Understanding groundwater components for Wetbud

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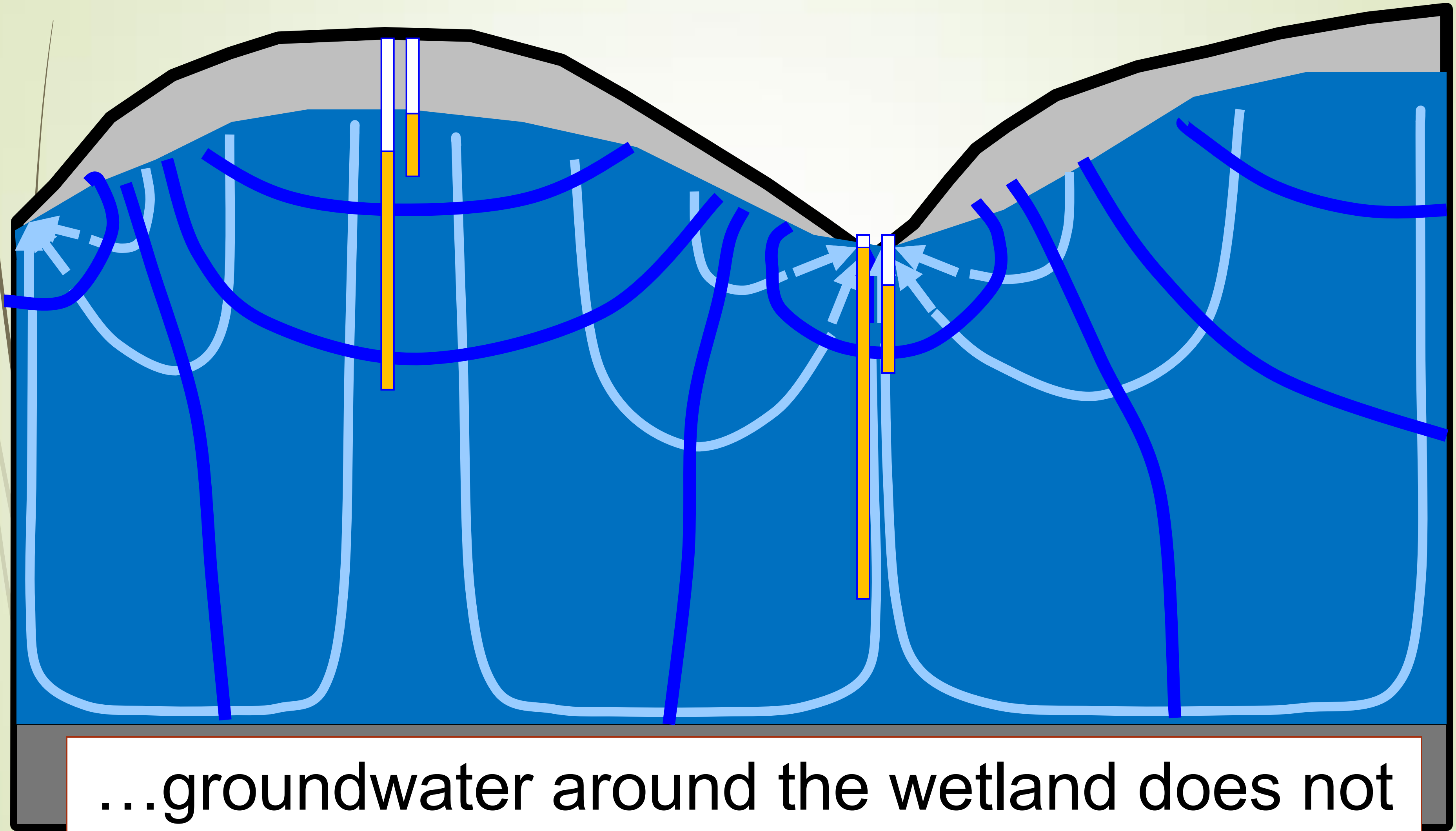
Groundwater Considerations

1. **Landscape and Geology**
2. How and where GW used
3. New calcs: WND and W_{em}
4. Example applications

Wetbud is designed to handle the INs and OUTs seen at Toeslope Wetlands.

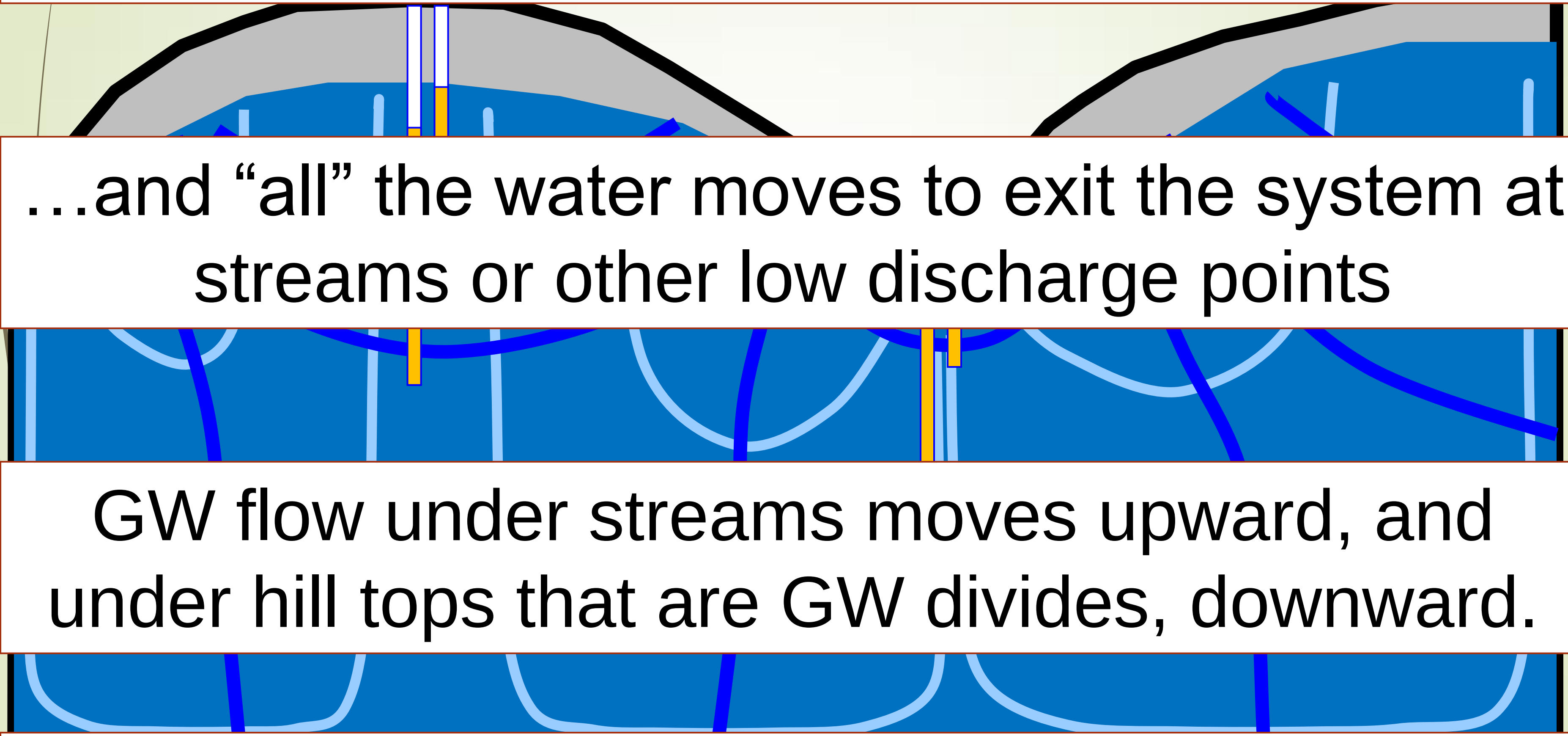
If you work on a wetland in a different landscape position, you MUST adjust your thinking…

You HAVE to understand where your wetland sits in the landscape because…



…groundwater around the wetland does not move the same in different locations!

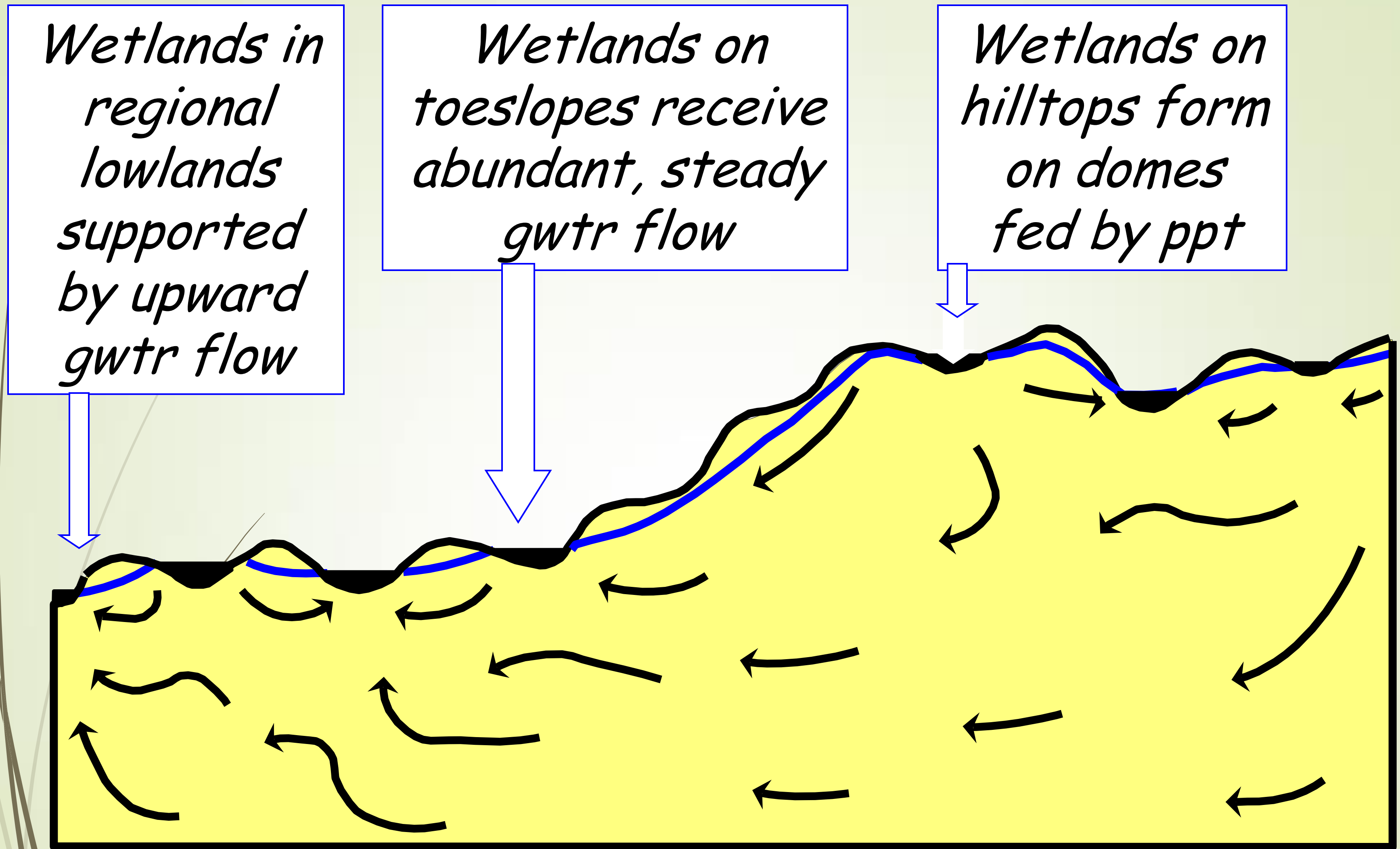
Rain that infiltrates over entire upland area (recharge) saturates the surficial aquifer ….



