Department of
Land, Air and Water Resources
University of California, Davis

Ecohydrology of Vernal Pools:

Applications to Conservation, Management, Restoration and Monitoring

Presentation by

Niall McCarten

Overview of Presentation

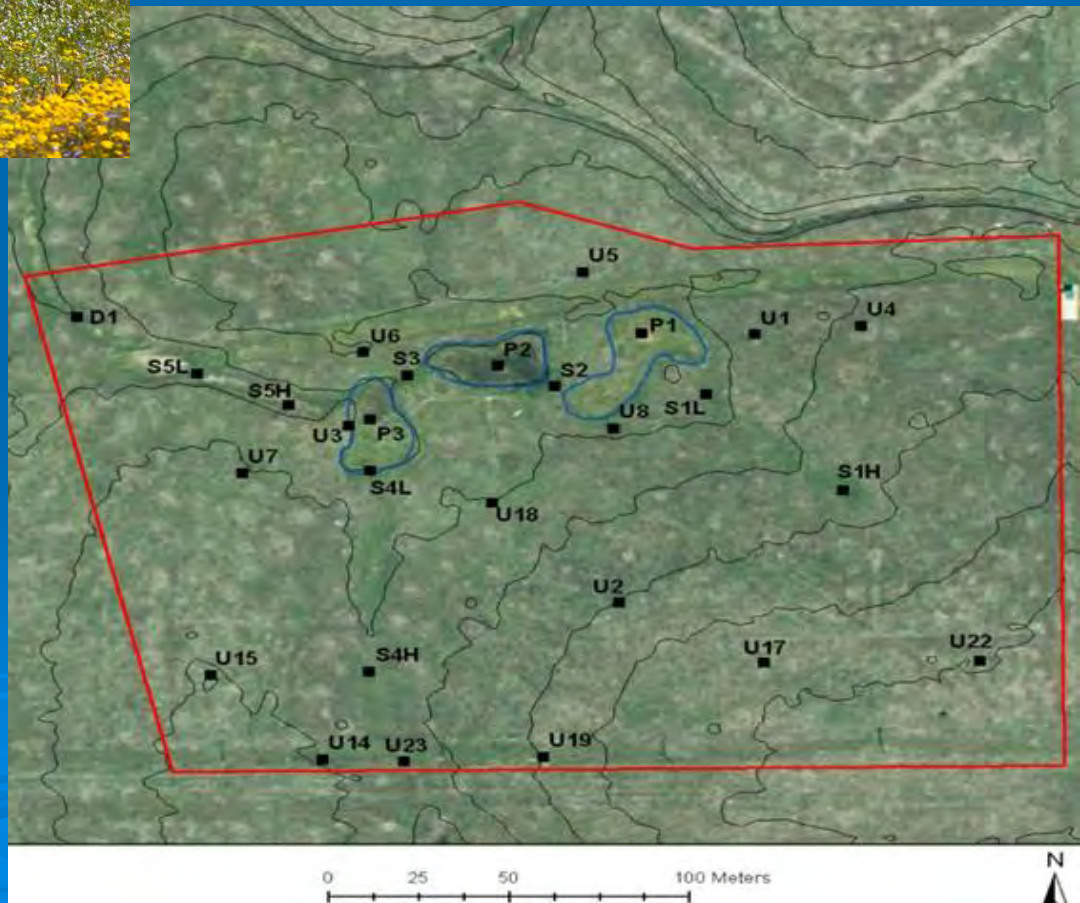
- Geophysical Structure and Hydrological Functioning of Vernal Pools
- Effect of Meteorological Variability on Vernal Pool Hydrology
- Vegetation Response to Annual Hydrological Variability,
- Methods in Evaluating and Monitoring Vernal Pool Landscapes
- Use of Computer Models to Evaluate Vernal Pool Ecosystems
- Using Natural Vernal Pool Ecosystems as a Model for Restoration and Creation

Vernal Pool Ecosystems

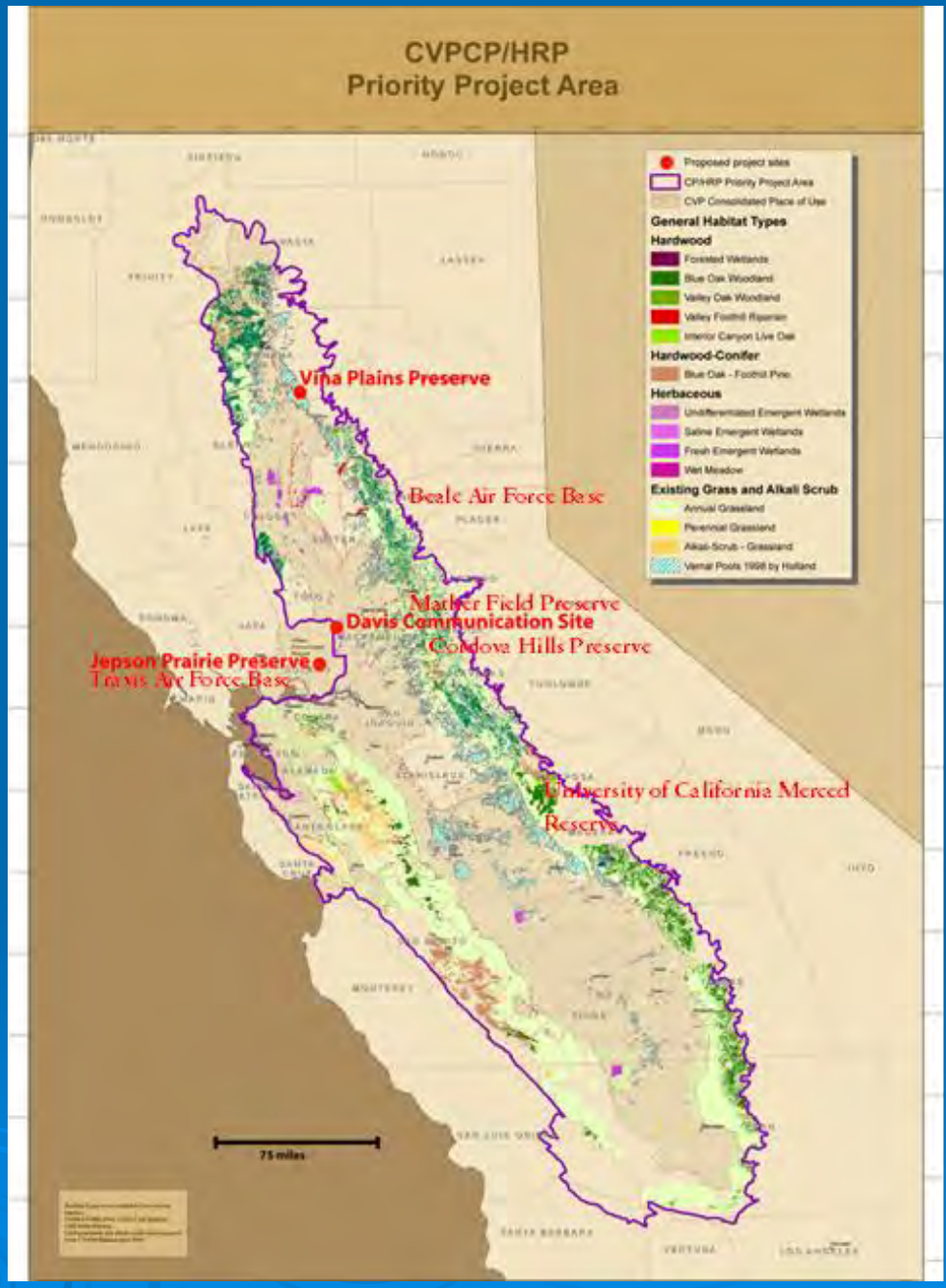
- Complex ecosystems
  - Water driven ecosystems
    - Function of
      - Weather
      - Geology
      - Soils
      - Topography
- Biological Components Respond to the Availability of Resources Affected by the Hydrology

Vernal Pools are Water Dependent Ecosystems

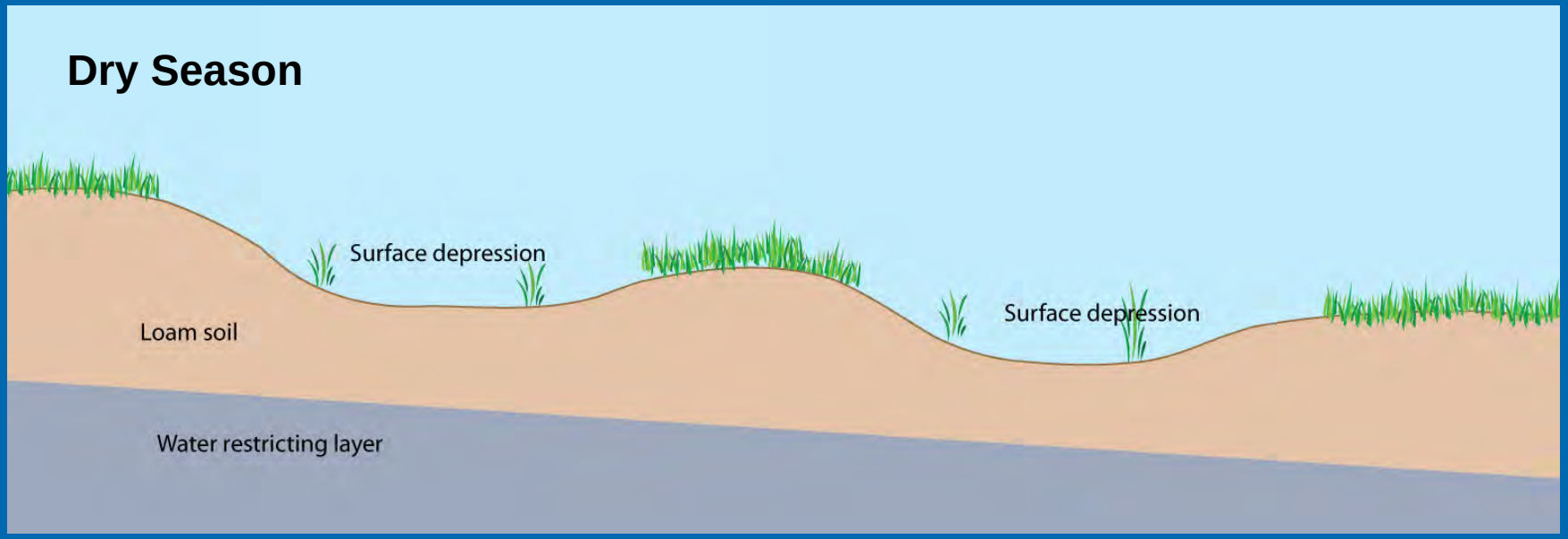
Field Hydrology Measurements

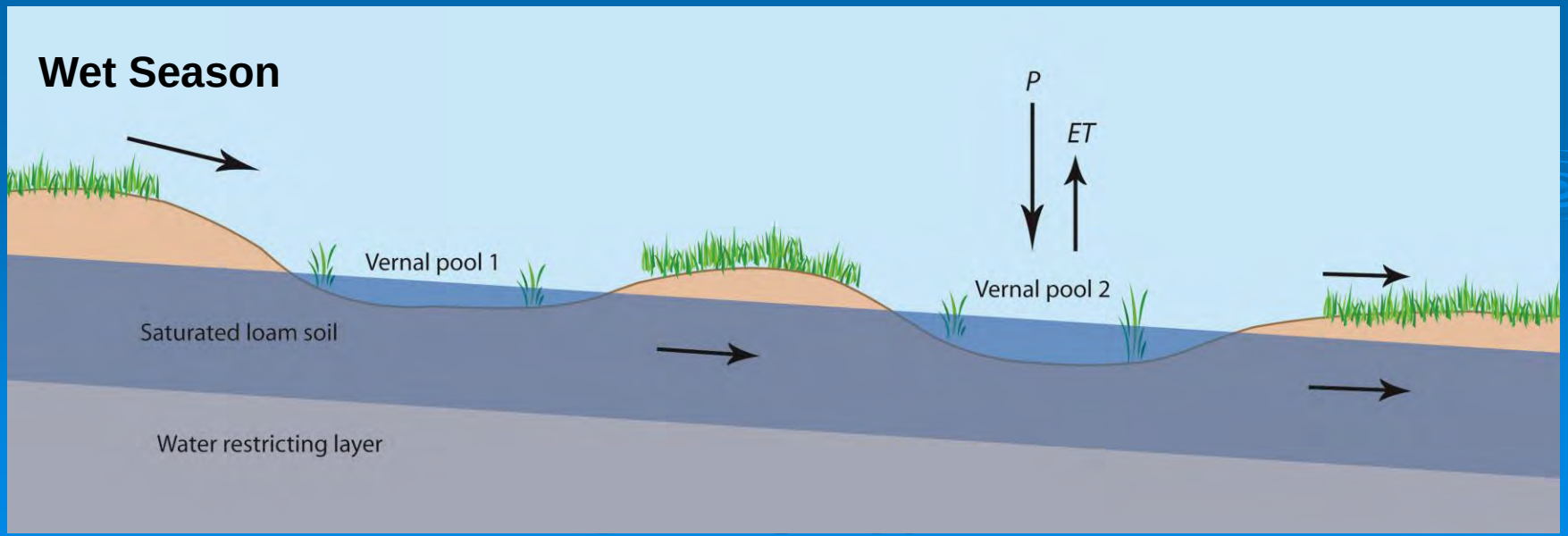


Locations of Vernal Pool Research and Monitoring

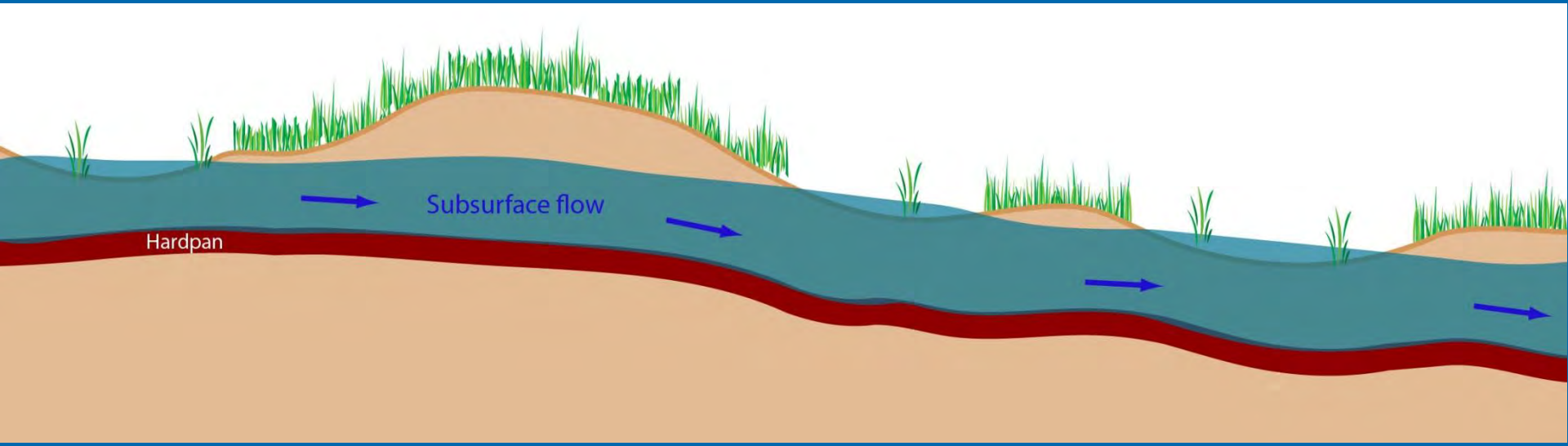


Conceptual Cross-section of a Vernal Pool Catchment





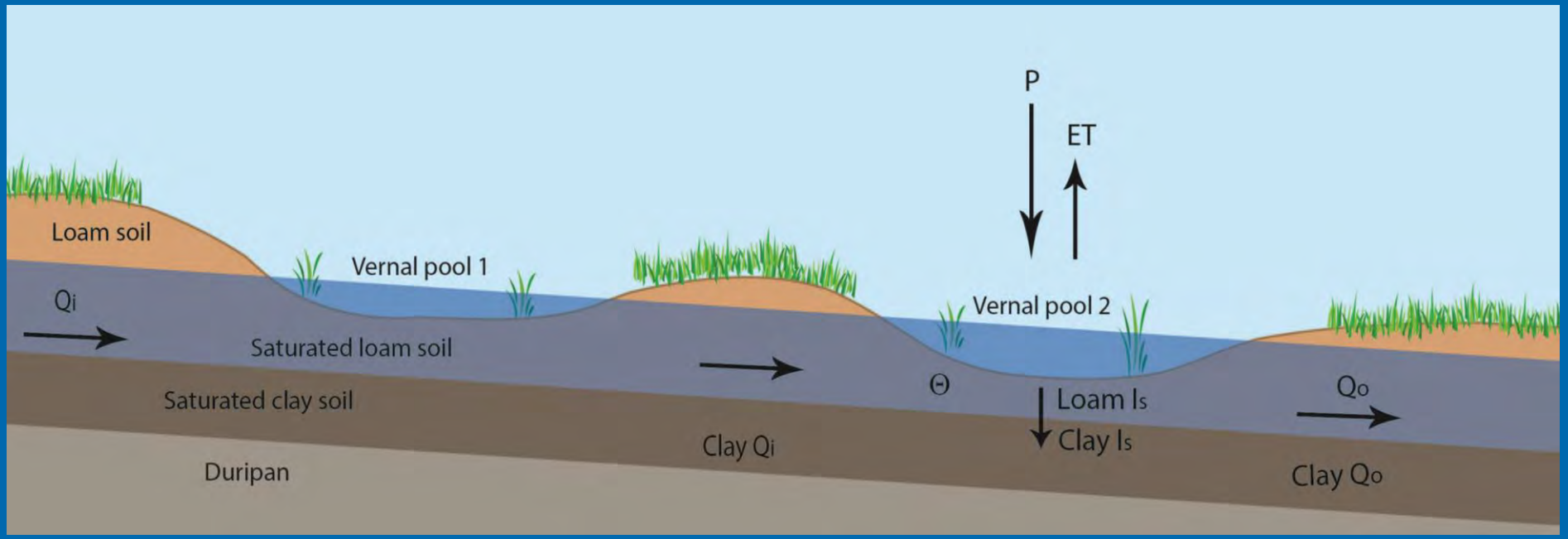
Soil Surface and Subsurface Water Relationships



Water Input: Rainfall (40% to 60%) + Uplands

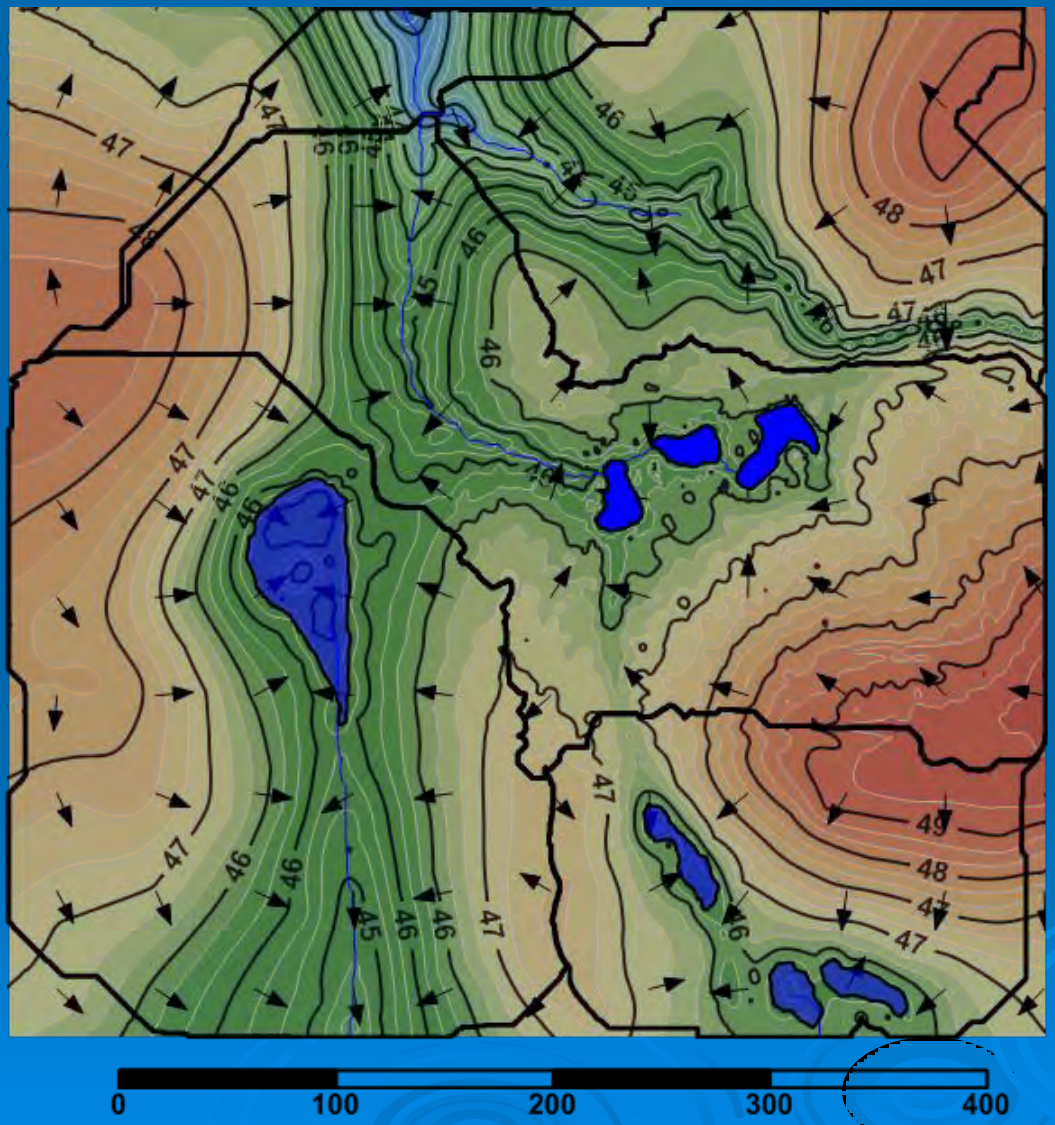
Enough Water to Saturate the Soil
(40% to 50% of soil is air)

