New methods for wetland water budgeting: WetBud

Tess Wynn Thompson and W. Lee Daniels, Virginia Tech

Rich Whittecar, Old Dominion University

Zach Agioutantis, Technical University of Crete

Students: Kerby Dobbs, Matt Gloe, John McLeod,

Eric Neuhaus, O. Waverly Parks,

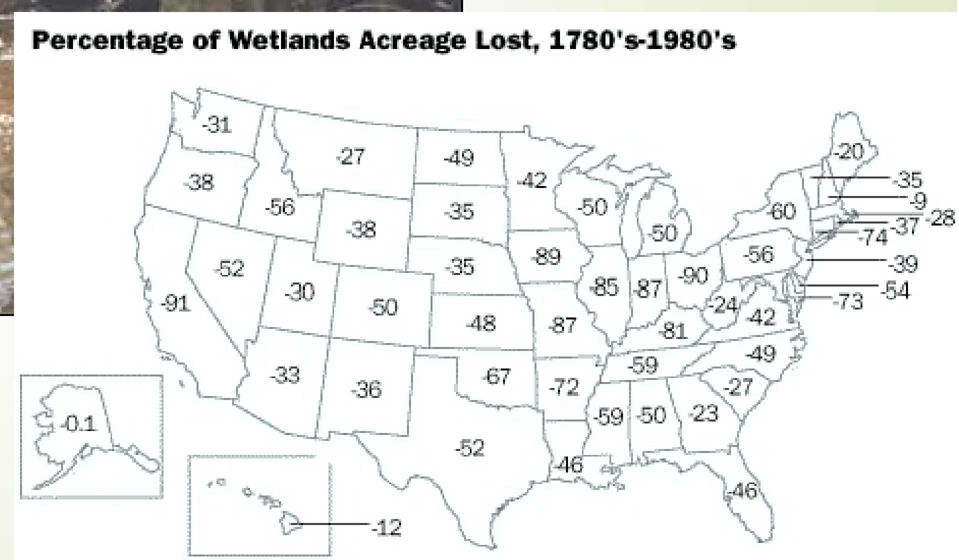
Candice Piercy, Tracy Thornton, Cal Smith

Topics

1. Background
2. Initial Studies
3. WetBud Capabilities and Interface
4. Verification Studies

Wetlands provide habitat, improve water quality, control erosion, and store flood water

Since the 1780's, about 53% of all US wetlands have been lost



from Mitch and Gosselink, 1993

(Dahl, 2000)

Wetland restoration and creation can help offset the effects of wetland loss

South Florida Water District – 62.5% of projects exhibited hydrologic problems

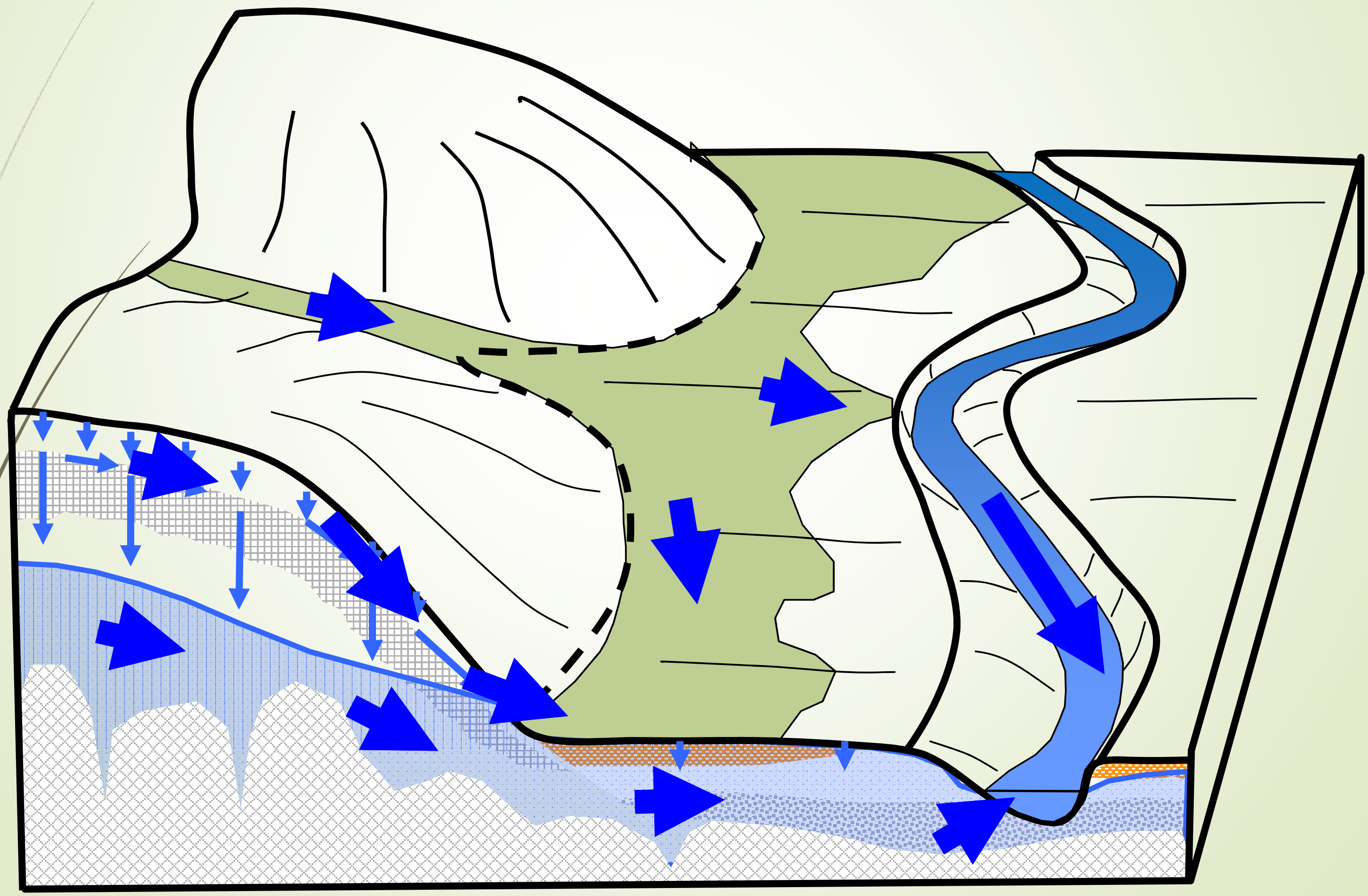
Erwin (1991)

from Dahl, 2000 (US Fish and Wildlife)

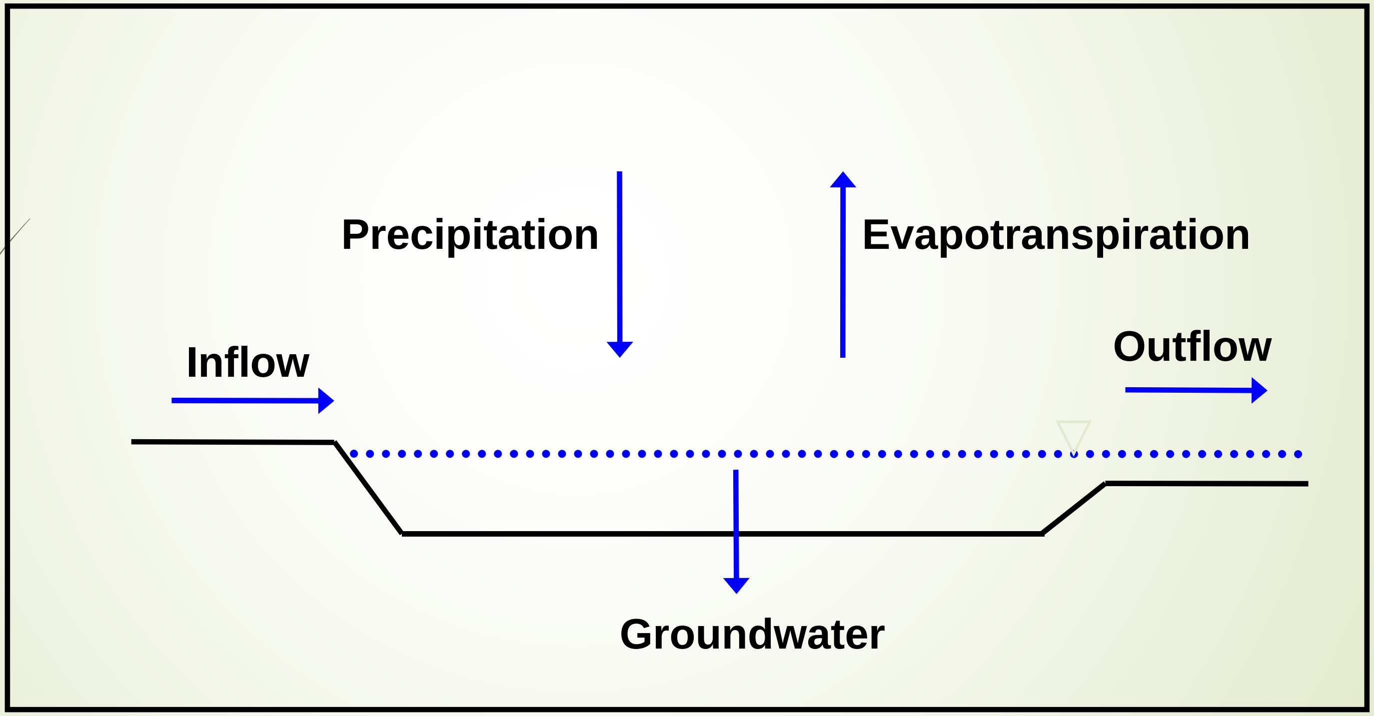
Many restored and created wetlands are too wet to effectively function

Cole & Brooks (2000)

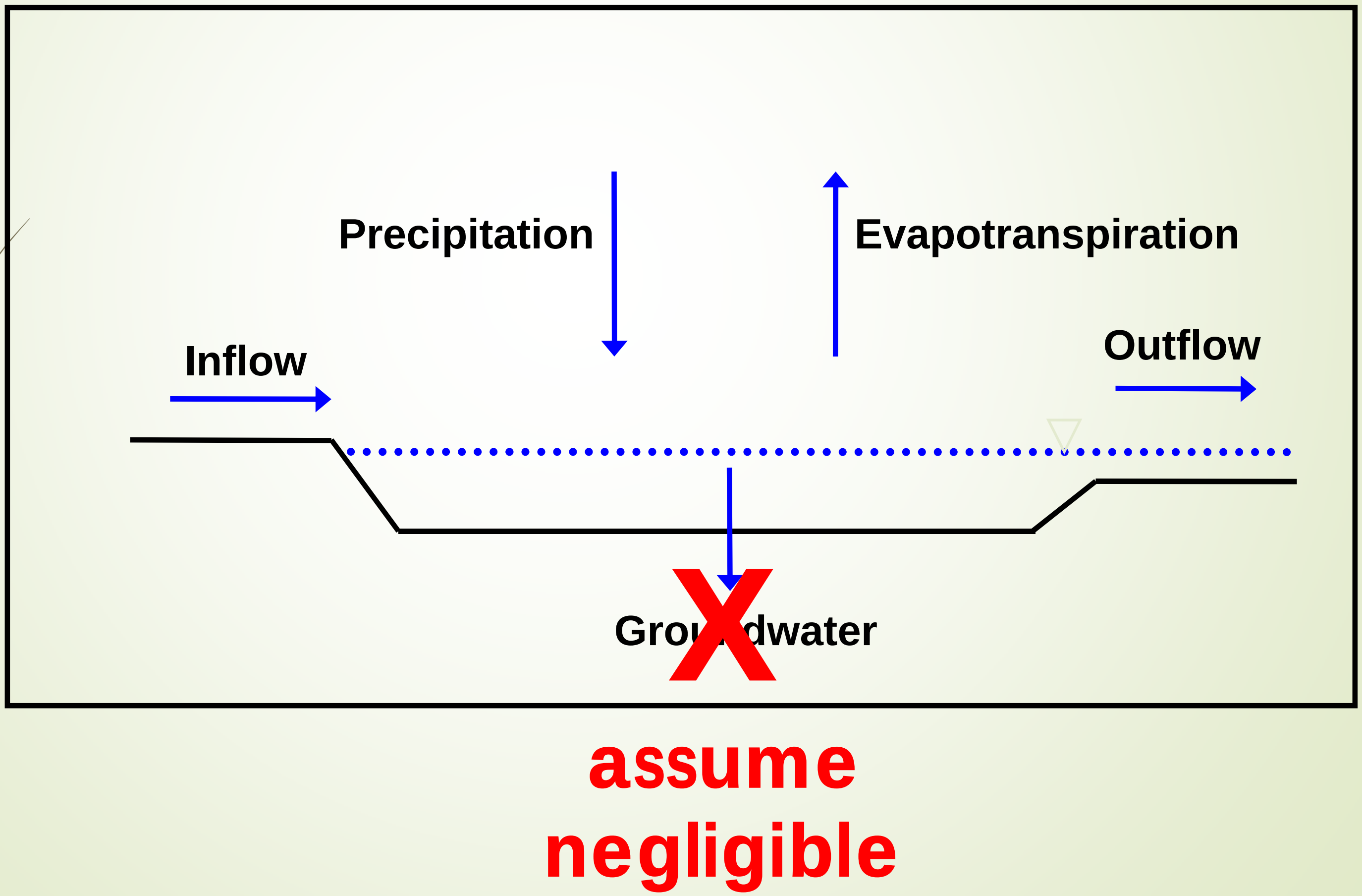
Piedmont Wetlands: the interface between uplands, groundwater, and surface water



A “simple” way to create a mitigation wetland is to create a perched system

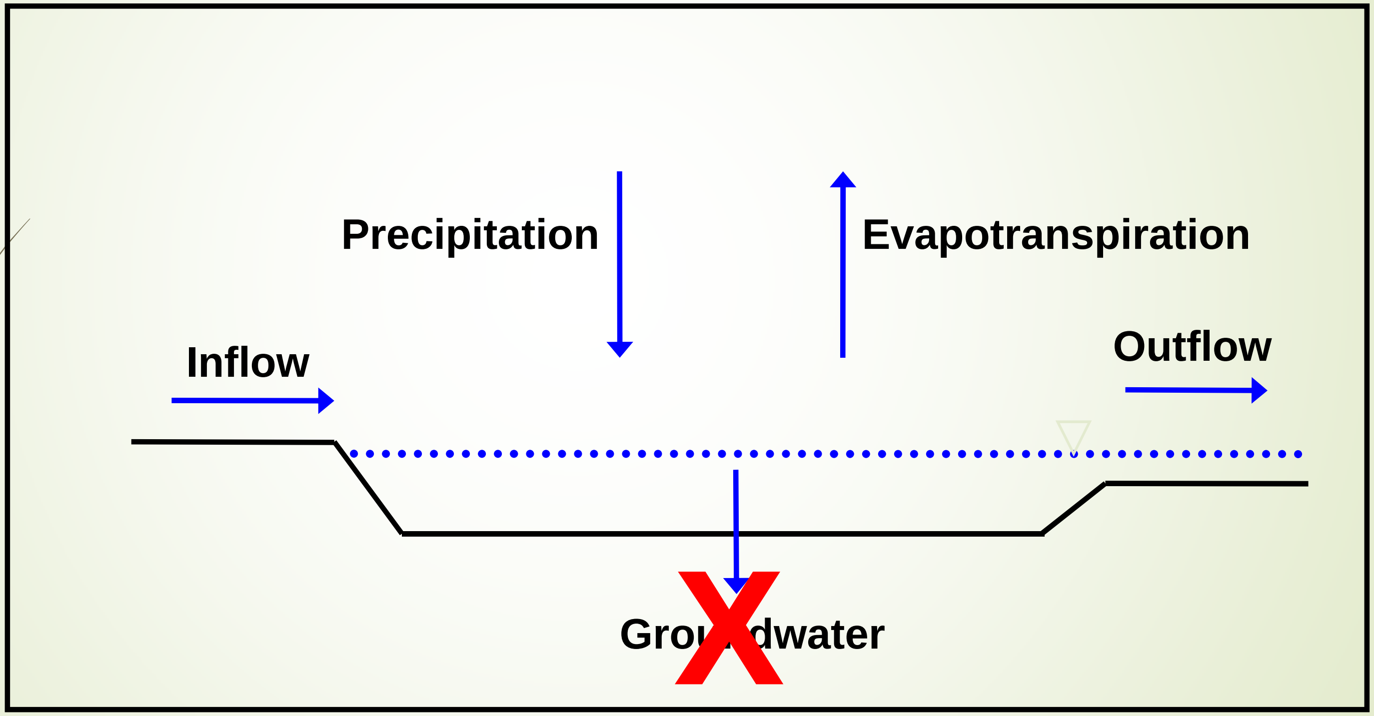


A "simple" way to create a mitigation wetland is to create a perched system



A "simple" way to create a mitigation wetland is to create a perched system

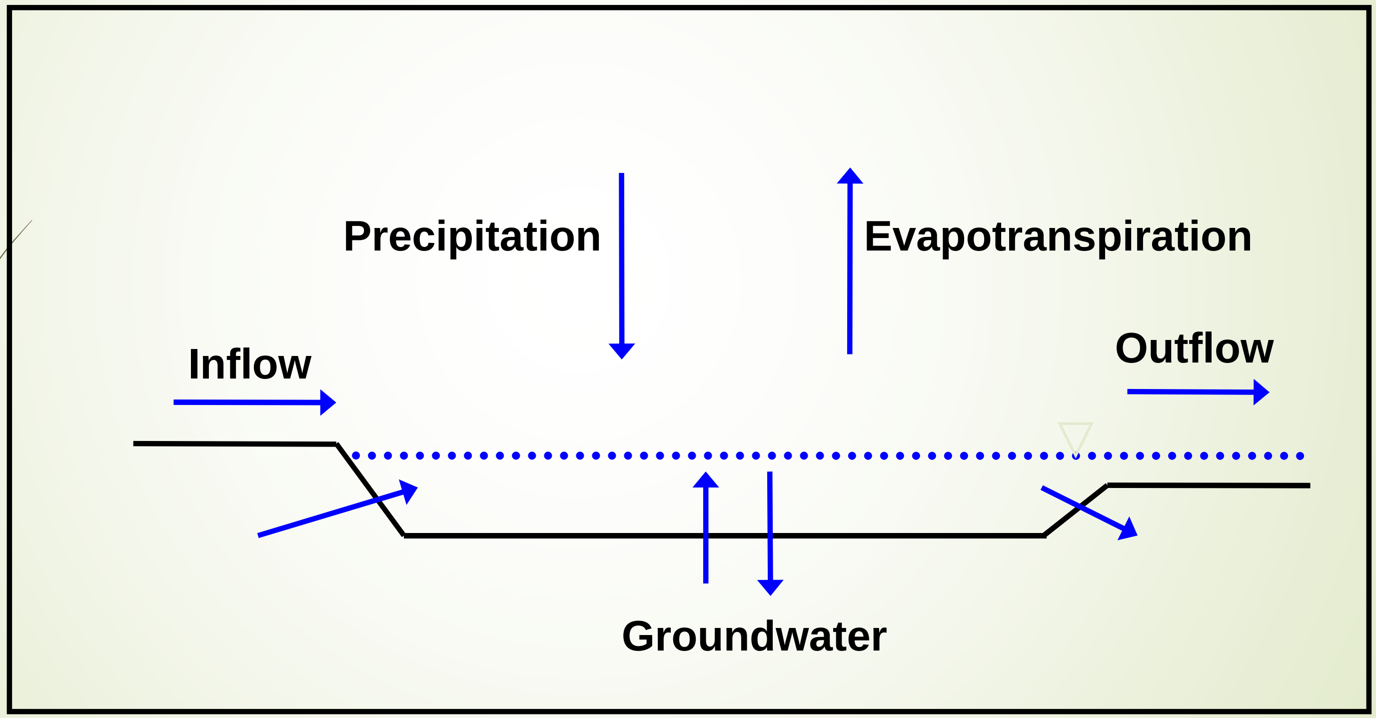
Can work on uplands with low permeability