…and “all” the water moves to exit the system at streams or other low discharge points

GW flow under streams moves upward, and under hill tops that are GW divides, downward.

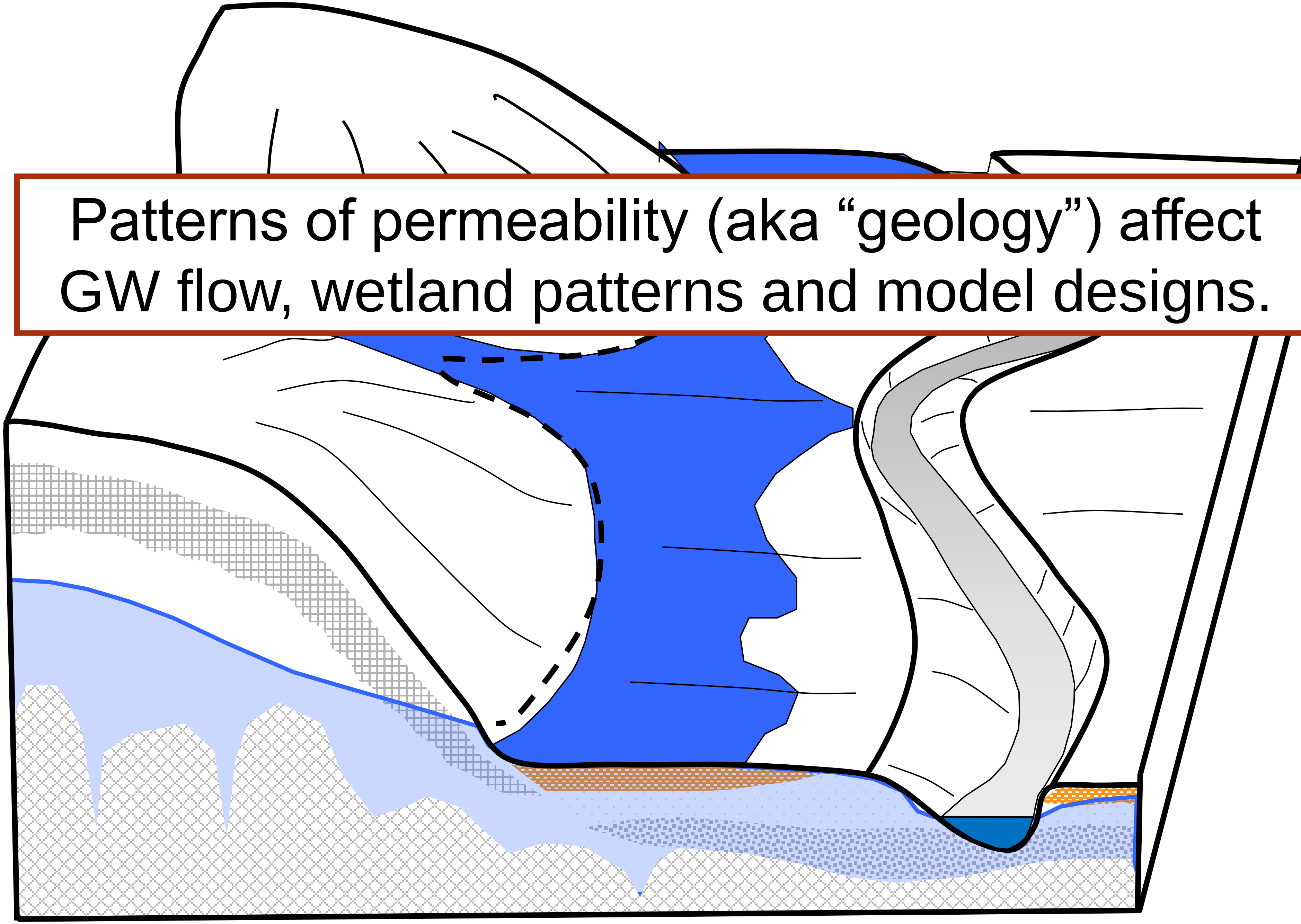
Use piezometers to confirm vertical component of GW movement

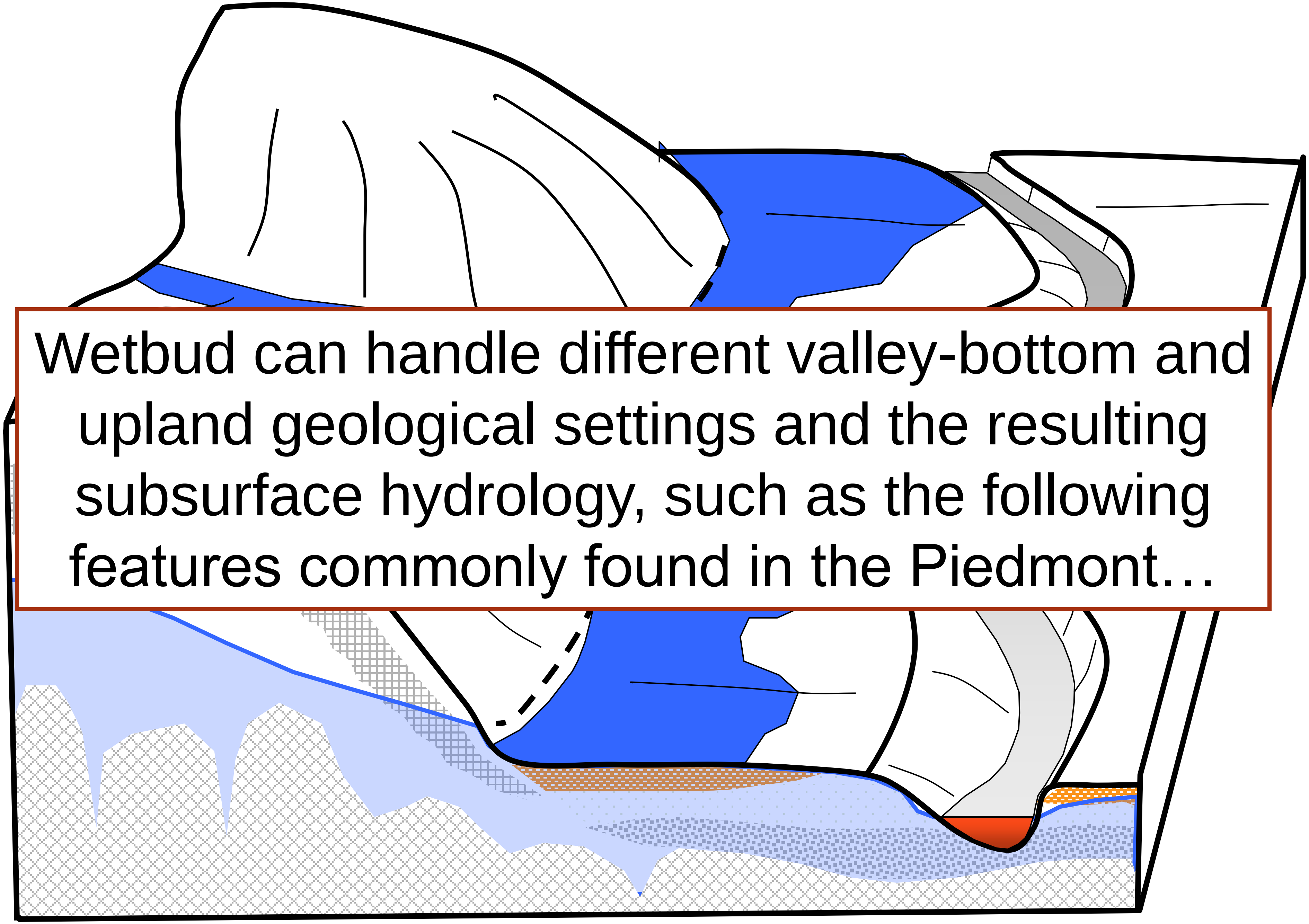


Effects of Topography on Regional Groundwater Flow

after Winter, 1988

Patterns of permeability (aka “geology”) affect GW flow, wetland patterns and model designs.



