Mexico Bureau of Mines and Mineral Resources, Socorro, USA, pp. 166–171.

Allmendinger, R.J., 1971. Preliminary evaluation of the role of the hydrologic cycle in the development of the white sands, White Sands National Monument, New Mexico. Abstracts with Programs—Geological Society of America 3, 231–232.

Allmendinger, R.J., 1972. Hydrologic control over the origin of gypsum at Lake Lucero, White Sands National Monument, New Mexico. Master's Thesis, New Mexico Institute of Mining and Technology, Socorro, NM, United States, 182pp.

Bachhuber, F.W., 1982. Quaternary history of the Estancia Valley, central New Mexico. In: Callender, J.F., Grambling, J.A., Wells, S.G. (Eds.), New Mexico Geological Society Guidebook: Albuquerque Country II, Socorro, USA, Vol. 33, pp. 343–346.

Basabilvazo, G.T., Myers, R.G., Nickerson, E.L., 1994. Geohydrology of the high energy laser system test facility site, White Sands Missile Range, Tularosa Basin, south-central New Mexico. US Geological Survey, Reston, VA, USA, 59pp.

Blair, T.C., Clark, J.S., Wells, S.G., 1990. Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla Piedmont and Tularosa graben floor, White Sands Missile Range, New Mexico; with Supplementary Data 90-08. Geological Society of America Bulletin 102, 749–759.

Buck, B.J., 1996. Late Quaternary landscape evolution, Paleoclimate and geoarchaeology, southern New Mexico West Texas. Ph.D. Thesis, New Mexico State University, Las Cruces, 398pp.

Buck, B.J., Monger, H.C., 1995. Stable isotopic evidence for Holocene environmental change, Hueco Basin, southern New Mexico and West Texas. In: Geological Society of America, Abstracts with Program, 1995 Annual Meeting, Vol. 27, 323pp.

Cruz, R.R., 1985. Annual Water-resources review, White Sands Missile Range, New Mexico, 1984. US Geological Survey, Reston, VA, USA, 25pp.

Dutkiewicz, A., Hereeg, A.L., Dighton, J.C., 2000. Past changes to isotope and solute balances in a continental playa: clues from stable isotopes. Chemical Geology 165, 309–329.

Frank, A.J., 1994. Models for airflow velocity profiles in natural settings; accounting for atmospheric conditions and secondary flow over eolian dunes. Doctoral Dissertation, University of Texas, Austin, 140pp.

Frank, A.J., Kocurek, G., 1996. Airflow up the stoss slope of sand dunes: limitations of current understanding. In: Lancaster, N. (Ed.), Response of Aeolian Processes to Global Change, Vol. 17. Elsevier, Amsterdam, Netherlands, pp. 47–54.

Fryberger, S.G., Schenk, C.J., Krystinik, L.F., 1988. Stokes surfaces and the effects of near-surface groundwater-table on aeolian deposition. Sedimentology 35, 21–41.

Gould, C.N., 1939. The great White Sands (of New Mexico). Mines Magazine 29, 379–381.

Haynes, C.V.J., Beukins, R.P., Jull, A.J. TH, Davis, O.K., 1992. New radiocarbon dates for some old Folsom sites: accelerator technology. In: Stanford, D.J., Day, J.S. (Eds.), Ice age Hunters of the Rockies. Denver Museum of Natural History, Denver, CO, pp. 83–100.

Herrick, C.L., 1904. Lake Otero, an ancient salt lake basin in southeastern New Mexico. Economic Geology 4, 174–189.

Ingbar, E., 1992. The Hanson site and Folsom on the Northwest Plains. In: Stanford, D.J., Day, J.S. (Eds.), Ice age Hunters of the Rockies. Denver Museum of Natural History, Denver, CO, pp. 169–192.

Jacobson, G., 1988. Hydrology of Lake Amadeus: a groundwater-discharge playa in central Australia. BMR Journal of Australian Geology and Geophysics 10, 301–308.

Jones, B.R., 1959. A sedimentary study of dune sands, Lamb and Bailey counties, Texas and White Sands National Monument, New Mexico. Master's Thesis, Texas Tech University, Lubbock, TX, USA, 95pp.

Kottlowski, F.E., 1958. Lake Otero: second phase in formation of New Mexico's gypsum dunes. Geological Society of America Bulletin 69, 1733–1734.

LeMone, D.V., 1987. White Sands National Monument, New Mexico. In: Beus, S.S. (Ed.), Centennial Field Guide Rocky Mountain section of the Geological Society of America, pp. 451–454.

LeMone, D.V., 1994. White Sands National Monument, New Mexico. In: Garber, R.A., Keller, D.R. (Eds.), Field Guide to the Paleozoic Section of the San Andres Mountains. West Texas Geological Society, Midland, TX, pp. 155–158.

McKee, E.D., 1966. Structures of dunes at White Sands National Monument, New Mexico (and a comparison with structures of dunes from other selected areas). Sedimentology 7, 3–69.

McKee, E.D., Douglass, J.R., 1971. Growth and movement of dunes at White Sands National Monument, New Mexico. US Geological Survey Professional Paper 0750-D, pp. D108–D114.

McKee, E.D., Moiola, R.J., 1975. Geometry and growth of the White Sands dune field, New Mexico. Journal of Research of the US Geological Survey 3, 59–66.

McLean, J.S., 1970a. Saline ground-water resources of the Tularosa basin, New Mexico, Report No. 561. US Office of Saline Water Research and Development, Progress Report, Vol. 571, p. 128.

McLean, J.S., 1970b. Objectives of a current study of saline ground water in the Tularosa Basin, New Mexico. In: 15th Annual Water Conference of the New Mexico Water Resources Research Institute Proceedings, New Mexico, pp. 95–100.

McLean, J.S., 1975. Saline ground water in the Tularosa Basin, New Mexico. In: Guidebook—New Mexico Geological Society. 26, Guidebook of the Las Cruces country, pp. 237–238.

Monger, H.C., Gallegos, R., 1997. Mineralogy and eolian sedimentation—Lost River Playa, Otero County New Mexico. Report submitted to Geo-Marine Inc., New Mexico: State University, Las Cruces, New Mexico, 16pp.

Myers, R.G., 1983. Test wells T21, T22, and T25, White Sands Missile Range, Dona Ana County, New Mexico. US Geological Survey, Reston, VA, USA, 37pp.

Myers, R.G., Pinckley, K.M., 1987. Test wells TW1, TW2, and TW3, White Sands Missile Range, Otero County, New Mexico. US Geological Survey, Reston, VA, USA. 19pp.

Myers, R.G., Sharp, S.C., 1989. Biannual water-resources review, White Sands Missile Range, New Mexico, 1986 and 1987. US Geological Survey, Reston, VA, USA, 36pp.

Myers, R.G., Sharp, S.C., 1992. Annual water-resources review, White Sands Missile Range, New Mexico, 1988. US Geological Survey, Reston, VA, USA, 23pp.

Rosen, M.R., 1994. The importance of groundwater in playas. A review of playa classifications and the sedimentology and hydrology of playas. In: Paleoclimate and Basin Evolution of Playa Systems. Geological Society of America Special Publication 289, 1–18.

Rowe, H.D., Allen, B.D., Geissman, J.W., Anderson, R.Y., 1995. Sedimentary magnetism and climate change: a detailed record from late Pleistocene Lake Estancia, New Mexico. Eos, Transactions AGU 1995 Spring Meeting 76, p. 161.

Schenk, C.J., Fryberger, S.G., 1988. Early diagenesis of eolian dune and interdune sands at White Sands, New Mexico. In: Hesp, P., Fryberger, S.G. (Eds.), Eolian Sediments, Vol. 55. Elsevier, Amsterdam, Netherlands, pp. 109–120.

Seager, W.R., 1980. Quaternary fault system in the Tularosa and Hueco basins, southern New Mexico and West Texas. In: Dickerson, P.W., Hoffer, J.M., Callender, J.F. (Eds.), Trans-Pecos

Region: Southeastern New Mexico and West Texas, Guidebook of the New Mexico Geological Society, New Mexico Geological Society, Socorro, Vol. 31, pp. 131–135.

Seager, W., Hawley, J., Kottlowski, F.E., Kelley, S.A., 1987. Geology of the East Half of the Las Cruces and Northeast El Paso 2-Degree Sheets Southern New Mexico. New Mexico Bureau of Mines and Mineral Resources, Socorro.

Simpson, E.L., Loope, D.B., 1985. Amalgamated interdune deposits, White Sands New Mexico. Journal of Sedimentary Petrology 15, 361–365.

Smith, L.N., Anderson, R.Y., 1982. Pleistocene–Holocene climate of the Estancia Basin, central New Mexico. In: Callender, J.F., Grambling, J.A. (Eds.), New Mexico Geological Society Guidebook, Albuquerque Country II, New Mexico Geological Society, Vol. 33. pp. 347–350.

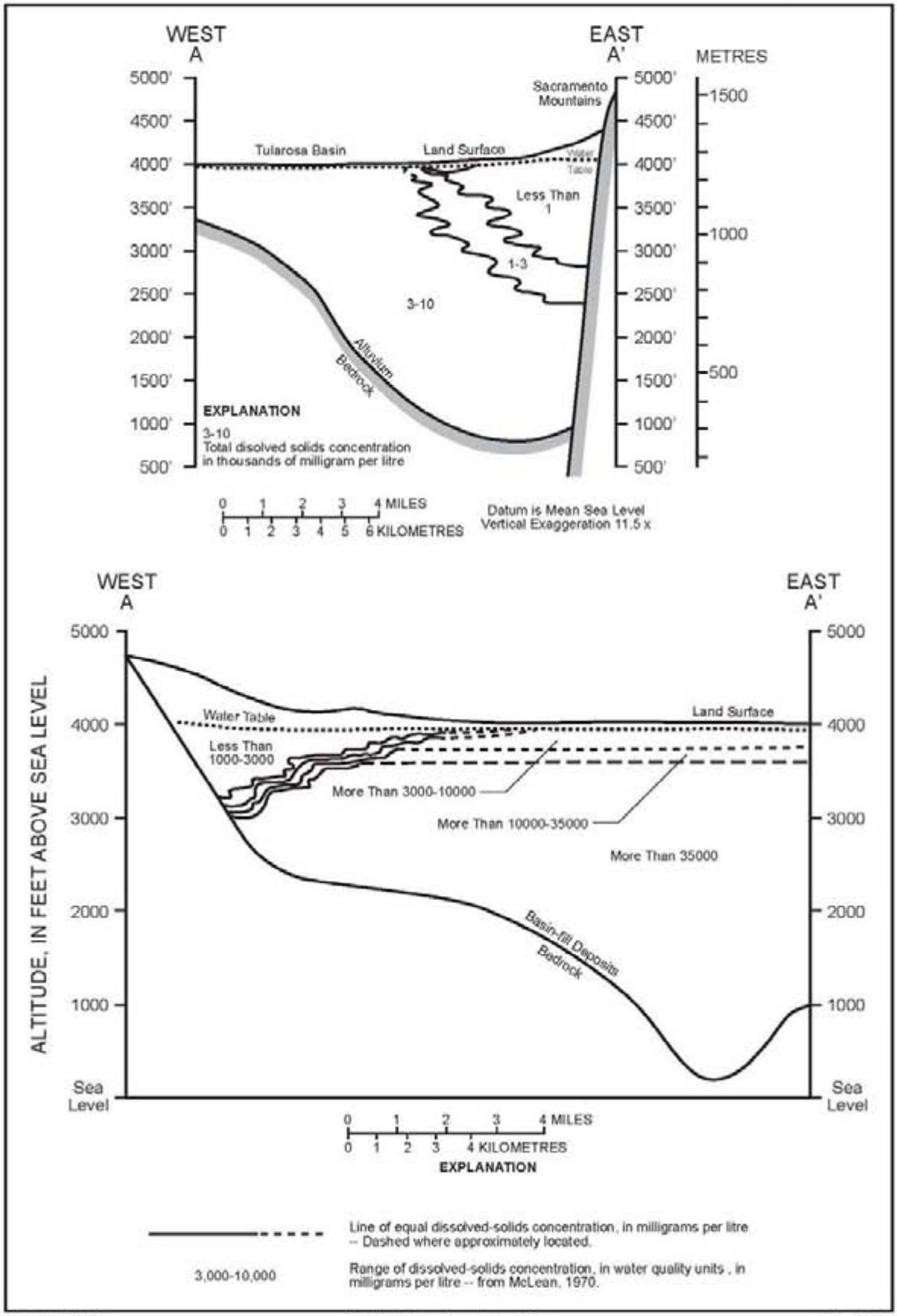
Sutton, V., Morse, E.L., Earl, L., Mitchell, R.E., 1988. Hydrogeologic investigation at White Sands Test Facility (WSTF), Las Cruces, New Mexico: New Mexico Geological Society Annual Spring Meeting. New Mexico Bureau of Mines and Mineral Resources 10, 66.

Sweet, M.L., Kocurek, G., 1990. An empirical model of aeolian dune lee-face airflow. Sedimentology 37, 1023–1038.

Talmadge, S.B., 1933. Source and growth of the white sands of New Mexico. Pan-American Geologist 60, 304.

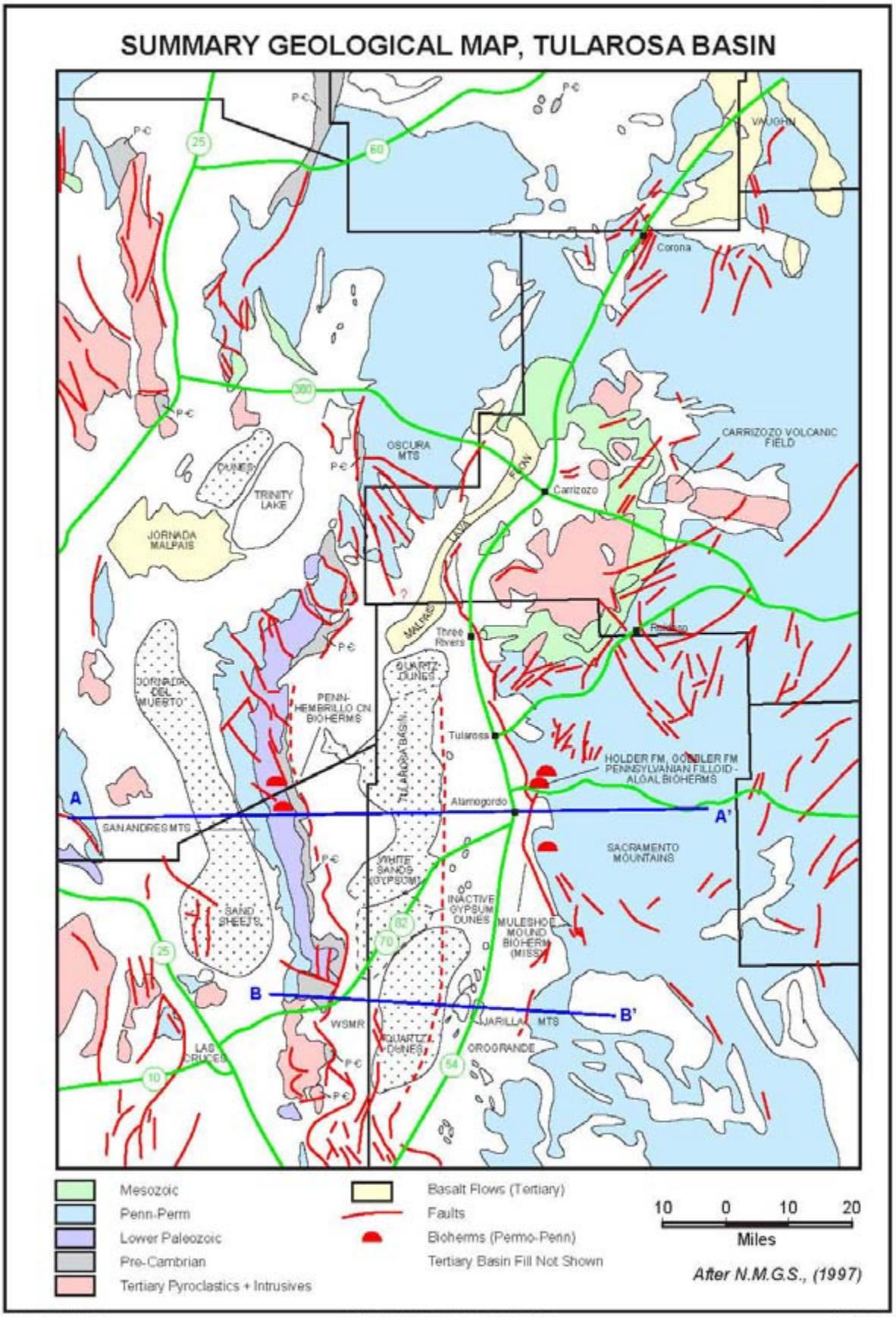
US Bureau of Land Management, 1990. L.C.D.O., Las Cruces, NM, United States, 1990. Resource Management Plan Amendment; McGregor Range, 51pp.

Figure 3-3



Drawn by UESG/31 Shell U.K. Exploration and Production April 2000 Drg. 122212

Figure 1-4



Drawn by UESG/31 Shell U.K. Exploration and Production August 1999 CDO 94816

Tuesday Tour

Jornada Experimental Range and LTER

The mission of Range Management Research at the Jornada Experimental Range is to produce new knowledge of ecosystem processes for development of technologies for monitoring, assessment, remediation and management of desert rangelands. This knowledge has application to hundreds of millions of acres of public and privately owned rangeland in the United States. Remediation is both the cessation of rangeland degradation, if occurring, and the restoration of land resources through the use of economically and ecologically appropriate technologies. Extensive interagency efforts involving the National Science Foundation, the Department of Interior, other USDA agencies, non-government organizations, and many universities in both agricultural and biological sciences augment the in-house research program. International agreements on three other continents extend this mission to the one-third of the world that is rangeland.

The science program traces back to field research initiated by the U.S. Department of Agriculture in 1912 when the 78,000 ha Jornada Experimental Range was first established by Presidential Executive Order.

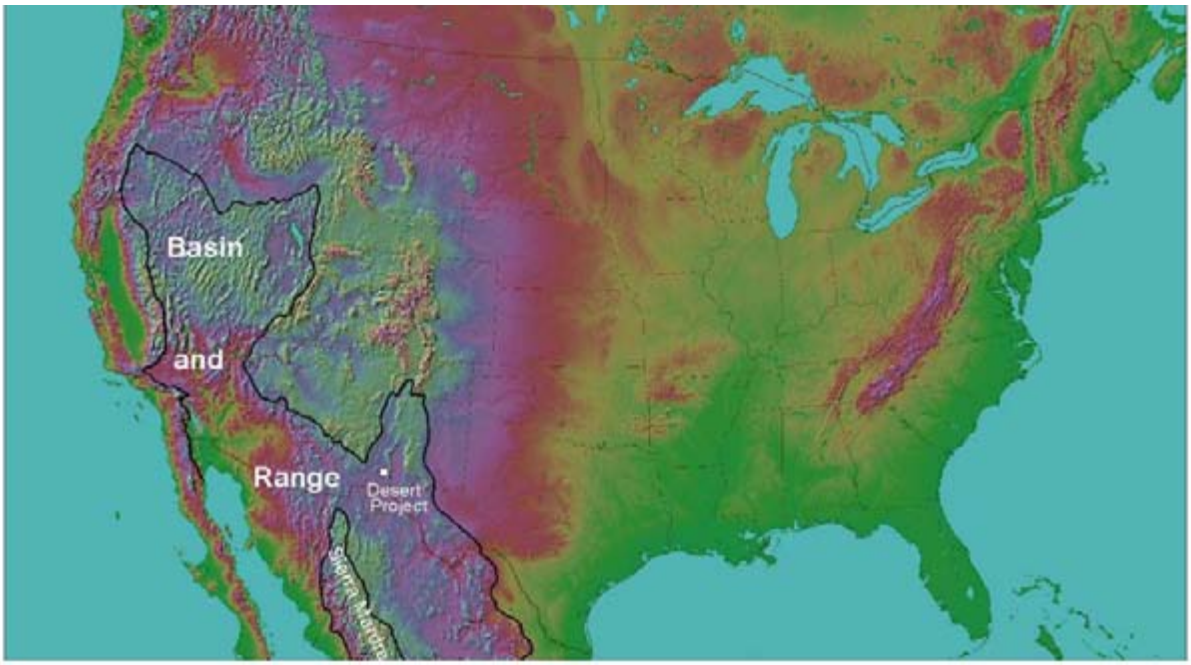
As a site within the National Science Foundation's Long-Term Ecological Research network, these activities are built on strong collaborations with other institutions and agencies interested in deserts, desert agriculture, desert ecology, and the management of desert rangelands. Our program is embedded within a larger research context in the Jornada Basin, the surrounding region, and in other deserts around the nation and the world where USDA, New Mexico State University, and our collaborating scientists work on objectives central to this mission or related topics.

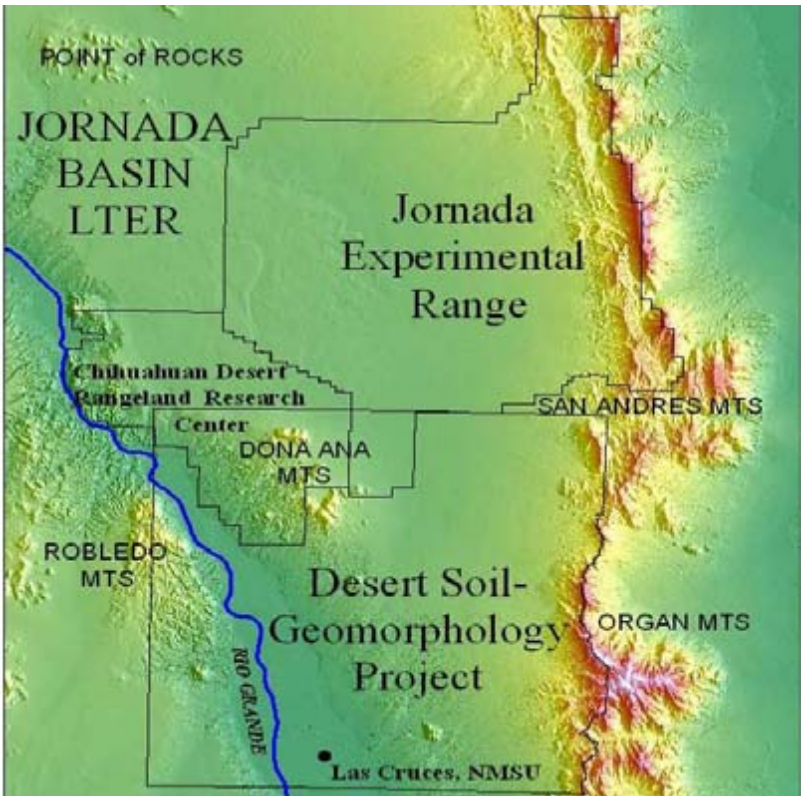
Tour Schedule

Each person will stay on the same bus for the morning, early- and late-afternoon tours. Each bus will go to a different workshop during each tour period. Everyone will be able to attend all 3 workshops if they stay with the same bus all day.

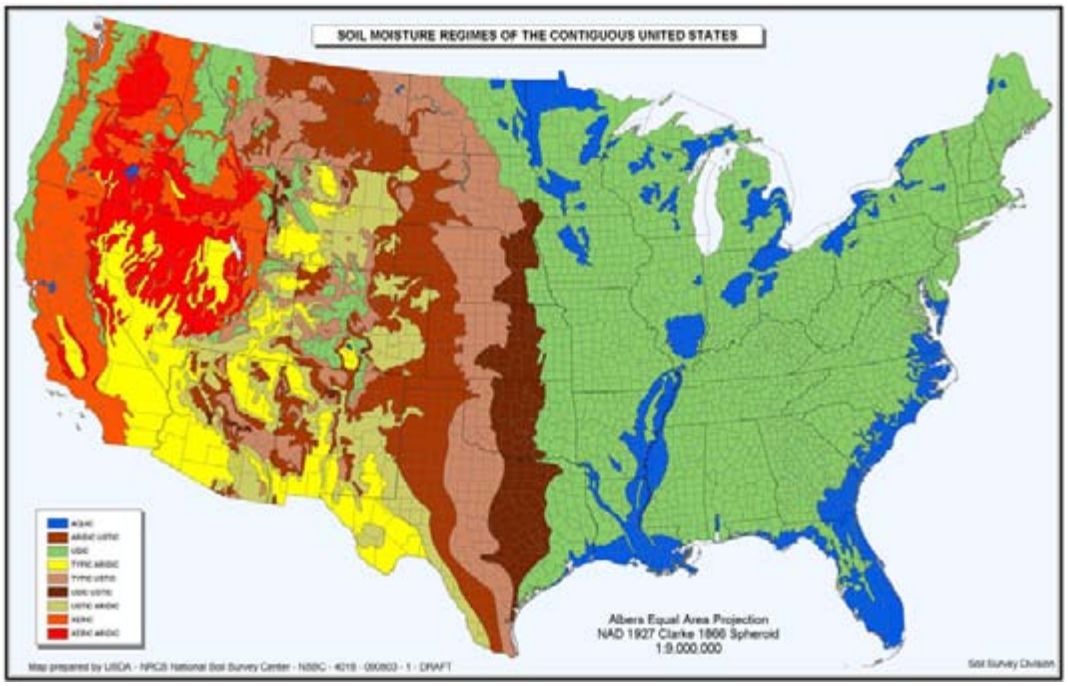
Tuesday schedule		
7:30 – 7:45		Orientation and board buses
7:45		Depart for Jornada
8:30 - 10:45	Morning tour	Workshop 1 -- Desert Project/Gypsum Workshop 2 -- Ecological Sites Workshop 3 -- Dynamic Soil Properties
10:45		Depart for Headquarters
11: 00 - 11:45	LUNCH	
11:45		Depart for next tour
12:00 - 2:15	Early afternoon tour	Workshop 1 -- Desert Project/Gypsum Workshop 2 -- Ecological Sites Workshop 3 -- Dynamic Soil Properties
2:15		Depart for Headquarters
2:30 - 2:45	BREAK	
2:45		Depart for next tour
3:00 - 5:15	Late afternoon tour	Workshop 1 -- Desert Project/Gypsum Workshop 2 -- Ecological Sites Workshop 3 -- Dynamic Soil Properties
5:15		Depart for Headquarters
5:30 - 6:30		Social at Headquarters
6:30 - ??		Bar-B-Que dinner at Headquarters
8 - 8:30ish		Drive to Las Cruces

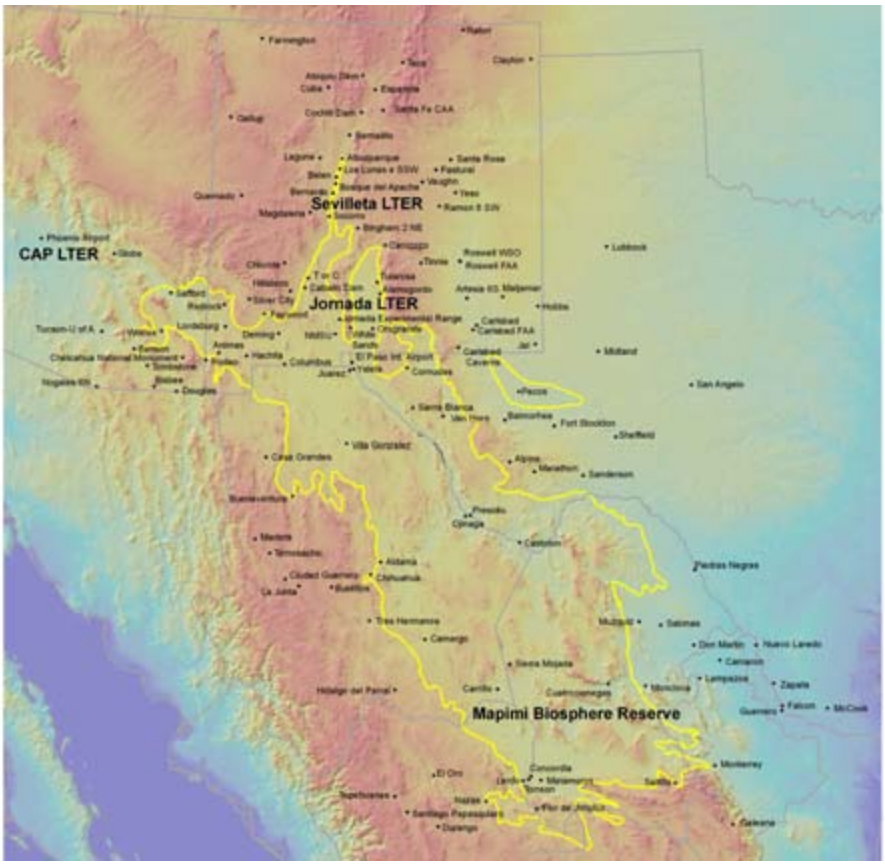
Workshop 1 - Desert Project and Gypsiferous Soil



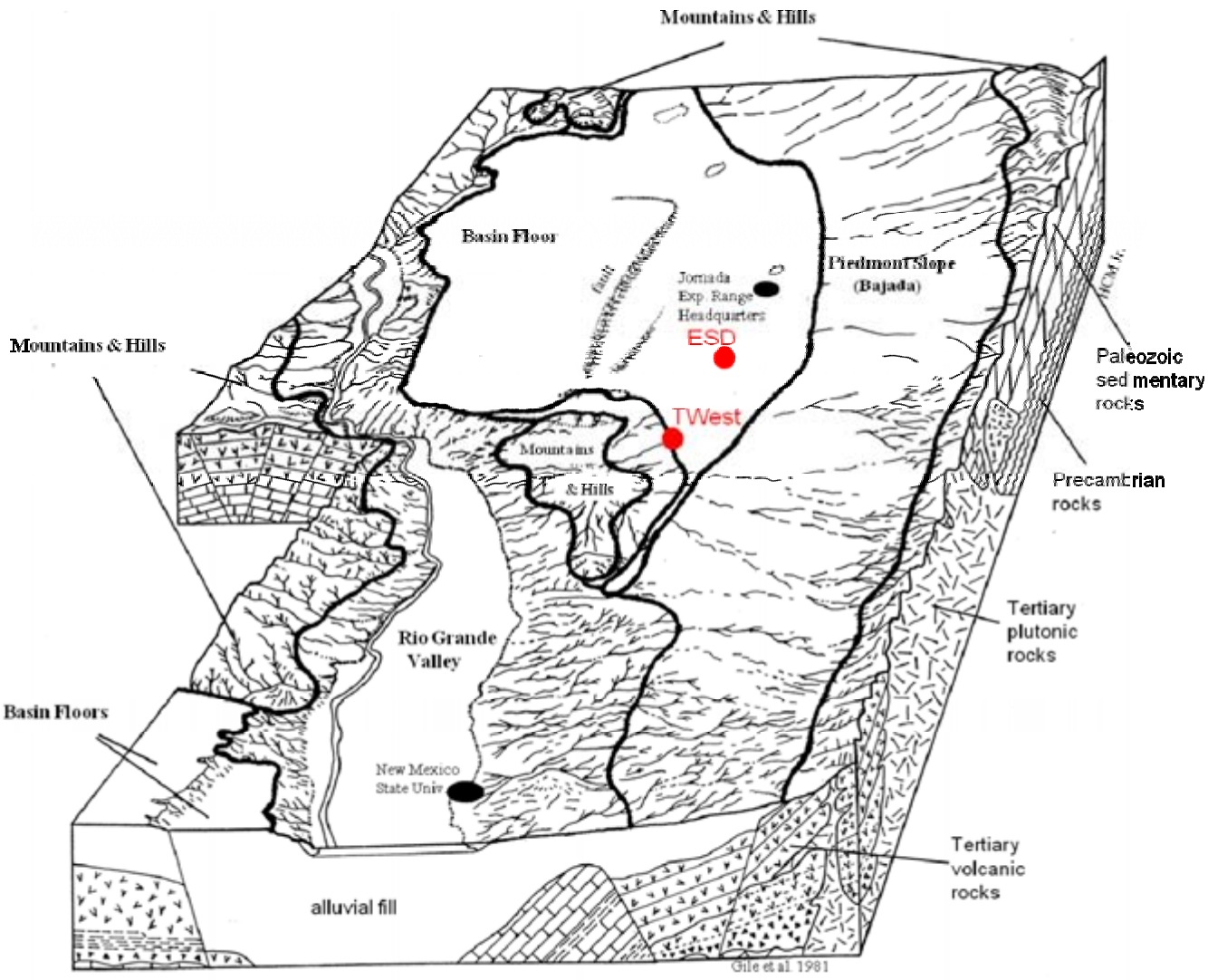


Stop 1 San Agustin Pass Overview: (Top) Desert Project location with respect to Basin and Range Province and Jornada Experimental Range (Bottom).





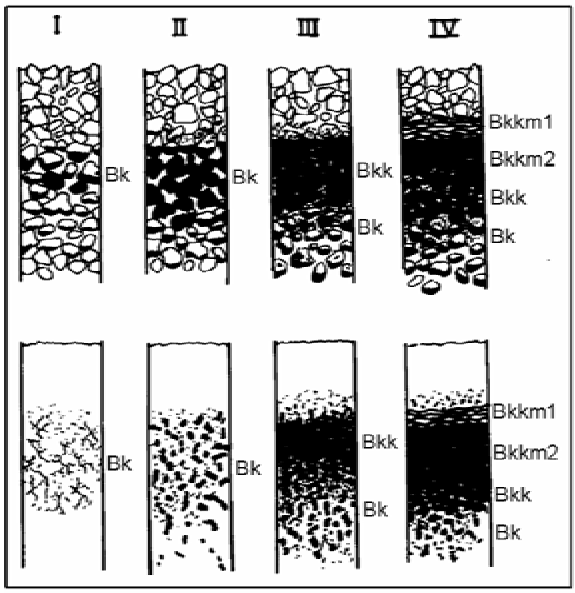
Climatic Information: (Top) Soil moisture regimes and (Bottom) boundary of Chihuahuan Desert in yellow based on an aridity index (Ia) ≤ 10, where Ia = Annual ppt (mm)/(annual temp (°C) + 10).



Desert Project Overview at TWest: Block diagram showing landforms and subsurface geology of Desert Project and Jornada Basin LTER research areas. Soil profiles to be viewed on Tuesday tour will be at TWest, ESD, and Jornada Exp Range Headquarters. After Monger et al. 2006. Regional setting of the Jornada LTER. p. 15-43. *In* K. Havstad, et al., eds. *Structure and function of a Chihuahuan Desert ecosystem: the Jornada Basin Long Term Ecological Research site.* Oxford Univ. Press, Oxford.

Schematic diagram of diagnostic carbonate morphology for the stages of carbonate accumulation in the two morphogenetic sequences (left below). Stages are described (right below), including stages V and VI not shown in diagram.

Carbonate Morphogenetic Stages



Definitions of Carbonate Morphogenetic Stages

	Diagnostic carbonate morphology	
Stage	Gravelly sequence[1]	Nongravelly sequence
I	Thin pebble coatings, continuous in last part of stage.	Few[2] filaments, masses, or faint coatings.
II	Continuous pebble coatings, some interpebble masses.	Few to common nodules or masses.
III	Many interpebble masses; plugged horizon[3] develops in last part of stage.	Many nodules and intermodular masses; plugged horizon develops in last part of stage.
IV	Laminar horizon overlying plugged horizon.	Laminar horizon overlying plugged horizon.
V	Very strongly cemented to indurated with > 1 cm thick laminae; may contain pisoliths and have vertical faces and fractures coated with laminated carbonate.	
VI	Indurated with multiple generations of recemented laminae, breccia, and pisoliths.	

[1] Morphologies are best expressed where "nongravelly" materials contain less than about 20 % by volume of rock fragments (fragments 2 mm or larger in diameter), and "gravelly" materials contain more than about 60 % by volume of rock fragments. Materials that have between 20 % and 60 % by volume of rock fragments have intermediate morphologies.

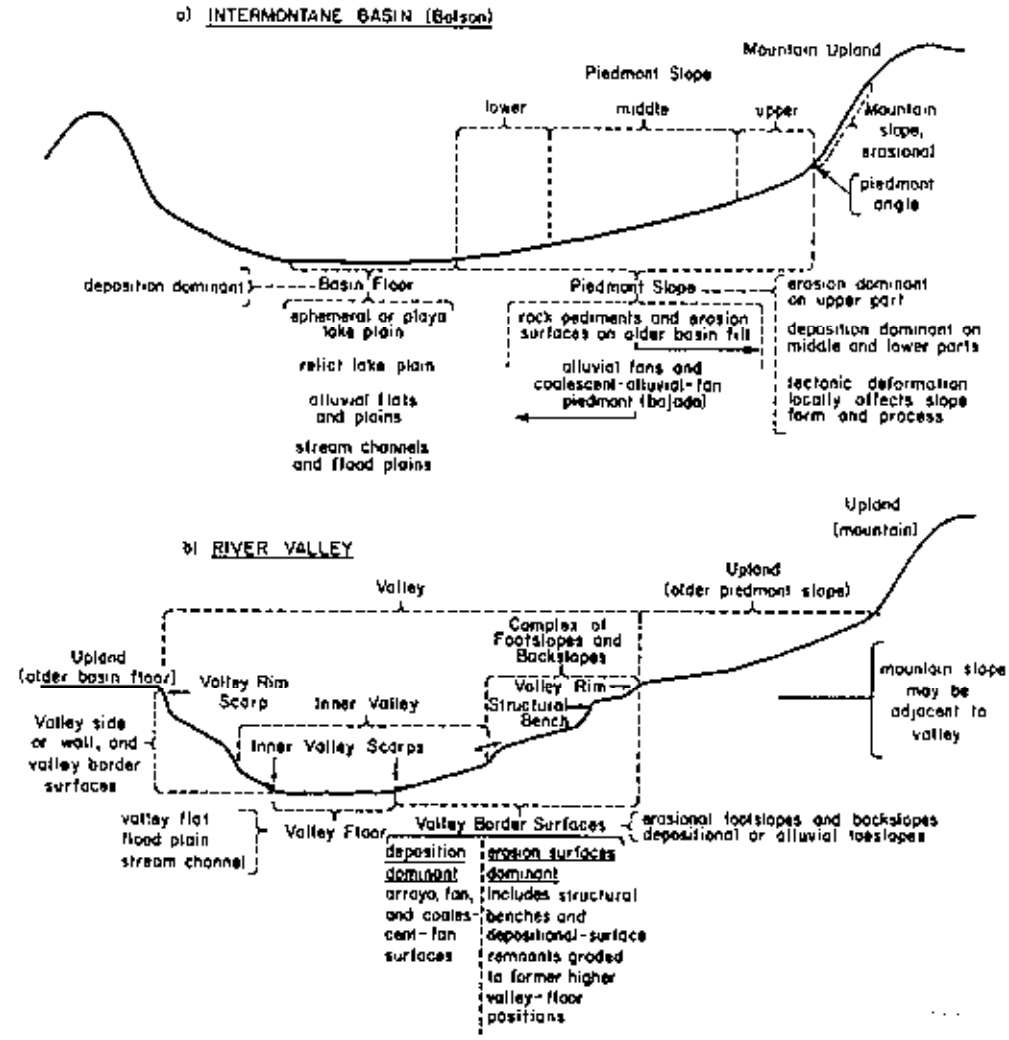
[2] Few < 2, common 2 to < 20, many = 20 or greater percent of area covered.

[3] Plugged horizon contains 50 percent or more pedogenic carbonate (by vol).