Water Balance of a Vernal Pool

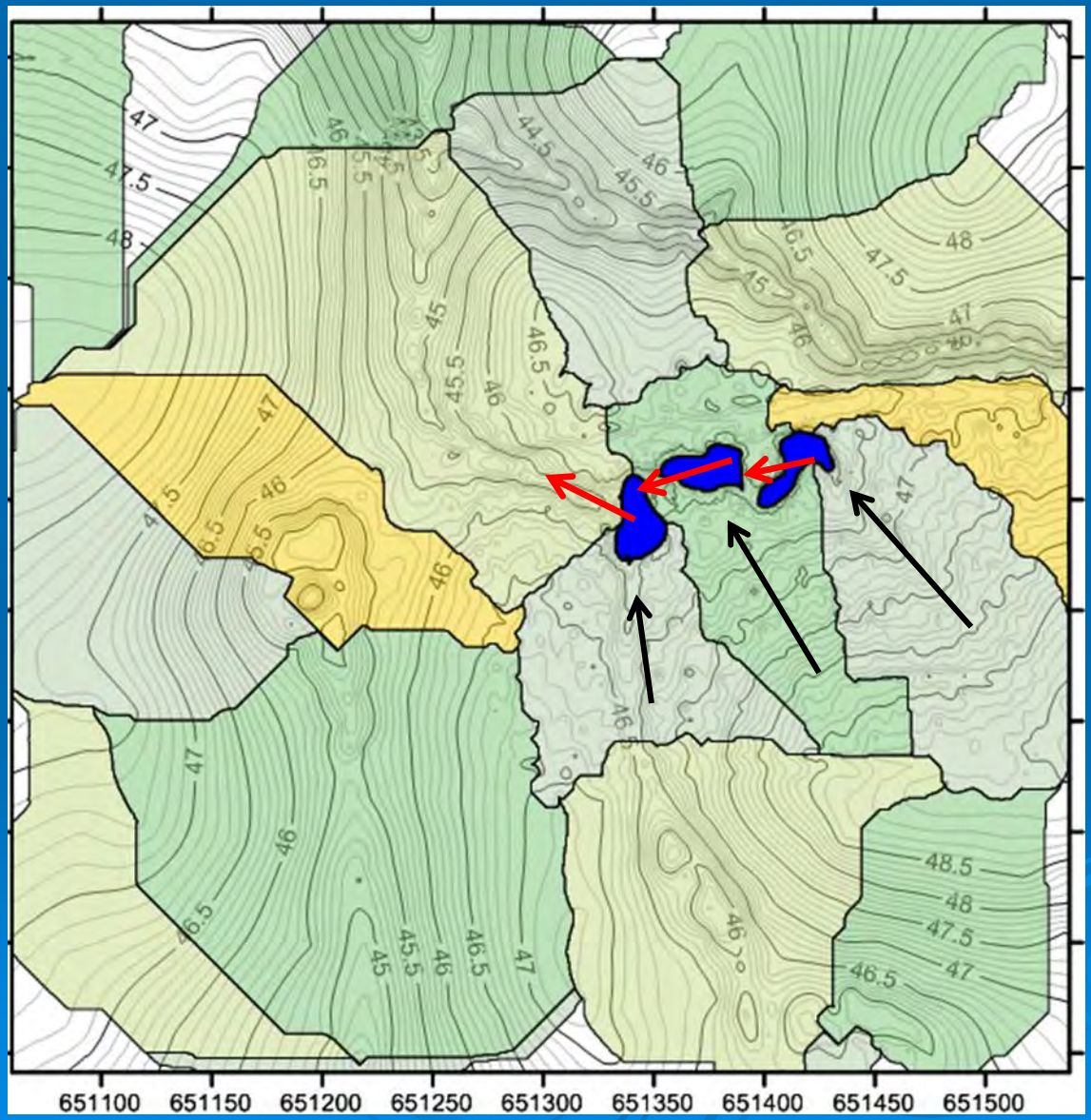


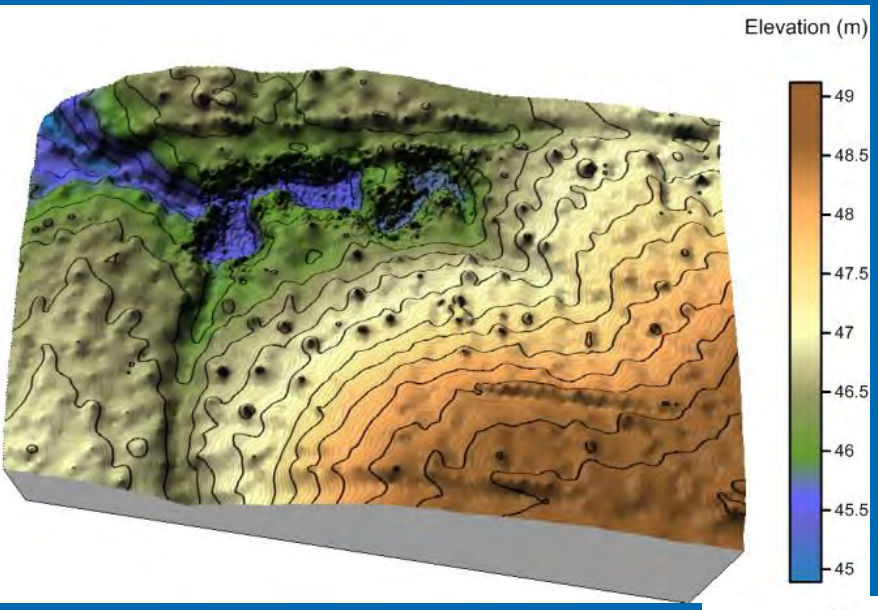
$$\Delta S = (P + Qi) - (ET + Qo)$$

Mather Field Catchments

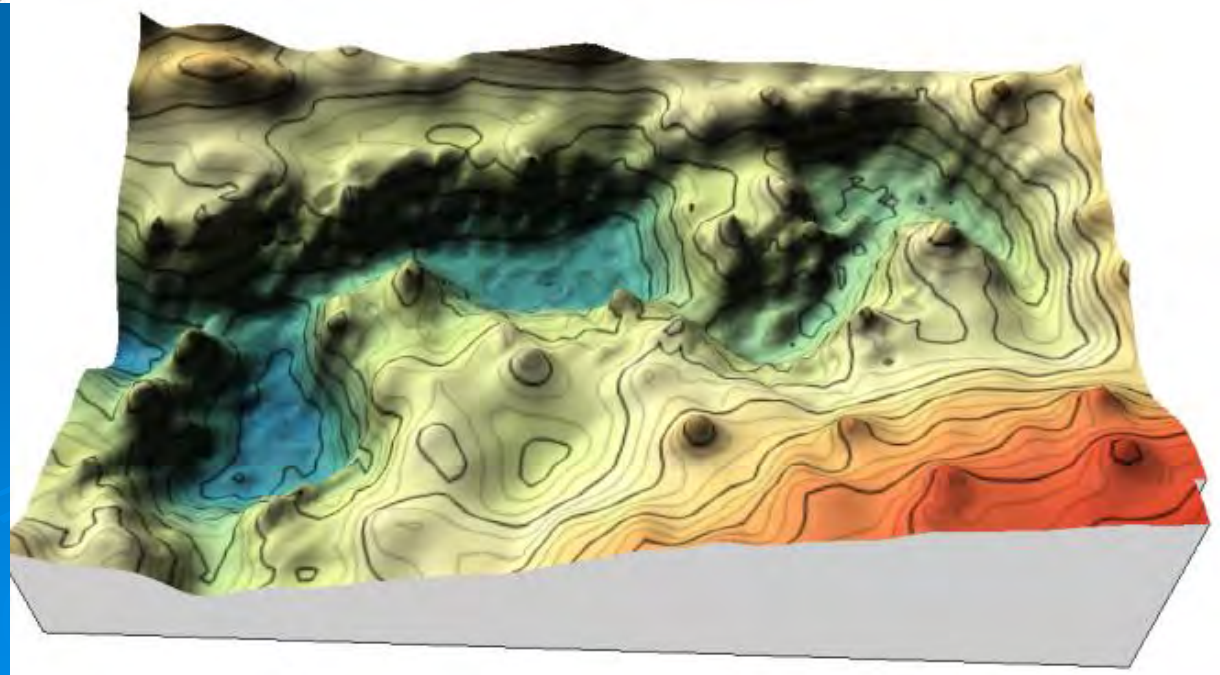


Catchment & Cascading Vernal Pools





Topographic Structure of Catchment



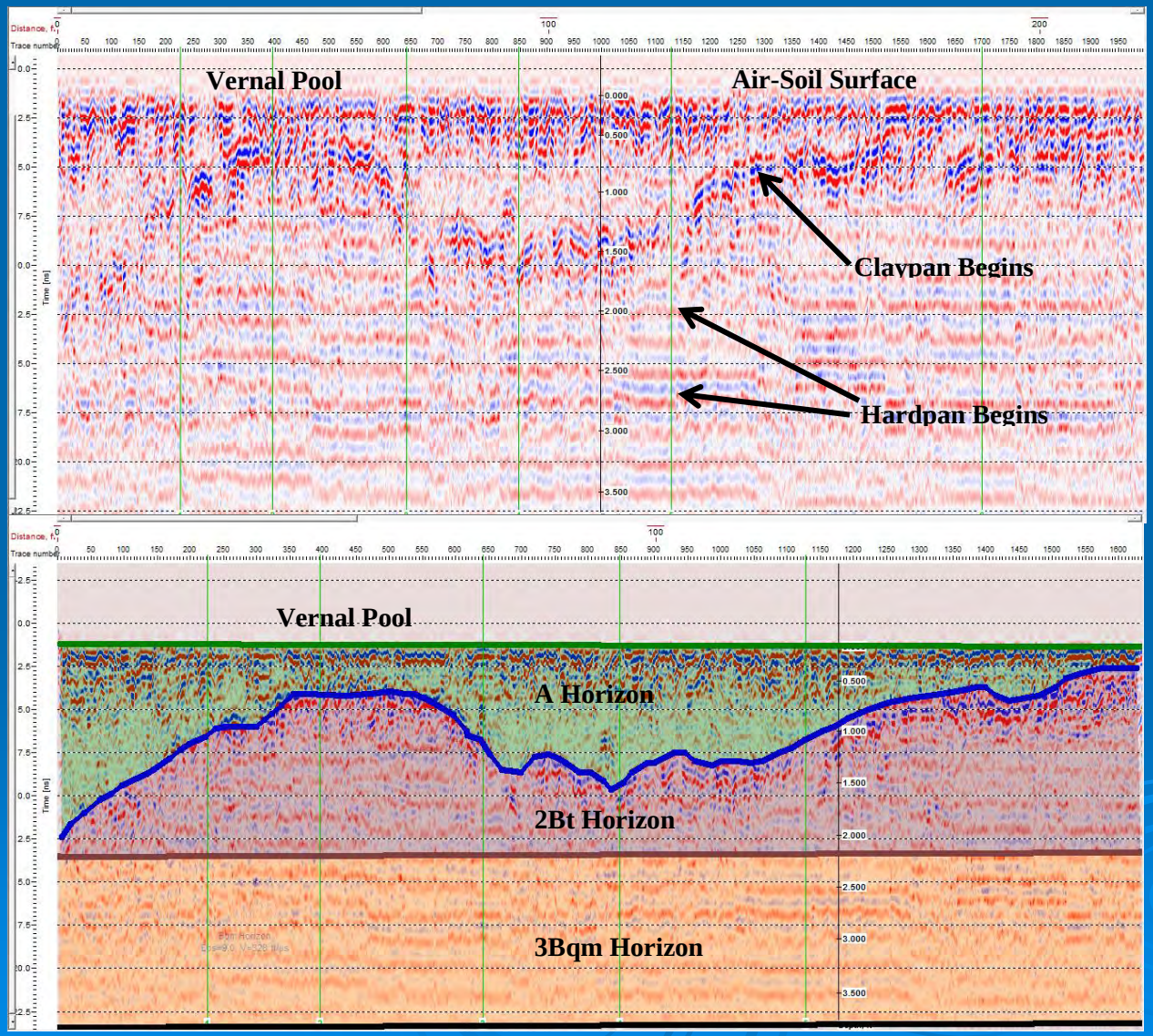
Measuring Soil Water-Restricting Layers

Ground Penetrating Radar

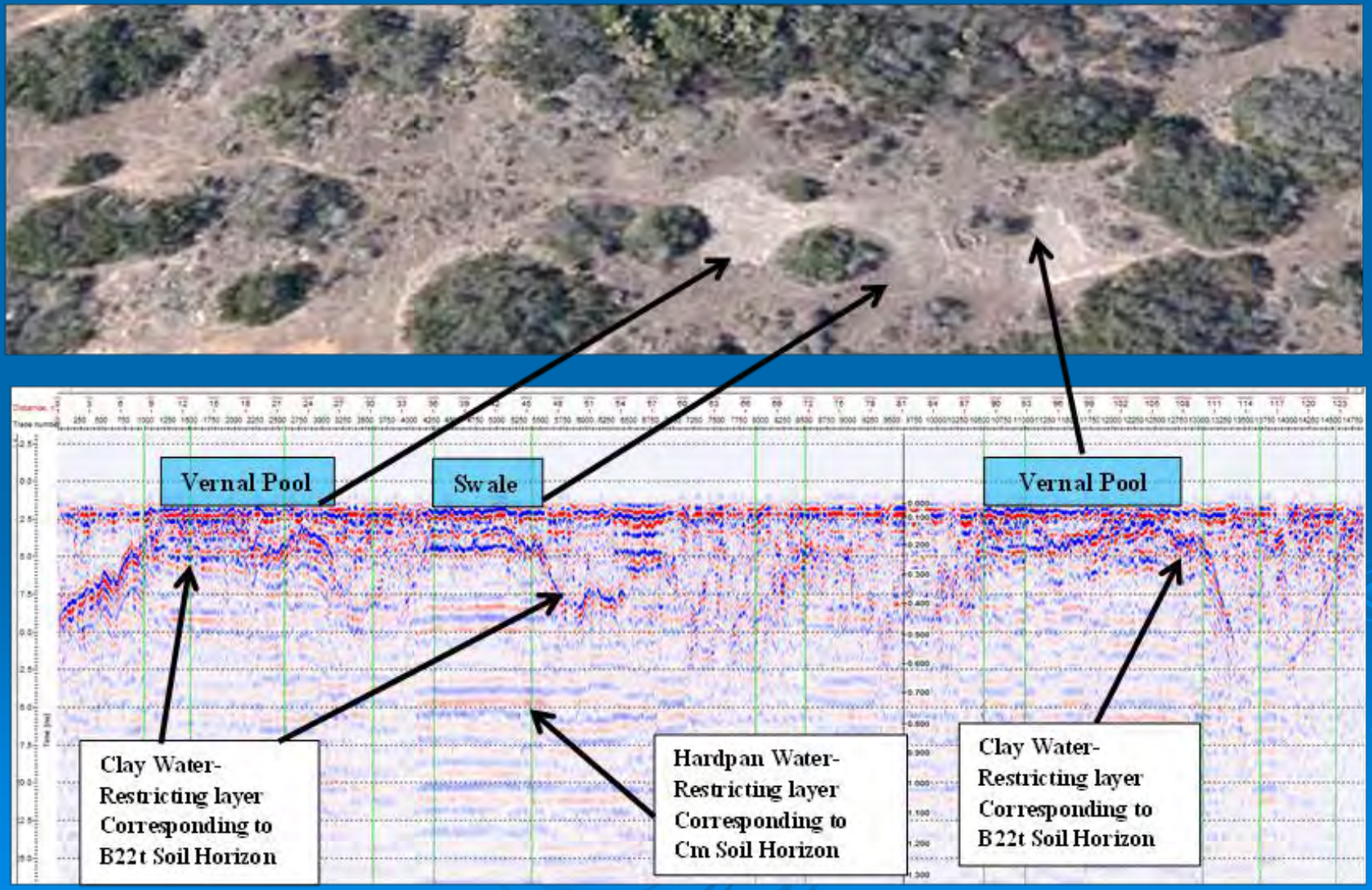
Soil Stratigraphy

Soil Profile

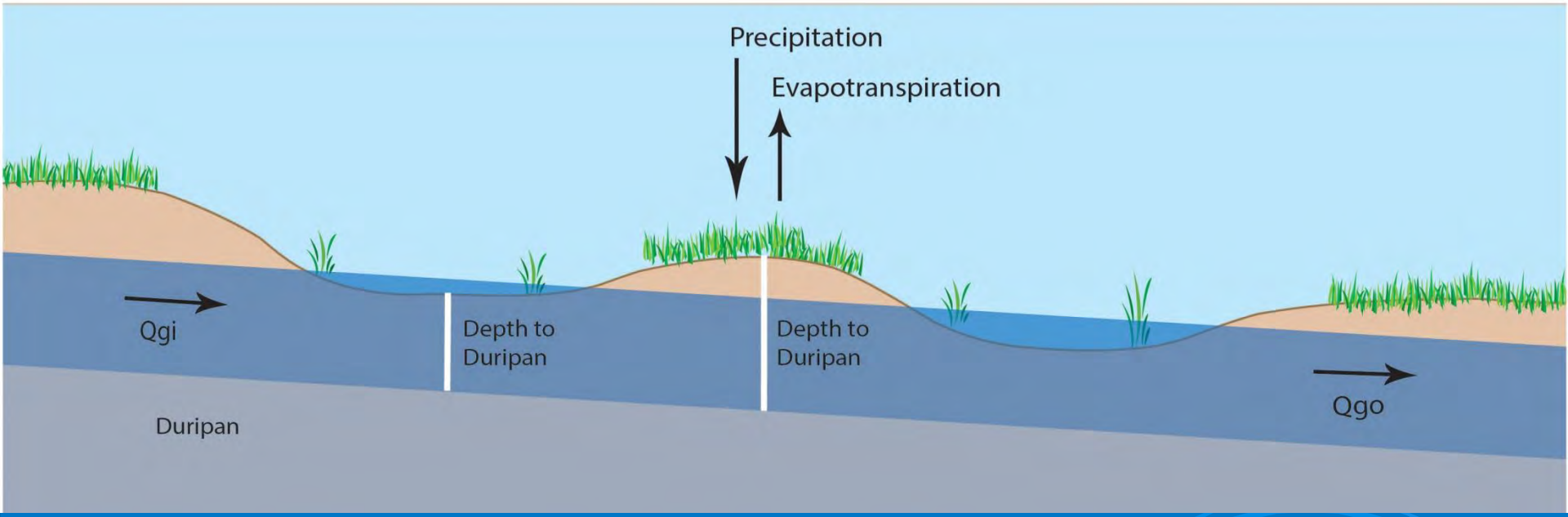
GPR Profiles & Soil Profiles



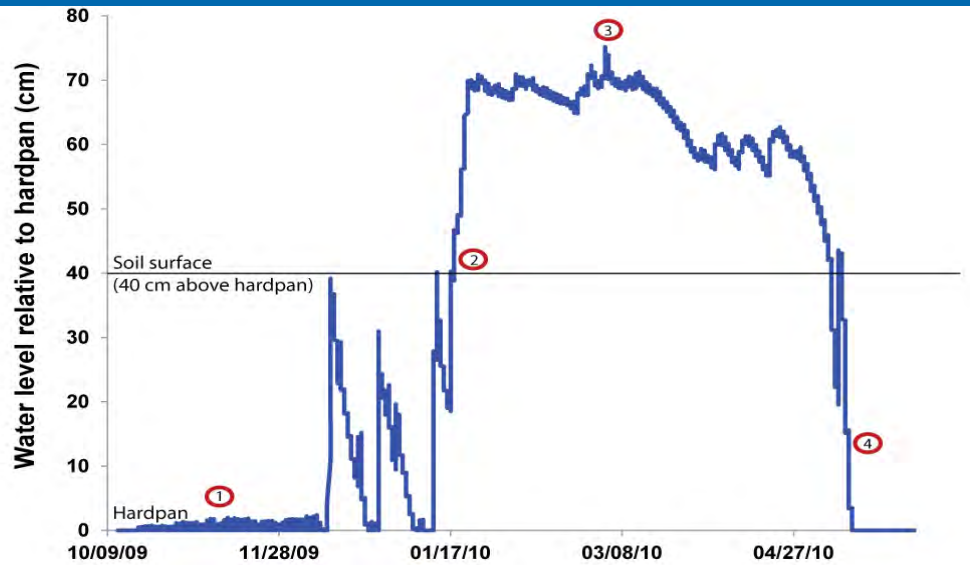
Variation of Water-Restricting Horizon Depth

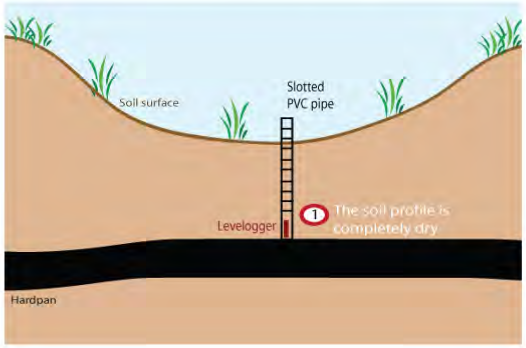


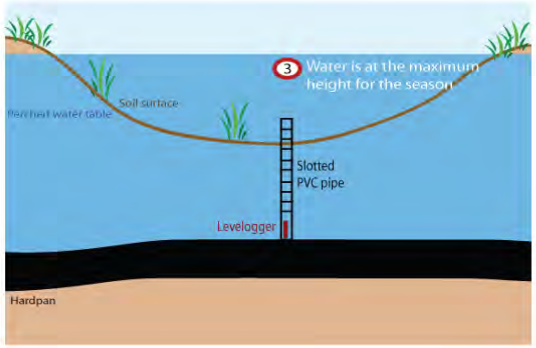
Vernal Pool Hydrology

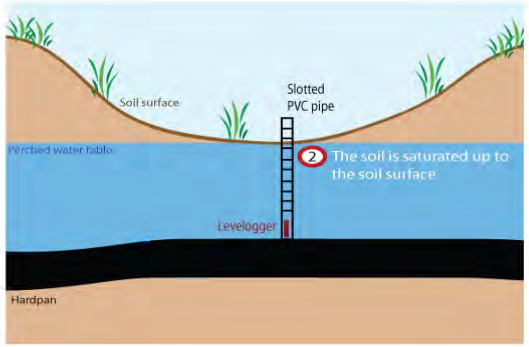


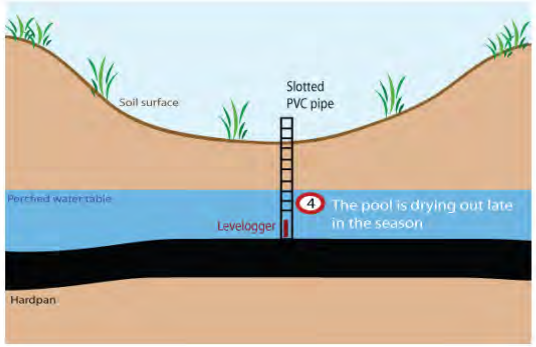
Hydrology of a Vernal Pool During One Year





