LA-UR-06-3792

4047

Technical Area 49 Material Disposal Area AB Moisture Monitoring

TA49

Data Review and Path Forward

May 2006

Los Alamos
NATIONAL LABORATORY
EST. 1943
The World's Greatest Science Protecting America

NNSA

Purpose of Moisture Monitoring at TA-49

- Determine the effect to vadose zone processes due to the removal of the asphalt cover over MDA AB, Area 2, and emplacement of an evapotranspiration (ET) cover during the 1998 IM.

- Monitor subsurface moisture across TA-49 for comparison of disturbed and undisturbed vadose zone conditions.

Monitoring Program History

1998 – Asphalt cover removed, ET cover installed.

2000 – Three neutron access holes installed within the ET cover along with 4 TDR probes. Moisture monitoring of 11 neutron access holes occurs on a monthly basis.

2002 reduce sampling frequency from monthly to bi-monthly

2003 – Moisture monitoring frequency is reduced to bi-monthly with the approval of NMED.

2003-2004 – Six additional boreholes are added to the moisture monitoring program.

2005 – Moisture monitoring occurred during only three of the required six periods due to neutron probe repairs.

2006 – Neutron logging has occurred only once this fiscal year (November 2005), and will not be resumed until NES operational requirements for the site have been completed. The anticipated completion of these requirements is June 2006.

Data Points

- 17 Neutron Access Holes, divided accordingly:
  - Three located within the ET cover;
  - Three located within unused test shaft locations not drilled, or drilled and backfilled with crushed tuff; and,
  - Eleven located in surrounding locations, through undisturbed conditions.

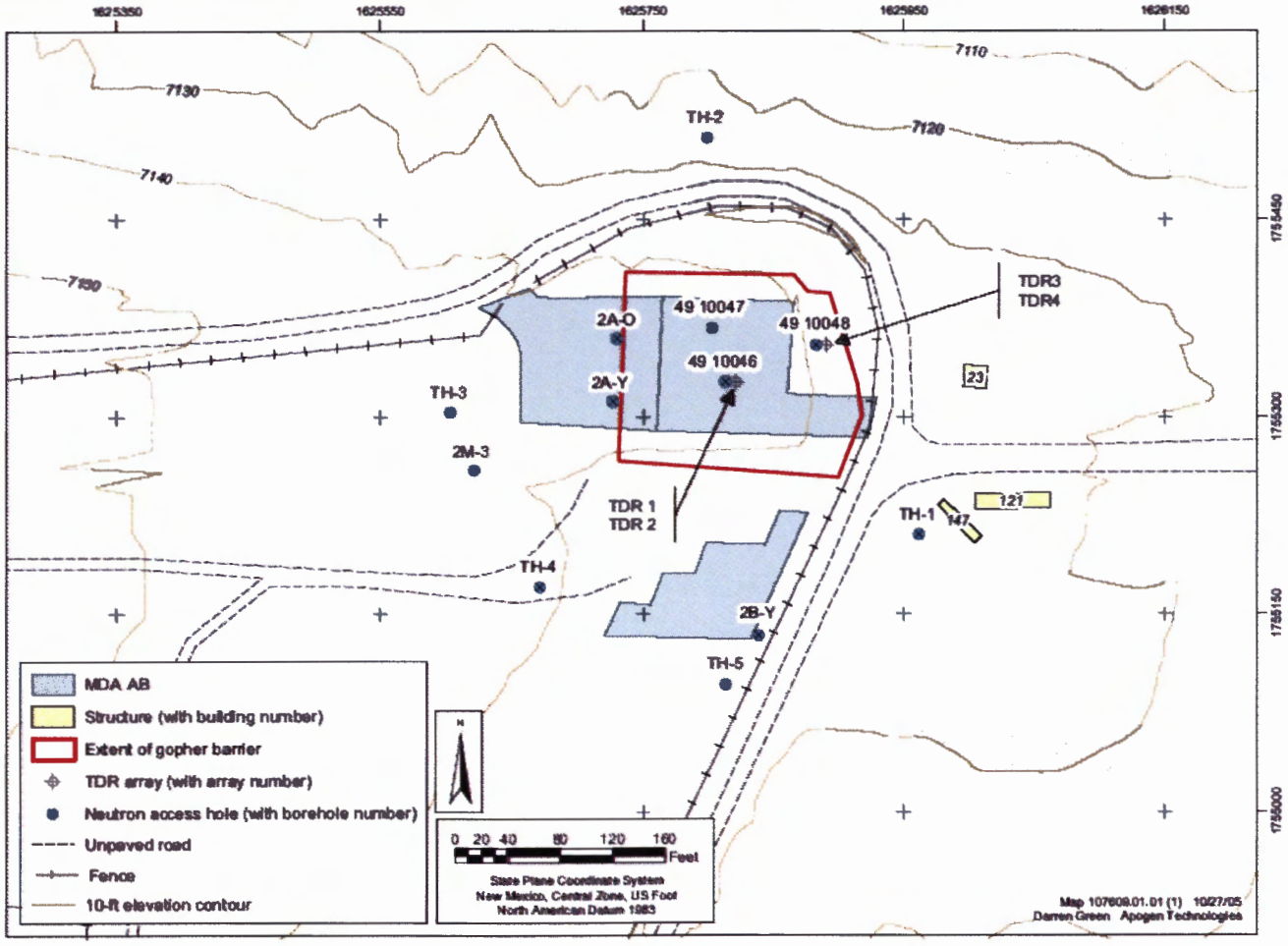
Data Points

- Four TDR probes
  - Two probes at each of two locations, collocated with neutron access holes, within the ET cover.