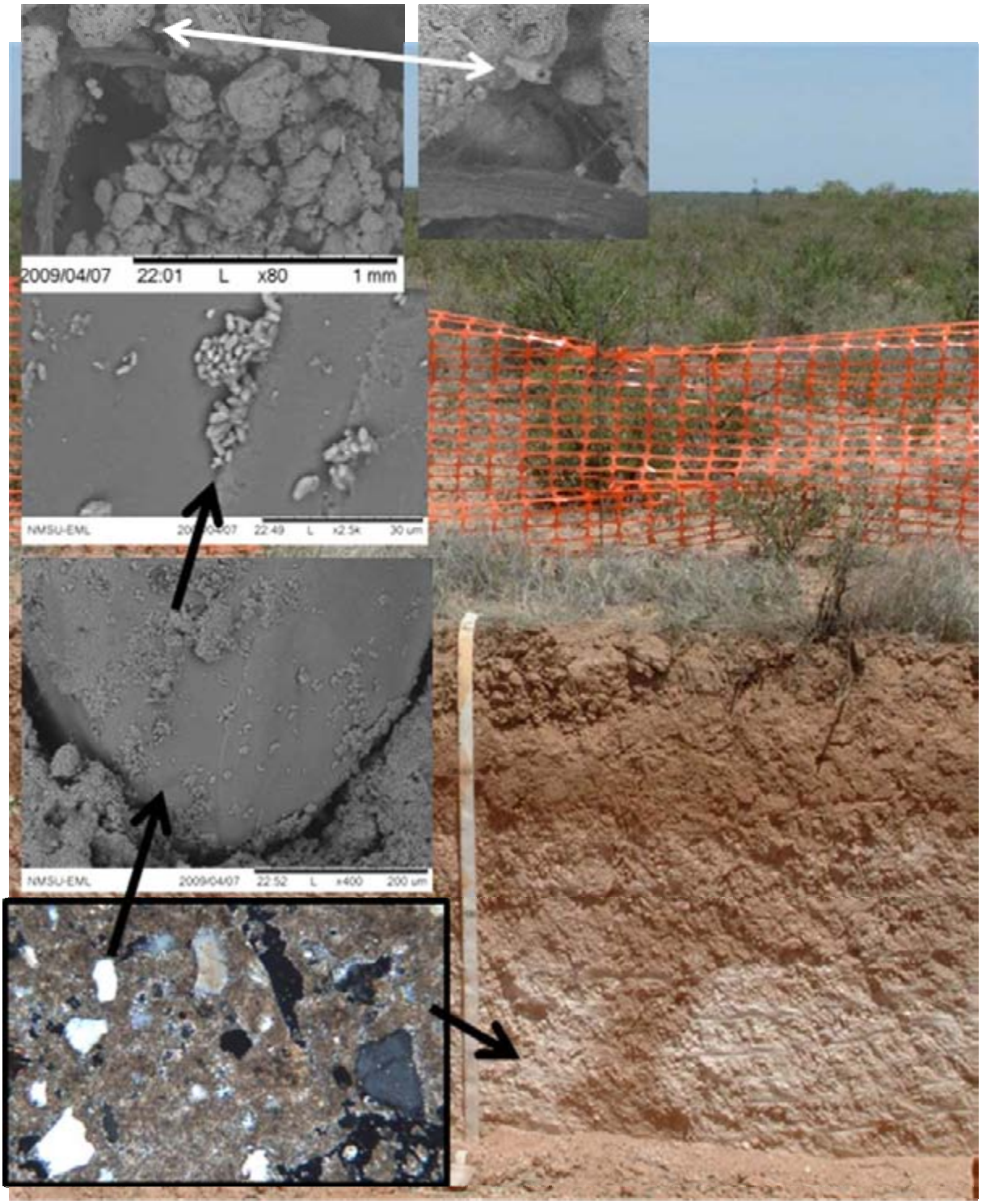
Desert Project Overview at TWest: Morphogenetic stages of pedogenic carbonate accumulation. Modified from Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, no. 5, p. 347-360

Table of Geomorphic Surfaces: The age of a geomorphic surface and its soils is considered to be the same. On a constructional surface, for example, all would date from the approximate time that sedimentation stopped and soil development started.

Geomorphic surface			Carbonate stage		Estimated soil age
Valley border	**Piedmont slope**	**Basin floor**	**Nongravelly materials**	**Gravelly materials**	**(years B.P. or epoch)**
Coppice dunes	Coppice dunes	Whitebottom			Historical (since 1850 A.D.)
		Lake Tank			present to 150,000
					Middle to late Holocene
Fillmore	Organ		0, I	I	100 – 7,000
	III		I	I	100(?) – 1,000
	II		I	I	1,100 – 2,100
	I		I	I	2,200 – 7,000
Leasburg	Isaacks' Ranch		II	II, III	Latest Pleistocene (10,000 – 15,000)
Butterfield	Baylor		III	III	Late Pleistocene (15,000 – 100,000)
Picacho	Jornada II	Petts Tank	III	III, IV	Late to middle Pleistocene (100,000 -250,000)
Tortugas	Modoc		III	IV	Late middle Pleistocene (250,000 – 500,000)
Jornada I	Jornada I	Jornada I	III	IV	Middle Pleistocene (500,000 – 700,000)
	Doña Ana			IV	>700,000
Buried surfaces and soils					700,000 – 2,000,000
Lower La Mesa			III, IV		Middle to early Pleistocene (780,000)
JER La Mesa			IV, V		Early Pleistocene to Late Pliocene (780,000-2,000,000)
Upper La Mesa			V		Late Pliocene (2,000,000 – 2,500,000)



Desert Project Overview: Landform profiles in the Desert Project. Top profile is of intermontane landforms. Bottom profile is of river valley landforms. From Gile, L.H., Hawley, J.W., and Grossman, R.B. 1981, Soils and geomorphology in the Basin and Range area of Southern New Mexico—Guidebook to the Desert Project: New Mexico Bureau of Mines and Mineral Resources, Memoir 39, 222 p.



TWest Micromorphology of calcic horizon showing progressive magnifications of areas located with arrows. Top shows biogenic carbonate in the form of a calcified filament.

TWest Profile Description

USDA NRCS Pedon Description

PEDON DESCRIPTION

Print Date: 07/20/2005
Description Date: 06/07/2004
Describer: C. Monger, R. Burt, D. Sprankle, G. Cates, W. Shoup, R. Kraimer, V. Anne
Site ID: S04NM013-001

Site Note:
Pedon ID: 04NM013001
Pedon Note:

Lab Source ID: SSL
Lab Pedon #: 04N0942
Soil Name as Described/Sampled: T-WEST
Soil Name as Correlated:
Classification: Fine-loamy, mixed, superactive, thermic Ustic Haplargids
Pedon Type:
Pedon Purpose: research site

Taxon Kind:

Associated Soils:
Physiographic Division: Intermontane Plateaus
Physiographic Province: Basin and Range Province
Physiographic Section: Mexican Highland

State Physiographic Area:
Local Physiographic Area:
Geomorphic Setting: alluvial flat
basin floor
Upslope Shape:
Cross Slope Shape:
Particle Size Control Section: 30 to 80 cm.
Diagnostic Features: ochric epipedon 0 to 18 cm.
argillic horizon 30 to 150 cm.
calcic horizon 62 to 183 cm.

Country:
State: New Mexico
County: Dona Ana
MLRA: 42 -- Southern Desertic Basins, Plains, and Mountains
Soil Survey Area:
Map Unit:
Quad Name: Taylor Well, New Mexico
Location Description:
Legal Description:
Latitude:
Longitude:
Datum: NAD83
UTM Zone: 13
UTM Easting: 336268 meters
UTM Northing: 3598627 meters

Primary Earth Cover:
Secondary Earth Cover:
Existing Vegetation: honey mesquite, Yucca, black grama
Parent Material: Igneous
Bedrock Kind:
Bedrock Depth:
Bedrock Hardness:
Bedrock Fracture Interval:
Surface Fragments:

A1--0 to 10 centimeters; brown (7.5YR 5/4) crushed fine sandy loam, dark yellowish brown (10YR 3/6) crushed, moist; 13 percent clay; weak fine platy, and weak medium platy structure; very friable, slightly hard, nonsticky, nonplastic; common fine roots throughout and common very fine roots throughout; common fine dendritic tubular and common medium dendritic tubular pores; strong effervescence, by HCl, 1 normal; abrupt smooth boundary. Lab sample # 04N05151

A2--10 to 18 centimeters; light brown (7.5YR 6/4) crushed sandy clay loam, brown (7.5YR 4/4) crushed, moist; 24 percent clay; moderate medium subangular blocky structure; very friable, moderately hard, slightly sticky, moderately plastic; common very fine roots throughout; common fine dendritic tubular and common medium tubular pores; strong effervescence, by HCl, 1 normal; clear smooth boundary. Lab sample # 04N05152

BA--18 to 30 centimeters; light brown (7.5YR 6/4) crushed sandy clay loam, strong brown (7.5YR 4/6) crushed, moist; 24 percent clay; moderate medium subangular blocky structure; friable, moderately hard, slightly sticky, slightly plastic; many fine roots throughout and many very fine roots throughout; common fine dendritic tubular and common very fine tubular and common very fine vesicular pores; 1 percent fine threadlike carbonate masses on faces of peds; 1 percent subrounded 2- to 5-millimeter igneous rock fragments; strong effervescence, by HCl, 1 normal; clear smooth boundary. Lab sample # 04N05153

Btk1--30 to 50 centimeters; brown (7.5YR 5/4) crushed sandy clay loam, brown (7.5YR 4/4) crushed, moist; 26 percent clay; moderate medium subangular blocky, and moderate fine subangular blocky structure; friable, hard, moderately sticky, moderately plastic; common fine roots throughout and common very fine roots throughout; common fine vesicular and common very fine dendritic tubular and common very fine tubular pores; 15 percent distinct clay films on all faces of peds; 1 percent fine dendritic carbonate masses on faces of peds and 1 percent fine threadlike carbonate masses on faces of peds; 3 percent subrounded 2- to 20-millimeter igneous rock fragments; strong effervescence, by HCl, 1 normal; clear smooth boundary. Lab sample # 04N05154

Btk2--50 to 62 centimeters; reddish yellow (7.5YR 6/6) crushed sandy clay loam, strong brown (7.5YR 4/6) crushed, moist; 32 percent clay; weak medium subangular blocky structure; friable, hard, very sticky, very plastic; common very fine roots throughout; common very fine vesicular and common very fine tubular pores; 8 percent faint clay films on all faces of peds; 4 percent fine threadlike carbonate masses on faces of peds and 1 percent medium cylindrical carbonate masses infused into matrix along faces of peds; 2 percent subrounded 2- to 20-millimeter igneous rock fragments; strong effervescence, by HCl, 1 normal; clear smooth boundary. Lab sample # 04N05155

Btk3--62 to 87 centimeters; pink (7.5YR 7/3) crushed clay loam, strong brown (7.5YR 4/6) crushed, moist; 30 percent clay; weak medium subangular blocky, and weak fine subangular blocky structure; firm, hard, moderately sticky, moderately plastic; common very fine roots throughout; common very fine tubular pores; 5 percent faint clay films on all faces of peds; 25 percent medium irregular carbonate masses on faces of peds; 7 percent subrounded 2- to 20-millimeter igneous rock fragments; violent effervescence, by HCl, 1 normal; gradual smooth boundary. Lab sample # 04N05156

Btk4--87 to 110 centimeters; pink (7.5YR 7/3) crushed sandy clay loam, brown (7.5YR 5/4) crushed, moist; 30 percent clay; weak medium subangular blocky structure; very friable, very hard, moderately sticky, moderately plastic; common very fine roots throughout; common fine dendritic tubular and common medium dendritic tubular and common very fine tubular pores; 2 percent faint clay films on all faces of peds; 15 percent medium irregular carbonate masses on faces of peds; 10 percent subrounded 2- to 20-millimeter igneous rock fragments; violent effervescence, by HCl, 1 normal; gradual smooth boundary. Lab sample # 04N05157

Btk5--110 to 150 centimeters; pink (7.5YR 7/3) crushed gravelly sandy clay loam, pink (7.5YR 7/4) crushed, moist; 24 percent clay; moderate fine subangular blocky structure; friable, extremely hard, moderately sticky, moderately plastic; few very fine roots throughout; common fine tubular and common very fine vesicular pores; 2 percent faint clay films on all faces of peds; 35 percent medium irregular carbonate masses on faces of peds; 34 percent subrounded 2- to 20-millimeter igneous rock fragments; violent effervescence, by HCl, 1 normal; gradual smooth boundary. Lab sample # 04N05158

Bk--150 to 183 centimeters; pink (7.5YR 8/3) crushed gravelly sandy clay loam, pink (7.5YR 7/4) crushed, moist; 23 percent clay; moderate medium subangular blocky structure; friable, very hard, slightly sticky, slightly plastic; very few very fine roots throughout; common medium tubular pores; 85 percent coarse irregular carbonate masses in matrix; 60 percent subrounded 2- to 20-millimeter igneous rock fragments; violent effervescence, by HCl, 1 normal. Lab sample # 04N05159

PSDA & Rock Fragments

Layer	Depth (cm)	Horz	Prep	-1-		-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-
				(- - - - - Total - - - - - -)			(- - Clay - - -)		(- - - - Silt - - - - -)		(- - - - - - - - - - - - Sand - - - - - - - - - - - -)					(Rock Fragments (mm))					
				Clay	Silt	Sand	Fine	CO_3	Fine	Coarse	VF	F	M	C	VC	(- - - - - - - - Weight - - - - - - - -)					>2 mm
				< .002	.002 -.05	.05 -2	< .0002	< .002	.002 -.02	.02 -.05	.05 -.10	.10 -.25	.25 -.50	.5 -1	1 -2	2 -5	5 -20	20 -75	.1- 75		wt % whole soil
				(- % of <2mm Mineral Soil -)												(- - - - - - - % of <75mm - - - - - -)					
				3A1a1a			3A1a1a	3A1a1a	3A1a1a		3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a						
04N05151	0-10	A1	S	17.9	31.1	51.0	5.4	--	12.7	18.4	16.9	17.2	12.9	3.9	0.1				34		
04N05152	10-18	A2	S	22.0	25.3	52.7	5.4	1.3	11.5	13.8	14.5	17.9	14.6	5.6	0.1				38		
04N05153	18-30	BA	S	26.9	25.6	47.5	9.2	4.4	12.3	13.3	11.7	16.8	12.6	5.7	0.7				36		
04N05154	30-50	Btk1	S	29.2	26.6	44.2	12.2	2.1	13.3	13.3	12.3	13.1	11.8	5.8	1.2				32		
04N05155	50-62	Btk2	S	39.3	24.2	36.5	15.3	13.3	13.8	10.4	9.5	11.7	9.2	5.5	0.6				27		
04N05156	62-87	Btk3	S	37.8	24.2	38.0	11.8	19.8	15.4	8.8	9.6	11.7	9.6	6.7	0.4				28		
04N05157	87-112	Btk4	S	32.1	27.5	40.4	8.9	21.0	19.6	7.9	8.2	12.5	8.9	6.8	4.0				32		
04N05158	112-150	Btk5	S	32.6	31.9	35.5	6.6	25.7	25.1	6.8	8.6	11.2	9.0	5.0	1.7				27		
04N05159	150-180	Bk	S	33.0	30.1	36.9	8.3	22.3	23.5	6.6	9.8	12.7	8.5	4.7	1.2						

Bulk Density & Moisture

Layer	Depth (cm)	Horz	Prep	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
				(Bulk Density)		Cole	(- - - - - - - - - - - Water Content - - - - - - - - - - -)						WRD	Aggst		
				33 kPa	Oven Dry	Whole Soil	6 kPa	10 kPa	33 kPa	1500 kPa	1500 kPa Moist	Ratio AD/OD	Whole Soil	Stabl 2-0.5mm	(- - Ratio/Clay - -) CEC7	1500 kPa
				(- - - g cm^{-3} - - -)			(- - - - - - - - - - - - pct of < 2mm - - - - - - - - - - - -)						$cm^3\ cm^{-3}$	%		
				3B1b	3B1c		3C1a	3C1b	3C1c	3C2a1a		3D1				
04N05151	0-10	A1	S	1.48	1.55	0.016	20.2	19.0	16.4	8.1		1.028	0.12		0.91	0.45
04N05152	10-18	A2	S	1.41	1.50	0.021	21.8	20.2	17.3	9.3		1.032	0.11		0.73	0.42
04N05153	18-30	BA	S	1.35	1.44	0.022	23.3	21.8	18.7	10.3		1.033	0.11		0.54	0.38
04N05154	30-50	Btk1	S	1.46	1.56	0.022	22.2	21.3	18.8	10.7		1.035	0.12		0.51	0.37
04N05155	50-62	Btk2	S	1.44	1.59	0.034	25.4	24.2	20.7	12.6		1.038	0.12		0.39	0.32
04N05156	62-87	Btk3	S	1.40	1.53	0.030	25.1	23.8	20.6	10.2		1.029	0.15		0.30	0.27
04N05157	87-112	Btk4	S	1.53	1.63	0.021	20.3	19.1	16.4	7.9		1.021	0.13		0.24	0.25
04N05158	112-150	Btk5	S	1.52	1.58	0.013	21.0	19.9	17.1	7.1		1.017	0.15		0.17	0.22
04N05159	150-180	Bk	S	1.55	1.69	0.029	20.6	19.5	17.5	8.4		1.020	0.14		0.16	

Carbon & Extractions

Layer	Depth (cm)	Horz	Prep	-1- C	-2- N	-3- S	-4- Org C	-5- C/N Ratio	-6- Fe	-7- Al	-8- Mn	-9- Al+½Fe	-10- ODOE	-11- Fe	-12- Al	-13- Mn	-14- Si	-15- C	-16- Fe	-17- Al	-18- Mn
				(- - - - - Total - - - - -)					(- - - Dith-Cit Ext - - -)			(- - - - - - - - Acid Oxalate Extraction - - - - - - - -)						(- - - Na Pyro-Phosphate - - -)			
				(- - - - - - % of <2 mm - - - - - -)					(- - - - - - - - - - - - - - - - % of < 2mm - - - - - - - - - - - - - -)							mg kg^{-1}	(- - - - - - - - - % of < 2mm - - - - - - - - -)			
				4H2a	4H2a	4H2a			4G1	4G1	4G1		4G2a	4G2a	4G2a	4G2a	4G2a		4G3	4G3	4G3
04N05151	0-10	A1	S	1.06	0.092	0.01		9	0.8	0.1	tr	0.16	0.02	0.07	0.13	217.6	0.07		--	--	--
04N05152	10-18	A2	S	1.08	0.061	0.01		10	0.7	0.1	tr	0.15	0.03	0.07	0.12	218.9	0.07		--	--	--
04N05153	18-30	BA	S	1.53	0.045	0.01		10	0.7	0.1	tr	0.14	0.03	0.07	0.11	165.5	0.07		--	--	--
04N05154	30-50	Btk1	S	1.60	0.050	0.01		9	0.7	0.1	tr	0.14	0.02	0.07	0.10	169.6	0.07		--	--	--
04N05155	50-62	Btk2	S	2.71	0.039	0.01		13	0.5	tr	tr	0.12	0.02	0.07	0.09	104.0	0.06		--	--	--
04N05156	62-87	Btk3	S	4.08	0.019	0.01		21	0.3	tr	--	0.09	0.01	0.04	0.06	60.7	0.05		--	--	--
04N05157	87-112	Btk4	S	5.09	0.016	0.01		11	0.2	tr	--	0.06	0.01	0.03	0.04	30.5	0.03		--	--	--
04N05158	112-150	Btk5	S	6.56	0.007	0.01		20	0.1	--	--	0.05	tr	0.03	0.03	20.2	0.02		--	--	--
04N05159	150-180	Bk	S	5.76	0.003	0.02		71	0.1	--	--	0.05	0.01	0.03	0.03	19.4	0.04		--	--	--

Pedon ID: S04NM-013-001 (Dona Ana County, New Mexico) Print Date: Jul 29 2005 3:28PM

Sampled As : Fine-loamy, mixed, superactive, thermic Ustic Haplargid

USDA-NRCS-NSSC-National Soil Survey Laboratory ; Pedon No.

pH & Carbonates

Layer	Depth (cm)	Horz	Prep	-1- KCl	-2- $CaCl_2$ 0.01M 1:2	-3- H_2O 1:1	-4- Sat Paste	-5- Sulf	-6- NaF	-7- (- Carbonate -) <2mm	-8- <20mm	-9- (- Gypsum -) <2mm	-10- <20mm	-11- Resist ohms cm^{-1}
				(- - - - - - - - - - - - - - - - - - pH - - - - - - - - - - - - - - - - -)						(- - - - - - - - - - - - % - - - - - - - - - - -)				
					As $CaCO_3$							As $CaSO_4$*$2H_2O$		
					4C1a2a2	4C1a2a1	4C1a1a2			4E1a1a1a1				
04N05151	0-10	A1	S		7.9	8.4				2				
04N05152	10-18	A2	S		8.0	8.5				4				
04N05153	18-30	BA	S		7.9	8.5				9				
04N05154	30-50	Btk1	S		7.9	8.4				9				
04N05155	50-62	Btk2	S		8.0	8.4				18				
04N05156	62-87	Btk3	S		8.0	8.5				31				
04N05157	87-112	Btk4	S		8.0	8.5				41				
04N05158	112-150	Btk5	S		8.2	8.6				54				
04N05159	150-180	Bk	S		8.4	8.6	8.3			46				

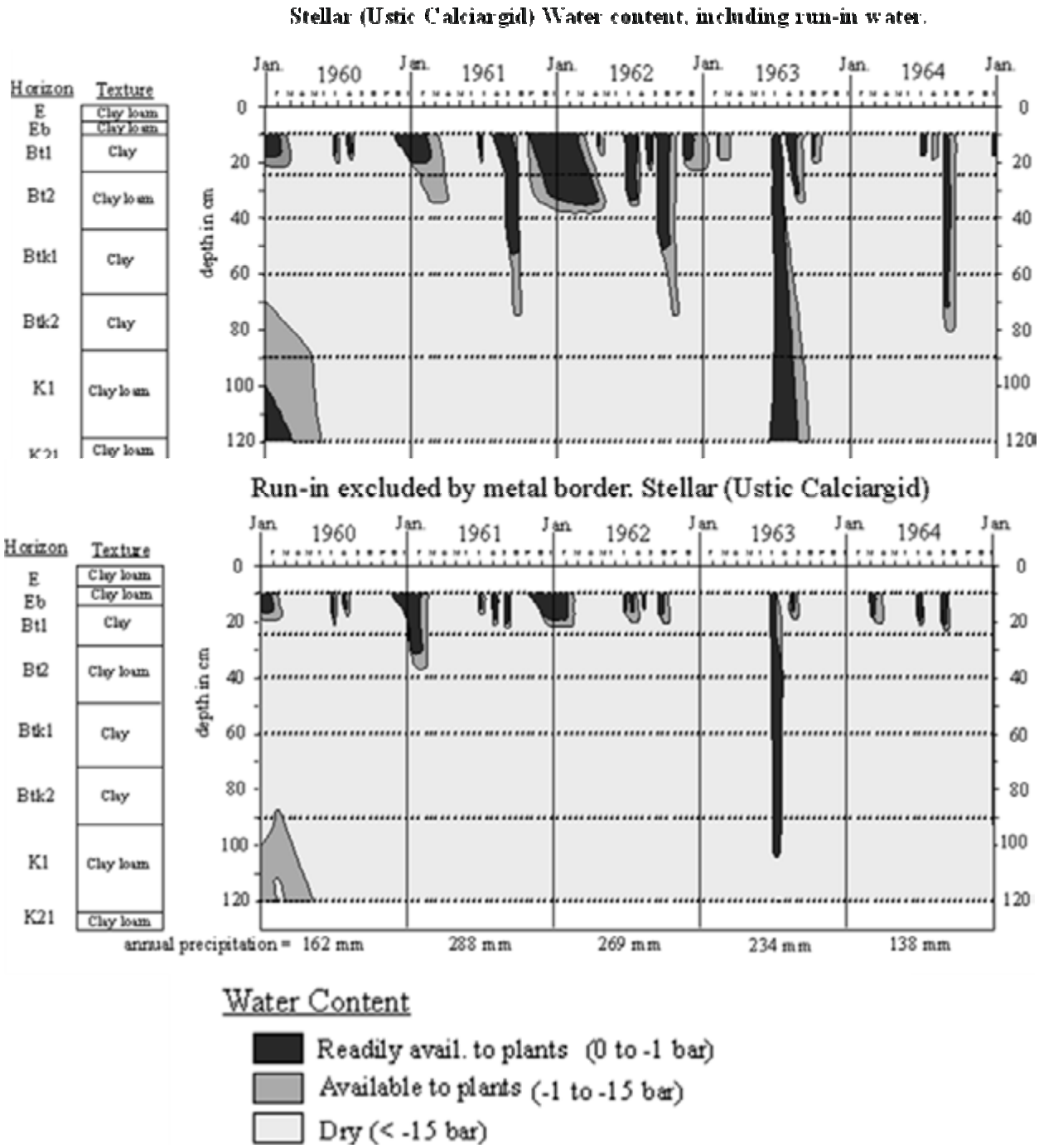


Illustration of the importance of run-in water in TWest vicinity. After Herbel, C.H., Gile, L.H., Fredrickson, E.L., and Gibbens, R.P., 1994. Soil water and soils at soil water sites, Jornada Experimental Range. L.H. Gile and R.J. Ahrens (eds.) Soil Survey Investigations Report No. 44. Soil Conservation Service, Lincoln, NE.

Gypsum Profile at JER Headquarters: From Herbel, C.H., Gile, L.H., Fredrickson, E.L., and Gibbens, R.P., 1994, Soil water and soils at soil water sites, Jornada Experimental Range. L.H. Gile and R.J. Ahrens (eds.) Soil Survey Investigations Report No. 44. Soil Conservation Service, Lincoln, NE.

244

USDA-Soil Conservation Service
Pedon Narrative Description
Soil Series: Wink, deep gypsum phase
Classification: Coarse-loamy, mixed, thermic Typic Calciorthid
NSSL ID#: 90P0495
Soil Survey #: S90NM-013-004
Location: The SE1/4NE1/NW1/4 section 33, T.19S., R.2E., in the former exclosure at Headquarters. This exclosure has been dismantled and the rain gauge has been moved to another site at Headquarters. ARS personnel indicate that the sampled pedon is very close to the former location of the soil moisture blocks.

Elevation: 4320 ft, 1317 m
Landform: Ridge side sloping 2% to the east
Geomorphic Surface: Eolian analogue of Jornada II, late phase?
Parent Material: Late phase Jornada II (?) sand
Vegetation: Dropseed, soaptree yucca, fourwing saltbush
Described By: L.H. Gile
Date: Jan. 29, 1990

Soil surface: A layer of loose reddish sand occurs over most of the surface.

C--0 to 9 cm; stratified pinkish gray to light brown (7.5YR 6/3) loamy sand; brown (7.5YR 4.5/3) moist; massive but with horizontal cleavage to thin and medium lenses; generally soft, with some lenses separated by soft fine granules or loose, single-grain material; few and common fine roots; 90P2736; strongly effervescent; abrupt smooth boundary.

Ab--9 to 18 cm; brown (7.5YR 5/2.5) loamy sand; dark brown (7YR 3.5/3) moist; very weak medium subangular blocky structure; slightly hard, very friable; few fine roots; 90P2737; strongly effervescent; clear wavy boundary.

Akb--18 to 30 cm; pinkish gray to light brown (7.5YR 6/3) loamy sand; brown to dark brown (7.5YR 4/3) moist; very weak medium subangular blocky structure; slightly hard, very friable; few fine roots; 90P2738; very few carbonate filaments; strongly effervescent; clear wavy boundary.

Bk1b--30 to 42 cm; pinkish gray to light brown (7.5YR 6.5/3) fine sandy loam; brown (7.5YR 5/3.5) moist; weak medium subangular blocky structure; slightly hard and hard, very friable; few fine roots; 90P2739; very few filaments; strongly effervescent; clear wavy boundary.

Bk2b--42 to 58 cm; pinkish gray to light brown (7.5YR 6.5/3) fine sandy loam; brown (7.5YR 5/3.5) moist; weak medium subangular blocky structure; slightly hard and hard, friable, few fine roots; 90P2740; few carbonate filaments; strongly effervescent; clear wavy boundary.

Bk3b--58 to 78 cm; pinkish gray to pink (7.5YR 7/3) fine sandy loam; brown (7.5YR 5/3.5) moist; weak medium subangular blocky structure; slightly hard and hard, friable; few fine roots; 90P2741; few carbonate filaments; strongly effervescent; clear wavy boundary.

K2b--78 to 101 cm; pinkish gray to pink (7.5YR 7.5/3) sandy clay loam; pinkish gray to light brown (7.5YR 6/3) moist; occurring as nodules and as internodular K-fabric, with lesser amount of 7.5YR 9/2 and 8/2; moderate medium subangular blocky structure; hard and very hard, firm; very few fine mottles; strongly effervescent; clear wavy boundary.

K3b--101 to 117 cm; pinkish gray to pink (7.5YR 7.5/3) sandy clay loam; pinkish gray to light brown (7.5YR 6/3) moist; these colors occur as carbonate nodules and as internodular K-fabric with lesser amount of 7.5YR 9/2, 8/2, and 6.5/3; moderate medium subangular blocky structure; very hard, firm; very few fine roots; 90P2743; few medium yellow and brownish yellow (10YR 7/6. 6/6) mottles; strongly effervescent; clear wavy boundary.

Bkb--117 to 127 cm; pinkish gray to light brown (7.5YR 6.5/3) sandy clay loam; brown (7.5YR 5/3) moist; weak medium subangular blocky structure; fine yellow and brownish yellow (10YR 7/6, 6/6) mottles and streaks; strongly effervescent; abrupt smooth boundary.

C--127 to 136 cm; white (10YR 9/2) sandy loam; very pale brown (10YR 8/3) moist; weak medium and coarse subangular blocky structure; very hard, firm; no roots; 90P2745; some parts noncalcareous, other parts weakly or strongly effervescent. This material appears to be primarily gypsum, and needs further study. It may be partly or wholly of lacustrine origin.

*** P R I M A R Y C H A R A C T E R I Z A T I O N D A T A ***

S98NM-013-004

Soil series:Wink,deep gypsum phase, COARSE-LOAMY, MIXED, THERMIC TYPIC CALCIORTHID

PRINT DATE 91/23/1

WHEL - PROJECT 96P TX, DONA ANA CO,
- PEDON 96P A95, SAMPLES 96P2736-2747
- GENERAL METHODS 1B1A, 2A1, 2B

N. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA 68508-3866

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	DEPTH (CM)	HORIZON	TOTAL CLAY LT .002	TOTAL SILT .002 -.05	TOTAL SAND .05 -2	CLAY FINE LT .002	CLAY COS LT .002	SILT FINE .002 -.02	SILT COARSE .02 -.05	SAND VF .05 -.10	SAND F .10 -.25	SAND M .25 -.50	SAND C .5 -1	SAND VC 1 -2	COARSE FRACTIONS(MM) 2 -5	5 -20	20 -75	.1-75 WHOLE SOIL	>2MM PCT OF SOIL
			<- - - - - - - - - - - PCT OF <2MM (3A1) - - - - - - - - - - ->												<- PCT OF <75MM(3B1)->				
96P2736S	0- 9	C	6.4	4.5	87.1			2.5	2.0	10.0	41.0	24.7	2.5	0.1	--	--	--	69	--
96P2737S	9- 18	AB	9.3	6.6	84.1		0.9	3.5	3.1	16.0	42.6	23.1	2.1	0.1	--	--	--	66	--
96P2738S	18- 30	AXB	10.6	5.9	83.5		0.9	3.0	0.9	16.6	40.9	25.3	2.6	0.1	--	--	--	69	--
96P2739S	30- 42	BK1B	12.7	5.9	81.4		2.0	3.8	2.1	14.0	39.5	24.4	3.3	0.2	TR	TR	--	67	--
96P2740S	42- 58	BK2B	13.4	7.2	79.4		2.7	4.5	2.7	13.0	36.0	25.7	3.7	0.2	TR	TR	--	66	--
96P2741S	58- 78	BK3B	14.3	8.4	77.3		3.0	5.6	2.8	13.9	33.4	25.5	3.6	0.3	TR	TR	--	61	TR
96P2742S	78-101	K2B	22.1	14.3	63.7		7.0	10.7	3.5	14.6	25.9	19.2	3.4	0.6	1	TR	--	50	1
96P2743S	101-117	K3B	23.3	17.1	59.6		7.0	13.3	4.0	13.3	25.4	17.0	3.2	0.7	--	--	--	46	--
96P2744S	117-127	BK6	21.4	14.1	64.5		9.5	4.8	5.3	14.2	26.1	18.0	3.5	0.7	1	--	--	51	1
96P2745S	127-136	C	8.4	30.6	61.0		1.2	19.5	11.1	21.5	24.9	12.9	1.6	0.1	--	--	--	39	--
															--	--	--		--

DEPTH (CM)	ORGN C 6A3c PCT	TOTAL N 6B3a <2MM	EXTR P 6B3 PPM	TOTAL S 6B1a	EXTRACTABLE FE 6C1b	AL 6G7a	MN 6D2a	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LL 8F1 PCT	PI 8F <0.4MM	BULK DENSITY FIELD MOIST 8A3a	1/3 BAR 8A1d	OVEN DRY 8A1h	COLE WHOLE SOIL 8D1 CM/CM	WATER CONTENT FIELD MOIST 4B1	1/10 BAR 4B1c	1/3 BAR 4B1e	15 BAR 4B2b	WHOLE SOIL 8C1 CM/CM
				<- PERCENT			OF <2MM -->					<- - G/CC - - ->				<- - -PCT OF <2MM - ->				
0- 9	0.26							0.76	0.35										2.9	
9- 18	0.26							0.81	0.34				1.69	1.73	0.000			4.5	3.2	0.02
18- 30	0.23							0.67	0.33										3.5	
30- 42	0.23							0.69	0.35				1.59	1.62	0.006			5.3	4.4	0.01
42- 58	0.21							0.35	0.34										4.5	
58- 78	0.18							0.53	0.34										4.0	
78-101	0.22							0.43	0.38				1.57	1.61	0.019			11.2	6.7	0.07
101-117	0.18							0.55	0.33				1.55	1.65	0.025			13.2	7.7	0.04
117-127	0.19							0.61	0.36										7.7	
127-136	0.08							0.46	0.71				1.50	1.58	--			19.7	8.0	0.10

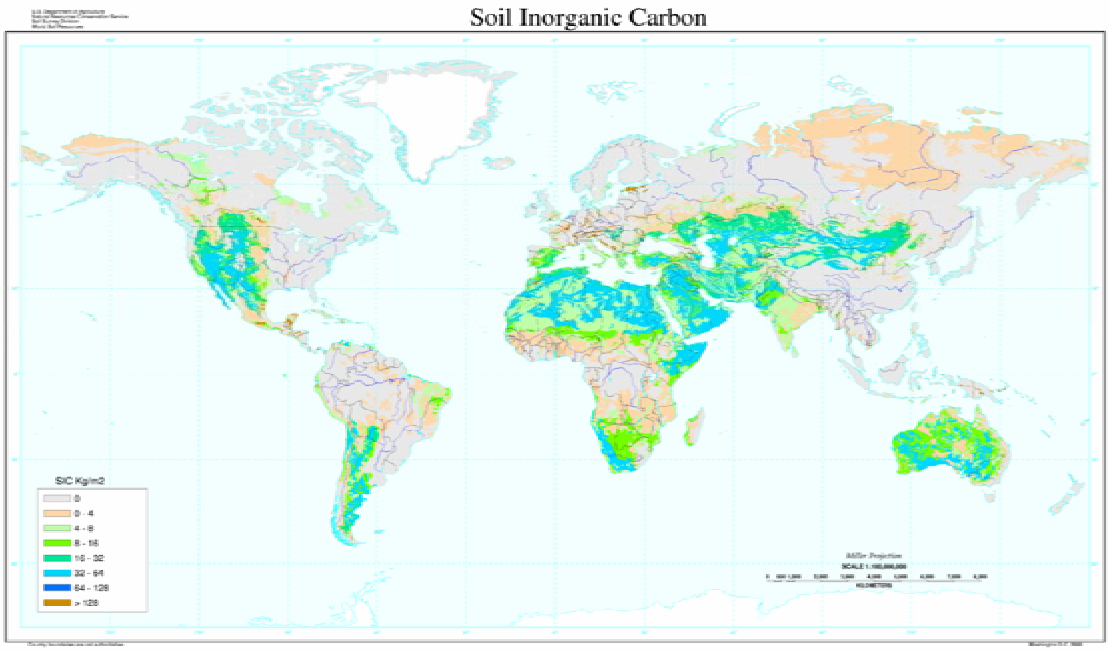
AVERAGES, DEPTH 25-100: PCT CLAY 12 PCT .1-75MM 61

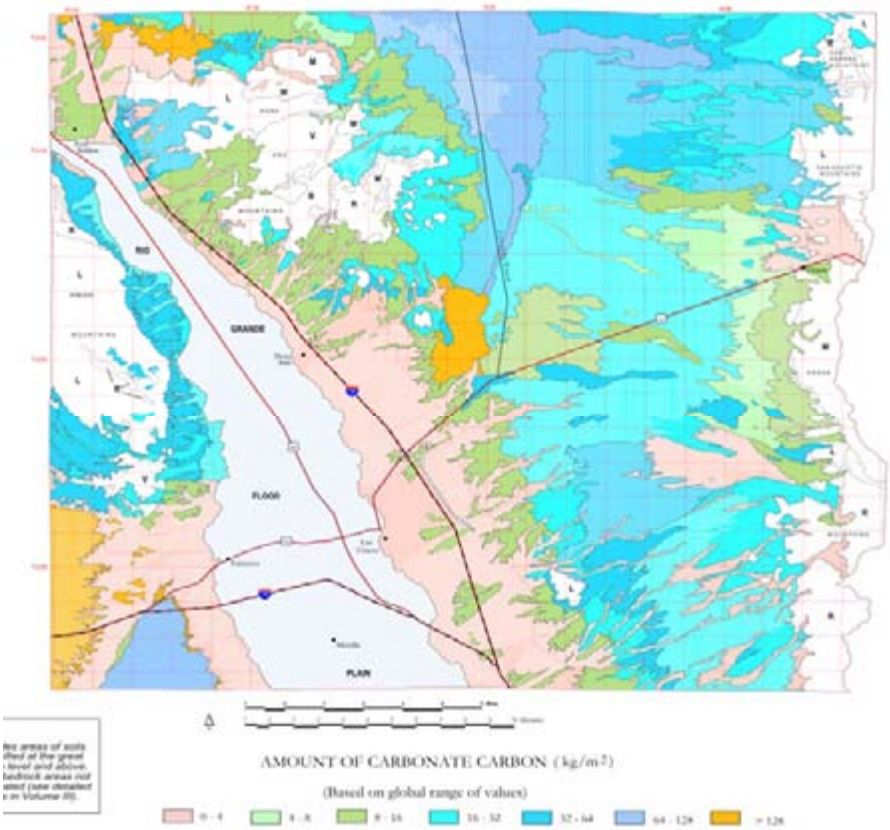
DEPTH (CM)	NH4OAC EXTRACTABLE BASES CA 5B3a 6N2d	MG 5B3a 6Q2d	NA 5B3a 6P2b	K 5B3a 6R2b	SUM BASES	ACID-ITY 6H5a	CEC- SUM CATS 5A3a	NH4-OAC 5A4b	EXCH NA 5B5b PCT	SAR 5E	BASE SATURATION SUM 5C3	NH4OAC 5C1	CO3 AS CACO3 <2MM 6E1g PCT	REG. OHMS /CM 6E1	CASO4 AS GYPSUM <2MM 6F1a	<20MM 6F4	SAT PASTE 8C1b	PH CACL2 .01M 8C1f 1:2	H2O 8C1f 1:1
	<- - - - - - - - - - -MEQ / 100 G - - - - - - - - - - ->								PCT		<- -PCT- >		PCT		<- -PCT ->				
0- 9		0.8	--	0.6					6.4	TR		100	100	1				7.8	8.4
9- 18		0.6	--	0.6					7.5	TR		100	100	1				7.6	8.5
18- 30		0.7	TR	0.4					7.1	1		100	100	2				7.8	8.3
30- 42		0.5	--	0.3					7.4	TR		100	100	5				7.8	8.4
42- 58		0.4	TR	0.3					7.4	TR		100	100	7				7.8	8.6
58- 78		0.9	TR	0.3					7.6	1		100	100	6				7.8	8.2
78-101		1.0	0.1	0.3					9.6	1	TR	100	100	17	2000		7.6	7.8	8.1
101-117		1.2	0.3	0.4					12.0	2	1	100	100	12		--	7.5	7.7	7.6
117-127		1.2	0.3	0.4					13.0	2	1	100	100	10		TR	7.5	7.7	7.6
127-136		0.4	0.1	0.1					3.9	1	TR	100	100	2		54	7.6	7.6	7.4

DEPTH (CM)	WATER EXTRACTED FROM SATURATED PASTE CA 6N1b	MG 6Q1b	NA 6P1b	K 6Q1b	CO3 6A1b	HCO3 6A1b	CL 6K1c	SO4 6L1c	NO3 6M1c	N2O BA	TOTAL SALTS EST. 8D5	ELEC. COND. 8A3a MMHOS /CM
	<- - - - - - - - - - -MEQ / LITER - - - - - - - - - - ->									<- -PCT ->		
0- 9												0.22
9- 18												0.16
18- 30												0.15
30- 42												0.16
42- 58												0.16
58- 78												0.18
78-101	10.5	0.9	0.9	0.2	--	1.4	2.6	7.5	--	35.8	TR	1.12
101-117	20.5	1.5	2.1	0.2	--	1.5	5.5	15.2	--	39.5	0.1	1.96
117-127	31.3	1.9	3.1	0.3	--	1.6	5.7	29.5	--	44.1	0.1	2.60
127-136	28.8	1.1	1.5	0.3	--	1.0	1.1	26.9	--	52.2	0.1	2.20

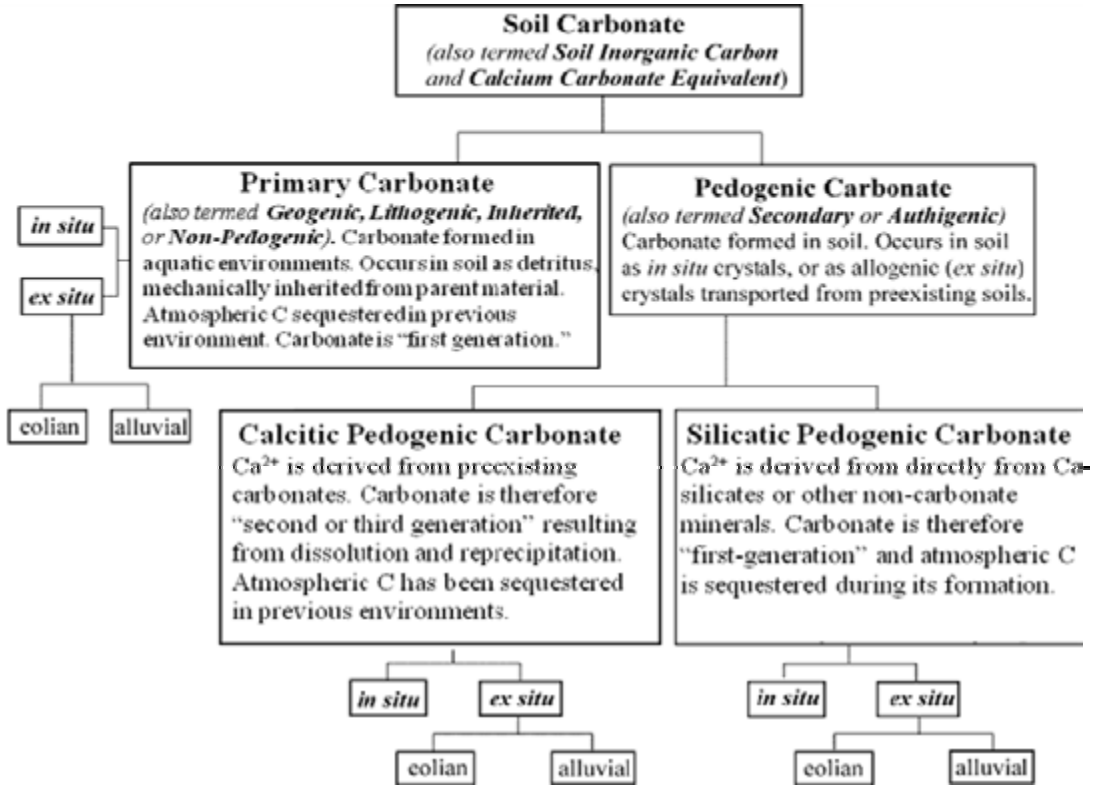
MMHOS/CM OF 1:2 WATER EXTRACT (8I) & EXCH NA AS EXTRACTABLE NA FOR LAYERS 1, 2, 3, 4, 5, 6,

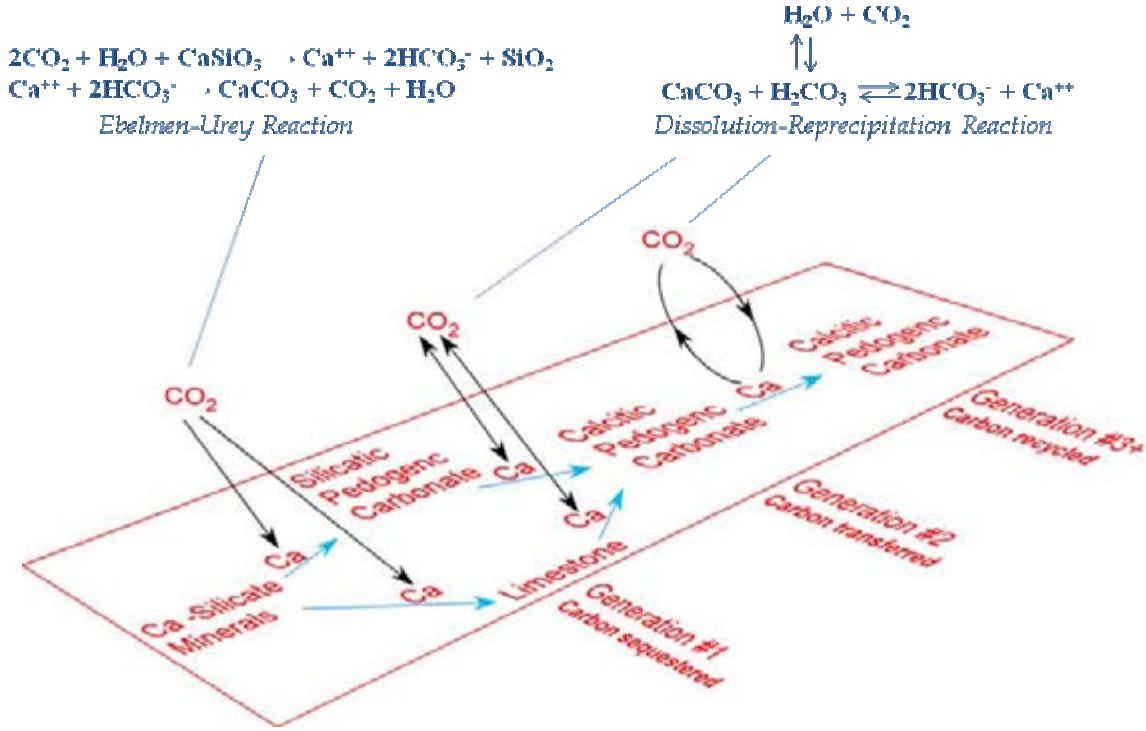
ANALYSES: S= ALL ON SIEVED <2MM BASIS





Distribution of soil carbonate (inorganic carbon) at the global scale and in the Desert Project (Bottom), from Gile, et al. 2007. A 50th anniversary guidebook for the Desert Project. U.S. Dept. of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE. 279 p.