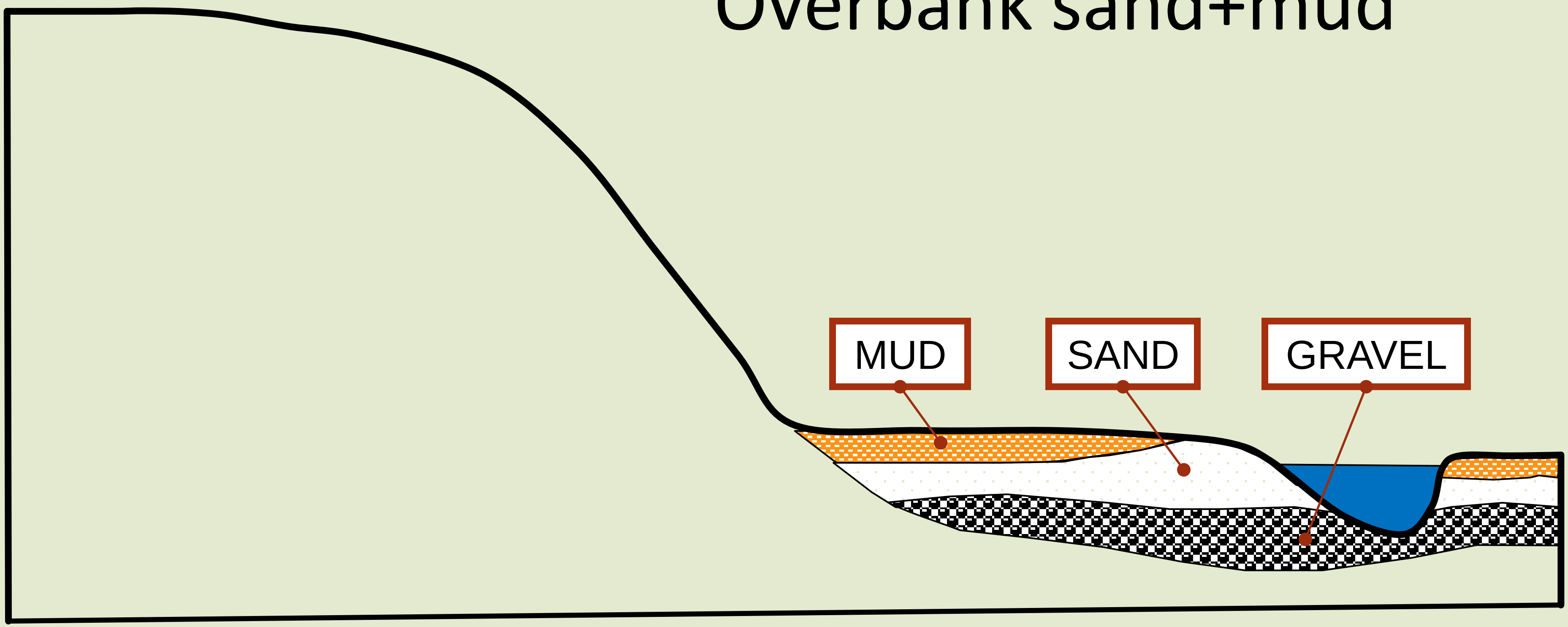


Wetbud can handle different valley-bottom and upland geological settings and the resulting subsurface hydrology, such as the following features commonly found in the Piedmont…

River Bottom Sediments

Channel gravel+sand

Overbank sand+mud



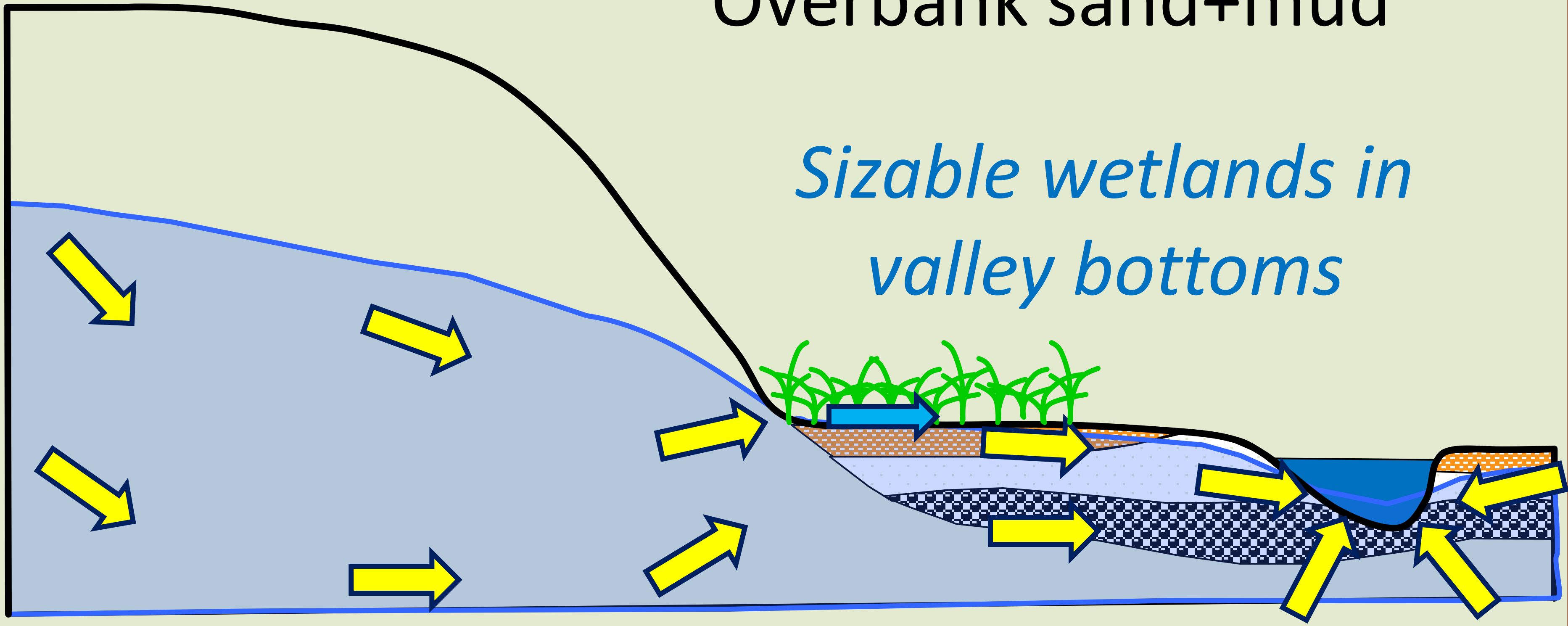
Under valley bottoms, expect stream sediments to be a fining-upwards package.

River Bottom Sediments

Channel gravel+sand

Overbank sand+mud

Sizable wetlands in valley bottoms

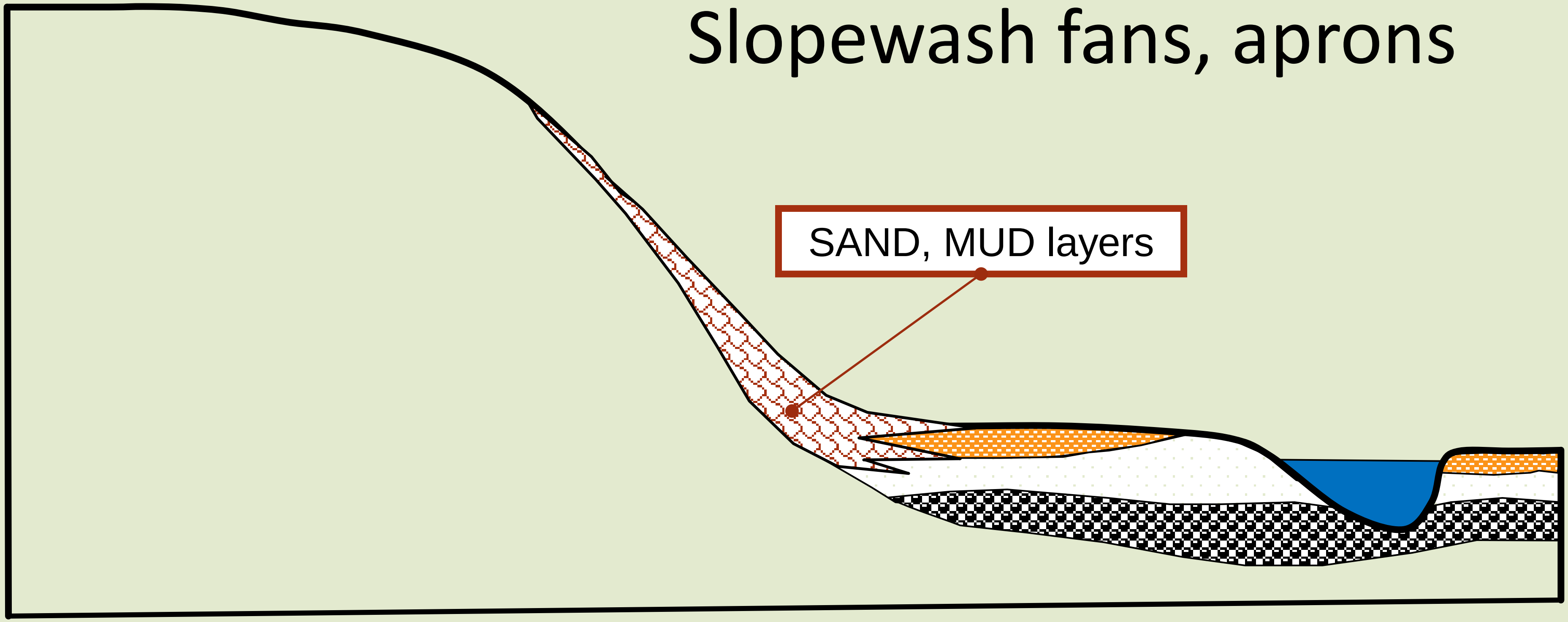


Expect GW seepage along toeslopes with distinct breaks to form persistant wetlands.