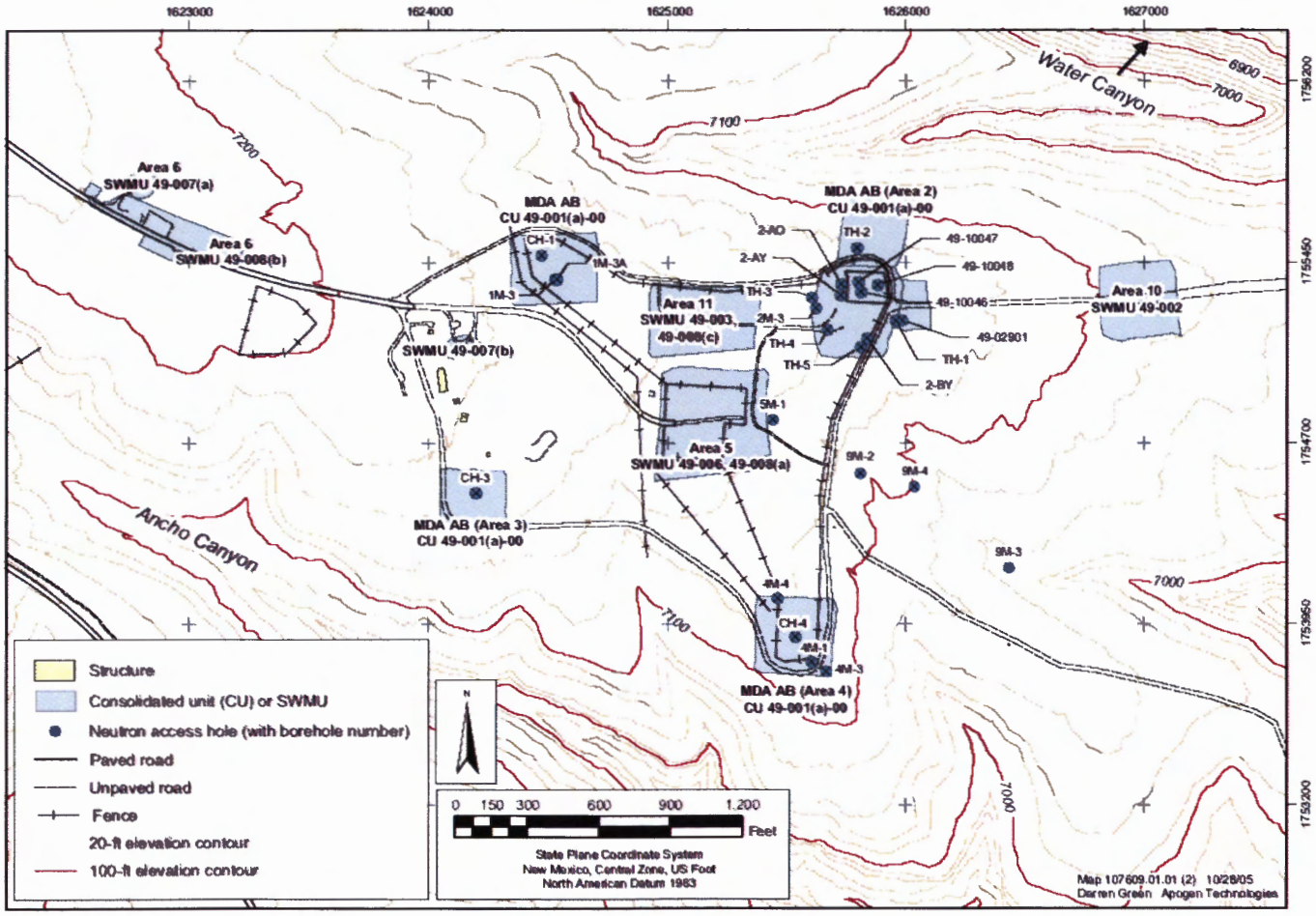
Location	TDR Number	Array Type	Depth (ft)
Central	TDR1	Vertical, within soil overlaying Bandelier Tuff	6.0
	TDR2	Horizontal, at bottom of topsoil	0.5
Eastern	TDR3	Vertical, within El Cajete pumice formation	10.0
	TDR4	Horizontal, at bottom of topsoil	0.5

  - Temperature and moisture content are recorded on 12 hr. intervals by a datalogger.

Data Points


1625350
1625550
1625750
1625950
1626150
7110
7130
7120
7140
7150
TH-2
TDR3
TDR4
2A-O
49 10047
49 10048
49 10046
2A-Y
TH-3
2M-3
23
TDR 1
TDR 2
TH-1
147
121
TH-4
2B-Y
TH-5
1755450
1755300
1755150
1755000
MDA AB
Structure (with building number)
Extent of gopher barrier
TDR array (with array number)
Neutron access hole (with borehole number)
Unpaved road
Fence
10-ft elevation contour
N
0 20 40 80 120 160
Feet
State Plane Coordinate System
New Mexico, Central Zone, US Foot
North American Datum 1983
Map 107609.01.01 (1) 10/27/05
Darren Green Apogen Technologies

Data Points


1623000
1624000
1625000
1626000
1627000
1756200
1755450
1754700
1753950
1753200
Water Canyon
Ancho Canyon
6900
7000
7100
7200
Area 6
SWMU 49-007(a)
Area 6
SWMU 49-008(b)
MDA AB
CU 49-001(a)-00
CH-1
1M-3A
1M-3
SWMU 49-007(b)
Area 11
SWMU 49-003,
49-008(c)
MDA AB (Area 2)
CU 49-001(a)-00
TH-2
2-AO
2-AY
TH-3
2M-3
TH-4
TH-5
TH-1
2-BY
49-10047
49-10048
49-10046
49-02901
Area 10
SWMU 49-002
5M-1
Area 5
SWMU 49-006, 49-008(a)
5M-2
5M-4
5M-3
CH-3
MDA AB (Area 3)
CU 49-001(a)-00
4M-4
CH-4
4M-1
4M-3
MDA AB (Area 4)
CU 49-001(a)-00
Structure
Consolidated unit (CU) or SWMU
Neutron access hole (with borehole number)
Paved road
Unpaved road
Fence
20-ft elevation contour
100-ft elevation contour
N
0 150 300 600 900 1,200
Feet
State Plane Coordinate System
New Mexico, Central Zone, US Foot
North American Datum 1983
Map 107609.01.01 (2) 10/28/05
Darren Green Apogen Technologies

Data Points

- Other data available for comparison:
  - Laboratory measured hydrgeologic properties of core samples from:
    - 49-10046
    - 49-10047
    - 49-10048
    - 49-02906
    - 49-02907
    - CH-2
  - Sporadic pre-1999 neutron logging results from:
    - 49-02906
    - 49-02907
    - CH-2

Data Points

not measured

- Water balance data contributing to the analysis of subsurface moisture content trends:
  - Meso-scale climate variations
  - Weather
  - Vegetation growth on the ET cover