Carbon Sequestration by Soil Carbonate: A Classification System. After Monger and Martinez-Rios 2001. In: R.F. Follett et al. (eds) *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*. CRC Press, New York.

Workshop 2: Ecological Sites

Workshop Summary

We will discuss concepts for ecological sites, state-and-transition models (STM), and the kinds of data that can be collected to support soil-site correlation and STM development. Specifically, we will focus on the Sandy (MLRA 42.2) ecological site. The Sandy site has a rich source of data and is a relatively well-understood example of a fairly complex ecological site. Thus, it illustrates many of the issues and dynamics that will be observed in ecological sites across the U.S.

Specifically, we will discuss the following points:

- Soil-site correlation groups several similar soil map unit components within a single ecological site; to do otherwise would result in too many classes.

- Alternative states occur on similar soil profiles and thresholds separate these states. Thresholds are caused by feedbacks between biological and soil-surface processes that tend to produce large differences in ecological conditions.

- Any representative of a soil map unit component correlated to an ecological site will be observed in one of several states of the STM. Soil components correlated to an ecological site should be *capable* of existing in any of the states of its STM. Nonetheless, certain soil components *will more often* be observed in some states than others. This is because soil components exhibit gradational variation in soil climate at a regional scale and in properties that affect plant resource availability and therefore the likelihood of a transition to an alternative state.

- States are best regarded as being composed of patches that represent distinct functional units. Recognizing the proportions of patches can help visualize states in the field.

- Data should be collected across a broad extent to develop an ecological site concept and STM. We will discuss the three tiers of data collection and demonstrate a version of the "Tier 1" traverse method (see Bestelmeyer, B. T., A. J. Tugel, G. L. Peacock, Jr., D. G. Robinett, P. L. Shaver, J. R. Brown, J. E. Herrick, H. Sanchez, and K. M. Havstad. 2009. State-and-transition models for heterogeneous landscapes: A strategy for development and application. **Rangeland Ecology and Management** 62:1-15).

- In the process of discussing the traverse method, we will learn about three new "Pedoderm and Pattern Class" indicators that reflect soil surface processes and vegetation spatial arrangement that are useful for describing ecological states.

Note the patterns in the Google image (Quickbird satellite) and locations for the stops.

Stop 1. Black grama grassland (reference state and reference phase).

Stop 2. Shrub-encroaching state A (black grama/bunchgrasses).

Vista 1. The “scrape site”; an experiment to measure what happens when all vegetation is removed from a Sandy soil.

Stop 3. Mesquite shrubland (incipient stage).

Stop 4. Shrub-encroaching state B (bunchgrasses; *Sporobolus flexuosus*, *S. contractus*, *Aristida purpurea*, *Eragrostis lehmanniana* [invasive], remnant *Bouteloua eriopoda*). Soil pit present.

A. MLRA 42.2: Sandy Ecological Site

Summary

Distinguishing soil features: Loamy sand to sandy loam surface with a calcic or petrocalcic horizon and/or an argillic or cambic horizon featuring some clay increase with depth. Petrocalcic horizon, when present, is > 50 cm deep.

Landscape features: Sand sheets; relict basin floors, sand-buried piedmont slopes.

Related ecological sites: *Shallow sandy* has a petrocalcic horizon < 50 cm and *Deep sand* does not have a calcic, cambic, or argillic horizon. *Sandy* often exists as a fine mosaic with *Shallow Sandy*. Mesquite coppice dunes (torripsamments) are sometimes correlated to Deep sand (c.f. soil series in Hennessy et al. 1983b, 1985) but dunes actually represent a soil component of a state of the Sandy site.

Dominant soil taxa: Calciargids, Petrocalcids, Haplocalcids, Petroargids, Haplocambids, not shallow, usually coarse-loamy and non-gravelly.

Common series: Yucca, Harrisburg, Berino, Wink, Onite, Hueco, Nations, Pajarito, Pendero, Pintura, Rotura, Bucklebar, Cacique, Mohave.

Reference state: Historical plant communities were dominated by continuous black grama (*Bouteloua eriopoda*) mixed with other grasses, especially dropseeds (*Sporobolus* spp.). Representatives of the reference state are still common. Spatial variation in vegetation within the state may be governed by slight variations in soil texture of the A and/or B horizons within the site. For example, dropseeds may increase as soils become coarser. Continuous heavy grazing coupled to drought periods can lead to loss and fragmentation of black grama plants and increasing representation of dropseeds, threeawns (*Aristida* spp.), and snakeweed (*Gutierrezia sarothrae*) within this state. Black grama recovery is driven by recruitment from stolons into bare gaps. Scattered adult honey mesquite (*Prosopis glandulosa*) may be present.

Transitions: Year-long continuous grazing during multi-year periods of summer or spring drought can cause severe reduction, fragmentation, or total loss of black grama. Loss of black grama and increasingly large bare ground patches allow wind and water erosion. Feedbacks to grass mortality ensue. Recovery by stolons is increasingly difficult as black grama patches become isolated and inter-patch areas erode. Climatic conditions are seldom suitable for black grama recovery and establishment by seed is limited in this species. Concurrently, honey mesquite can be introduced (or is present) and expands due to one or more of the following processes; spread of seed by livestock, climatic events favorable to establishment, reduced competition for soil water, and reduced fire frequency. Continued heavy grazing on remnant grasses, perhaps exacerbated by native rodent and lagomorph herbivores and competition with shrubs, leads to loss of grasses in shrub interspaces, interspace erosion, and the formation of mesquite dunelands.

Alternative states:

Black grama-limited state: Black grama patches surrounded by a matrix of bunchgrasses/ subshrubs. During droughts, bunchgrass cover declines considerably leading to patchy erosion. Black grama does not recolonize eroded bunchgrass patches. Few adult mesquite.

Bunchgrass grassland: Black grama is absent or represented by a few relict plants. Sheet and wind erosion is common and continuous. Few adult mesquite.

Shrub encroaching/black grama: Black grama is usually patchy, mesquite are common with a mixed age structure or with many smaller mesquite suggesting a recent establishment event or ongoing recruitment and competition with grasses.

Shrub encroaching/bunchgrass: Bunchgrasses, subshrubs, or mesquite may be dominant; black grama may be present as a few isolated relict patches. Mesquite are common with a mixed age structure or with many smaller mesquite suggesting recent establishment or ongoing recruitment. Mesquite cover may be high, but loss of soil from shrub interspaces is moderate.

Mesquite shrubland: Mesquite are dominant with significant coppicing around shrubs and deflation in shrub interspaces. Soil loss and redistribution is significant.

Patch types composing states:

Black grama (stoloniferous grass): Often densely vegetated with small interspaces and persistent in drought if minimally disturbed by grazing; accumulates soil deposits (usually has a thin C horizon); may have abundant BSCs. May include scattered *Ephedra* and *Yucca*.

Bunchgrass/subshrub: Densely to sparsely vegetated often with large interspaces, soil surface often moderately eroded and with platy structure. May include scattered *Ephedra* and *Yucca*.

Lehmann's lovegrass (invasive/fire-tolerant): Densely vegetated, often intermixed with bunchgrasses on moderately eroded soils, similar to bunchgrass patch.

Barren/ephemeral forb: Sparsely to non-vegetated, often observed with *Croton* after rains. Moderately to deeply eroded, platy soils

Barren/eroded: Usually non-vegetated with a hard, often cemented, subsoil exposed at the surface that may be overlain with thin sheets of sorted sand.

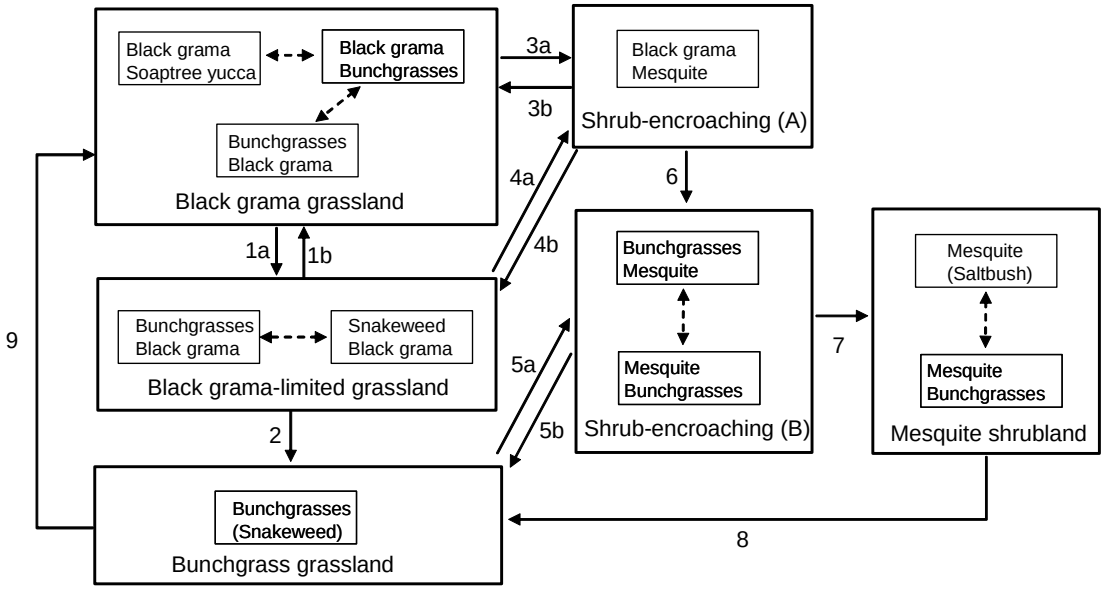
Mesquite/non-buried: Mesquite plant and area below its canopy, often featuring a thin O horizon and grasses such as *Setaria leucopila*. Often associated with high levels of pedoturbation by rodents.

Coppice dune/mesquite: Mesquite plant and accumulated soil deposits forming a thick C horizon. Litter abundant. Coppice may harbor other shrubs (*Atriplex*) and bunchgrasses.

Restoration: Restoration from mesquite shrubland and shrub-dominated states has generally been unsuccessful. Use of herbicide within shrub-encroaching states is believed to have promoted persistence of grass cover, although shrub regrowth is generally observed (i.e., these states are resilient). Black grama recovery within black grama-limited and bunchgrass states has not been

observed, although recent high-rainfall years have led to increases in black grama cover within these and shrub-encroaching states.

State-Transition model: MLRA 42.2; Upland sandy site group: Sandy



1a. Grazing in drought periods, black grama fragmentation. **1b.** Unknown, possible role for extreme wet periods
2. Black grama extinction due to heavy grazing in drought, soil erosion.
3a. Mesquite seed introduction with black grama fragmentation, lack of fire. **3b**.Shrub removal
4a, **5a**. Mesquite seed introduction or mesquite release from biological constraint. **4b**, **5b**. Shrub removal
6. Heavy grazing, drought causes black grama extinction, greater opportunities for mesquite expansion, wind erosion/deposition from adjacent shrublands
7. Heavy grazing or ORV disturbance, bunchgrass loss, wind/sheet erosion, soil truncation
8. Mesquite removal coupled to soil stabilization, nutrient addition, seeding during wet periods.
9. Unknown, possibly via reseeding in extreme wet periods

MLRA 42.2; Sandy

Black-grama dominated state

•Black grama, soaptree yucca, dropseeds threeawns. No mesquite in immediate area.
•Black grama cover and stature is high
• Small patches of bare ground, covered with litter and BSCs.
•Berino-Buckelbar map unit, Jornada Experimental Range, Dona Ana Co.

Black grama-limited state

•Black grama, threeawns, snakeweed, few mesquite.
•Black grama cover and stature is low
• Large patches of bare ground, unprotected by litter and eroding.
•Wink-Harrisburg map unit, Jornada Experimental Range, Dona Ana Co.

Shrub encroaching state A

•Black grama common, but fragmented
•Several size classes of mesquite
•High bare ground cover despite recent high rainfall, moderate erosion.
•Berino taxadjunct, CDRRC, Dona Ana Co.

Shrub-encroaching state B

•Snakeweed, some threeawns, many mesquite
•Grass cover very low, no black grama
• Note evidence of wind erosion, litter accumulations in small depressions
•Wink Harrisburg map unit, Dona Ana Co.

Mesquite shrubland state (advanced)

•Mesquite, some snakeweed
•No grass cover in interdunes, some dropseeds associated with mesquite coppices
• Soil surface indurated and rich in carbonate, exposed roots.
•Copia-Nations complex,Fort Bliss, Otero Co.

Black grama grassland: The reference plant community is dominated by black grama. Dropseeds (*Sporobolus flexuosus, S. cryptandrus,* and *S. contractus*) are often secondary dominants, intermixed with black grama or occurring as discrete patches. Bush muhly (*Muhlenbergia porteri*) and threeawns (*Aristida* spp.) are other common grasses. Soaptree yucca (*Yucca elata*), longleaf ephedra (*Ephedra trifurca*), and sand sage (*Artemisia filifolia*) are common shrubs. Scattered, adult mesquite (*Prosopis glandulosa*) can be present. This state is defined by the capacity of black grama to persist indefinitely (e.g. some permanent quadrats on the Jornada Experimental Range). The caespitose, bushy growth form of black grama cover stabilizes the sandy soil surface, leading to low erosion rates relative to the cover of other bunchgrasses (Paulsen and Ares 1962). Soil stability is sometimes reflected in biological soil crusts that proliferate in bare interspaces surrounded by black grama. Extensive black grama grasslands are believed to have established during the Little Ice Age, the most recent minimum of which was in the mid-1800s. Currently, black grama grasslands are sustained by vegetative reproduction (often from stolons) into small (usually <50 cm) bare interspaces. Reproduction by seeding is believed to be rare under current climate (Jackson 1928, Nielson 1986) so black grama grasslands are sometimes considered relict vegetation (in MLRA 42.2) in which mortality typically outpaces reproduction. Mesquite establishment within this state is not significant. Fires may or may not be an important reason for low mesquite recruitment and it is not clear why mesquite recruitment is limited.

Black grama plants maintain carbohydrates in their tillers and stolons (vegetative reproduction structures) above ground throughout the winter (Miller and Donart 1979). Thus, this species is preferred in winter months and declines with increasing stocking rates (Holechek et al., 1994). In addition, black grama's dominant mode of local colonization is via stolons and stolon establishment is vulnerable to trampling and drought (Nelson 1934, Wright and Van Dyne 1976). Heavy grazing results in an increasing relative cover of dropseeds, threeawns, or snakeweed. It is also possible that in coarser soils, such as loamy sands, dropseeds tends to exhibit high cover relative to black grama irrespective of grazing pressure. Two seasons without summer rains will also lead to black grama decline (Robert P. Gibbens, personal communication). Grasses such as dropseeds and threeawns are thought to be more sensitive to drought than black grama (Herbel et al. 1972) but can recover more rapidly via seeding. Snakeweed or dropseeds may become dominant within this state due to grazing effects as long as the capacity of black grama to recover after cessation of grazing is not compromised. An even distribution of black grama plants capable of reoccupying areas between plants via stolon-based reproduction is suspected to be a prerequisite for resilience of this state. Gibbens and Beck (1987) and some unpublished records from the USDA-ARS Jornada Experimental Range, Las Cruces, NM provide evidence for recovery of black grama from dropseed dominance at a local scale (1 m^2). Campbell and Bombarger (1934) indicate that black grama can recover in areas dominated by subshrubs such as snakeweed (*Gutierrezia sarothrae*).

<u>Diagnosis</u>: Black grama is dominant and/or cover is continuous, canopy can exceed 60%. There is evidence of black grama reproduction by stolons. Large basal gaps (> 2 m) are typically not more than 30% of line, gaps often covered with biological soil crusts. Pedoderm Class = WP or PDB; Resource Retention Class = 1-2; Soil Redistribution Class = 0-2. Litter cover is abundant. Soil stability values range from 4-6. There are no mesquite or a few, scattered adult individuals (< 1% cover).

Transition to black-grama limited state (1a): Disturbance and death of black grama plants across large areas (due to grazing and trampling), possibly in concert with climate change, is the trigger of the transition. Once black grama plants are reduced to widely-scattered patches they are incapable of reestablishing dominance via vegetative reproduction (the threshold). Subsequent loss of soil fertility by moderate erosion may contribute to the threshold and the persistence of the black grama-limited state. Wright and Van Dyne (1976) noted that the effects of cattle trampling may be more important than the effects of grazing per se. Furthermore, those authors found an effect of grazing on only loamy sands suggesting that relatively minor variations in soil texture may determine the sensitivity of black grama to grazing. Herrick et al. (2002) suggest that loss of litter cover, plant cover, and perhaps biological soil crusts leads to soil degradation that creates an unfavorable environment for black grama. In particular, the loss of soil carbon that maintains microbial populations and soil moisture at rooting depth may be an important mechanism (Jerry Barrow, personal communication). Increases in threeawns seem to be an especially ominous indicator of a transition, although it is unclear why. According to the review by Howard (1987), *Aristida purpurea* is favored by winter-spring precipitation, is animal dispersed, is disturbance-adapted, and is usually unpalatable. Thus, the variety of processes postulated to reduce black grama may all favor this grass.

Key indicators of approach to threshold: Increases in bare ground, decreases in litter cover and black grama cover, increasing distance between black grama plants, decreased soil surface resistance to erosion, decreases in soil organic matter, increases in disturbance-adapted grass species (including threeawns and fluffgrass [*Dasyochloa pulchella*]).

Transition to the shrub-encroaching state (3a): Fragmentation of black grama can co-occur with accelerating establishment of mesquite shrubs. Some investigators believe that shrub invasion is facilitated by reductions in black grama (i.e., the trigger). On the contrary, Herbel and Gibbens (1996) suggest that mesquite expansion can occur within apparently intact black grama stands. It is possible that the latter pattern emerges when the propagule load to an intact site is very high due its proximity to adjacent mesquite-dominated areas. Alternatively, mesquite propagules are typically present as seeds but are able to achieve maturity in the absence of fire. If the competition hypothesis is true, selective herbivory on black grama with continued grazing promotes establishment of mesquite. If the fire hypothesis is true, then the reduction of fire frequency associated with the loss of fine fuels promotes mesquite establishment. If the small animal shrub herbivory hypothesis is true, then the elimination or reduction of mesquite seedling predators promotes mesquite establishment, independent of grass cover. If the dispersal hypothesis is true, then once introduced, mesquite may expand despite cessation of grazing. It is likely that several of these processes work in parallel or in different instances. Widespread establishment of mesquite within fragmented, black grama grasslands constitutes a threshold because mesquite are unlikely to die over a management timeframe.

Key indicators of approach to threshold: Same as for transition 1a if the competition hypothesis is true. If the fire hypothesis is true then a reduction of black grama annual production and litter cover are indicators. If the dispersal hypothesis is true then there are no suitable indicators, other than the presence of potential seed vectors (i.e. livestock) and their connection to a seed source (a mesquite-invaded area).

Black grama-limited grassland state: Black grama has been reduced to a subordinate component of the plant community and dropseeds and threeawns dominate. Black grama often exists as discrete, widely-distributed patches in a matrix of bunchgrasses and subshrubs exhibiting

substantial bare ground cover and high connectivity. Evidence of erosion is common, larger black grama patches are often elevated by several inches relative to the surrounding matrix. Snakeweed may achieve dominance for long periods because it is less palatable than the grasses. Furthermore, once snakeweed attains a high density, some feel that allelopathic (Tirmenstein 1999) or competitive effects may inhibit the growth of grass populations. Jameson (1970), however, failed to document any competitive suppression of snakeweed on black grama. Climate (Campbell and Bombarger 1934), fire (McDaniel et al. 2000) and beetle herbivory (*Crossidius* spp.; Thompson et al. 1996) may regulate patterns of snakeweed abundance. Because snakeweed is a cool-season plant, it tends to increase in response to increases in winter-spring precipitation.

It is not clear why black grama does not recover over long time periods. It is possible that the rate of expansion of remnant black grama patches is very slow and tiller establishment from stolons is difficult in large, bare interspaces. Reduced soil quality due to erosion and loss of soil organic matter in large bare interspaces, unfavorable microclimate (high heat, low soil moisture), or rodent/lagomorph herbivory on grasses at patch edges may contribute to this limitation.

Following the drought of the 1950s, black grama basal cover increased from 1957-1977 on the Jornada Experimental Range but dropseeds often increased at a greater rate and became dominant or co-dominant (Herbel and Gibbens 1996). This pattern may be consistent with black grama reproductive limitation in this state. In either black grama or bunchgrass (snakeweed)-dominated communities, soil stability may be considerably lower than in the black-grama dominated grassland state.

Diagnosis: Black grama cover is fragmented and canopy cover is lower than that of bunchgrasses. Black grama often occurs as discrete patches. Mesquite plants are uncommon. Evidence of erosion is common, including pedestalled plants, water flow patterns, and small blowouts. Pedoderm Class = WP; Resource Retention Class = 3-4; Soil Redistribution Class = 2-3.

Transition to bunchgrass grassland state (2): The local extinction of black grama is caused by heavy grazing in combination with drought.

Key indicators of approach to threshold: Fragmentation of remnant black grama patches, decadence of remnant black grama plants, pedestalling or sand burial of black grama plants, lack of black grama reproduction (stolon production).

Transition to shrub-encroaching state (4a): Accelerated mesquite establishment may occur years after black grama reproduction has become limited and/or black grama dominance declines. Environmental conditions are likely to be suitable for mesquite establishment within the black-grama limited state. Thus, only the presence of a mesquite-seed vector or climatic conditions favorable for establishment is required for this transition to take place.

Key indicators of approach to threshold: There are no suitable indicators, other than the presence of potential seed vectors (i.e. livestock) and their connection to a seed source (a mesquite-invaded area).

Restoration to black grama grassland state (1b): Black grama has been observed to survive in certain patches on the Jornada Experimental Range through the drought periods (R. P. Gibbens, personal communication). Understanding what properties distinguish these patches from areas where black grama has declined may hold important clues to preventing grassland degradation and restoring black grama. Methods for reversing the transition are currently unknown. It is

possible that black grama patches could expand via vegetative (stolon) reproduction to reoccupy a site during a multi-year period of high summer rainfall over several decades.

Bunchgrass grassland state: This state is characterized dominance by bunchgrasses (threeawns or dropseeds) or snakeweed. Lehman's lovegrass (*Eragrostis lehmanniana*) has recently begun to increase in abundance within representatives of this state. Black grama is absent or represented by very few relict patches. Mesquite are present but are uncommon. Erosion by wind and water may be significant in this state. The absence of black grama leads to large fluctuations in grass cover between high and low rainfall periods as bunchgrasses die off and reestablish.

Diagnosis: Absence of black grama plants or a few scattered individuals. Canopy cover is highly variable. Mesquite is uncommon. Pedoderm Class = WP; Resource Retention Class = 3-5; Soil Redistribution Class = 3.

Transition to shrub-dominated state (5a): Similar to 4a. Bunchgrass cover is highly variable, so shrubs often dominate the aspect and function of the site once they spread.

Restoration to black grama grassland state (9): Intensive restoration (e.g., re-seeding, re-planting) techniques are not known to be successful or practical. Climatic conditions would need to be suitable for seed production in adjacent areas and establishment from seed.

Shrub-encroaching states (A and B): Mesquite recruitment is common and many young mesquite are present. On soils with > 5% gravel content, some creosotebush (*Larrea tridentata*) may expand as well. In some cases, accelerating mesquite establishment occurs in continuous or patchy black grama grassland (*Shrub-encroaching/black grama state A*). In other cases, mesquite expands after significant black grama degradation has already occurred and bunchgrasses are dominant (*Shrub-encroaching/bunchgrass state B*). It is believed that black grama loss (**transition 6**) and increases in shrub density eventually occur unless grazing rest and/or shrub control is applied (e.g. Hennessy et al. 1983b). Where mesquite densities are highest (>20% canopy cover), black grama tends to absent (*Shrub-encroaching/bunchgrass state B).*

Mesquite plants may be very small and difficult to detect with casual observation. Although fire may kill small (< 1.5 yr old; Wright et al. 1976) mesquite, it is unlikely that fire return intervals are sufficiently short to remove mesquite from a grassland if mesquite seed flow to a grassland is significant. Livestock and native animals, particularly coyotes (*Canis latrans*), are common vectors of viable mesquite seeds (Kramp et al., 1998). Thus, it is likely that mesquite seedlings are a normal component of black-grama-dominated grassland but are suppressed by fire, small mammal herbivory, and/or competition in the black grama-dominated state (Brown and Archer 1999). Areas of high mesquite density tend to exhibit fragmentation of black grama grass due to competition, heavy grazing, or rodent herbivory. There are no data available, however, that relate grass reproduction to levels of invasion. Valentine (1936), however, indicates that beyond a height of 1-2 feet, mesquite begins to exclude grasses from around plant bases. Mesquites may provide cover and nest sites for rodents (e.g. kangaroo rats) and lagomorphs (jackrabbits, cottontails) that increase herbivory on black grama adults and seedlings (Campbell 1929, Bestelmeyer et al., 2007). If black grama reproduction is limited, it may be rapidly extirpated with grazing and interactions with shrubs and only bunchgrasses may remain to stabilize soils (**transition 6**).

Within shrub-encroaching state B, bunchgrass cover can be highly variable. Depending on shrub density, herbaceous production may exceed shrub cover in wet years whereas in other years shrubs and subshrubs such as snakeweed are clearly dominant. Shrub canopy cover may

exceed 40% but coexist with a substantial cover of bunchgrasses (10%). We do not understand the causes of variation in grass and shrub densities within this state.

Within this state, brush control using herbicides (e.g. 2,4,5-T) resulting in at least a 30% mesquite kill can result in increases in grasses (Herbel et al. 1983). Gibbens et al. (1992) suggests that the duration of mesquite suppression typically lasts 20-30 years before mesquite densities return to (or surpass) pre-treatment levels. It is therefore valid to regard herbicide use within the shrub-encroaching states as within-state management, rather than restoration to grassland.

Diagnosis: Mesquite are common and usually conspicuous. Many small mesquite indicate recent recruitment and a recent transition to this state. Black grama cover is substantial, but often fragmented by bare ground, in Shrub-encroaching state A. Bunchgrasses may be dominant or sparse, depending on recent climate, in Shrub-encroaching state B. Canopy cover and indicator values are highly variable.

Restoration to black grama grassland, black grama-limited, or bunchgrass grassland states (3b, 4b, 5b): Mesquite removal via herbicide use (typically via clopyralid and triclopyror) or physical means in the early phases of mesquite establishment might be able to circumvent (or significantly delay) mesquite expansion. Mesquite removal coupled with high grass cover could be used to shorten fire return intervals and control mesquite if fire governs grassland resilience. The successful use of fire in black grama grasslands, however, depends strongly upon the size of mesquite and probably on post-fire precipitation patterns that favor black grama recovery (Drewa and Havstad 2001). At this point, it is unclear if fire can be effectively used as a management tool to promote black grama dominance. Increased black grama cover following mesquite removal and high rainfall years might preclude mesquite recovery via competition, although this has not been observed. Neither fire nor competition is likely to keep mesquite from recovering in black-grama limited or bunchgrass grassland cover levels. If climate or mesquite seed availability alone is responsible for transitions 3a, 4a, or 5a, transitions to grasslands may be impossible.

Transition to mesquite shrubland state (7): Fragmentation or loss of remaining interspace plant cover due to heavy grazing and/or drought leads to increasing erosion and redistribution of soil to shrubs (Schlesinger et al., 1990) or out of the site (Gillette and Monger 2006). Erosion leads to loss of remaining grasses due to soil destabilization, exacerbated by increasingly concentrated rodent and livestock herbivory on grasses. The factors responsible for the apparently great variation in the occurrence of this transition are unknown. Variation in landscape position and soils currently correlated to this site may be responsible. Soils with well-developed clay-rich horizons tend to form hardpans after erosion and soil truncation. Soils without strongly contrasting horizons may retain the capacity to support grasses (usually dropseeds) even after erosion. In some rare instances, as yet not understood, perennial grasses and mesquite may coexist within the shrub encroaching state with high cover values (e.g., both > 10% canopy cover) with no apparent progress to mesquite duneland.

Key indicators of approach to threshold: Continued loss of grass cover, evidence of increased bare ground and connectivity of bare ground, and evidence of wind and sheet erosion (e.g. pedestalling, blowouts, or the accumulation of caliche chunks and stones at the surface).

Mesquite shrubland: Mesquite are dominant and intershrub areas are typically eroded with a sparse vegetation cover of annual plants and subshrubs. Wind-eroded soil accumulates on

mesquite to form coppice dunes (or *nabkas*; Langford 2000) over time. Perennial grasses, restricted to bunchgrasses, may be observed only during the wettest periods. In other periods, grasses cannot colonize interdunes due to the instability of the substrate, high soil surface temperatures (Hennessy et al. 1985), or low nutrient availability. Rodent and rabbit herbivory on grass seedlings may be important where other physical factors are not limiting. In some cases, mesquite does not dominate and erosion to B horizons (e.g. sandy clay loams) leads to dominance by snakeweed and saltbush (*Atriplex canescens*). In some cases, soil truncation exposes clay- and carbonate-rich subsoil that is very hard and does not permit plant establishment.

Differential mortality or recruitment and growth of mesquite shrubs occur in response in wind erosion, leading to the formation of "mesquite streets" oriented in the direction of erosive winds (Gillette et al., 2006, McGlynn and Okin 2006). The mesquite streets are especially hostile for vegetation establishment due to sand abrasion and deposition. Thus, even though mesquite interdune soils have not been shown to exhibit reduced plant-available soil water (Herbel and Gibbens 1987, Hennessy et al. 1985) or a loss of organic matter (Hennessy et al. 1985) relative to a grassland state, erosion processes may constrain grass recovery. Herbivory by native mammals may also be an important constraint.

Coppice soils are more or less homogenous to depths of a meter or more and are often classified as Pintura or Copia soil series. This soil classification has prompted some investigators to refer to these dunes as Deep sand ecological sites. Deep sand sites occur naturally and support a distinct plant community, so it is preferable to consider recently-formed coppice dunes as a soil element of the mesquite shrubland state. Perennial grasses and other shrubs, especially saltbush, can colonize dune soils because of the greater availability of water there (Hennessy et al. 1985).

Diagnosis: Mesquite is dominant. Coppice dunes from over time, and range from 0.5-3 m high (depending on age and depth to caliche). Bunchgrasses are usually rare or absent; when present they are often restricted to coppice dunes. In extremely wet years, dropseeds may colonize interdunes where impermeable horizons have not been exposed. There is often evidence of wind erosion and deposition including extreme pedestalling, plant burial, highly sorted sand, ripples, and an exposed B horizon in interdunes. Pedoderm Class = S, SP, or CEM; Resource Retention Class = 5; Soil Redistribution Class = 4b.

Transition to bunchgrass grassland (8): In principle, it may be possible to kill mesquite, redistribute or add soil nutrients, and stabilize soil during periods favorable to the germination of bunchgrasses, perhaps in conjunction with seeding. The use of municipal biosolids may aid in restoring soil fertility (Walton et al. 2001).

B. Three tiers of data collection

Tier 1: Low-intensity, extensive survey (traverse)

- Explore relationships among states, soils, landforms, climate, and land-uses across the MLRA or LRU.
- Develop or rapidly verify ecological site and state concepts
- Rapid soil, plant, and indicator collection (30 minutes) at arbitrary or stratified-random points

Tier 2: Medium-intensity inventory (transecting or stratified inventory)

- Develop quantitative statistical relationships between the properties of states and soils/landforms across a broad extent.
- Quantitative descriptions of state-soil relationships across the MLRA or LRU at stratified-random points
- Plant cover estimated ocularly or measured precisely; soil mini-pit characterized (1-2 hours).

Tier 3: High intensity characterization

- Detailed quantification of vegetation, pedoderm, and soil profile properties for representatives of alternative states, particularly the reference state.
- Allows tests of resilience mechanisms postulated in STMs and allows properties to be generalized via maps of states.
- Plant cover via line-point intercept, production, dynamic soil properties, soil pit at random points within state units or within carefully-selected representatives (several hours).

C. Forms used for Tier 1 and Tier 2 data collection

In the pages that follow we offer a "Pedoderm and Pattern Class" form developed for Tier 2 use. In addition, we use a Soil form to characterize the soil profile and a Plant Data form in Tier 2. These are available at http://usda-ars.nmsu.edu/esd/esdResources.html. Finally, we present an example of the Tier 1 "ESD Traverse" form, which we will use in the field.

ESD Pedoderm and Pattern Classes (assessed for ___ x ___m plot)

Site:	Plot:	State & Co:	MLRA:	LRU:
Investigators:	Date:	Location:		
UTM Datum & Zone:	Easting:	Northing:	Elev: m or ft	SMU:

Pedoderm Class in ___ x ___ m	select one	[1]Dom Biol Crust or VC	**Notes**
S = Soil; pedoderm is characterized by bare mineral soil and none of the classes below.			
SA = Well-formed or distinct structural aggregates at the soil surface and no other class below (well aggregated, stable soils).			
WP = Weak physical or biological crust; can be disrupted by rainfall, none to few cyanobacterial sheaths dangling from ped, no darkening from cyanobacteria.			
SP = Strong physical crust; usually platy or massive (structure not disrupted by rainfall), no substantial biological component.			
CEM = Cemented pan exposed at surface			
SC = Salt crust of fine to extremely coarse evaporite crystals or visible whitening on the soil surface; may include biological components.			
PDB = Poorly developed biological crust assemblage, many cyanobacterial sheaths, may be slightly dark, can include other functional/structural groups (algae, lichen, moss).[1]			
SDB = Strongly developed biological crust assemblage, obvious dark cyanobacteria, rubbery algal, moss or lichen crust.[1]			
CB = Cracking or curling, rubbery algal crusts, with or without lichen.[1]			
EP = Erosion pavement; a concentration of rock fragments at the soil surface caused by erosion and removal of finer soil material; individual fragments may be displaced during runoff events.			
DP = Desert pavement; a concentration of closely packed and polished rock fragments at the soil surface, embedded in a vesicular crust.			
D = Duff; partially and fully decomposed plant & organic matter; above the A horizon.			

[1] List 1-2 dominant biological crust functional structural groups from this list: Cyano (Cyanobacteria), LC (Lichen Crust), M (Moss), LV (Liverwort), A (Algae). Vesicular crusts (VC) should be noted when present

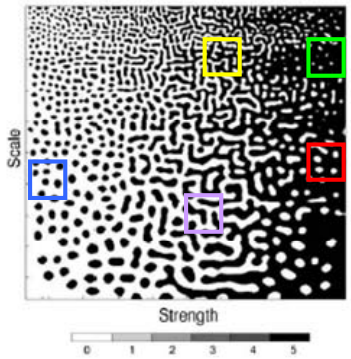
Resource Retention Class in ___ x ___ m (choose one)	cm	**Notes:**
1. Interconnected grass cover or dense bunchgrasses and surrounding round bare patches <30cm		
2. Grass cover interconnected and surrounding round/oval bare patches 30-___cm across		
3. Grass cover fragmented by elongate bare areas to ___ cm wide but bounded in plot		
4. Grass cover fragmented by elongate bare areas to ___ cm wide that cross through the plot		
5. Bare ground interconnected in several directions and isolated grass patches up to ___ cm		
6. Bare ground interconnected with scattered or no grass plants		

Soil Redistribution Class in ___ x ___ m (check erosion and/or deposition observed)	**Eros**	**Depo**	**Notes:**
0. No evidence of erosion or deposition.			
1. Minor soil redistribution.			
2. Patchy soil loss and deposition[2].			
3. Moderate soil loss across the plot and patchy sediment deposition.			
4. Extensive, deep soil loss and/or deep deposition[3].			
a. Erosion with exposed subsoil (little deposition).			
b. Erosion with exposed subsoil coupled with patchy sediment deposition.			
c. Extensive sediment deposition.			