River Bottom Sediments

Alluvium – floodplain, channel

Slopewash fans, aprons



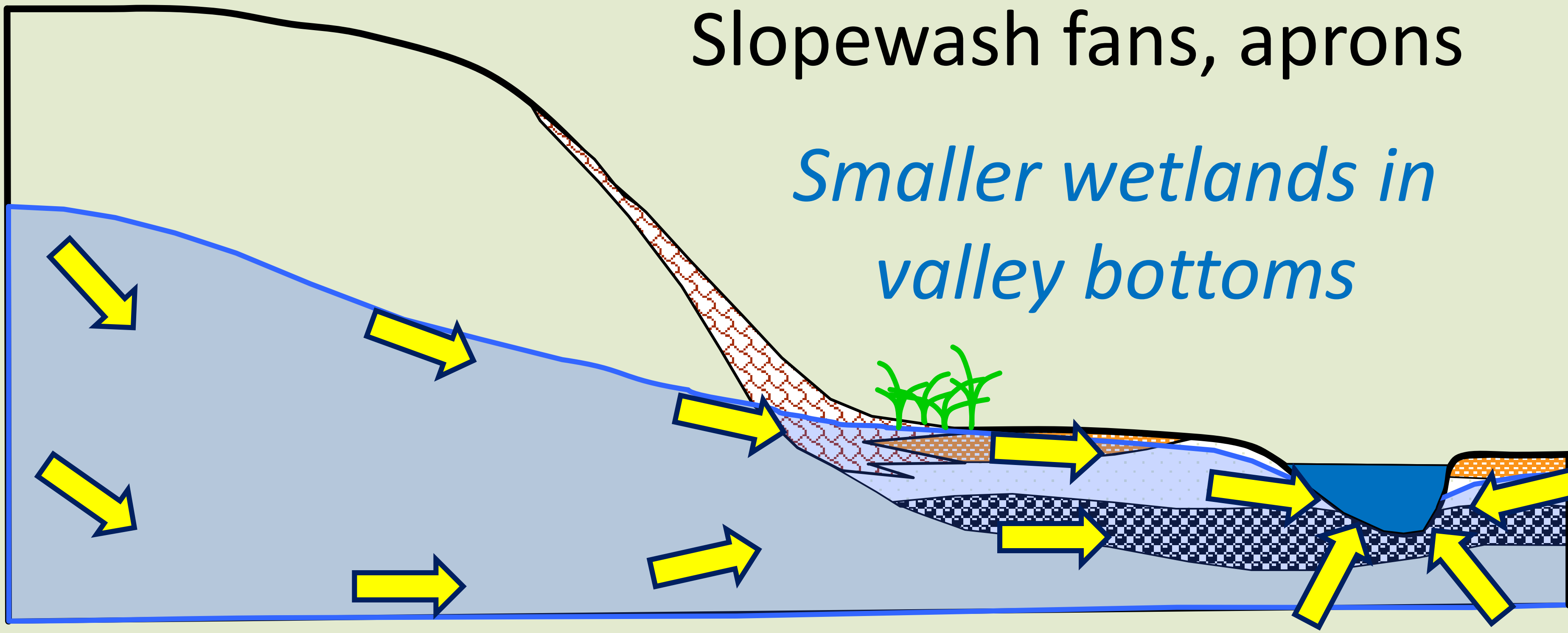
Colluvial aprons bury many toeslopes with layers of sediments eroded from hillsides.

River Bottom Sediments

Alluvium – floodplain, channel

Slopewash fans, aprons

Smaller wetlands in valley bottoms

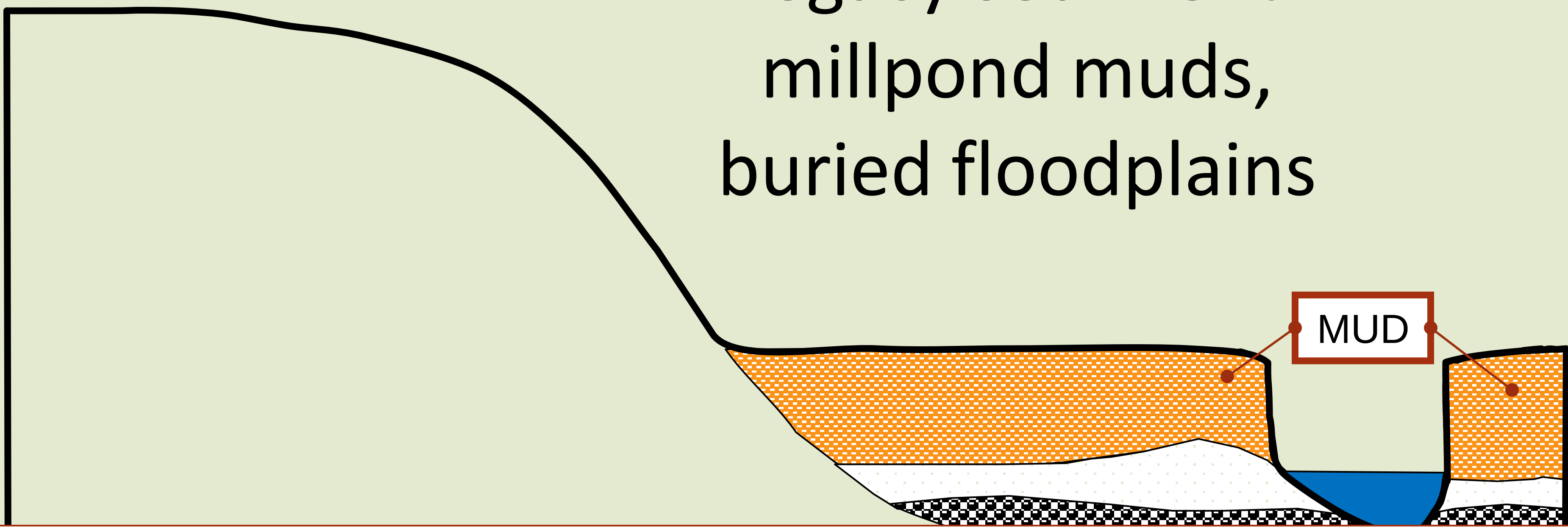


Fans often transmit large GW volumes to valley floor – potential resource for future wetlands.

River Bottom Sediments

Alluvium – floodplain, channel

Legacy sediment:
millpond muds,
buried floodplains



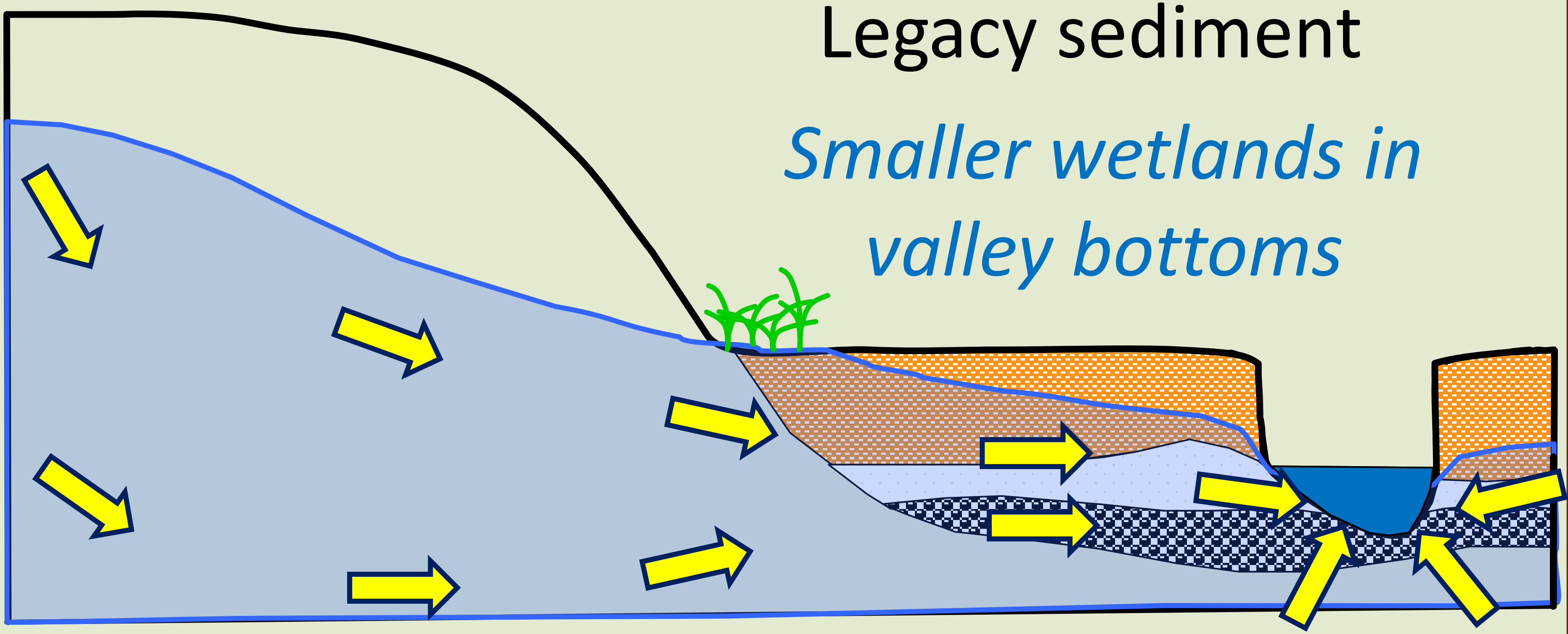
Thick beds of mud+sand washed from eroded farmed land and washed onto floodplains or trapped in millponds (now destroyed) underlie terraces beside down-cutting streams.

River Bottom Sediments

Alluvium – floodplain, channel

Legacy sediment

Smaller wetlands in valley bottoms

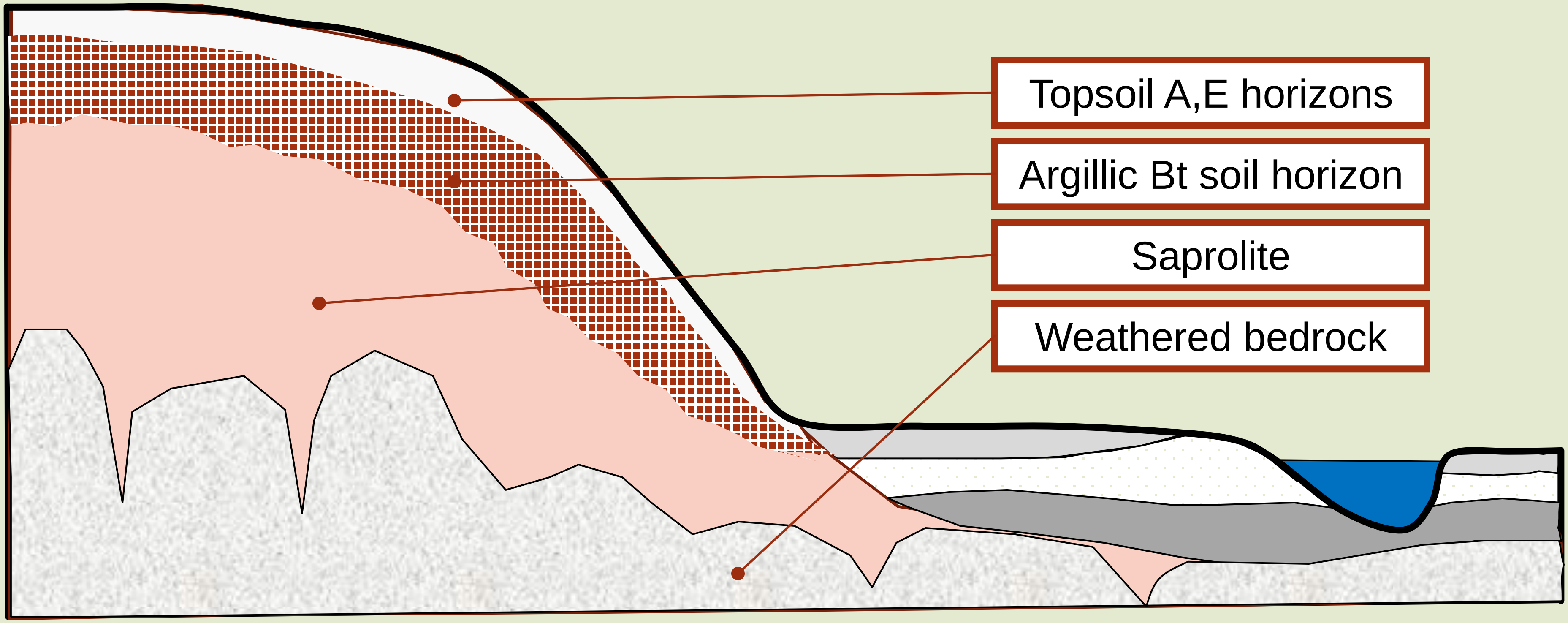


Legacy silt-clay may help constructed wetland designs, but creates major problems for stream reconstruction/sed load reduction designs.