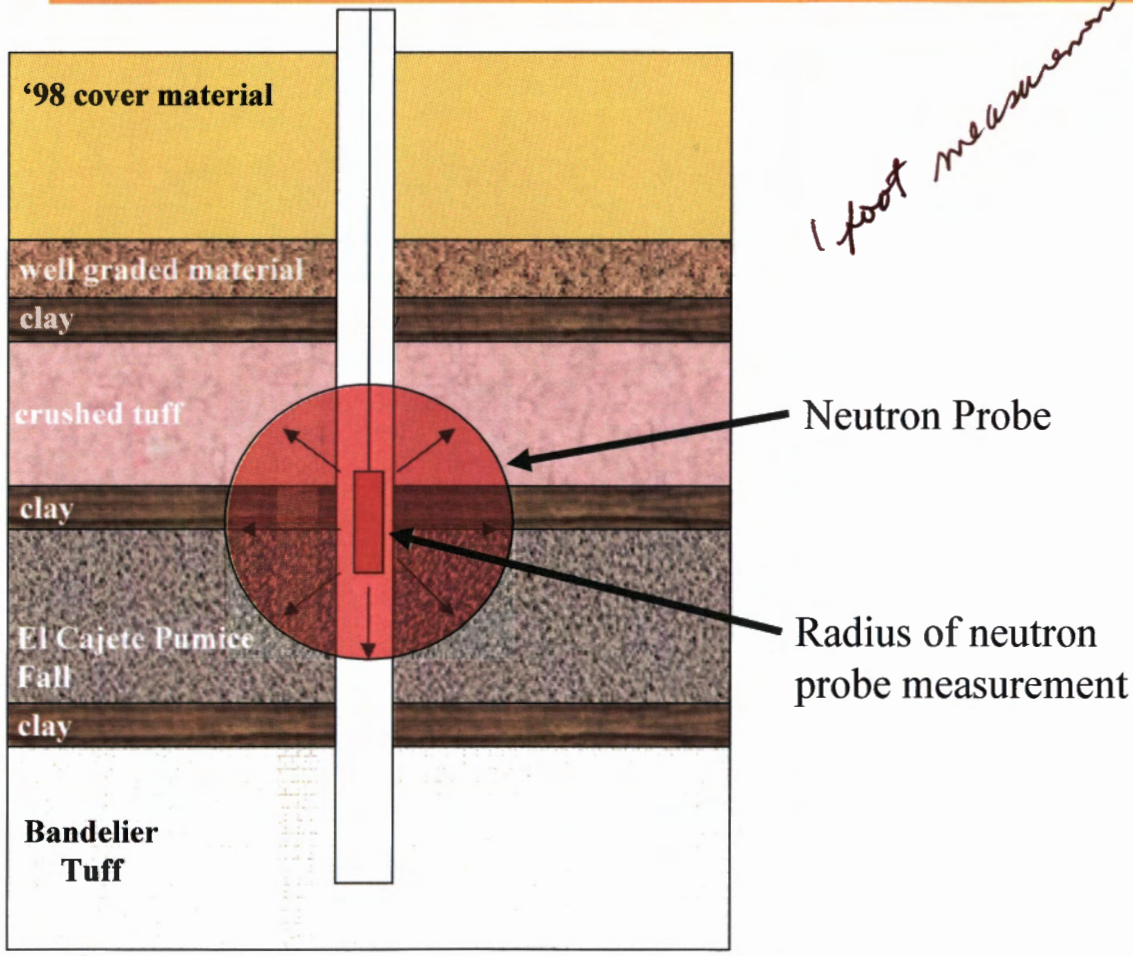
Volumetric vs. Gravimetric Moisture Content

Neutron Probe and TDR measure volumetric moisture content

- Volumetric moisture content
  - Volume of liquid water per volume of soil
  - Determined from gamma ray attenuation, neutron ray attenuation, or time domain reflectometry

- Gravimetric moisture content
  - Mass of water per mass of dry soil
  - Determined by laboratory measurements (weighing), and through estimation of mass and volume.

Neutron Probe vs. TDR



1 foot measurements

Neutron Probe Measurement Method

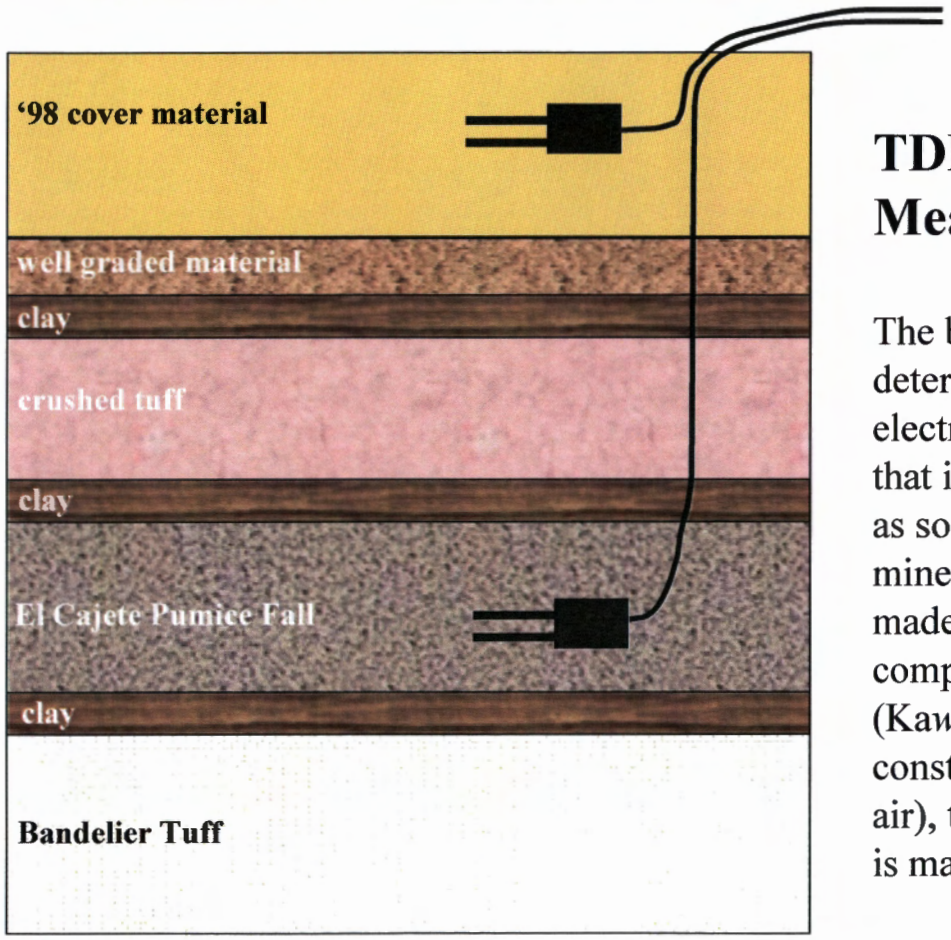
The Am-241:Beryllium source emits neutron radiation into the geologic media. The high energy neutrons are moderated by colliding with hydrogen atoms (moisture). Only the low-energy, moderated neutrons are detected by a Helium-3 detector. The higher the count of moderated neutrons, the higher the moisture content.