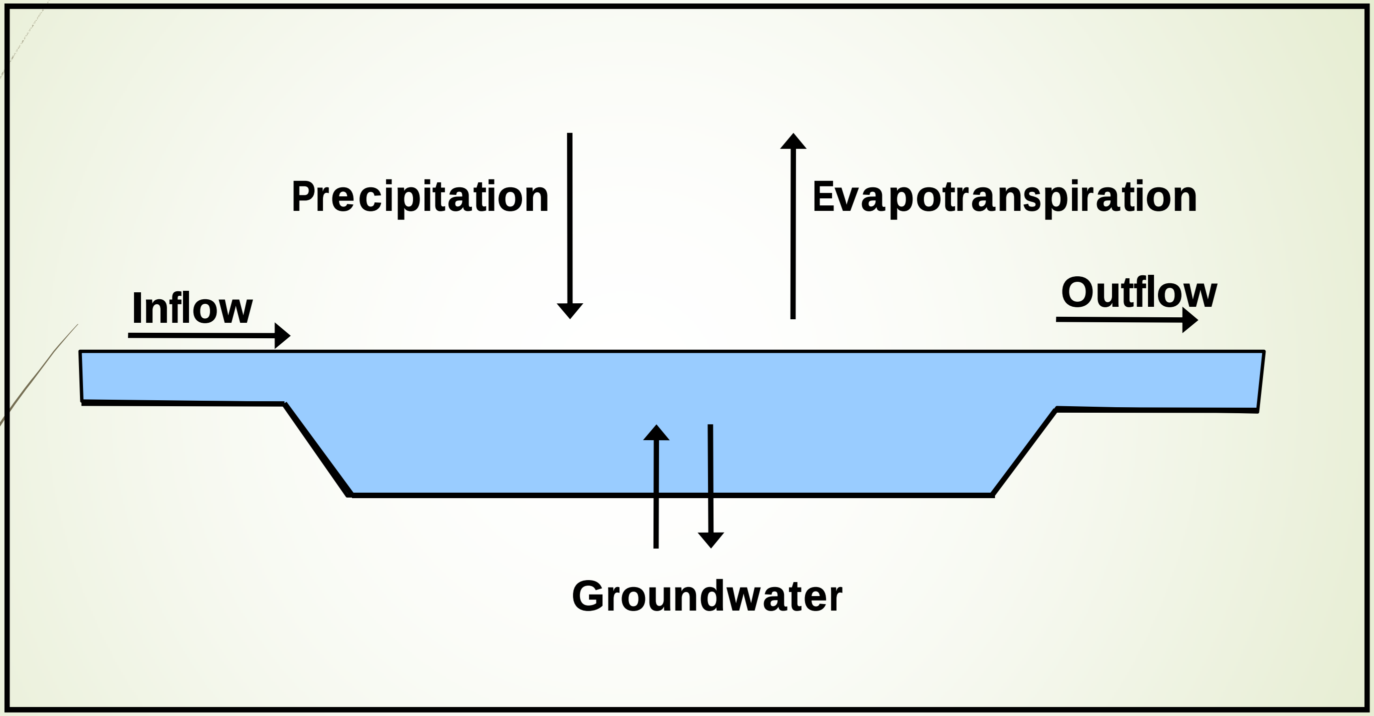
assume negligible

In most wetlands, Groundwater can seep IN and OUT many places

Ignore GW? the wetland can be “too wet”

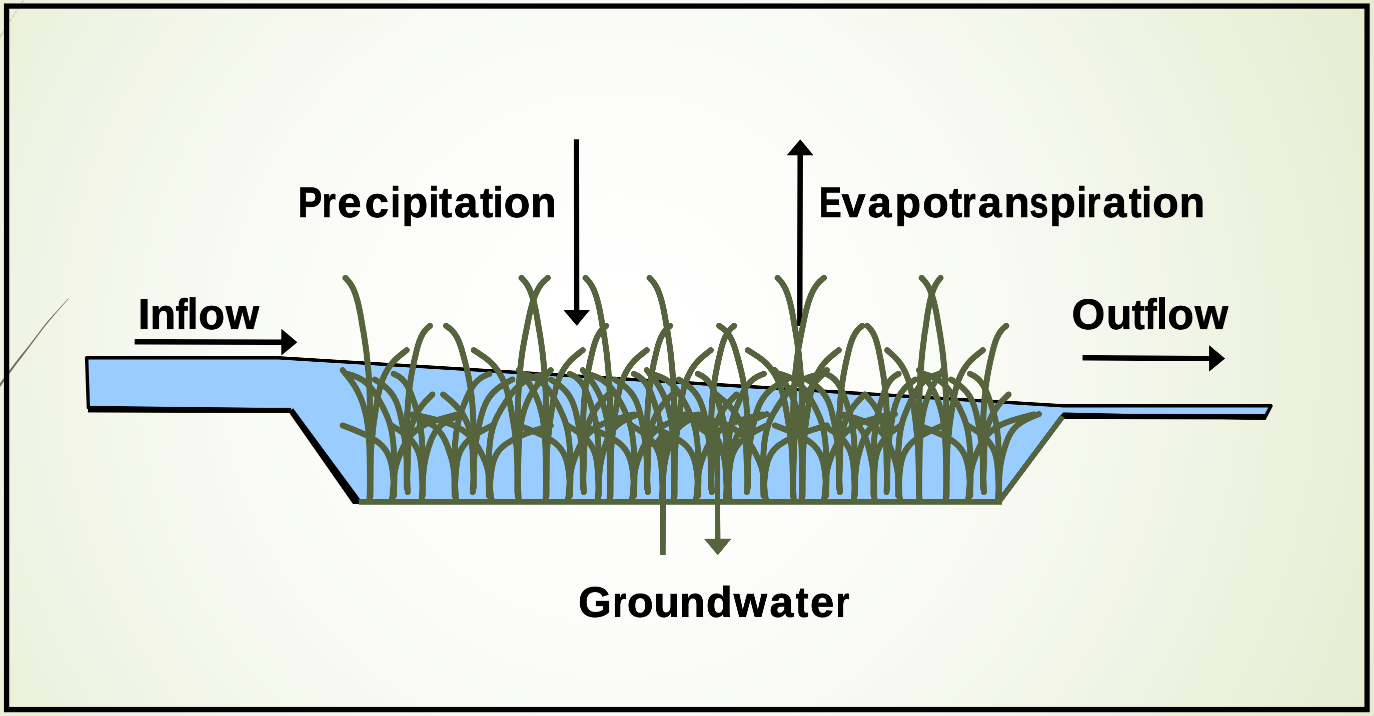


Hydraulic resistance due to vegetation is typically ignored



(Kadlec, 1990)

Hydraulic resistance due to vegetation is typically ignored



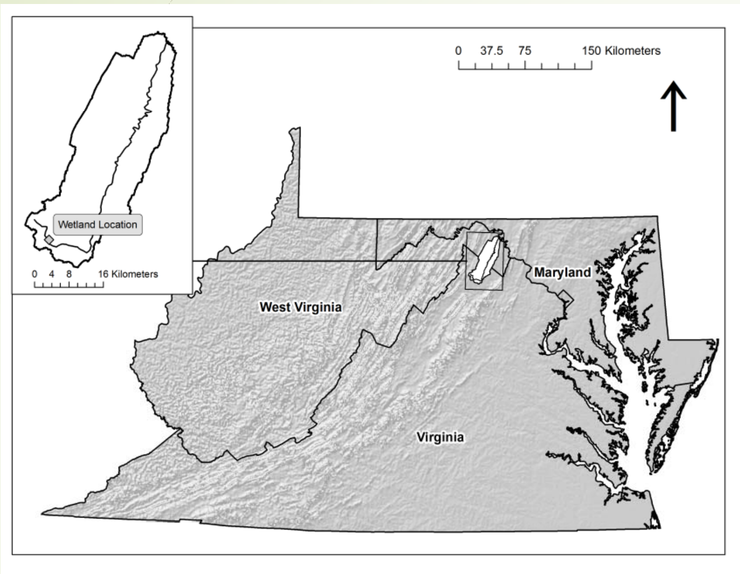
In designed wetland systems, Outflow is determined, all or in part, by hydraulic resistance due to vegetation

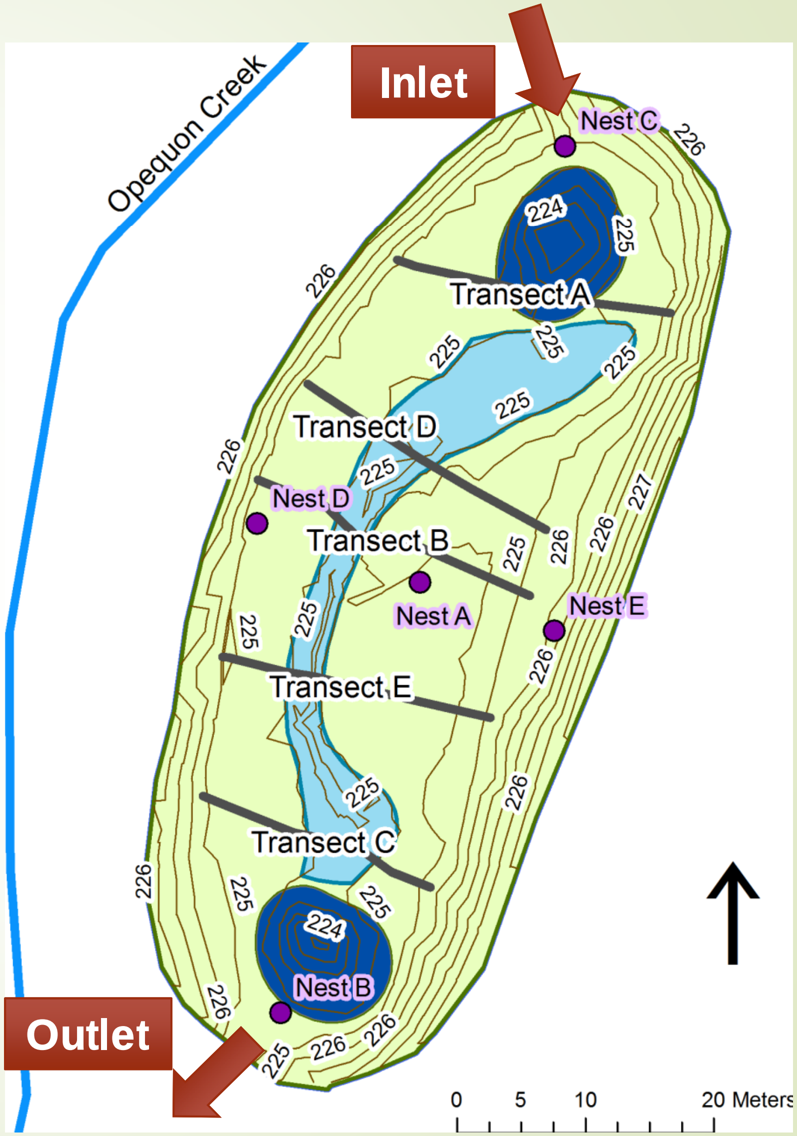
(Kadlec, 1990)

Wetland Water Budget Modeling

- **Document known water budget methodologies;**
- **Document existing design and construction issues;**
- **Assess existing software and individual process-models;**

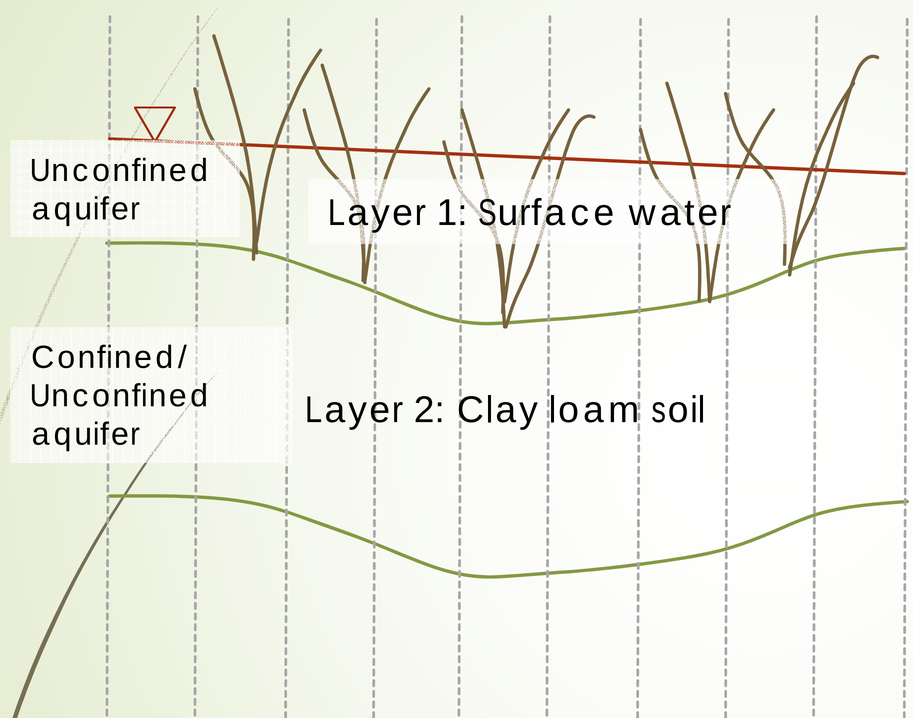
Modflow was tested as a possible tool to model wetlands

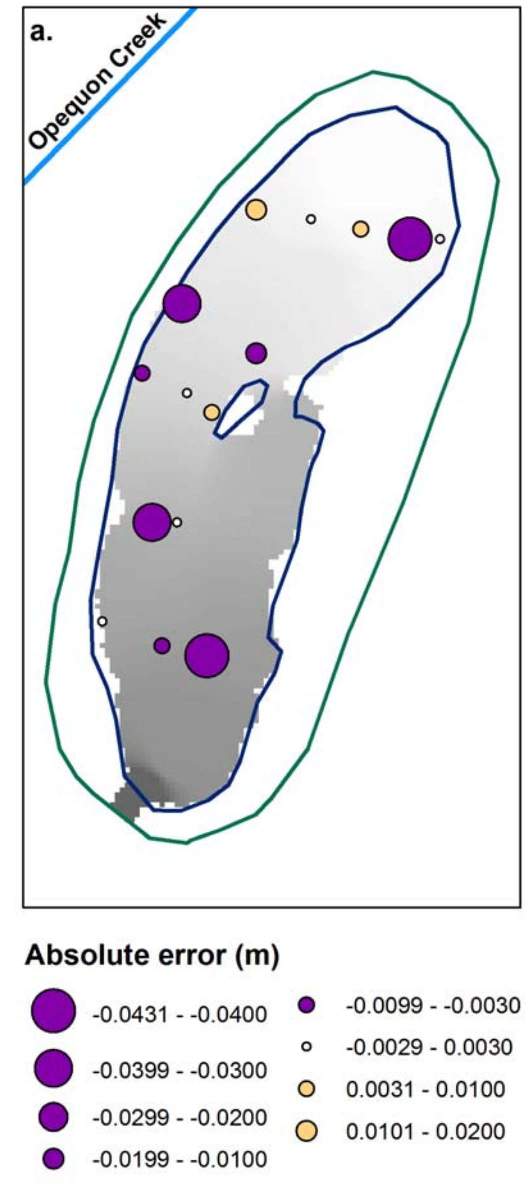




* Field study conducted by W. Cully Hession and Andrea Ludwig *

Wetland was modeled in MODFLOW as a two-layer aquifer system



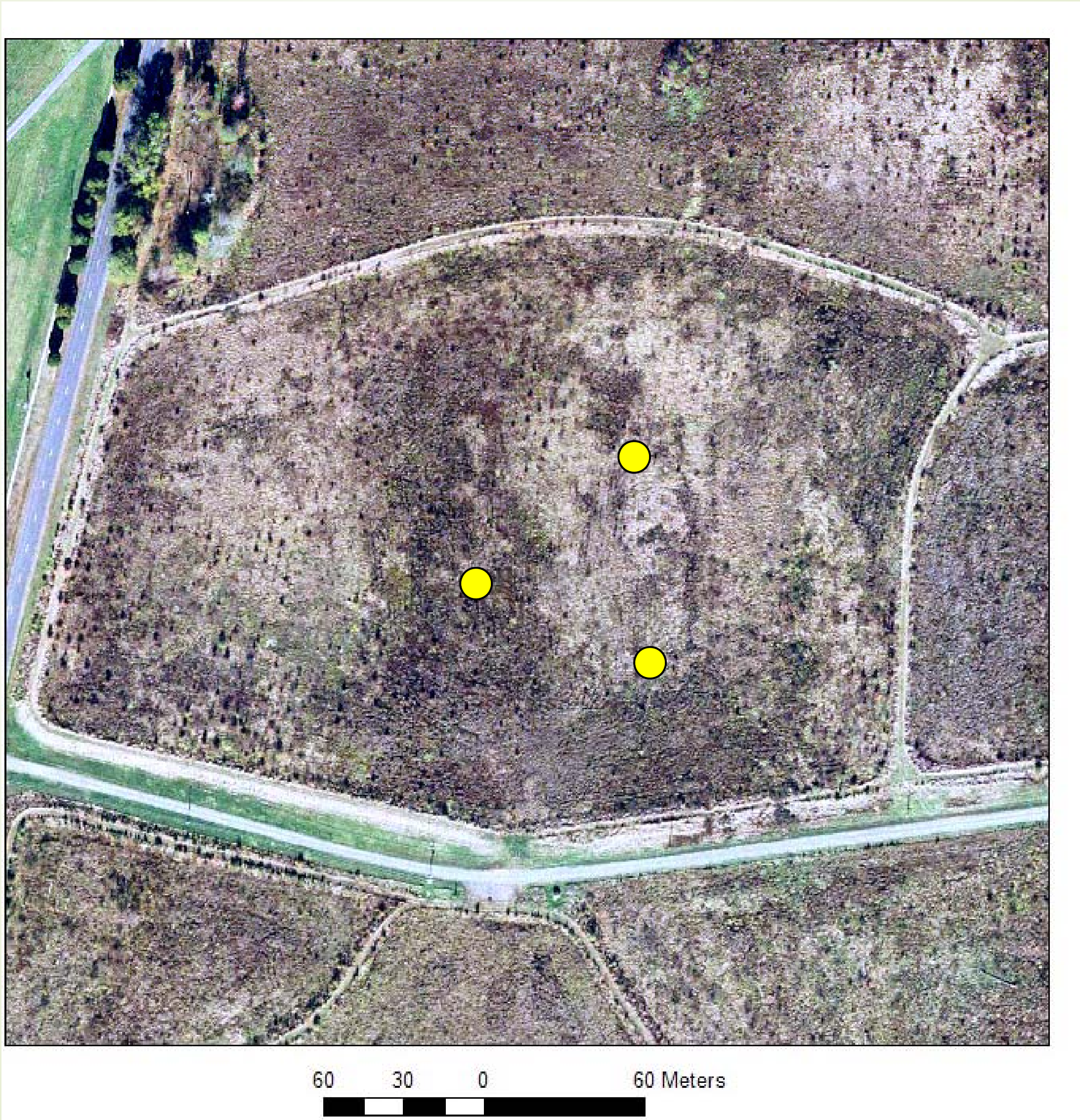


Error ranged from -4.3 cm to 1.4 cm with a mean error of -1.1 cm

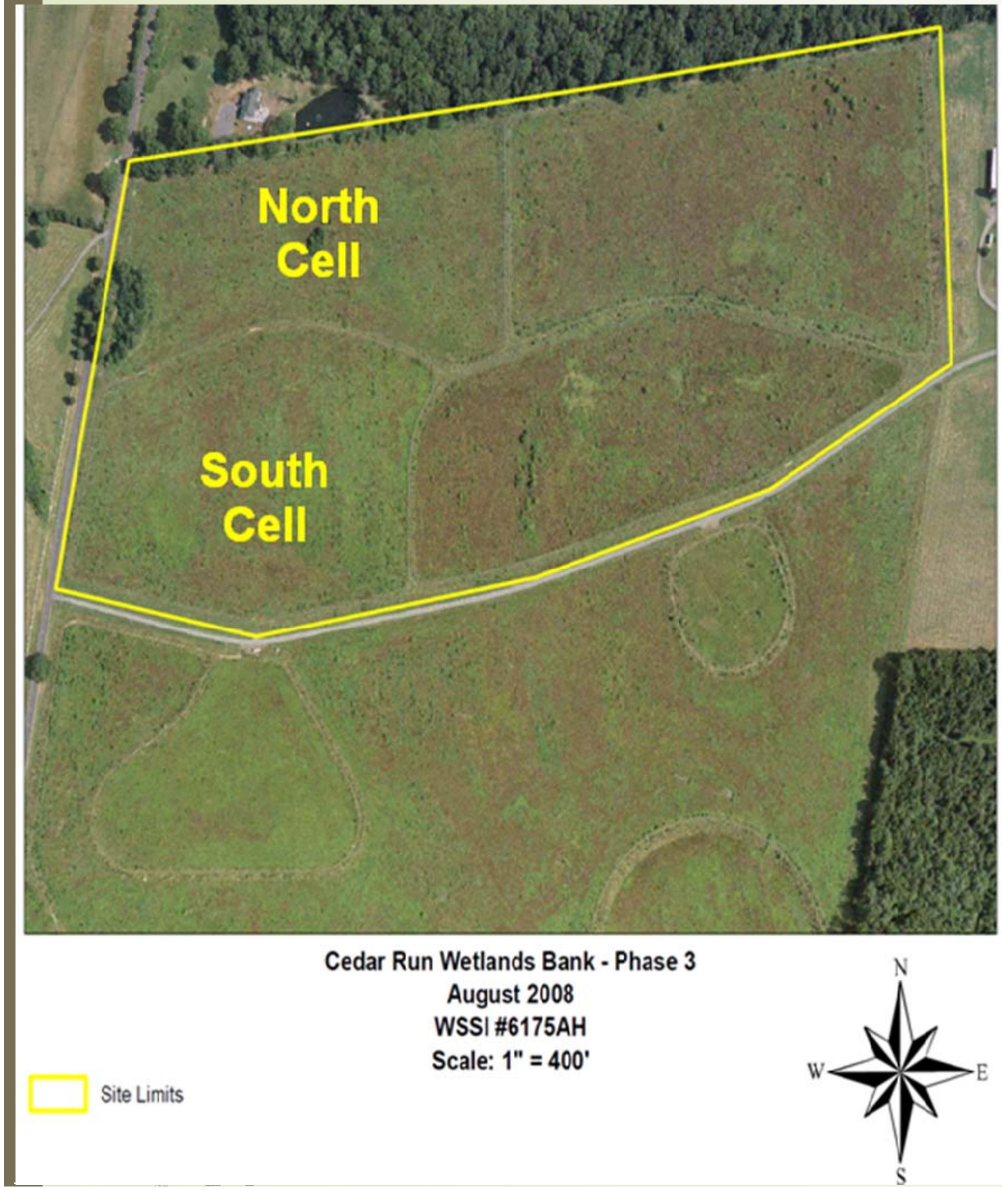
- close to the survey and digitization error