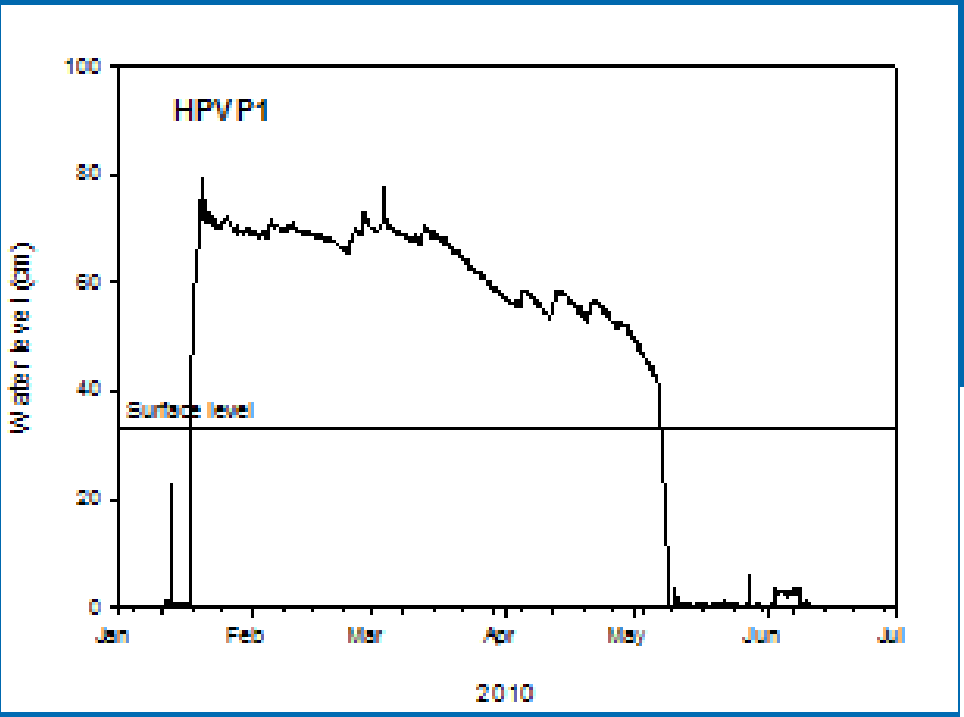


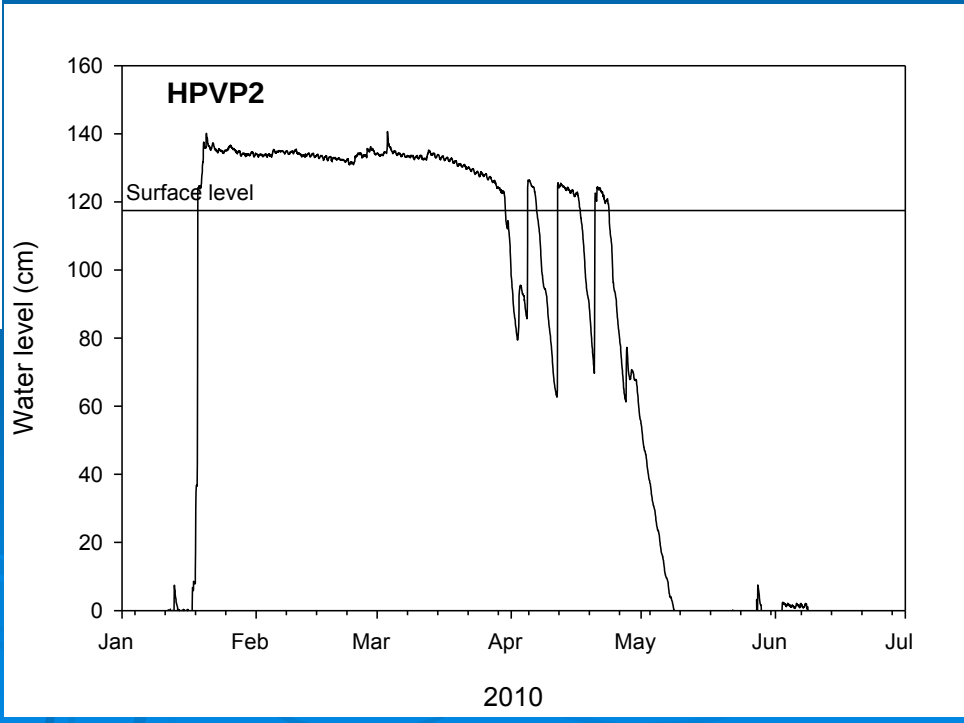




Four Phases of Soil Water Recharge to Surface Inundation and Dry Down

Hydrological Variation Due to Soil Depth to Hardpan





Hydrology Technology

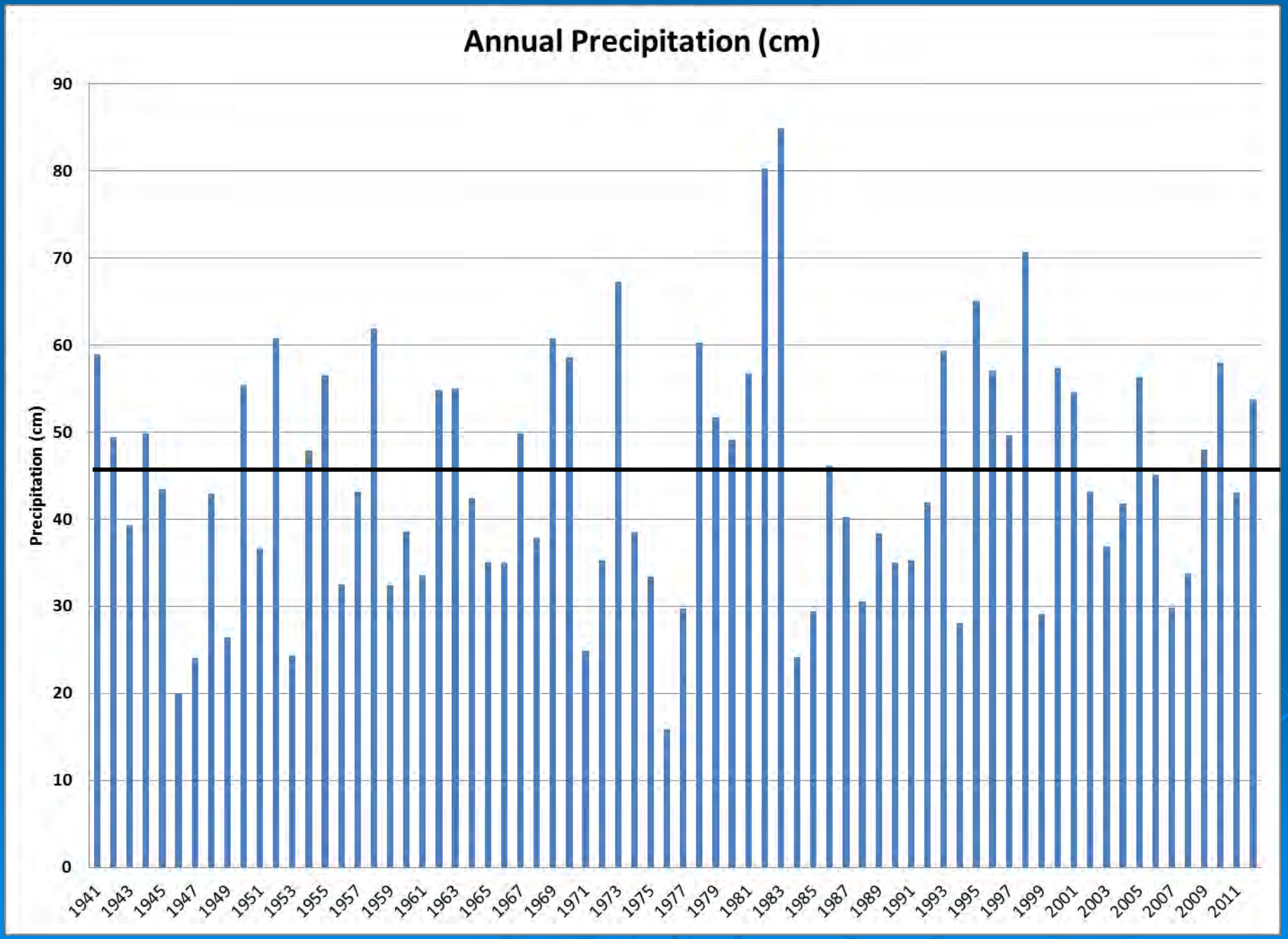
Leveloggers

- Programmed and placed into pools, swales, and uplands
- Hourly measurements

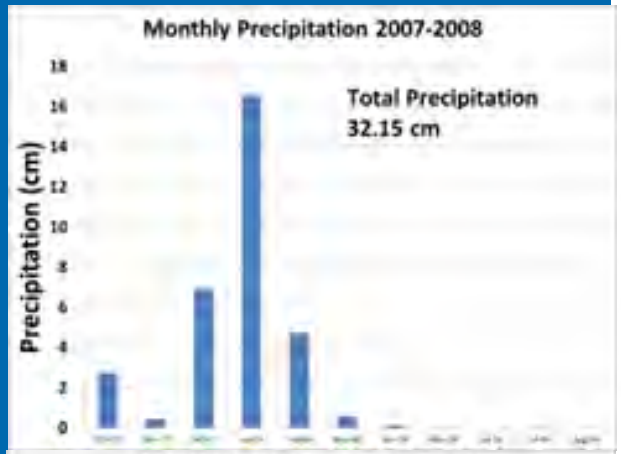
Meteorological Parameters

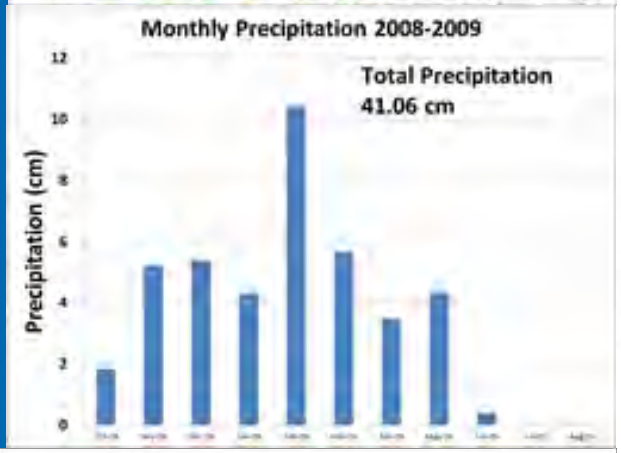
Hydrological Input - Precipitation

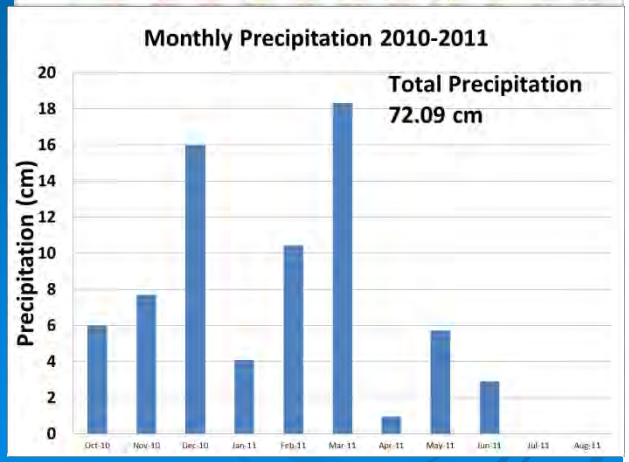
Hydrological Output – Evapotranspiration

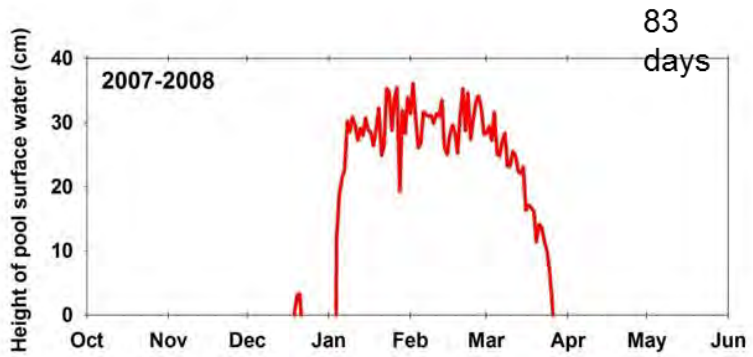

Annual Precipitation (cm)
Precipitation (cm)
90
80
70
60
50
40
30
20
10
0
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011

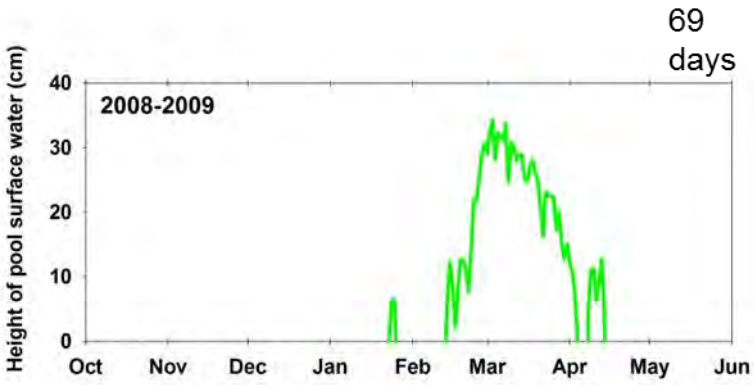
Vernal Pool Hydrology and the Amount and Distribution of Rainfall

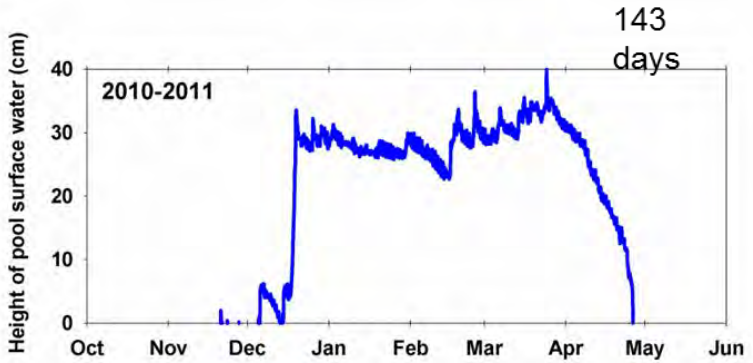




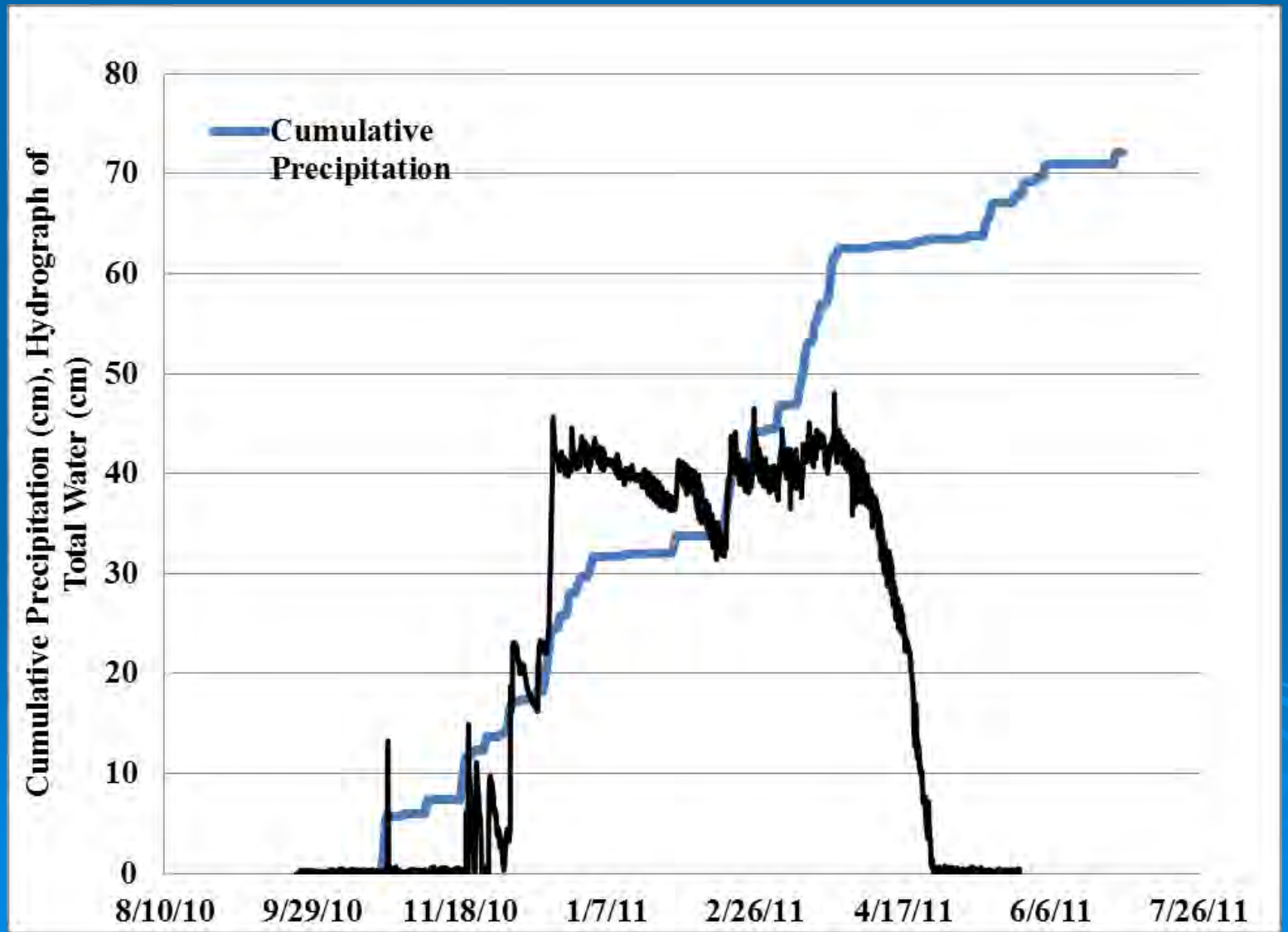


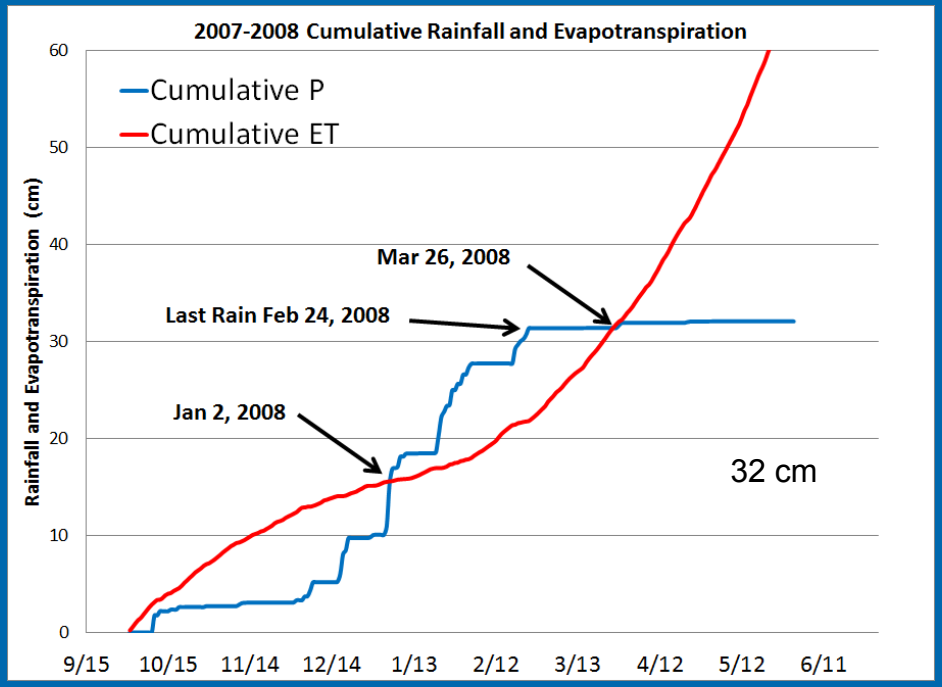


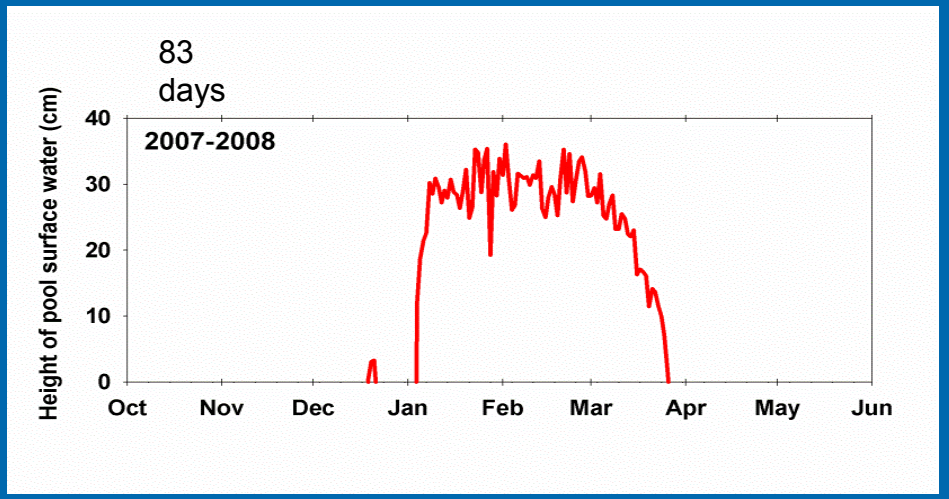


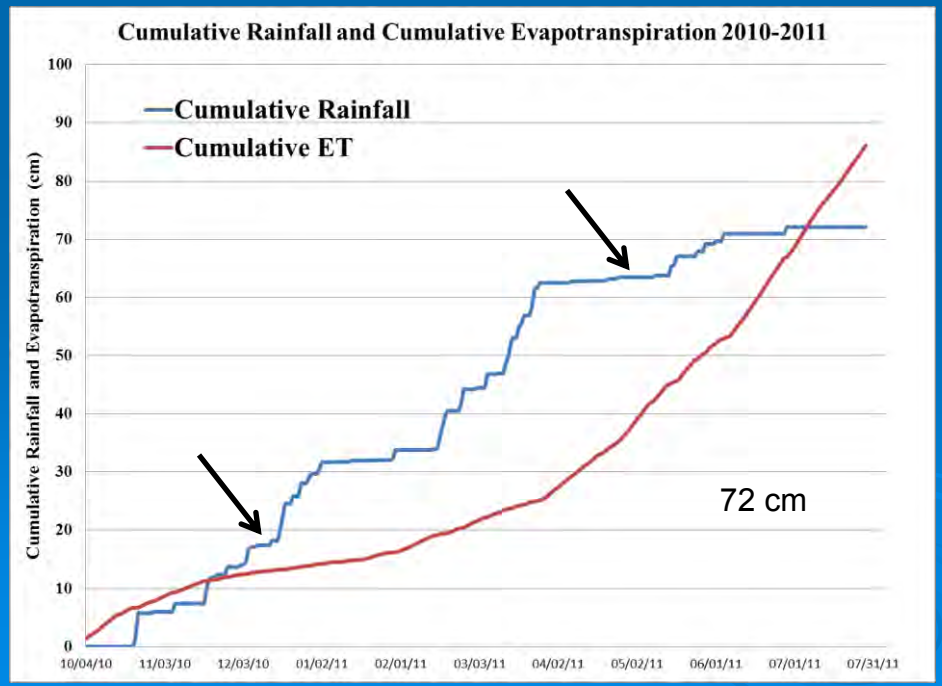


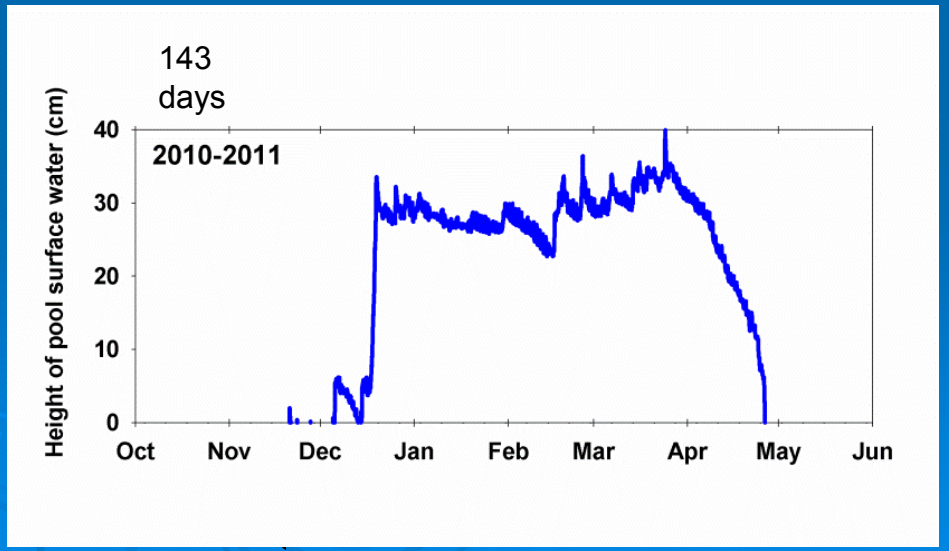
Rainfall and Vernal Pool Hydrology




2007-2008 Cumulative Rainfall and Evapotranspiration
Cumulative P
Cumulative ET
Rainfall and Evapotranspiration (cm)
Mar 26, 2008
Last Rain Feb 24, 2008
Jan 2, 2008
32 cm
0
10
20
30
40
50
60
9/15
10/15
11/14
12/14
1/13
2/12
3/13
4/12
5/12
6/11


83
days
2007-2008
Height of pool surface water (cm)
0
10
20
30
40
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Cumulative Rainfall and Cumulative Evapotranspiration 2010-2011
Cumulative Rainfall
Cumulative ET
Cumulative Rainfall and Evapotranspiration (cm)
72 cm
0
10
20
30
40
50
60
70
80
90
100
10/04/10
11/03/10
12/03/10
01/02/11
02/01/11
03/03/11
04/02/11
05/02/11
06/01/11
07/01/11
07/31/11


143
days
2010-2011
Height of pool surface water (cm)
0
10
20
30
40
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

Landscape Scale, Seasonal Dynamics & Environmental Gradients

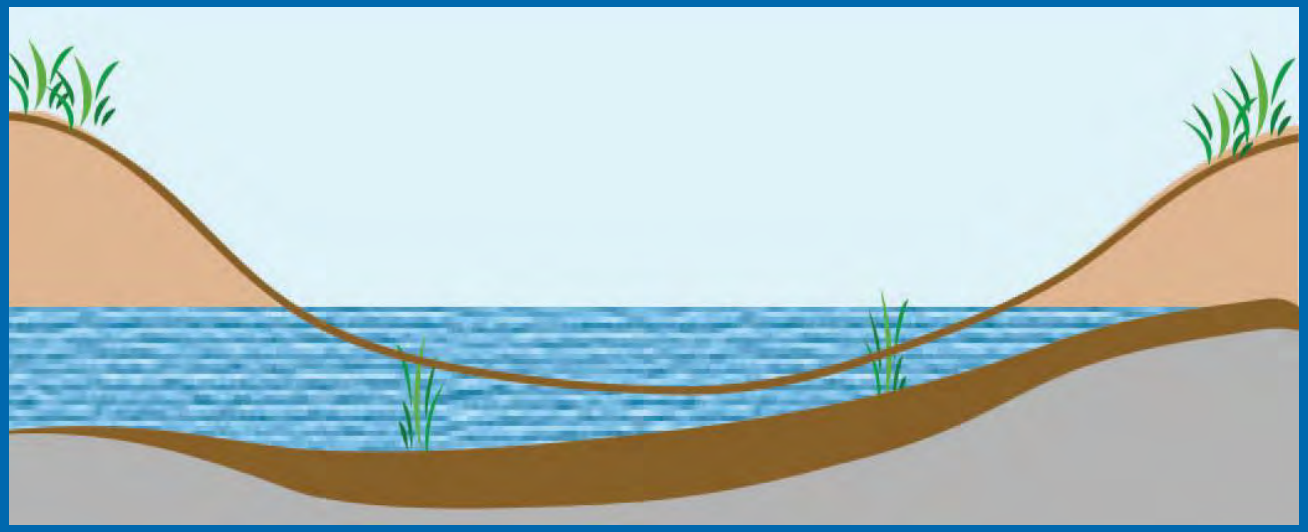
Hydrological gradients create environmental heterogeneity including anaerobic soil zones

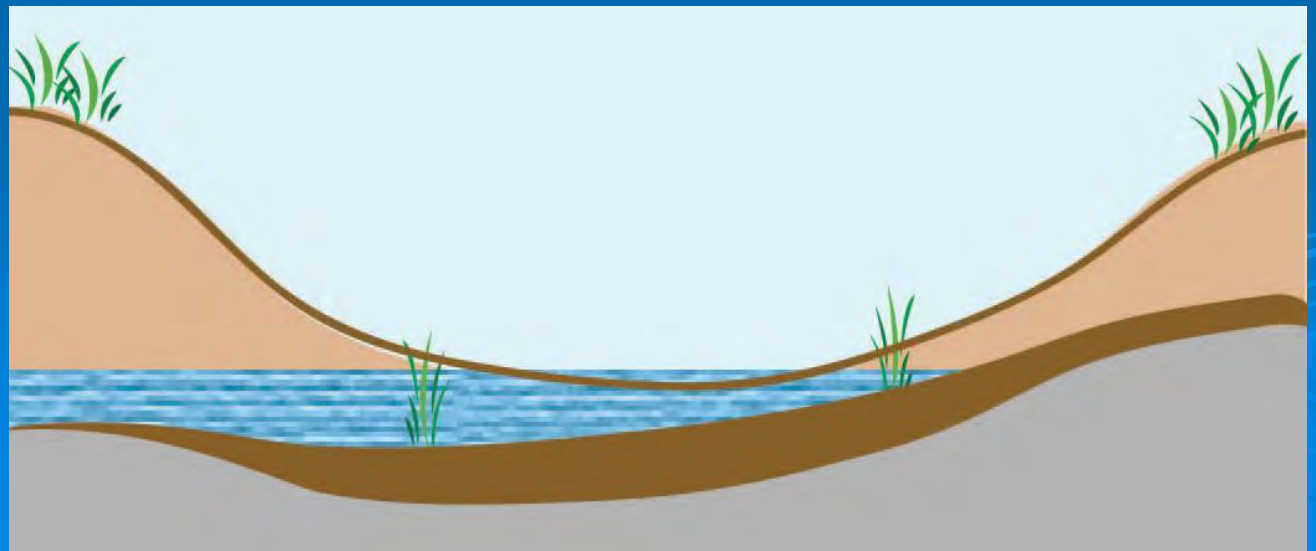
Wetlands characterized by hydric soils

Spatial Distribution & Abundance of Vegetation in Vernal Pools

Vegetation Monitoring for Comparison with Hydrology

Spatial Structure of Vernal Pool Basin





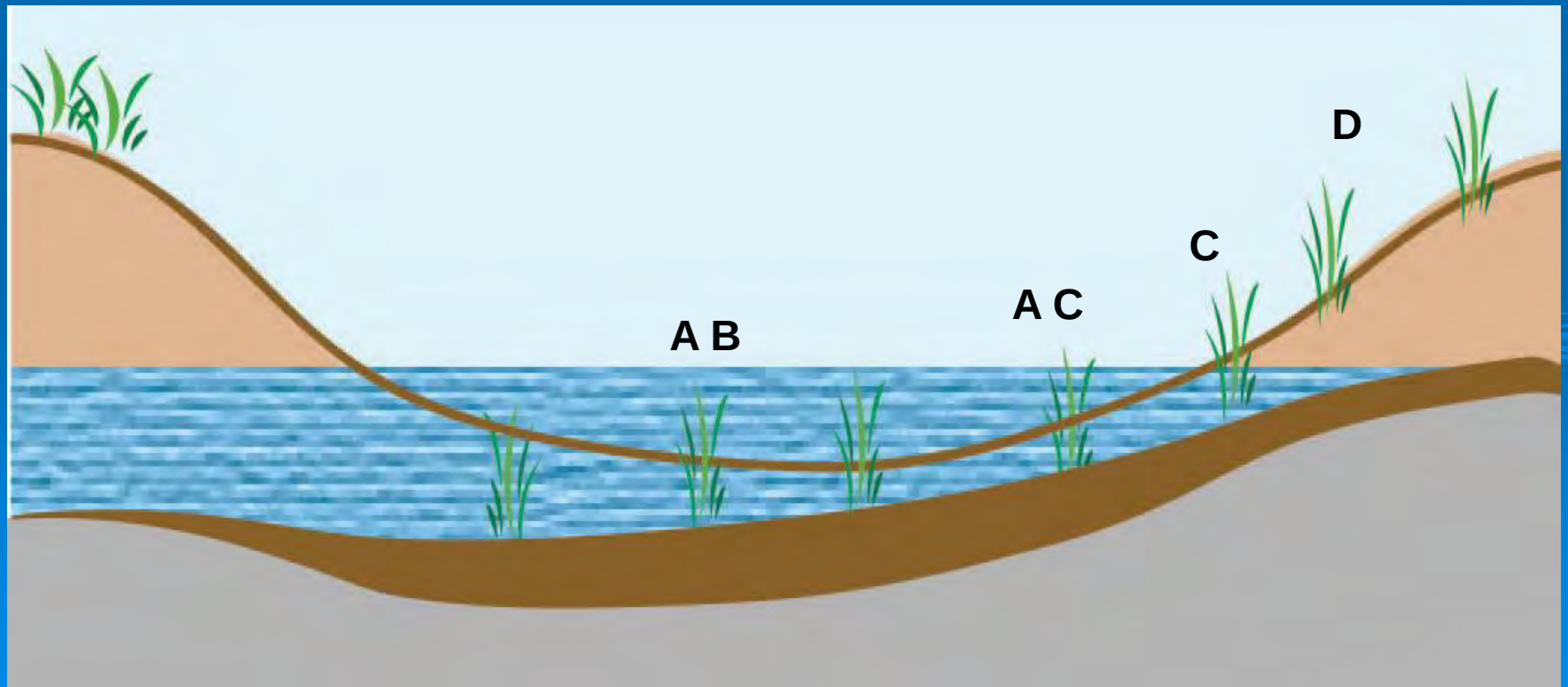
Plant Response to Hydrological Gradient

A Complete Submersion (Resource Limitation of Light and CO_2)