Neutron Probe vs. TDR

Neutron Probe

- *Advantages*
  - Robust and accurate
  - One probe allows for measuring at different soil depths
  - Large soil sensing volume (sphere of influence with 4-16 in. radius, depending on moisture content)
  - Not affected by salinity or air gaps
- *Drawbacks*
  - Safety hazard, since it implies working with radiation. Even at 16 in. depth, radiation losses through soil surface have been detected
  - Requires soil-specific calibration
  - The sphere of influence may vary with the soils physical properties
  - Higher potential for field user error

Neutron Probe vs. TDR



TDR
Measurement Method

The bulk soil permittivity (or dielectric constant) is determined by measuring the time it takes for an electromagnetic pulse to travel along a transmission line that is surrounded by soil. In a composite material, such as soil (i.e., made up of different components like minerals, air and water), the value of the permittivity is made up by the relative contribution of each of the components. Since the dielectric constant of liquid water (K_{aw} = 81) is much larger than that of the other soil constituents (e.g. K_{as} = 2-5 for soil minerals and 1 for air), the total permittivity of the soil or bulk permittivity is mainly governed by the presence of liquid water.

Neutron Probe vs. TDR

TDR

- *Advantages*
  - Accurate
  - Soil specific-calibration is usually not required
  - Easily expanded by multiplexing
  - Wide variety of probe configurations
  - Minimal soil disturbance
  - Relatively insensitive to normal salinity levels
- *Drawbacks*
  - Potentially limited applicability under highly saline conditions or in highly conductive heavy clay soils
  - Soil-specific calibration required for soils having large amounts of bound water
  - Relatively small sensing volume (about 1.2 inch radius around length of waveguides)
  - Susceptible to lightening

Statistical Analysis of Neutron Data

- Student's t-test analysis
  - Tracks, and determines the significance of, trends in moisture content in depth intervals over time.
  - Can determine positive or negative trends over long periods of time, even though data may be confounded with short term cyclical (e.g. seasonal) trends.

Statistical Analysis of Neutron Data

- Student's t-test analysis
  - Methodology
    - Average moisture contents on a selected interval, 2 ft for shallow holes and 5 ft for deep holes, for each neutron logging event.
    - Utilize a 95% confidence interval to complete the statistical analysis for each depth interval in the access hole for the entire time span of data available.
    - Results will indicate if there is significant change, and the direction of change (i.e. increasing or decreasing moisture).

Statistical Analysis of Neutron Data

- Utilize the r correlation coefficient calculated from the series of data points at a given depth interval to generate the t-statistic:

$$t_r = r * \text{sqrt}(n-2/1-r^2)$$

- Then test for significance:

If $t_r > t_c$ then significant

t_c based on level of confidence; function of n

- If the trend is significant, then the slope of the data is calculated to determine whether it is increasing or decreasing.

Statistical Analysis of Neutron Data

- Example trend analysis calculations

T-critical,
Alpha = 0.05, 2 sided
$t_c = 2.365$

Date	8/6/2003	9/25/2003	1/27/2004	3/19/2004
n	1	1	1	1
1 to 5	16.23	20.23	17.99	18.66
6 to 10	8.68	8.99	8.85	8.94
11 to 15	12.04	12.55	12.67	12.46
16 to 20	14.43	14.91	15.51	14.94
21 to 25	15.28	15.97	16.28	15.72
26 to 30	13.52	13.74	14.06	13.63
31 to 35	13.72	13.89	14.22	13.82
36 to 40	14.92	15.19	15.08	14.76
41 to 45	13.37	13.47	13.59	12.80

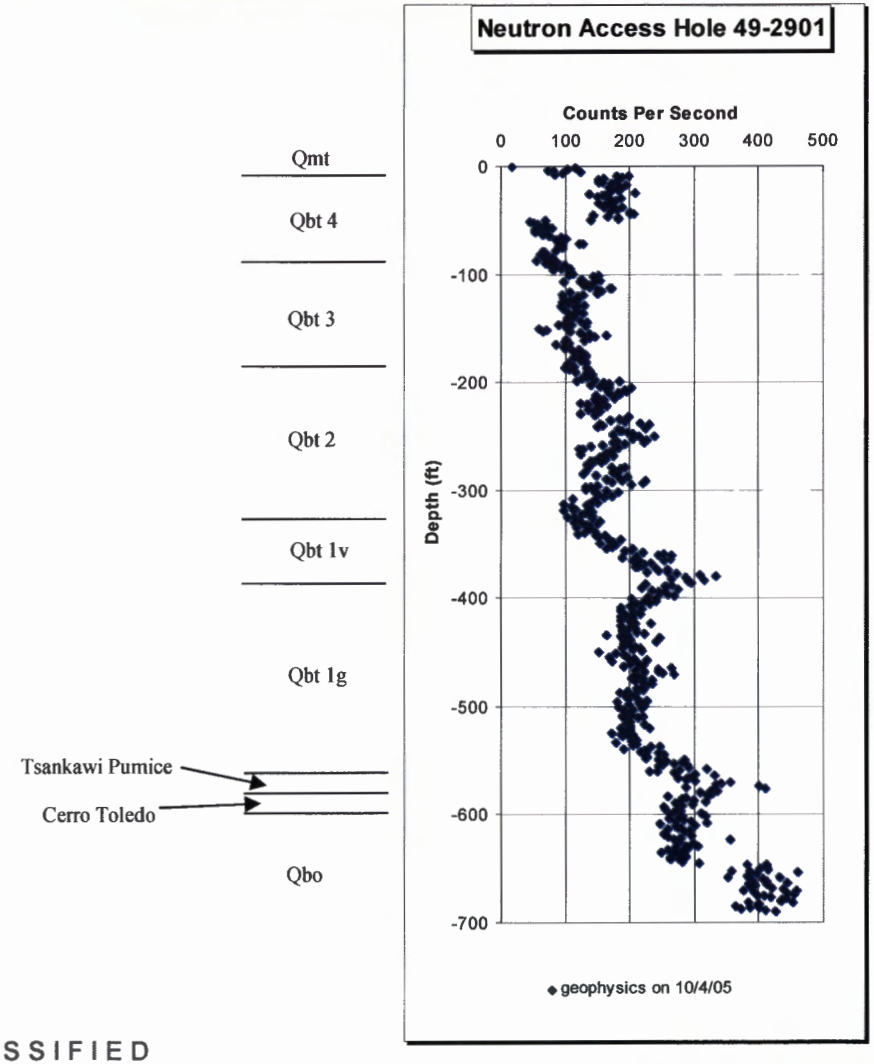
11/29/2005	R Squared	R	n	t_r	Sig. Slope?	Slope (%vol/day)
1			9			
22.25	0.0605	0.2460		0.6715	FALSE	
11.82	0.7396	0.8600		4.4588	TRUE	0.00531
11.53	0.5427	0.7367		2.8823	TRUE	-0.00160
14.15	0.5027	0.7090		2.6600	TRUE	-0.00180
15.73	0.4165	0.6454		2.2353	FALSE	
13.13	0.6190	0.7868		3.3725	TRUE	-0.00093
13.57	0.4160	0.6450		2.2328	FALSE	
14.63	0.3590	0.5992		1.9802	FALSE	
13.05	0.0141	0.1186		0.3161	FALSE	