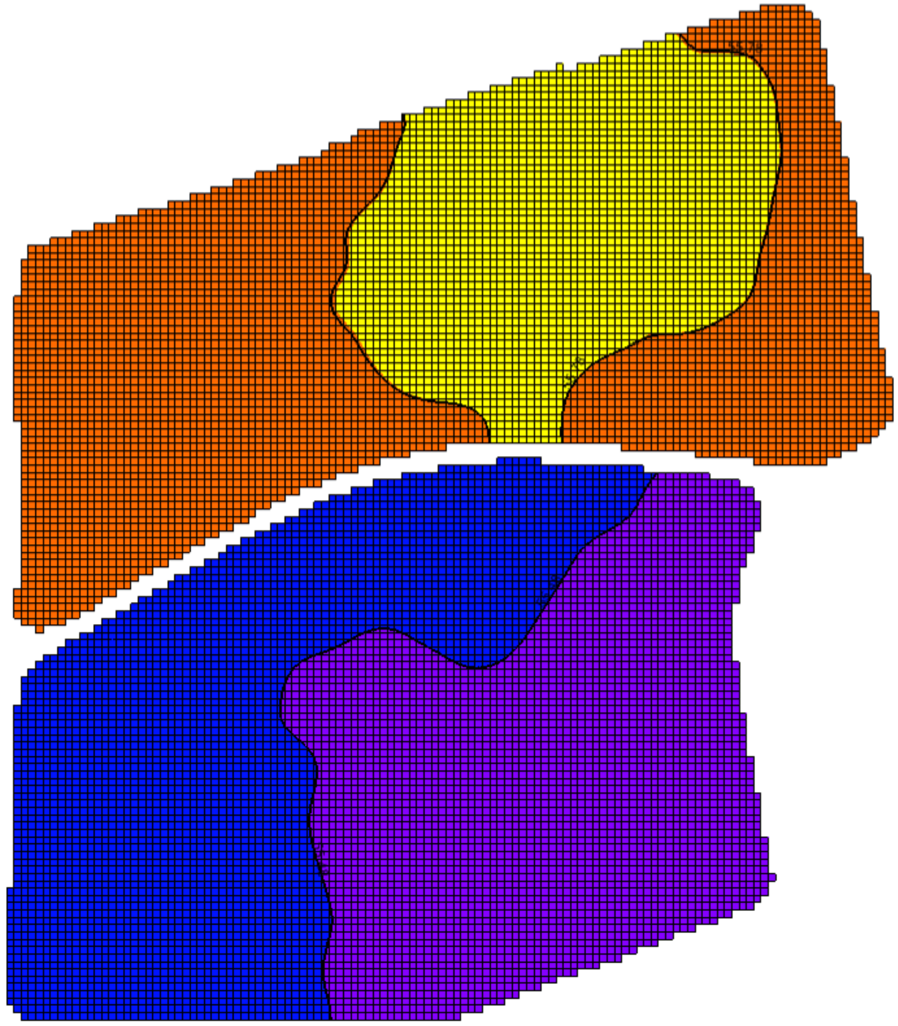
Modflow was also tested as a possible tool to model wetlands at Cedar Run 3 Wetland Bank

Water level data were collected in the southern cell via USACOE standard observation well installations



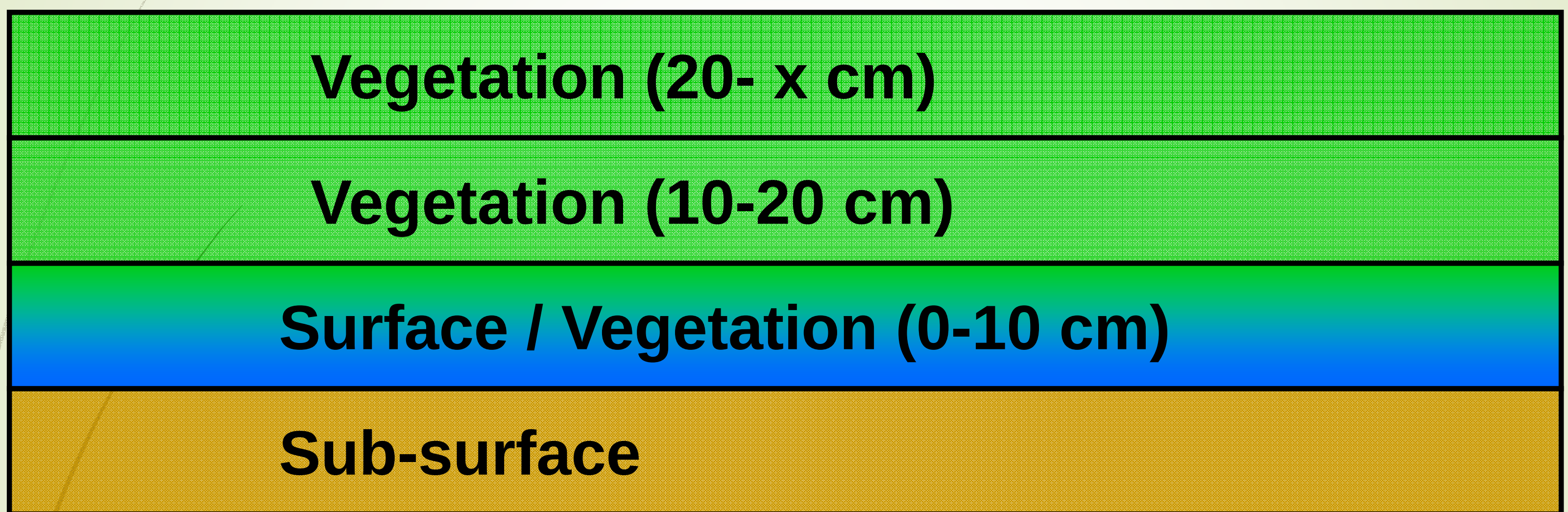
MODFLOW-2005



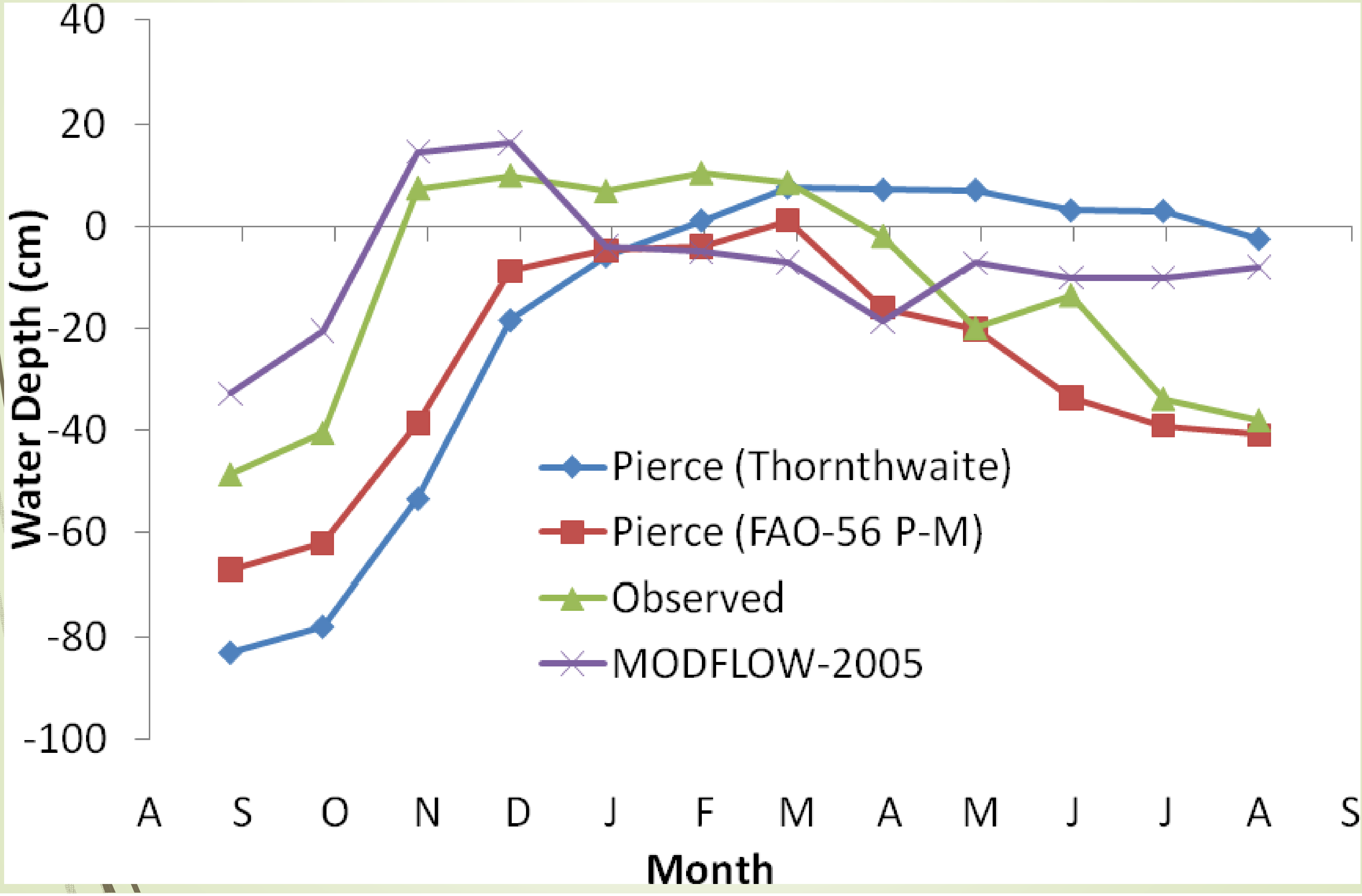


Aquaveo GMS 8.0

the wetland was represented as...



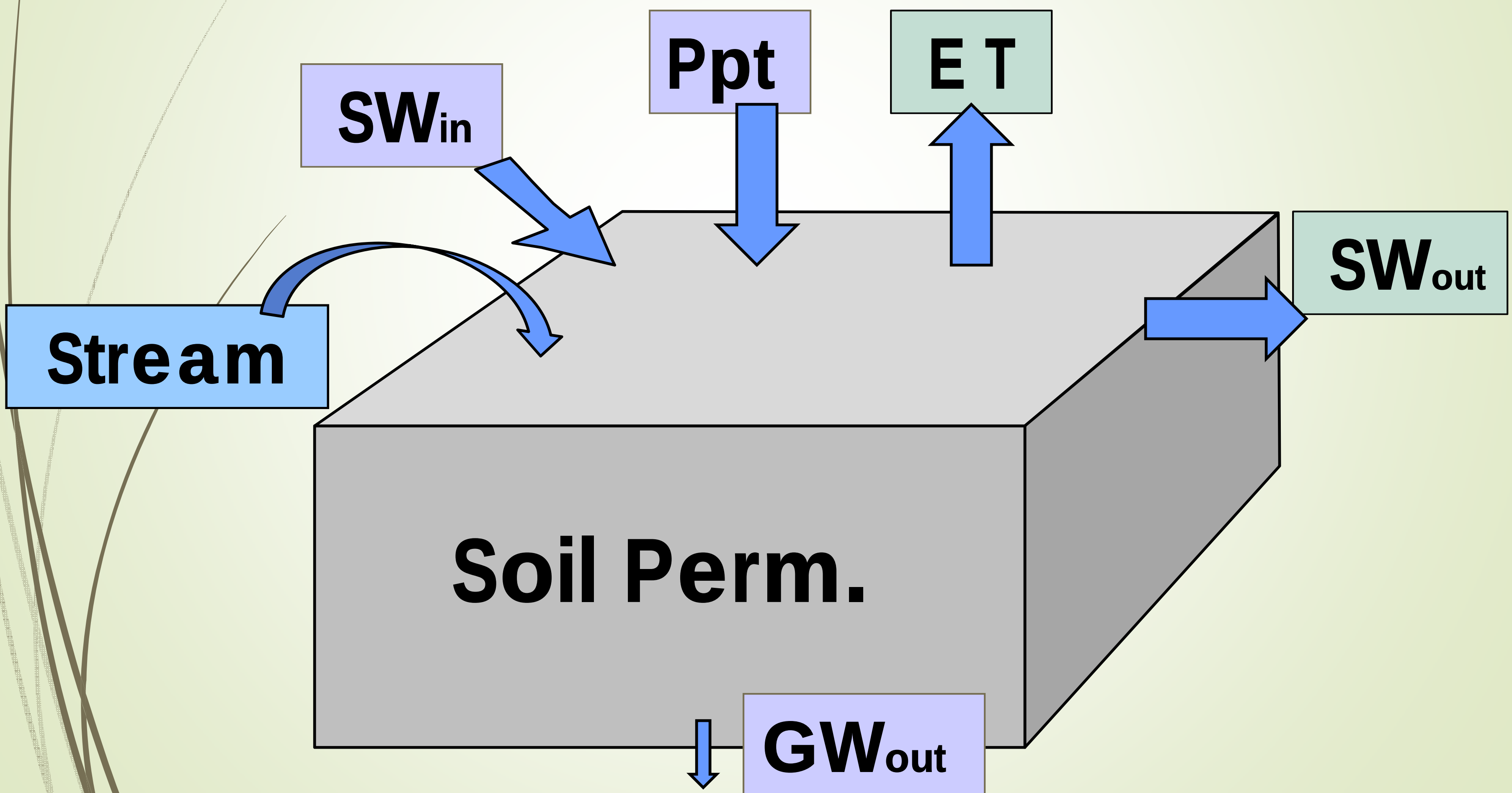
The Pierce model with FAO-Penman ET and Modflow performed best



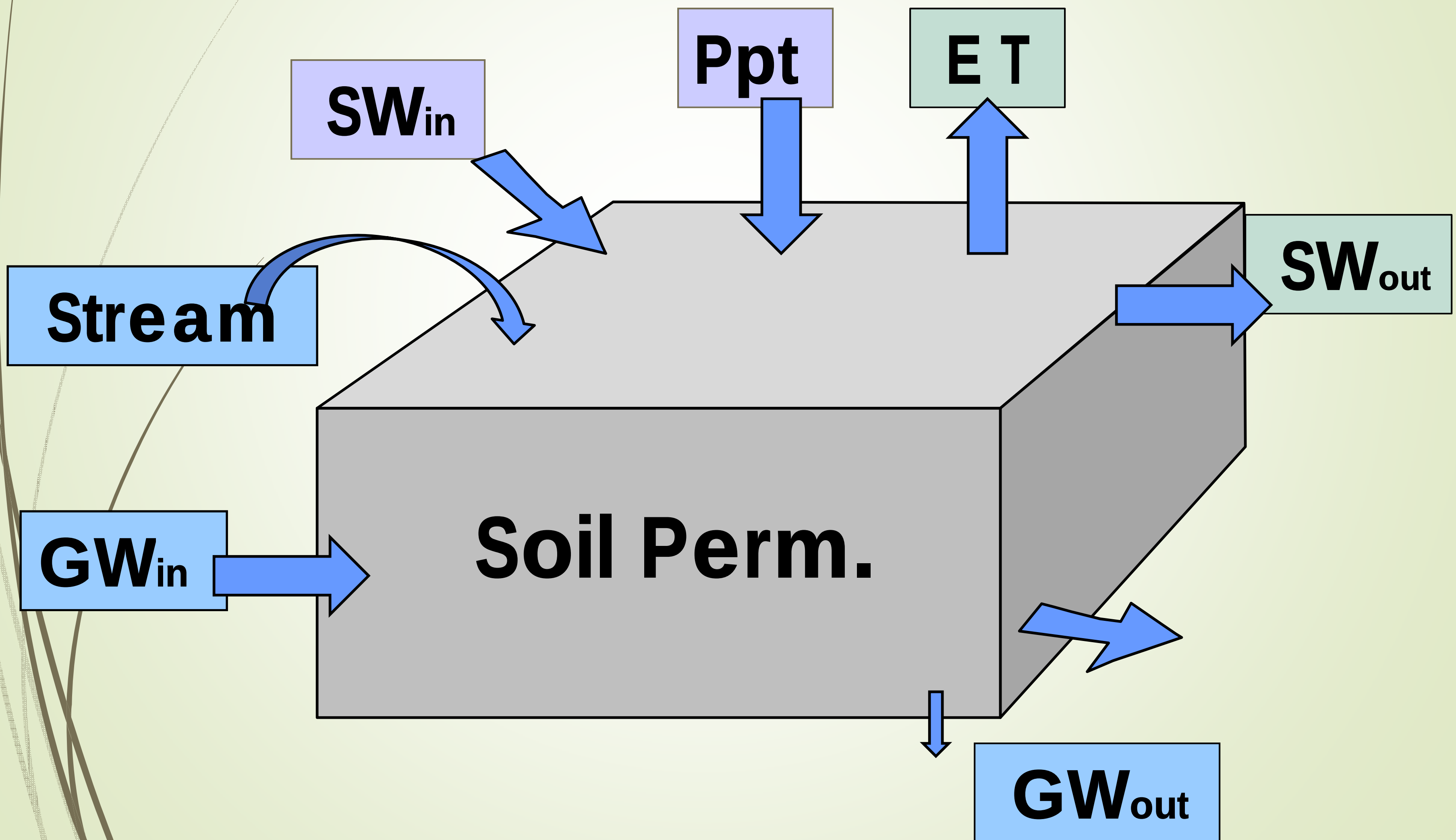
Wetland Water Budget Modeling

- Document known water budget methodologies;
- Document existing design and construction issues;
- Assess existing software and individual process-models;
- Develop a library of historic rainfall data;
- Classify each year as “dry,” “typical,” or “wet”;
- Develop model inputs based on Piedmont soil conditions;
- Provide additional model capability:
    1. Sloped wetlands
    2. Groundwater inputs
    3. Vegetation resistance
- Test model using data sets developed from two field sites;

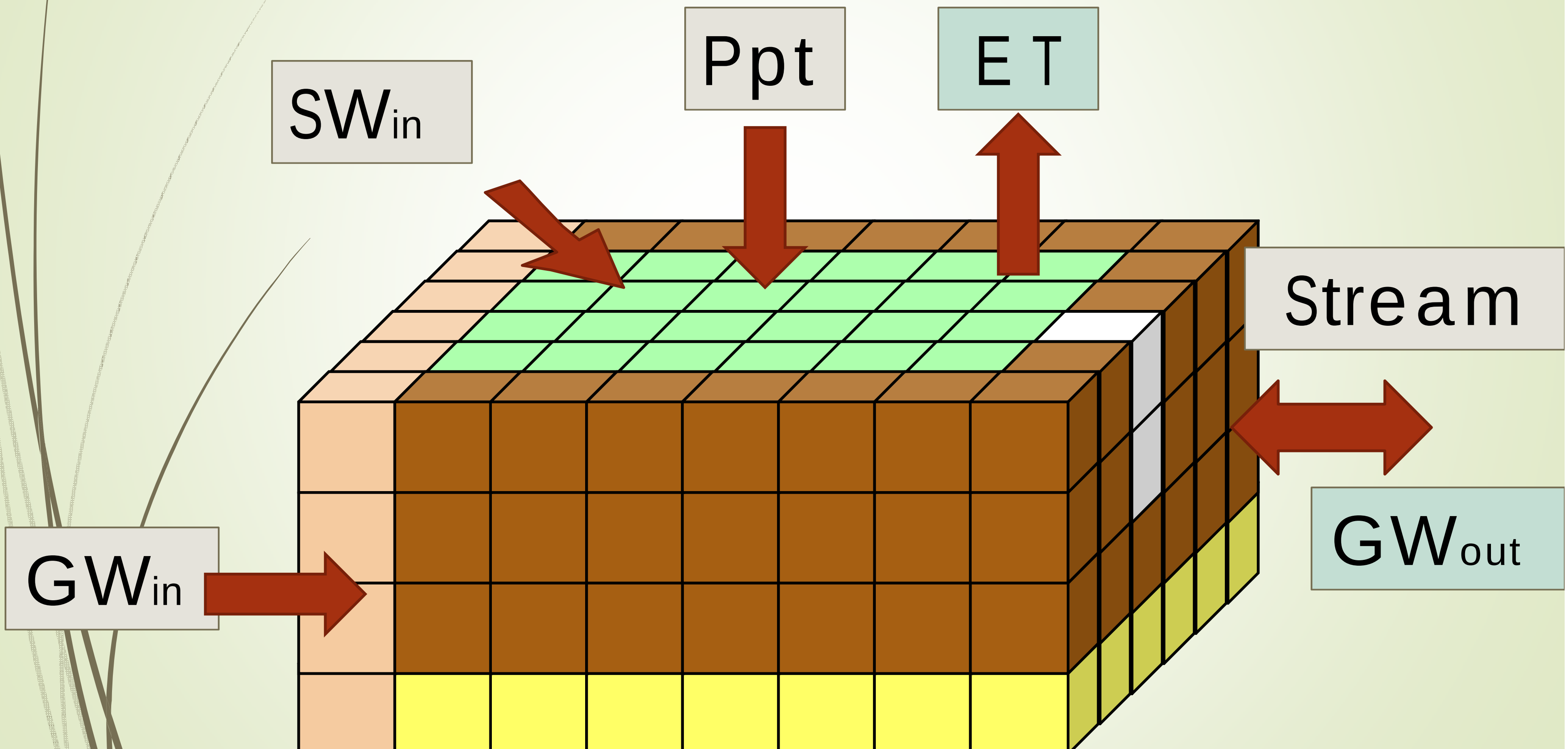
Pierce's model for depressional wetlands