[2] Depositional mounds are formed by the settling of sediment transported by wind and/or water movement; mounds can occur on or behind obstructions to flow or where flow speeds are reduced.

[3] Confirm deposition within a soil pit. Recently deposited material is usually seen as a thinly or finely stratified soil surface with alternating thin layers of varying textures; lacks structure.

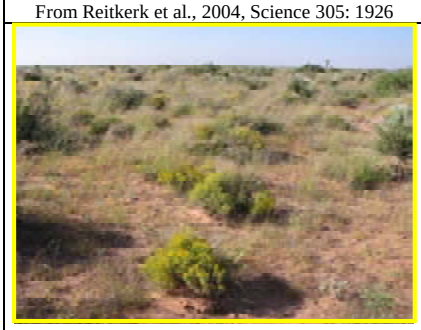
Resource Retention Class Guide



From Reitkerk et al., 2004, Science 305: 1926

1. Interconnected grass cover or dense bunchgrasses; and surrounding bare patches <30cm

2. Grass cover interconnected and surrounding round bare patches from 30-___cm



3. Grass cover fragmented by elongate bare areas to ___ cm wide but bounded in plot

4. Grass cover fragmented by elongate bare areas to ___ cm wide that cross entire width of plot

5. Bare ground interconnected in several directions and isolated grass patches up to ___ cm

Soil Redistribution Class Definitions

0. **No evidence of erosion or deposition**.

1. **Minor soil redistribution**. Evidence includes narrow, elongate, sometimes tortuous, water flow patterns, and litter movement indicating loss of thin soil layers and thin soil deposits from wind or water. No noticeable thinning of the A horizon and soil movement occurs within a matrix of vegetated/stable soil.

2. **Patchy soil loss and deposition.** Evidence includes small pedestals, soil lines on rock fragments, terracettes, water flow patterns, litter dams, wind scouring, small (e.g., < 10 cm tall) depositional mounds[1]. A horizon thinned in discrete patches within a matrix of vegetated/stable soil. Note approximate size of eroded patches. Sediment source may be on or off of the plot.

3. **Moderate soil loss across the plot and patchy sediment deposition**. Evidence includes prominent pedestals, soil lines on rock fragments, gravel lag, water flow patterns, rills, and depositional mounds suggesting significant soil loss and/or deposition from eroded areas. Noticeable thinning of A horizon across plot with patches of stable/vegetated soil and patchy sediment deposits. Sediment source may be on or off of the plot.

4. **Extensive, deep soil loss and/or deep deposition**. Evidence includes scarps/scarplets, prominent pedestals, rills, gullies, extensive wind scouring, exposed roots, large (e.g., > 20 cm tall) depositional mounds, and buried plants indicating substantial deposition[2]. A plot is often embedded in an extensive area of erosion and deposition and expresses one of the following (choose only one below):

a. *Erosion with exposed subsoil (little deposition)* . Prominent pedestals, often with decadent or dead plants, and rills/gullies exposing subsoil horizons. Usually associated with fluvial processes.

b. *Erosion with exposed subsoil coupled with patchy sediment deposition.* As above and includes sediment accumulation (e.g., coppice dunes) intermixed with areas of eroded soil. Usually associated with a mix of fluvial and eolian processes.

c. *Extensive sediment deposition* . Sediment sheets continuous across plot, usually indicated by buried plants/stones or hummocky surface. May be hard to detect without excavation. Sediments originate from outside of the plot. Rills may be present. Associated with fluvial or eolian processes.

ESD Traverse Data Form

Site:	State:	County:	MLRA:	LRU:
Investigators:	Date:	Location:		

WP	Elev	Slope (%)	Aspect (°)	Top depth (cm)	Bot-tom depth (cm)	% GR	Texture or Horizon	Eff	Ecological Site	List Dominant Plants in Order	Cover class	Dom Shrub/ Tree Ht.	Pedoderm Class	Resource Retention Class	Soil Redistri-bution Class	State / Plant Community	Notes
										1							
										2							
										3							
										4							
										5				____cm			
										1							
										2							
										3							
										4							
										5				____cm			
										1							
										2							
										3							
										4							
										5				____cm			
										1							
										2							
										3							
										4							
										5				____cm			
										1							
										2							
										3							
										4							
										5				____cm			
										1							
										2							
										3							
										4							
										5				____cm			

References for Workshops 2 and 3

An abbreviated ecological site description is provided. For a complete description: http://esis.sc.egov.usda.gov/Welcome/pgReportLocation.aspx?type=ESD

ECOLOGICAL SITE DESCRIPTION

ECOLOGICAL SITE CHARACTERISTICS

Site Type: Rangeland

Site Name: Sandy

Site ID: R042XB012NM

Major Land Resource Area: 042 - Southern Desertic Basins, Plains, and Mountains

Physiographic Features
This upland site occurs on alluvial fans, fan piedmonts, fan remnants or fan terraces between the foothills of mountains and the floodplains. These fans are often dissected by small arroyos. Slopes range from 1 to 8 percent. It occurs on all exposures. Elevations range from about 4,500 feet above sea level to 5,500 feet.

Climatic Features
This site has an arid climate with distinct seasonal temperature variations and large annual and diurnal temperature changes characteristic of a continental climate. Precipitation averages 8 to 10 inches annually. Deviations of 4 inches or more from the average are quite common. Fifty percent of the precipitation is received from July to November, which is the dominant growing season of native plants. Summer precipitation is characterized by high-intensity, short-duration rainstorms. Winter precipitation averages less than one-half inch per month, usually in the form of rain. There are occasional snowstorms of short duration. Temperatures vary from a mean monthly average of 77 F in July to 34 F in January, with a maximum of 104 F and a minimum of -10 F. The average last killing frost in the spring is April 15 and the average first killing frost in the fall is October 28. Frost-free season averages 185 days. Temperatures are conducive to native grass and forb growth from March through November. Spring winds of 15 to 40 miles per hour are common from February to June.

Influencing Water Features

Representative Soil Features
These soils are deep to moderately deep. The surface textures are sandy loam, gravelly sandy loam, gravelly fine sandy loam, fine sandy loam, gravelly loamy fine sand. The subsoil textures are sandy clay loam, sandy loam, gravelly loam, or gravelly sandy loam. The substrata are loamy fine sand, fine sandy loam, very cobbly loam, gravelly sandy loam, or gravelly loamy sand. The soils are usually calcareous throughout.

Plant Communities
See Workshop 2 and 3

Ecological Dynamics of the Site
See Workshop 2

Ecological Site Interpretations (animals, hydrology, recreation, products)

Supporting Information (associated and similar sites, references, approvals)

Stop 1

*** Primary Characterization Data ***

Pedon ID: S01NM-013-001 (Dona Ana, New Mexico) Print Date: Apr 22 2009 12:18PM

Sampled As : Jer1

USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 01N0517

PSDA & Rock Fragments				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-
				(- - - - - Total - - - - - -)			(- - Clay - - -)		(- - - - Silt - - - - -)		(- - - - - - - - - - - - Sand - - - - - - - - - - - -)					(Rock Fragments (mm))				
				Clay	Silt	Sand	Fine	CO_3	Fine	Coarse	VF	F	M	C	VC	(- - - - - - - - Weight - - - - - - - -)				>2 mm
				<	.002	.05	<	<	.002	.02	.05	.10	.25	.5	1	2	5	20	.1-	wt %
	Depth			.002	-.05	-2	.0002	.002	-.02	-.05	-.10	-.25	-.50	-1	-2	-5	-20	-75	75	whole
Layer	(cm)	Horz	Prep	(- % of <2mm Mineral Soil -)												(- - - - - - - % of <75mm - - - - - -)				soil
				3A1a1a			3A1a1a	3A1a1a	3A1a1a		3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a					
01N02927	0-1	C1	S	6.5	9.3	84.2	2.2		2.0	7.3	12.4	38.0	27.8	5.9	0.1	--	--	--	72	--
01N02928	1-7	C2	S	7.0	7.8	85.2	2.7		1.8	6.0	11.7	35.9	30.0	7.5	0.1	--	--	--	74	--
01N02929	7-17	A	S	10.8	11.6	77.6	3.6	1.0	3.2	8.4	14.7	34.2	22.8	5.8	0.1	--	--	--	63	--
01N02930	17-27	Btk1	S	12.9	10.4	76.7	4.9	2.3	3.4	7.0	11.0	30.2	26.1	9.2	0.2	--	--	--	66	--
01N02931	27-44	Btk2	S	13.1	10.4	76.5	5.5	2.9	4.1	6.3	9.0	30.5	28.2	8.2	0.6	--	--	--	68	--
01N02932	44-65	Btk3	S	17.2	11.6	71.2	7.3	4.5	4.8	6.8	8.9	26.5	27.0	8.3	0.5	tr	tr	--	62	tr
01N02933	65-87	Btk4	S	24.6	11.6	63.8	8.6	13.5	6.5	5.1	7.7	28.1	21.7	5.7	0.6	8	36	19	84	63
01N02934	87-105	Bkm/Bt	S	23.5	15.7	60.8	8.1	13.7	9.0	6.7	8.5	24.0	17.7	8.2	2.4	14	35	10	80	59
01N02935	105-130	2Bkm	S	14.0	17.5	68.5	4.6	9.9	10.0	7.5	10.9	27.7	21.3	6.5	2.1	7	27	47	92	81
01N02936	130-157	3Bk1	S	11.9	18.0	70.1	3.7	8.0	9.0	9.0	11.5	25.2	22.2	7.0	4.2	2	22	65	95	89
01N02937	157-187	3Bk2	S	9.3	22.8	67.9	3.3	5.5	10.7	12.1	20.0	27.1	12.4	3.8	4.6	5	26	55	93	86
01N02941	87-105	Bkm	S													15	47	11	--	73
01N02942	87-105	Bt	S													--	--	--	--	--

Bulk Density & Moisture				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
				(Bulk Density)		Cole	(- - - - - - - - - - - Water Content - - - - - - - - - - -)						WRD	Aggst		
				33	Oven	Whole	6	10	33	1500	1500 kPa	Ratio	Whole	Stabl	(- - Ratio/Clay - -)	
	Depth			kPa	Dry	Soil	kPa	kPa	kPa	kPa	Moist	AD/OD	Soil	2-0.5mm	CEC7	1500 kPa
Layer	(cm)	Horz	Prep	(- - - g cm^{-3} - - -)			(- - - - - - - - - - - - % of < 2mm - - - - - - - - - - - -)						cm^3 cm^{-3}	%		
				DbWR1	DbWR1		DbWR1	DbWR1	DbWR1	3C2a1a		3D1		3F1a1a		
01N02927	0-1	C1	S							3.0		1.010		32	1.09	0.46
01N02928	1-7	C2	S							3.1		1.010		15	0.97	0.44
01N02929	7-17	A	S	1.50	1.55	0.011	14.1	11.6	11.5	5.1		1.018	0.10	22	0.95	0.47
01N02930	17-27	Btk1	S	1.51	1.54	0.007	13.3	11.1	10.5	5.1		1.016	0.08		0.71	0.40
01N02931	27-44	Btk2	S	1.51	1.55	0.009	15.4	14.8	12.2	5.2		1.017	0.11		0.66	0.40
01N02932	44-65	Btk3	S	1.53	1.59	0.013	20.0	15.7	14.9	6.6		1.021	0.13		0.56	0.38
01N02933	65-87	Btk4	S	1.64	1.73	0.009	17.3	16.1	15.5	8.4		1.020	0.06		0.34	0.34
01N02933	65-87	Btk4	S_SK									1.018				
01N02934	87-105	Bkm/Bt	S							8.4		1.020			0.30	0.36
01N02934	87-105	Bkm/Bt	S_SK									1.016				
01N02935	105-130	2Bkm	S	1.56	1.60	0.002	17.4	21.4	20.2	8.9		1.018	0.05		0.31	0.64
01N02935	105-130	2Bkm	S_SK									1.018				
01N02936	130-157	3Bk1	S							8.7		1.016			0.31	0.73
01N02936	130-157	3Bk1	S_SK									1.012				
01N02937	157-187	3Bk2	S	1.71	1.72	tr	18.2	16.2	15.6	9.3		1.029	0.02		0.56	1.00
01N02937	157-187	3Bk2	S_SK									1.020				
01N02941	87-105	Bkm	S							8.7		1.021				
01N02941	87-105	Bkm	S_SK									1.016				
01N02942	87-105	Bt	S							8.4		1.022				

pH & Carbonates

Layer	Depth (cm)	Horz	Prep	-1- KCl	-2- $CaCl_2$ 0.01M 1:2 4C1a2a	-3- H_2O 1:1 4C1a2a	-4- Sat Paste 4F2	-5- Sulf	-6- NaF 4C1a1a1	-7- Carbonate As $CaCO_3$ <2mm 4E1a1a1a1	-8- Carbonate As $CaCO_3$ <20mm 4E1a1a1a1	-9- Gypsum As $CaSO_4$*$2H_2O$ <2mm 4E2a1a1a1	-10- Gypsum As $CaSO_4$*$2H_2O$ <20mm 4E2a1a1a1	-11- Resist ohms cm^{-1}
				(- - - - - - - - - - - - - - - - - - pH					- - - - - - - - - - - - - - - - -)	(- - Carbonate	- -)	(- - Gypsum	- - -)	
										%				
01N02927	0-1	C1	S		7.5	7.9	7.2		10.0	1				
01N02928	1-7	C2	S		7.6	8.1			10.0	1				
01N02929	7-17	A	S		7.7	8.1			10.3	2				
01N02930	17-27	Btk1	S		7.7	8.2			10.5	5				
01N02931	27-44	Btk2	S		7.8	8.2			10.6	5				
01N02932	44-65	Btk3	S		7.8	8.2			10.6	5				
01N02933	65-87	Btk4	S		7.8	8.2	7.7		10.7	21	22			
01N02934	87-105	Bkm/Bt	S		7.8	8.2	7.7		10.7	33	41			
01N02935	105-130	2Bkm	S		8.0	8.3	7.9		10.8	38	39	--		
01N02936	130-157	3Bk1	S		8.0	8.2	7.8		10.8	50	62	--		
01N02937	157-187	3Bk2	S		7.9	7.9	7.7		10.7	46	55	2		
01N02941	87-105	Bkm	S		7.9	8.2			10.7					
01N02942	87-105	Bt	S		7.8	8.2			10.7					

Stop 3

Pedon ID: 95NM013003 (Dona Ana, New Mexico) Print Date: Apr 22 2009 12:25PM
Sampled As : Yucca Coarse-loamy, mixed, thermic Typic Calciargid
USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 95P0455

PSDA & Rock Fragments

				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-
				(- - - - - Total - - - - - -)			(- - Clay - - -)		(- - - - Silt - - - - -)		(- - - - - - - - - - - - Sand - - - - - - - - - - - - -)					(Rock Fragments (mm))				
				Clay	Silt	Sand	Fine	CO_3	Fine	Coarse	VF	F	M	C	VC	(- - - - - - - - Weight - - - - - - - -)				>2 mm
				<	.002	.05	<	<	.002	.02	.05	.10	.25	.5	1	2	5	20	.1-	wt %
	Depth			.002	-.05	-2	.0002	.002	-.02	-.05	-.10	-.25	-.50	-1	-2	-5	-20	-75	75	whole
Layer	(cm)	Horz	Prep	(- % of <2mm Mineral Soil -)												(- - - - - - - % of <75mm - - - - - -)				soil
				3A1	3A1	3A1		3A1	3A1	3A1	3A1	3A1	3A1	3A1	3A1	3B1	3B1	3B1		
95P03343	0-5	A	S	10.4	11.4	78.2			4.3	7.1	11.3	37.1	26.2	3.3	0.3	tr	tr	--	67	tr
95P03344	5-18	Btk1	S	8.9	10.6	80.5		2.1	5.0	5.6	10.5	38.7	28.6	2.5	0.2	tr	--	--	70	--
95P03345	18-31	Btk2	S	12.3	11.2	76.5		2.6	4.3	6.9	9.4	34.8	27.4	4.2	0.7	1	tr	--	67	1
95P03346	31-48	Bk21	S	21.3	15.8	62.9		13.2	9.4	6.4	9.6	27.3	21.0	3.7	1.3	tr	1	--	54	1
95P03347	48-65	Bk22	S	18.6	14.1	67.3		10.5	8.2	5.9	10.9	30.9	21.3	3.4	0.8	1	tr	--	57	1
95P03348	65-85	Bk31	S	15.8	13.6	70.6		7.5	8.2	5.4	11.4	32.6	22.3	3.3	1.0	1	tr	--	60	1
95P03349	85-114	Bk32	S	13.3	13.7	73.0		4.8	8.4	5.3	11.4	33.5	23.8	3.6	0.7	1	1	--	62	2
95P03350	114-141	Bk33	S	13.3	12.3	74.4			6.4	5.9	10.9	33.3	25.4	3.9	0.9	1	tr	--	64	1

Bulk Density & Moisture

Layer	Depth (cm)	Horz	Prep	-1- (Bulk Density) 33 kPa (- - - g cm^{-3} - - -)	-2- Oven Dry	-3- Cole Whole Soil	-4- (- - - - - - - - - - - Water Content - - - - - - - - - - -) 6 kPa (- - - - - - - - - - - - % of < 2mm - - - - - - - - - - - -)	-5- 10 kPa	-6- 33 kPa	-7- 1500 kPa 4B2a	-8- 1500 kPa Moist	-9- Ratio AD/OD 4B5	-10- WRD Whole Soil cm^3 cm^{-3}	-11- Aggst Stabl 2-0.5mm %	-12- (- - Ratio/Clay - -) CEC7 8D1	-13- 1500 kPa 8D1
95P03343	0-5	A	S							4.4		1.011			0.84	0.42
95P03344	5-18	Btk1	S							4.2		1.011			0.81	0.47
95P03345	18-31	Btk2	S							5.1		1.012			0.68	0.41
95P03346	31-48	Bk21	S							6.9		1.013			0.34	0.32
95P03347	48-65	Bk22	S							10.8		1.012			0.35	0.58
95P03348	65-85	Bk31	S							5.3		1.012			0.41	0.34
95P03349	85-114	Bk32	S							5.2		1.012			0.50	0.39
95P03350	114-141	Bk33	S							5.8		1.013			0.56	0.44

Carbon & Extractions

Layer	Depth (cm)	Horz	Prep	-1- (- - - - - Total - - - - -) C (- - - - - - % of <2 mm - - - - - -)	-2- N	-3- S	-4- Org C 6A1c	-5- C/N Ratio	-6- (- - - Dith-Cit Ext - - -) Fe (- % of < 2mm - - - - - - - - - - - - - - - - -)	-7- Al	-8- Mn	-9- Al+½Fe	-10- (- - - - - - Ammonium Oxalate Extraction - - - - - -) ODOE	-11- Fe	-12- Al	-13- Si	-14- Mn mg kg^{-1}	-15- (- - - Na Pyro-Phosphate - - -) C (- - - - - - % of < 2mm - - - - - -)	-16- Fe	-17- Al	-18- Mn
95P03343	0-5	A	S				0.29														
95P03344	5-18	Btk1	S				0.27														
95P03345	18-31	Btk2	S				0.28														
95P03346	31-48	Bk21	S				0.25														
95P03347	48-65	Bk22	S				0.09														
95P03348	65-85	Bk31	S				0.04														
95P03349	85-114	Bk32	S				0.04														
95P03350	114-141	Bk33	S				0.02														

pH & Carbonates

Layer	Depth (cm)	Horz	Prep	-1- KCl	-2- $CaCl_2$ 0.01M 1:2 4C1a2a	-3- H_2O 1:1 4C1a2a	-4- Sat Paste 8C1b	-5- Sulf	-6- NaF	-7- (- Carbonate - -) As $CaCO_3$ <2mm (- % -) 6E1g	-8- (- Carbonate - -) As $CaCO_3$ <20mm (- % -)	-9- (- Gypsum - -) As $CaSO_4$*$2H_2O$ <2mm (- % -) 6F1a	-10- (- Gypsum - -) As $CaSO_4$*$2H_2O$ <20mm (- % -)	-11- Resist ohms cm^{-1}
				(- pH -)										
95P03343	0-5	A	S		7.9	8.5				4				
95P03344	5-18	Btk1	S		7.9	8.5				5				
95P03345	18-31	Btk2	S		7.8	8.4				8				
95P03346	31-48	Bk21	S		7.8	8.3				25				
95P03347	48-65	Bk22	S		7.8	8.3				22				
95P03348	65-85	Bk31	S		8.0	8.5				17				
95P03349	85-114	Bk32	S		7.9	8.7	8.2			12				
95P03350	114-141	Bk33	S		8.0	8.7	8.1			9				

Stop 4

Berino, taxadjunct

Fine-loamy, mixed, superactive, thermic Typic Petroargids
Particle Size Control Section: 39 to 89 cm.

Diagnostic Features:	ochric epipedon	11 to 22 cm.
	cambic horizon	22 to 39 cm.
	argillic horizon	39 to 123 cm.
	calcic horizon	72 to 200 cm.
	petrocalcic horizon	123 to 143 cm.

Soil Survey Area: NM690 -- Dona Ana County Area, New Mexico. Map Unit: BJ -- Berino-Bucklebar association

Landform: Relict basin floor
Parent Material: Aolian sands over mixed alluvium of the Rio Grande River
Elevation: 4316ft, 1315m

C1--0 to 6 centimeters; yellowish red (5YR 5/6) broken face loamy fine sand, yellowish red (5YR 4/6) broken face, moist; 5 percent clay; strong thick platy structure, and strong very thin platy structure; friable, slightly hard, nonsticky, nonplastic; common fine roots and few very fine roots; many very fine irregular pores; noneffervescent, by HCl, 1 normal; abrupt smooth boundary.

C2--6 to 11 centimeters; yellowish red (5YR 4/6) broken face loamy fine sand, reddish brown (5YR 4/4) broken face, moist; 8 percent clay; strong very thick platy structure, and moderate medium subangular blocky structure; very friable, slightly hard, nonsticky, nonplastic; common fine roots and few very fine roots; few fine tubular and many very fine irregular pores; very slight effervescence, by HCl, 1 normal; abrupt wavy boundary.

Ab--11 to 22 centimeters; reddish brown (5YR 5/4) broken face loamy fine sand, reddish brown (5YR 4/4) broken face, moist; 9 percent clay; weak medium subangular blocky structure; very friable, slightly hard, nonsticky, nonplastic; common medium roots and few very fine roots; many very fine irregular pores; strong effervescence, by HCl, 1 normal; clear wavy boundary.

Bwb1--22 to 39 centimeters; strong brown (7.5YR 4/6) broken face fine sandy loam, reddish brown (5YR 4/4) broken face, moist; 11 percent clay; weak coarse subangular blocky structure; very friable, slightly hard, nonsticky, nonplastic; few medium roots and few very fine roots; many very fine irregular pores; 1 percent subrounded igneous rock fragments; violent effervescence, by HCl, 1 normal; clear wavy boundary.

Bwb2--39 to 53 centimeters; strong brown (7.5YR 4/6) broken face fine sandy loam, reddish brown (5YR 4/4) broken face, moist; 13 percent clay; weak very coarse subangular blocky structure; very friable, slightly hard, slightly sticky, nonplastic; few very fine roots; many very fine irregular pores; 1 percent subrounded igneous rock fragments; strong effervescence, by HCl, 1 normal; clear wavy boundary.

Btkb1--53 to 72 centimeters; strong brown (7.5YR 4/6) broken face fine sandy loam, reddish brown (5YR 4/4) broken face, moist; 18 percent clay; moderate very coarse subangular blocky structure; friable, slightly hard, slightly sticky, slightly plastic; few very fine roots; common very fine irregular and few very fine tubular pores; 10 percent fine threadlike carbonate masses throughout; 2 percent subrounded igneous rock fragments; violent effervescence, by HCl, 1 normal; clear wavy boundary.

Btkb2--72 to 86 centimeters; yellowish red (5YR 5/6) broken face sandy clay loam, yellowish red (5YR 4/6) broken face, moist; 24 percent clay; weak very coarse subangular blocky structure; friable, slightly hard, slightly sticky, slightly plastic; few very fine roots; few very fine tubular and common very fine irregular pores; 15 percent medium irregular carbonate masses throughout; 1 percent subrounded igneous rock fragments; violent effervescence, by HCl, 1 normal; clear wavy boundary.

Btkb3--86 to 123 centimeters; reddish yellow (5YR 6/6) broken face loam, yellowish red (5YR 5/6), moist; 22 percent clay; weak very coarse subangular blocky structure; friable, slightly hard, slightly sticky, slightly plastic; few very fine roots; few very fine tubular and common very fine irregular pores; 10 percent fine spherical carbonate nodules throughout and 35 percent very coarse irregular carbonate masses; 2 percent subrounded igneous rock fragments; violent effervescence, by HCl, 1 normal; abrupt wavy boundary.

Bkkmb--123 to 143 centimeters; pink (7.5YR 8/3) broken face, pink (7.5YR 7/4) broken face, moist; weak very thick platy structure; weakly cemented; moderate excavation difficulty; 2 percent subrounded igneous rock fragments; violent effervescence, by HCl, 1 normal; clear irregular boundary.

Bkkb--143 to 162 centimeters; pink (5YR 8/3) broken face sandy loam, pink (7.5YR 7/4) broken face, moist; 16 percent clay; moderate coarse subangular blocky structure; firm, hard, nonsticky, nonplastic; few very fine irregular pores; carbonate, finely disseminated throughout and 22 percent medium spherical carbonate nodules throughout and 15 percent coarse irregular carbonate masses throughout; violent effervescence, by HCl, 1 normal; clear irregular boundary.

Bkb--162 to 200 centimeters; 90 percent pink (5YR 8/3) broken face and 10 percent yellowish red (5YR 5/6) broken face sandy clay loam, 90 percent light reddish brown (5YR 6/4) broken face and 10 percent reddish brown (5YR 4/4) broken face, moist; 22 percent clay; moderate medium prismatic structure, and moderate coarse subangular blocky structure; firm, hard, slightly sticky, slightly plastic; carbonate, finely disseminated throughout and 5 percent fine spherical carbonate nodules throughout and 15 percent fine threadlike carbonate masses throughout and 8 percent coarse irregular carbonate masses throughout; violent effervescence, by HCl, 1 normal.

*** Primary Characterization Data ***

Pedon ID: S09NM013001 (Dona Ana County, New Mexico) Print Date: Apr 17 2009 12:37PM

Sampled As : Berino Fine-loamy, mixed, superactive, thermic Typic Petroargid

USDA-NRCS-NSSC-National Soil Survey Laboratory ; Pedon No. 09N0343

PSDA & Rock Fragments

Layer	Depth (cm)	Horz	Prep	-1- (- - - - - Total - - - - - -) Clay < .002	-2- Silt .002 -.05	-3- Sand .05 -2	-4- (- - Clay - - -) Fine < .0002	-5- CO$_3$ < .002	-6- (- - - - Silt - - - - -) Fine .002 -.02	-7- Coarse .02 -.05	-8- (- - - - - - - - - - - Sand - - - - - - - - - - - -) VF .05 -.10	-9- F .10 -.25	-10- M .25 -.50	-11- C .5 -1	-12- VC 1 -2	-13- (Rock Fragments (mm)) (- - - - - - - - Weight - - - - - - - -) 2 -5	-14- 5 -20	-15- 20 -75	-16- .1-75	-17- >2 mm wt % whole soil
				(- % of <2mm Mineral Soil -)												(- - - - - - - % of <75mm - - - - - -)				
				3A1a1a			3A1a1a	3A1a1a	3A1a1a		3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a					
09N02008	0-6	C1	S	6.9	3.6	89.5	3.9		0.7	2.9	12.3	45.3	30.5	1.2	0.2	--	--	--	77	--
09N02009	6-11	C2	S	8.8	5.5	85.7	4.1		1.1	4.4	16.3	44.5	23.5	1.3	0.1	--	--	--	69	--
09N02010	11-22	Ab	S	9.6	5.6	84.8	4.6	--	1.8	3.8	11.3	42.2	29.2	2.0	0.1	--	--	--	74	--
09N02011	22-39	Bwb1	S	10.4	5.2	84.4	5.1	1.3	1.8	3.4	13.0	43.4	26.8	1.1	0.1	--	--	--	71	--
09N02012	39-53	Bwb2	S	12.0	5.8	82.2	6.1	2.1	2.1	3.7	9.9	38.5	30.5	3.0	0.3	--	tr	--	72	tr
09N02013	53-72	Btkb1	S	16.0	6.6	77.4	7.6	3.2	3.1	3.5	11.5	34.6	26.7	4.1	0.5	tr	--	--	66	tr
09N02014	72-86	Btkb2	S	26.0	9.0	65.0	11.1	10.6	5.6	3.4	7.6	33.6	19.6	3.6	0.6	tr	--	--	57	tr
09N02015	86-123	Btkb3	S	23.8	9.8	66.4	9.1	10.8	6.9	2.9	9.6	27.5	26.5	2.4	0.4	tr	--	--	57	tr
09N02016	123-143	Bkkmb	S	17.4	20.8	61.8	5.2	10.7	14.7	6.1	12.1	27.3	18.1	3.5	0.8	1	tr	--	50	1
09N02017	143-162	Bkkb	S	15.3	17.4	67.3	4.2	8.5	12.9	4.5	11.8	31.0	21.3	3.0	0.2	tr	--	--	56	tr
09N02018	162-200	Bkb	S	16.2	18.8	65.0	5.4	6.2	13.8	5.0	10.4	30.8	20.2	3.3	0.3	tr	tr	--	55	1

Bulk Density & Moisture

Layer	Depth (cm)	Horz	Prep	-1- (Bulk Density) 33 kPa	-2- Oven Dry	-3- Cole Whole Soil	-4- (- - - - - - - - - - Water Content - - - - - - - - - - -) 6 kPa	-5- 10 kPa	-6- 33 kPa	-7- 1500 kPa	-8- 1500 kPa Moist	-9- Ratio AD/OD	-10- WRD Whole Soil	-11- Aggst Stabl 2-0.5mm	-12- (- - Ratio/Clay - -) CEC7	-13- 1500 kPa
				(- - - g cm^{-3} - - -)			(- - - - - - - - - - - - pct of < 2mm - - - - - - - - - - - - -)						cm^3 cm^{-3} %			
				DbWR1	DbWR1				DbWR1	3C2a1a		3D1		3F1a1a		
09N02008	0-6	C1	S							2.8		1.006		6	0.77	0.41
09N02009	6-11	C2	S							3.3		1.007		6	0.80	0.38
09N02010	11-22	Ab	S	1.54	1.58	0.009			6.9	4.2		1.009	0.04	12	0.82	0.44
09N02011	22-39	Bwb1	S	1.52	1.57	0.011			7.8	4.4		1.009	0.05	11	0.64	0.42
09N02012	39-53	Bwb2	S	1.47	1.55	0.018			8.7	5.0		1.010	0.05	10	0.62	0.42
09N02013	53-72	Btkb1	S	1.41	1.48	0.016			10.4	6.1		1.012	0.06	14	0.56	0.38
09N02014	72-86	Btkb2	S	1.43	1.51	0.018			13.0	8.9		1.016	0.06	8	0.41	0.34
09N02015	86-123	Btkb3	S	1.58	1.66	0.017			12.1	8.1		1.014	0.06	9	0.35	0.34
09N02016	123-143	Bkkmb	S	1.57	1.65	0.017			13.7	9.1		1.012	0.07	93	0.33	0.52
09N02017	143-162	Bkkb	S	1.43	1.51	0.018			16.2	8.3		1.012	0.11	90	0.39	0.54
09N02018	162-200	Bkb	S	1.37	1.44	0.017			19.3	9.0		1.014	0.14	81	0.47	0.56

*** Primary Characterization Data ***

Pedon ID: S09NM013001 (Dona Ana County, New Mexico) Print Date: Apr 17 2009 12:37PM

Sampled As : Berino Fine-loamy, mixed, superactive, thermic Typic Petroargid

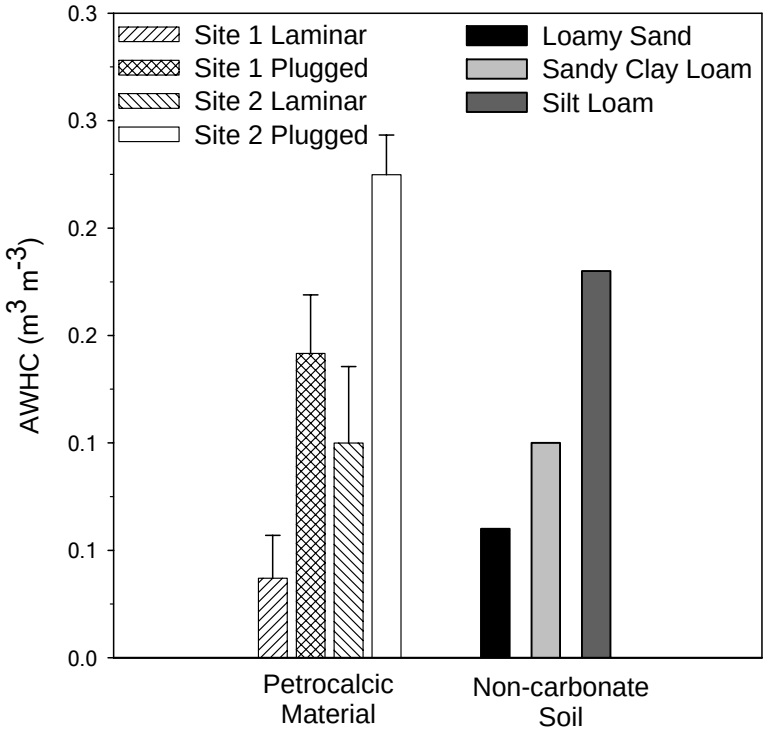
USDA-NRCS-NSSC-National Soil Survey Laboratory ; Pedon No. 09N0343

Carbon & Extractions

Layer	Depth (cm)	Horz	Prep	-1- (- - - - - Total - - - - -) C	-2- N	-3- S	-4- Org C	-5- C/N Ratio	-6- (- - - Dith-Cit Ext - - -) Fe	-7- Al	-8- Mn	-9- (- - - - - - Ammonium Oxalate Extraction - - - - - -) Al+½Fe	-10- ODOE Fe	-11- Al	-12- Si	-13-	-14- Mn	-15- (- - - Na Pyro-Phosphate - - -) C	-16- Fe	-17- Al	-18- Mn
				(- - - - - - % of <2 mm - - - - - -)					(- % of < 2mm - - - - - - - - - - - - - - - - - -)							mg kg^{-1}	(- - - - - - % of < 2mm - - - - -)			
				4H2a	4H2a	4H2a			4G1	4G1	4G1		4G2a	4G2a	4G2a	4G2a	4G2a				
09N02008	0-6	C1	S	0.20	0.026	0.02		5	0.3	--	--	0.04	tr	0.02	0.03	0.02	34.5				
09N02009	6-11	C2	S	0.21	0.001	0.01		121	0.5	--	--	0.05	0.01	0.02	0.04	0.02	44.8				
09N02010	11-22	Ab	S	0.37	0.044	0.01		4	0.4	--	--	0.05	0.01	0.02	0.04	0.02	40.3				
09N02011	22-39	Bwb1	S	0.47	0.018	0.01		8	0.4	tr	--	0.05	0.01	0.02	0.04	0.02	35.4				
09N02012	39-53	Bwb2	S	0.61	0.047	--		5	0.5	--	--	0.06	0.01	0.02	0.05	0.02	32.6				
09N02013	53-72	Btkb1	S	0.91	0.047	tr		5	0.4	tr	--	0.06	0.01	0.02	0.05	0.03	32.2				
09N02014	72-86	Btkb2	S	2.06	0.035	0.01		6	0.4	--	--	0.05	0.01	0.02	0.05	0.03	20.4				
09N02015	86-123	Btkb3	S	2.37	0.010	tr		12	0.3	--	--	0.04	tr	0.01	0.03	0.02	15.5				
09N02016	123-143	Bkkmb	S	4.13	0.020	0.01		5	0.2	--	--	0.04	0.01	0.01	0.03	0.02	16.6				
09N02017	143-162	Bkkb	S	3.52	--	0.02			0.2	--	--	0.02	tr	0.01	0.01	0.01	7.3				
09N02018	162-200	Bkb	S	2.84	0.030	0.02		3	0.2	--	--	0.02	tr	0.01	0.02	0.02	9.3				

pH & Carbonates

Layer	Depth (cm)	Horz	Prep	-1- (- - - - - - - - - - - - - - - - - - pH - - - - - - - - - - - - - - - - - -) KCl	-2- $CaCl_2$ 0.01M 1:2	-3- H_2O 1:1	-4- Sat Paste	-5- Oxid	-6- NaF	-7- (- - Carbonate - - -) As $CaCO_3$ <2mm	-8- As $CaCO_3$ <20mm	-9- (- - Gypsum - - -) As $CaSO_4$*$2H_2O$ <2mm	-10- As $CaSO_4$*$2H_2O$ <20mm	-11- Resist ohms cm^{-1}
					(- - - - - - - - - - - - % - - - - - - - - - - - -)									
					4C1a2a	4C1a2a	4F2			4E1a1a1a1		4E2a1a1a1		
09N02008	0-6	C1	S		7.7	8.3				1				
09N02009	6-11	C2	S		7.8	8.5				1				
09N02010	11-22	Ab	S		7.8	8.5				2				
09N02011	22-39	Bwb1	S		7.8	8.5				3				
09N02012	39-53	Bwb2	S		7.8	8.4				3				
09N02013	53-72	Btkb1	S		7.9	8.4				6				
09N02014	72-86	Btkb2	S		7.8	8.5				15				
09N02015	86-123	Btkb3	S		8.0	8.7	8.1			19				
09N02016	123-143	Bkkmb	S		8.1	8.5	8.3			34		--		
09N02017	143-162	Bkkb	S		8.3	8.6	8.4			28		--		
09N02018	162-200	Bkb	S		8.4	8.6	8.4			23		--		



Available water holding capacity (AWHC) of two morphologies of petrocalcic horizon compared to non-carbonate AWHC of three soil textures. Error bars represent sample standard deviations (adapted from Duniway et al. 2007).

Duniway MC, Herrick JE, Monger HC. 2007. The high water-holding capacity of petrocalcic horizons. *Soil Science Society of America Journal* **71** : 812-819.

Additional References

Herrick, J.E., J.W. Van Zee, K.M. Havastad, L.M. Burkett, and W.G. Whitford, 2005. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems. http://usda-ars.nmsu.edu/monit_assess/monitoring.php

Tugel, A.J., S,A. Wills, and J.E. Herrick. 2009. Soil Change Guide – Procedures for Soil Survey and Resource Inventory. http://soils.usda.gov/technical/soil_change/index.html

Ecological Site Information System (ESIS). http://esis.sc.egov.usda.gov/

Ecological Site Description, Sandy (42D). Site ID: R042XB012NM.

Rangeland Database. http://usda-ars.nmsu.edu/monit_assess/monitoring.php

Workshop 3
Dynamic Soil Properties Demonstration

How this Workshop Will Be Run

- After the **Introduction**, split into 3 groups and go to **Station 1, 2, or 3**.
- At the end of 30 minutes, move to the next station.
- Everyone goes to each station once.
- If time is available at the end, revisit any station.

Station 1. Plot Design and Pedoderm Features
Station 2. Soil Profile and Soil Samples
Station 3. Vegetation Sampling

Workshop Summary
The purposes of this workshop are to 1) discuss the soil survey vision for documenting dynamic soil properties and soil change and 2) demonstrate field methods used in a comparison study. The **Soil Change Guide: Procedures for Soil Survey and Resource Inventory** provides a detailed description of how to conduct a comparison study for a phase of a soil map unit component. The outcome is an inventory of management-dependent soil properties at multiple scales. The procedures apply to all land uses. We will demonstrate data collection procedures on rangeland and provide examples of summary data that can be developed from a project. The new soil survey data will be used to meet customer needs, including:

- Products for agency programs and planners to help recommend and evaluate practices.
- Products to educate the public about how soils change in response to human activity.
- Information to assist in quantifying the benefits of conservation systems.
- Interpretations for use by decision makers to help identify and protect lands at risk of irreversible change (e.g. erosion, salinization, contamination, sulfurization).
- Soil survey data and interpretations to support sustainable land management, including maintenance or improvement of soil quality, soil function, and ecosystem services.

Introduction and Sampling at Multiple Scales — 30 min

Karl Hipple, Nat. Ldr, Soil Interpretations
Larry West, Nat. Ldr, Soil Research and Laboratory
Arlene Tugel, Soil Scientist, NRCS

What is the Current Situation?