Statistical Analysis of Neutron Data – 2005 Annual Report (LA-UR-05-8256)

Neutron Access Hole Number	Moisture Trending Results
TH-1	Analysis shows a decreasing moisture trend from 1 to 111 ft.
TH-2	Analysis shows a decreasing moisture trend from 6 to 104 ft.
TH-3	Analysis shows a decreasing moisture trend from 61 to 85 ft, 96 to 105 ft.
TH-4	Analysis shows a decreasing moisture trend from 1 to 10 ft, and 21to 90 ft.
TH-5	Analysis shows a decreasing moisture trend from 6 to 114 ft.
2B-Y	Analysis shows no significant change in moisture trends.
2A-Y	Analysis shows an increasing moisture trend from 6 to 27 ft. thin crushed tuffs
2A-O	Analysis shows an increasing moisture trend from 26 to 59 ft.
49-10046	Analysis shows a decreasing moisture trend from 7 to 13 ft.
49-10047	Analysis shows a decreasing moisture trend from 7 to 12 ft.
49-10048	Analysis shows a decreasing moisture trend from 5 to 12 ft.
1M-3	Analysis shows a decreasing moisture trend from 16 to 18 ft.
1M-3A	Analysis shows an increasing moisture trend from 6 to 10 ft. and a decreasing moisture trend from 21 to 30 ft.
2M-3	Analysis shows no significant change in moisture trends.
4M-3	Analysis shows an increasing moisture trend from 11 to 15 ft.
4M-4	Analysis shows no significant change in moisture trends.
5M-1	Analysis shows an increasing moisture trend from 6 to 10 ft.

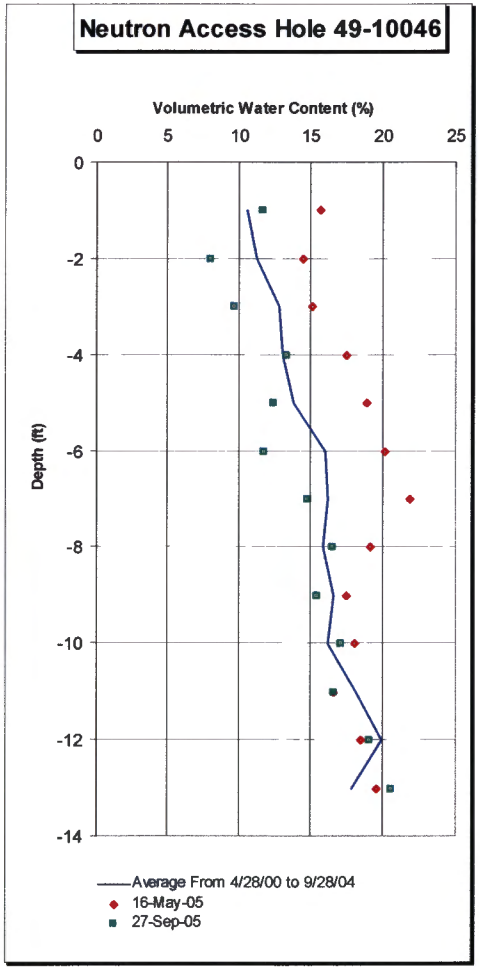
Individual Borehole Plots of Moisture Content

- Plots visually display the variability of moisture contents in the near surface, and stability of deep moisture contents.
- Higher moisture contents at depth in deep neutron access holes at TA-49 is a factor of rock unit porosity and water vapor content.



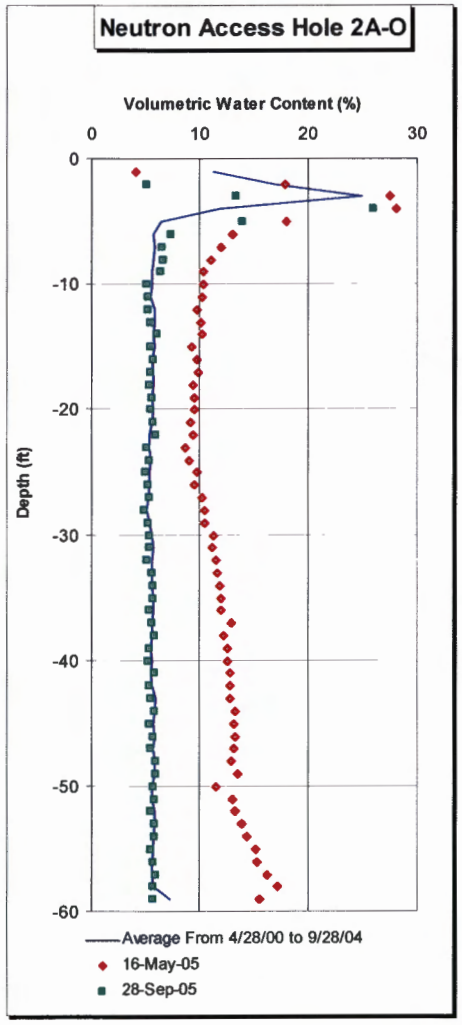
Individual Borehole Plots of Moisture Content

- Shallow holes may always have increasing moisture content with depth, even though the moisture content is decreasing over any given depth interval as indicated by statistical analysis.