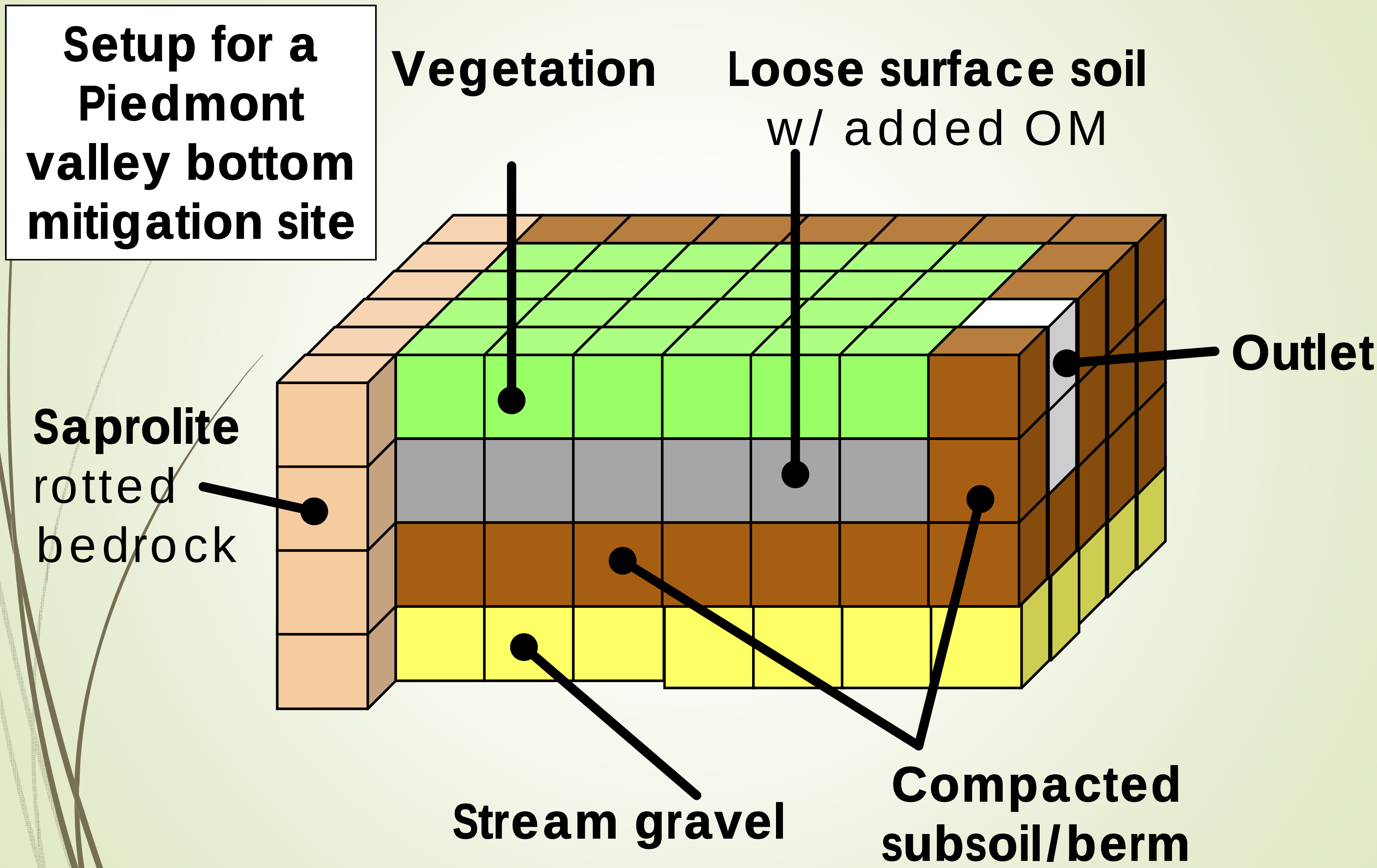
WetBud Basic Version



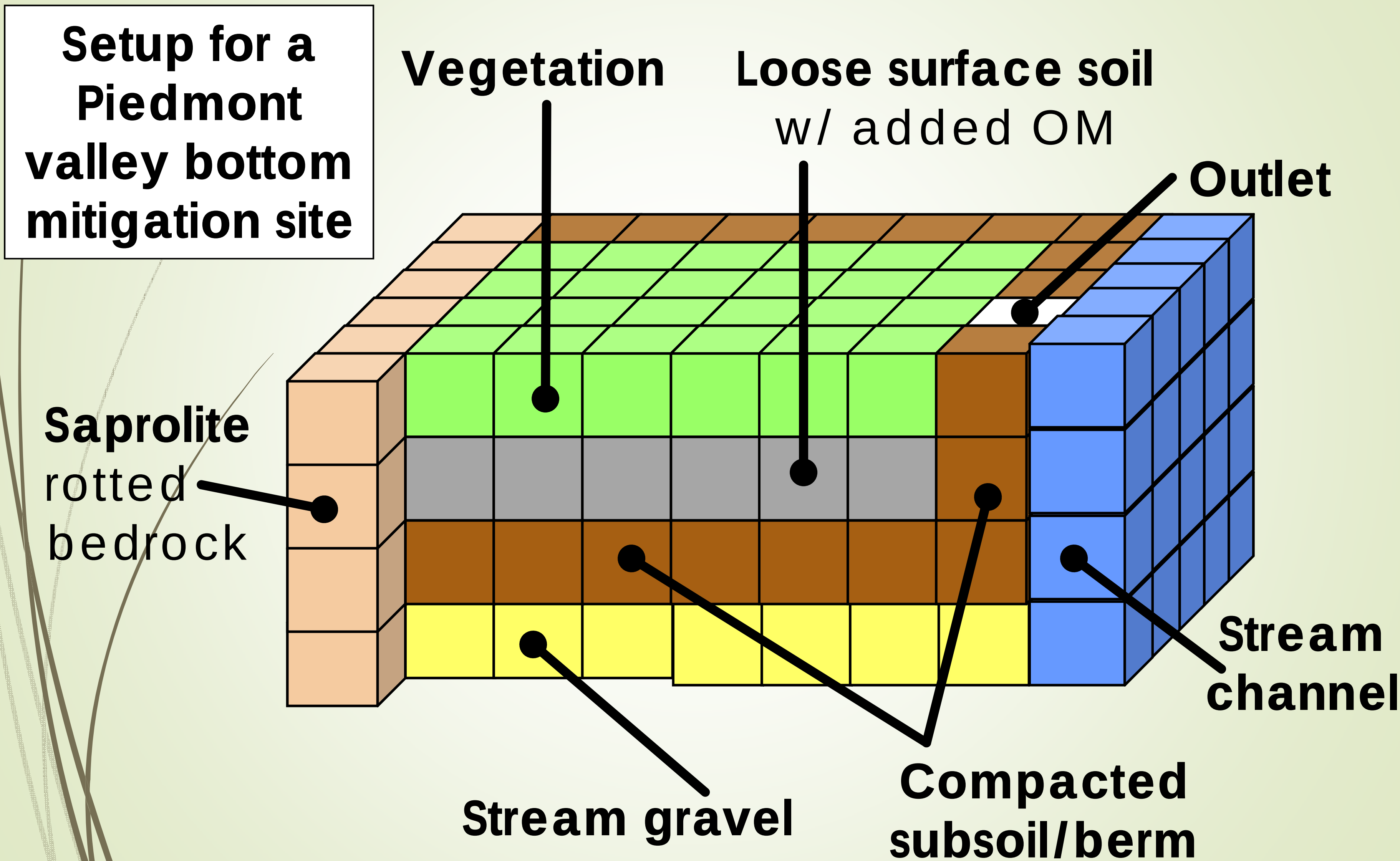
WetBud – Advanced Version



WetBud – Advanced Version

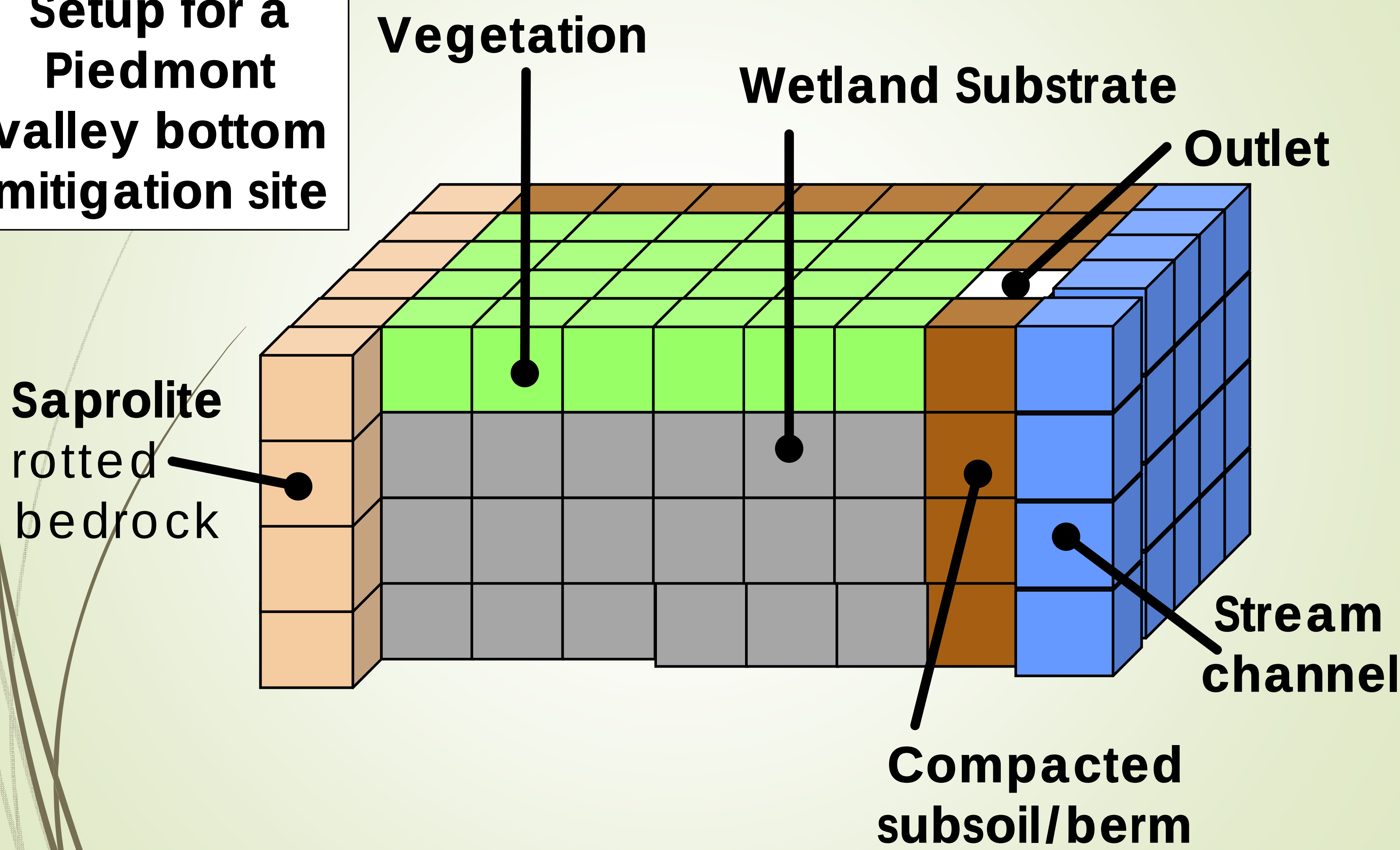


WetBud – Advanced Version



WetBud – Advanced Version

Setup for a Piedmont valley bottom mitigation site

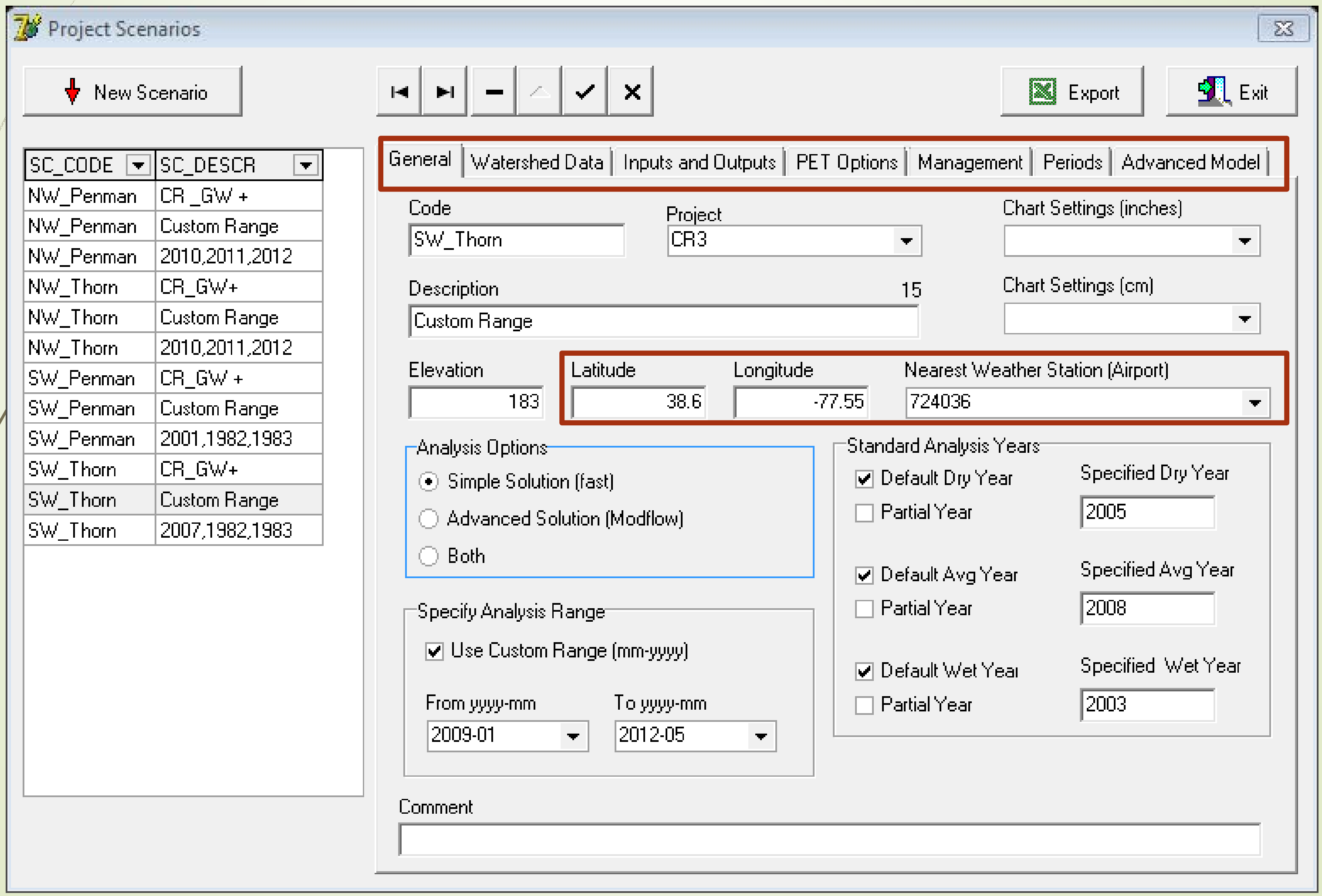


Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
    1. Calculate ET for WDN years (Thornthwaite, Penman)
    2. Calculate SW_{in} using Curve Numbers
    3. Input GW_{in} or calculate using W_{em} (well data)
    4. Input or calculate Gw_{out}
    5. Input or calculate overbank flow