B Anaerobic Soil (Resource Limitation of O_2 Long Period)

C Root Inundation Period (Resource Limitation of O_2 Short Period)

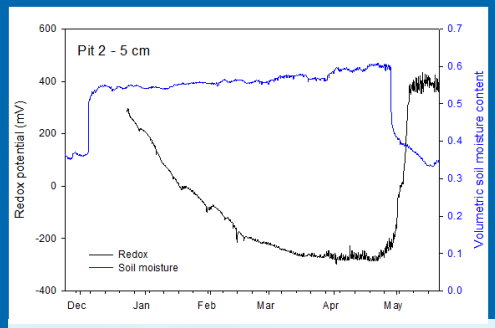
D No Inundation (Water Resource Limitation)

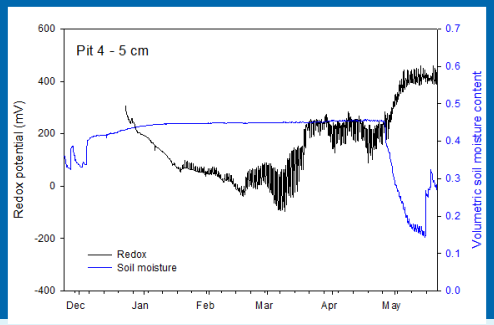


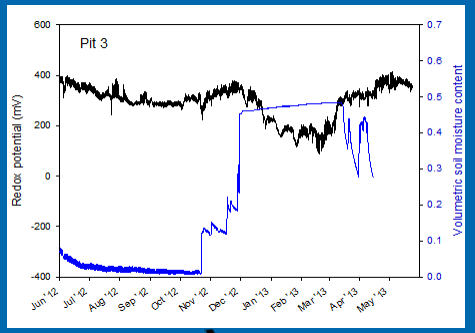
Plant Adaptation to Wetland Habitats

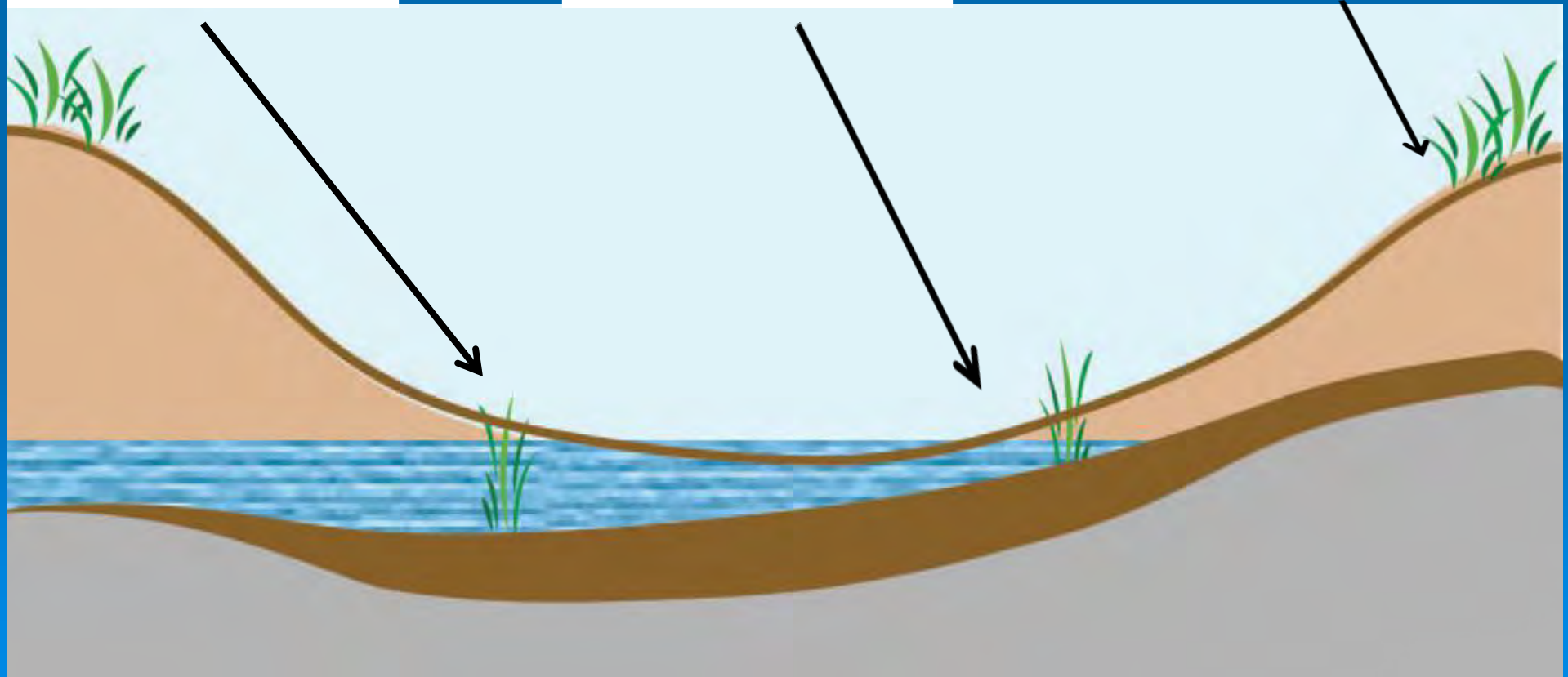
- Morphology
  - Aerenchyma (oxygen diffusion to roots)
  - Dimorphic leaves (submerged & floating)
- Physiology
  - Carbon uptake through leaves in water
  - Carbon uptake through roots
  - Crassulacean Acid Metabolism
  - Low oxygen tolerance

Redox in Different Soil Pit Locations in Vernal Pool

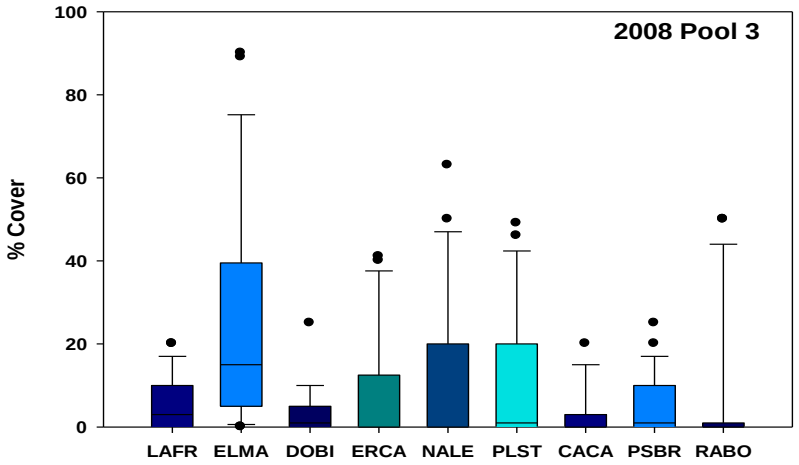


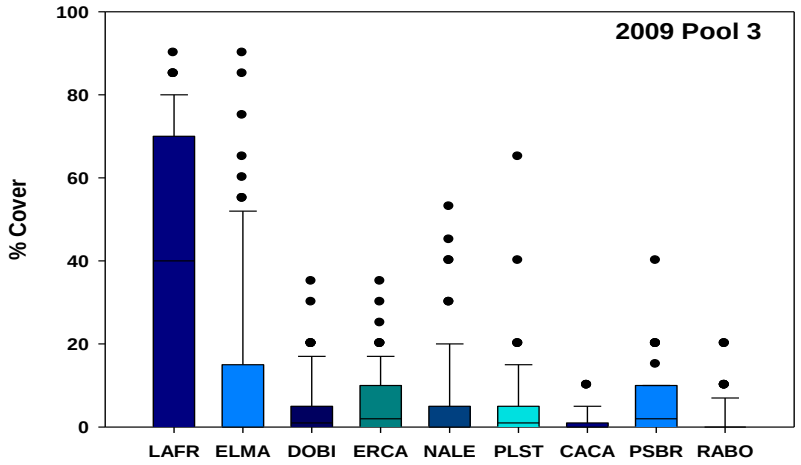


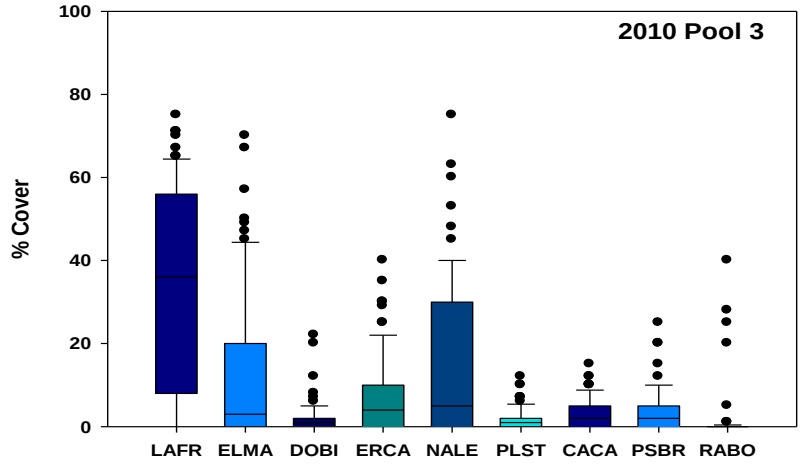


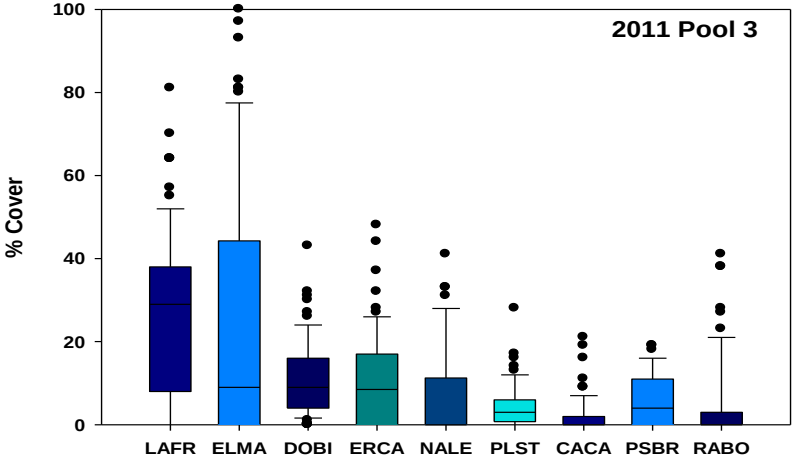


Annual Changes in Plant Species Cover

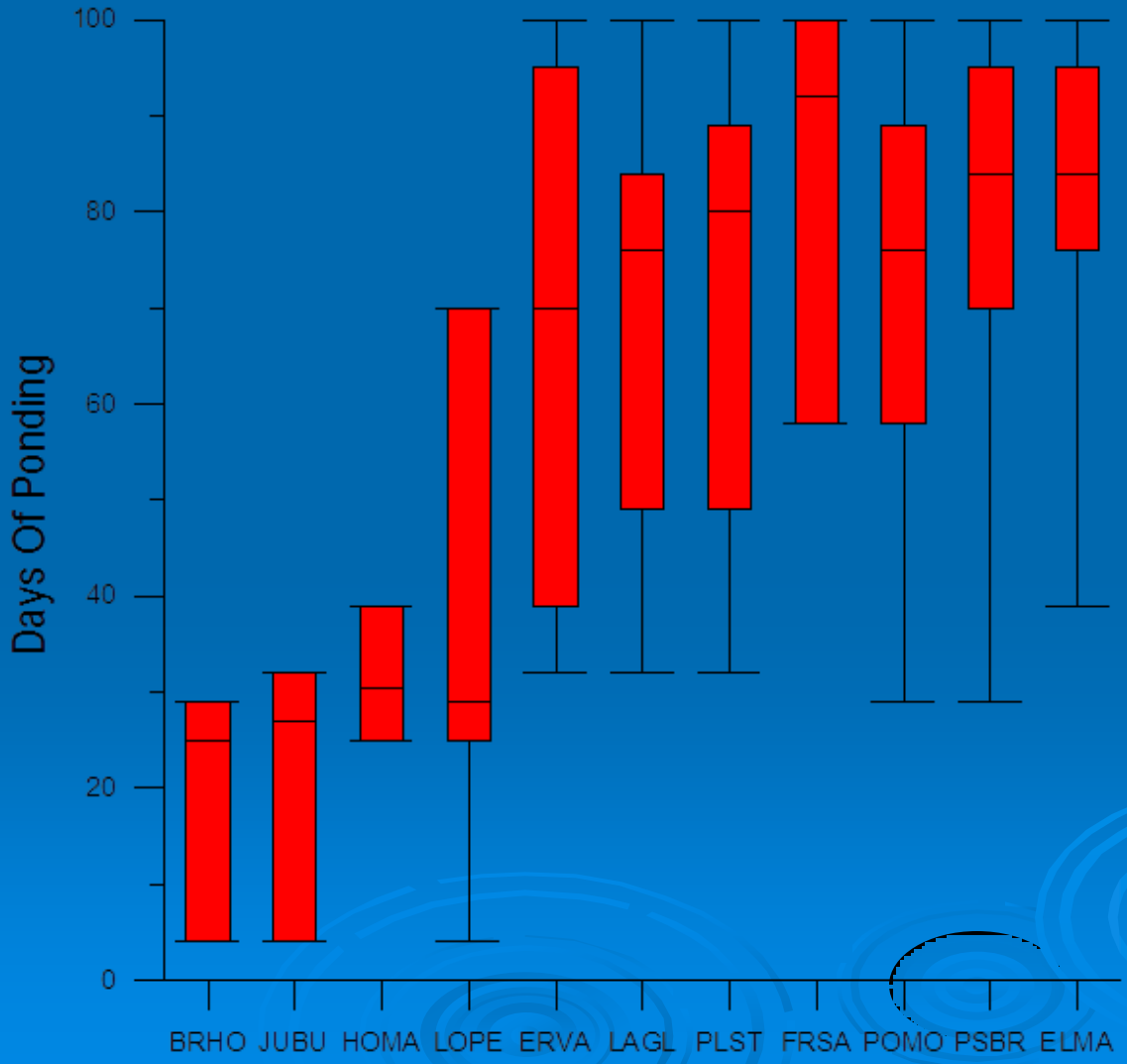




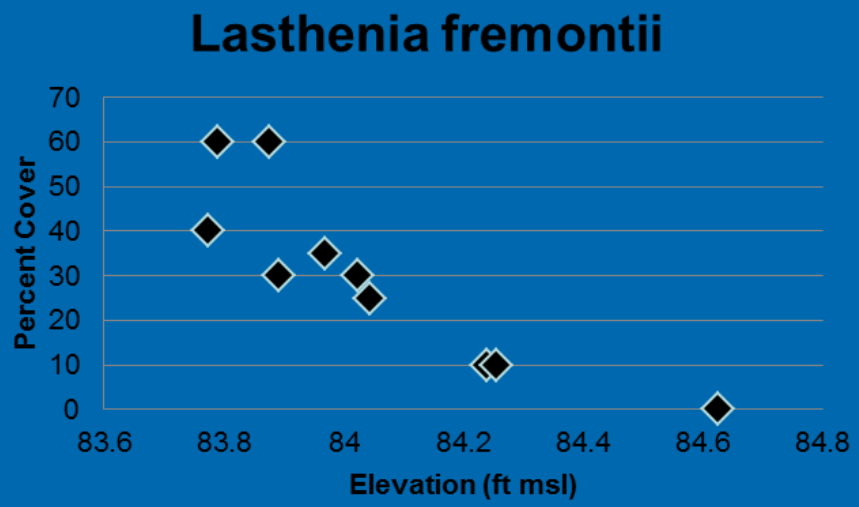


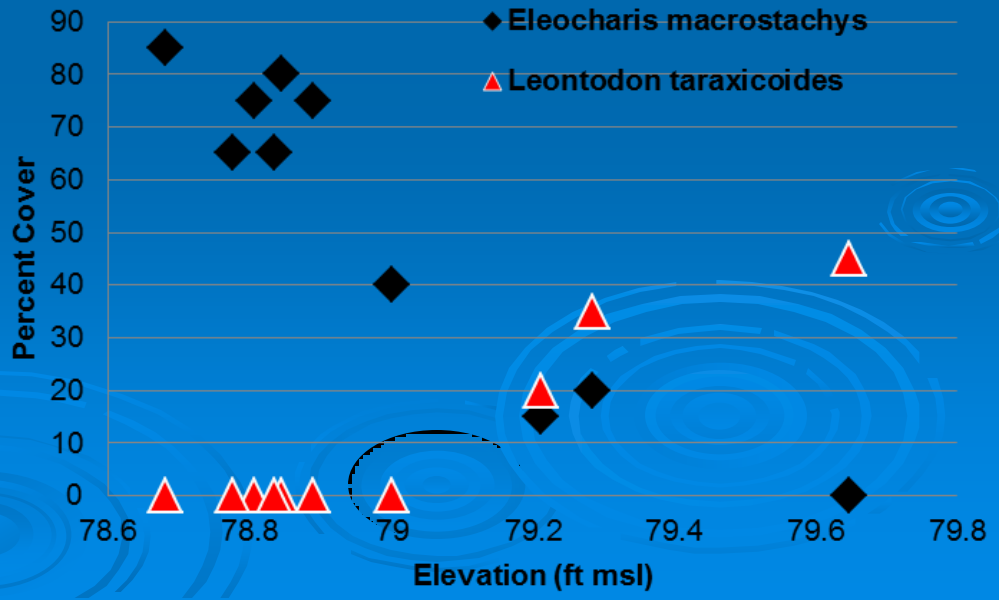


Plant Abundance and Inundation



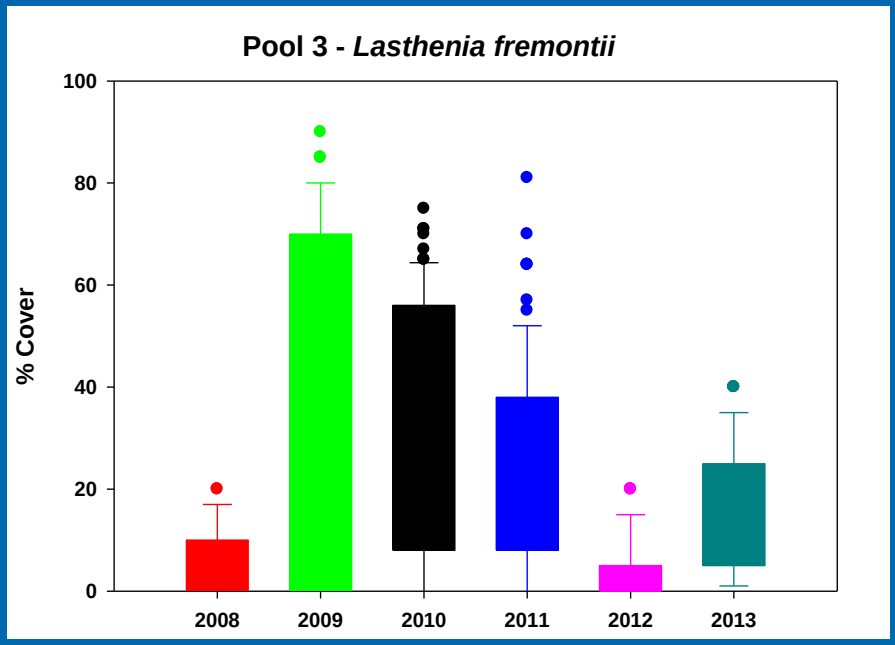
Relationship of Species Abundance to Vernal Pool Topography

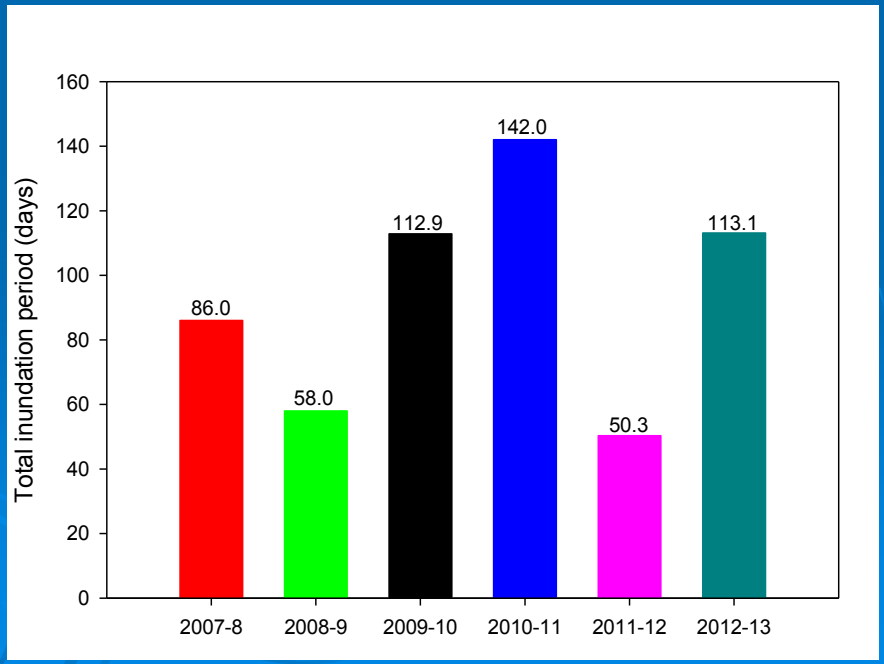




Lasthenia fremontii

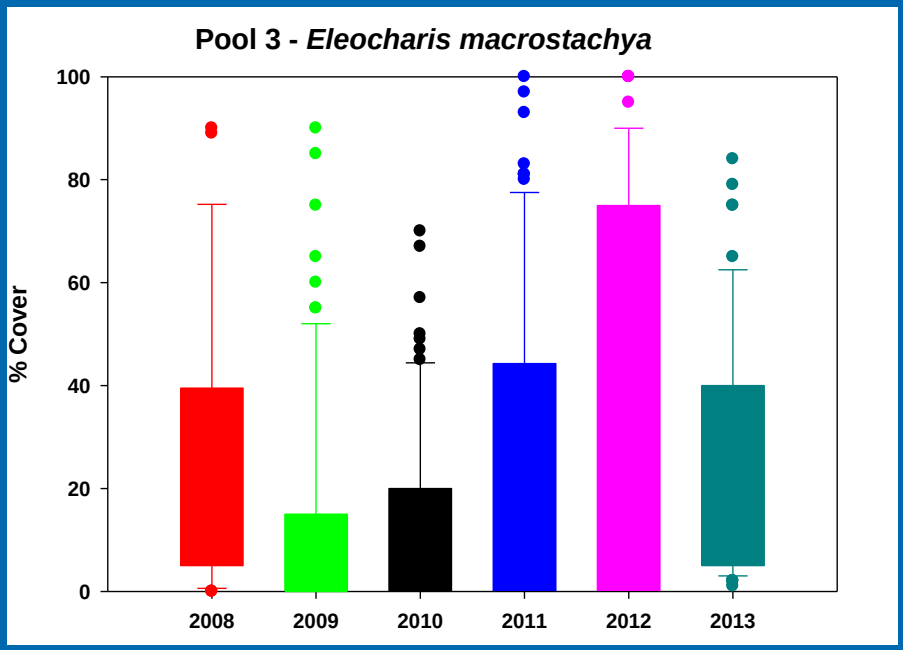
- Increase and subsequent decrease in percent cover relative to increased rainfall
-