Many soil properties have changed and can change as a result of management or natural factors such as drought, interacting with land use. Furthermore, changes in dynamic soil properties can affect the land manager's ability to meet productivity, economic and environmental goals. With information about management effects on the soil, managers can select and apply sustainable practices. With a better understanding of how soils change, policy makers can develop programs to limit undesired change. Soil survey customers need information about dynamic soil properties and ecosystem change for many purposes. These include:

- Plan for long-term productivity and sustainability,
- Protect and restore ecosystem functions and services provided by soil,
- Design monitoring plans and interpret assessments for resource condition,
- Predict land use and management effects on soil, and
- Adjust management practices for changes in near-surface conditions.

Currently, national soil survey databases include soil property information for relatively static soil properties, such as texture. The databases also include properties affected by management, such as soil organic matter. The databases do not, however, distinguish the values of soil properties according to their land use, management system, ecological state, or plant community. In other words, they do not include the dynamic soil property information that is needed by customers. Capturing information about changes in soil and communicating it to a wide variety of audiences will require new procedures and new technologies for soil survey.

> Dynamic soil properties are soil properties that change within the human time scale (centuries, decades or less). Examples include soil organic matter, bulk density, pH, EC, and infiltration rate.

What is the Vision?

In NRCS, soil change is a part of the new soil survey. The soil change vision and mission statements are as follows:

Enhancing the National Cooperative Soil Survey data and products with information about soil change and its consequences.

The soil survey of the future will inventory and predict soil change over the human time scale, determine the mechanisms, and interpret the consequences of those changes.

The Soil Survey Division has a strategic plan to incorporate management-based information in soil survey databases. The emphasis is on soil change within the human time scale. In addition to improving the accuracy of existing information, new soil survey data will be used to:

- Build a point data set of management-dependent properties (build DATABASES).

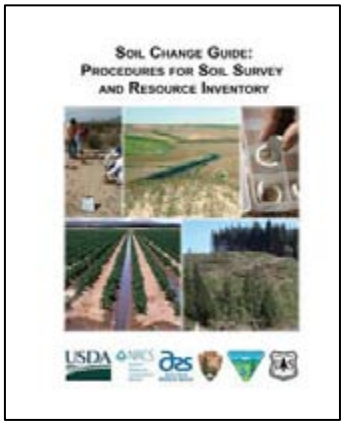
- Determine what is attainable (set PLANNING goals).
- Interpret soil function (predict consequences of soil change for PLANNING).
- Establish benchmark soil values (support MODELS that extend or simulate data).

How will We Get It Done?

There is a basic long-term strategy for achieving the objectives. Data will be collected on replicated plots on the same kind of soil, stored in a point database and summarized for specific management systems. The summarized data will be used to build a dynamic soil properties data set and interpretations for benchmark soils. Using simulation models and other extrapolation methods, information in the point data set will be applied to other similar soils and then used to populate the soil map unit database (aggregated database) for Web Soil Survey and the Soil Data Mart. NCSS participation is needed in research, development and testing for methods and new interpretations.

What Procedures will We Use?

Procedures are now available. The ***Soil Change Guide: Procedures for Soil Survey and Resource Inventory, Version 1.1*** (**Guide**) is designed primarily for soil survey update projects on benchmark soils. It can also be used for ecological site inventory work.



http://soils.usda.gov/technical/soil_change/index.html

The **Guide** describes how to conduct a comparison study for a phase of a soil map unit component. Instructions are provided for project planning, data collection, data analysis, and storage. The **Guide** is not intended to be used as a monitoring guide, although some of the field methods are useful for monitoring. Projects conducted according to the **Guide** will provide important information about soil quality and soil function.

*The **Guide** was developed by the Natural Resources Conservation Service, the Jornada Experimental Range of the Agricultural Research Service, and the National Park Service in cooperation with the Forest Service and Bureau of Land Management. Procedures were field tested by soil survey, field, and state offices and cooperators during several pilot projects.*

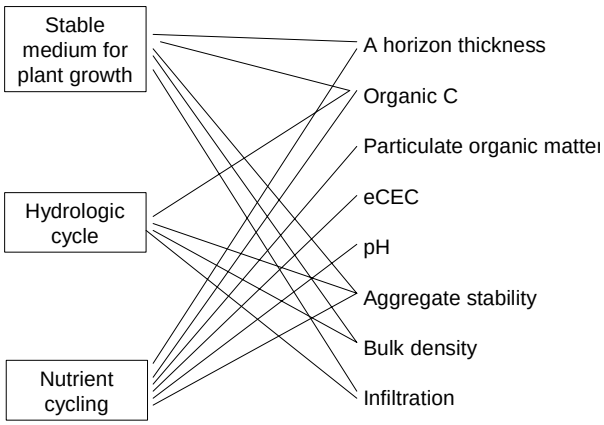
What is the Minimum Data Set?

Building the dynamic soil properties point data set for the nation requires a consistent, standardized approach. In order to ensure comparability of data, a core set of soil and vegetation properties, called the minimum data set, will be included in each project. The minimum data set of dynamic soil properties were selected by a group of over 40 people using five criteria (Table 1). Each project also includes properties that are important for interpreting dynamic soil properties and may be relatively stable (e.g., soil horizon thickness, particle size distribution, properties used in lieu of texture, rock fragments, CEC, and mineralogy).

Table 1. Minimum Data Set and Criteria.

Dynamic soil properties	Criteria
Organic C pH EC Bulk density/soil porosity Soil Structure Aggregate stability (wet) Total N Soil Stability Test Kit	• The properties should be sensitive to disturbances or management. The properties could recover within a few hundred years in the absence of anthropogenic disturbance or under proper management, or the change may be nearly irreversible. • The relationships between the properties and the processes or functions they reflect should be clearly defined (Figure 1). • They should be relatively insensitive to daily or seasonal fluctuations in environmental conditions of moisture, temperature, and light, or such fluctuations are well-understood and can be quantitatively predicted. • They should be easy to measure accurately and precisely by different people and by the same person at different times. • The cost and time, both in the field and the laboratory, to obtain the required number of measurements is low.

Figure 1. Functions and their Relationship to Important Dynamic Soil Properties.



What are Supplemental and Experimental Properties?

Properties in addition to the minimum data set can be included in a project. Some supplemental properties are functionally important for some but not all soils (e.g., SAR, forest floor carbon). Other supplemental properties do not meet all the criteria for the minimum data set, often for reasons of cost or reproducibility of the measurement. Infiltration is an example. Experimental properties are generally difficult to interpret or they are from a method is not standardized. A number of biological properties are considered experimental. Additional research is needed to simplify methods and help interpret many of these properties.

Table 2. Supplemental and Experimental Soil Properties.

Soil Property			
Soil horizon: chemical, carbon and biological measures	**Soil horizon: hydrology**	**Other field measures**	**Forest floor**
eCEC, mineral CEC	Saturated hydraulic conductivity (by horizon) Amoozemeter	Dry aggregate stability	Forest floor (O horizon), mass
KCl-Al	Ponded infiltration, single ring	Pocket penetrometer	Forest floor (O horizon), total C
$CaCO_3$	Water retention	Impact penetrometer	Forest floor (O horizon), total N
SAR	Pore size distribution	Modified singleton blade	Forest floor (O horizon), OM (loss on ignition)
C:N ratio (Organic C:Total N)	Other	Torvane	Downed wood, total mass
Plant available P		Albedo, bare soil	Downed wood, total C
Total ions (Ion resin capsules)		Soil temperature	Downed wood, total N
Potentially mineralizable N		Other	Downed wood, OM (loss on ignition)
POM (Total, POM-C and POM-N)			Other
Active C			
Active C kit (field)			
Microbial biomass-C			
B-glucosidase			
Other			

Vegetation properties will be measured where a plant community is present. Minimum data sets for use on rangelands and forest lands are provided in the **Guide**. Supplemental or experimental properties can be added.

What is a Comparison Study?

A comparison study is a project in which two or more different management conditions on the same kind of soil are compared. Primary features of a comparison study are listed below.

- Documents spatial variability at two scales.
- Integrates soil and vegetation data collection. Methods are tailored to each land use.
- Uses a minimum data set of functionally important soil and vegetation properties.
- Uses the space-for-time substitution technique. We infer that differences between a reference state and some other management system represent changes in soil properties over time.

What Scales Are Included?

The sample design for a project includes two spatial scales in the standard method.

- Capture regional-scale variability across the MLRA or other region (entire extent of the soil map unit).
- Capture fine-scale variability on plots.

Multiple plots for each management system are selected from the entire MLRA (minimum of 5). Soil sample locations are randomly or systematically placed on each plot (minimum of 5). Data are summarized by plot, and plot means are summarized for each management system sampled. Then the means for management systems are compared.

What are the Soil, Ecological Site and Ecological State at this Plot?

The soil is Berino, taxadjunct, a fine-loamy, mixed, superactive, thermic Typic Petroargid.

Berino, tax. is correlated to the Sandy Ecological Site in MLRA 42D (MLRA 42, Southern Desertic Basins, Plains and Mountains).

The ecological state is a shrub-encroached bunchgrass grassland.

Data collected from this plot will be compared to data for the "reference state," a black grama grassland (see Ecological Site Workshop). Additional information about the ecological site, the state and transition model, and a representative soil profile will be provided during tour stops in the Ecological Site Workshop.

Reference State	This Plot
Black Grama Grassland Summary of 3 plot means	**Shrub-encroached Bunchgrass Grassland** Summary of 1 plot

Station 1. Plot Design and Pedoderm Features — 30 min

Arlene Tugel, Soil Scientist, NRCS
Dave Lightle, Agronomist, NRCS

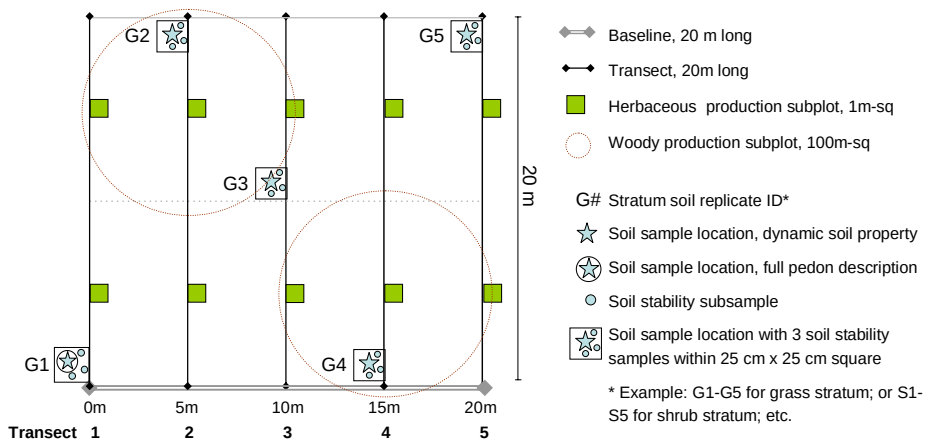
Instructions for plot layout and methods to collect information for the pedoderm (the air-soil interface) are described in the **Soil Change Guide**.

1. Plot configuration

The plot is the primary sampling unit for a project (Figure 2). The plot should be large enough to capture variability in the plant community but not so large that it encompasses more than one kind of soil. The standard method for grasslands, shrublands and savanna ecosystems uses a 20m by 20m plot. Smaller plots can be used, but the same size plot should be used for the entire comparison study. Plot elements include:

- Vegetation transects for line-point and gap observations,
- Subplots for woody and herbaceous production, and
- Replicate soil sample locations (minimum, 5/plot).

Figure 2. Flags are used to mark production subplots and soil sample locations (see star).

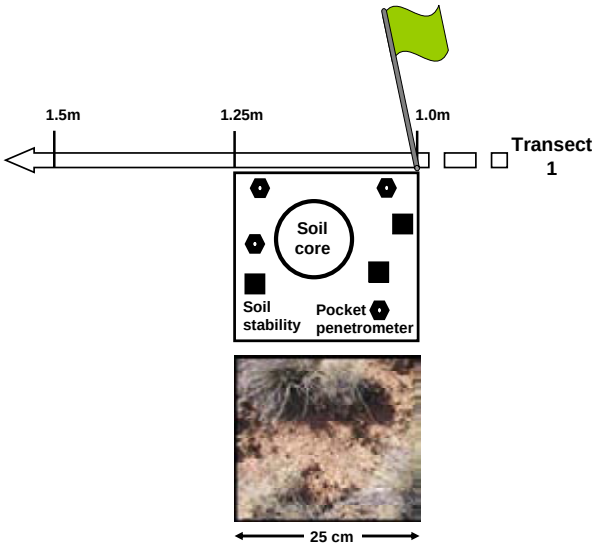


2. Soil Sample Location
A 25cm x 25cm plot is placed adjacent to the transect tape and the flag (Figure 3). Soil samples are collected on one side of the tape and vegetation data on the other to avoid trampling problems.

Measurements at each soil sample location include:

- Bulk density and soil samples (demonstrated at Station 2).
- Soil stability
- Penetration resistance
- Cover and
- Pedoderm classes.

Figure 3.



3. Cover and pedoderm classes
Cover over the 25cm x 25cm area is described by assigning a code for the dominant type of vegetation in the canopy (NC = no canopy, PG = perennial grass, AG = annual grass, F = forb, Sh = shrub, T = tree). The cover code can be used to group and analyze soils data for similar cover types. Soil surface features such as physical, chemical or biological crusts, rock pavement, and duff are described by assigning the dominant pedoderm class observed at the soil sample location. Pedoderm classes are used to describe the air-soil interface and reflect resistance to erosion as well as conditions affecting infiltration.

4. Penetration resistance
A pocket penetrometer is used to measure the penetration resistance of the soil surface. This measure is useful for characterizing physical crusts.

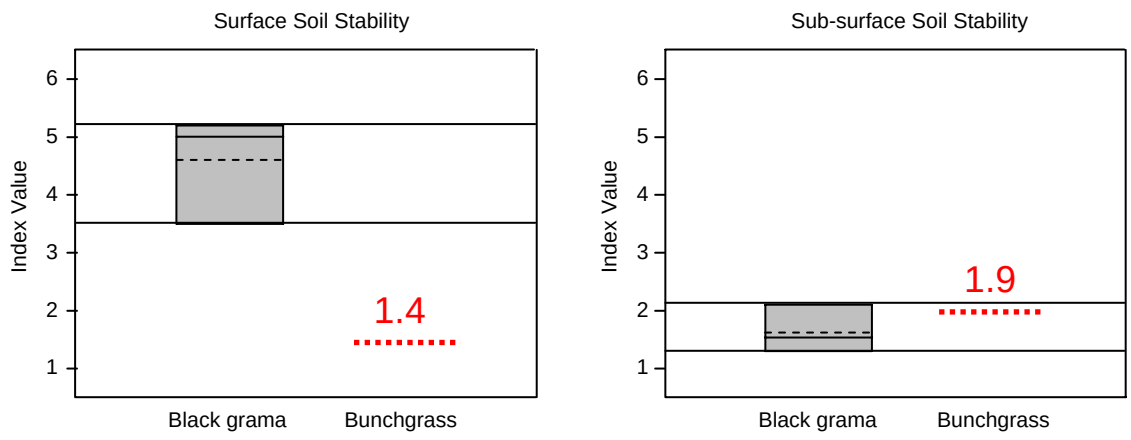
5. Soil stability
The soil stability test is conducted to provide information about soil structural development, resistance to erosion, and biological activity. It is part of the minimum data set. Three samples each are collected of the surface 2-3mm and the sub-surface (2-2.5cm) and analyzed using the field soil stability kit (Herrick et al., 2005). A stability class of 1 thru 6 is assigned to each sample. Class 6 has the greatest stability and resistance to erosion. Soils with low subsurface values have low resistance to erosion after a physical disturbance.

6. Data summary--Pedoderm
- Soil pedoderm class at the 25cm x 25cm soil sample location: WP, weak physical or biological crust, which can be disrupted by raindrop impact.
- Soil surface stability of the shrub-encroached bunchgrass grassland ecological state is lower than the reference state (black grama grassland). Soil sub-surface stability is very similar. Low stability values indicate low resistance to erosion.
- Control charts (Figure 4) of soil stability allow easy comparison of the bunchgrass state (dashed red line) to the reference state.

Figure 4. Control Charts for Two Ecological States: Surface and Subsurface Soil Stability.

Legend

Each box plot shows high and low plot means as well as mean and median of 3 plots for the black grama grassland state. Solid line = median. Dashed line = mean.
Long horizontal lines indicate high and low plot means of the reference state.
Dashed red line represents 1 plot mean for the shrub-encroached bunchgrass state.



Station 2. Soil Profile and Soil Samples — 30 min

Cindy Stiles, Research Soil Scientist, NRCS
Susan Andrews, Soil Ecologist, NRCS

Standard Methods and the Minimum Data Set

The standard methods for soil horizons are shown at this station and include: detailed description of significant soil features that affect movement of water and root growth, penetration resistance, bulk density, and sample collection for laboratory analyses. These methods are completed at each soil sample location on a plot. The properties of the minimum data set that are obtained for soil horizons include: organic C, pH, EC, bulk density/soil porosity, soil structure, aggregate stability (wet), and total N. The following methods, described in the **Soil Change Guide**, are used to collect this information.

1. Profile Description

Soil descriptions in the context of DSP sampling are observations that assist in determining horizon thickness, soil morphology, and site variability. At each of the soil sample locations marked by flags within the standard plot layout, a pit is excavated adjacent to the 25 cm x 25 cm soil sampling plot along the transect line. This pit, which is excavated to a depth of 50 cm, is described in detail similar to characterization pits. Following the standard methods in the NRCS Field Book for Describing and Sampling Soils, the genetic horizons are assessed for color, field texture, rocks and fragments, structure, ped and void features, consistence, roots and other special features, and boundary clarity. Information is entered on a standard description sheet (or a tablet PC) and should include georeferencing as well as the appropriate soil sample location identification symbol.

2. Penetration Resistance

This method uses the pocket penetrometer to collect a set of measures on the profile face. These measures ostensibly detect layers that inhibit root penetration and water infiltration and are in support of observed trends made in the soil description. A ruler marked with ten depth intervals (3 cm increments) is hung on the pit face and four measures are made at each depth across the horizon. Because of the wide range of conditions experienced in the pit, moisture status, the type of penetrometer tip and the calibrated spring class used for the measure must be recorded for each measurement. This is an experimental method.

3. Bulk Density

Bulk density sampling for DSP is done primarily using the core method, sampling the whole horizon. Horizon thickness is indicated by a rubber band placed around the core. Horizons that are deeper than the length of the core must be divided into two depths and each sampled to complete the entire process. The depth to the top of the soil (ring height) is measured at four locations around the outer circumference of the ring prior to removing the sample from the soil. Once removed from the horizon, samples are transferred to tightly sealed bags and field moisture content is determined off-site. Bags must be clearly labeled with appropriate redundant labeling as described in the **Soil Change Guide**. Samples are collected for each horizon, with additional samples taken for the biologically active upper portion of the A horizon (e.g., 0-2, 2-5, 5-10 cm). The base of the last soil core should be equivalent to the standard depth of 40 cm. If there is a surface O horizon, the base of the last core should be 40 cm below the mineral soil boundary.

4. Soil Samples

Bulk soil samples are necessary for analytical procedures that may be performed in the local soil survey office or other lab (e.g., Soil Survey Laboratory). Samples are taken from each horizon, collecting materials within the whole depth of each horizon and coinciding with bulk density core collection. Soil materials scraped away from the core can be scooped to the large soil pan, where it is then mixed and transferred to a labeled bag. Labeling follows the DSP convention as described in the **Soil Change Guide**. Recommended minimum sample size is about three quarts (1500 g).

5. Data summary—Soil horizons

Soil samples were collected for prescribed depths (0-1, 1-5, 5-18, 18-50cm) on black grama plots. Data for the reference state (black grama grassland) is a mean of 3 plot means. For the shrub-encroached bunchgrass community, only one plot was sampled; samples were collected and analyzed by horizon and then converted to prescribed depths.

In a non-statistical comparison, we observe the following: the bunchgrass state organic carbon is lower and bulk density and sand content are higher than for the reference state.

Table 3. Plot Average of Selected Soil Properties for the Shrub-encroached Bunchgrass Ecological State. Summary of 5 soil sample locations.

	Average thickness (cm)	Bulk density (g/cm^3)	Estimated organic carbon* (%)	$CaCO_3$ Equivalent (%)	Soil Particle Size (%) Pipette			Aggregate stability (%)
Horizon					**Clay**	**Silt**	**Sand**	
C	6	1.53	0.26	0.2	9.0	5.8	85.2	3.2
Ab	11	1.58	0.20	0.1	9.7	5.7	84.6	5.8
Bwb	33	1.53	0.18	0.6	11.1	4.7	84.3	5.2

*Estimated organic carbon is $C_{total} - C_{CaCO3}$.

Table 4. Summary Soil Data for Two Ecological States.

		Reference state Black grama†		DSP Demo Plot Shrub-encroached bunchgrass‡
Variable	**Depth**	**Mean**	**Std. dev**	**Mean**
Soil Stability	Surface	4.6	0.93	1.4
	Sub-surface	1.6	0.44	1.9
Bulk Density	0-1	n/a	n/a	1.57
(g * cm-3)	1-5	1.49	0.02	1.53
	5-18	1.55	0.03	1.56
	18-50	1.41	0.04	1.53
% Carbon (organic)	0-1	0.44	0.02	0.29
	1-5	0.30	0.02	0.27
	5-18	0.34	0.05	0.20
	18-50	0.32	0.04	0.18
Soil Carbon (organic)	1-5	1.8	0.1	1.7
(Mg C * ha-1)	5-18	6.9	0.9	4.1
	18-50	14.4	0.9	8.8
Soil Carbon (organic)	1-5	1.0	0.1	0.9
(t C * acre-1)	5-18	3.8	0.4	2.3
	18-50	8.0	0.4	4.9
%Clay	0-1	5.7	0.5	8.2
	1-5	6.3	0.6	8.4
	5-18	8.4	1.2	9.6
	18-50	11.8	2.4	11.2
%Silt	0-1	10.4	0.9	5.8
	1-5	10.0	0.5	6.0
	5-18	10.5	1.1	5.5
	18-50	10.4	0.9	4.7
%Sand	0-1	83.9	1.3	86.0
	1-5	83.7	1.0	85.5
	5-18	81.1	2.2	84.9
	18-50	77.8	3.2	84.1

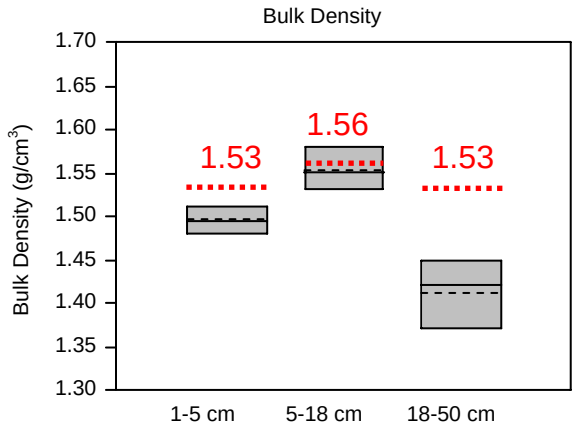
† clay, silt, sand by hydrometer. ‡ clay, silt, sand by pipette.

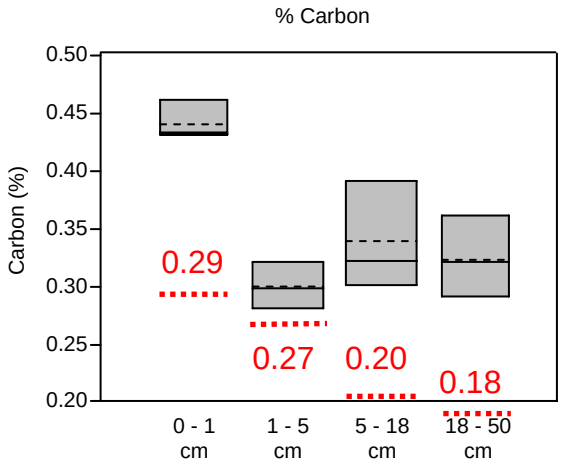
Figure 5. Box Plots for Two Ecological States: Selected Properties.

Legend

Each box plot shows high and low plot means as well as mean and median of 3 plots for the black grama grassland state. Soil line = median. Dashed line = mean.
Dashed red line represents 1 plot mean for the shrub-encroached bunchgrass state.

..





Station 3. Vegetation Sampling — 30 min

Curtis Talbot, Range Management Specialist, NRCS
Laura Burkett, Range Technician, ARS

Standard Methods and the Minimum Data Set

The standard methods for vegetation are shown at this station. The minimum vegetation data set for grassland, shrubland, and savanna ecosystems, as described in the **Soil Change Guide**, includes total canopy (foliar) cover, canopy cover by functional group, bare ground, litter cover, biological crust cover, rock fragment cover, canopy gaps, basal gaps, and annual herbaceous production. Annual woody production is collected for plant communities with woody species. Three field methods are used to collect these data. Data can be recorded on a paper form or a tablet PC.

1. Line-point Intercept

This method is used to collect data for total canopy (foliar) cover, canopy cover by functional group, bare ground, litter cover biological crust cover, and rock fragment cover. It is relatively rapid to conduct and requires good plant ID skills. It records the presence or absence and kind of cover for a set of specific points along a transect. The results are used to describe soil-water-vegetation relationships (especially in reference to erosion and infiltration) and changes in species composition.

2. Gap Intercept

This method is used to collect data for canopy and basal gaps. It is relatively rapid to conduct and requires no plant ID skills. It measures the percentage of line covered in gaps of predetermined sizes in the vegetative community. The minimum gap size observed is 20 cm, and can be adjusted if needed. The results are used to interpret the potential for wind and water erosion, as well as susceptibility to exotic plant invasion.

3. Herbaceous Plant Production – Double Sampling

This method is used to collect data for annual herbaceous production. It is relatively slow to conduct and requires good plant ID skills. It is based on the establishment of verified weight units, the estimation of number of weight units, and then the destructive sampling of a subset of the estimated plots to validate the estimations. The results are used to describe the community composition, productive capability, energy flow, and herbivore carrying capacity.

4. Supplemental or Experimental Methods

Additional questions regarding vegetation could require data collection methods in addition to the minimum data set (Table 5). Other methods can be proposed to provide other required data or to increase the efficiency of data collection. New methods would initially be conducted along with the standard methods. However, it is conceivable that once a thorough validation is complete, additional methods may be adopted as standards.

Table 5. Methods and Properties: Grassland, Shrubland and Savanna Ecosystems.

Minimum data set (June, 2008)		
Field protocol or method	**Used for**	**Property**
Line-point intercept	Soil-vegetation relationships, cover and extent estimates, properties affecting air-soil interface functions (resistance to erosion, infiltration, etc.)	Total canopy (foliar) cover (%) Canopy (foliar) cover by plant functional group (%) Canopy cover by functional group (%) (not foliar) Bare ground (%) (no canopy over no soil cover) Litter cover (%) Biological crust cover by functional group (%) (moss, lichen, dark cyanobacteria, light cyanobacteria) Rock fragment cover
Canopy and basal gap intercept (transect)	Wind erosion and exotic plant invasion (canopy); water erosion risk and; infiltration (gap)	Canopy gaps by size (%) Basal gaps by size (%) (Gap sizes: 25-50, 51-100, 101-200, 201-500, 500-1000, >1000)
Plant production-herbaceous. Double sampling method	Annual production, soil-vegetation relationships	Annual herbaceous production
Plant production-woody	Annual production, soil-vegetation relationships	Annual woody production
Resource retention class	Resource retention, soil-plant interactions, grass fragmentation, shrub encroachment	Resource retention class
Soil redistribution class	Current or past erosion, resource redistribution	Soil redistribution class
Pedoderm/ Soil Crust class	Resistance to erosion, biological crust development	Pedoderm/crust class
Supplemental or experimental properties		
Belt transect	Detection of changes in species with low cover or density, esp. woody/invasive species	Plant density Plant density by size class
Plant species richness	Precise estimates of species richness	Species richness
Vegetation structure	Indicator of habitat cover	Visual obstruction Foliage height diversity
Tree density	Populations too widely dispersed for belt transects	Plant density Plant density by size class
Riparian channel vegetation survey	Documenting vegetation change along streambanks	Canopy (foliar) cover (%) Cover by functional group (%)
Riparian channel and gully profile	Where channel morphology is expected to change or gullies are deepening or recovering	Width-depth ratio Bank angle

Figure 6. Control Charts for Two Ecological States: Selected Functional Indicators Derived from the Line Point Intercept Method.

Legend

Each box plot shows high and low plot means as well as mean and median of 3 plots for the black grama grassland state. Solid line = median. Dashed line = mean.
Dashed red line represents 1 plot mean for the shrub-encroached bunchgrass grassland state.

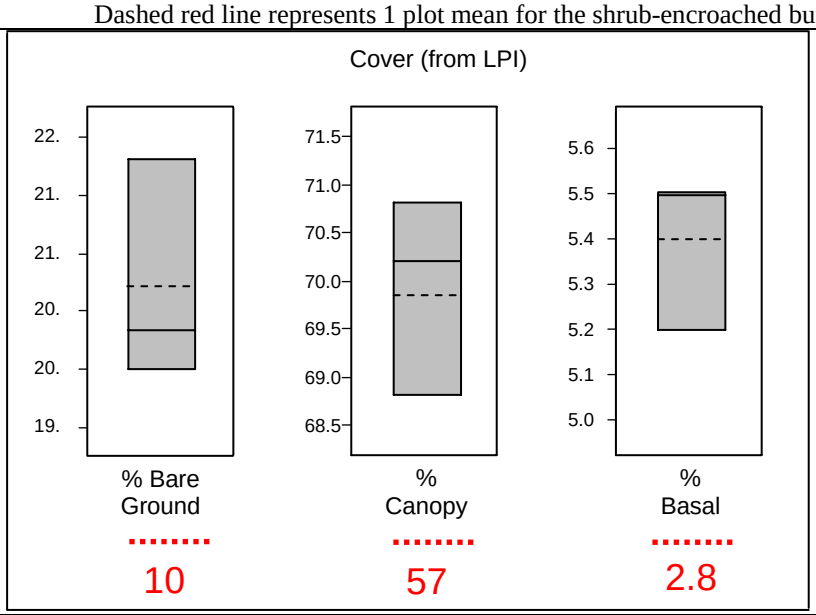


Table 6. Plot Average of Canopy and Basal Gaps for Two Ecological States. Mean values are for 3 black grama grassland plots and 1 shrub-encroached bunchgrass plot.

		Canopy Gaps				Basal Gaps (cm)			
		25-50 cm	51-100 cm	101-200 cm	>200 cm	25-50 cm	51-100 cm	101-200 cm	>200 cm
Ecological state									
Black grama	% of Line	13.4	17.6	13.6	3.1	13.0	22.3	30.2	18.9
Bunchgrass	% of Line	6.5	20.6	23.9	28.1	6.9	24	26.3	32.4

Table 7. Annual Production and Foliar Cover for Two Ecological States.

	Annual production (%)		Cover, foliar (%)	
Ecological state	**Black Grama Grassland**	**Shrub-encroached Bunchgrass**	**Black Grama Grassland**	**Shrub-encroached Bunchgrass**
Source of data	Ecosite description, aggregate data	1 plot mean	Summary of 3 plot means	1 plot mean
Species				
Black grama	26	4	58.8	-
Spike dropseed	17	14		22.0
Sand dropseed			0.8	
Mesa dropseed			0.6	
Bush muhly	7	6		-
Bristlegrass	3	6		-
Cane bluestem	7	-		-
Arizona cottontop				
Tobosagrass	3	-		-
Threeawn	7	15	2.7	4.6
Blue grama	3	1		
Low woollygrass				1.4
Lehmann lovegrass	-	8		3.0
Mexican panicgrass	-	2		
Vine mesquite				-
Longleaf jointfir	7	1		
Soaptree yucca			0.6	-
Sand sagebrush	3	-		
Fourwing saltbush				
Winterfat				
Broom dalea				-
Plains pricklypear	2	-		7.0
Broom snakeweed	2	15	3.7	-
Mesquite	-	2	1.1	0.4
Croton	4	4	0.2	
Buckwheat				
Spurge				
Globemallow				4.6
Desert marigold				
Touristplant				
Redstem stork's bill				-
Dwarf desert peony				
Milkvetch				
Lamsquarters				
Herb Sophia				
Russian thistle				
Threadleaf ragwort				
Silverleaf nightshade			0.1	4.0
Other forbs	3	2	0.5	
Annual grass (unident.)			0.3	
Fuffgrass			0.2	
Dead grass (unident.)			0.2	
Desert holly			0.2	
Dead shrub (unident.)			0.1	

Wednesday - Agronomy Tour

Pecan trees are native to the Mississippi River Valley and probably first arrived in New Mexico along with American settlers around the turn of the 20th century. Fabian Garcia, the first director of the New Mexico Agricultural Experiment Station, planted some of New Mexico's first pecan trees in the Mesilla Valley in 1913. Many of these original trees are still standing at New Mexico State University's Fabian Garcia Horticultural Science Center.

(http://aces.nmsu.edu/ces/pecans/pecan-history.html)

CONSERVATION Showcase

Role of Soil Health Promoted

Continued success of agricultural systems in our world is dependent upon the ability to maintain soil health and manage water resources through conservation planning, according to New Mexico NRCS agronomists, water quality specialist, and soil scientists. And, they are out to increase understanding of the role conservation planning plays in the maintenance and improvement of soil health.

"Conservation planning seeks to take soil health and productivity from its current level and manage it to achieve its full potential," said Ken Scheffe, state soil scientist. "One of the most powerful tools to deliver soils information to farmers, ranchers, conservationists, and homeowners is the Web Soil Survey which is on the Internet."

The Web Soil Survey puts local soil maps, descriptions, data, and suitability ratings into the hands of users.

Another source of information NRCS New Mexico is making available to land and water users, in its efforts to continually provide more and better information, is the Integrated Water Management Handbook. This handbook incorporates materials that emphasize the effects of tillage, irrigation, and nutrient and pest management upon long term soil productivity. This information was used this past summer for training session for conservation planners and NRCS partners.

In addition, NRCS New Mexico has acquired soil quality test kits so its local field and soil survey offices can assess soil conditions for farmers and ranchers, and offer options and recommendations for improving soil health. Because recognizing soil health indicators is so important, NRCS New Mexico is also scheduling workshops for farmers and ranchers this year to provide hands-on demonstrations of soil sampling, testing, and evaluation of soil conditions.

"Global reduction in agricultural productivity due to soil erosion and degradation, depletion of irrigation water supplies, and competing land uses is putting a squeeze on capacity to meet increasing world-wide demand for food and fiber," said Scheffe. "Even when looking at the local picture, to continually succeed as producers we must maintain soil health and manage water resources through conservation planning."

Integration of needed conservation practices and management assures water quality, soil quality, and overall ecosystem health is maintained.

For more information about the Web Soil Survey and Integrated Water Management Handbook go to www.nm.nrcs.usda.gov

NRCS
Natural Resources Conservation Service

The USDA is an equal opportunity provider and employer.

Station 1- Soil Health and Soil Quality - A National Perspective

USDA-NRCS and Soil Quality at the National Level

What is Soil Quality?

Soil quality is defined as 'the capacity to function' (Karlen et al., 1997). Dynamic soil quality refers to the effects of management practices on soil function. Soil or ecosystem function is defined in various ways. Some important soil functions (or services) include: water and solute retention and flow, physical stability and support; retention and cycling of nutrients; buffering and filtering of potentially toxic materials; and maintenance of biodiversity and habitat (Daily, 1997). Although dominated by soil scientists, the study of soil quality is largely an ecological endeavor due to its ultimate concern with ecosystem function.

Historically, productivity is has been used as the only measure functional performance. However, in highly managed systems, this function could be subsidized with external resources to the point where it is not actually indicative of the ecosystem's health or soil's true ability to function. Larson and Pierce (1991) argued that soil quality should no longer be limited to productivity, inferring that the sole emphasis on productivity may have contributed to soil degradation in the past. Soil quality (SQ) assessment is one area of agricultural research that attempts to estimate performance of multiple essential soil functions (e.g., Larson and Pierce 1991; Doran and Parkin, 1994; Andrews et al., 2004).

In order to address the emerging need to address the full spectrum of soil functions at the national level, NRCS created the Soil Quality Institute 1995-1994; then March 1995, the National Soil Quality Technology Development Team was formed.

The NRCS National Soil Quality Technology Development Team (SQ NTDT)

Background

Our Vision

Healthy ecosystems built on a foundation of well-functioning, high quality, productive soils

Our Mission

Cooperate with partners in the development, acquisition and dissemination of soil quality technology and training to help people conserve and sustain our natural resources and the environment

Soil is the foundation for other natural resources. The quality of soil directly impacts water and air quality as well as food quality; indirectly, it affects wildlife habitat and animal and human health. The concept of soil quality and the understanding of how soils function to enhance other resources and provide ecosystem services have the potential to raise the bar for natural resource conservation by recognizing these interactions and managing for them. Dynamic soil quality must be understood as human-induced soil change and interpreted within the context of inherent soil properties and management history. The complex issues affecting soil quality require a multidisciplinary approach to include soil scientists, ecologists, agronomists, range specialists and others. The main contributions of soil quality to soil science, soil survey and resource conservation are:

- Recognition of the importance of dynamic soil properties, especially soil carbon, and indicators of soil function that move beyond managing for “T.”
- Promotion of soil function and ecosystem service concepts can lead producers to reduce costly and limited petroleum based inputs, including fuel use and effective pest and nutrient management strategies.
- Bringing soil biology to the fore (on par with soil chemistry and physics), providing a more complete picture of soil properties and processes.
- The focus on dynamic soil change exemplifying the need for land use- and management-specific interpretations for soil properties (i.e., a soil change properties database as part of NASIS)
- The application of ecological concepts, such as function and thresholds, allowing for a view of soils as a vital part of ecosystems, including limits to soil resistance and resilience.
- Provision of a holistic framework for decision making and conservation planning at multiple scales and land uses.
- The creation and dissemination of simple tools for assessment and monitoring, such as the Health Card, SQ Test Kit or Soil Management Assessment Framework, and simple models, such as the Soil Conditioning Index (SCI), and practice-based eligibility tools, such as the Conservation Management Tool.
    - comparing alternative practices or systems
    - allowing for quantification of conservation practice effects, and

- providing measurable targets for resource quality criteria and remediation.

National Soil Quality Team Partners and Customers

To accomplish our mission the SQ NTDT will partner with universities, organizations and agencies to develop and accelerate transfer of soil quality technology and training to facilitate natural resource conservation and promote ecosystem health. Our primary customers are NRCS field office and state offices. National Headquarters, other agencies, universities and the public are also assisted as requested. Internal partners include (but are not limited to) other Technology Development Teams and National Technology Support Center staff, National Soil Survey Center, Resource Inventory and Assessment Division, Ecological Sciences Division, Plant Materials Centers, National Geospatial Data Center, State Staffs and local field offices. External partners include universities, ARS, SWCS, National Park Service, Forest Service, and others.

Technical Excellence:

Technology acquisition and development are needed to improve NRCS technical capacity in resource assessment (for program eligibility and accountability), conservation technical assistance, and program implementation. The Soil Quality Team (SQT) will pursue technologies in five main areas: 1) resource assessment models; 2) in-field assessment tools; 3) soil dynamic properties inventory; 4) adoption of soil-building practices; and 5) conservation planning tools. **The development of any and all such tools must be accompanied by validation and calibration efforts to uphold NRCS's reputation for scientifically-defensible technical excellence.**

1) Resource Assessment Modeling: Additional efforts are needed in modeling conservation practices and practice interactions to predict changes in soil, water and air quality and the economic impacts thereof.

- *Conservation Effects Assessment*: is needed to improve NRCS program funding accountability. The Soil Quality Team will help with model interpretation for the Conservation Effects Assessment Project (CEAP), as the co-lead for the National Soil Quality Assessment Project. These efforts have several potential applications in addition to their planned practice effects assessment, including: creation of a dynamic soil properties database, provision of baselines for CSP enhancement standards, and development of guidelines for residue harvest.
    - Collaborate with Soil Science and Resource Assessment Deputy Area on the development of interpretation curves for EPIC model output.
    - Collaborate with USDA-ARS on the testing and development of the Soil Management Assessment Framework (SMAF), a tool for site-specific soil assessment. ARS has adopted the tool as part of its Soils National Program (202). It was designed for use with measured soil properties, as such has potential for use with CSP enhancements and the watershed portion of CEAP. It is being modified for use with model output for the national level CEAP.
- *Assessment of NRCS Carbon Modeling Needs*: Currently, NRCS is using or pursuing the development of at least 5 different carbon models. These various

groups are not in communication with each other. The agency would be better served if model development was done after careful assessment of needs and uses. The SQT will lead a consensus building project to identify NRCS' carbon modeling needs, culminating in a white paper, in collaboration with the Air Quality and Atmospheric Change NTDT and others.