Piedmont Landscapes

Alluvium – floodplain, channel

Regolith weathered from crystalline rocks

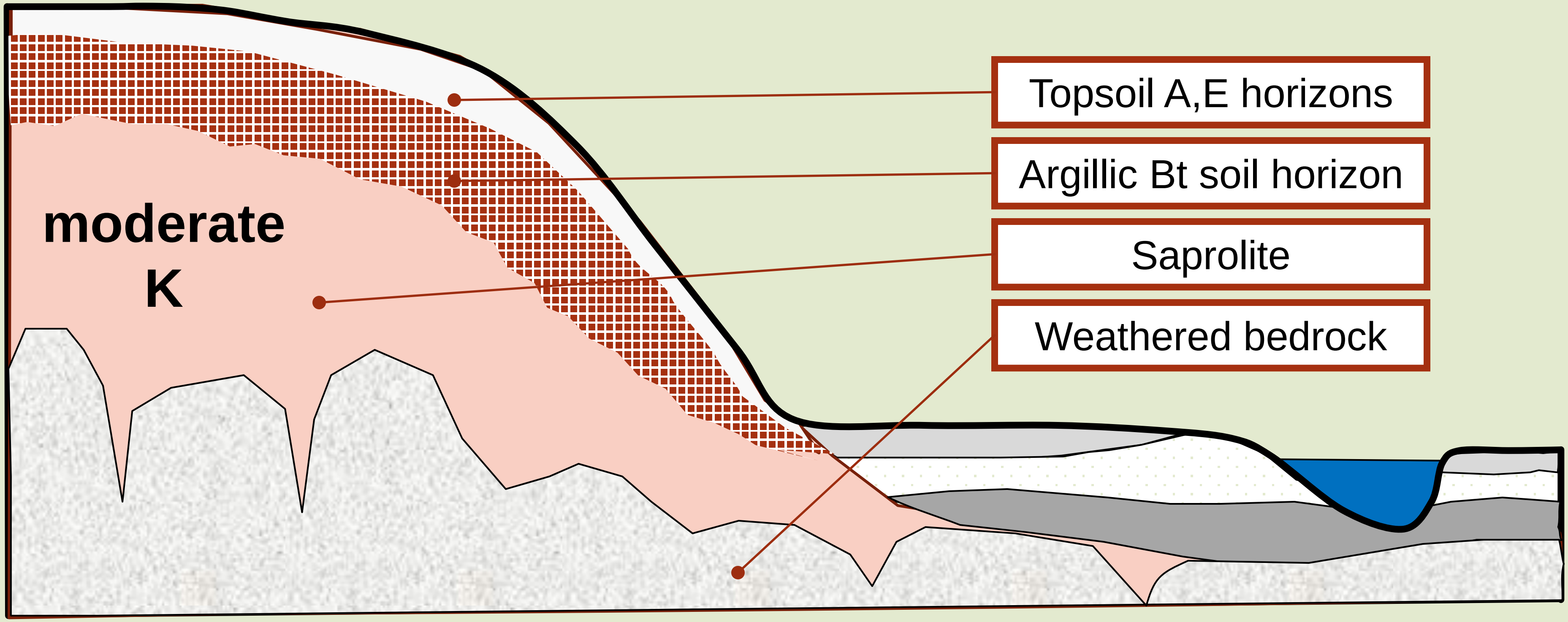


Wetbud requires data about K and heads in geologic material uphill of analyzed wetland. In the Piedmont, expect saprolite, …

Piedmont Landscapes

Alluvium – floodplain, channel

Regolith weathered from crystalline rocks

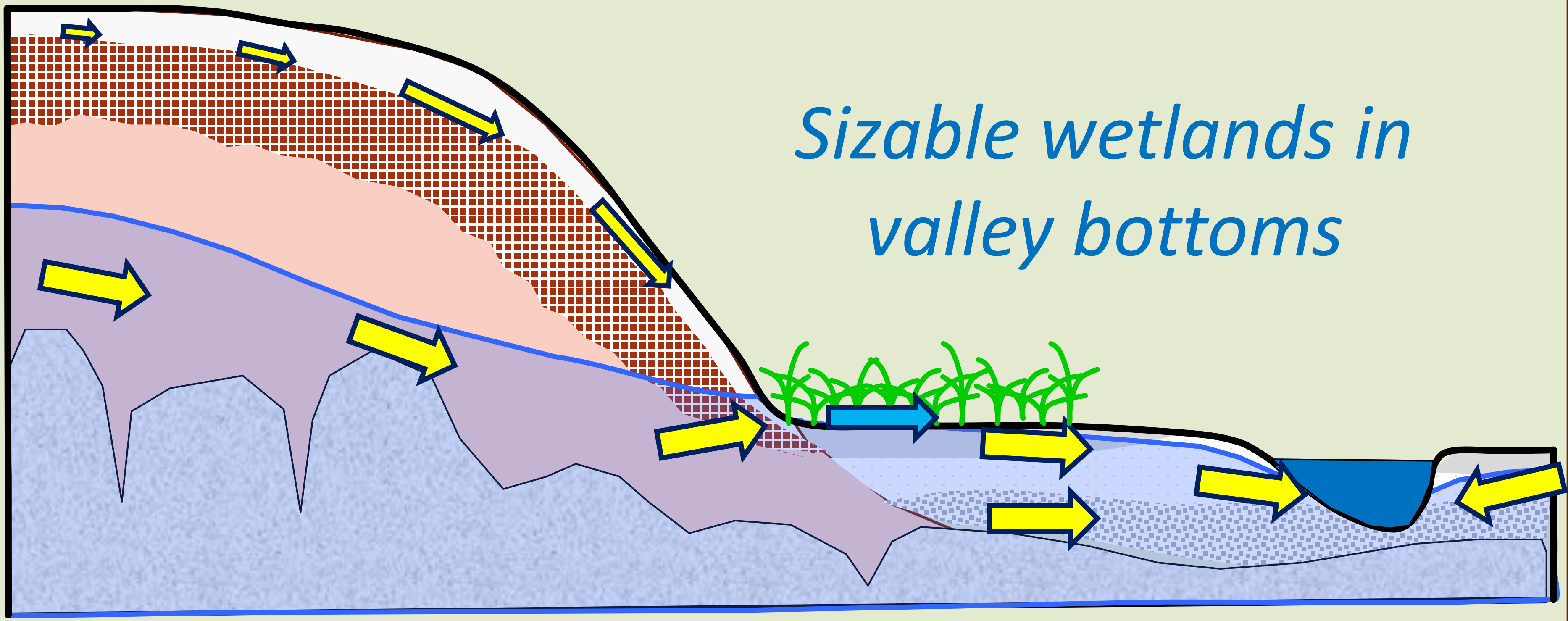


..deeply weathered residual bedrock. Although often very silty, its high porosity holds abundant GW that leaks out via megapores.

Piedmont Landscapes

Alluvium – floodplain, channel

Regolith – saprolite, soil horizons

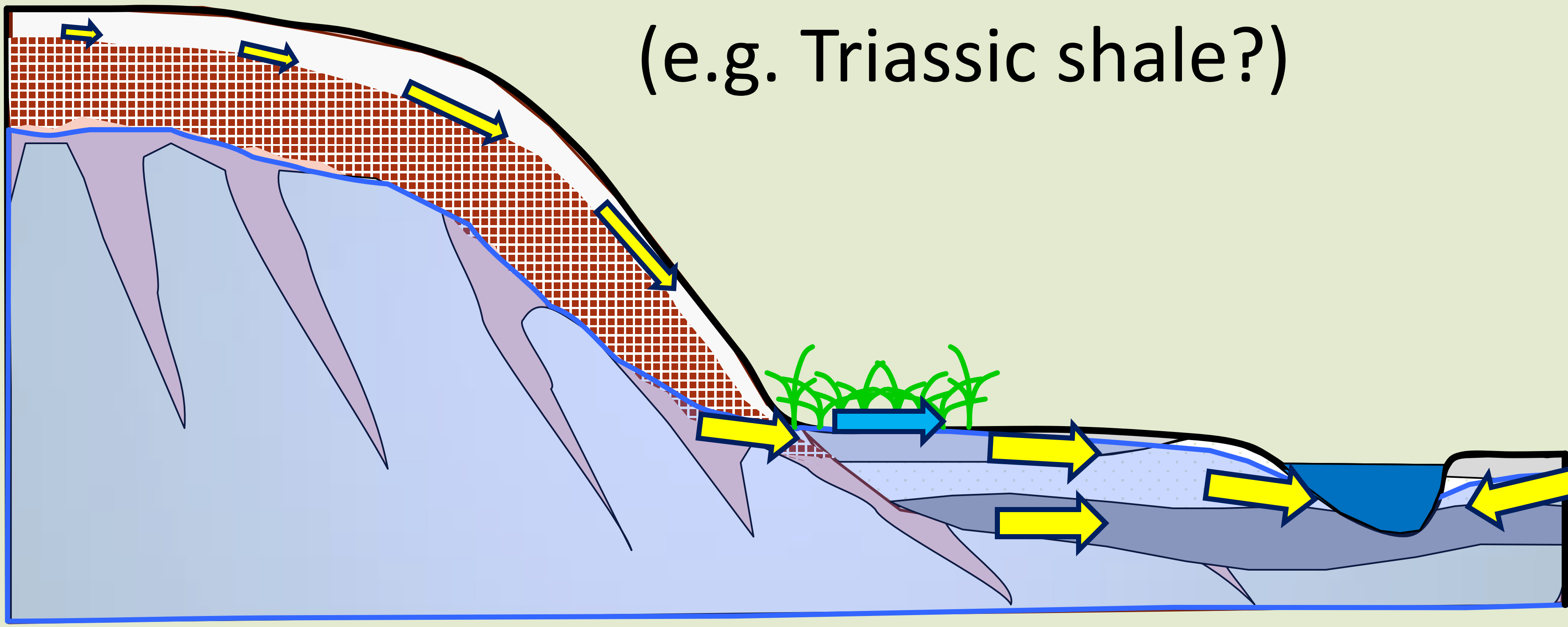


The typical Piedmont wetland commonly has these geologic and hydrologic elements.