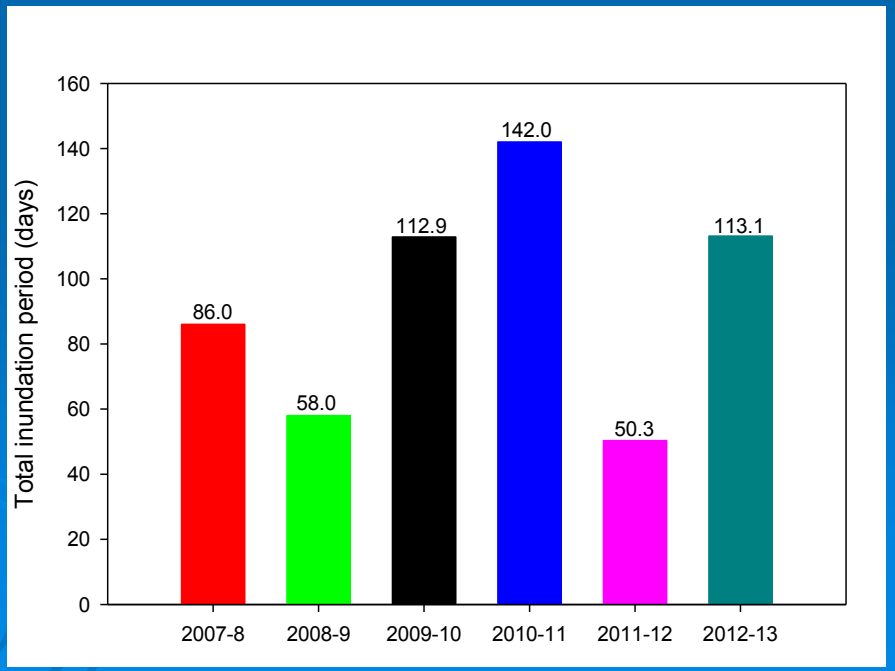




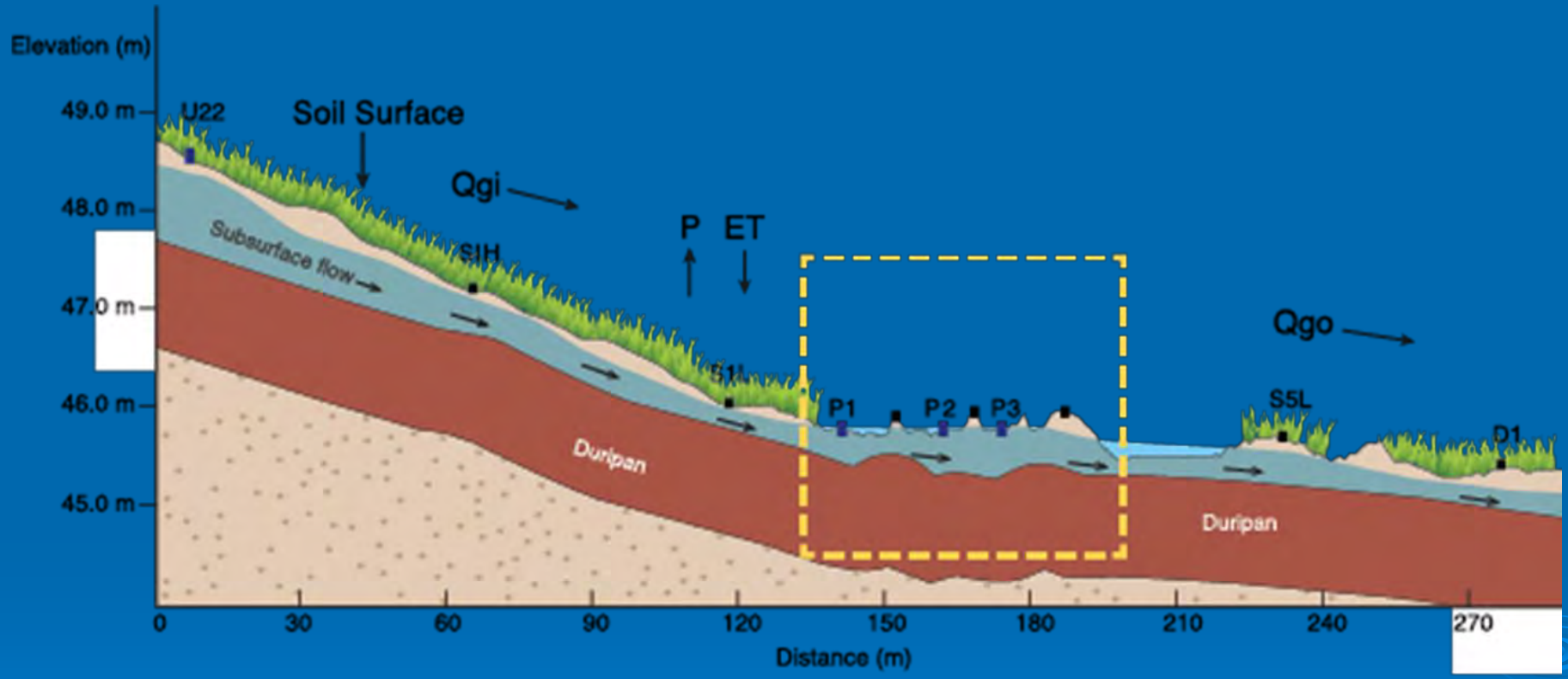
Eleocharis macrostachya

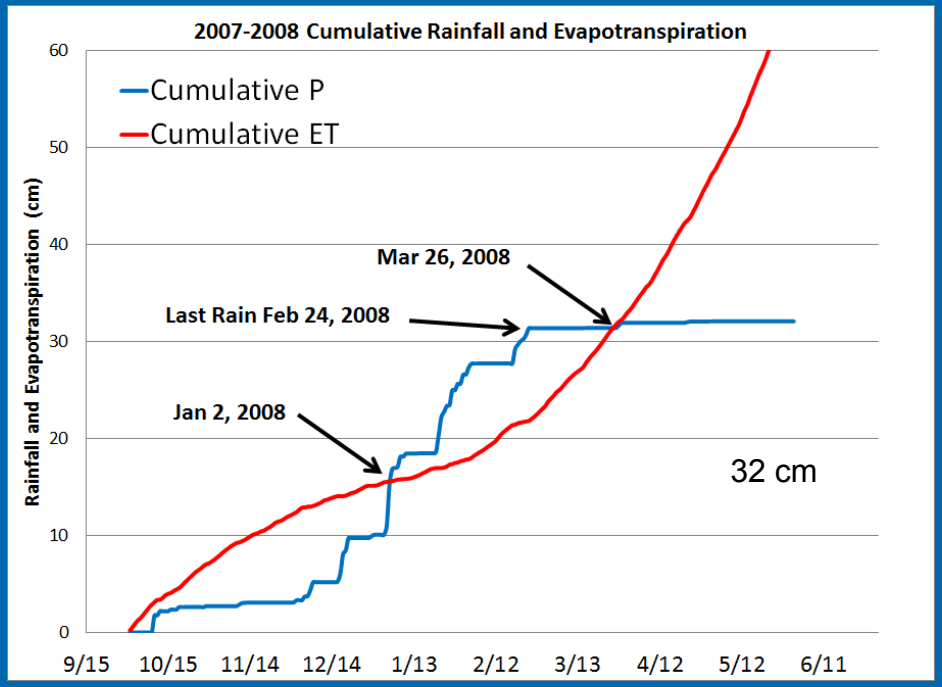
- Reverse trend in *Eleocharis* species percent cover values with decreasing and subsequent increasing relative to increased rainfall

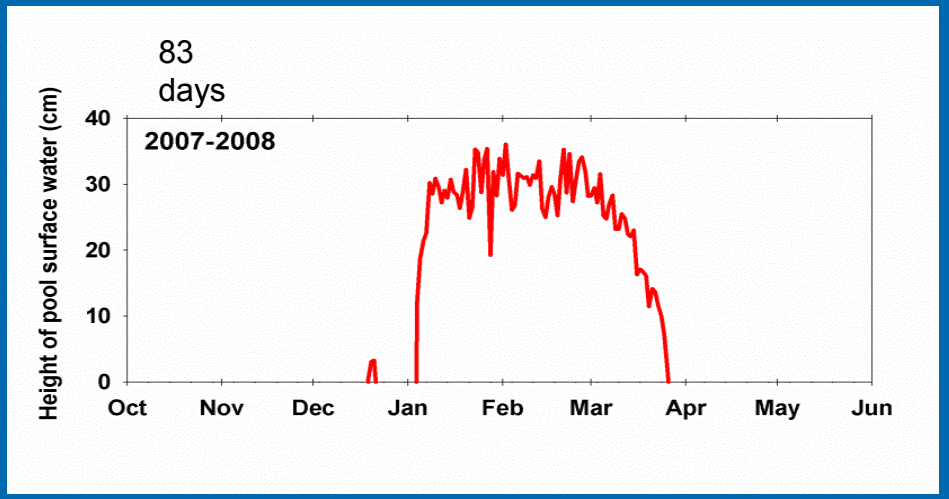


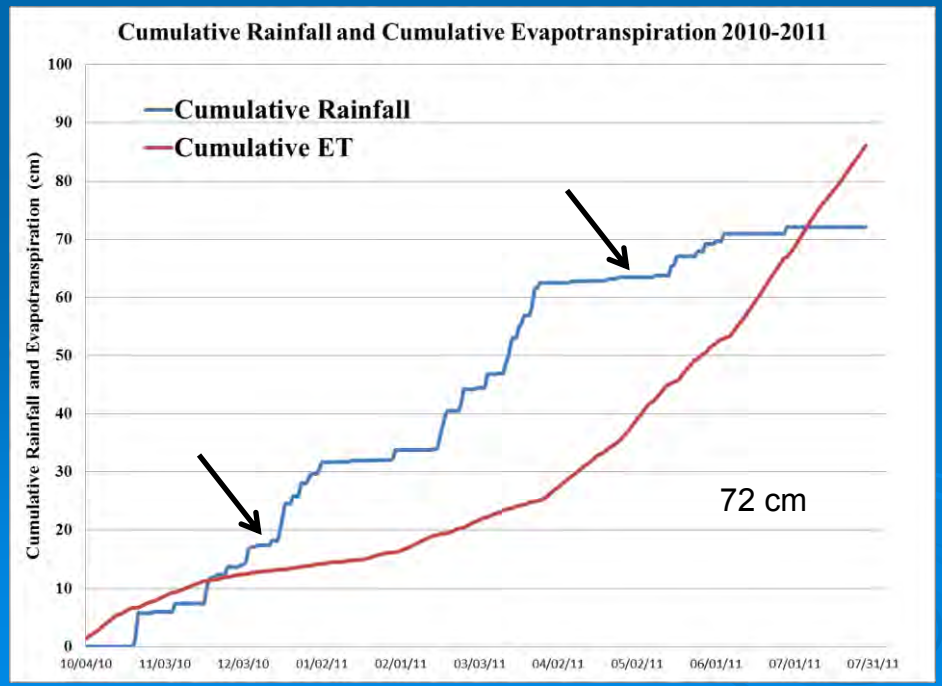


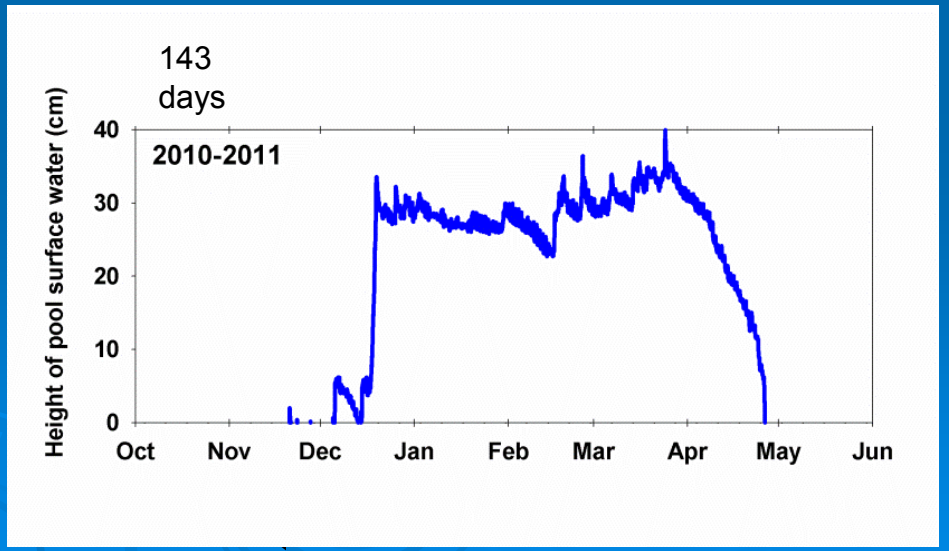
Modeling Water Balance



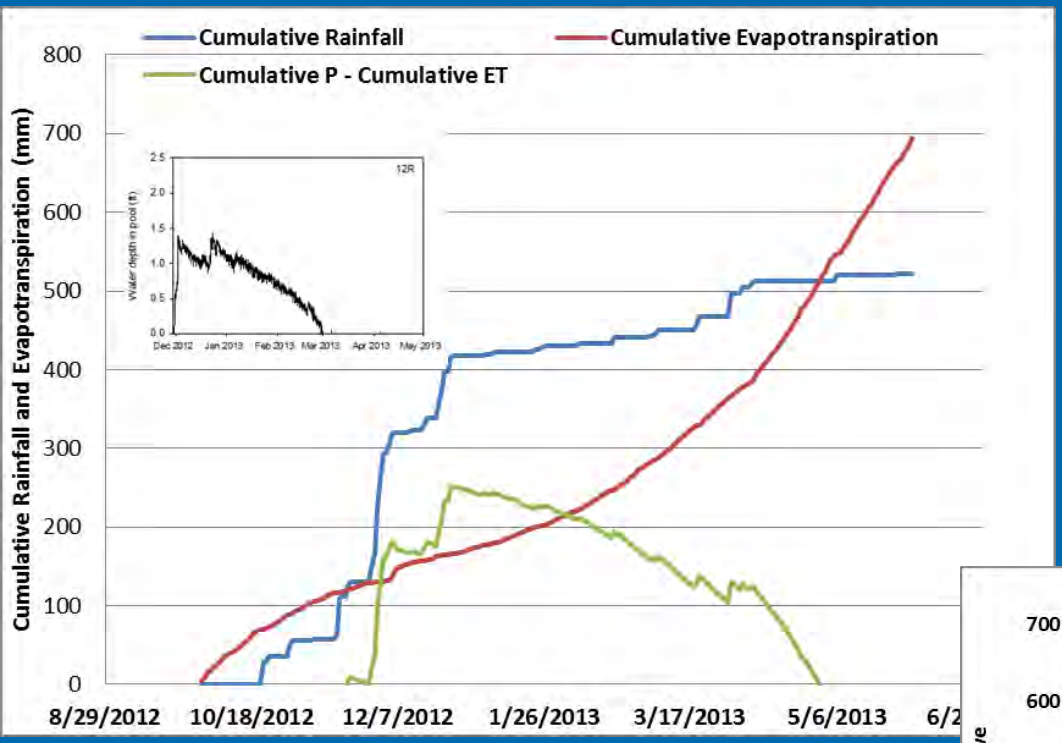

2007-2008 Cumulative Rainfall and Evapotranspiration
Cumulative P
Cumulative ET
Rainfall and Evapotranspiration (cm)
Mar 26, 2008
Last Rain Feb 24, 2008
Jan 2, 2008
32 cm
0
10
20
30
40
50
60
9/15
10/15
11/14
12/14
1/13
2/12
3/13
4/12
5/12
6/11

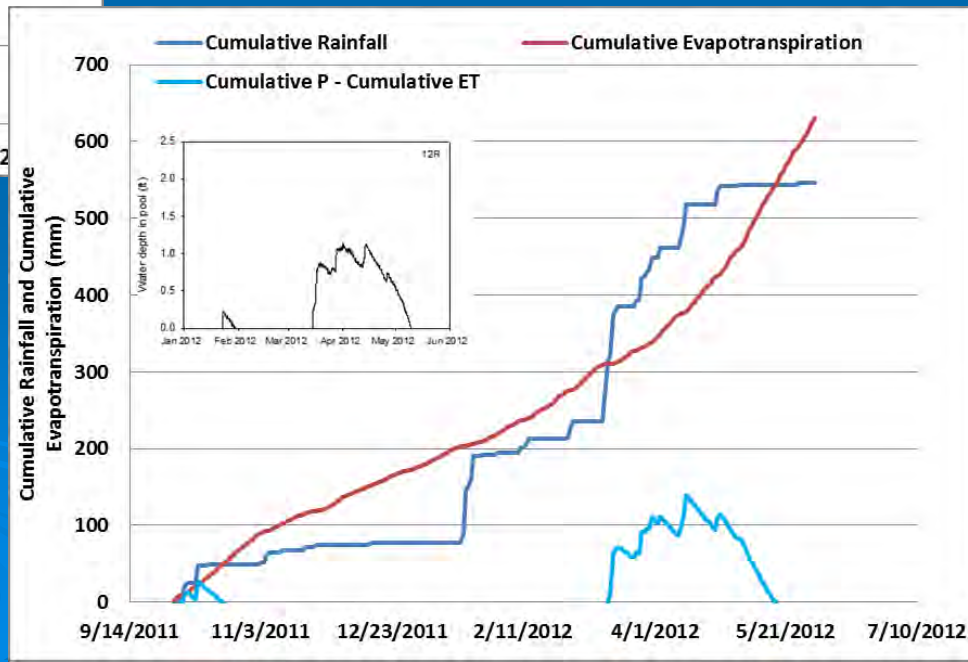

83
days
2007-2008
Height of pool surface water (cm)
0
10
20
30
40
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun


Cumulative Rainfall and Cumulative Evapotranspiration 2010-2011
Cumulative Rainfall
Cumulative ET
Cumulative Rainfall and Evapotranspiration (cm)
72 cm
0
10
20
30
40
50
60
70
80
90
100
10/04/10
11/03/10
12/03/10
01/02/11
02/01/11
03/03/11
04/02/11
05/02/11
06/01/11
07/01/11
07/31/11


143
days
2010-2011
Height of pool surface water (cm)
0
10
20
30
40
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun

Modelling Weather Variables





Modelling Hydrology

Water Balance

Storage = Input (Q + P) – Output (ET + Qout)

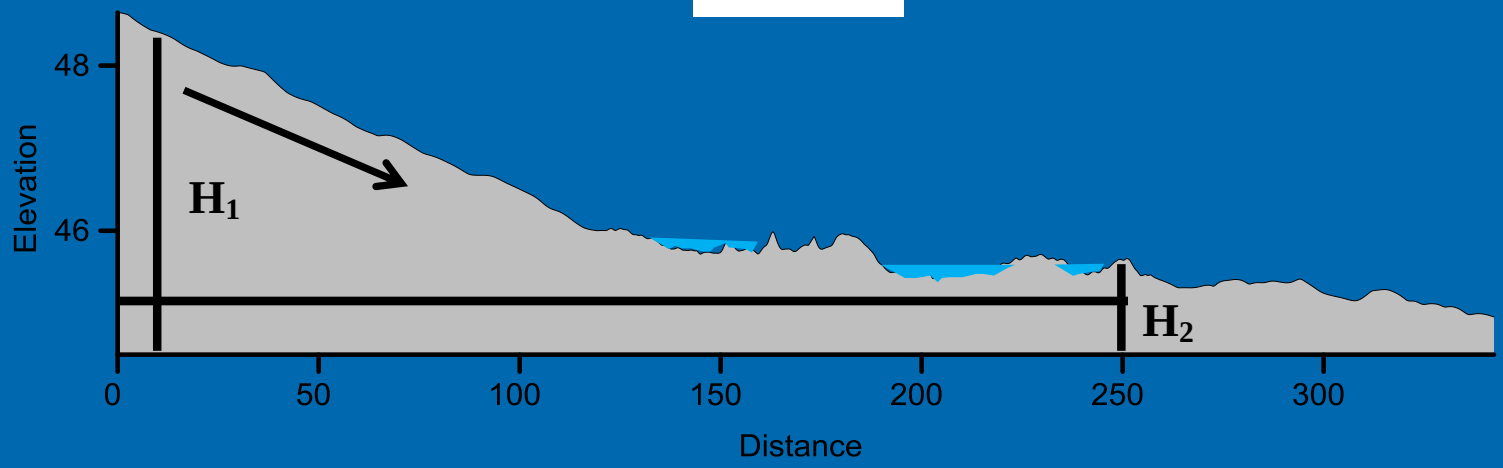
S = s1(Qin) - s2(Qout) + S3(P) – S4(ET) + error.

Using Generalized Additive Linear Partial Model in R,

Where s1, s2, s3, S4 are some smooth functions which will be generated in R.

McCarten and Gu. In press. Water Balance Model for Vernal Pool Wetlands. Advances in Water Resources.