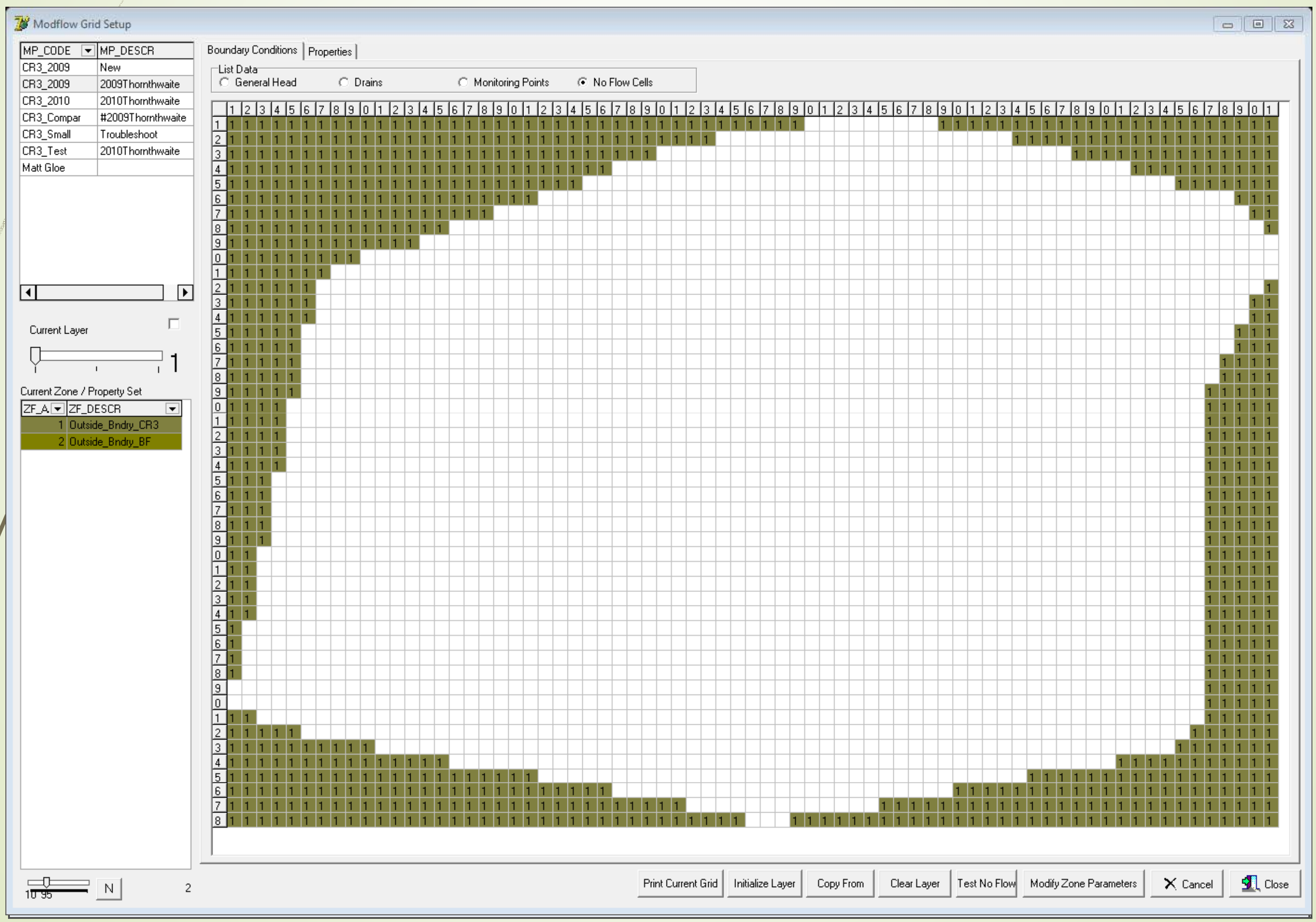
Create Project and Scenario

Basic



Create Project and Scenario

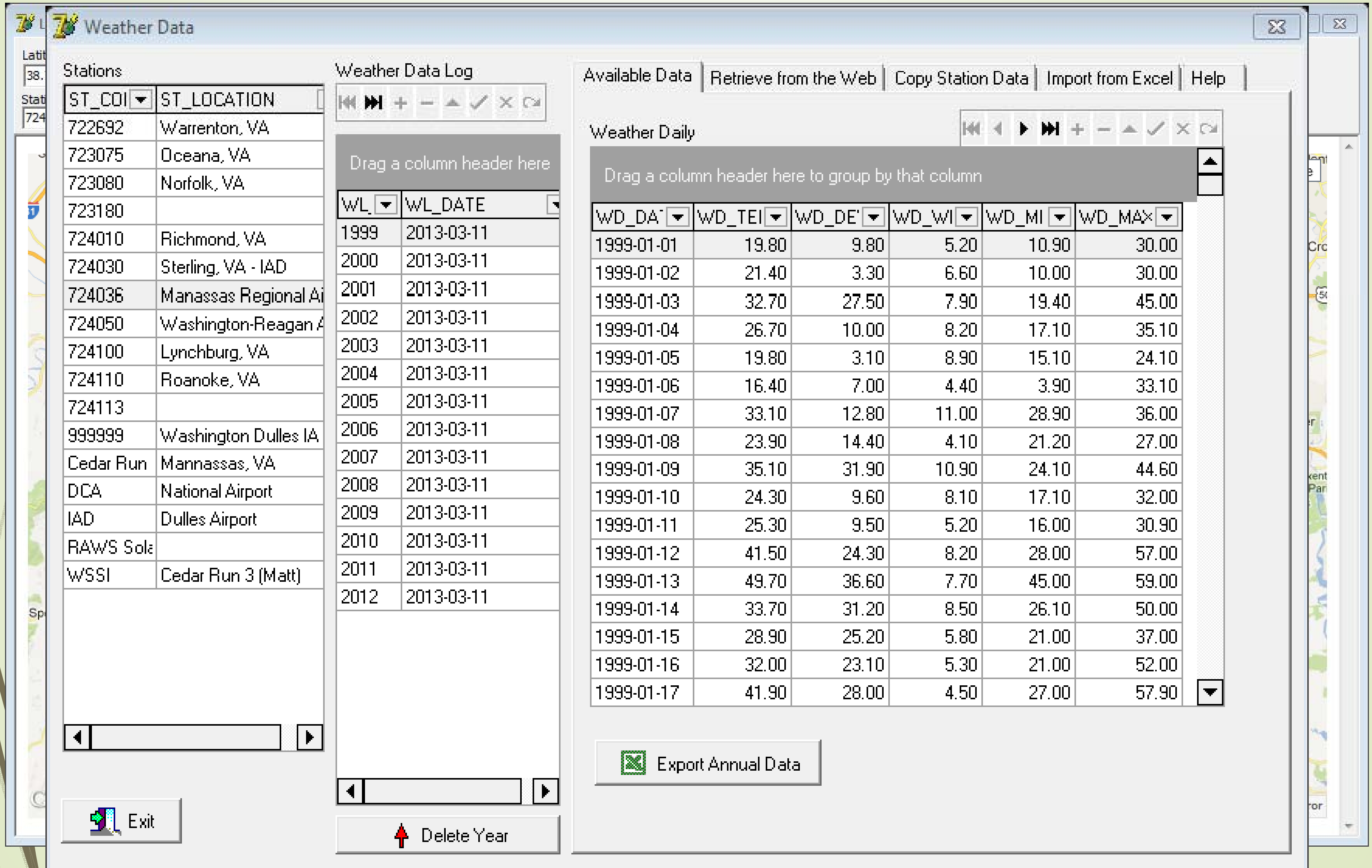
Advanced



Building WetBud Model(s)

1. Create Project and Scenario
2. **Build weather data**
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
   1. Calculate ET for WDN years (Thornthwaite, Penman)
   2. Calculate SW_{in} using Curve Numbers
   3. Input GW_{in} or calculate using W_{em} (well data)
   4. Input or calculate Gw_{out}
   5. Input or calculate overbank flow

Build weather data

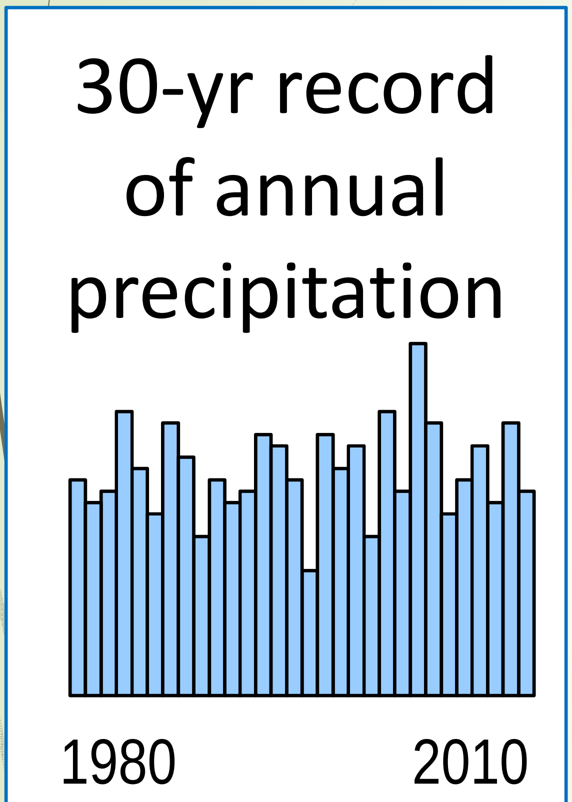


Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
   1. Calculate ET for WDN years (Thornthwaite, Penman)
   2. Calculate SW_{in} using Curve Numbers
   3. Input GW_{in} or calculate using W_{em} (well data)
   4. Input or calculate Gw_{out}
   5. Input or calculate overbank flow

Determine WND years w/ WETS tables:

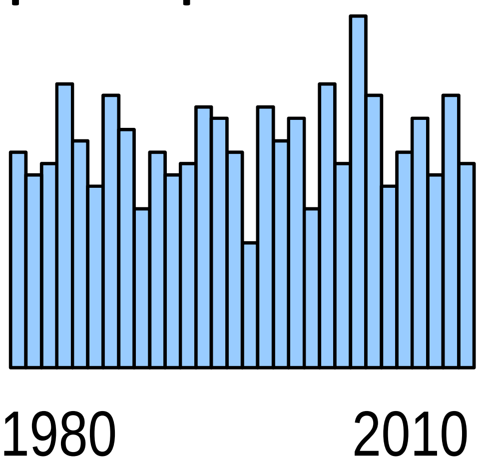
#1: Which years have WET (or DRY or NORM) total ppt?



Determine WND years w/ WETS tables:

#1: Which years have WET (or DRY or NORM) total ppt?

30-yr record of annual precipitation



29.32
29.62
29.95
30.67
31.74
32.57
33.82
34.99
35.77
35.84
35.94
35.96
36.16
36.38
36.63
37.57
37.73
38.07
39.57
39.80
40.23
40.60
40.84
41.41
46.02
47.33
50.32
50.50
51.02
51.89
51.97

DRY

35.33”

NORM

42.04”

WET

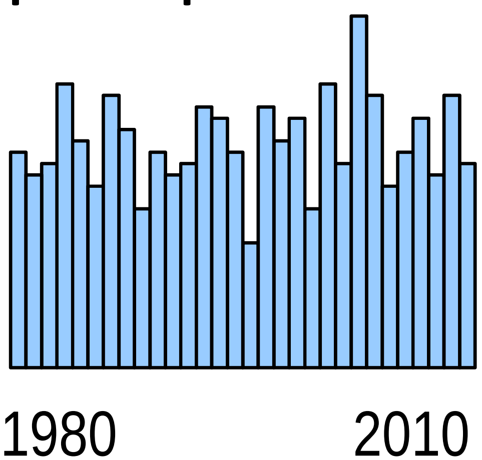
Rank order annual ppt. values

Make splits with WETS Table Statistics

Determine WND years w/ WETS tables:

#1: Which years have WET (or DRY or NORM) total ppt?

30-yr record of annual precipitation



29.32
29.62
29.95
30.67
31.74
32.57
33.82
34.99
35.77
35.84
35.94
35.96
36.16
36.38
36.63
37.57
37.73
38.07
39.57
39.80
40.23
40.60
40.84
41.41
46.02
47.33
50.32
50.50
51.02
51.89
51.97

DRY — 1988

35.33”

Select the median value in each split

NORM — 1994

42.04”

WET — 1975

Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2

D | J | F | **M** | **A** | **M** | **J** | ....

N

##

N D W

2 1 3

x1 x2 x3

2+2+9=

13

(6 to 18)

Do a WETS analysis for each Spring month

Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2 +2

D	J	F	M	A	M	J	……..

##

D W N

1 3 2

x1 x2 x3

2+6+6=

14

(6 to 18)

N

Do a WETS analysis for each Spring month

Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2 +2 +3

D	J	F	**M**	**A**	**M**	**J**	……..

##

W N W

3 2 3

x1 x2 x3

3+4+9=

16

(6 to 18)

W

Do a WETS analysis for each Spring month

Determine WND years w/ WETS tables

#2: Did 1975 have a WET "spring"?

2 +2 +3 +3

D	J	F	M	A	M	J	……..	

##

N W W

2 3 3

x1 x2 x3

2+6+9=

17

(6 to 18)

W

Do a WETS analysis for each Spring month

Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2 +2 +3 +3 = 10

D	J	F	**M**	**A**	**M**	**J**	…….
			N	N	W	W	

Score determines if Spring is WND

4-6 : DRY
7-9 : NORM
10-12: WET

Determine WND years w/ WETS tables:

#2: Did 1975 have a WET "spring"?

2 +2 +3 +2 = 10

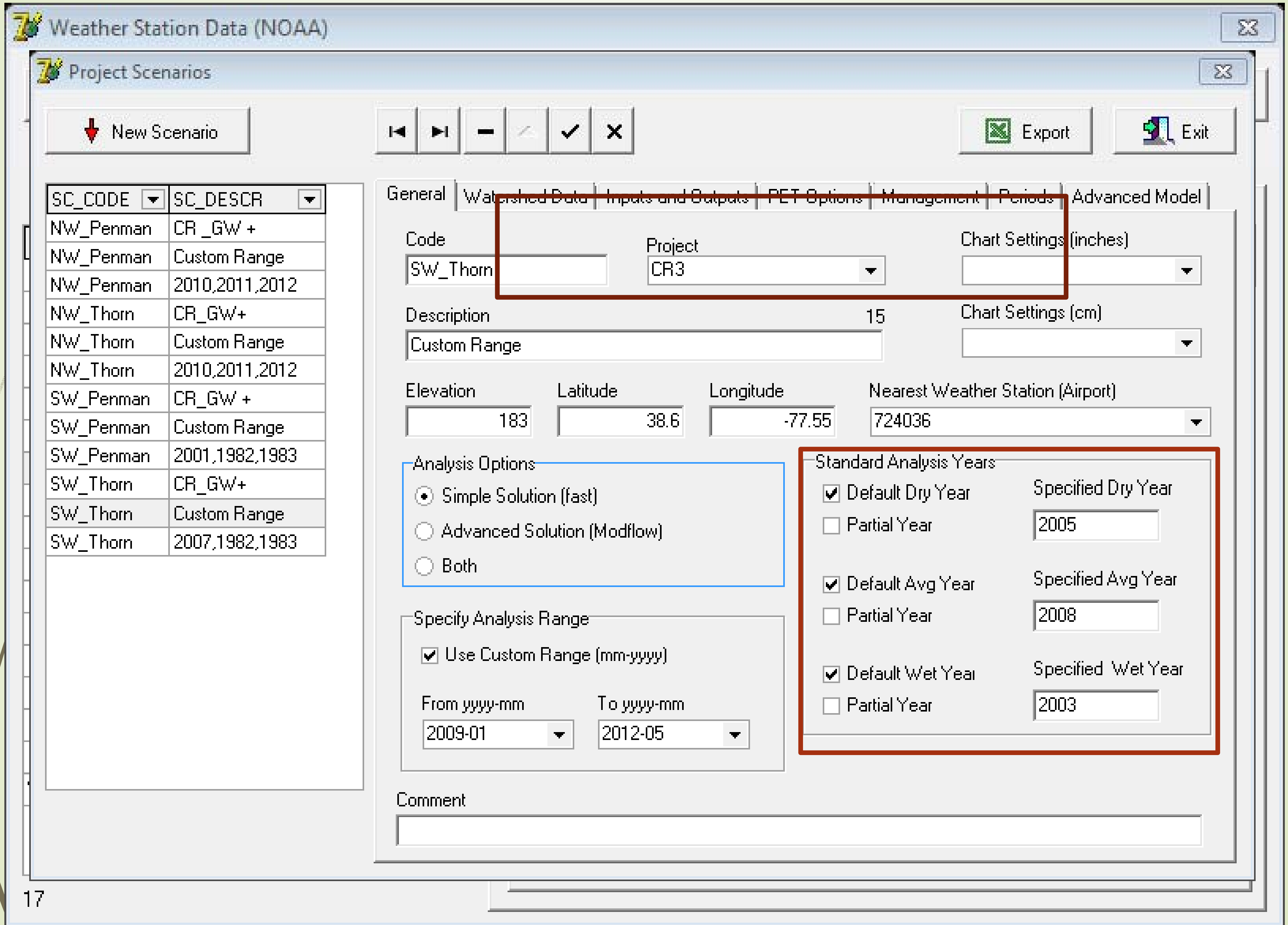
D	J	F	M	A	M	J	…….
			N	N	W	W	

4-6 : DRY
7-9 : NORM
10-12: WET

Score determines if Spring is WND

A Year is WET if both the Spring and the Annual Precipitation are both WET

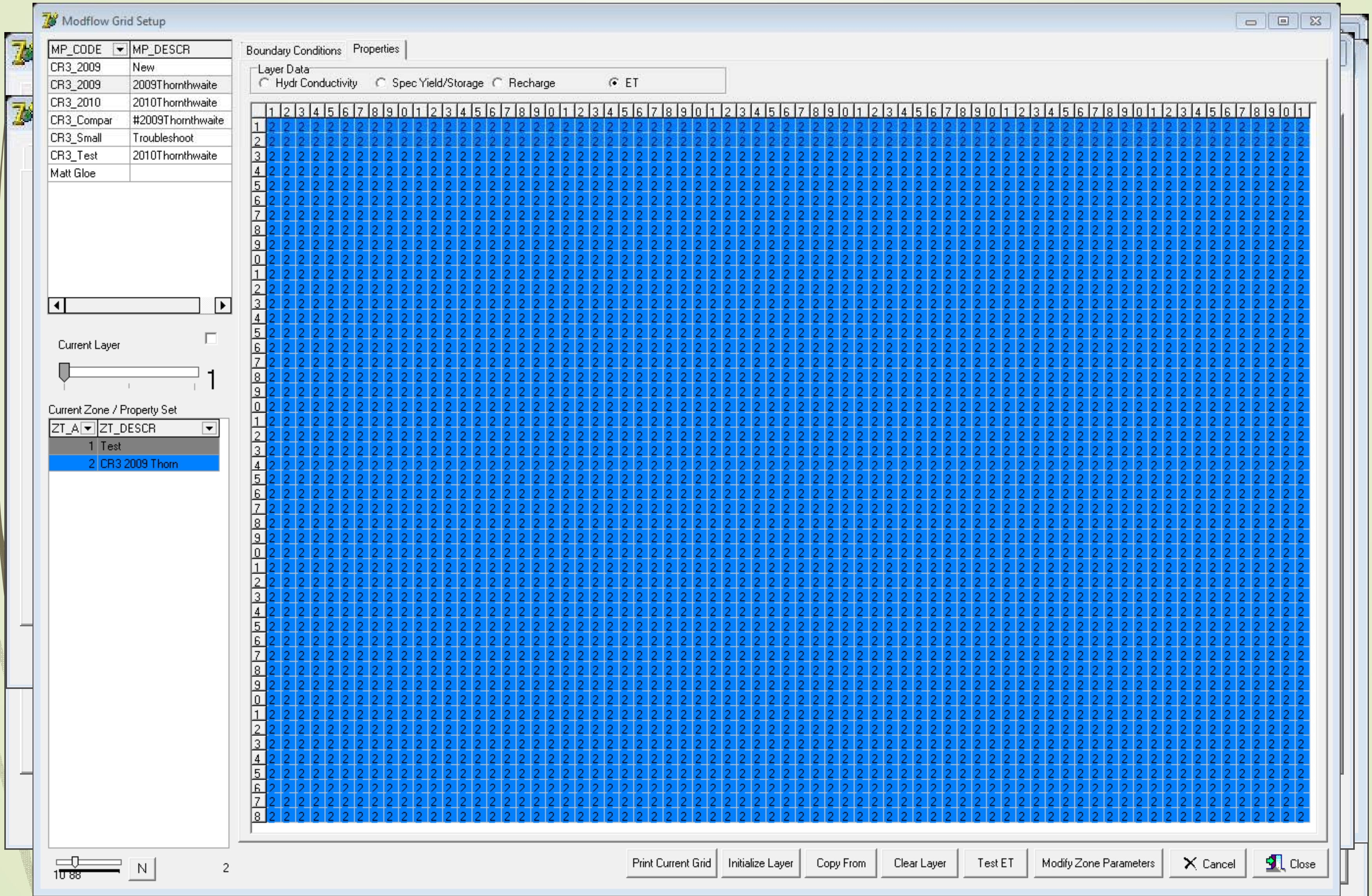
Determine WND years



Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
    1. Calculate ET for WDN years (Thornthwaite, Penman)
    2. Calculate SW_{in} using Curve Numbers
    3. Input GW_{in} or calculate using W_{em} (well data)
    4. Input or calculate Gw_{out}
    5. Input or calculate overbank flow

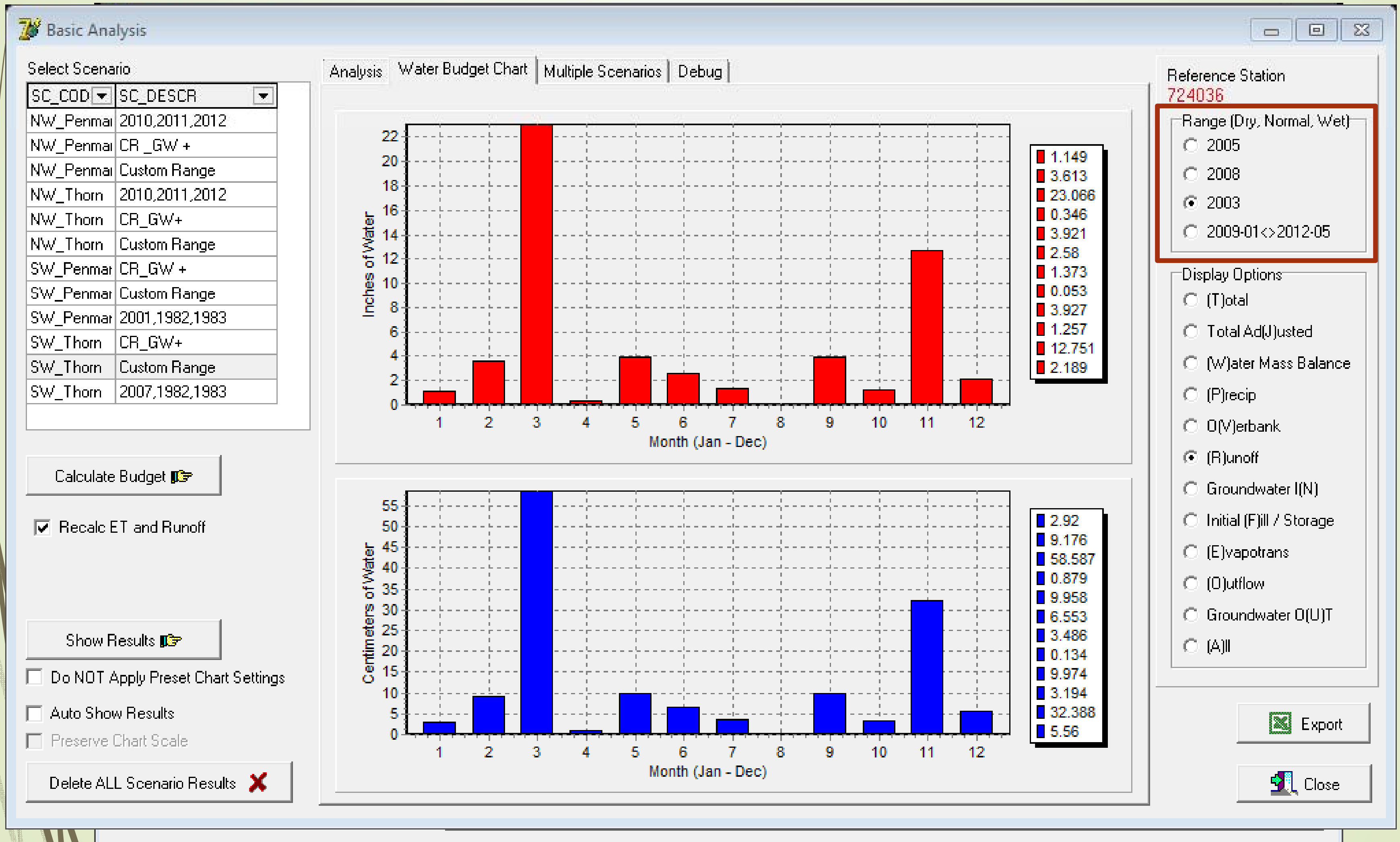
Calculate ET for WND years



Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
    1. Calculate ET for WDN years (Thornthwaite, Penman)
    2. Calculate SWin using Curve Numbers
    3. Input GW_{in} or calculate using W_{em} (well data)
    4. Input or calculate Gw_{out}
    5. Input or calculate overbank flow