Piedmont Landscapes

Alluvium – floodplain, channel

Regolith weathered from ***sedimentary*** rock (e.g. Triassic shale?)

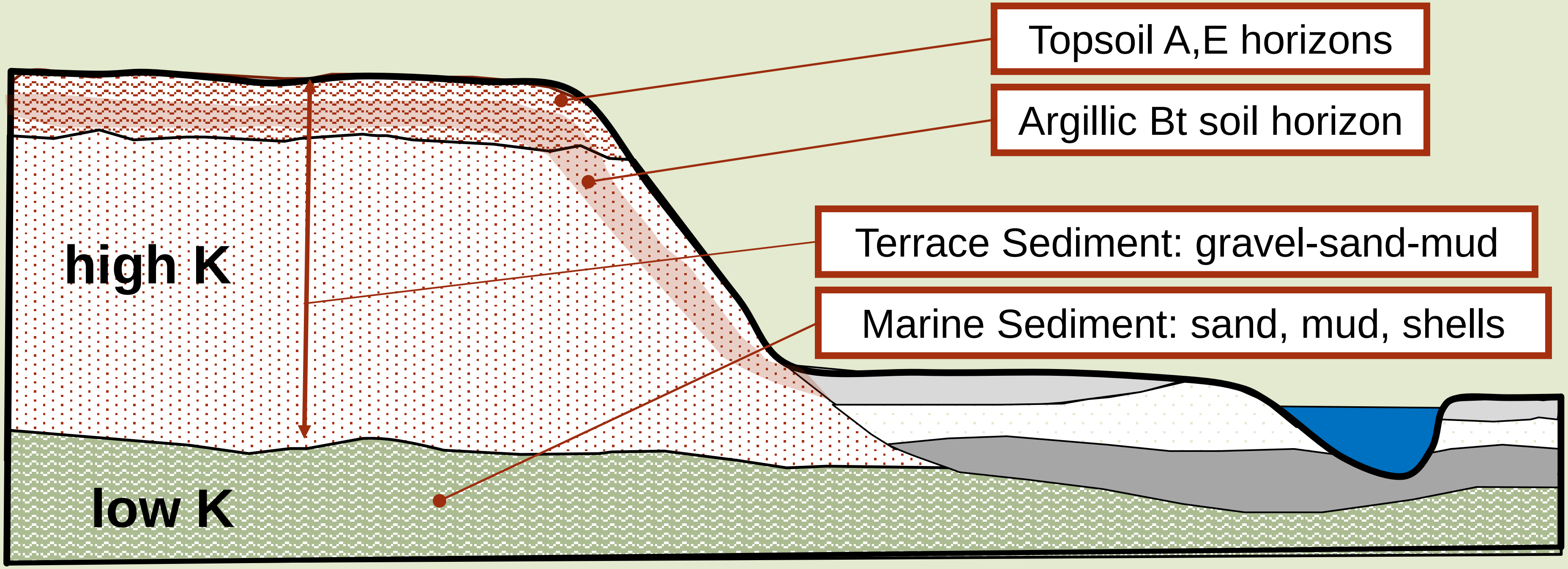


Areas with thin, clayey saprolite and low K soils may have very little GW flow from uplands.

Coastal Plain Landscapes

Alluvium – floodplain, channel

Marine, estuarine, fluvial sediments

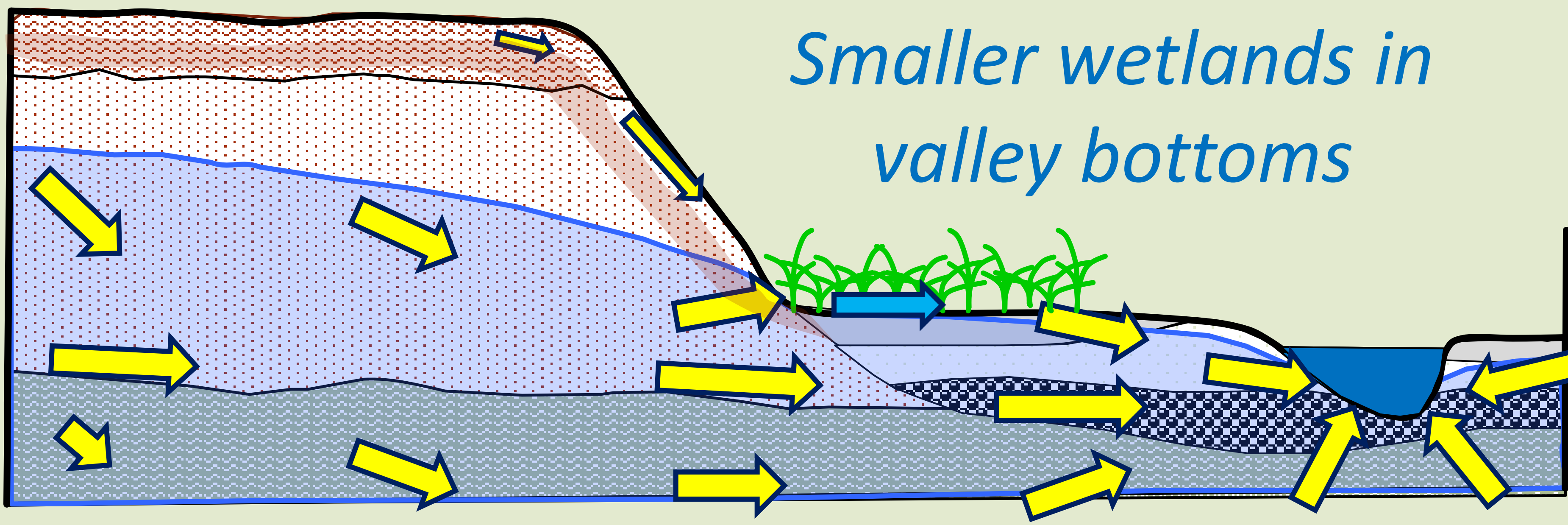


Each geologic setting can have distinctive patterns of permeability that must be understood. On the Coastal Plain of Virginia…

Coastal Plain Landscapes

Alluvium – floodplain, channel

Marine, estuarine, fluvial sediments

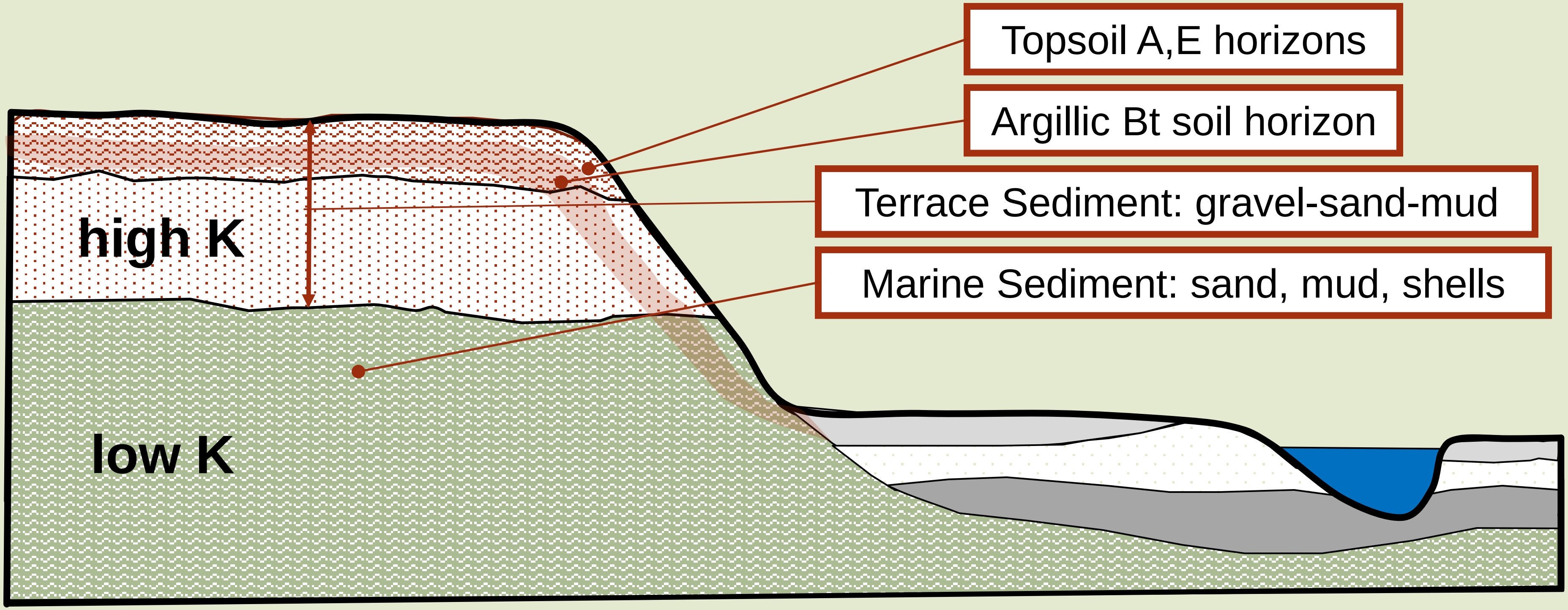


…high K estuary and stream sediments often lie over low K marine sediments to make a relatively permeable landscape.