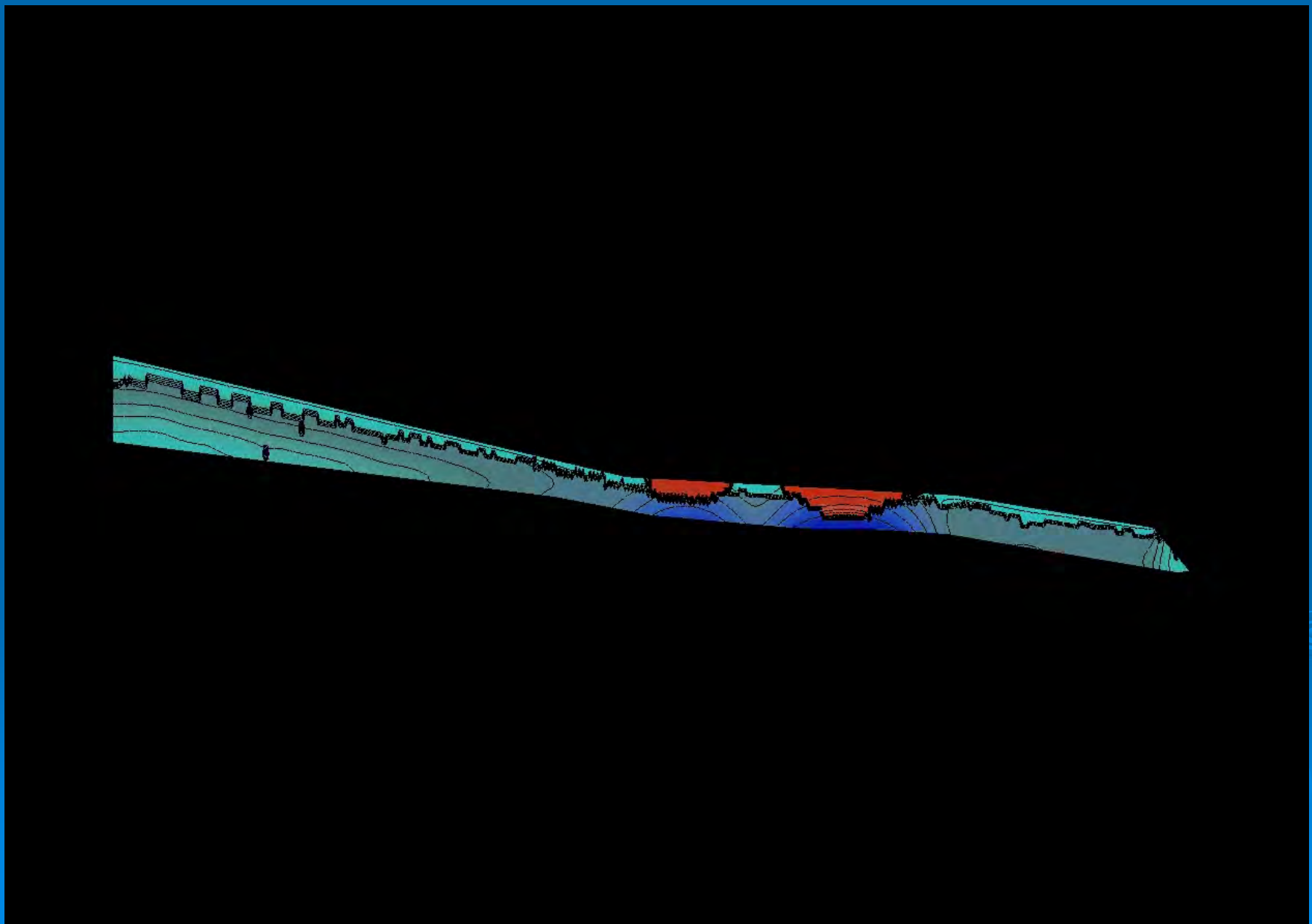
Calculating Water Flux



$$q = K \frac{H_1^2 - H_2^2}{2L}$$

$$h(x) = \sqrt{H_2^2 + 2xq/K}$$

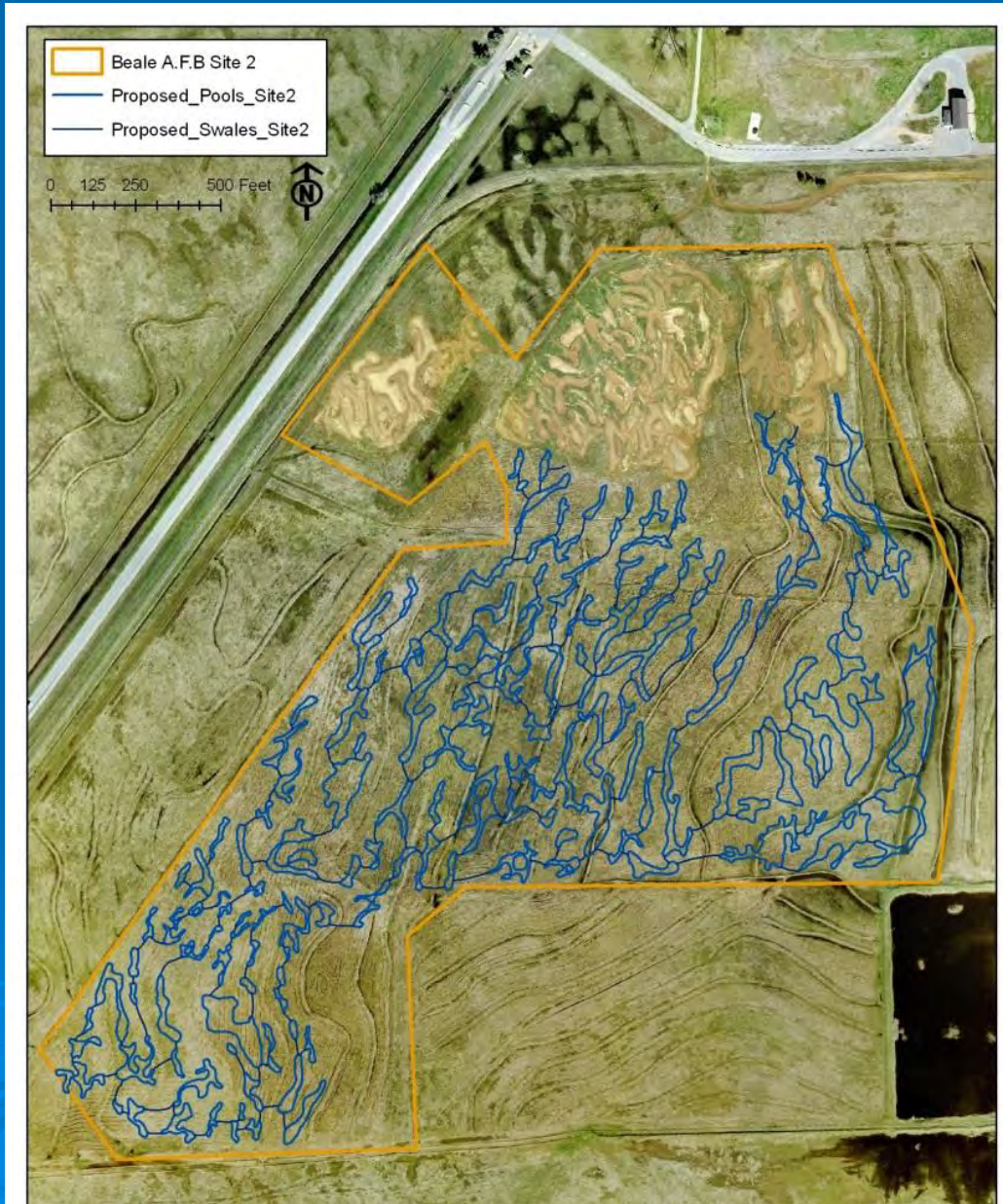
HYDRUS Model



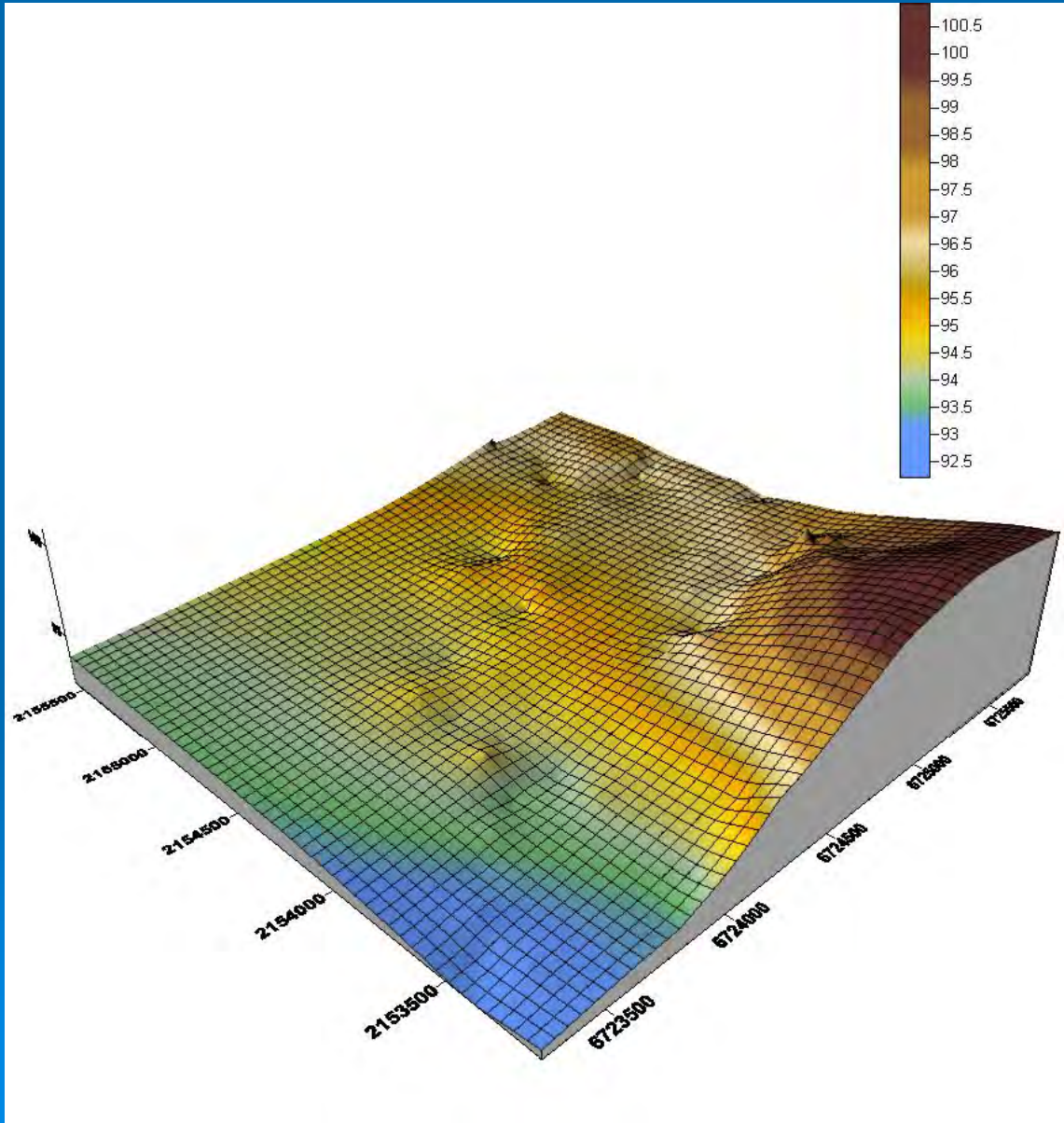
Vernal Pool Restoration

Original Landscape Architect Design

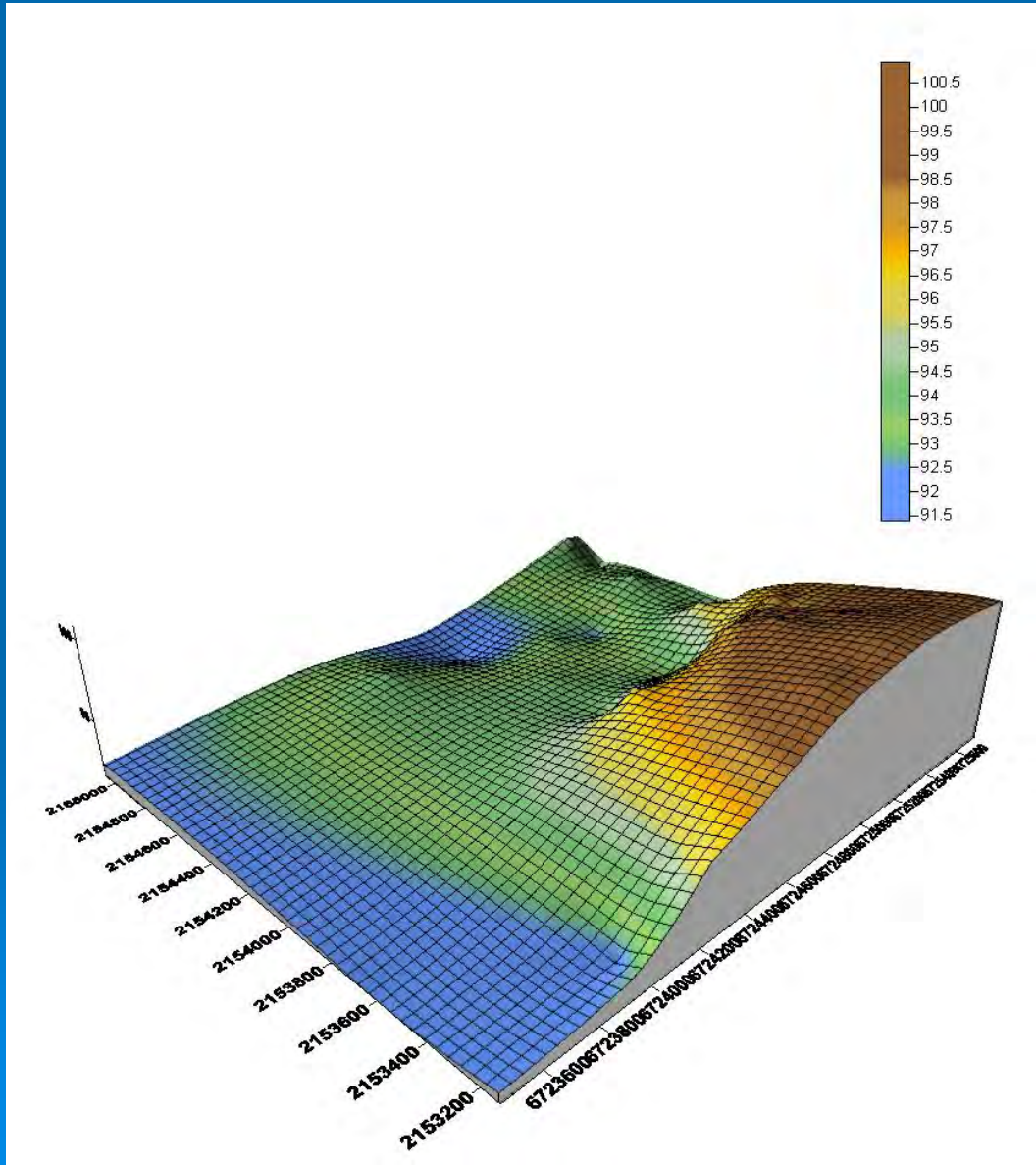
Beale AFB
Wheatland Gate
Rice Field
Restoration Project



Beale AFB Wheatland Gate Surface DEM

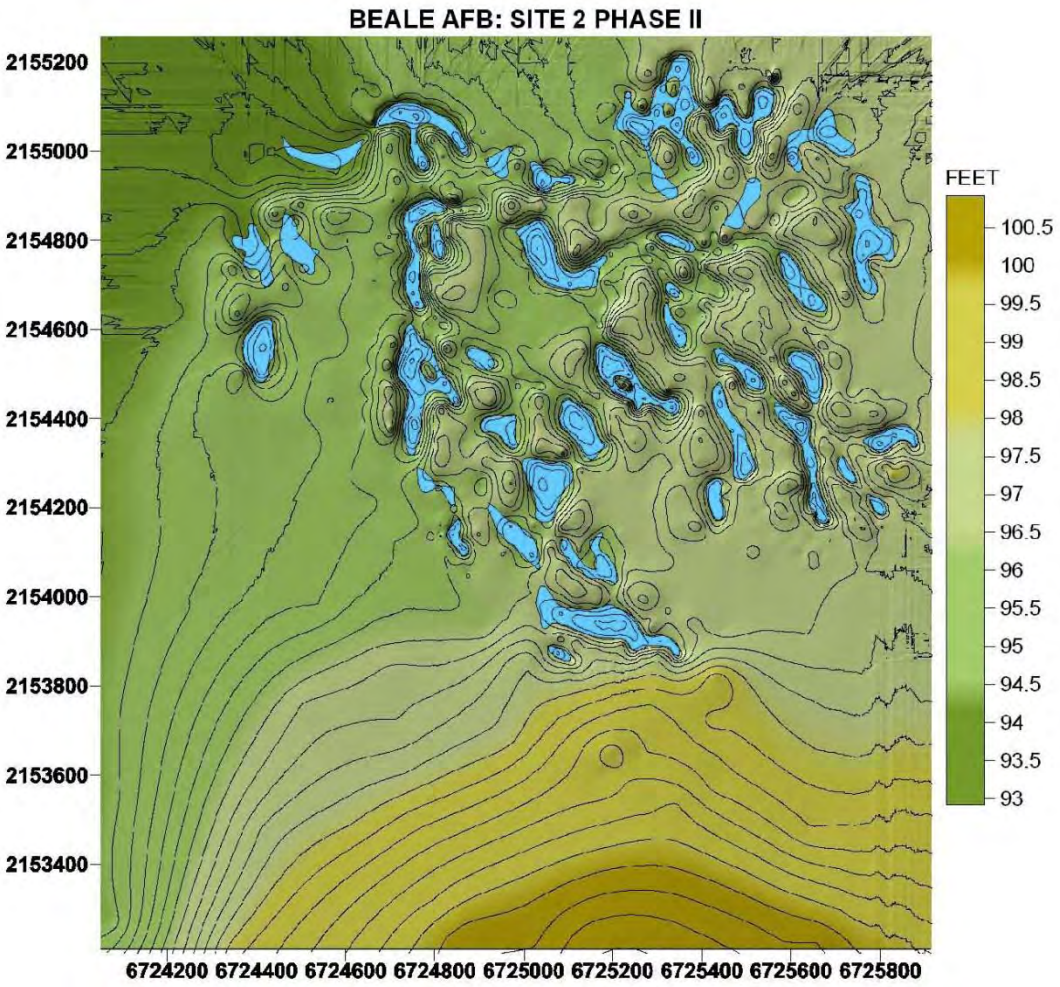


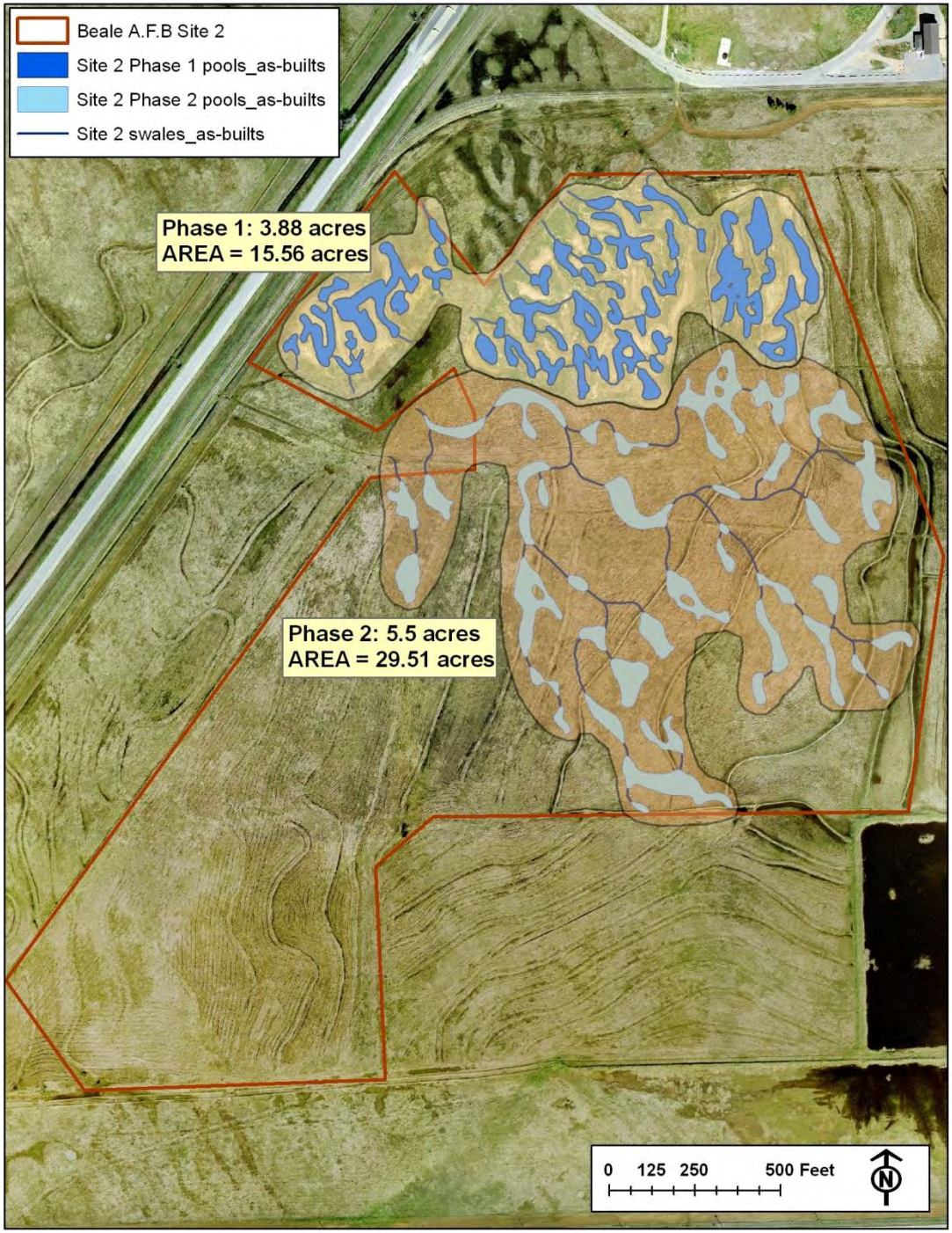
Wheatland Gate Soil DEM



Catchment Topography

Site 2 Phase 2Monitoring Pools (See Map 4 for individual mitigation pool numbers).