Individual Borehole Plots of Moisture Content

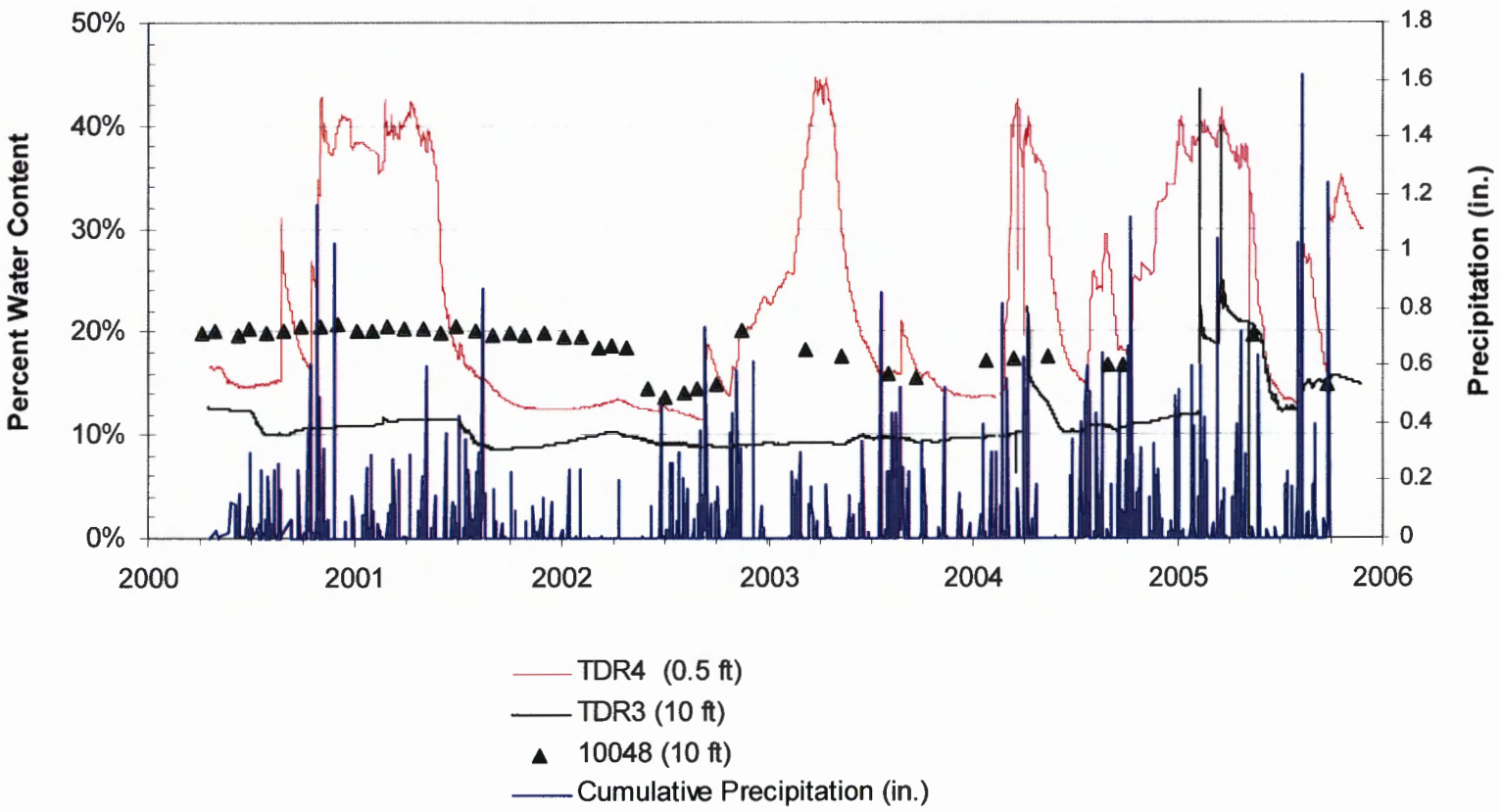
- Although there may be times when the moisture content has increased markedly due to large precipitation events, these moisture levels quickly return to normal levels.
  - Neutron access hole 2A-O (at right) shows the response, inside of a unused, backfilled shaft, to the increased precipitation of winter 2005. The subsequent recovery to normal as measured in the following fall is also displayed.



TDR Data

- TDRs located near the surface of the ET material have indicated that moisture penetrates easily into this zone during most precipitation events.
  - Moisture contents >40% can occur at this depth indicating saturated soil conditions
- Deep TDRs (10 ft below surface of ET cover) indicate that moisture contents are very stable at <10%, and only very large precipitation events provide enough moisture to penetrate to this depth.
  - The two events which caused deeper infiltration in 2005 were a 0.97 in rainfall event, and the melting of 1.31 in. of water equivalent snowfall.
  - Increases in the moisture content measured at the deep TDRs return to values <10% within 2 months.
  - Pulses may be reduced or eliminated as the ET cover vegetation matures.

TDR Data


50%
40%
30%
20%
10%
0%
Percent Water Content
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Precipitation (in.)
2000
2001
2002
2003
2004
2005
2006
TDR4 (0.5 ft)
TDR3 (10 ft)
10048 (10 ft)
Cumulative Precipitation (in.)

TDR Data

- The TDR system has recently been upgraded with new wiring, and the PVC conduit has been replaced with steel conduit. In addition, the data logger is now equipped with a telemetry system allowing for remote access of the data. Previous problems with lost data have been resolved.