Calculate SW_{in} using Curve Numbers

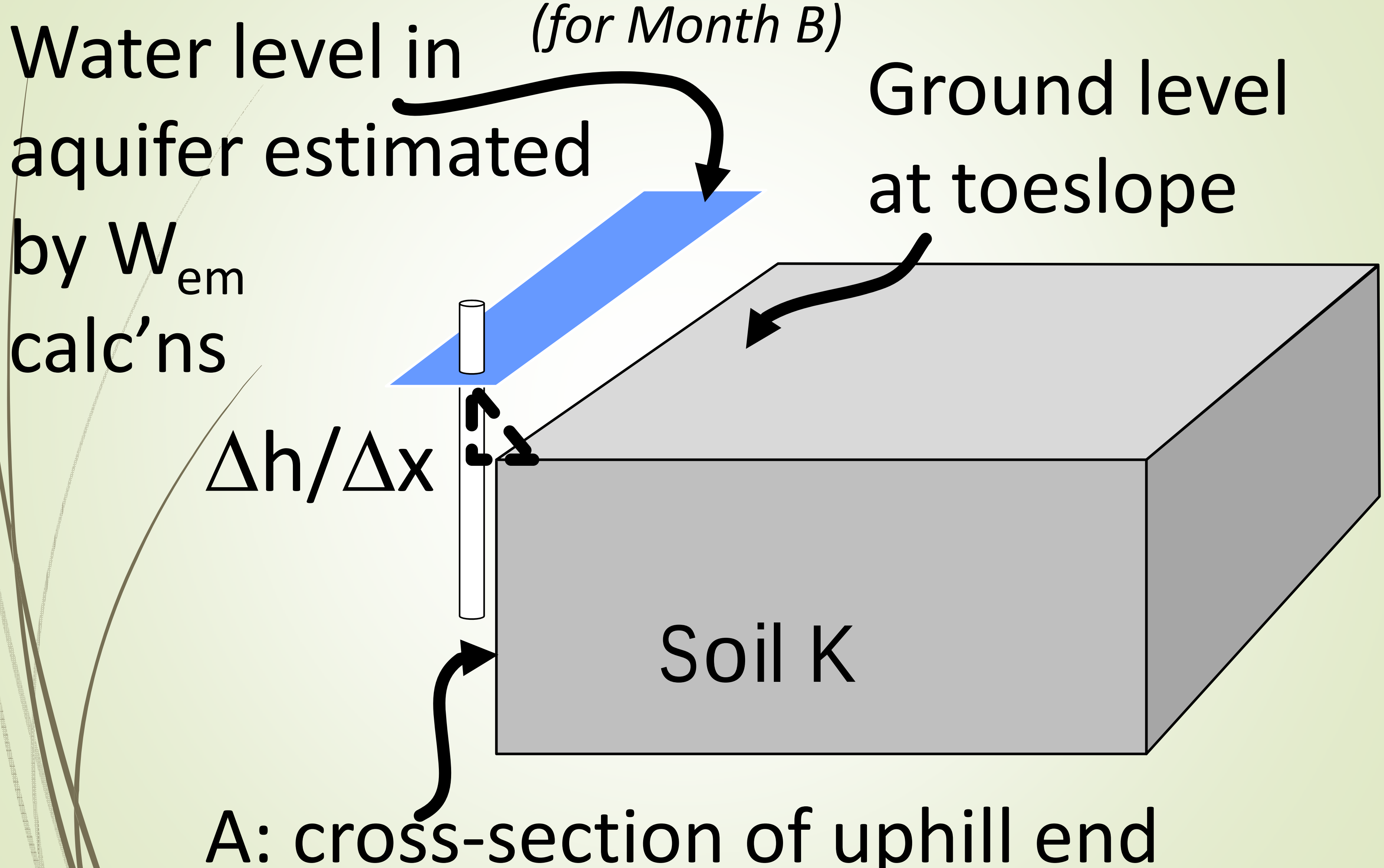


Building WetBud Model(s)

1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
    1. Calculate ET for WDN years (Thornthwaite, Penman)
    2. Calculate SWin using Curve Numbers
    3. Input GW_{in} or calculate using W_{em} (well data)
    4. Input or calculate Gw_{out}
    5. Input or calculate overbank flow

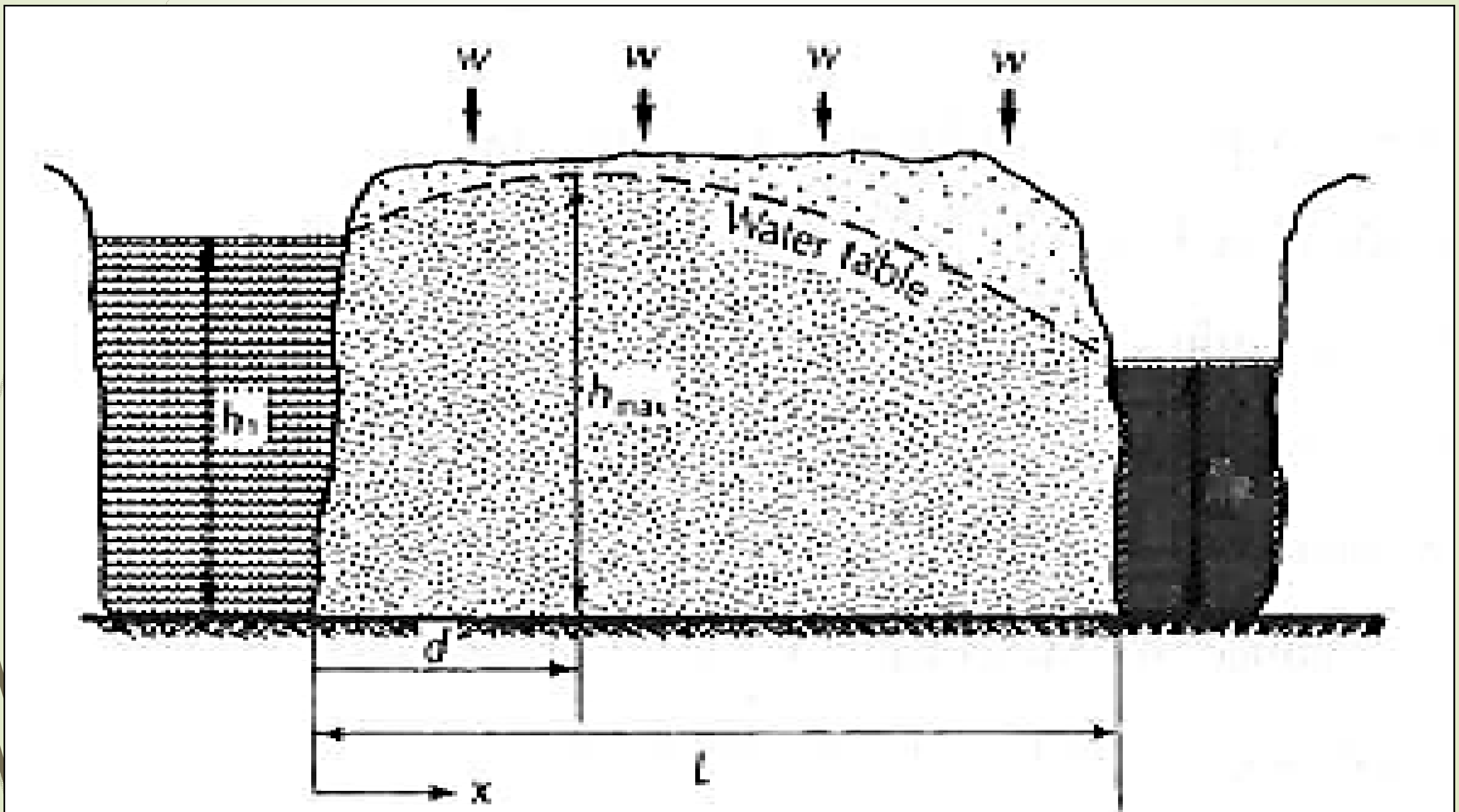
$$GW_{in} = K \; A \; \Delta h/\Delta x$$

(for Month B)



W_{em} = “Effective Monthly Recharge”

W_{mo} = “Monthly Recharge” = Ppt_{mo} - ET_{mo}



Effective Monthly Recharge: W_{em}

A time-weighted average recharge value

$$W_{em} = \sum_{a=1}^{n} W_{mo} \times d^{a-1}$$

n= # preceding months

Each month's recharge (Ppt - ET)

Response-decay factor (<1.0)

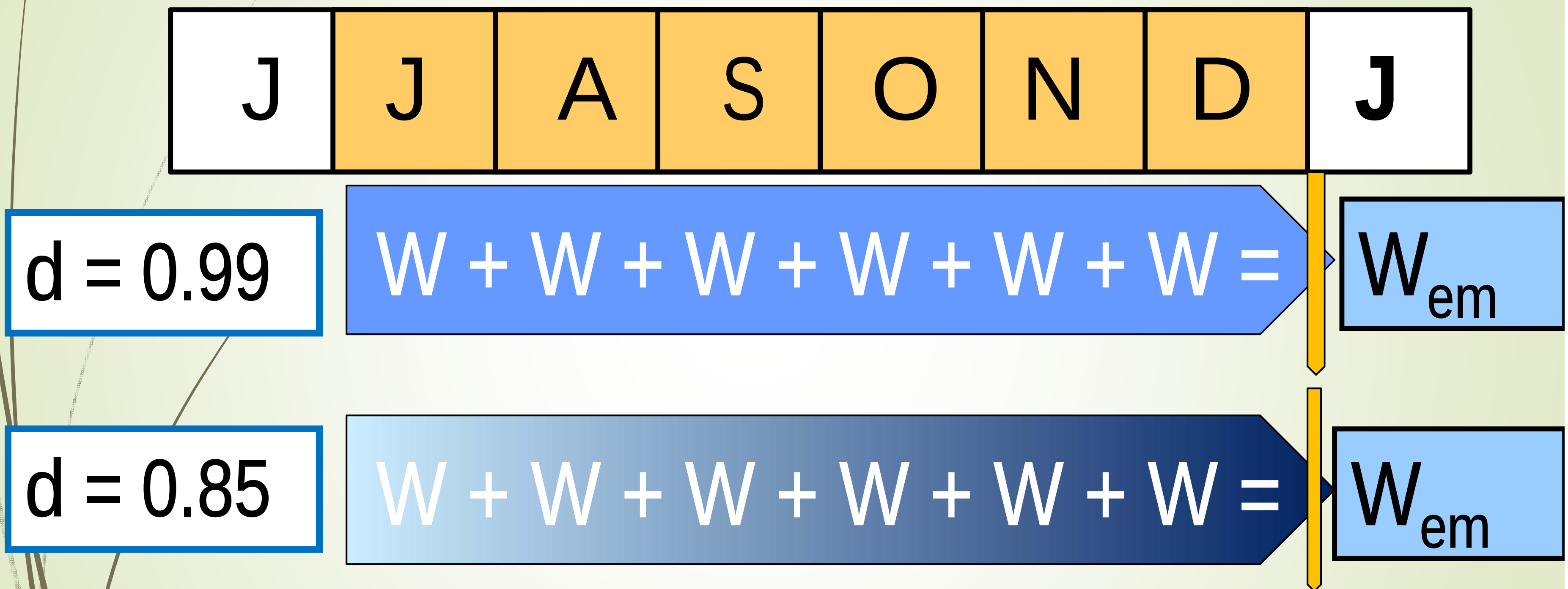
To predict the water table in Month A, how many month's W must you use?

J	J	A	S	O	N	D	**J**

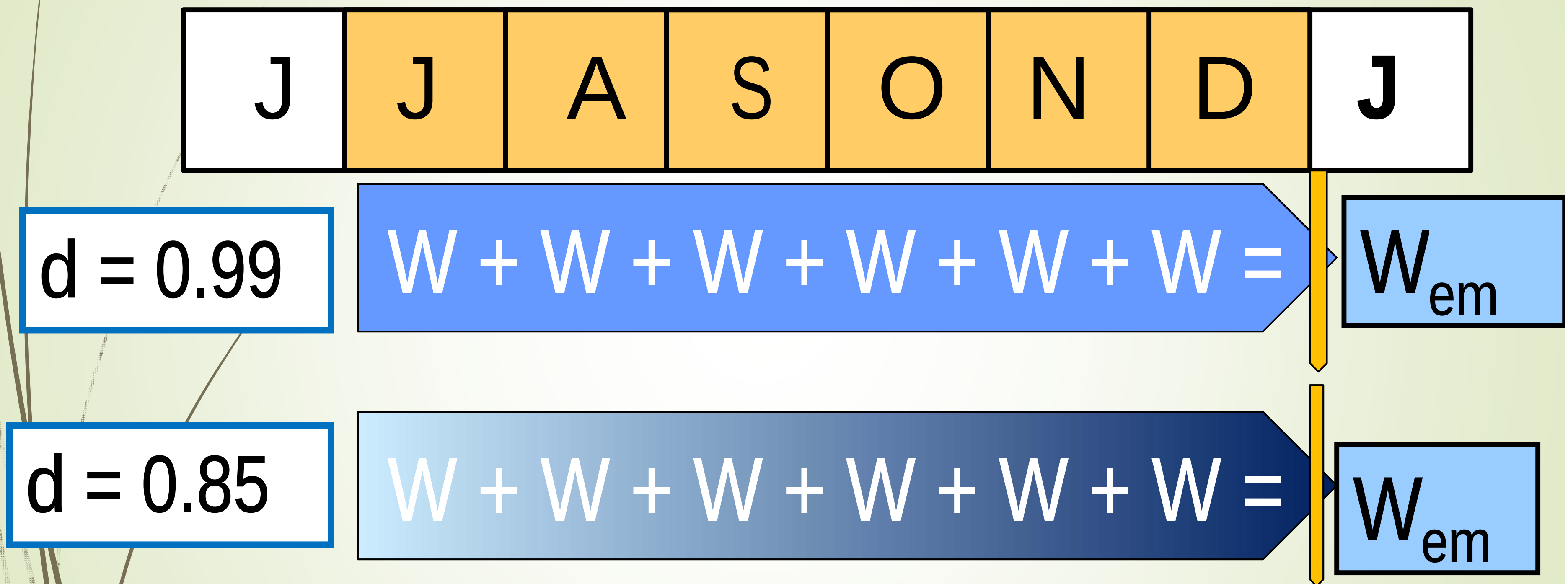
n = 6

W + W + W + W + W + W = W_{em}

How much influence do past months have on water levels in Month A?



How much influence do past months have on water levels in Month A?



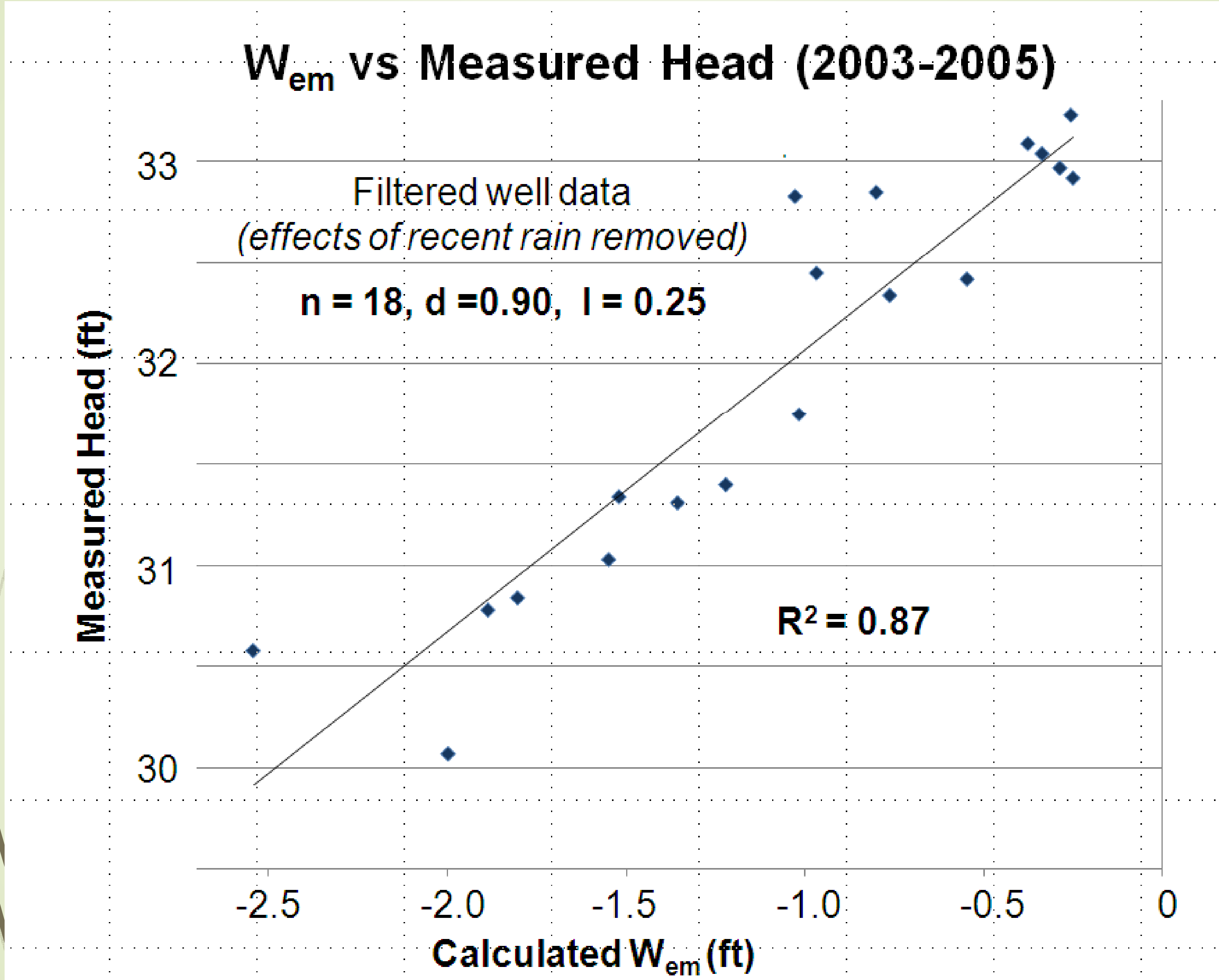
Must run every combination of n and d to find the best for prediction