As-Built Drawings of Vernal Pool Restoration at Beale AFB

Results

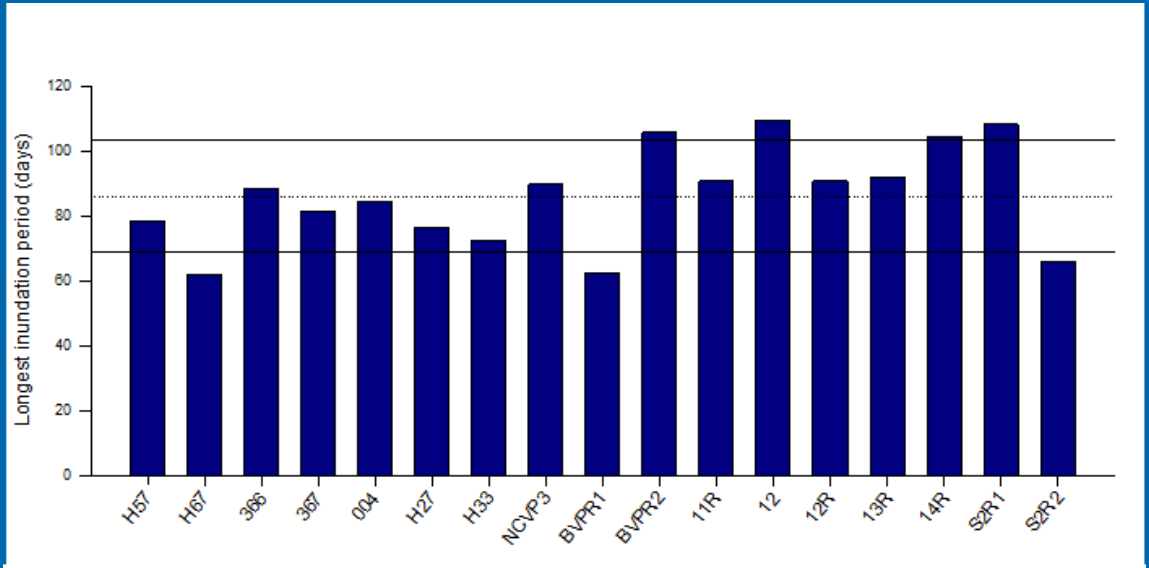
Phase 1 after 4 years

Phase 2 after 5 months

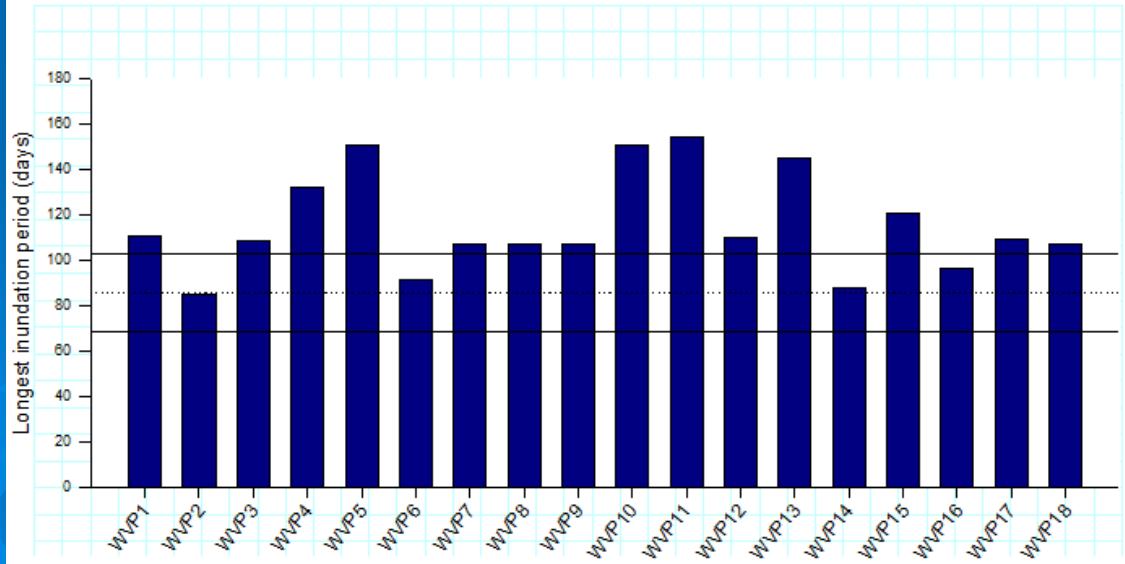
Rainfall 30 % below average

Hydrology of Natural vs Created Pools

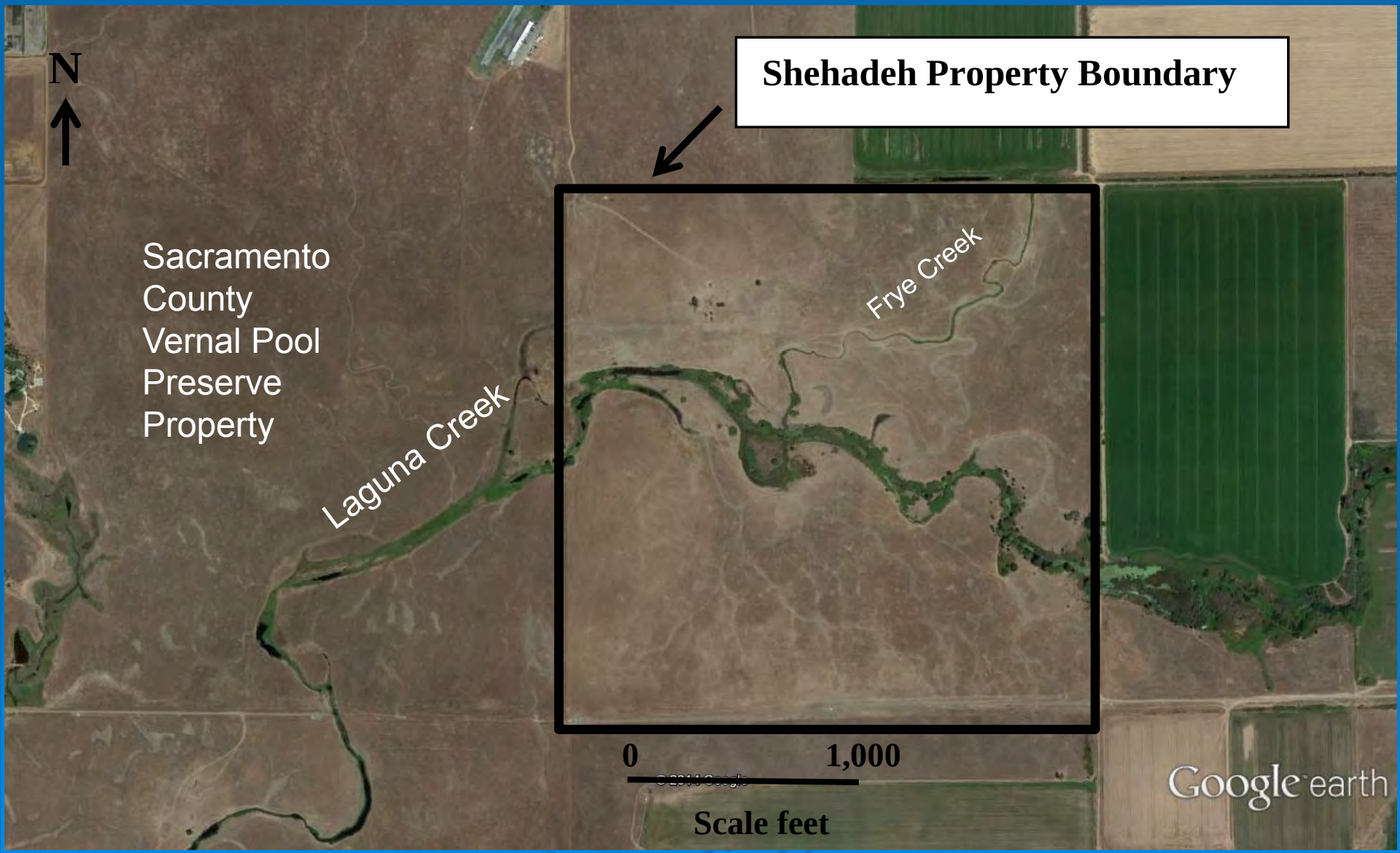
Natural Pools



Created Pools



Shehadeh Property Boundary

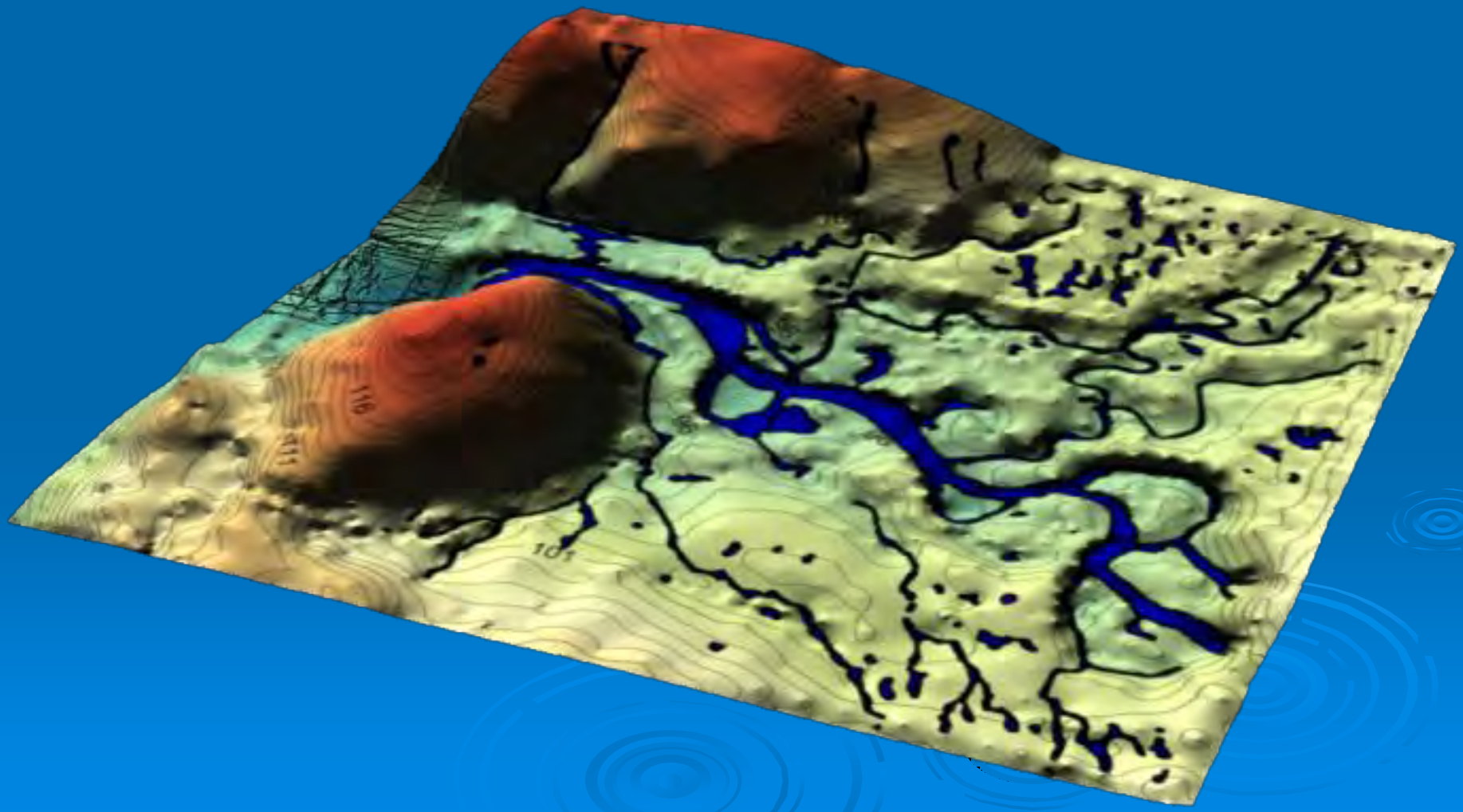


Shehadeh Property Dry & Wet Season

Existing Wetlands & Catchments

Existing Wetlands and Catchments

Digital Elevation Model of Site and Existing Wetlands



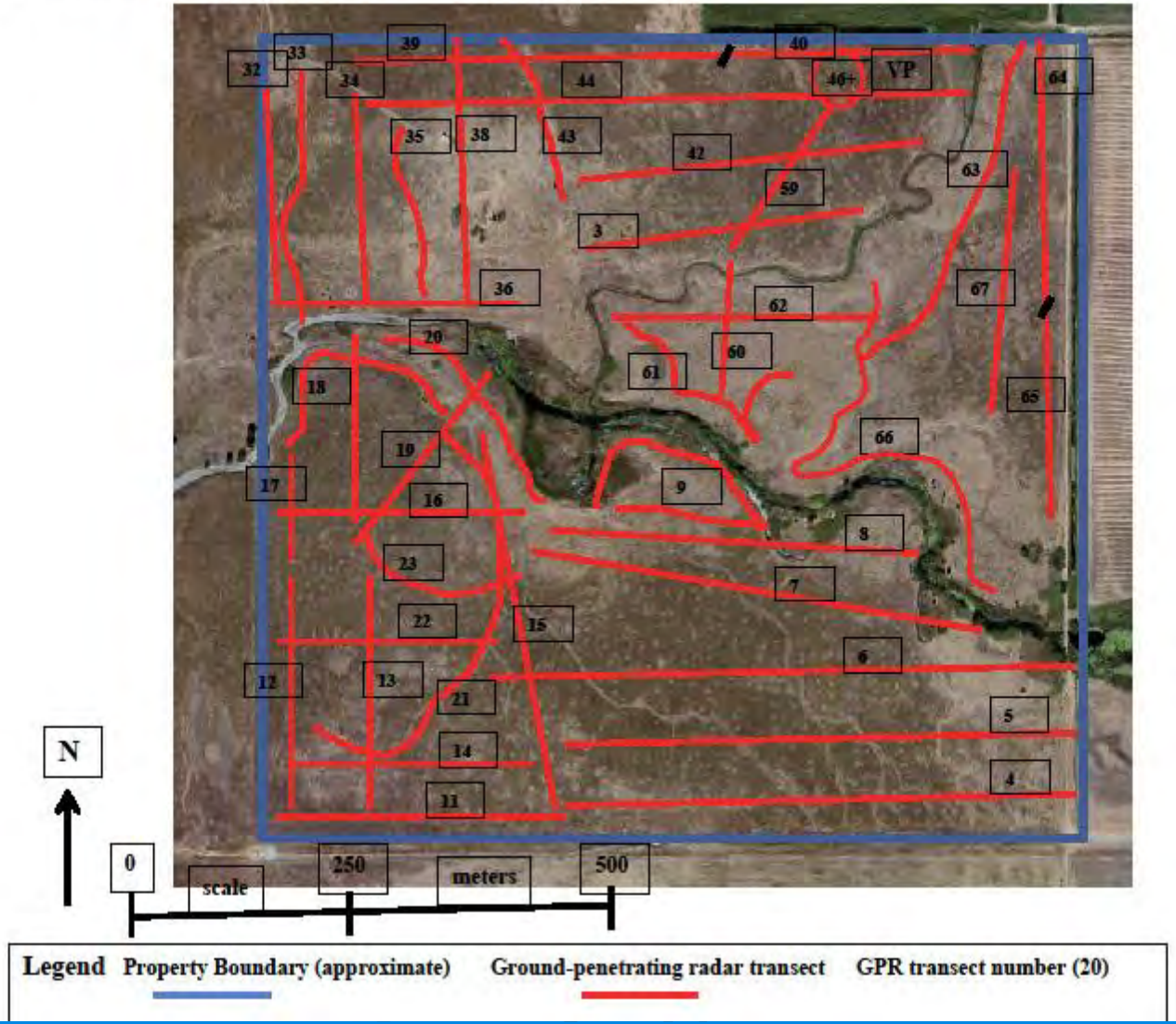
Soils

Key Soil Characteristics:

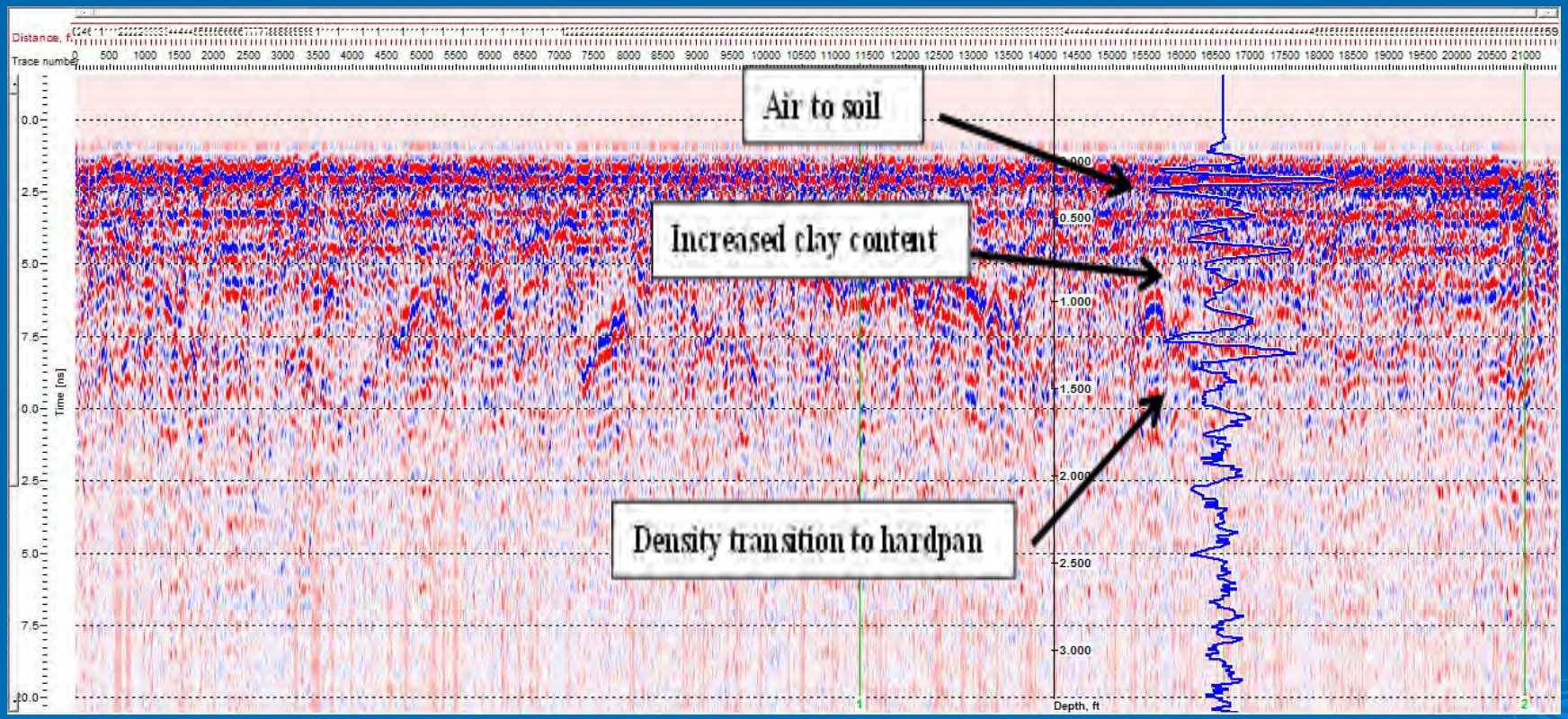
- A water-restricting soil layer present,
- Water-restricting layer continuous through vernal pool and swale system,
- Depth to water-restricting layer similar to natural vernal pools

Ground-Penetrating Radar

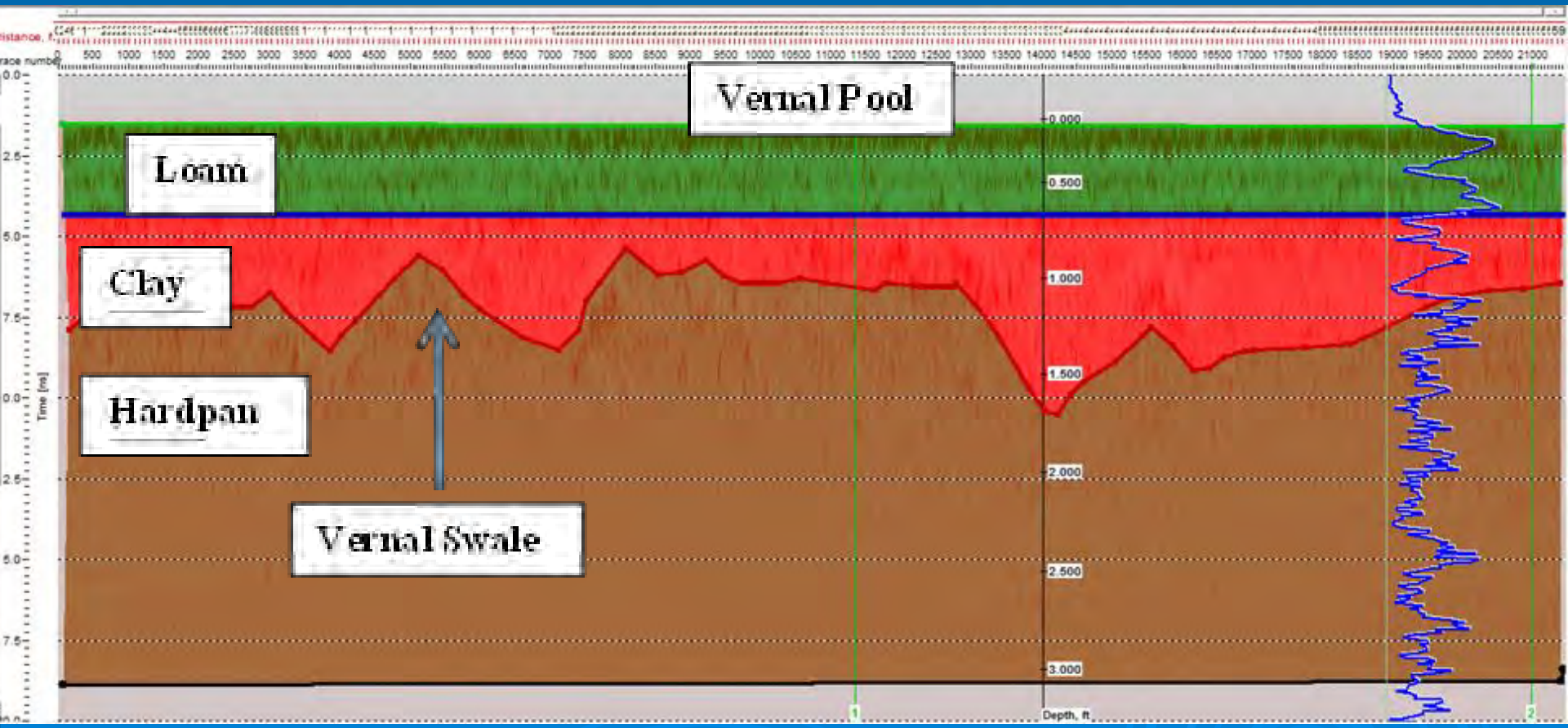
Figure 7. Ground-penetrating radar transects.



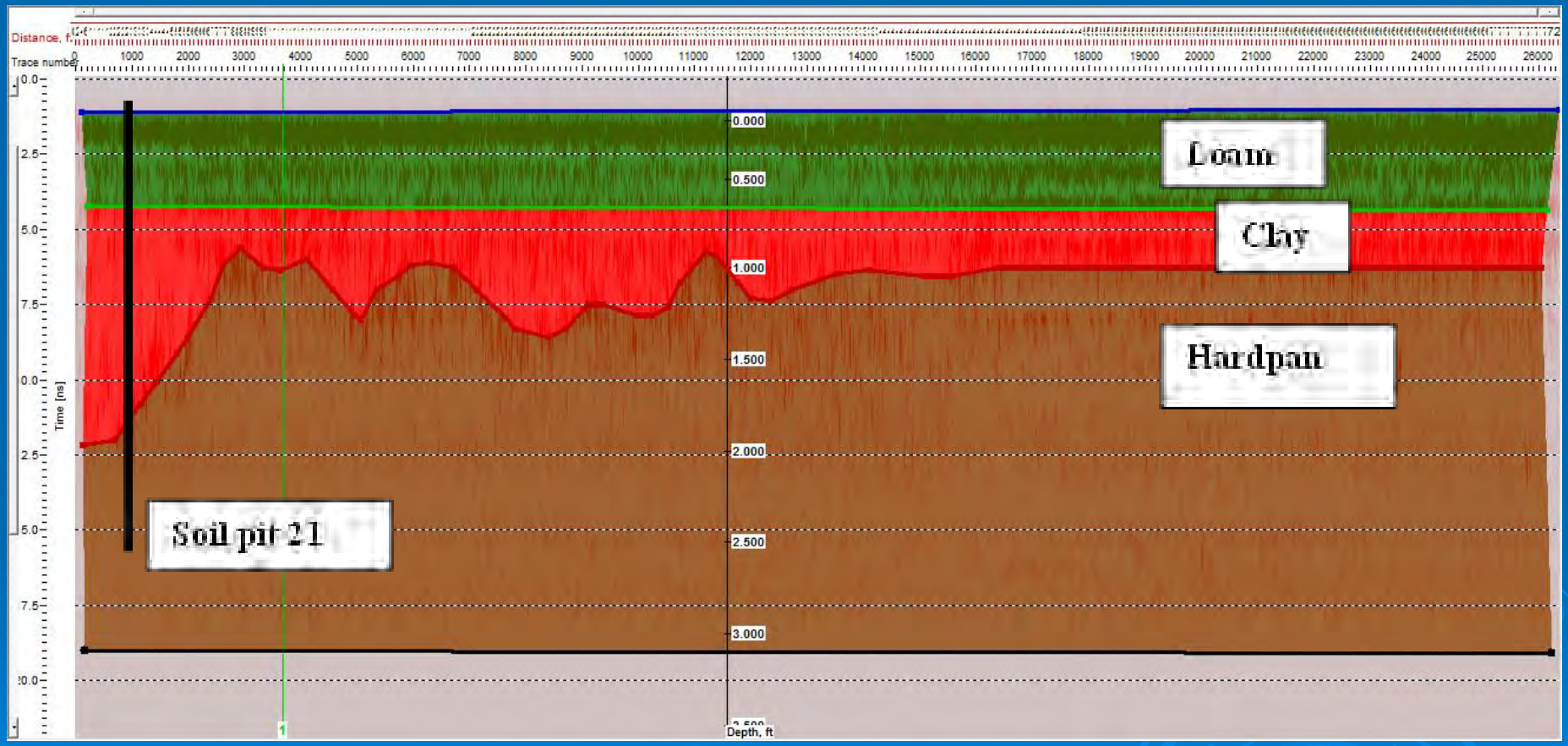
GPR Soil Profiles



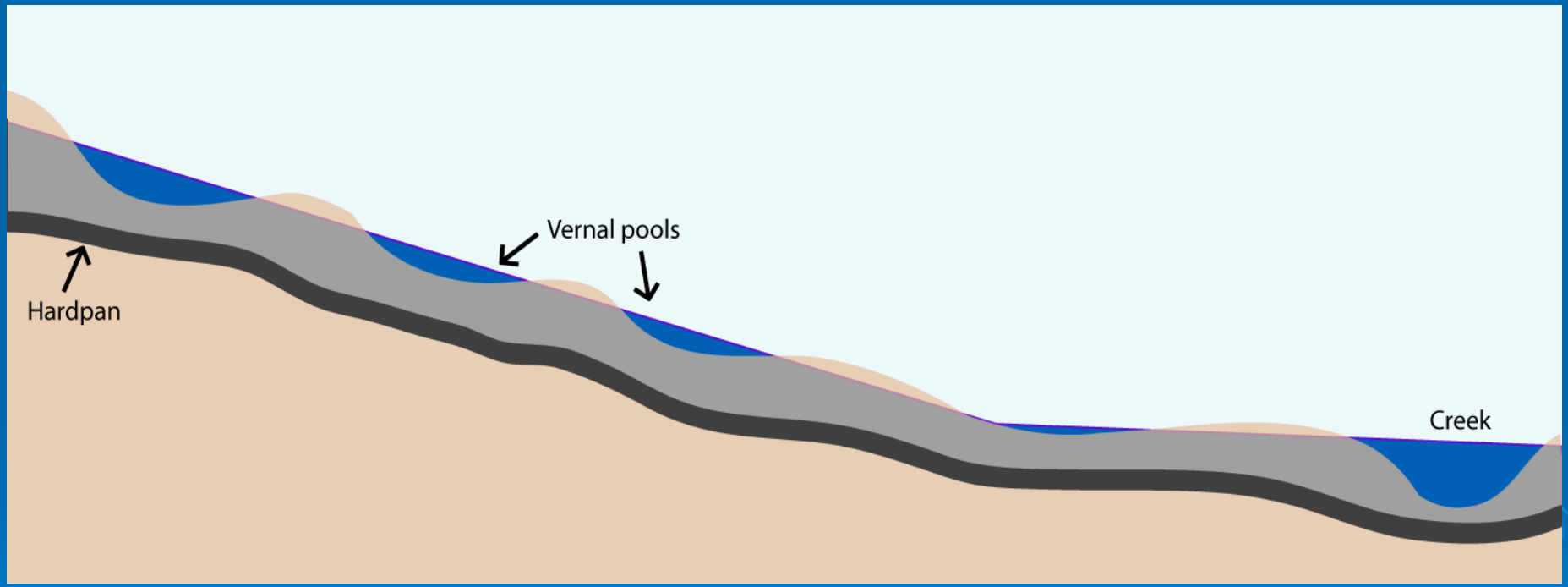
GPR Soil Profile

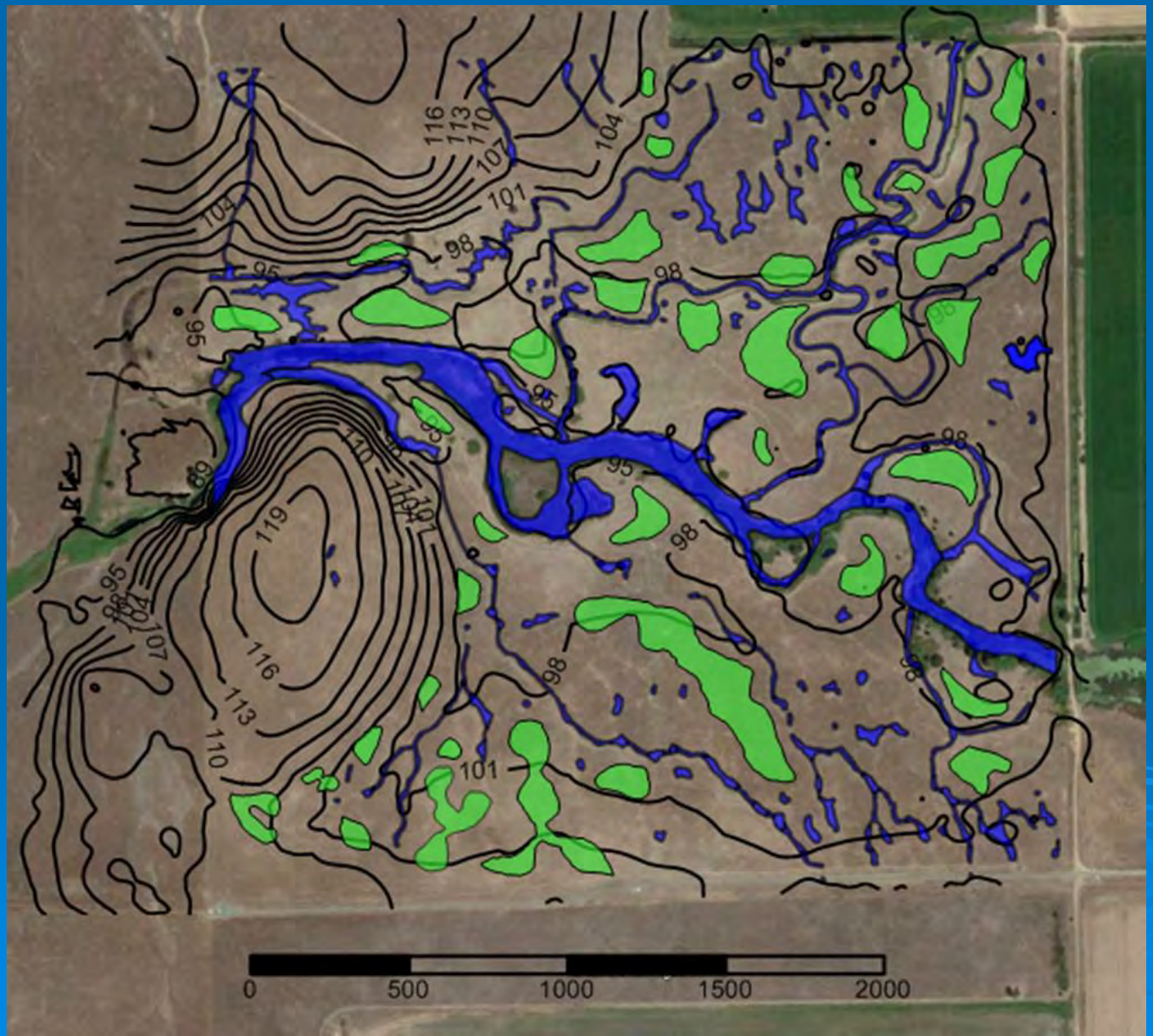


GPR and Soil Pits



Vernal Pool Drainage Model

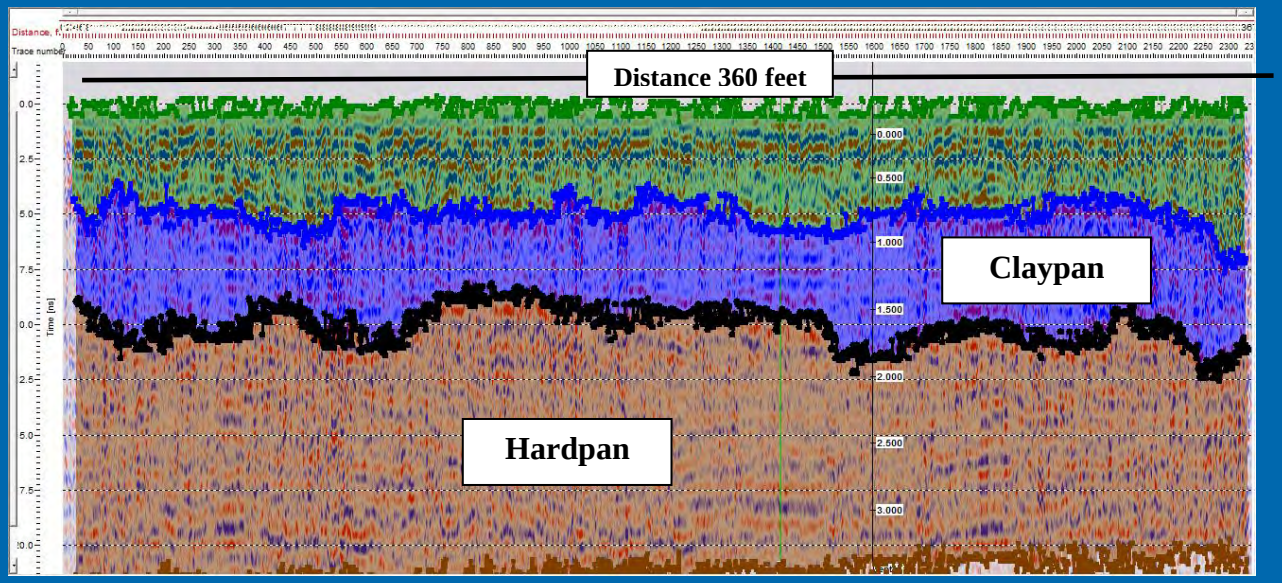



116
113
110
107
104
101
98
95
119
0
500
1000
1500
2000

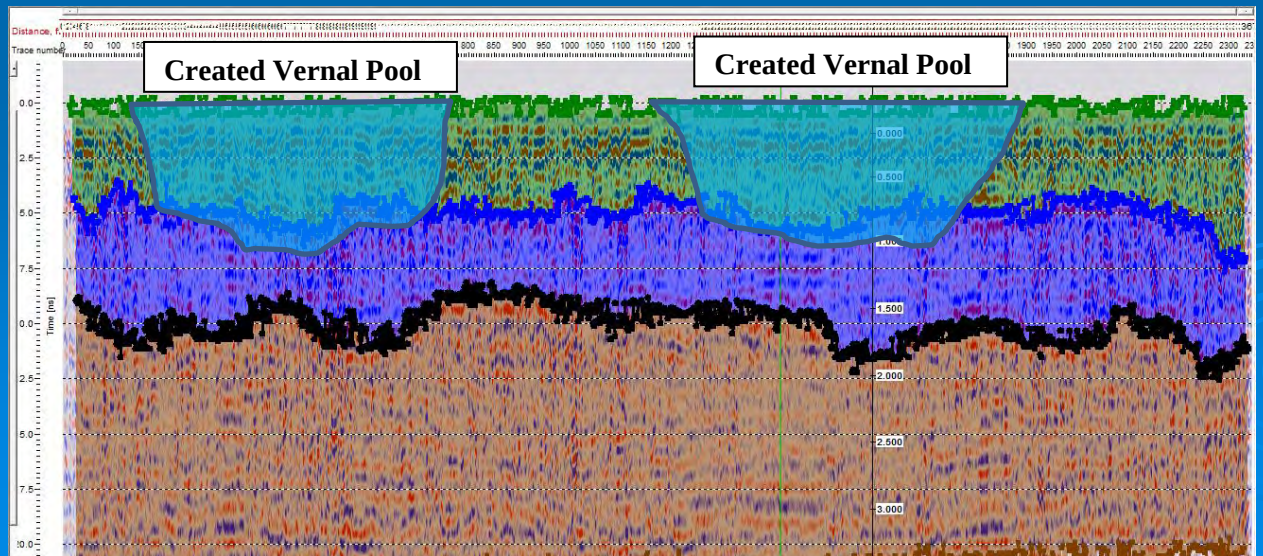

116
106
96
96
96
106
96
96
96
106
116

GPR Profiles & Proposed Vernal Pools

GPR Transect (DAT 105) Potential Vernal Pool Creation Area Pools 3 and 4

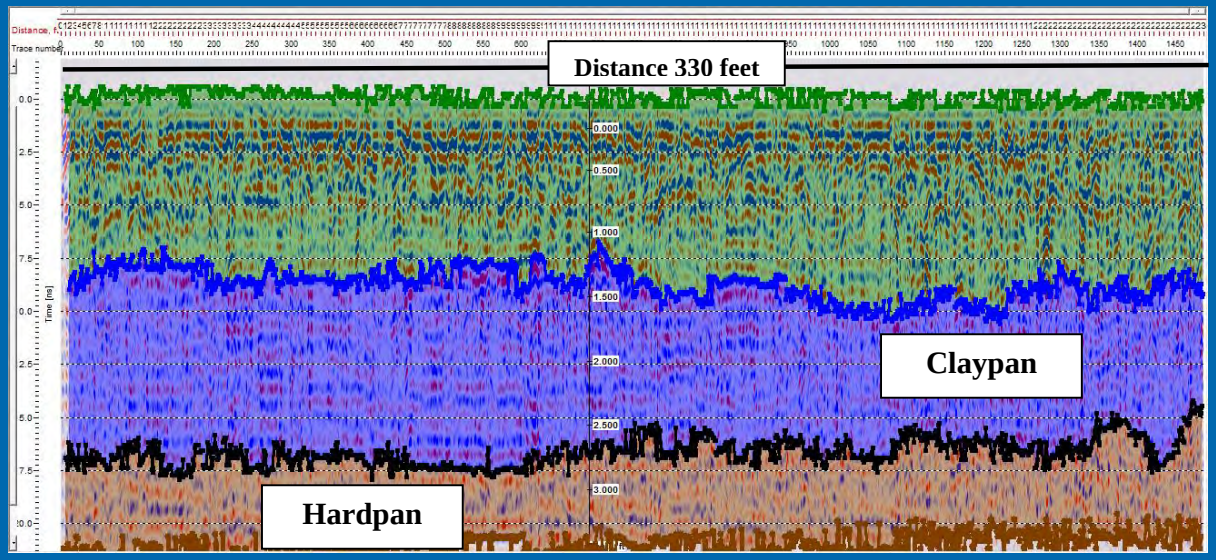


Cross Section Showing Proposed Pools 3 and 4.