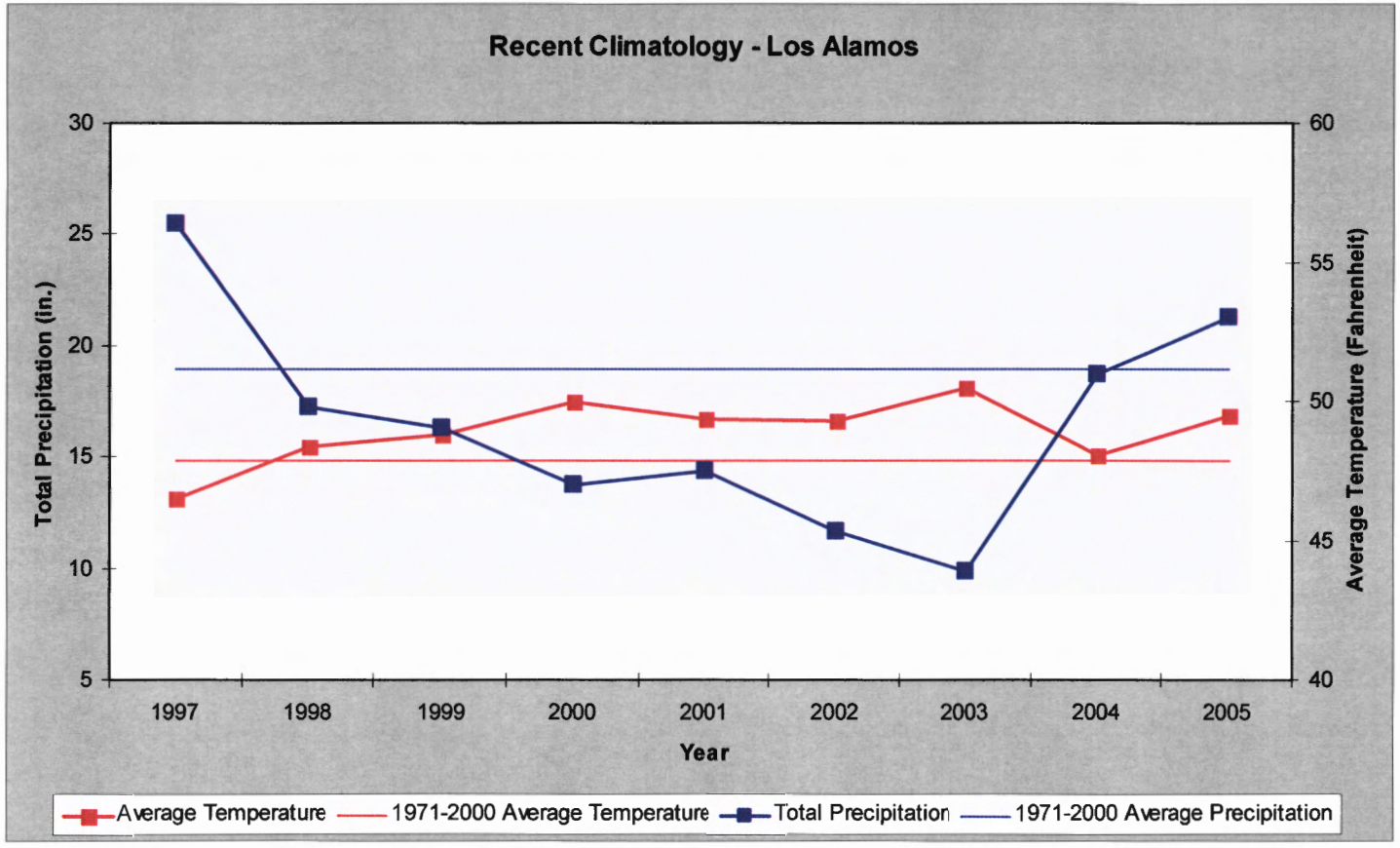
Hydrogeologic Properties of ET Cover Material

- Hydrogeologic analysis of the ET cover material indicates an average calculated porosity of 38.75 %.
  - Therefore, a conservative estimate of saturation (i.e. water content equals porosity) is a volumetric moisture content of 35%.
  - 35% volumetric water content has only been achieved in the shallow TDRs (0.5 ft in depth) five times over the last 5 years.
  - 35% volumetric water content has been achieved twice in one of the deep TDRs (TDR 3, 10 ft in depth, within El Cajete Pumice). Both occurrences were in the late winter / early spring of 2005.