Coastal Plain Landscapes

Alluvium – floodplain, channel

Marine, estuarine, fluvial sediments



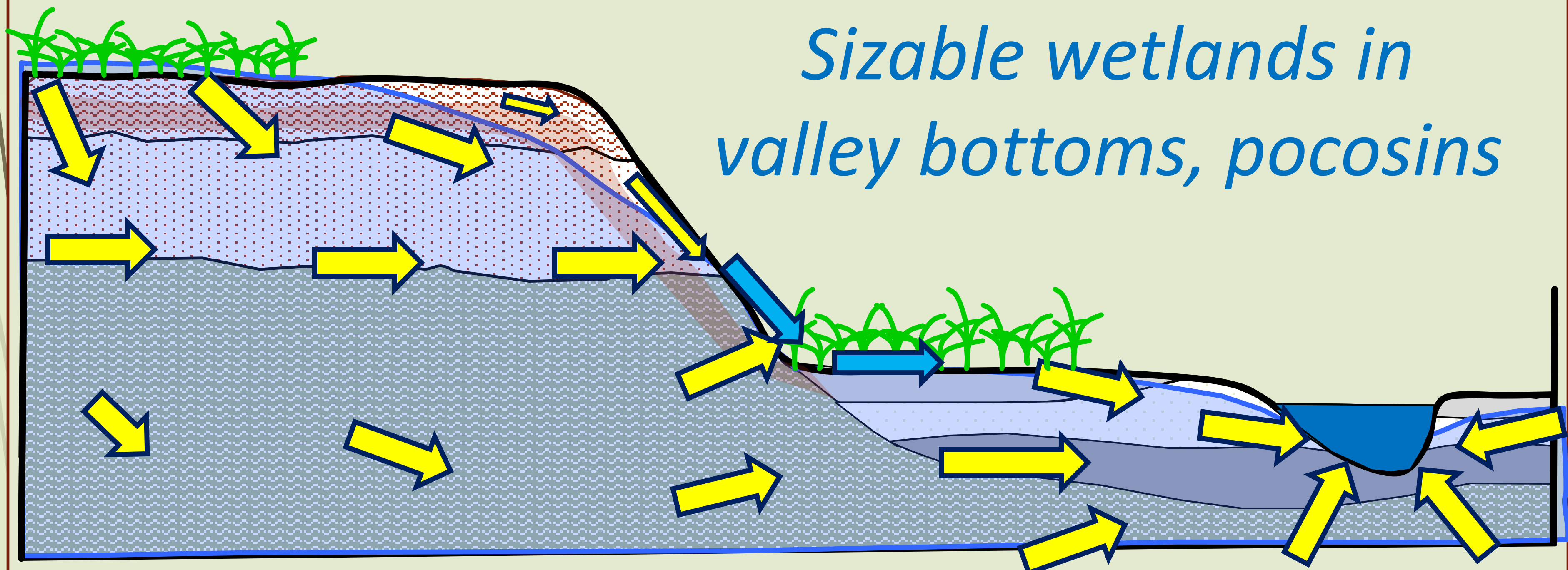
Where high K surface beds are relatively thin over lower K beds under the uplands…

Coastal Plain Landscapes

Alluvium – floodplain, channel

Marine, estuarine, fluvial sediments

Sizable wetlands in valley bottoms, pocosins

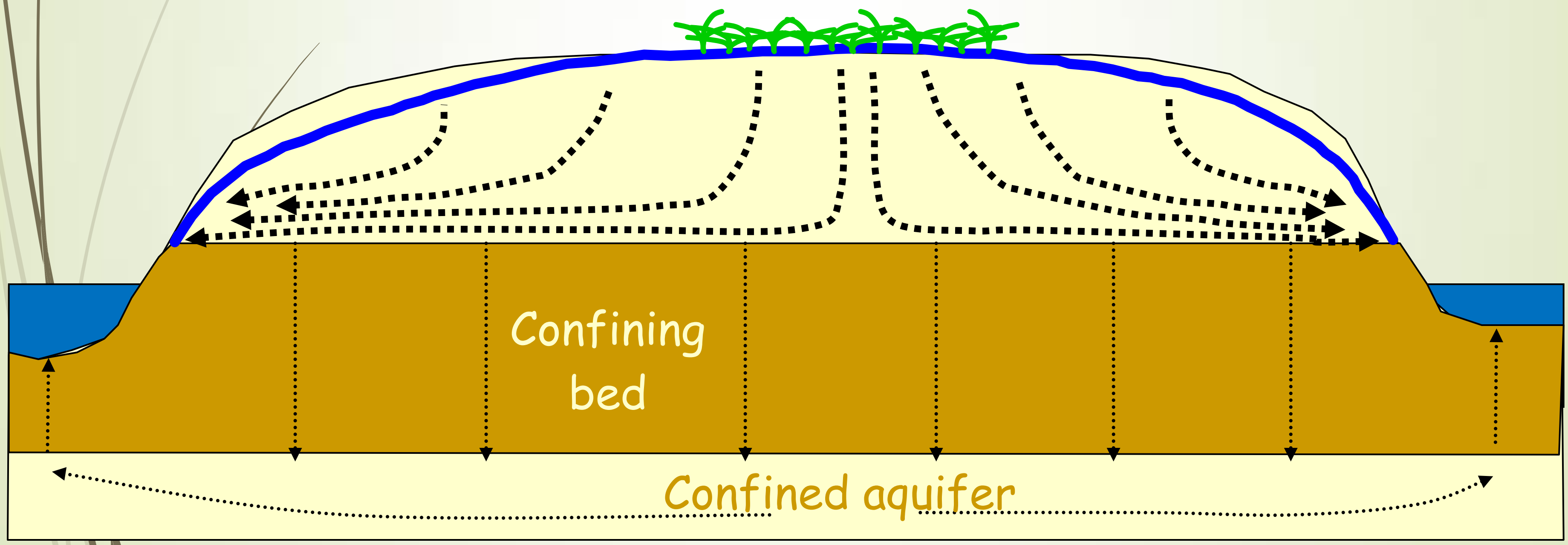


... pocosins form on interfluves and slope wetlands develop where springs drain from the bottom of surficial aquifers.

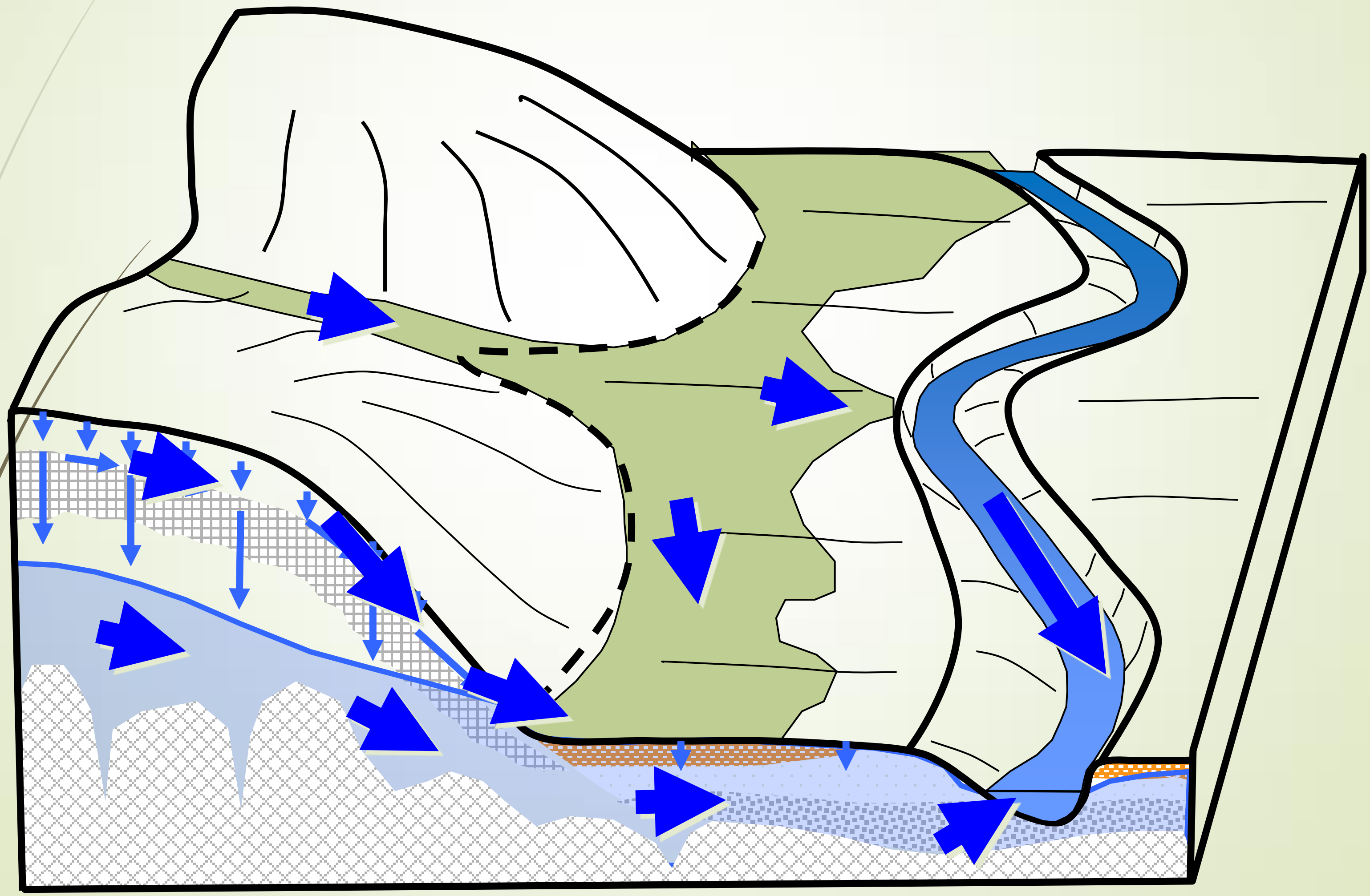
Precipitation forms GW Domes

Recharge soaks into the surface aquifer and flows down and laterally to streams

Wetlands form in the middle of the peninsula where the water table rises to the surface