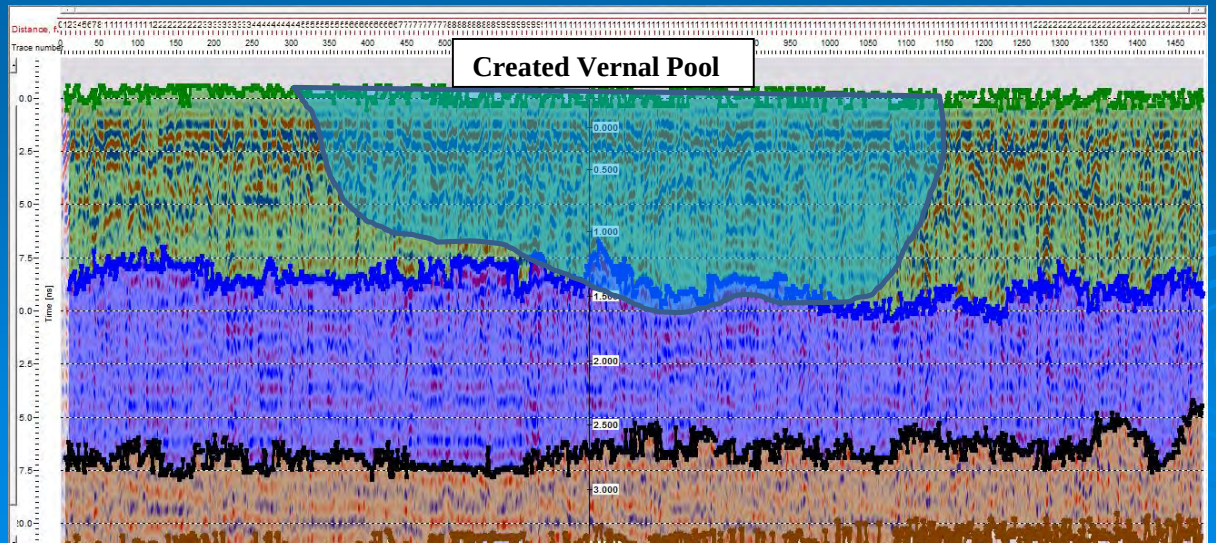


GPR Profiles and Proposed Vernal Pools

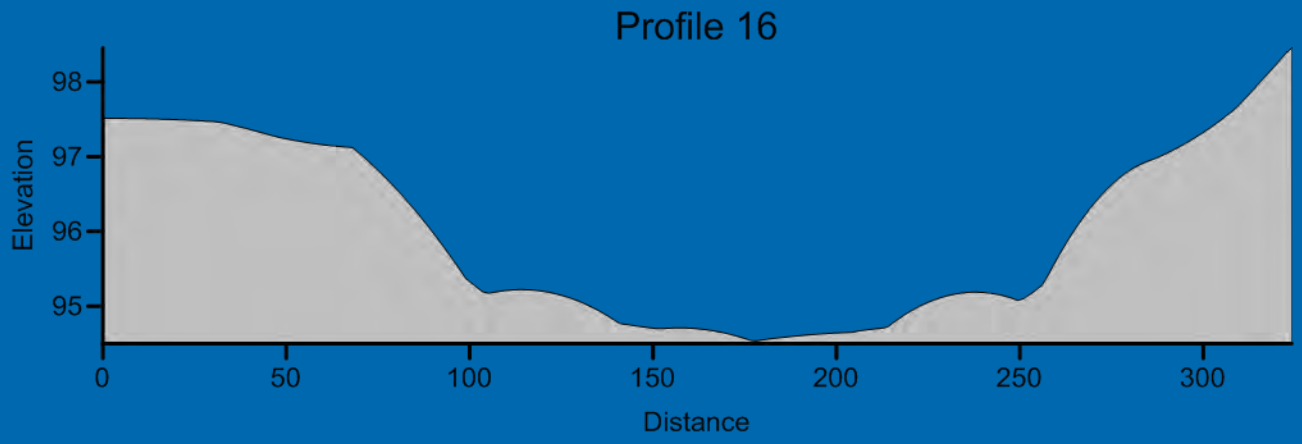
GPR Transect (DAT 111) Proposed Vernal Pool Creation Area Pool 6

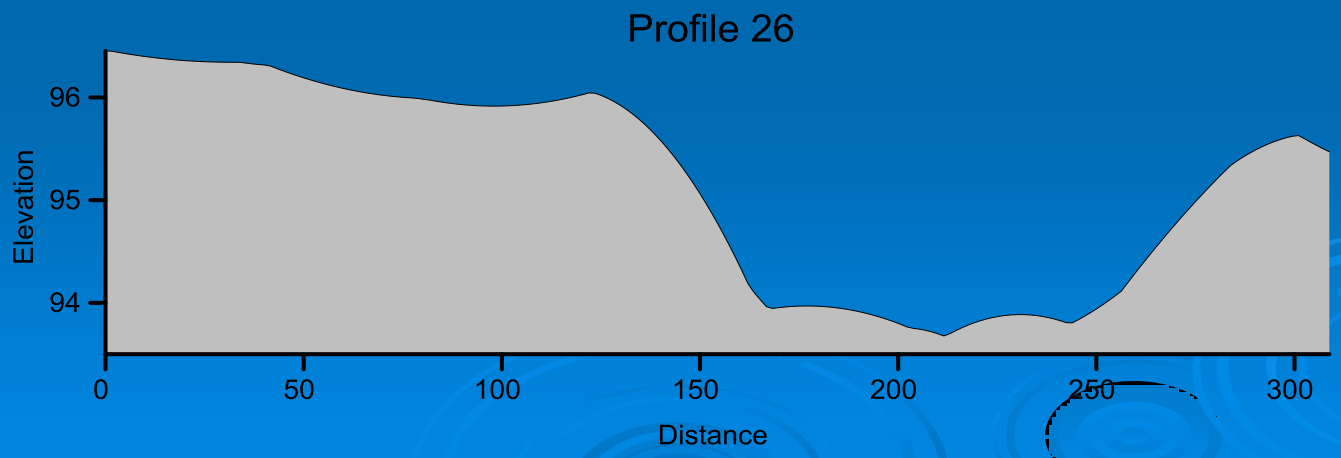


GPR Cross Section Showing Proposed Pool 6



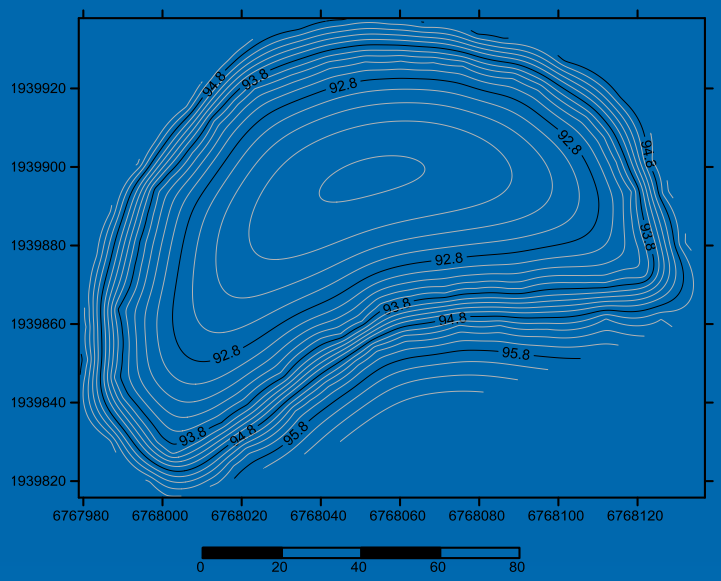
Cross-Sections of Each Vernal Pool



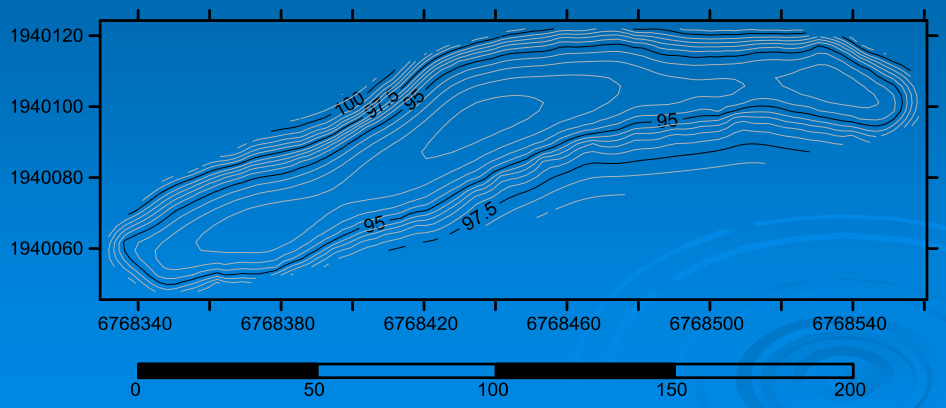


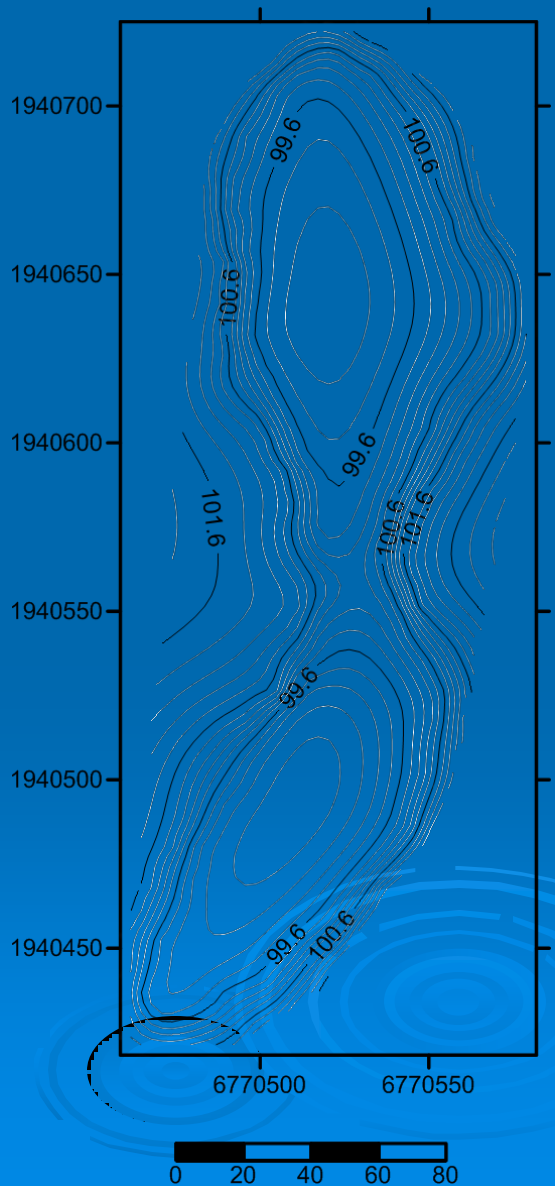
Individual Pool Contours

VERNAL POOL 1

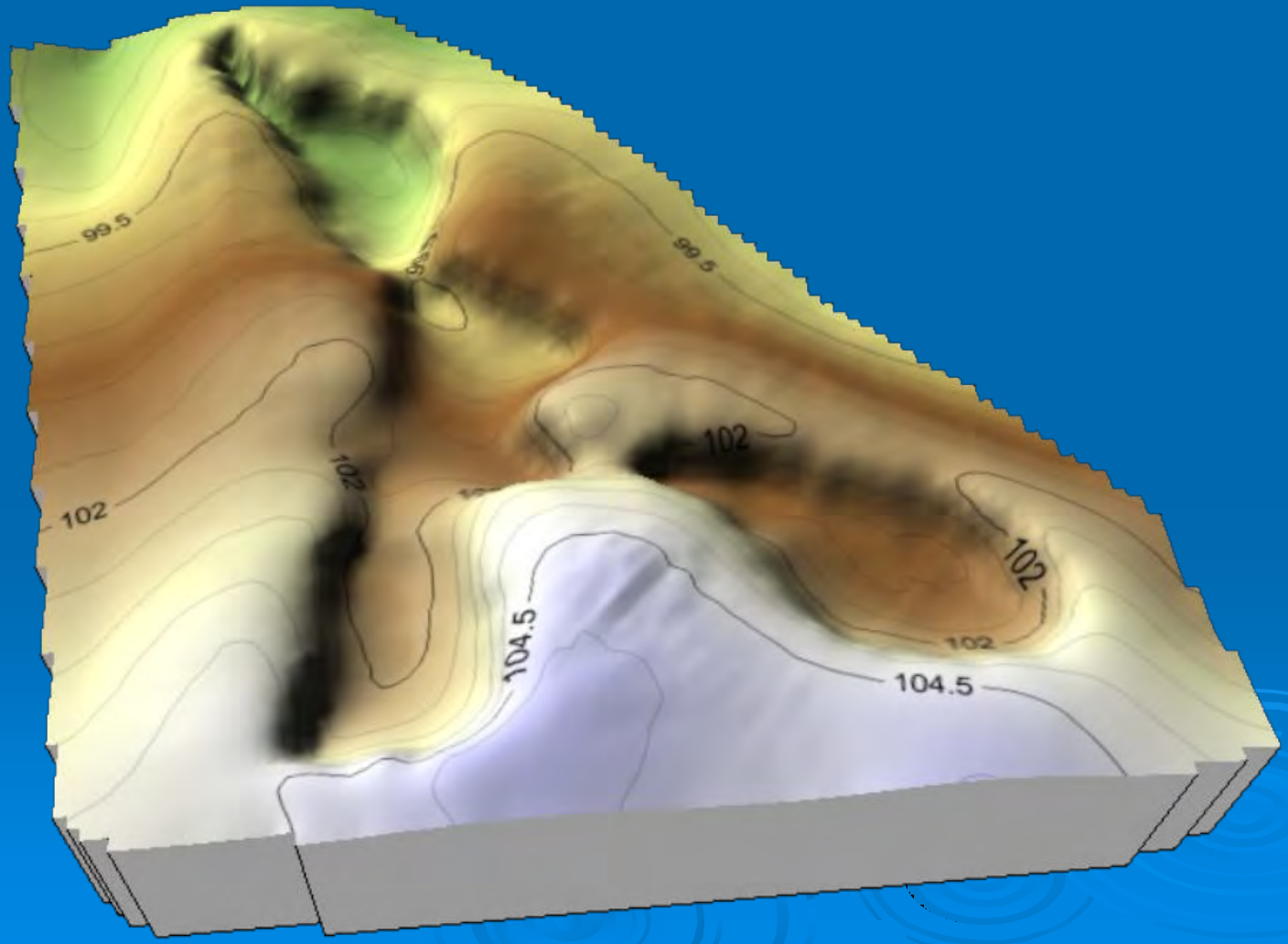


VERNAL POOL 2

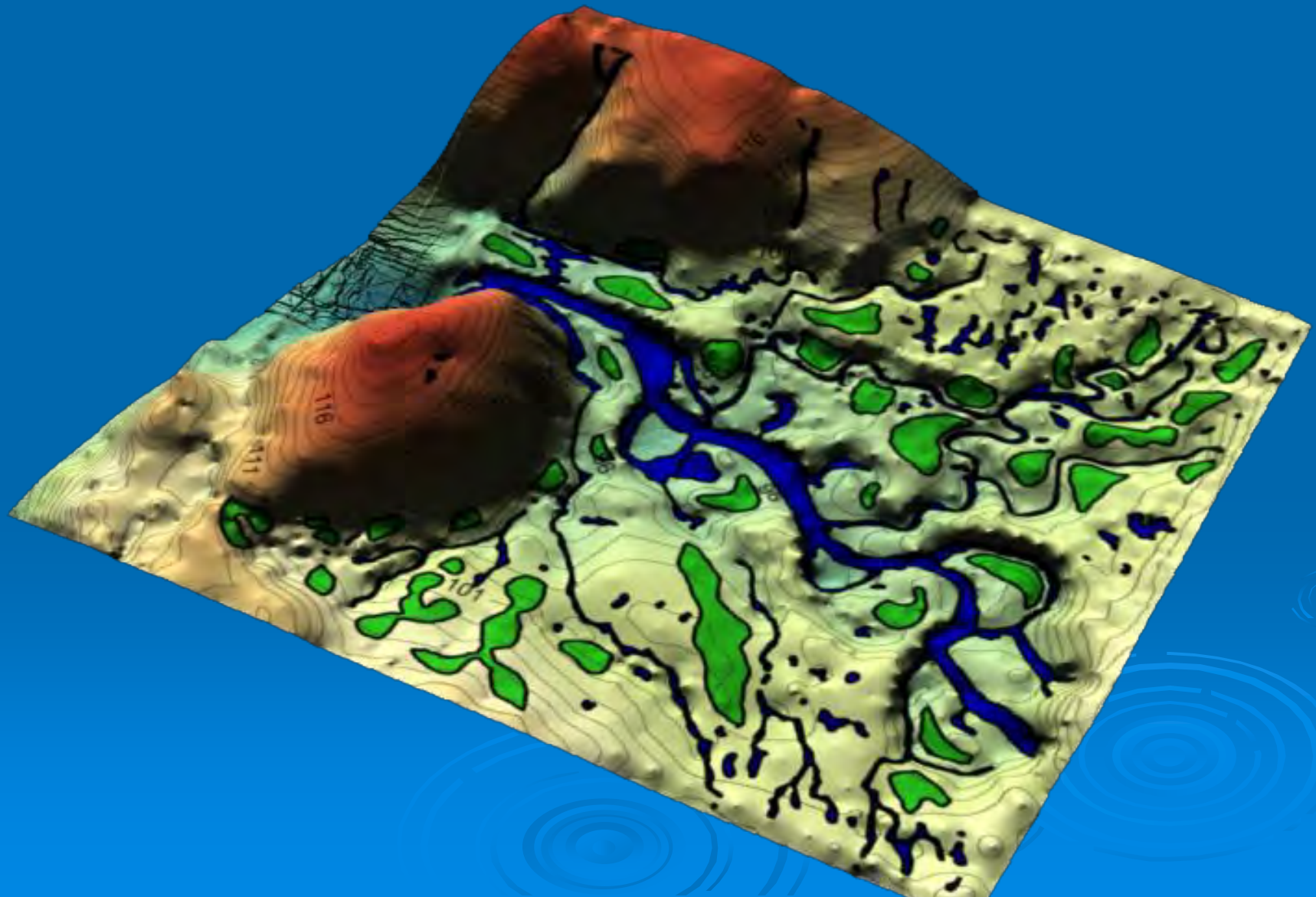




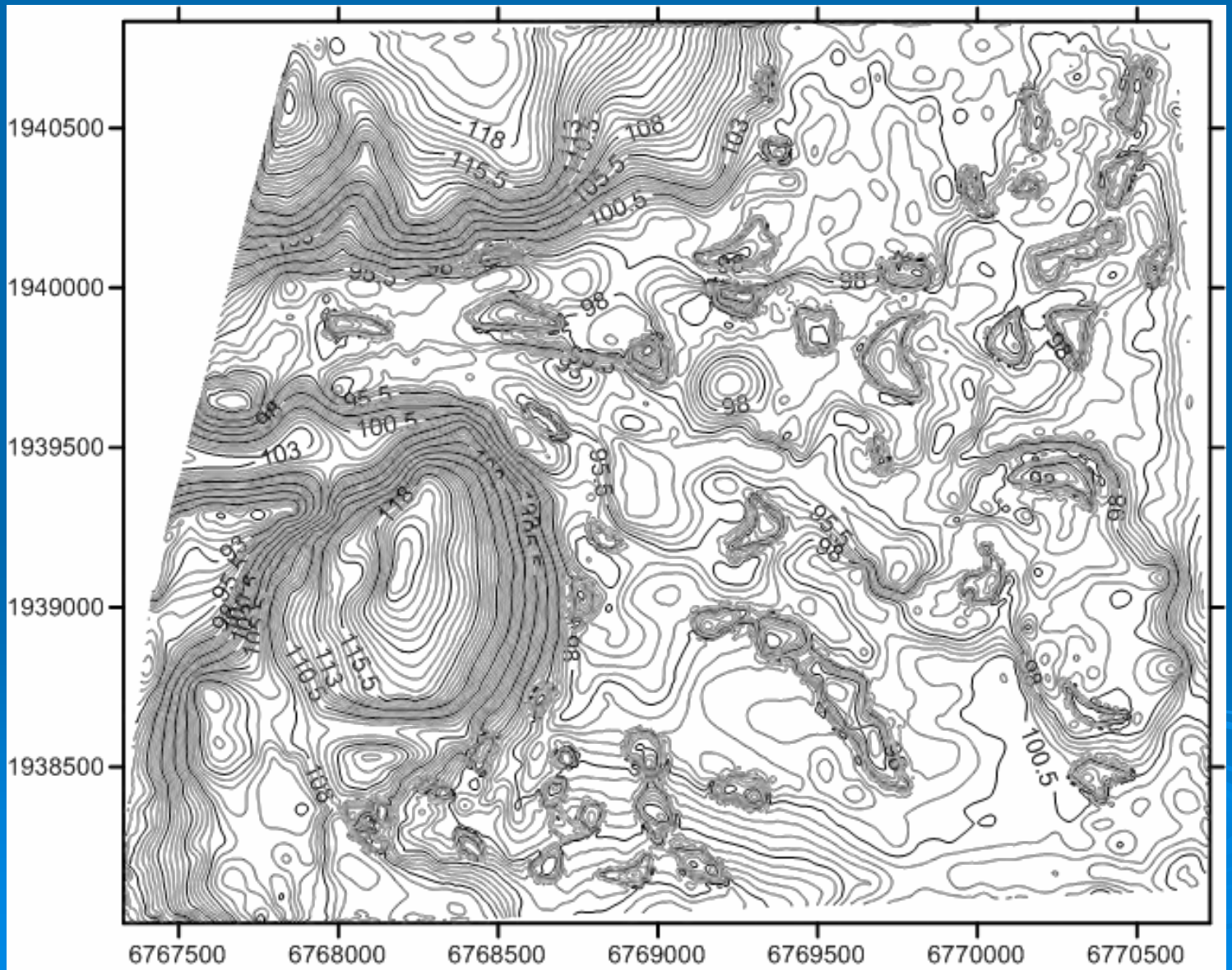
Digital Elevation Model of Every Vernal Pool



3-D Model of Constructed Site



Complete Vernal Pool Grading Model



Construction August 28 – October 8, 2015

Planning, Engineering to Construction Does the Design Equal the Constructed Pools?

Post Construction October 2015

Photos January 2016

Photos January 2016

Pool Numbers	Modelled Pool Area (Acres)	As-Built Pool Area (Acres)	Difference (Acres)
1	0.307	0.28	-0.029
2	0.169	0.17	-0.002
7	0.335	0.36	0.026
20	0.176	0.16	-0.013
21	0.150	0.16	0.006
22	0.560	0.58	0.023
23	0.088	0.09	0.002
24	0.337	0.31	-0.030
25	0.106	0.11	0.002
26	2.321	2.57	0.247
27	0.315	0.30	0.016
28	0.073	0.08	0.002
29	0.336	0.37	0.032
30	0.167	0.20	0.033
31	0.368	0.34	0.027
32	1.283	1.32	0.042
35	0.481	0.50	0.015
36	0.143	0.17	0.023
37	0.103	0.10	-0.006
38	0.106	0.13	0.025
39	0.707	0.68	-0.023
	14.789		
Totals	14.789	15.23	0.531

Modelled vs Created Vernal Pool Acres

Adaptive management during construction allowed for 0.5 additional acres

Questions