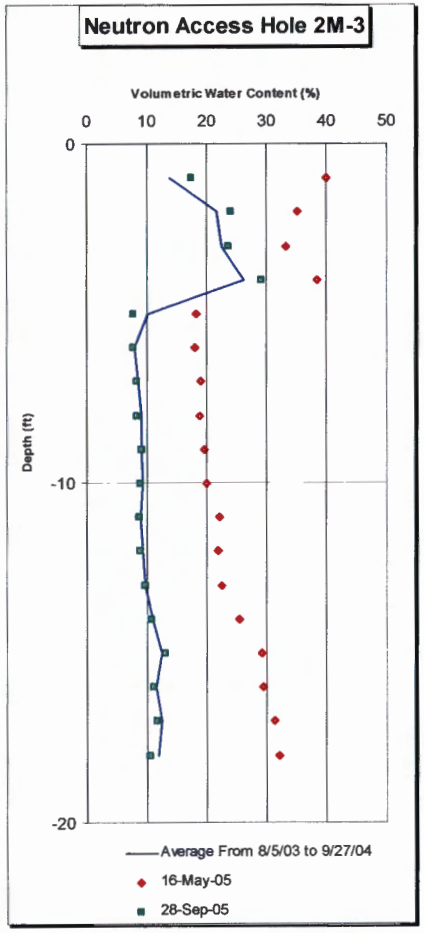
Climate and Weather

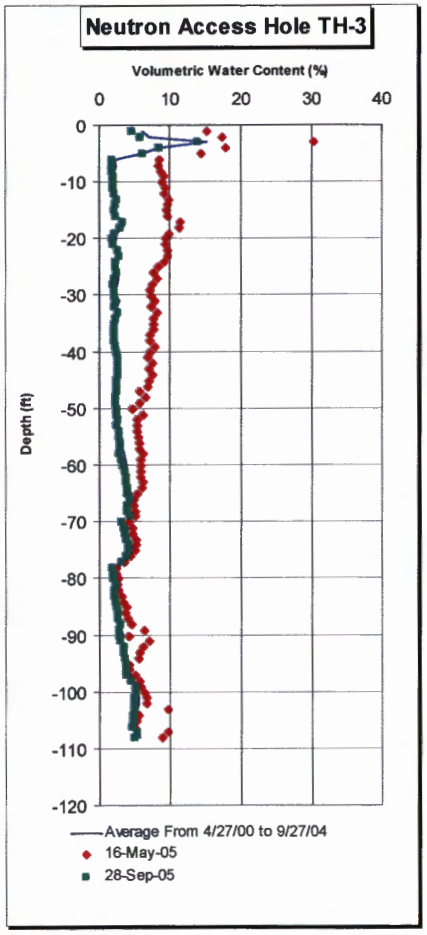
- Climatologic trends at Los Alamos since removal of the Area 2 asphalt cover:
  - Increasing temperatures – up to 2.5 degrees Fahrenheit above average.
  - Decrease in precipitation – except for 2005, an "El Nino" year
- The long term decrease in subsurface moisture content may be partially attributed to the El Nino year of 1997-1998 (immediately before the removal of the asphalt cover), followed by a period of warm and relatively dry weather 1999-2003. However, after the increase moisture contents associated with another El Nino winter in 2004-2005, subsurface moisture contents had returned to normal by September of 2005.

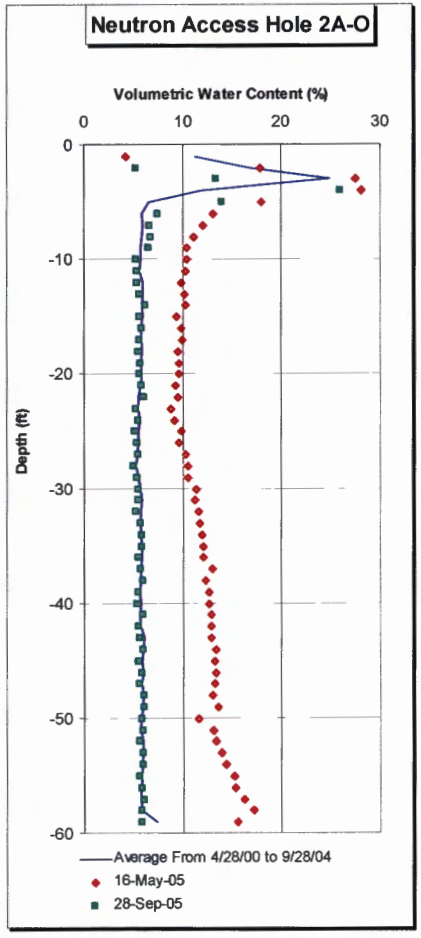
Climate and Weather

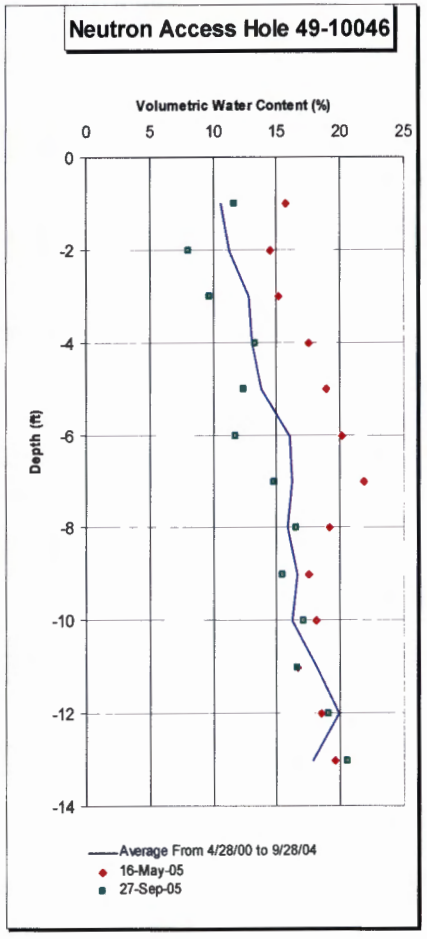


Climate and Weather









Cover Vegetation

- The amount of cover vegetation varies with the amount of precipitation leading up to the growing season, and can be quite variable.

	2004	2005
Spring		
Summer		

Conclusions

- Neutron log and TDR data indicate that subsurface moisture levels fluctuate in the near surface (<10 ft) and remain constant at greater depth, as expected in a moisture-limited, semiarid climate.

- Subsurface moisture contents, as measured in neutron access holes 49-10046, 49-10047, and 49-10048, within and below the ET cover material, have continued to decrease since the installation of these neutron access holes in 1998.

<5% decrease

- Moisture contents have not yet returned to those seen in undisturbed areas, but will continue to do so with continued growth of vegetation and increased transpiration. Current models indicate that this may take hundreds of years (Birdsell et al., 2005).

- Subsurface conditions, in both disturbed and undisturbed locations, return to normal soon after a large season influx of precipitation.

Conclusions

- No climatic conditions have existed, since the emplacement of the ET cover, that created significant periods of increased recharge and decreased evaporation. No increase in moisture content due to strong seasonal trends has lasted more than 6 months.

- Climatic conditions that reduce recharge and increase evaporation have prevailed, reducing moisture contents to depths over 100 ft in undisturbed locations.

- The greatest change in the subsurface moisture contents at Area 2 occurred directly after removal of the asphalt cover. The primary long term controls of subsurface moisture content beneath the ET cover are climactic conditions and precipitation.

Recommendations

- Increase TDR data recording frequency to 6 hour intervals.
  - Monitor weekly
  - Precipitation events creating near saturated conditions (35%), as measured by TDR probes in the near surface (0.5 ft depth), will trigger neutron logging of the three access holes located within the cover.

If you saw a slug then continue to log for every few days to see a slug moving through system.

- Discontinue scheduled neutron logging events

- Discontinue quarterly/annual reporting
  - Data collected after October 1, 2005 will be reported in the Historical Investigation Report contained in the Investigation Work Plan for MDA AB (due to NMED in Oct. 2007), and in the subsequent Investigation Report.

Recommendations

- Targeting periods of increased moisture input into the system will allow for better analysis of ET cover performance, and timely investigation of potential deeper infiltration.

- The use of the TDR system to monitor for increased subsurface moisture and drive additional logging events is consistent with previous NMED guidance, as stated in their 2003 letter of approval for the bimonthly moisture monitoring frequency:

  …if there is a significant change in storm events and rainfall patterns or an increase in moisture content, NMED may require more frequent or additional monitoring to investigate the affect subsurface water percolation and consequent changes in soil moisture content.