Matrix of correlation coefficients (R^2)

d: response-decay factor

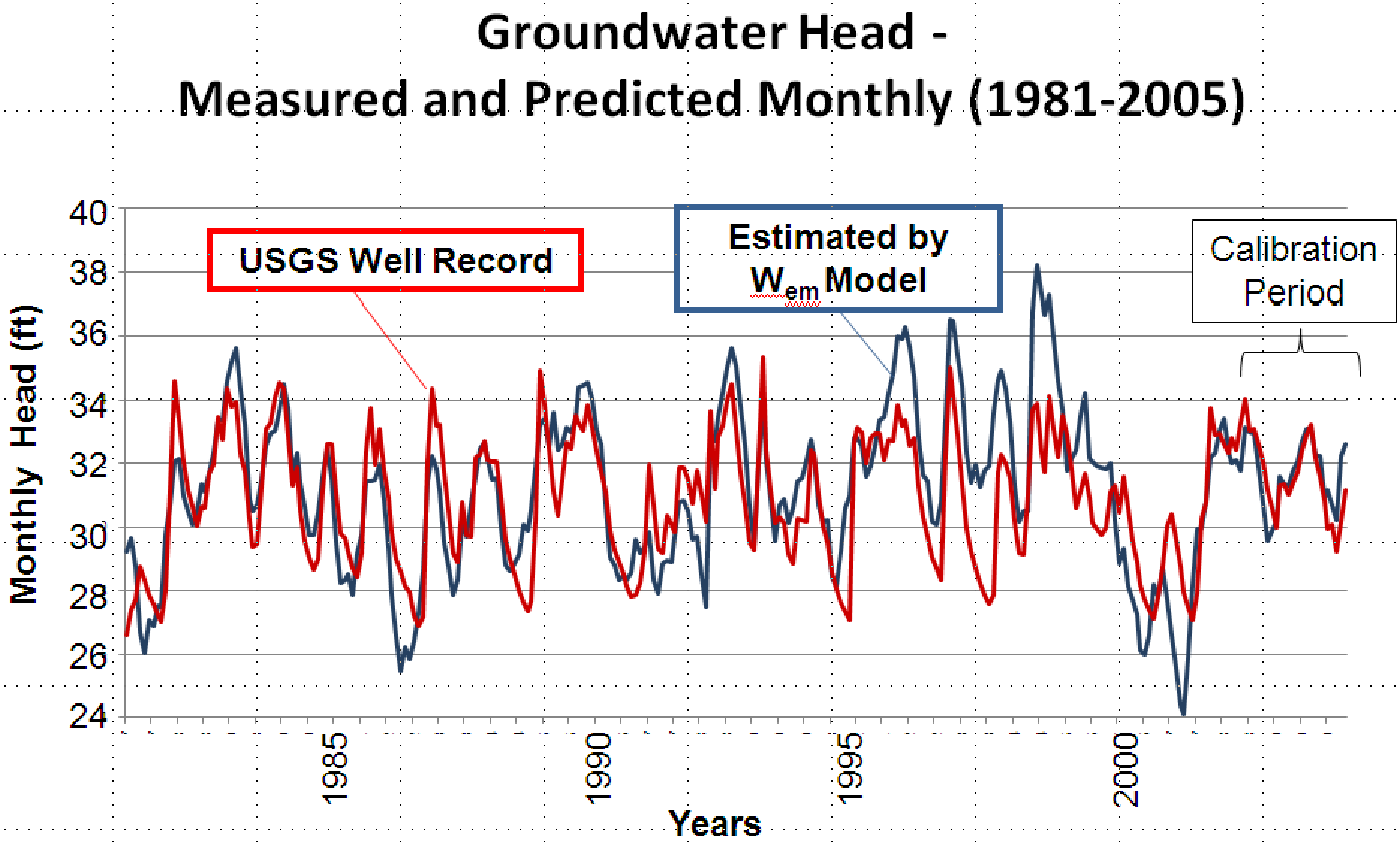
n: # of antecedent months

n	0.99	0.9	0.85	0.8	0.7
1	0.045	0.045	0.045	0.045	0.045
2	0.1135	0.1135	0.1132	0.1125	0.1099
3	0.1336	0.1369	0.1382	0.139	0.1385
4	0.0953	0.1062	0.1121	0.1178	0.1267
5	0.2135	0.2135	0.212	0.2089	0.1972
6	0.3747	0.3565	0.3402	0.3198	0.2694
7	0.1452	0.1452	0.1452	0.1452	0.1452
8	0.4705	0.5043	0.4858	0.4438	0.3329
9	0.0849	0.0861	0.0861	0.4794	0.3428
10	0.4622	0.6484	0.6151	0.5259	0.3512
11	0.2021	0.2021	0.2021	0.2021	0.2021
12	0.2533	0.6793	0.6636	0.5451	0.3494
13	0.1567	0.6551	0.6473	0.5316	0.3455
14	0.188	0.705	0.662	0.5346	0.3457
15	0.258	0.7742	0.6955	0.5477	0.3475
16	0.4136	0.824	0.72	0.5597	0.3494
17	0.3884	0.8587	0.7356	0.5638	0.3496
18	0.3661	0.8711	0.7412	0.5653	0.3497
19	0.2022	0.858	0.7445	0.5652	0.3494
20	0.0474	0.8327	0.7263	0.5548	0.348
21	0.0013	0.7233	0.7023	0.5455	0.3468
22	0.0149	0.5455	0.6768	0.5405	0.3463



Wem vs Measured Head (2003-2005)
Filtered well data
(effects of recent rain removed)
n = 18, d =0.90, I = 0.25
R2 = 0.87
Measured Head (ft)
33
32
31
30
-2.5
-2.0
-1.5
-1.0
-0.5
0
Calculated Wem (ft)

Verification of W_{em} Calculations



W_{em} = "Effective Monthly Recharge"

W_{mo} = "Monthly Recharge" = $Ppt_{mo} - ET_{mo}$

Must have at least 6 months of water level measurements from a well just uphill of site

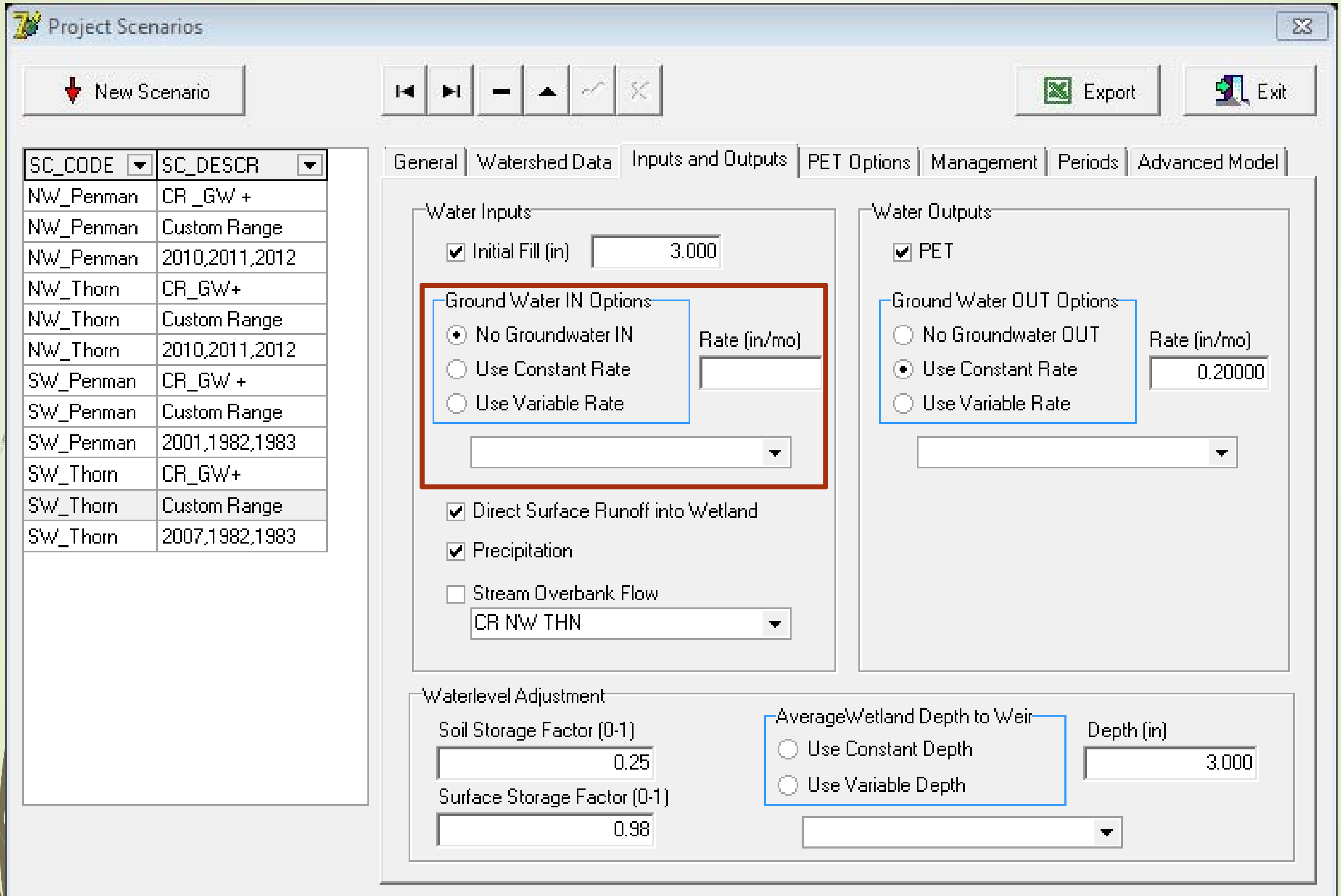
W_{em} = "Effective Monthly Recharge"

W_{mo} = "Monthly Recharge" = Ppt_{mo} - ET_{mo}

Must have at least 6 months of water level measurements from a well just uphill of site

Can reconstruct GW levels using weather data for times with no well data

Input GW_{in} or calculate using W_{em}



Building WetBud Model(s)

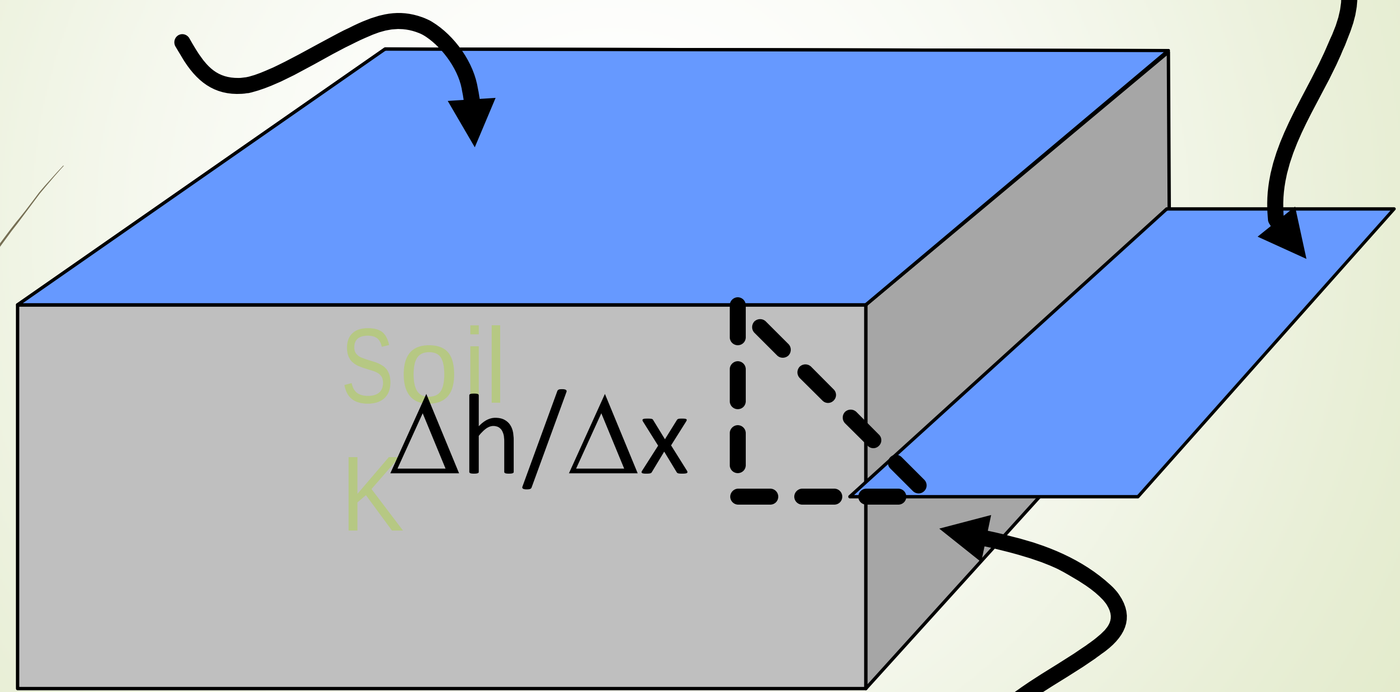
1. Create Project and Scenario
2. Build weather data
3. Determine WND years w/ WETS tables
4. User determines inputs and outputs
    1. Calculate ET for WDN years (Thornthwaite, Penman)
    2. Calculate SW_{in} using Curve Numbers
    3. Input GW_{in} or calculate using W_{em} (well data)
    4. Input or calculate GW_{out}
    5. Input or calculate overbank flow

$$GW_{out} = K \ A \ \Delta h/\Delta x$$

(for Month B)