- *Development and Validation of Program Eligibility Tools*: The SQT is currently collaborating on the development of the Conservation Measurement Tool, which will serve as an eligibility tool for the Conservation Stewardship Program. The SQ NTDT is also collaborating on two CESUs with university partners: 1) to help validate the tool by comparison with measured and modeled data and 2) to capture farmer's perceptions of understandability, fairness and equity of the tool.
- The SQ NTDT with explore partnerships with the Land Institute, Rodale Institute and Dakota Lake Research Center for improving the crop diversity index model for improving soil function. Improving crop diversity will reduce chemical inputs.

2) In-field Assessment:
The soil quality test kit is one of the most used products of the former SQ Institute. The simple, in-field tests contained in the kit make it attractive for field office use. It has value as an educational tool to demonstrate to landowners the impact their management choices have on soil function. These assays can also be used to evaluate quality criteria for not only soil, but also water, air, and wildlife (soil biota). However, since the kit was first developed, new methods have emerged with potential to greatly enhance the value of the kit for: field staff tools for assessment and land-owner education; Resource Quality Criteria; CSP enhancement measures; soil survey/dynamic properties database additions; criteria for practice standard revisions (e.g., tillage standards); and restoration assessment tools. The SQT will investigate these methods, and when appropriate, accelerate their development to include transfer of this technology to field and state offices.

- *Collaborate on the development of an in-field carbon assessment too with agency and university partners. Promising technologies include*:
    - Permanganate Oxidation (Active C) methodology development
    - decomposition incubation strips
    - Soil Color via data mining
- *Investigate in-field indicators for water relations*, to improve the functionality of pedo-transfer functions being developed by NSSC staff, to include:
    - *Explore adaptations to the Cornell Infiltrometer (for surface) and Amoozemeter (for subsurface)* as in-field measures of infiltration and/or aggregate stability.
    - *Collaborate on the development of an in-field dry aggregate stability* as an indicator for wind erosion potential
- *Collaborate on the development of in-field enzyme assays for biological activity and active carbon*
- *Partner with National Park Service, Plant Materials Centers, Manure Management NTDT and others on the development of soil quality assessment tools and methods for restoration and remediation.*

3) Soil Change and Dynamic Soil Properties Database Development: The NSSC has been charged with development of a dynamic properties database. This is needed

because the ranges found for various soil properties encompass all land uses, making them so broad as to render them meaningless in many cases. Current research shows that different soils under similar management become more similar over time, due to human management acting as a sixth soil forming factor. Soil quality is concerned with soil change as a result of management. The appropriate design and implementation of the database will require input from soil quality experts.

- The SQ NTDT will collaborate with SSD as part of their DSP Leadership and Technical Leads teams for:
    - identification of resource concerns related to near-surface properties in-field sampling methodology development
    - database design, and
    - property interpretations, among other needs.
- The SQ NTDT will take leadership responsibility for the development of a cross-section working group for the Soil Science Society of America to explore knowledge gaps in soil change technology and information.
- The SQ NTDT is also co-lead in the development of a Soil Change Working Group for the National Cooperative Soil Survey, meeting for the first time at the Las Cruces Conference.

4) Adoption of Soil-building Conservation Practices: Basic practices for improving soil quality, such as Tillage & Residue Management, Conservation Crop Rotations, and Cover Crops, are well known but often underutilized. Barriers to adoption of these technologies vary by practice, region and individual land manager. Often the barriers are economic or social, such as attitude, traditional bias, perceived costs, length of return on investments, or land tenure. Other barriers include lack of knowledge about the specifics on how to implement the practice, e.g., dealing with cold, wet soils, irrigation systems (furrow), managing residues, planters, seeding rates, planting dates, and rotations etc. Opportunities and challenges in dryland and irrigated cropland, organic agriculture, pasture, rangeland, urban, prairie, and forested systems should be explored. The SQT will partner with researchers in soil science, agronomy, social science and economics to investigate and eliminate these barriers to adoption via applied research collaborations; on-farm trials; marketing; and other techniques as needed. This will be accomplished primarily via technical collaborations on Conservation Innovation Grants and via updates to the following guidance documents:

- National Practice Standards, in which soil conservation or soil quality is a purpose (or a consideration), in collaboration with the National Agronomist
- Conservation Practices Physical Effects document via review for appropriate consideration of soil quality criteria

5) Conservation Planning Tools: Currently, NRCS works toward maintaining or enhancing soil quality through the use of RUSLE2 technology, to meet T. While this is an important part of soil conservation, our efforts could be improved by adding tools that consider soil carbon, such as the Soil Conditioning Index (SCI). The Soil Quality Team will work to streamline consideration of soil quality in conservation planning by:

- Collaborating with Programs Deputy Area to report the outcomes of new CMT or other assessment tools.

- Continually evaluating new practices for their effect on soil quality and accelerating the development of new standards, when appropriate. One example is roller-crimper technology.
- Accelerating the development and use of crop diversity indices for cropland.
- Collaborating with ARS on the development of guidelines for residue removal. DOE and associated industries currently plan to use corn stover and wheat straw as cheap feedstocks for bioenergy production. The removal of these crop residues has major potential to degrade the soil. Development of guidelines for this practice may help reduce this problem.

What are the current challenges to SQ?

1) How to Assess Soil Quality at Different Spatial Scales

Across many disciplines, there is recognition that complex spatial and temporal dynamics must be addressed for effective resource assessment and management (e.g., Christensen et al., 1996; Herrick et al., 2002). Systems approaches and hierarchical organizational tools can help scientists and managers deal with complexity in soil ecosystems (Carter et al., 2003). According to Norton (1992), hierarchical environmental management is necessary because, "Processes are not related equally but unfold in systems within systems, which differ mainly regarding the temporal and spatial scale on which they are organized." Using a hierarchical systems approach may also help soil scientists relate dynamic soil changes to broader system outcomes, such as changes in air or water quality.

All systems exhibit hierarchical organization (Allen & Starr, 1982; O'Neill et al., 1986; Stephens and Hess, 1997). C.R.W. Spedding (1988), one of the earliest adopters of systems thinking in agriculture, offered the following definition:

> "A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli: it is unaffected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedbacks."

Ellert et al. (1997) and Gliessman (1998) argue that an understanding of these system interactions and properties is prerequisite to effective agroecosystem management. (If you question the validity of this approach for soil science, substitute the word 'soil' for 'system' in the above definition.)

While there has been much debate about whether hierarchies are a human construct or a true phenomenon (Allen and Starr, 1982), the ability to organize our thinking into spatio-temporal units has clear benefits for research, inventory, and management, including understanding soils, their position in the landscape, and the changes with time under a variety of land use and management practices.

Hierarchical systems constructs can naturally navigate the complex issues of scale, in large part because temporal and spatial scales usually coincide. Spatially larger processes often require longer time periods compared to spatially smaller ones. Ellert et al. (1997) define the relationships between spatial and temporal scales for a variety of

soil systems, subsystems and components, illustrating this proportionality between space and time for soils.

As a result of this relationship, different management approaches or practices may require different levels of systems analysis for assessment of sustainability or quality. For example, soil biophysical processes are often defined at the field level, while rotational cropping might be assessed at a field or farm level using a time scale at least equivalent to the rotation length. Filter strip systems probably need to be assessed at a watershed or regional level at a time scale long enough to allow species establishment and account for precipitation variability. Microeconomics would be properly addressed at the farm level. A watershed or regional level analysis would be appropriate to examine macroeconomic sustainability (Lowrance, 1990).

2) Soil Quality Interpretations

We recognize sustainable management practices as site- or system-specific. Therefore, conservation alternatives must be compared for each system at a variety of hierarchical levels. Because appropriate scale is essential to assessment, inventory, and management of system processes and functions, many authors suggest a systems-based approach to understanding and managing agroecosystems (Hart, 1984; Lowrance et al., 1987) and the inherent soil properties that comprise their foundation (Carter et al., 2003).

Ellert et al. (1997) conclude that using a systems approach: 1) places soil within a larger ecosystem; 2) recognizes a broad array of support services or soil functions (beyond crop production); 3) incorporates humans as internal controllers; 4) allows for multiple management goals including production, conservation and aesthetics; and 5) uses integrative science to identify possible pathways to sustainability. It is necessary to utilize these approaches such that each hierarchical level of an agroecosystem, from soil to region, is adaptively managed to meet the multiple goals of conservation ecosystem sustainability.

a) Assessment and Inventory Methods

One way to interpret soil properties as indicators of soil function is through the use on non-linear scoring curves. Non-linear scoring techniques involve the use of curvilinear algorithms with an x-axis representing a site-specific range for the given indicator and a y-axis representing performance of ecosystem function (Karlen and Stott, 1994). This type of scoring is used widely under various guises in economics as utility functions (Norgaard, 1994), multi-objective decision making as decision functions (Yakowitz et al., 1993), and systems engineering as a tool for modeling (Wymore, 1993). The NRCS-NSSC's National Soil Information System (NASIS) also uses a non-linear scoring system as part of its fuzzy logic backbone. This method requires in-depth knowledge of each indicator's behavior and function within the system.

Many researchers have used non-linear scoring to quantify the effects of management on soil function. Andrews and Carroll (2001) used scoring curves to compare

alternative poultry litter amendments to fescue pastures. Karlen et al. (1998) used weighted scores to assess land coming out of the Conservation Reserve Program (CRP). Hussain et al. (1999) also used scoring curves to compare tillage systems. Yakowitz et al. (1993) used non-linear scoring to compare the overall effects of alternative farming systems. Inventory will be assess in depth during the soil change field trip and therefore not specifically addressed here.

b) Field –Scale Site-specificity or Tool Transferability

Some efforts have been made to assess the site-specificity and transferability of scoring curves. For example, Hussain et al. (1999) and Glover et al. (2000) adjusted the index weighting and indicator threshold values to be applicable to their respective systems. Andrews and Carroll (2001) also shifted the expected ranges for indicators between sites.

A tool under continued development, the Soil Management Assessment Framework, was shown to improve the interpretation ability of scoring curves (Andrews et al. 2004). As before, the shape of an indicator's scoring curve (or algorithm) is dictated by the relationship between the indicator and the soil function. However, the expected range for each indicator is determined using site-specific factors, such as crop, climate or soil type. Changes in expected range due to site-specific differences result in automatic parameter shifts in the scoring curve (Figure 1).

Comparisons of scored indicators' ability to explain variation in performance outcomes for four case studies across the U.S. were performed. Results showed good ability of the scored indicators to represent (often difficult to measure) performance outcomes. For example, scored indicator-endpoint regressions for the Iowa case study had R^2 results of 0.99, 0.84, and 0.61 with sedimentation in surface water, atrazine applied, and crop yield, respectively (Andrews and Karlen, manuscript in preparation). This test seemed to confirm that the new scoring method was capturing intended information about the soils' performance of ecosystem functions. It has been used in various studies since then as well (e.g. Cambardella et al., 2004; Karlen et al., 2006; Wienhold et al., 2006;). This tool has also been used to interpret model data for CEAP (Potter et al., 2006). Next steps include new curves for additional soil properties (Wienhold et al., review; Stott et al., in review), potential application of the method for dynamic soil properties interpretation in soil survey, and further use in the CEAP efforts.
Website and Excel format versions for the scoring framework are available for review (contact S. Andrews at susan.andrews@gnb.usda.gov). An interactive website is still under construction but can be viewed and tested at http://soilquality.org .

References

Allen, T.F.H. and T.B. Starr. 1982. Hierarchy: Perspectives for ecological complexity. Chicago, University of Chicago Press.

Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework: A quantitative soil quality evaluation method with case studies. *Soil Science Society of America Journal*. 68: 1945-1962.

Andrews, S.S., Carroll, C.R. 2001. Designing a decision tool for sustainable agroecosystem management: Soil quality assessment of a poultry litter management case study. Ecological Applications 11(6):1573-1585.

Cambardella, C.A., T. B. Moorman, S. S. Andrews, and D.L. Karlen. 2004. Watershed-scale assessment of soil quality in the Loess Hills of Southwestern Iowa. *Soil and Tillage Research* 78:237-247.

Carter, M., Andrews, S.S., and L.E. Drinkwater. 2003. Systems approaches for improving soil quality. In: P. Schjønning, S. Elmholt, B.T. Christensen, (eds.) Managing Soil Quality – Challenges in Modern Agriculture. CABI Publishing, Wallingford, England.

Christensen, N.L., A.M. Bartuska, J.H. Brown, S.C. Carpenter, C. D'Antonio, R. Francis, J.F. Franklin,
J.A. MacMahon, R.F. Noss, D.J. Parsons, C.H. Peterson, M.G. Turner and R.G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications 6(3): 665-691.

Daily, G. (ed.) 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D.C. 392 pp.

Doran, J.W., Parkin, T.B. 1994. Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.), Defining soil quality for a sustainable environment. SSSA Spec. Publ. 35. ASA and SSSA, Madison, WI. pp. 3-21.

Ellert, B.H., M.J. Clapperton and D.W. Anderson. 1997. An ecosystem perspective of soil quality. Soil quality for crop production and ecosystem health. E.G. Gregorich and M.R. Carter. New York, Elsevier**:** 115-141.

Gliessman, S.R. 1998. Agroecology: Ecological Processes in Sustainable Agriculture. Lewis Publishers, New York. 357 pp.

Glover, J.D., Reganold, J.P., Andrews, P.K. 2000. Systematic method for rating soil quality of conventional, organic, and integrated apple orchard in Washington State. Agric. Ecosys. Environ. 80, 29-45.

Hart, R.D. 1984. The effect of interlevel hierarchical system communication on agricultural system input-output relationships. Options: 111-124.

Herrick, J.E., J.R. Brown, A.J. Tugel, P.L. Shaver and K.M. Havstad. 2002. Application of soil quality to monitoring and management: Paradigms from rangeland ecology. Agronomy Journal 94: 3-11.

Hussian, I., Olson, K.R., Wander, M.M., Karlen, D.L. 1999. Adaptation of soil quality indices and application to three tillage systems in southern Illinois. Soil Till. Res. 50, 237-249.

Karlen, D.L., Gardner, J.C., Rosek, M.J. 1998. A soil quality framework for evaluating the impact of CRP. J. Prod. Agric. 11, 56-60.

Karlen, D.L., E.G. Hurley, S.S. Andrews, C.A. Cambardella, D.W. Meek, M.D. Duffy, and A.P. Mallarino. 2006. Crop Rotation Effects on Soil Quality at Three Northern Corn/Soybean Belt Locations. *Agronomy Journal* 98:484-495Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Science Society of America Journal 61: 4-10.

Karlen, D.L., Stott, D.E. 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J. W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A. (Eds.), Defining soil quality for a sustainable environment. SSSA Spec. Publ. No. 35. SSSA, Madison, WI. pp. 53-72.

Larson, W.E., Pierce, F.J. 1991. Conservation and enhancement of soil quality. In: Evaluation of Sustainable Land Management in the Developing World. Vol. 2. IBSRAM Proc. 12(2). Int. Board for Soil Res. and Management, Bangkok, Thailand.

Lowrance, R. 1990. Research approaches for ecological sustainability. Journal of Soil and Water Conservation 45: 51-54.

Lowrance, R., P.F. Hendrix and E.P. Odum. 1987. A hierarchical approach to sustainable agriculture. American Journal of Alternative Agriculture I (4): 169-173.

Norgaard, R.B. 1994. Ecology, politics, and economics: Finding the common ground for decision making in conservation. Pages 439-465 *In* G.K. Meffe and C.R. Carroll, editors. Principles of Conservation Biology. Sinauer Associates, Inc., Sunderland, MA, USA.

Norton, B.G. 1992. A new paradigm for environmental management. Ecosystem Health: New Goals for Environmental Health. R. Costanza, B.G. Norton and B.D. Haskell, eds. Washington, D.C., Island Press. pp. 23–41.

O'Neill, R.V., D.L. DeAngelis, J.B. Waide and T.F.H. Allen. 1986. A hierarchical concept of ecosystems. Princeton, NJ, Princeton University Press.

Potter, S.R., S.S. Andrews. J.D. Atwood, R.L. Kellogg, J. Lemunyon, M.L. Norfleet, and D. Oman 2006. Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production. USDA-NRCS Conservation Effects Assessment Project. Washington D.C. Available online at: http://www.nrcs.usda.gov/technical/nri/ceap/croplandreport/

Spedding, C.R.W. 1988. An introduction to agricultural systems. New York, Elsevier Applied Science.

Stephens, W. and T. Hess. 1999. Systems approaches to water management research. Agricultural Water Management 40: 3-13.

Wienhold, B.J., J.L. Pikul, Jr., M.A. Liebig, M.M Mikha, G.E. Varvel, J.W. Doran, and S.S. Andrews. 2006. Cropping system effects on soil quality in the Great Plains: Synthesis form a regional project. *Renewable Agriculture and Food Systems* 21(1): 49-59.

Wymore, A.W. 1993. Model-based systems engineering: An introduction to the mathematical theory of discrete systems and to the tricotyledon theory of system design. CRC Press, Boca Raton, FL, USA.

Yakowitz, D.S., Stone, J.J., Lane, L.J., Heilman, P., Masterson, J., Abolt, J., Imam, B. 1993. A decision support system for evaluating the effect of alternative farm management systems on water quality and economics. Wat. Sci. Tech. 28(3-5), 47-54.

Station 2 - Soil, Water, and Plant Analysis in Conservation Planning

New Mexico Sustainable Agriculture Producer Guide

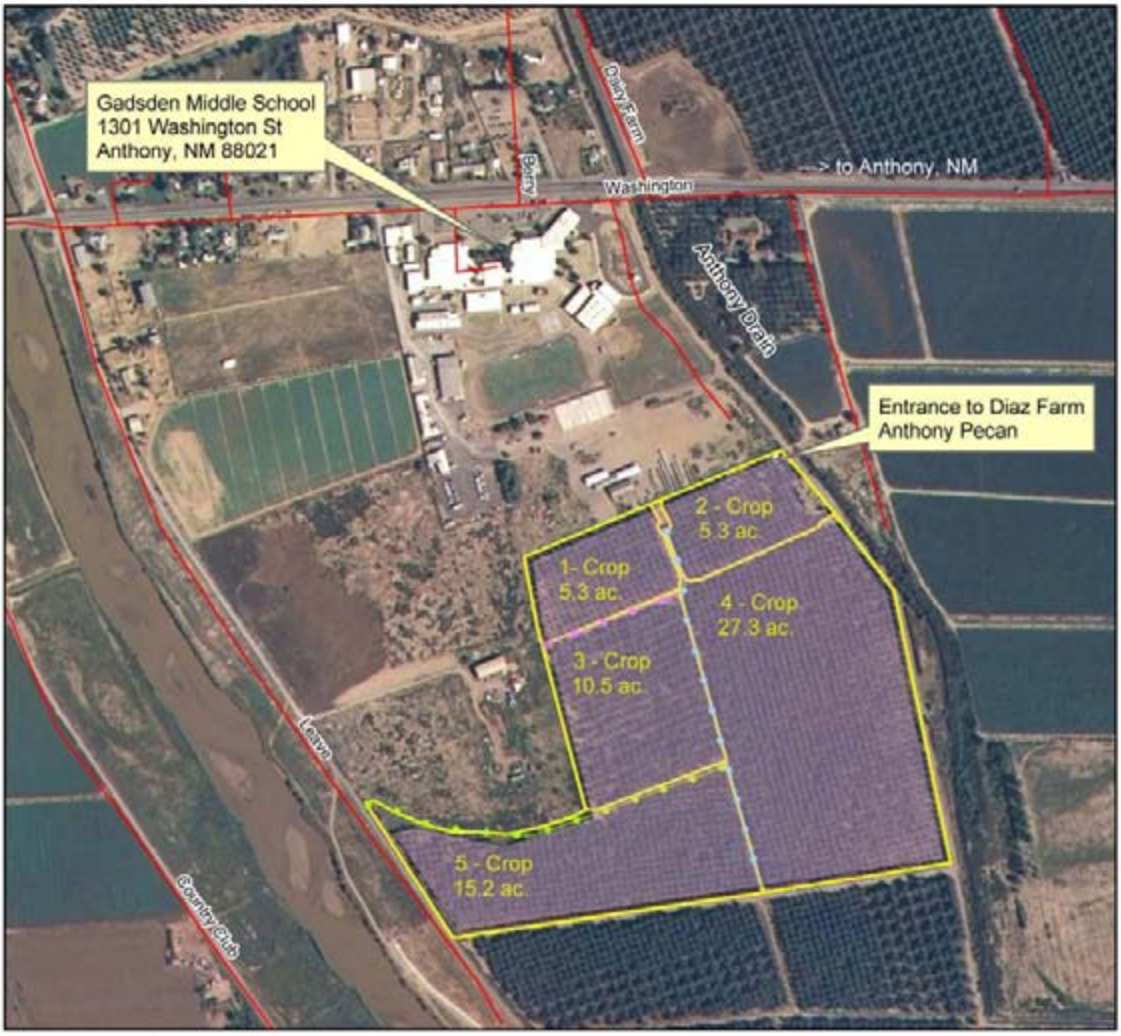
The Natural Resources Conservation Service, formerly the Soil Conservation Service, works hand-in-hand with the American people to conserve natural resources on private lands.

THE USDA IS AN EQUAL OPPORTUNITY PROVIDER AND EMPLOYER

Plan Map

Customer(s): ANTHONY PECAN COMPANY
District: Dona Ana Soil & Water Conservation District
Approximate Acres: 63.6

Field Office: LAS CRUCES SERVICE CENTER
Agency: USDA - NRCS
Date: 4/13/2009
State and County: NM, DONA ANA



Legend

LABEL	R&I (Line)
441 -drip	LABEL, FEET
Consplan	428 - Ditch, 1551 ft
Roads	428 -Ditch, 1586 ft
	428 -Ditch, 603 ft

340 0 340 680 1,020 1,360 Feet

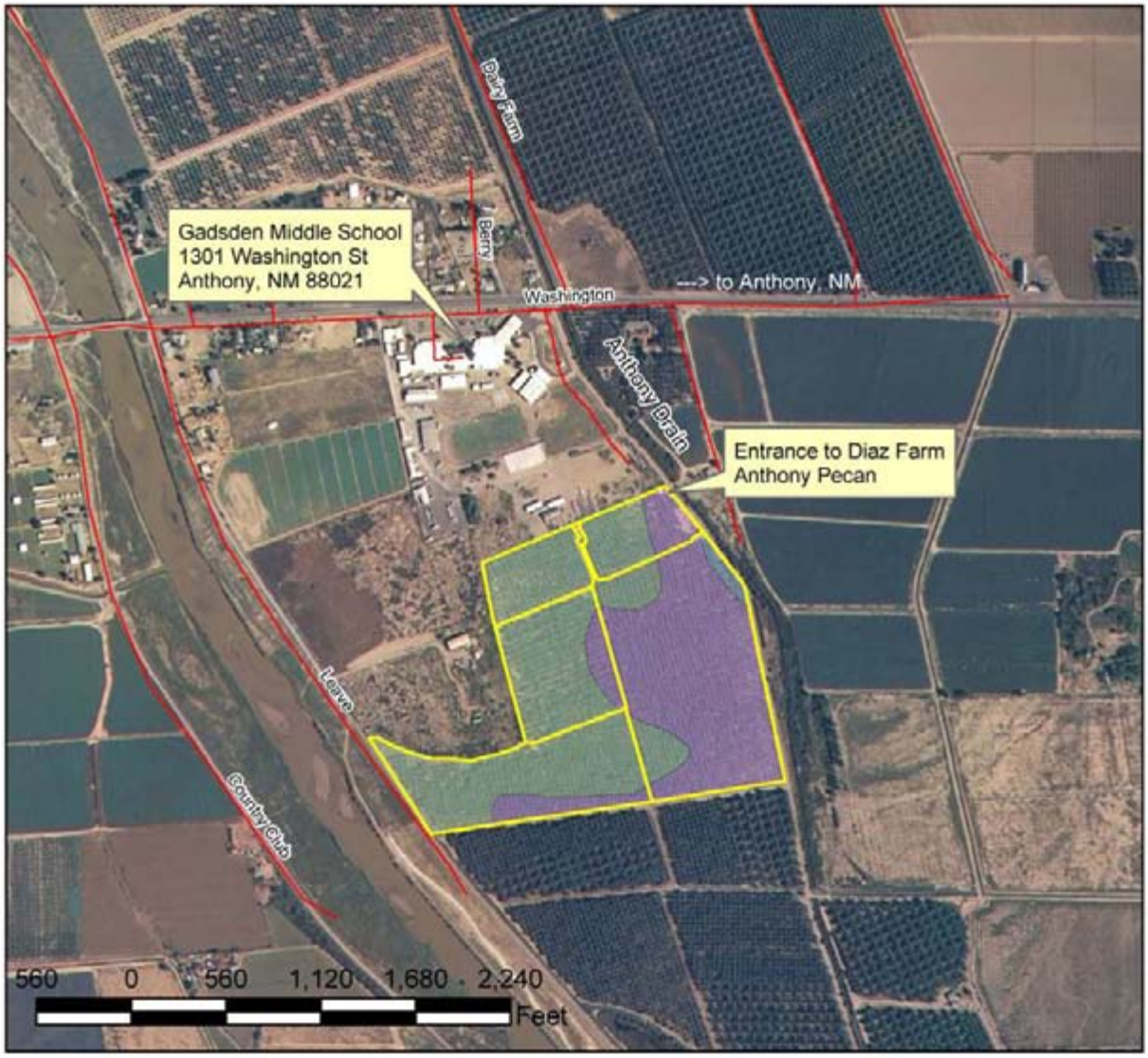
N W E S

Soils Map

Date: 4/13/2009

Customer(s): ANTHONY PECAN COMPANY
District: Dona Ana Soil & Water Conservation District
Approximate Acres: 63.6

Field Office: LAS CRUCES SERVICE CENTER
Agency: USDA - NRCS
Assisted By:
State and County: NM, DONA ANA
Land Units:



Legend

Consplan **musym, muname**

Roads

Soils Map

- Ap, Anthony-Vinton fine sandy loams
- Br, Brazito loamy fine sand
- Ge, Glendale loam
- Hg, Harkey loam

Purpose of NM Integrated Water Management Handbook:

http://www.nm.nrcs.usda.gov/technical/handbooks/iwm/nmiwm.html

Irrigation water management is an integral part of a complete farming system of soil, water, air, plant, animal, and human resources. The New Mexico Integrated Water Management Handbook is intended to be user friendly for use by planners with producers. It provides guidance on "how-to" evaluate and understand site-specific field conditions, including chemical, biological and physical. This enables us to evaluate and implement best management practices/approaches for cropland management within an integrated farming system. Considering how the farm fits into broader watershed management (e.g. off-site effects and resource opportunities) is also essential to problem-posing and problem-solving resource management success.

The Natural Resources Conservation Service provides technical assistance for producers in all aspects of cropland conservation, including irrigation water management (e.g. installation of irrigation water management practices, water measuring, irrigation scheduling, irrigation system design, reduced cultivation), and nutrient management (e.g. soil, water, and plant nutrient analysis, developing basic nutrient budgets, and determining appropriate fertilizer and manure applications). Other technical assistance areas have included agronomic-related practices and management such as reduced tillage, crop rotations, green manure crops, cover crops, salinity and integrated pest management. This Handbook provides guidance on understanding and improving soil quality, water quantity/quality, air quality, nutrient and salinity management, crop yield and quality, irrigation water management, integrated pest management. It also provides guidance on reducing overall on-farm energy use, inputs, production costs, pest incidences, pumping costs, as well as soil and water losses. The end result targets becoming a more economical, sustainable farming enterprise, including resource efficient and resource conserving.

The key approach to achieving integrated sustainable management is to think system (ecosystem, whole farm, and watershed), think critically (connect the dots), actively seek resource opportunities, emphasize technology "exchange" vs. "transfer" with other producers and partners, plan creatively and flexibly, and focus on keeping energy flow through the integrated system. A reemphasis on biological factors is also necessary since recent agriculture has essentially forgotten biological, but rather focused on chemical and physical factors. Improving soil quality is key to improving soil, water, air, plant, and animal resources. Case studies, field trials, demonstrations are all important approaches for technology exchange.

This Handbook is intended for use by planners with producers, so individual producers are strongly advised to work closely with their local chemical consultants, crop consultants, extension specialists, and the Natural Resources Conservation Service on any subject covered in the Handbook. We hope that the Handbook will assist water users in reducing water quantities used, energy use and costs for crop production, and the opportunity for ground and surface water contamination. The greater the understanding we have of our soil, water, air, plant, and animal resources, the better will be our ability to build healthier, sustainable communities.

Linda Scheffe, 2008

Potential Benefits of Integrated Water Management

Water resource:

- Conserves surface and ground water supplies
- Protects surface and ground water quality
- Substantial reduction in irrigation labor costs
- Significant increase in irrigation application efficiencies (higher yields)
- Reduced pumping costs
- Potential detrimental effects of water quality (pH, salinity & sodium) on plants and soils are properly assessed and managed for
- Irrigation water losses through evaporation, runoff and deep percolation are minimized

Soil resource:

- Improved soil quality is possible because of increased biomass production (more crop residues are produced)
- Reduced soil erosion from both water and wind
- Proper assessment, management and prevention of Saline, Saline-Sodic and Sodic soils is attained
- Reduced use of soil amendments
- Reduction in water-logged soils
- Reduced leaching results in higher nitrogen-use efficiency

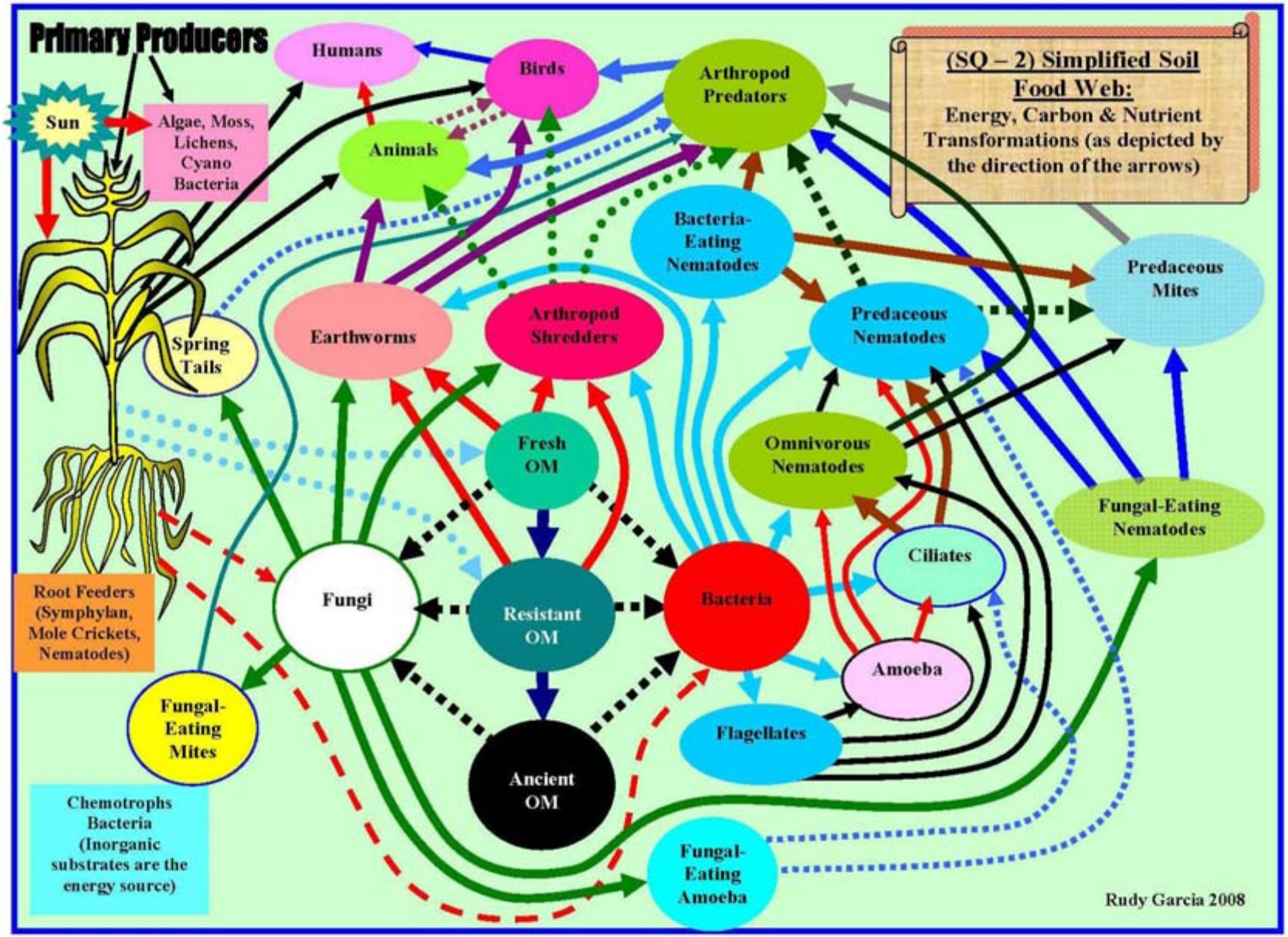
Plant resource:

- Cost for crop production is reduced due to integration of IWM with nutrient management practices
- Significant increases in yield and crop quality
- Reduced incidences of diseases and pests
- Available water quantity and quality meet the specific requirements of the crop (consumptive use, leaching)

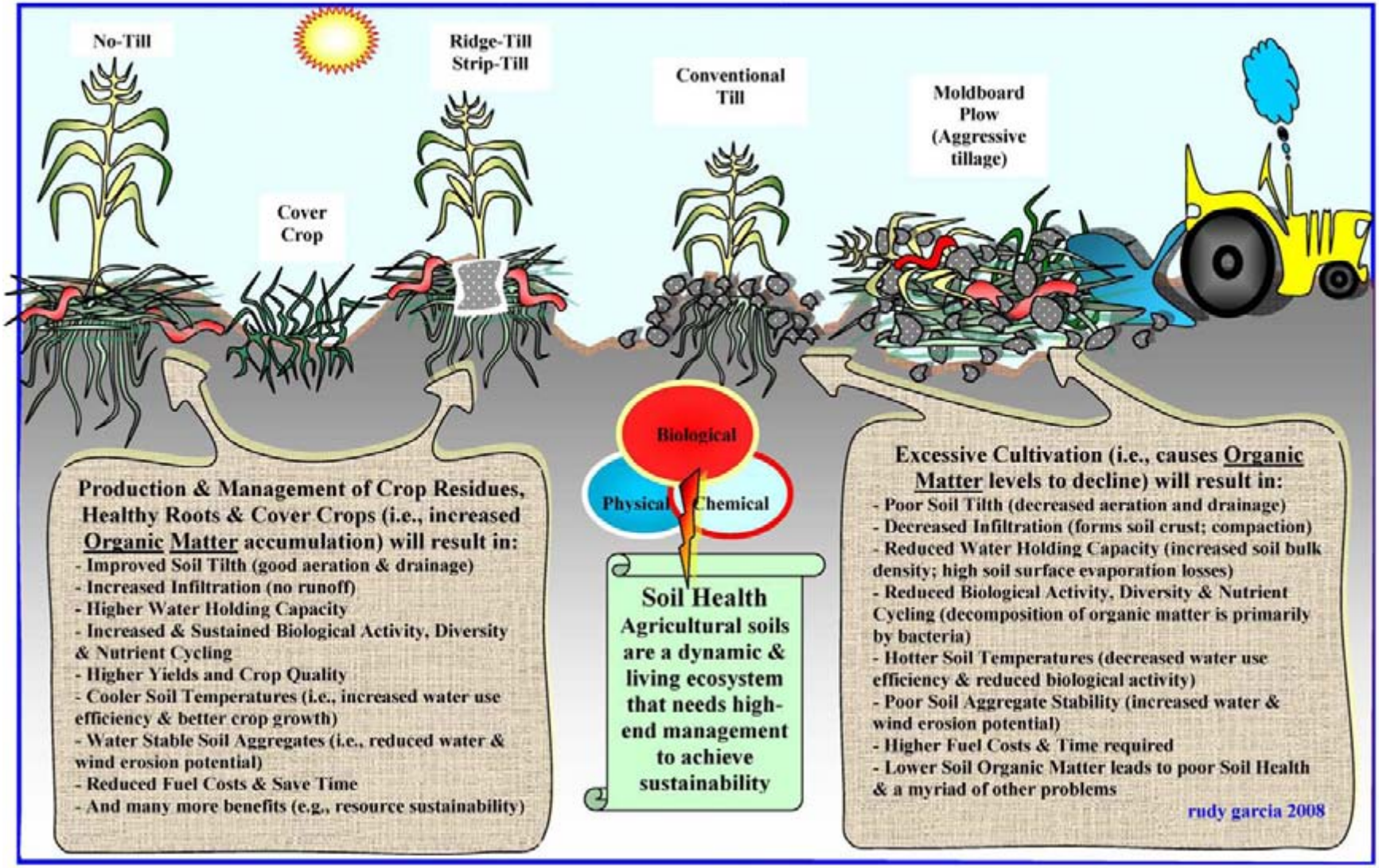
Other:

- Increased beneficial use of fertilizer and soil amendment inputs
- Reduction in over all on-farm energy use
- Protects the environment by the planned judicious use of water, fertilizers and other inputs
- Record keeping is used as an invaluable planning tool in the decision and management of current and future water resources
- All the major aspects involved in the farm operation are integrated in this IWM Handbook
- Analysis of soil, plant/petiole tissue and water samples allows the producer to make informed decisions on all inputs and their relationship to IWM principles
- An effective IWM Plan should be updated to reflect mgmt. changes, learning, etc.

Rudy Garcia 2008


Primary Producers
Sun
Algae, Moss, Lichens, Cyano Bacteria
Humans
Birds
Animals
Arthropod Predators
(SQ – 2) Simplified Soil Food Web:
Energy, Carbon & Nutrient Transformations (as depicted by the direction of the arrows)
Bacteria-Eating Nematodes
Predaceous Mites
Predaceous Nematodes
Earthworms
Arthropod Shredders
Spring Tails
Fresh OM
Omnivorous Nematodes
Fungal-Eating Nematodes
Ciliates
Root Feeders (Symphylan, Mole Crickets, Nematodes)
Fungi
Resistant OM
Bacteria
Amoeba
Fungal-Eating Mites
Flagellates
Ancient OM
Chemotrophs Bacteria (Inorganic substrates are the energy source)
Fungal-Eating Amoeba
Rudy Garcia 2008

(SQ – 13) Soil Health-Quality Assessment



SQ – 8a. Benefits of Conservation Tillage

Environmental:

- Reduces soil erosion from both water and wind (90% erosion reduction can be expected when using a no-till instead of intensive tillage system).
- Increases organic matter (each tillage trip oxidizes some organic matter; research shows continuous no-till can increase organic matter in the top 2 inches of soil about 0.1% each year).
- Improves water quality (when combined with irrigation water management, crop nutrient management, integrated pest management, conservation crop rotation, in integrated system, conservation tillage plays an important role in improving both runoff to streams, rivers, and lakes as well as water that finds its way into aquifers).
- Improves wildlife habitat (the crop's residue provides food and shelter. In addition, if combined with other needed habitat, such as grassy cover and woody areas, wildlife may increase significantly).
- Other benefits include reduced soil compaction, utilization of marginal land, some harvesting advantages, and conservation compliance.

Economic:

- Yields are good, if not better, than reduced or intensive tillage system when managed properly.
- Optimizes soil moisture (improved infiltration and increased organic matter are especially important on droughty soils and may help the crop through a persistent dry period. Tillage reduces available moisture by about ½" per trip).
- Saves time (On a 1000 acre farm, an additional 100 hours are needed for every pass (example based on 18' disk, 160 hp FWD). Many growers take advantage of the time savings by exploring other "opportunities").
- Reduces fuel consumption (no-till can reduce fuel use by 3.5 gallons/acre compared to intensive tillage).
- Reduces overall production costs (NMSU reports that irrigated wheat yields in Clovis are comparable between conventional and conservation tillage, but production costs for conservation tillage are lower by as much as $50 per acre).
- Reduces machinery wear (less machinery means fewer pieces need to be replaced. Economists report this amounts to a $5/acre reduction in costs).