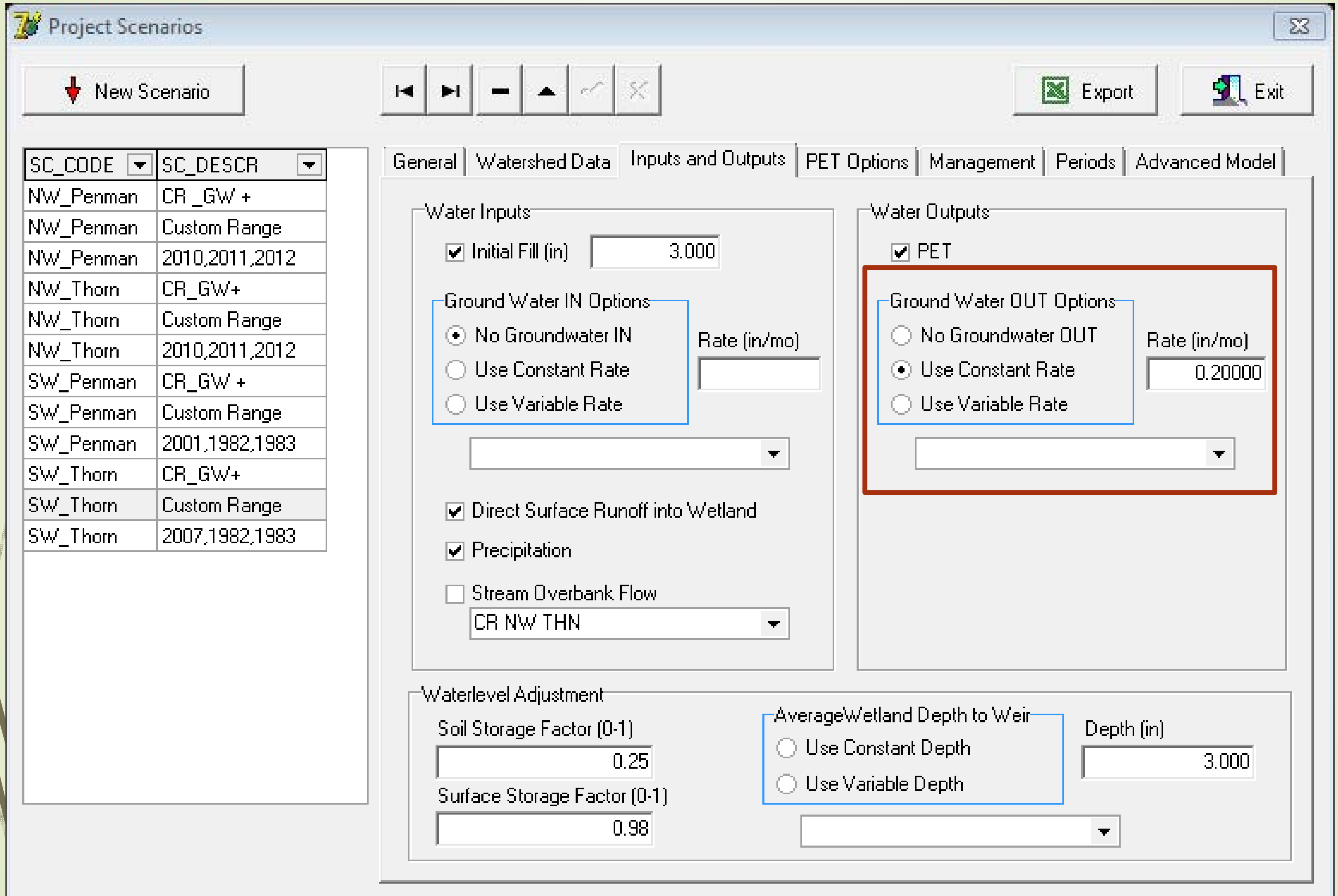
Water level at end of Month A

Water level below outlet



A: cross-section of downhill end

Input or calculate GW_{out}



WetBud is being tested at four sites

Cedar Run 3 Wetland Bank

completed in October 2001 by WSSI

Bender Farms Wetland Bank

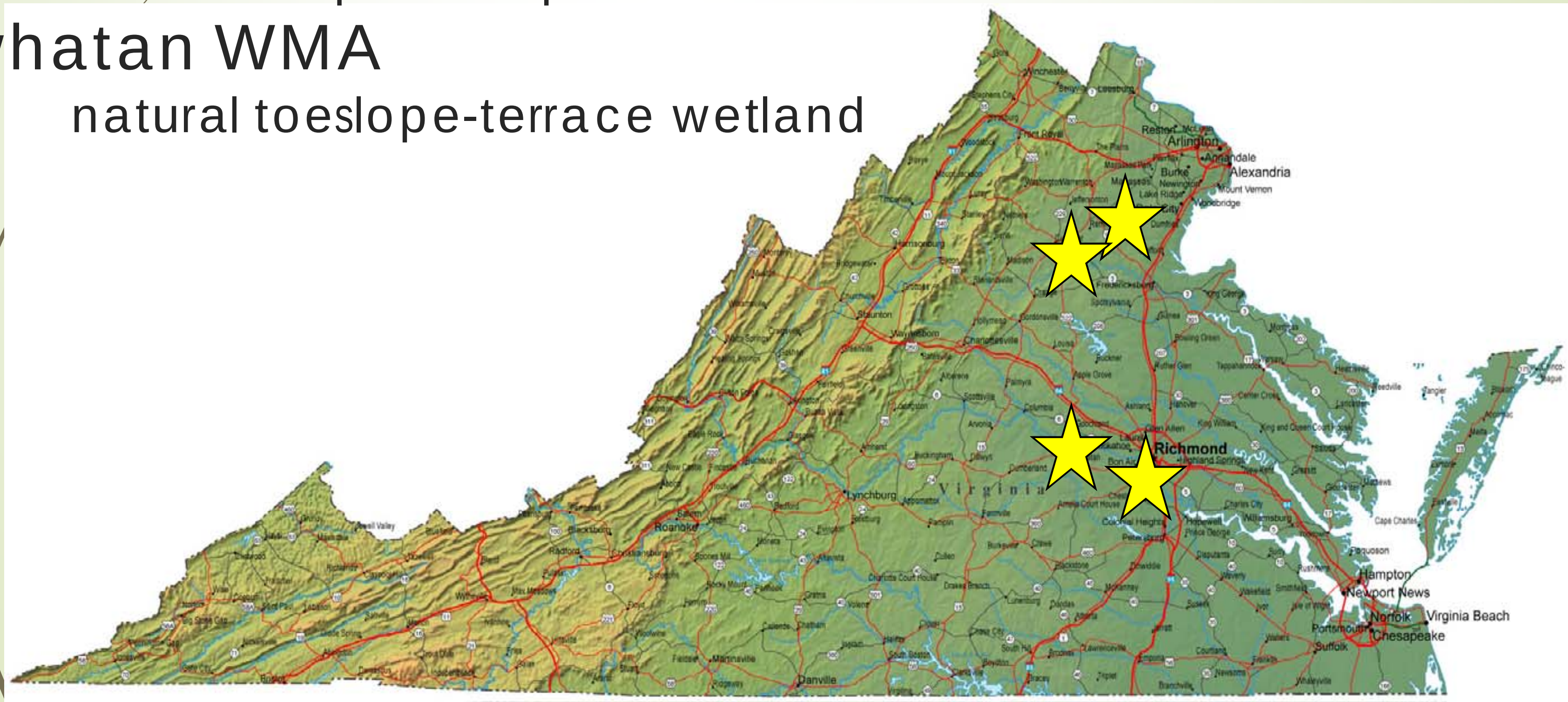
completed by Acorn Environ

Pocahontas State Park

natural toeslope-floodplain wetland

Powhatan WMA

natural toeslope-terrace wetland



WetBud is being tested at four sites

Cedar Run 3 Wetland Bank

completed in October 2001 by WSSI

Bender Farms Wetland Bank

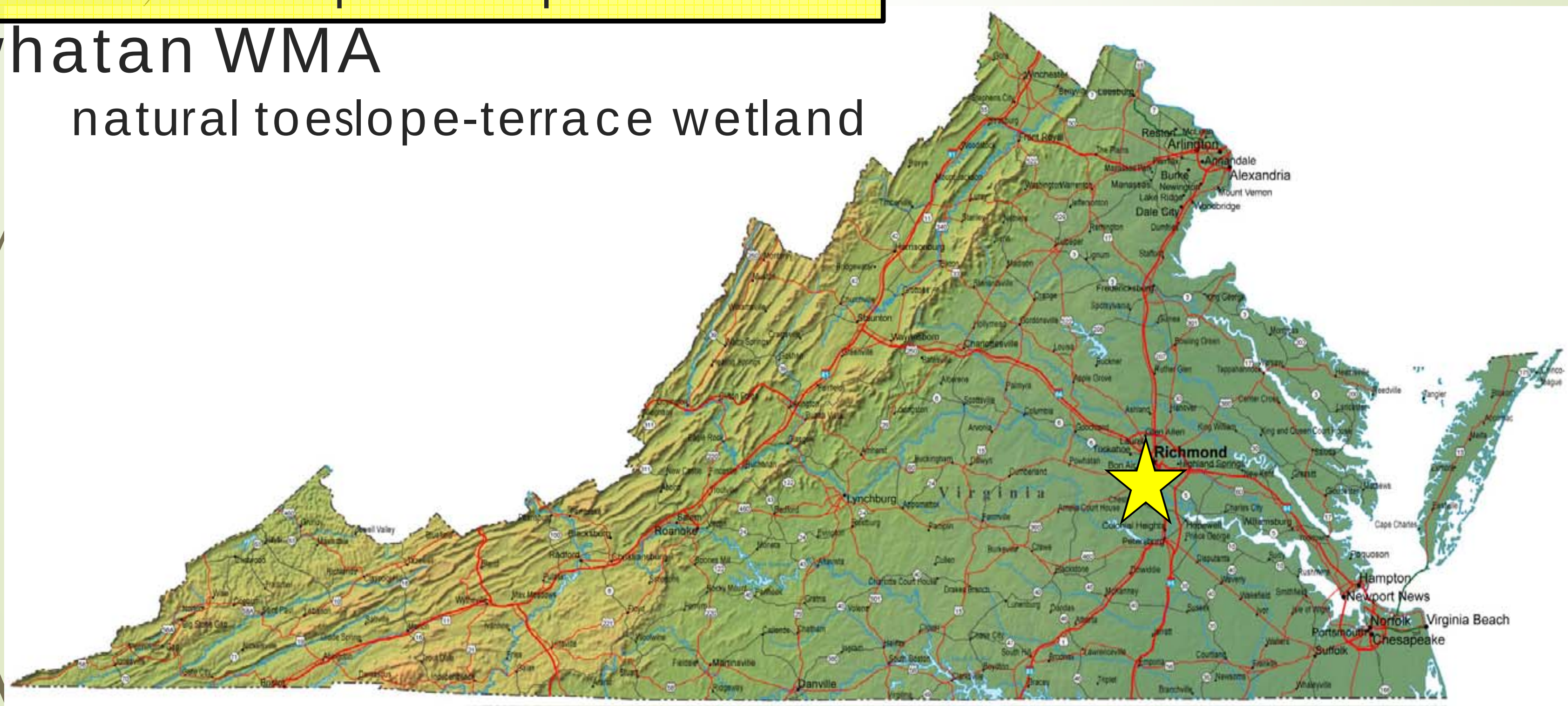
completed by Acorn Environ

Pocahontas State Park

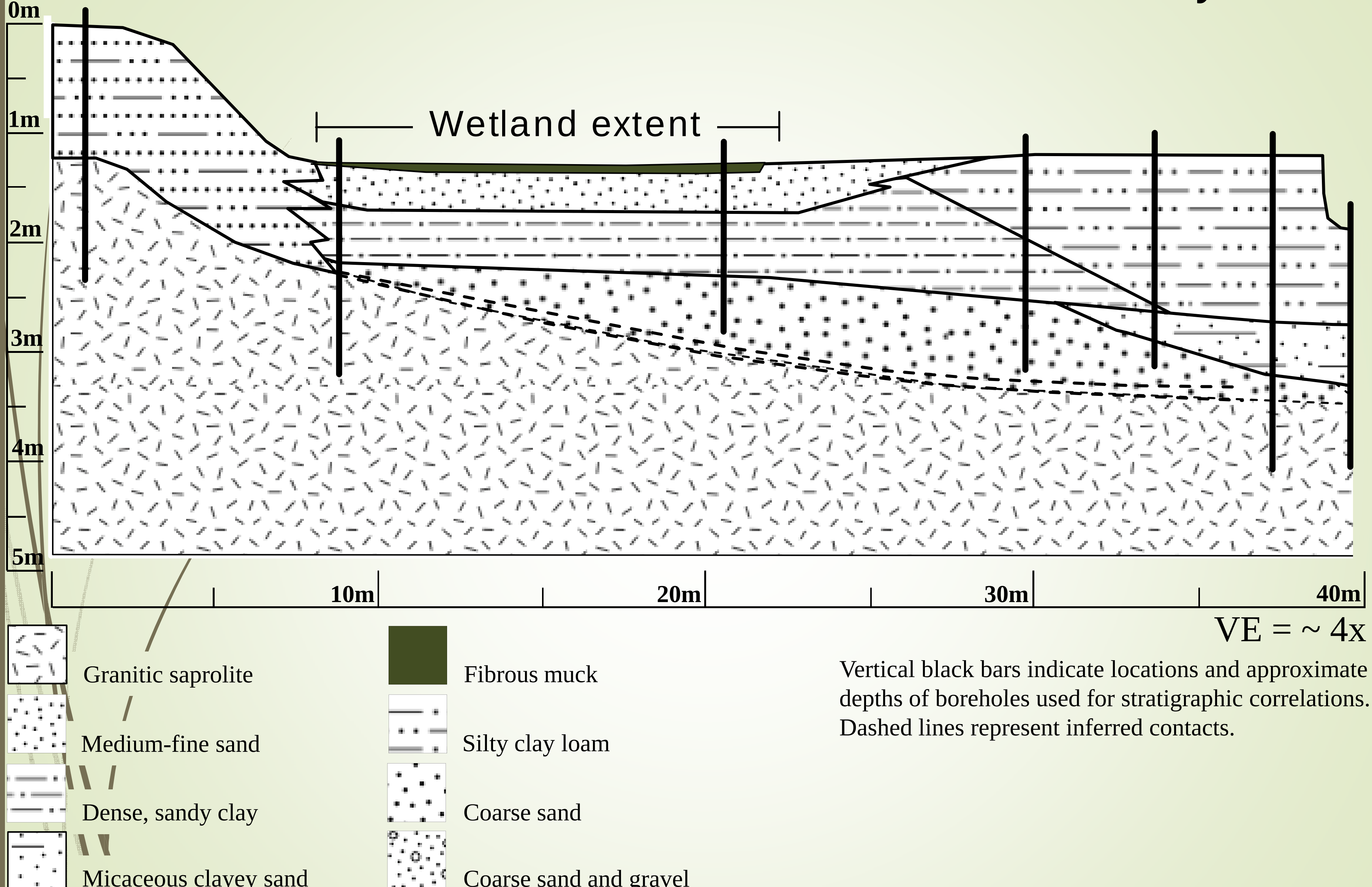
natural toeslope-floodplain wetland

Powhatan WMA

natural toeslope-terrace wetland



Cross-section of Pocahontas State Park study site

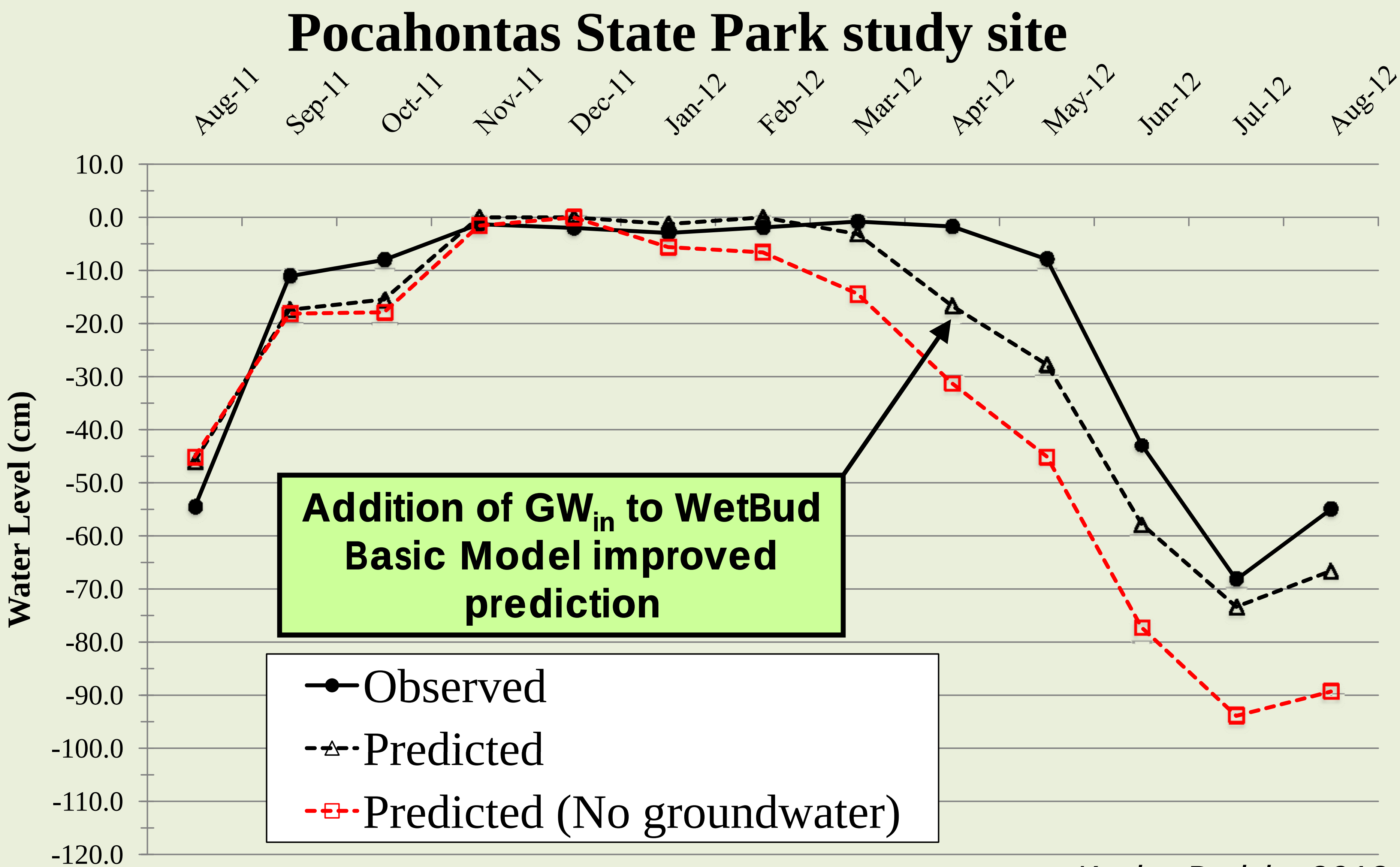


VE = ~ 4x

Vertical black bars indicate locations and approximate depths of boreholes used for stratigraphic correlations. Dashed lines represent inferred contacts.

- Kerby Dobbs 2013

Basic Model output: toe-slope water level



- Kerby Dobbs 2013

WetBud is being tested at four sites

Cedar Run 3 Wetland Bank

completed in October 2001 by WSSI

Bender Farms Wetland Bank

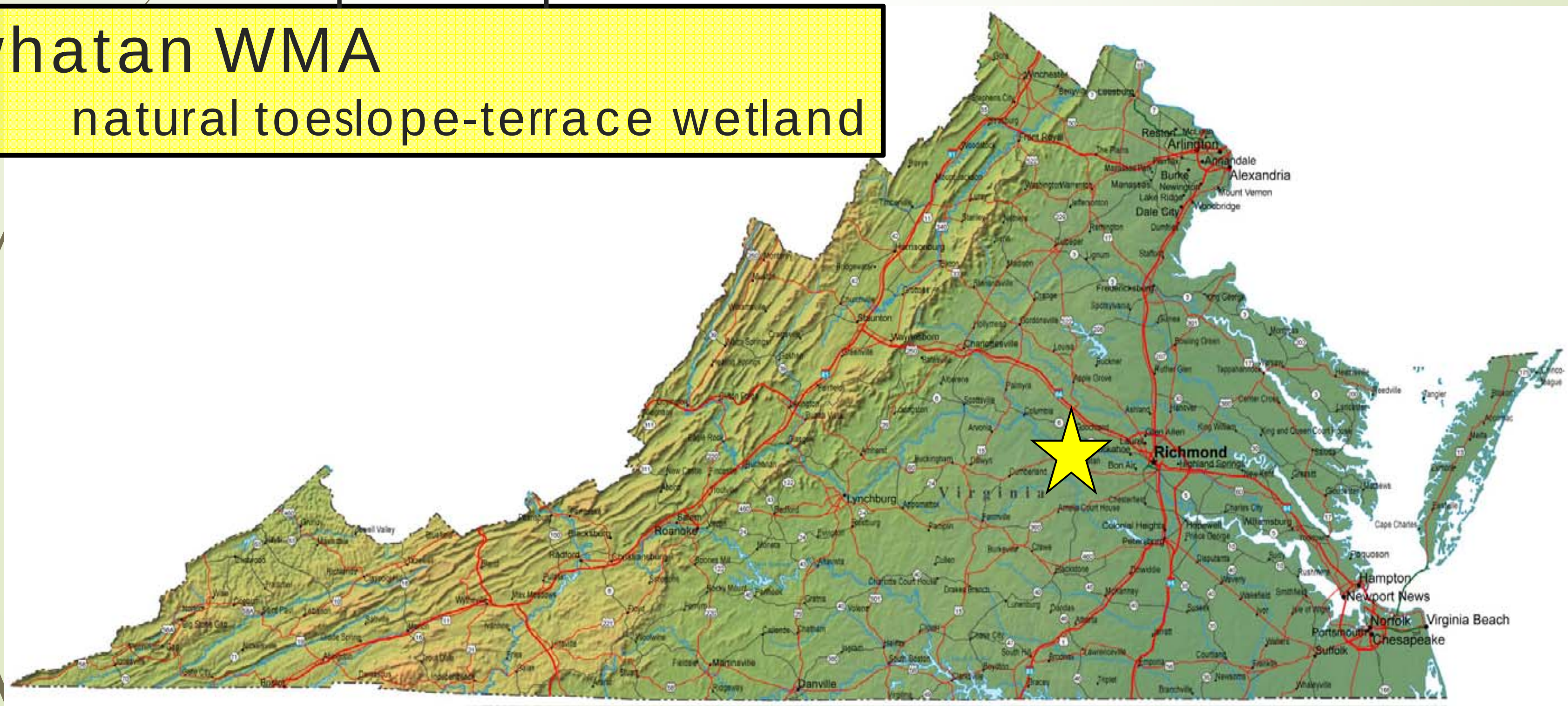
completed by Acorn Environ

Pocahontas State Park

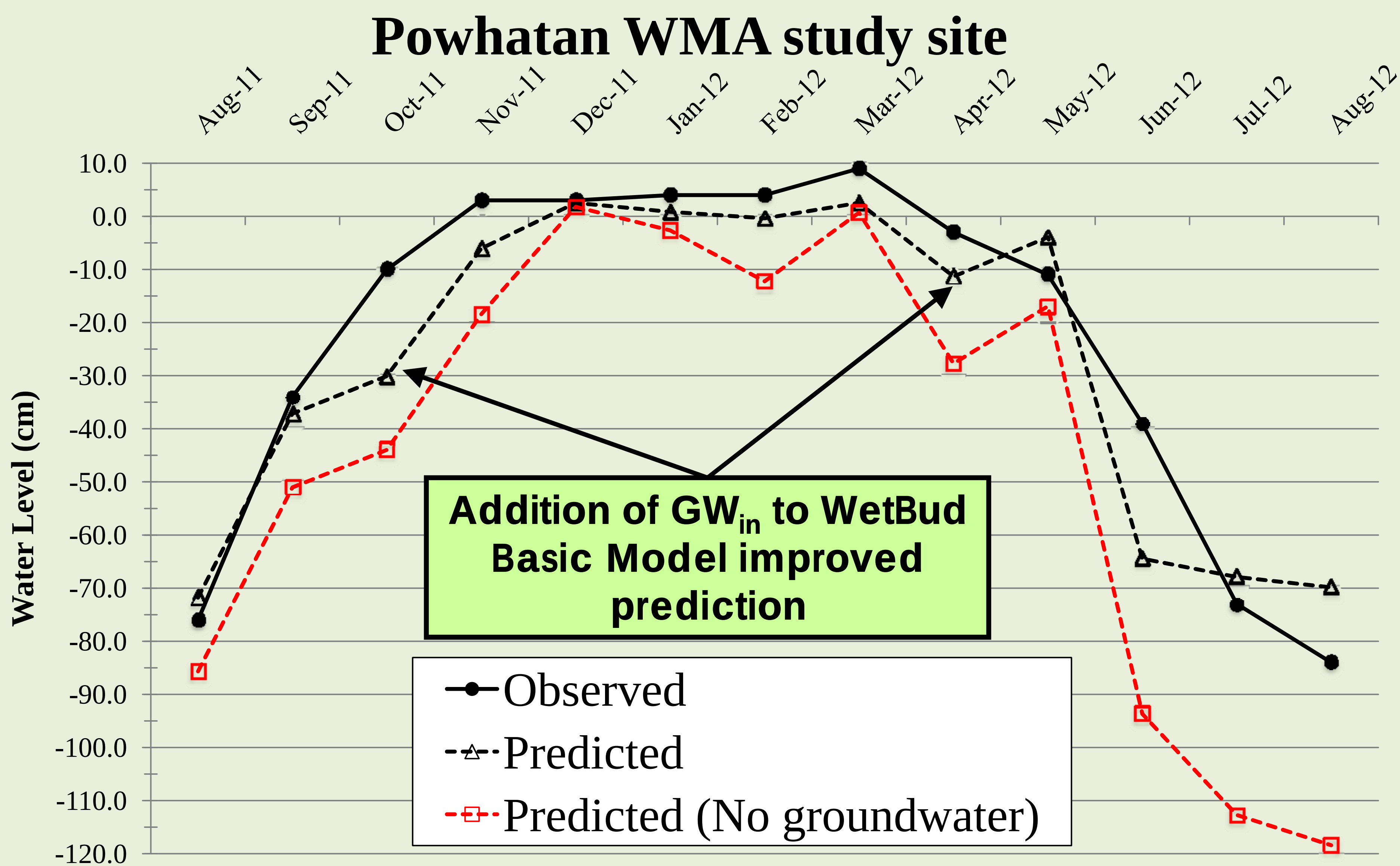
natural toeslope-floodplain wetland

Powhatan WMA

natural toeslope-terrace wetland

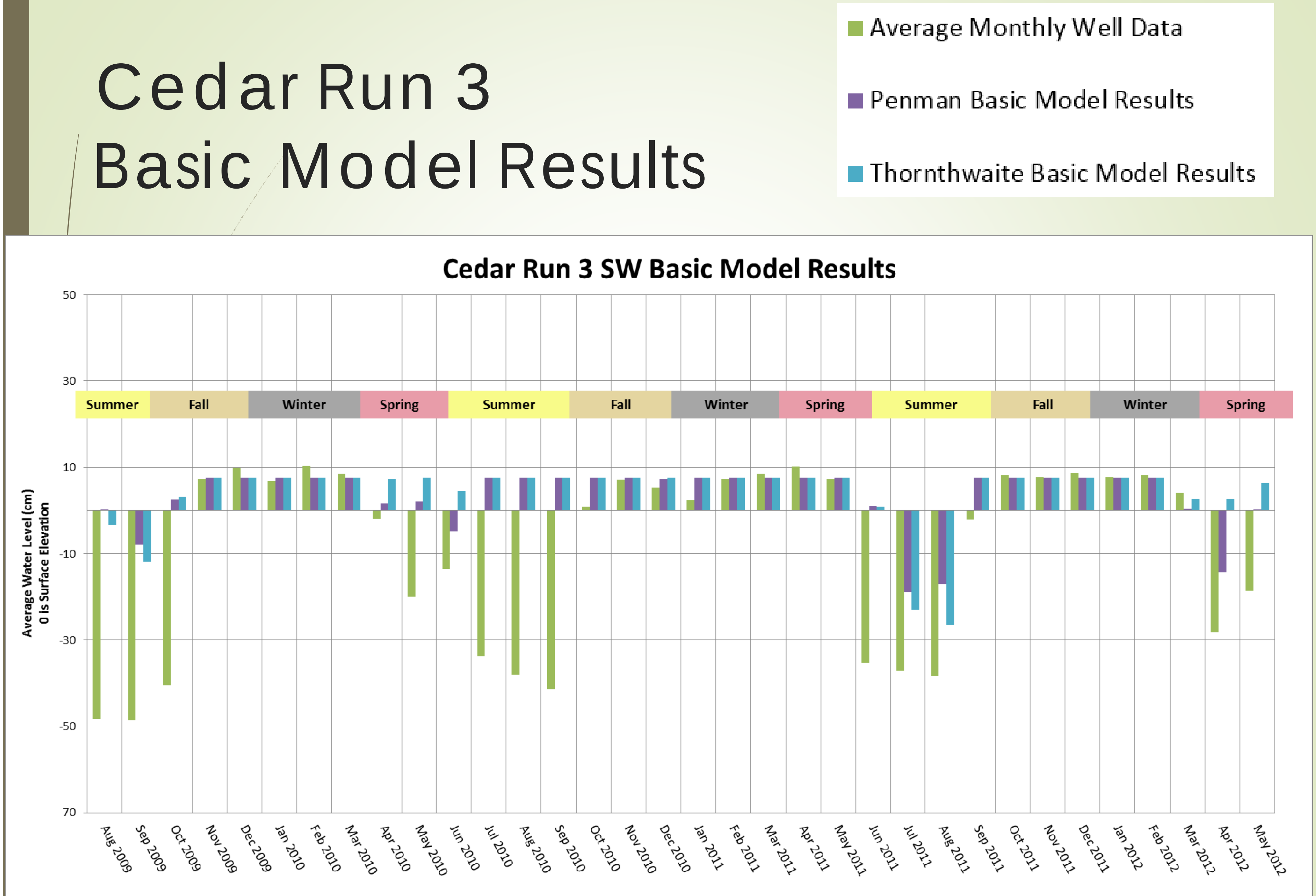


Basic Model output: toe-slope water level



- *Kerby Dobbs 2013*

Cedar Run 3
Basic Model Results



Ongoing Work

- Fully integrating Wem
- Overbank flow routines
- Advanced model wizard
- Completing testing (5 sites)
- Developing output for use in wetland hydrologic assessments;
- Developing an instruction manual;
- Developing training materials and workshops


Questions?