Linda Scheffe, 2008

(WQ – 4) Irrigation Water Salinity & Sodium Adsorption Ratio (SAR) Assessment Guide

Irrigation Water Lab Analysis for Soluble Salts and SAR (mg/l = milligrams/liter; meq/l = milliequivalents/liter)

	Major Cations (ions with a positive charge)	example		Enter Lab Results			Major Anions (ions with a negative charge)	example		Enter Lab Results	
		mg/l	meq/l	mg/l	meq/l			mg/l	meq/l	mg/l	meq/l
Hardness	Calcium (Ca^{++}) 20.04 mg/meq	80	4				Chloride (Cl^{-}) 35.46 mg/meq	92	2.6		
Hardness	Magnesium (Mg^{++}) 12.16 mg/meq	14	1.2				Sulfate ($SO4^{--}$) 48.03 mg/meq	192	4		
	Sodium (Na^{+}) 22.99 mg/meq	115	5			Alkalinity	Bicarbonate (HCO_3^{-}) 61.02 mg/meq	183	3		
	Potassium (K^{+}) 39.10 mg/meq	8	0.2			Alkalinity	Carbonate (CO_3^{--}) 30.01 mg/meq	6	0.2		
	Sum of Total Cations:	**217**	**10.4**				Sum of Total Anions:	**473**	**9.8**		

Total Dissolved Solids (i.e., Soluble Salts) is: 217 mg/l + 473 mg/l = 690 mg/l (or 690 ppm). 0.23 x TDS (ppm) = lbs. of salts/ac-in
690 mg/l ÷ 640 ≈ ECiw of 1.1 dS/m (i.e., Electrical Conductivity of Irrigation Water in decisiemens/meter)

Irrigation Water Salinity Assessment

Salinity (Soluble Salts): affects crop water availability
Note: Be sure to compare the Irrigation Salinity (ECiw) with the Soil Test (ECe), in order to evaluate the potential yield reduction of your crop (i.e., Refer to a Crop Threshold Soil Salinity (ECe(ct)) Table)

Degree of Restriction on Use – ECiw (dS/m)		
None	Slight to Moderate	Severe
< 0.7	0.7 – 3.0	> 3.0

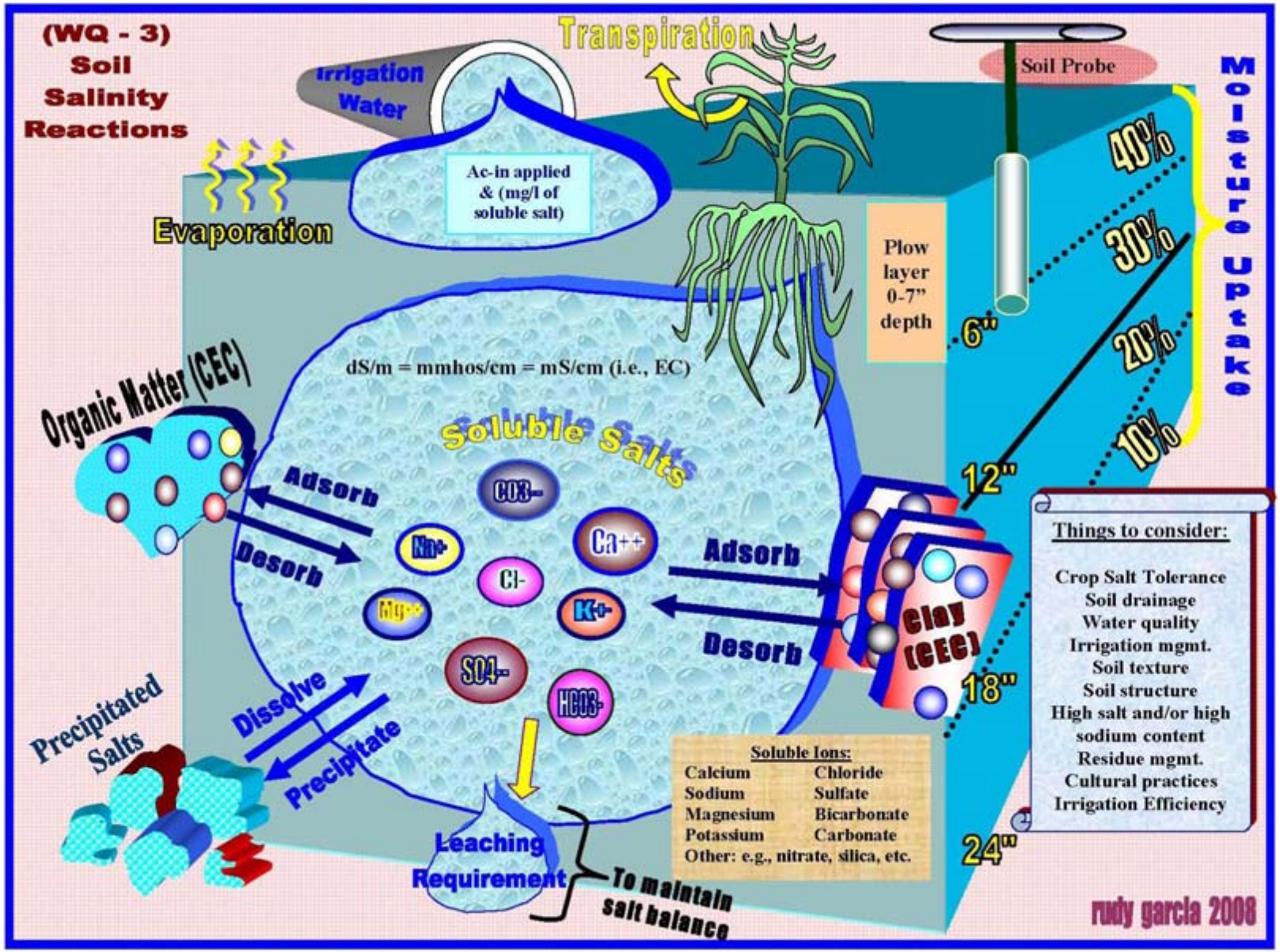
Irrigation Water Quality and its potential effects on Infiltration

The amount of **Sodium** and **soluble salts** in the Irrigation Water affects the rate of water infiltration into the soil. This is evaluated using the **SAR** (**Sodium Adsorption Ratio**) and Electrical Conductivity of the Irrigation Water **(ECiw in dS/m)**.

Use meq/l for calculating the SAR
SAR = Na/√(Ca + Mg)/2

SAR	Degree of Restriction on Use – ECiw (dS/m)		
	None	Slight to Moderate	Severe
0 – 3	> 0.7	0.7 – 0.2	< 0.2
3 – 6	> 1.2	1.2 – 0.3	< 0.3
6 – 12	> 1.9	1.9 – 0.5	< 0.5
12 – 20	> 2.9	2.9 – 1.3	< 1.3
20 - 40	> 5.0	5.0 – 2.9	< 2.9

Rudy Garcia 2008


(WQ - 3)
Soil
Salinity
Reactions
Transpiration
Irrigation Water
Soil Probe
Moisture Uptake
Ac-in applied & (mg/l of soluble salt)
Evaporation
Plow layer 0-7" depth
40%
30%
20%
10%
6"
12"
18"
24"
Organic Matter (CEC)
dS/m = mmhos/cm = mS/cm (i.e., EC)
Soluble Salts
Adsorb
Desorb
CO3--
Na+
Ca++
Cl-
Mg++
K+
SO4--
HCO3-
Adsorb
Desorb
Clay (CEC)
Things to consider:
Crop Salt Tolerance
Soil drainage
Water quality
Irrigation mgmt.
Soil texture
Soil structure
High salt and/or high sodium content
Residue mgmt.
Cultural practices
Irrigation Efficiency
Precipitated Salts
Dissolve
Precipitate
Soluble Ions:
Calcium Chloride
Sodium Sulfate
Magnesium Bicarbonate
Potassium Carbonate
Other: e.g., nitrate, silica, etc.
Leaching Requirement
To maintain salt balance
rudy garcia 2008

(PW-1) Irrigation Water, Soil and Plant Tissue Analysis GUIDE (for Planning & Mgmt. of Cropping Systems)

Producer: Anthony **Crop:** Pecans **Yield:** 2500 lb/ac **Field #:** **Ac.:** **Soil Texture:** sandy loam **Irr. Water (ac-in/ac):** 60

Nitrogen (**N**), Phosphorus (**P**), Potassium (**K**), Sulfur (**S**), Calcium (**Ca**), Magnesium (**Mg**), Zinc (**Zn**), Iron (**Fe**), Manganese (**Mn**), Copper (**Cu**), Sodium (**Na**), Chloride (**Cl**)

Water Analysis Date: 1/30/09 well

Nutrient	NO_3-N	P	K	SO_4-S	Ca	Mg	Zn	Fe	Mn	Cu	Na	Cl
mg/l = ppm	0.1	Not	6	54	80	12	Not	Not	Not	Not	109	80
Total Lbs/ac 1/	1.4	analyzed	83	745	1104	166	analyzed	analyzed	analyzed	analyzed	1504	1104

mg/l x 0.23 = lbs. of Nutrient/ac.-in. of H_2O; 1/ lbs Nut x in. H_2O applied = Total lbs Nut/ac

Bicarbonate (HCO_3): 263 mg/l; Boron (B): 0.19 mg/l; pH: 7.1
Carbonate (CO_3): <1 mg/l ; Hydrogen Sulfide (H_2S): mg/l

Sodium Adsorption Ratio (SAR): 3.0
Soluble Salts (ECiw-mmhos/cm): 0.98

TDS (mg/l) = ECiw (mmhos/cm) x 640, for ECiw between 0.1 and 5.0 mmhos/cm

TDS (mg/l) = ECiw (mmhos/cm) x 800, for EC > 5.0 mmhos/cm

Example: 0.34 mmhos/cm x 640 = 218 mg/l (TDS)
218 mg/l x 2.72 = 593 lbs. of soluble salts/ac.-ft. of water applied

Soil Analysis Date: 3-20-09 Soil Depth:0-12"

Nutrient	NO_3-N	P	K 3/	SO_4-S	Ca 3/	Mg 3/	Zn	Fe	Mn	Cu	Na 3/	Cl
ppm	2	2	28	89	4079	308	0.3	6	2	0.8	110	not
Classification 2/	Very Low	Very Low	Low	High	Very High	Very High	Low	High	Moderate	Moderate	n/a	analyzed
Lbs./ac.	8	8	112	356	16136	1232	1	24	8	3	440	

A Very Low or Low Classification indicates a High Probability for obtaining a fertilizer response.

A Moderate Classification indicates a fertilizer response May or May Not occur.

A High or Very High Classification indicates a fertilizer response is Not likely to occur.

ppm x 4.0 = lbs. of nutrient/ac.-ft. (i.e., based on soil weighing 4 million lbs. per acre-foot). Or ppm x 2.0 = lbs. of nutrient per acre 6" depth.

Free Lime ($CaCO_3$): ____; pH: 8.2
Organic Matter (%): 0.5

Sodium Adsorption Ratio (SAR): 0.4
Soluble Salts (ECe – mmhos/cm): 0.5

3/ CEC - Typical proportions of major adsorbed cations: Ca = 65%, Mg = 20%, K = 10% & Na = 5% (Table 8.1, Nature & Properties of Soils 11th Edition)

Nutrient Inputs: (Recommendations)

Nutrient	N	P_2O_5	K_2O	S	Ca	Mg	Zn	Fe	Mn	Cu	Na	Cl
Lbs./ac.	250	120	90				30					

lbs. of P_2O_5 x 0.44 = _____lbs. P (Phosphorus)
lbs. of K_2O x 0.83 = _____lbs. of K (Potassium)

lbs. of S ÷ 0.33 = _____lbs. of SO_4 (Sulfate)

Split Apply Nutrient applications to meet plant needs & improve efficiency. Refer to fertilizer recommendations for guidance.

Plant Tissue Analysis Date: 7/01/08

Nutrient	Total N	Total P	K	Total S	Ca	Mg	Zn	Fe	Mn	Cu	Na	Cl
ppm or %	2.2	0.25	0.9	n/a	2.4	0.5	40	100	90	20	0.05	0.2
Sufficiency Range Low (L) to High (H)	2.5-2.9%	0.12-0.30%	0.75-0.95%		1.3-2.5%	0.3-0.6%	50-100 ppm	50-300 ppm	100-800 ppm	10-30 ppm	Excessive >0.10 %	Excessive > 0.3 %

Nutrient levels at or below the Low Sufficiency Range indicate a High Probability of a fertilizer response.

A fertilizer response May or May Not be obtained when the nutrient levels are Within the Sufficiency Range.

Nutrient levels at or above the High Sufficiency Range indicate a Low Probability of a fertilizer response.

Note: NO_3-N; PO_4-P & SO_4-S are in ppm for Petiole Samples.

For some crops, Boron (B= __42_____ppm) and Molybdenum (Mo= _n/a____ ppm) may need to be analyzed. (Boron = 35-50__ppm Sufficiency Range; Molybdenum = _____ppm Sufficiency Range)

In suspected Saline or Sodic areas, Sodium & Chloride should be analyzed.

Harvested Nutrients @15%

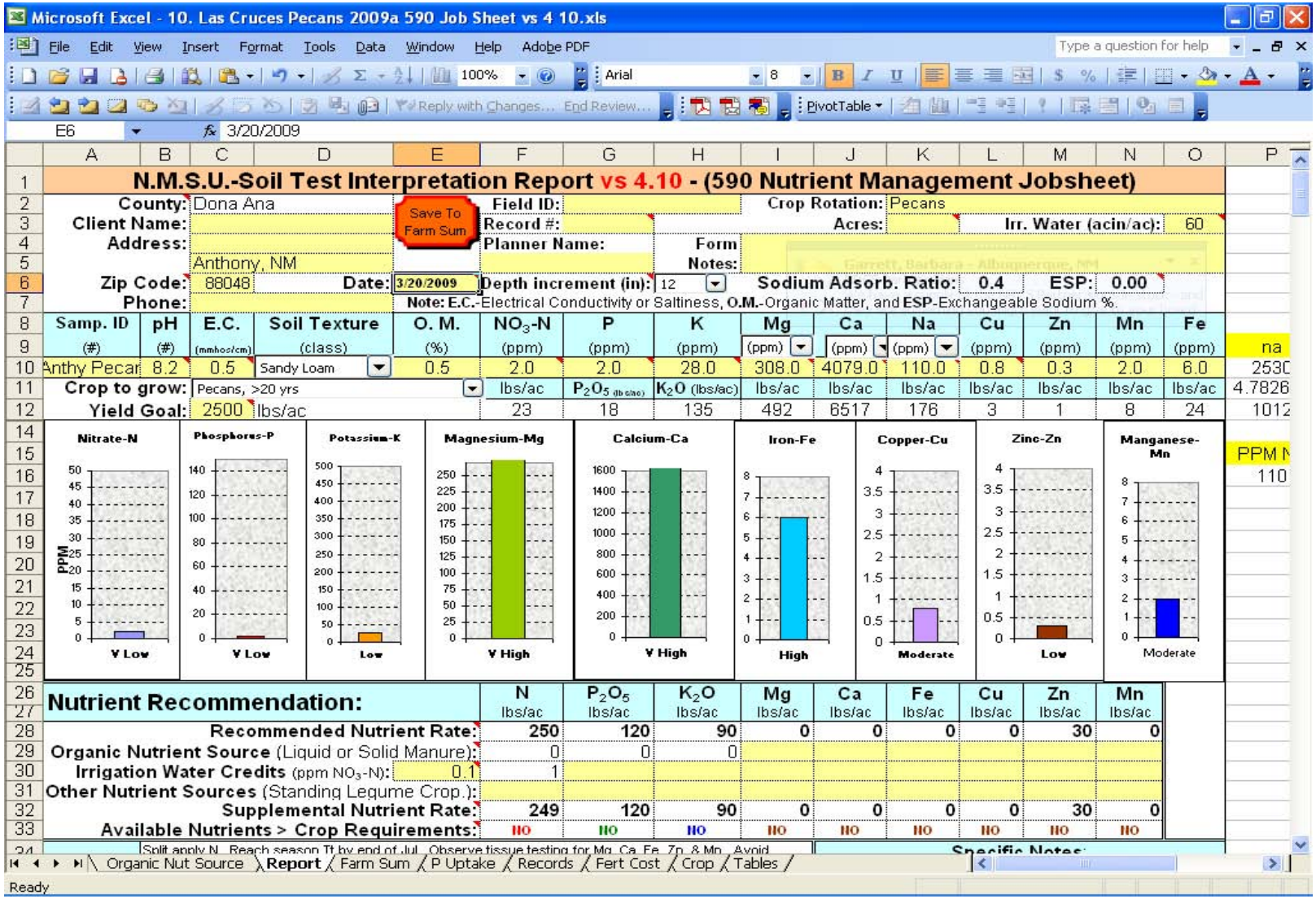
Nutrient	N	P	K
%	2.4		
Total lb/ac 4/	51		

4/ Crop (lbs./ac) x % dry matter = lb. Crop (dry weight)/ac
Crop (lb/ac dry wt.) x % Nutrient = lbs. Nutrient removed/ac
Note: For NPK % averages & % Moisture Content, refer to NRCS Nutrient Uptake Tool: http://npk.nrcs.usda.gov/

2/ Classification NRCS Nutrient Management Jobsheet (590): click on Tables & Crop Tabs

Rating for ppm	N	P	K	Ca	Mg	Zn	Fe	Mn	Cu
Very Low	.01-4	.01-7	.01-9	.01-99	.01-14	.01-.09	.01-0.9	.01-.09	.01-.09
Low	5-9	8-14	10-29	100-199	15-29	0.1-0.4	1-2.4	0.1-0.9	0.1-0.2
Moderate	10-29	15-22	30-59	200-399	30-59	0.5-0.9	2.5-4.4	1-2.4	0.3-0.9
High	30-49	23-30	60-79	400-799	60-99	1-9	4.5-9	2.5-9	1-9
Very High	> 49	> 30	> 79	> 799	> 99	> 9	> 9	> 9	> 9

Note: Evaluate above data with Soil Quality (e.g., aggregate stability), IWM, IPM and Tillage Operations records for best understanding of results. rudy garcia 2009



Excel Spreadsheet is used with Practice Code 590 Nutrient Management Job Sheet to record and calculate nutrient status and needs based upon soil analysis, nutrient sources, and crop needs.

WQ-6 Crop Salt Tolerance Table for NM

Crop Salt Tolerances

Crop (name)	Yield loss 0%		Yield loss 10%		Yield loss 25%		Yield loss 50% %		Maximum
	ECe[1]	ECw[2]	ECe[1]	ECw[2]	ECe[1]	ECw[2]	ECe[1]	ECw[2]	ECe[3]
Alfalfa	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	15.5
Almond	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.7	7.0
Apple	1.7	1.0	2.3	1.6	3.3	2.2	4.8	3.2	8.0
Apricot	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	6.0
Barley	8.0	5.3	10.0	6.7	13.0	8.7	18.0	12.0	28.0
Beans	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.5
Beets	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15.0
Bermuda Grass	6.9	4.6	8.5	5.7	10.8	7.2	14.7	9.8	22.5
Blackberry	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0
Broccoli	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	13.5
Cabbage	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12.0
Cantaloupe	2.2	1.5	3.6	2.4	5.7	3.8	9.1	6.1	16.0
Clover	1.5	1,0	2.3	1.6	3.6	2.4	5.7	3.8	10.0
Corn, Grain & Silage	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Corn Silage	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15.5
Corn, Sweet	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Cotton	7.7	5.1	9.6	6.4	13.0	8.4	17.0	12.0	27.0
Fescue, Tall	3.9	2.6	5.8	3.9	8.6	5.7	13.3	8.9	23.0
Grape	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12.0
Lettuce	1.3	0.9	2.1	1.4	3.2	2.1	5.2	3.4	9.0
Love Grass	2.0	1.3	3.2	2.1	5.0	3.3	8.0	5.3	14.0
Meadow Foxtail	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.6	12.0
Onion	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.5
Orchard Grass	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	17.5
Pear	1.7	1.0	2.3	1.6	3.3	2.2	4.8	3.2	8.0
Pecan[4]	1.9	1.3**	2.4*	1.6**	3.2*	2.4**	4.6	3.0**	8.0*
Pepper	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.5
Potato, Irish	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10.0
Potato, Sweet	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	10.5
Radish	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	9.0
Ryegrass, Perennial	5.6	3.7	6.9	4.6	8.9	5.9	12.2	8.1	19.0
Safflower	5.3	3.5	6.2	4.1	7.6	5.0	9.9	6.6	14.5
Soybean	5.0	3.3	5.5	3.7	6.2	4.2	7.5	5.0	10.0
Spinach	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15.0
Sudan Grass	2.8	1.9	5.1	3.4	8.6	5.7	14.4	9.6	26.0
Tomato	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	12.5
Trefoil, Big	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.5
Trefoil, Birdsfoot	5.0	3.3	6.0	4.0	7.5	5.0	10.0	6.7	15.0
Wheat	6.0	4.0	7.4	4.9	9.5	6.4	13.0	8.7	20.0
Wheatgrass, Crested	3.5	2.3	6.0	4.0	9.8	6.5	16.0	11.0	28.5
Wheatgrass, Tall	7.5	5.0	9.9	6.6	13.3	9.0	19.4	13.0	31.5
Wild Rye, beardless	2.7	1.8	4.4	2.9	6.9	4.6	11.0	7.4	19.5

[1] ECe is the electrical conductivity of saturated soil extract, reported in millimhos per centimeter at 25°C.

[2] ECw is the electrical conductivity of the irrigation water, reported in millimhos per centimeter at 25°C.

[3] Maximum ECe is the conductivity of saturated soil extract, reported in millimhos per centimeter at 25°C, at which the plant dies.

[4] Complete data is not currently available for pecans. The * is an interpolation between the 0% and 50% range. The ** for ECw is calculated as ECe x 0.67, which is a general rule of thumb for these ratios under average conditions. RDFischer , 2/09

(WQ – 9)Gypsum ($CaSO_4 \cdot 2H_2O$) & Elemental Sulfur (S^0) Soil Amendment GUIDE

NOTE: If you're not sure of the benefits of gypsum or elemental sulfur, then demonstrate on a small portion of a field & evaluate results.

Soil Texture	% Clay	CEC Range (meq/100 g)	Cation Exchange Capacity (CEC) is based on % Clay & mineral type (e.g. Kaolinite, Montmorillonite) & % Organic Matter	Soil Bulk Density (g/cm^3)
Sands	2 – 8	2 – 6		1.65
Loamy Sands	2 – 14			1.6
Fine Sands				
Very Fine Sands	2 – 8			1.65
Loamy Fine Sands				
Loamy Very F. Sands	2 – 14			1.6
Sandy Loam				
Fine Sandy Loam	2 – 18	3 – 8		1.56
Very F. Sandy Loam				1.53
Loam	10 – 26	7 – 15		1.42
Silt Loam	2 – 26			1.46
Silt	2 – 10	10 – 19		1.47
Sandy Clay Loam	22 – 36			1.4
Silty Clay Loam				1.27
Clay Loam	28 – 38			1.32
Sandy Clay	38 – 54			1.33
Silty Clay	42 – 58	15 - 30		1.23
Clay	42 - 98			1.25

Soils Intake Family	Inches Applied 1.0	2.0	3.0
	Infiltration Time (Hrs)		
0.1	2.8	10.5	22.3
0.3	1.0	3.5	6.8
0.5	0.63	2.0	3.8
0.75	0.48	1.5	2.8
1.0	0.33	1.0	1.8
1.25	0.28	0.8	1.5
1.5	0.23	0.7	1.3
1.75	0.20	0.6	1.1

Infiltration Assessment			
SAR	Restriction on Use Units: ECiw (dS/m)		
	None	Slight to Mod.	Severe
0 – 3	> 0.7	0.7 – 0.2	< 0.2
3 – 6	> 1.2	1.2 – 0.3	< 0.3
6 – 12	> 1.9	1.9 – 0.5	< 0.5
12 – 20	> 2.9	2.9 – 1.3	< 1.3
20 - 40	> 5.0	5.0 – 2.9	< 2.9

Soil Structure	Downward Movement of water
Single Grain	
Granular	Rapid
Blocky	
Prismatic	Moderate
Platy	
Massive	Slow

constant x soil depth x bulk density x CEC x (initial SAR – final SAR) x multiplication factor ÷ gypsum purity ÷ 2000 = gypsum requirement

(23.1) x (feet) x (g/cm^3) x (meq/100 g) x (initial SAR – final SAR) x (1.25) ÷ (%) ÷ (2000) = (tons/ac)

Gypsum Example	23.1 x 0.5 ft x 1.34 g/cm^3 x 14.0 meq/100 g x (13 – 6) x 1.25 ÷ 0.80 ÷ 2000 = 1.2 tons of Gypsum/ac
Sulfur Example	1.3 tons/ac of pure gypsum needed x 0.19* = 0.25 tons of Elemental Sulfur/ac needed (or 494 lbs./ac)

Considerations in the use of soil amendments: Soils Intake Family, Water Quality (ECiw & SAR), Soil Structure, Stratified Soils, Irrigation Water Management, crop rotations (residue management), leaching requirement, tillage operations (i.e., Soil Conditioning Index (SCI) and Soil Tillage Intensity Rating (STIR)), % Soil Organic Matter, etc. Important: Are Soils characterized as Saline, Saline-Sodic or Sodic.

*Use 0.19 to convert an equivalent amount of pure gypsum into an S^0 requirement (Ref. NRCS Salinity Mgmt. for Soil & Water – pg. 5.42). rudy garcia 2008

(CS -1)
Watershed Approach !!!
IWM & Cropping System
Planning Considerations
Climate
Crop Quality & Yield
Water Supply & Quality
Irrigation System
& Application Efficiency
Active Root Zone Depth
& Moisture Extraction Pattern
40% extraction here
30% here
20% here
10%
Drainage &
Water Quality Impacts
Soil Quality/Health
Rudy Garcia 2008

(CS – 2) Farm Record Form (Case Study)

Producer:	Crop:	Variety:	Soils:	Acres:	Irrigation Water Source (canal, well, spring):
Irrigation System:	Available GPM/CFS:	Gross Irrigation Application Needed (in.):			

ETc (in/ac): 33.03	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Cost per acre ($)	(%) of Total Cost	Labor Req. (hrs.)
	Average Daily Temp.			47 °F	59 °F	68 °F	73 °F	70 °F							
*Inputs & Mgmt. Practices	Corn Silage Monthly Crop Evapotranspiration (ETc)			1.75" 69 GDD	4.32" 443 GDD	8.33" 696 GDD	10.28" 856 GDD	8.35" 784 GDD		GDD = Growing Degree Days Total GDD to reach Crop Maturity = 2,848					
	Average Daily ETc (inches)			.06	.14	.28	.33	.28							
Irrigations (IWM Evaluation)															
Moisture Monitoring (cb)															
Water (W), Soil (S), Petiole (P) & Tissue (T) samples															
Fertilize (N, P, K Other)															
Pesticides (Pest Scouting)															
Herbicides (Weed ID)															
Cultivation (type)															
Soil amendments: Gypsum, Manure, Sulfur, other															
OTHER: Planting (Seeds, lbs/ac), Pruning, Harvest, Irrigation O&M, Marketing, etc.															
Field Observations e.g., Ponding, Soil Crusts, Erosion, Salinity, Disease, compaction, etc.													* Refer to IWM Field Manual Sections for Tech. Guidance on Inputs & Mgmt.		

Total Inputs & Mgmt. Costs/acre: _____; Avg. Yield/acre: _____; Product Market Value ($/acre): _____; Profit margin (%): _____

Rudy Garcia 2008

Station 3 – Soil Quality Test Kit Demonstration

"The nation that destroys its soil destroys itself"

- Franklin D. Roosevelt

Soil Quality Test Kit

What soil tests are in the kit?

Measuring soil quality-provides guidelines for sampling and site characterization.

Soil respiration-measured using an aluminum cylinder that is 6 inches in diameter and 5 inches long. The cylinder is capped and accumulated carbon dioxide respired by soil organisms and plant roots is measured. Respiration provides a measure of biological activity, which is related to nutrient cycling and breakdown of pollutants in the soil.

Infiltration-measured using the same cylinder as in the soil respiration test. Infiltration is important to reducing runoff and storing water in the soil for plant growth.

Bulk density-measured by inserting a 3-inch-diameter cylinder 3 inches into the soil surface and removing the intact soil. Bulk density is related to root growth, biological activity, and movement of water and air in the soil.

Electrical conductivity (EC)-measured with a pocket EC meter. It provides a measure of salinity (excess salts) in the soil.

Soil pH-measured with a pocket pH meter. It relates to nutrient availability and plant growth.

Soil nitrate-measured by dipping nitrate test strips into the solution filtered from a 1:1 ratio soil/water mixture. Soil nitrate levels are important for plant growth and water quality.

Aggregate stability-determined by sieving soil in water and measuring the amount of aggregates greater than 0.25 mm in diameter that remain on the sieve. Aggregation is important in decreasing erosion, increasing water and air movement, and preserving organic matter in the soil.

Soil slaking-determined by putting soil fragments or aggregates in water and estimating the degree of slaking. Slaking is important to reducing erosion and development of surface crusts.

Earthworms-determined by counting the number of earthworms found in a square-foot hole. They are important in nutrient cycling and creating large pores for water and air movement in the soil.

Soil physical observations and estimations-shows how to observe soil structure and root patterns and to estimate topsoil depth, penetration resistance, and soil texture in the soil profile.

<u>These properties are important to the physical environment for plant growth.</u>

Water quality tests: (estimates salinity, nitrate and nitrite levels in water).

Electrical conductivity (EC)-measured with a pocket EC meter. It provides a measure of salinity (excess salts) in the water.

Soil pH-measured with a pocket pH meter. It relates to nutrient availability and plant growth.

Soil nitrate-measured by dipping nitrate test strips into the solution filtered from a 1:1 ratio soil/water mixture. Soil nitrate levels are important for plant growth and water quality.

Clarence Chavez, 2009

Soil Respiration Test:

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt2.pdf

Simplified version of procedure:

1: Drive Ring into Soil. Make sure that the soil has been wet for at least 6 to 24 hours.
2: Cover the Ring with plastic lid and wait for 30 minutes to allow CO_2 to accumulate in the ring.

3. Connect all parts of the Draeger Tube Apparatus.

- Connect the needle to one of the section of plastic tubing.
- On the other end of the same tubing connect the Draeger tub (remember to break open both ends of the Draeger tube before connecting and note that the arrow on the tube points away from the needle).
- Connect the second piece of plastic tubing to the other end of the Draeger tub.
- Connect the syringe to the end of the plastic tubing.

4. Insert the needle on the end of the syringe apparatus in to the stopper on one of the plastic lid on the ring after the 30 minute wait.

- Insert another needle at the other end of the stopper on the plastic lid on the ring. This will create air flow when the syringe is drawn.

5. Start drawing the syringe at a rate of 100cc over a 15 second span.
6. Record the soil Temperature and the percent of CO_2.

7. Enter the reading from the Draeger tube apparatus on the data worksheet.
8. Run the Soil Respiration Calculations.

(lb CO_2-C/acre/day) = PF x TF x (%CO_2 - 0.035) x 22.91 x H

PF = pressure factor = 1

TF = temperature factor = (soil temperature in Celsius + 273) ÷ 273

H = inside height of ring = 5.08 cm (2 inches)

Soil respiration (lbs CO2-C/a/d)
Class Soil condition:

0.0 - No soil activity Soil has no biological activity and is virtually sterile.

< 9.5 - Very low soil activity
Soil is very depleted of available organic matter and has little biological activity.

9.5 – 16 - Moderately low soil activity
Soil is somewhat depleted of available organic matter, and biological activity is low.

16 – 32 - Medium soil activity
Soil is approaching or declining from an ideal state of biological activity.

32 – 64 - Ideal soil activity
Soil is in an ideal state of biological activity and has adequate organic matter and active populations of microorganisms.

> 64 - Unusually high soil activity
Soil has a very high level of microbial activity and has high levels of available organic matter, possibly from the addition of large quantities of fresh organic matter or manure.

Conversion of Woods End Solvita respiration levels: (mg CO2/kg/wk) x 0.039 x (1.2 g/cm3) x (7.6 cm depth) ÷ 10 x 0.89 = (lbs CO2-C/acre/day). It was assumed all respiration was coming from a 7.6 cm depth with an average bulk density of 1.2 g/cm3 (Doran et al., 1997).

((0.5 X 0.39 X1.2 X7.6) / 10) X 0.89 = 0.015

Infiltration Test:

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt3.pdf

Simplified version of procedure:

1. Firm the Soil along the inside edges of the 6 inch ring used in the respiration test.
2. Line the inside of the ring with plastic wrap.
3. Pour 444 mL of distilled water (15 oz or 1 inch of water).

4. Remove the plastic wrap (slowly) and record the time.
    - Record the amount of time (in minutes) it takes for the 1" of water to infiltrate the soil.
    - Stop timing when the surface is just glistening.

5. If the soil **was not** at field capacity it is recommended to repeat the infiltration test.
    - In the same ring, perform Steps 2, 3, & 4 with a second inch of water.
    - On the Soil Data worksheet, enter the number of minutes elapsed for the second infiltration measurement.

Note: A second respiration measurement will be performed, set the lid loosely on the ring and leave it covered for preferably 16 to 24 hours (6-hour minimum) before beginning the second test (Chapter 2). (Remove lid and replace it before beginning the second soil respiration measurement).

Bulk Density Test:

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt4.pdf

Simplified version of procedure:

1. **Drive Ring into Soil**
   - Using the hand sledge and block of wood, drive the 3-inch diameter ring, beveled edge down, to a depth of 3 inches .
   - The exact depth of the ring must be determined for accurate measurement of soil volume. To do this, the height of the ring above the soil should be measured. Take four measurements (evenly spaced) of the height from the soil surface to the top of the ring and calculate the average. Record the average on the Soil Data worksheet.

2. Dig around the ring.
3. With the trowel underneath it, carefully lift it out to prevent any loss of soil.
4. Remove excess soil from the sample with a flat bladed knife.
5. The bottom of the sample should be flat
6. and even with the edges of the ring

Note: the remainder of the procedure should be done in a lab or office or home.

7. Weigh the soil sample in its bag.
8. Extract Subsample to Determine Water Content and Dry Soil Weight.
   - Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic
   - Bag and place it in a paper cup (a glass or ceramic cup may be used).
9. Weigh and Record Subsample in its cup. (also weigh the cup w/o subsample) and record.
10. Dry the subsample in a microwave.
    - Two or more, four minute cycles at full power.
    - When its weight does not change after a drying cycle, then it is dry.
11. Calculations (see page 13) in the soil quality test kit guide.

Soil texture	Ideal bulk densities (g/cm3)	Bulk densities that may affect root growth (g/cm3)	Bulk densities that restrict root growth (g/cm3)
sands, loamy sands	< 1.60	1.69 >	1.80
sandy loams, loams	< 1.40	1.63 >	1.80
sandy clay loams, loams, clay loams	< 1.40	1.60 >	1.75
silts, silt loams	< 1.30	1.60 >	1.75
silt loams, silty clay loams	< 1.40	1.55 >	1.65
sandy clays, silty	< 1.10	1.49 >	1.58
clays, some clay loams (35-45% clay) clays (> 45% clay)	< 1.10	1.39 >	1.47

Soil bulk density can serve as an indicator of compaction and relative restrictions to root growth

Note: soils with rock fragments have their own procedure.

Electrical Conductivity Test

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt5.pdf

Electrical conductivity, pH, and soil nitrate are all measured from the same soil subsample

Pocket Meter for Electrical Conductivity (EC)

Pocket Meter for pH

Simplified version of procedure:

1. Collect a 1/8 cup of the soil surface.
   - Place it in the plastic container.

2. Add 1/8 cup of distilled water to the plastic container.
   - Put the lid on the container and shake vigorously about 30 to 45 seconds.

3. Insert the EC pocket meter into the soil-water mixture. (**See Calibration Tip).**
   - Take the reading while the soil particles are still suspended in solution
   - Do not immerse the meter above the immersion level.
   - Allow the reading to stabilize.

4. Turn the meter off and thoroughly rinse the meter with distilled water.
   - Save the soil-water mixture for the pH measurement

Note: This test can also be performed on irrigation water samples.

EC (dS m-1 at 25 C)	Salinity class	Crop response	Microbial response
0 - 0.98	Non saline	Almost negligible effects	Few organisms affected
0.98 - 1.71	Very slightly saline	Yields of very sensitive crops restricted	Selected microbial processes altered (nitrification/de-nitrification)
1.71 - 3.16	Slightly saline	Yields of most crops Restricted	Major microbial processes influenced (respiration/ ammonification)
3.16 - 6.07	Moderately saline	Only tolerant crops yield satisfactorily	Salt tolerant microorganisms predominate (fungi, actinomycetes, some bacteria)
> 6.07	Strongly saline	Only very tolerant crops yield satisfactorily	A select few halophytic organisms are active

Soil pH Test

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt6.pdf

Simplified version of procedure:

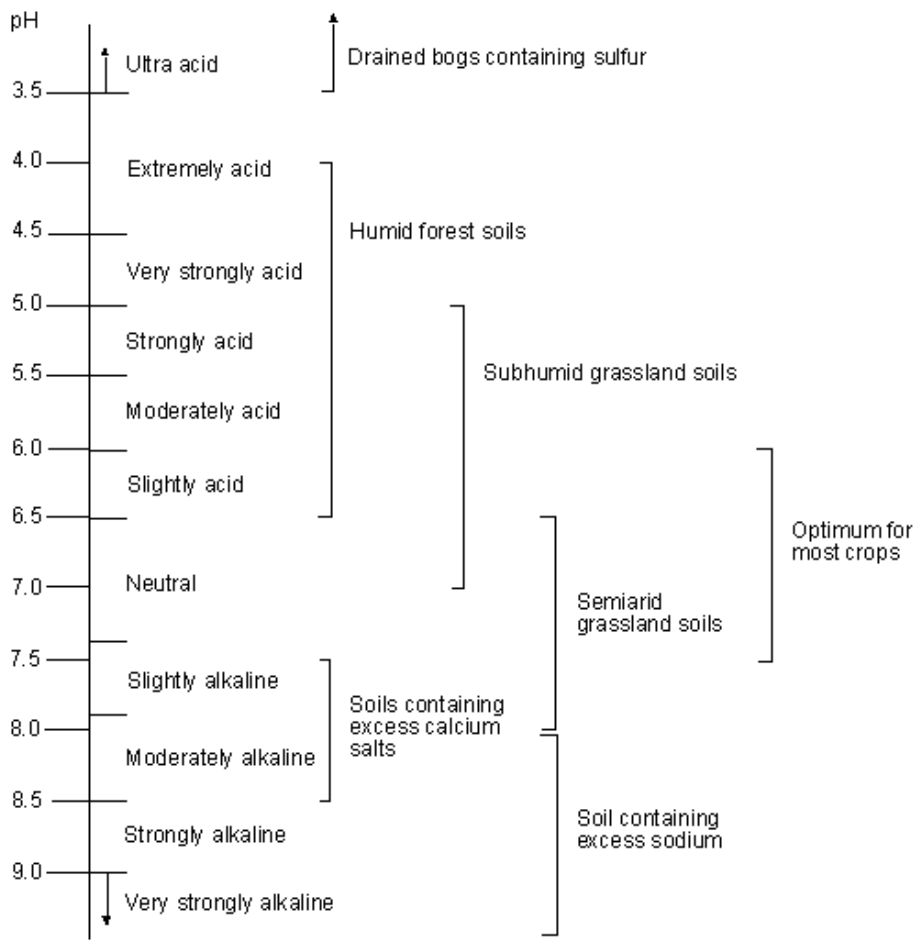
1 Collect a 1/8 cup of the soil surface.
- Place it in the plastic container.

2 Add 1/8 cup of distilled water to the plastic container.
- Put the lid on the container and shake vigorously about 30 to 45 seconds.

3. Insert the pH pocket meter into the soil-water mixture, (**See Calibration Tip).**
- Take the reading while the soil particles are still suspended in solution
- Do not immerse the meter above the immersion level.
- Allow the reading to stabilize.

5. Turn the meter off and thoroughly rinse the meter with

Note: this test can also be done on irrigation water samples.



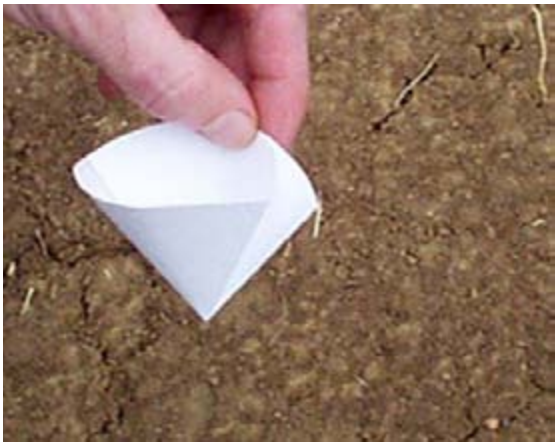
Soil Nitrate Test (NO_3^-)

Use the same sample prepared for the EC and pH tests to measure soil nitrates. **If you are starting with a fresh soil sample, read the introduction and follow Steps 1-3 in the EC Test Chapter on preparing the sample.**

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt7.pdf

Simplified version of procedure:

1. Fold the filter paper in half (into a cone).



2. Open the filter paper into the shape of a cone and push it quickly into the jar with the soil/water mixture.

3. **Wait** until about an eye dropper full of the solution has seeped through to the inside of the filter paper.

4. Using the eye dropper and on nitrate/nitrite test strip, place 1 or 2 drops of the filtered solution on each of the strips two pads. Note the time.

5. Record the time, after 60 seconds read the nitrate/nitrite test strip.
   - Estimate the nitrate amount according to the degree of color change.
   - Enter the value from the nitrate scale on the Soil Data worksheet in ppm

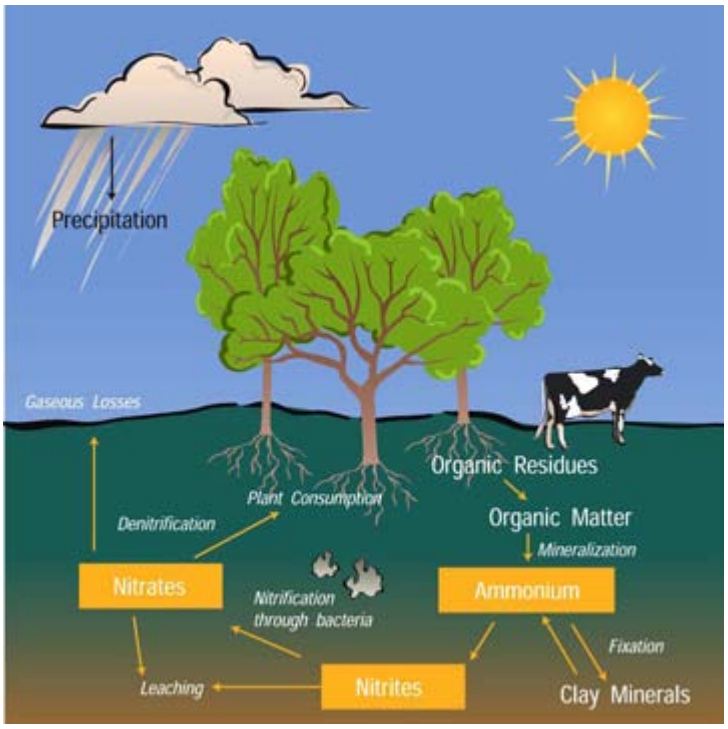
6. Using the value in ppm in the for Calculation (page 17 of the guide book).

Estimated (lb NO3-N/acre) =

$$\frac{\text{(ppm extract NO3-N) x (depth of soil sampled in cm) x bulk density x 0.89}}{10}$$

Note: this test can also be done on irrigation water samples.

Generalized soil nitrogen cycle:



Aggregate Stability

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt7.pdf

Simplified version of procedure:

Considerations: If the soil is moist, air-dry a sample before determining aggregate stability. When taking a soil sample, care should taken not to disrupt the soil aggregates.

1. Sieve an air dry soil sample.
    - Put about ¼ cup of soil in a 2mm sieve and shake
    - collecting the soil that is passing through.
    - Try and pass all of the soil particles. (no rock fragments).

2. weigh the sieved soil sample.
    - Record the weight on the worksheet

3. Weigh out 10 grams of the soil from the previous step.
    - Place the soil sample in the .25mm sieve.
    - Lay a terry cloth sheet with distilled water
    - Slow the soil to wet up slowly, wet the soil for five minutes.

4. Using the lid to the plastic container, place the sieve's with soil in to it.
    - Add distilled water to just above the soil sample.
    - Slowly move the sieve up and down in the water
    - Make sure the aggregates remain immersed in water on the upstroke.
    - After wetting, place the sieves on a dry terry cloth.

6. Place the sieve containing the aggregates on the drying apparatus
    - Allow the samples to dry using the low power setting.
    - Be careful when drying the soil to prevent particles from blowing out of the sieve.

7. After drying, weigh the sieve containing the aggregates.
    - Weight of the sieve and aggregates / recode the weight.

8. Prepare the calgon solution
    - Calgon solution: put about 2 tbsp of calgon per 1/2 gallon of tap water. (Or about 1/2 tbsp of calgon per 1 quart of tap water).
    - Let the aggregates in the sieve to soak for five minutes,
    - Moving the sieve up and down.
    - Only the sand particles should remain in the sieve.

9. Remove the excess water by first placing the sieve with the sand on a dry terry cloth.
    - Allow the sand to dry.
    - After drying, weigh the sieve containing the sand.
    - Record the weight of the sieve plus sand on the worksheet.

10. Complete the water stable aggregate calculations.

Table 8:

Organic Matter (%)	Water Stable Aggregates (%)	Clay (%)	Water Stable Aggregates (%)
0.4	53	5	60
0.8	66	**10**	65
1.2	70	20	70
2	75	30	74
4	77	40	78
8	81	60	82
12	85	80	86

Example: A soil with **2**% organic matter and **10**% clay, the suitable aggregate stability range (taken from Table 8) would be 65 to 75% water stable aggregates.

Slake Test

Full Description of the procedure is at:
http://soils.usda.gov/sqi/assessment/files/chpt9.pdf

Simplified version of procedure:

Considerations: The soil should be Air-Dry when running this test.

1. Carefully remove soil fragments or aggregates (little clods or ped) from the surface.
   - If there is a surface crust, carefully sample it.
   - Be careful not to shatter the soil fragments or ped's while sampling.
   - Collect 16 separate soil fragments/peds/clods.

2. Remove the baskets from the stability kit and set aside.
   - Fill the compartments in the box with water.
   - The water should be 2 cm deep
   - The temperature of water should be the same as the soil temperature.

3. Place soil fragments in the basket one at a time.
   - Lower one of the sieves into the box compartment filled with water.
   - Notice the soil fragment for five minutes.
   - After five minutes, raise the basket out of the water.
   - Then lower it back in to the bottom of the box compartment filled with water.
   - Repeat immersion four times (total of five immersions).
   - Refer to the stability class table below to determine classes…

Stability Class	Criteria for assignment to stability class (for "Standard Characterization")
0 -	Soil too unstable to sample (falls through sieve).
1 -	50 % of structural integrity lost within 5 seconds of insertion in water.
2 -	50 % of structural integrity lost 5 - 30 seconds after insertion.
3 -	50 % of structural integrity lost 30 - 300 seconds after insertion or < 10 % of soil remains on the sieve after 5 dipping cycles.
4 -	10 - 25% of soil remaining on sieve after 5 dipping cycles.
5 -	25 - 75% of soil remaining on sieve after 5 dipping cycles.
6 -	75 - 100% of soil remaining on sieve after 5 dipping cycles.

Earthworms

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt10.pdf

Simplified version of procedure:

Considerations: When examining the soil for earthworms, avoid places where their populations might be affected, such as near mulch or compost piles. The abundance of earthworms is usually patchy within a field and varies with season. Therefore, count earthworms several times during a season and use the average to gauge changes from year to year.

1. Dig a soil pit, about 12 inches wide, 12 inches long and 12 inches deep.
    - Try to minimize the number of cuts with the shovel to avoid damage to the earthworms.
    - Pile the soil to one side of the hole/pit.

2. Separate and count the number of earthworms.
    - Record the total number of earthworms (those found in the hole).
    - You could also use a mustard solution to flush out any additional earthworms
    - Mustard solution (2 tbs., of mustard powder in ½ gallon of tap water).
    - If you use the mustard solution, you should rinse the earthworms in water before returning them to the soil.

Note: About 10 earthworms per square foot of soil are generally considered a good population. Populations generally do not exceed 20 per square foot of soil generally.

Note: the action of microorganisms (breaking down plant and animal residues and creating soil organic matter and humus as a binding material).

Soil Physical Observations and Estimations.

Full Description of the procedure is at: http://soils.usda.gov/sqi/assessment/files/chpt11.pdf

Simplified version of procedure:

1. Dig a hole about 1 foot deep and 1 foot wide.

2. Measure the depth of the topsoil. Look for color changes from the soil surface downward through the soil pit face.
   - Record the darker surface layer.

3. Take a look at the roots in the hole.
   - The roots should be well branched with lots of fine root hairs.
   - Look for restrictive layers, the roots will tell you.

4. Feel for restrictive layers, with metal rod.
   - Feel for the resistance as you push the rod into the soil.

A penetrometer can also be used, it measures PSI.

5. Look at the soil structure and measure in the different layers. Soil structure affects the retention and transmission of water and air in the soil as well as the mechanical properties of the soil. Observing and describing soil structure in the field is subjective and qualitative.
   - Record the type, size and grade of the structural aggregates for each layer.
   - Type: Granular, Blocky, Platy, Single grain, or Massive.
   - Size: Platy or Blocky - Fine, medium or thick.

Soil processes involved in the development of soil structure are as follows (Rowell, 1994):

· Drying and wetting, which cause shrinking and swelling, creating cracks and channels;

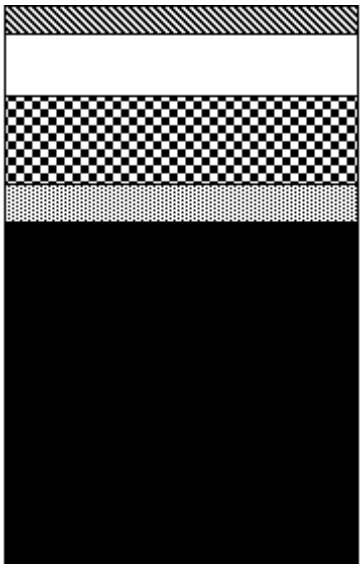
· Freezing and thawing, which creates spaces as ice is formed;

· The action of roots (removal of water, release of exudates (organic materials), and formation of root channels);

· The action of soil animals (moving soil material around, creating burrows, and bringing soil

Figure 4. General position of soil compaction zones in cultivated systems (Bennie, 1996)

CULTIVATED LAYER (9 inches) Zone 1 through 4:



Zone 1: Surface crusting, which may impede seedling emergence and water infiltration.
Zone 2: Low impedance zone for roots; loosened by tillage.

Zone 3: Plowed or deeply loosened cultivated soil that has been re-compacted by vehicular traffic.
LOWEST LAYER OF THE PROWLAYER (10 TO 14 inches) ZONE 4
Zone 4: Subsoil compaction by wheel traffic and tillage implement-soil interactions during tillage.

SUBSOIL LAYER (15 inches plus) ZONE 5
Zone 5: May contain high mechanical impedance due to inherent actors, such as duripans, fragipans, ortstein layers, petrocalcic layers etc. which may occur near the surface if topsoil is not present.

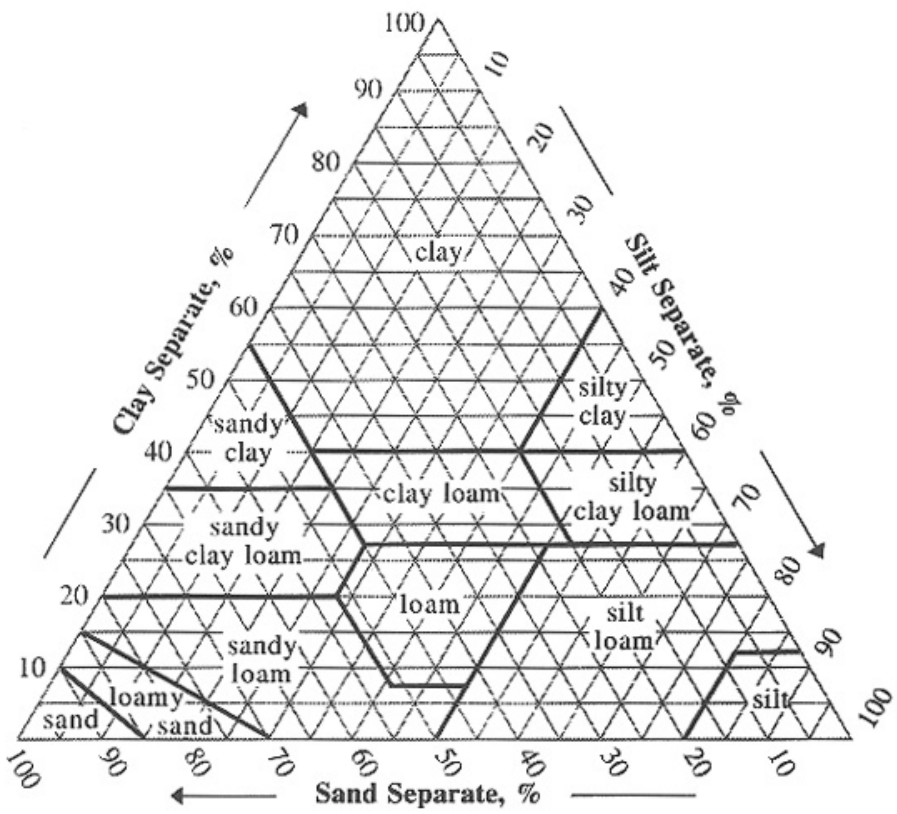
Penetration resistance depends strongly on the soil water content: the dryer the soil, the greater the resistance to penetration. Therefore, the water content of the soil should be noted when taking a measurement. Penetration resistance is best determined when the soil is at field capacity, which is a uniform condition that can be reproduced from season to season.

6. Texture can be determined by feel. Place approximately ¼ cup of soil in palm. Add water drop wise and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and moldable, like moist putty.

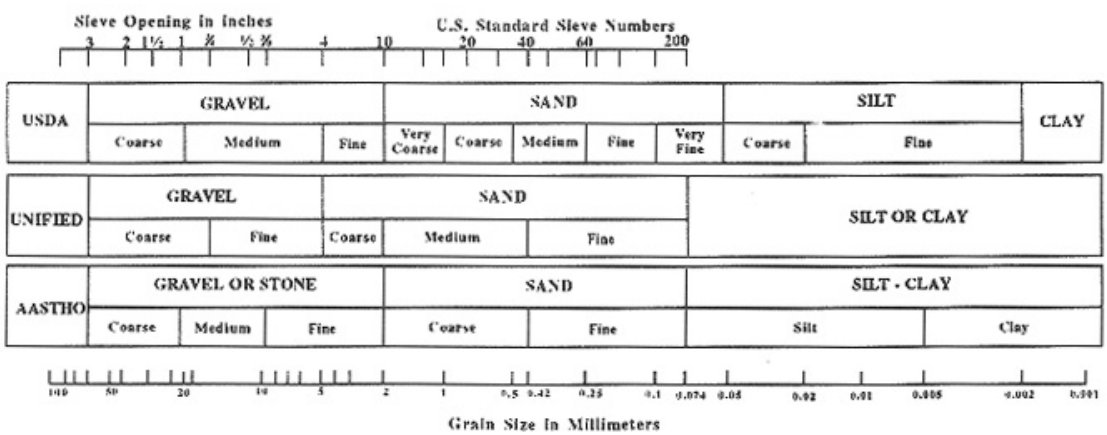
- Sand - feels gritty. - 2.0 mm (very coarse) to .05 mm (very fine);
- Silt - feels smooth like baby powder or foot powder. - .05 mm to .002 mm;
- Clay – feels sticky. - Smaller than .002 mm.

Twelve Soil Textural Classes. Definitions of the 12 textural classes are based on the relative proportion, or weight, of these three particle classifications. Sandy soil, for example, has a greater proportion of sand particles than silt or clay. In reading the textural triangle (Figure 5), any two particle size percentages will locate the textural class. For example, a soil containing 20% clay and 40% sand is located in the *loam* textural class (Figure 5).

USDA Soil Texture Triangle.

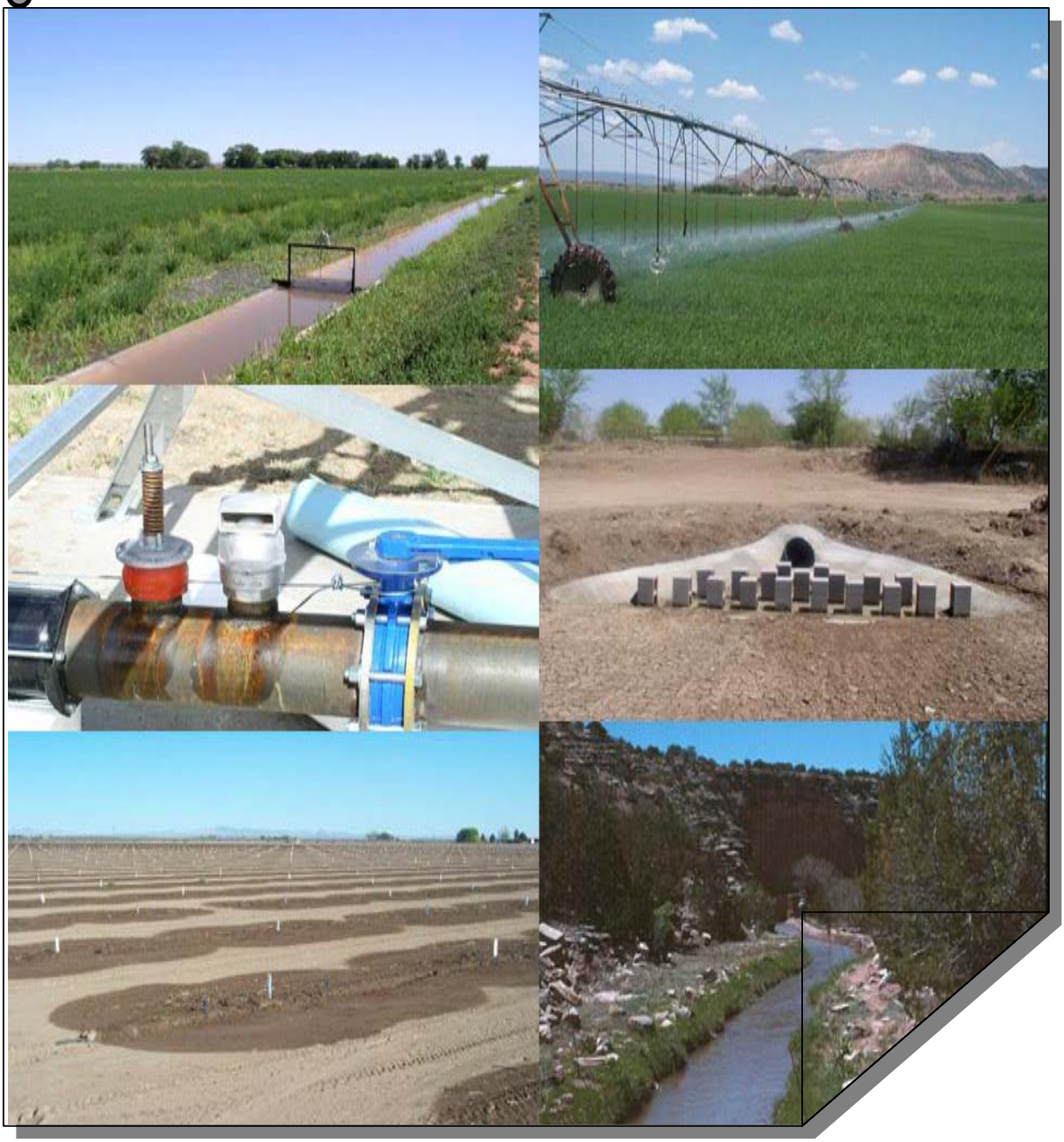


COMPARISON OF PARTICLE SIZE SCALES



Station 4 - Irrigation Water Management

NM Integrated Water Management Handbook



IWM – 1. - Planning for Irrigation Water Management

The Natural Resources Conservation Service provides technical assistance in planning and designing irrigation systems with landowners. This planning process includes the following steps:

1. Identify resources of concern,
2. Determine irrigator objectives,
3. Inventory resources,
4. Analyze resource data,
5. Formulate irrigation alternatives,
6. Evaluate alternatives,
7. Document decisions,
8. Water user implements irrigation plan,
9. Follow-up.

CONSIDERATIONS FOR PLANNING AN IRRIGATION SYSTEM

Some of the major items to consider in planning an on-farm irrigation system are:

- Water Quantity Available – How much water is available for irrigation and when is it available?
- Water Quantity Needed – Is there adequate water available to meet the demand of the crops to be grown while considering the irrigation efficiency?
- Water Quality – Is the salinity, pH and mineral content of the water compatible with the planned crops and irrigation method?
- Irrigation Method – Is the proposed irrigation method compatible for the crop to be grown?
- Soil Type – Is the proposed irrigation method compatible with the soil type, in terms of infiltration rate, water holding capacity, and stratification that may exist in the soil profile?
- Opportunities/Strategies for Saving Water – community/watershed meetings, action plans – see example this section

On lands used primarily for field and forage crop production, orchards, and ornamental crops, the producer's inputs and management practices may have a significant impact on the current and future conditions of Soil, Water, Air, Plant, Animal and Human (SWAPA + H). As well as soils, rainfall and other natural resource information, cropland inventory needs to include a description of current crops, crop rotations, tillage operations, nutrient and pest management inputs, livestock numbers and class, available equipment, and the timing and management of other important activities. The best source for this information is the client and is best collected when the client and the planner work together on-site in the planning area (field, tract or farm). The overall Cropland Inventory Worksheets (Agronomy Tech Note 70, http://www.nm.nrcs.usda.gov/technical/tech-notes/agro/ag70.doc) and the IWM Inventory (in the following section) can be used.

Linda Scheffe, 2008

(IWM – 2) IWM Resource Inventory

Producer: _____ Crop: _____ Variety: _____ Crop Rotations: _____ Predominant Soil(s): _____ Soil Texture: _____ Acres: _____ Field width (ft.) x Field length (ft.) ÷ 43,560 = _____Acres Irrigation System Type and Delivery System (concrete ditch, pipe, surface, sprinkler, drip, etc.): _____ Irrigation Application Efficiency: _____ %	Field #: _____ Planting Date: _____ Seeding Rate: _____ Row Spacing: _____ Soil Structure (e.g., granular, blocky, platy, etc.) _____ Soil Intake Family: _____ Soil Moisture Monitoring (Type):_____ Source of irrigation water (canal, well, spring, other): _____ Water Quality (ECiw & SAR): _____	IWM Evaluation Date: _____ Harvest date(s): _____ Yield: _____ Quality: _____ Soil Drainage (Rapid, Moderate and Slow): _____ Number of Irrigations/yr.: _____ Average time (hrs)/irrigation: _____ Net application depth (in.): _____ Total Water Applied to Crop: _____ When is irrigation water available (e.g., on demand, fixed schedule, rotation, pumped etc.): _____

Sprinkler System Description:

Mainline Size (in)		Revolution/ Set Time / Speed of Gun (hr)	
Lateral Spacing (ft)		Operating Pressure of Line (psi)	
Sprinkler Head Spacing (ft)		Pressure Regulator Rating (Y or N)	
Nozzle Size (in)		Nozzle output (gpm)	

Surface System:

Length of field(s) (ft)		Grade at end of field (Circle one)	Flat Moderate Steep
Furrow/Border Spacing		System Type	Siphon tubes Gated pipe High flow turnouts
% slope of land		Delivery System (type and condition)	
Turnout (cfs)			

Subsurface Drip:

Depth of Tubing (in)		Inch per day application rate (in/day)	
Emitter Size (gal/hr)		Design Efficiency (%)	
Emitter Spacing (in)		Type of filtration (explain)	

Record Field Observations such as runoff, water-induced soil erosion, deep percolation, shallow water table, soil stratification, clay lenses, shallow soils over coarse sand/cobbles/rocks, tail water, ponding, crusting, surface sealing, steep slopes, compaction, salt crust, etc.: _____

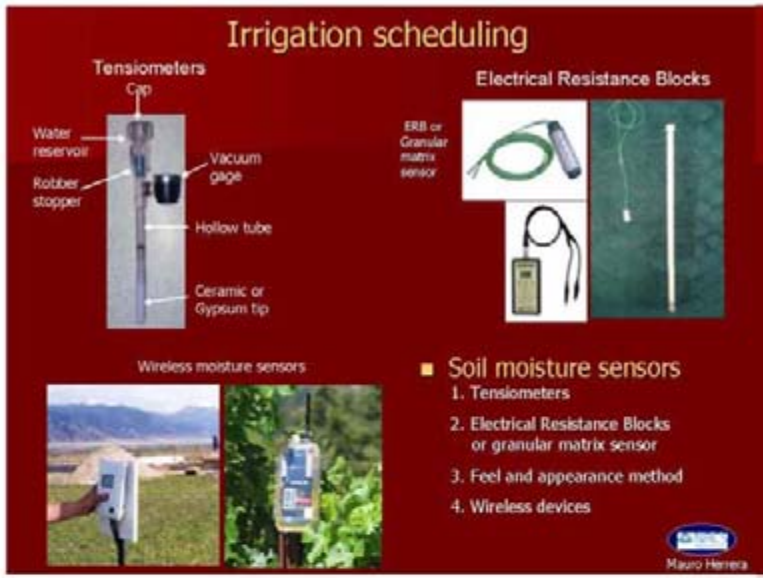
(IWM – 3) Soils Data Interpretation Table for IWM Planning

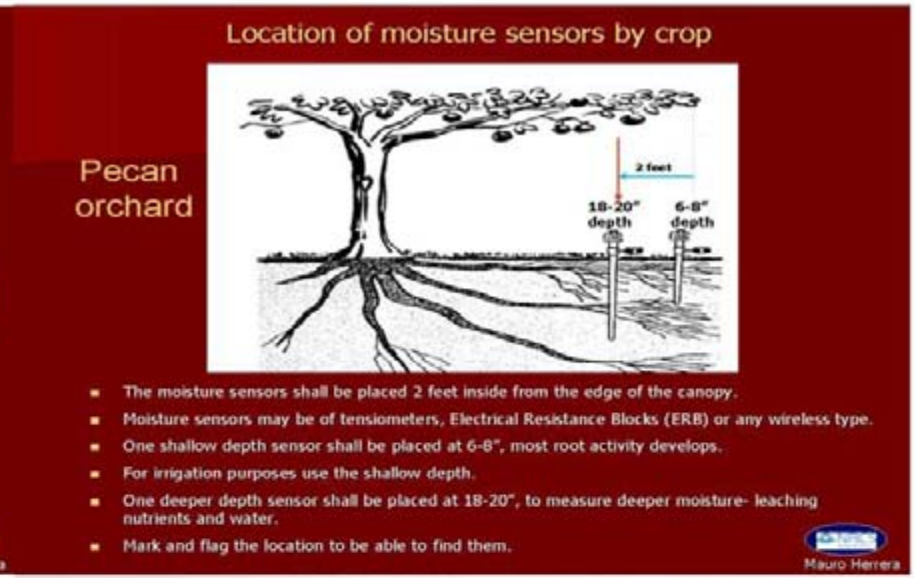
Soil Texture	% Sand	% Silt	% Clay	CEC Range (meq/100g)	Bulk Density (g/cm^3)	Soil weight (Million lbs. per ac-ft)	Soil Solids		Unavail-able Water		Available Water		Soil Porosity at FC	
							% Vol.	in/ft	% Vol.	in/ft	% Vol.	in/ft	% Vol.	in/ft
Sands	86 - 98	2 - 14	2 - 8	2 – 6	1.65	4.48	62.3	7.47	2.5	0.3	4.17	0.5	31.1	3.73
Loamy Sands	72 - 88	2 - 28	2 - 14		1.6	4.35	60.4	7.25	7.0	0.84	8.33	1.0	24.3	2.91
Fine Sands	86 - 98	2 - 14	2 - 8		1.65	4.48	61.5	7.38	10.2	1.22	10.4	1.25	17.9	2.15
V. F. Sands	86 - 98	2 - 14	2 - 8		1.65	4.48								
Loamy F. Sands	72 - 88	2 - 28	2 - 14		1.6	4.35								
Loamy V. F. Sands	72 - 88	2 - 28	2 - 14		1.6	4.35								
Sandy Loam	46 - 84	2 - 48	2- 18	3 – 8	1.56	4.24	58.8	7.06	12.3	1.48	12.5	1.5	16.3	1.96
Fine Sandy Loam	46 - 84	2 - 48	2 - 18		1.56	4.24								
V. F. Sandy Loam	46 - 84	2 - 48	2 - 18		1.53	4.16	55.4	6.65	16.2	1.94	16.7	2.0	11.8	1.41
Loam	26 - 50	30 - 48	10 - 26	7 – 15	1.42	3.86								
Silt Loam	2 - 48	52 - 78	2 - 26	10 –19	1.46	3.97								
Silt	2 - 18	82 - 98	2 - 10		1.47	3.99								
Sandy Clay Loam	46 - 78	2 - 26	22 - 36		1.4	3.8	50.2	6.02	20.0	2.4	18.3	2.2	11.5	1.38
Silty Clay Loam	2 - 18	42 - 70	28 - 38		1.27	3.45								
Clay Loam	22- 44	18 - 50	28 - 38		1.32	3.59								
Sandy Clay	46 - 62	2 - 16	38 - 54		1.33	3.61	47.9	5.75	21.5	2.58	16.7	2.0	13.9	1.67
Silty Clay	2 - 18	42 - 58	42 - 58		1.23	3.34								
Clay	2 - 44	2 - 38	42 - 98	15 - 30	1.25	3.4								

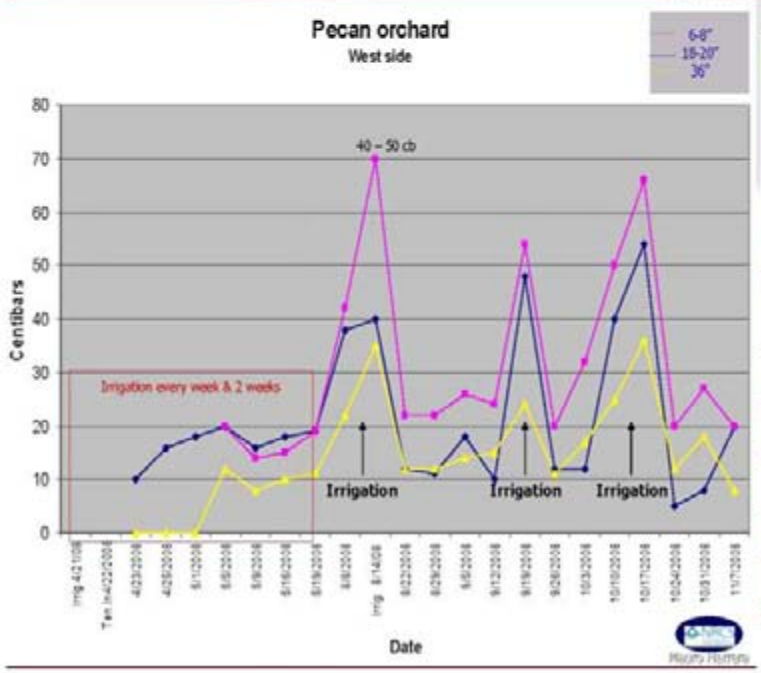
- V = Very & F = Fine
- Particle diameter (mm) for Sand, Silt & Clay: Very Coarse Sand (2.0 - 1.0), Coarse Sand (1.0 - 0.5), Med. Sand (0.5 - 0.25), Fine Sand (0.25 - 0.1), Very Fine Sand (0.1 - 0.05), Silt (0.05 - 0.002) and Clay (< 0.002)
- Cation Exchange Capacity (CEC) taken from the Western Fertilizer Handbook, 2nd ED., 1995
- Bulk Density (Ref. bulk density calculator @ Pedosphere.com)
- Unavailable Water (Ref. Figure 1-9 of the National Engineering Handbook; Section 15 – Irrigation)
- Available Water (Ref. NRCS Salinity Management for Soil & Water; Table 5.1, page 5.10)
- FC = Field Capacity.

NOTE: Soil structure is evaluated for its effect on downward movement of water: Single grain (rapid), Granular (rapid), Blocky (moderate), Prismatic (moderate), Platy (slow) and Massive (slow). The Soil Intake Family (typically 0.1 thru 2.0) is used in IWM field evaluations and irrigation system design. Irrigation Water Quality (i.e., Electrical Conductivity of irrigation water (ECiw) in dS/m & Sodium Adsorption Ratio (SAR)) is evaluated for its potential detrimental effects on plant moisture availability and water infiltration.

rudy garcia 2008







NRCS Soil moisture table by type of soil

Important: Monitoring the rate of change of the soil moisture tension, is just as important as the actual reading used to schedule the irrigation.	Coarse: Sands, f. sands, very f. sands, Loamy sands, Loamy f. sands & Loamy very fine sands	Moderately Coarse: Sandy loam fine Sandy loam	Medium: v. f. Sandy loam Loam Silt loam Silt	Moderately Fine: Sandy clay loam Silty clay loam Clay loam	Fine: Sandy clay Silty clay Clay
	*Approximate Soil Moisture Sensor readings at the time of Irrigation (Units: centibars - cb) (NOTE: Irrigation scheduling is typically based on sensor readings in the 6" – 9" root zone depth)				
	30 – 40 cb	40 – 50 cb	50 – 60 cb	60 – 70 cb	70 – 80 cb
	Enter the date of Irrigation and the sensor reading (read at least once a week)				
April	6-8" depth 36" depth 21/09 Irrigation 22/09 Tens. Inst. 25/09 16 cb 2 cb			18/09 25 cb 28 25/09 26 30 30/09 38 40	
May	2/09 18 4 10/09 22 6				
June					
July					
August					
September					
October					

Irrigation scheduling will depend of the type of soil

- Very coarse Sandy soil may be irrigated at 30-40 centibars.
- Coarse Sandy loam , fine Sandy loam soil irrigated at 40-50 centibars
- Medium Sandy loam, Silt loam irrigated at 50-60 centibars.
- Fine Sandy clay loam , Silt or Clay loam irrigate at 60-70 centibar
- Fine Sandy clay, Silt or clay irrigate at 70-80 centibars.

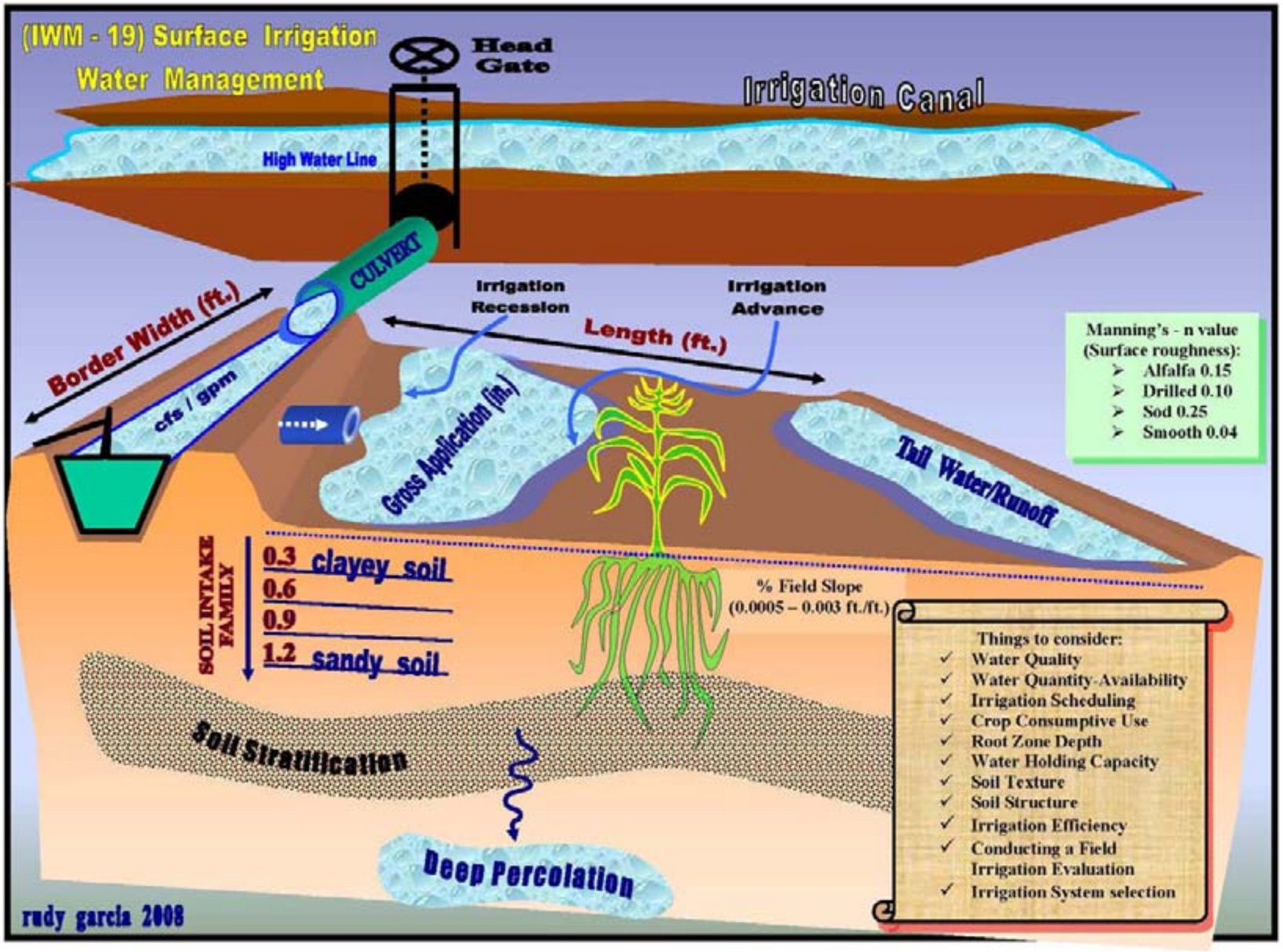
(IWM – 8) Gross Crop Irrigation Water Requirement GUIDE

	Steps to Calculate the Crop Irrigation Water Requirement	Enter Results	Example Calculation (Alfalfa)	Results	NM IWM Manual References & Notes:
STEP 1	Fc = ECe(ct)/ECiw Fc = Ratio of the Crop Threshold Salinity ($ECe_{(ct)}$) to the Electrical Conductivity of irrigation water (ECiw). Units: dS/m		Fc = 2.0/1.0 = Alfalfa ECe(ct) = 2.0 dS/m ECiw = 1.0 dS/m	2.0	➢ Crop Salt Tolerance Table for NM ➢ Irrigation Water Quality Sampling
STEP 2	$LF = 0.3086/Fc^{1.702}$ LF = Leaching Fraction (for conventional irrigation; e.g. surface irrigation).		LF = $LF = 0.3086/2.0^{1.702}$ LF = 0.3086/3.254	0.095	➢ Salinity Assessment GUIDE for Selected Crops
STEP 3	NIR = ETc/(1 – LF) NIR = Net Irrigation Requirement (in.) ETc = Crop Evapotranspiration (in.)		NIR = NIR = 40.01/(1 – 0.095) NIR = 40.01/0.905 ETc = 40.01 inches for Alfalfa	44.21"	➢ NM Crop Consumptive Use Requirements (NRCS FOTG – Section 1: Irrigation Guide for NM)
STEP 4	Ea = Irrigation needed (in.) ÷ Irrigation applied (in.) Ea = Irrigation Application Efficiency		Ea = Ea = 2.06/2.5 2.06" (Irr. needed) ÷ 2.5" (Irr. applied) <u>Irr. applied:</u> 7.5 (cfs) x 2.0 (hrs.) ÷ 6.0 (acres) = 2.5" applied.	0.824 (82.4%)	➢ Irrigation Water Req. Guide (e.g. 3' root zone & Silt Loam soil @ 10% LF = 2.06" needed) ➢ QT = DA Calculations for Assessing IWM Requirements
STEP 5	Fg = NIR/Ea Fg = Gross Irrigation Application needed		Fg = Fg = 44.21/0.824	53.7"	➢ The calculation of Fg is used in the Planning & Design of Irrigation Systems and the development of IWM Plans
STEP 6	(# Irr. /yr.) x (in. applied/Irr.) = Total in. applied/ac./yr. (Note: in. applied/Irr. is based on an avg.)		13 Irrigations x avg. of 2.5"/Irr. = (e.g., Irrigated field approximately every 2-wks on a fixed schedule (Apr. – Oct.)	32.5"	➢ Amount of Irr. Water applied can differ substantially from the planned Gross Irrigation application needed
STEP 7	Fg – (Total in. applied/ac./yr.) = (Note: evaluate reason(s) for the difference between Fg & Total in. applied/ac./yr.)		53.7" (Fg) – 32.5" (Total in. applied/ac./yr.) =	21.2"	➢ In this example, it is clear that consumptive use is not being met.

ECe(ct) is taken from a soil saturation extract & the ECiw value is taken from a water test (EC units: dS/m = mmhos/cm = mS/cm).

The LF equation used for High Frequency Irrigation is: $LF = 0.1794/Fc^{3.0417}$ (e.g. Drip irrigation)

rudy garcia 2008


(IWM - 19) Surface Irrigation
Water Management
Head Gate
Irrigation Canal
High Water Line
CULVERT
Border Width (ft.)
cfs / gpm
Irrigation Recession
Irrigation Advance
Length (ft.)
Gross Application (in.)
Tail Water/Runoff
Manning's - n value (Surface roughness):
Alfalfa 0.15
Drilled 0.10
Sod 0.25
Smooth 0.04
SOIL INTAKE FAMILY
0.3 clayey soil
0.6
0.9
1.2 sandy soil
% Field Slope (0.0005 – 0.003 ft./ft.)
Soil Stratification
Deep Percolation
Things to consider:
Water Quality
Water Quantity-Availability
Irrigation Scheduling
Crop Consumptive Use
Root Zone Depth
Water Holding Capacity
Soil Texture
Soil Structure
Irrigation Efficiency
Conducting a Field Irrigation Evaluation
Irrigation System selection
rudy garcia 2008