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



Groundwater Considerations

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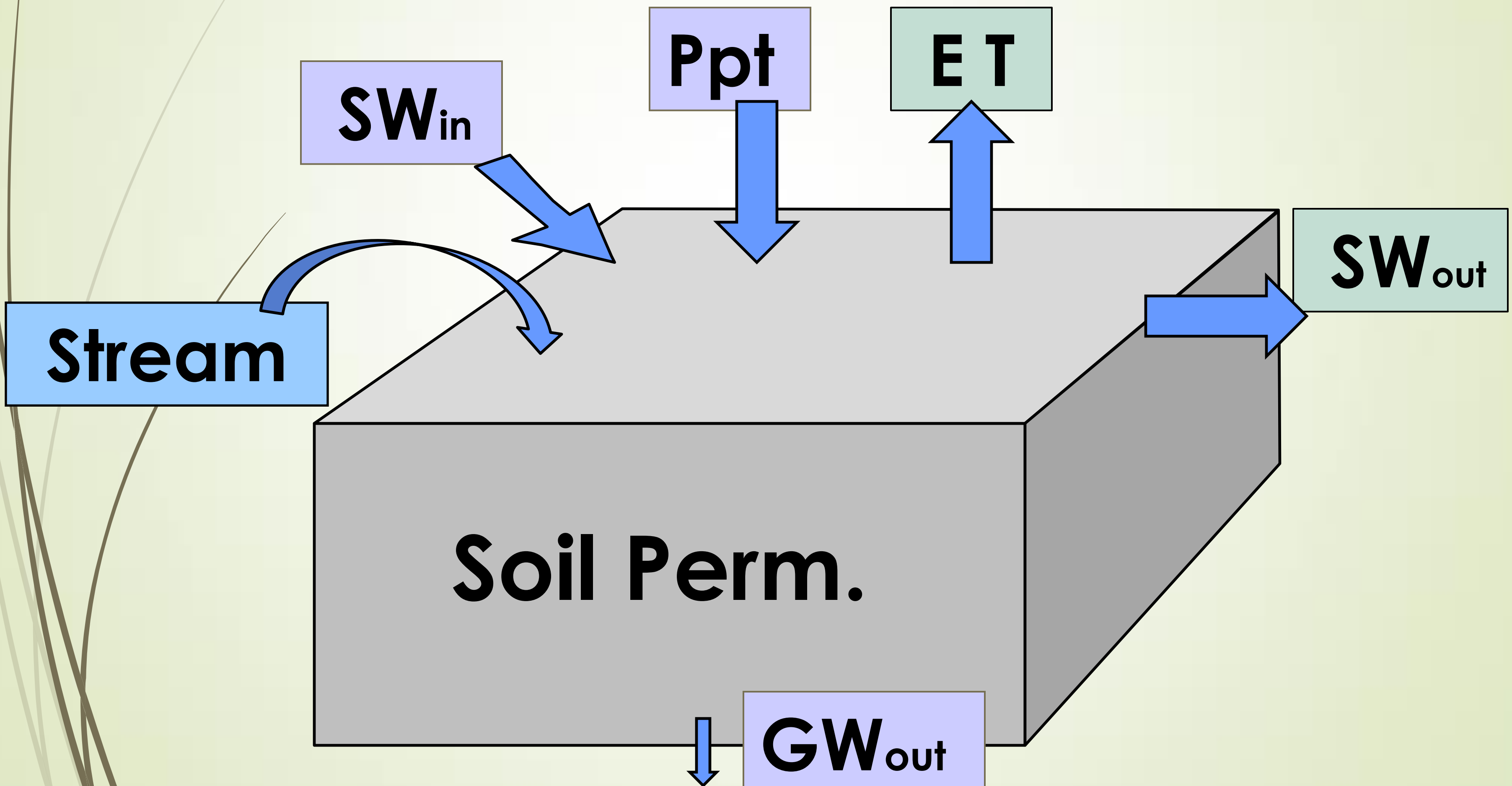
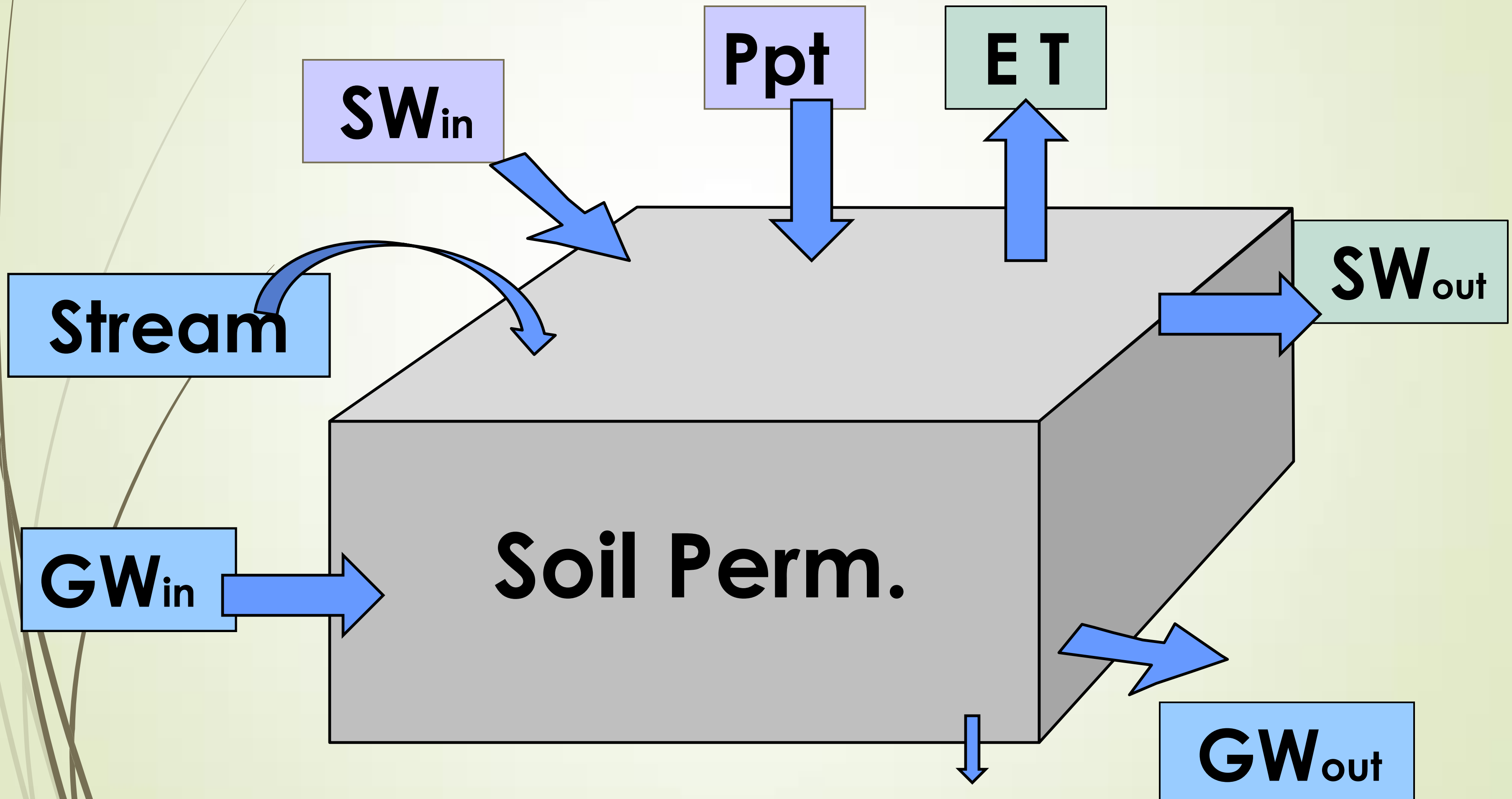
3. New calcs: WND and W_{em}
4. Example applications

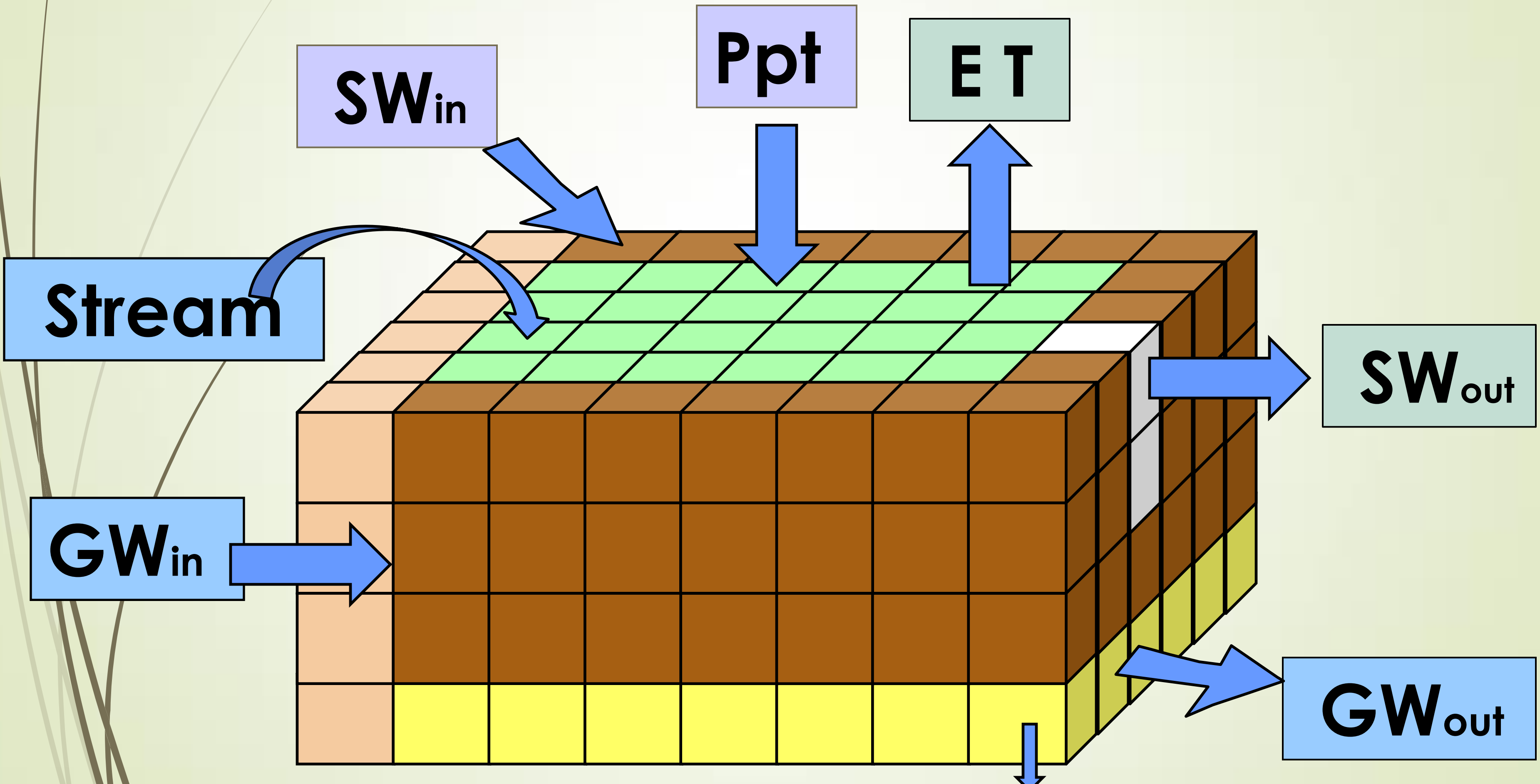
Pierce's model for depressional wetlands: allows only a constant downward GW seepage out



Wetbud Basic Version: allows GWin, GWout, seepage down

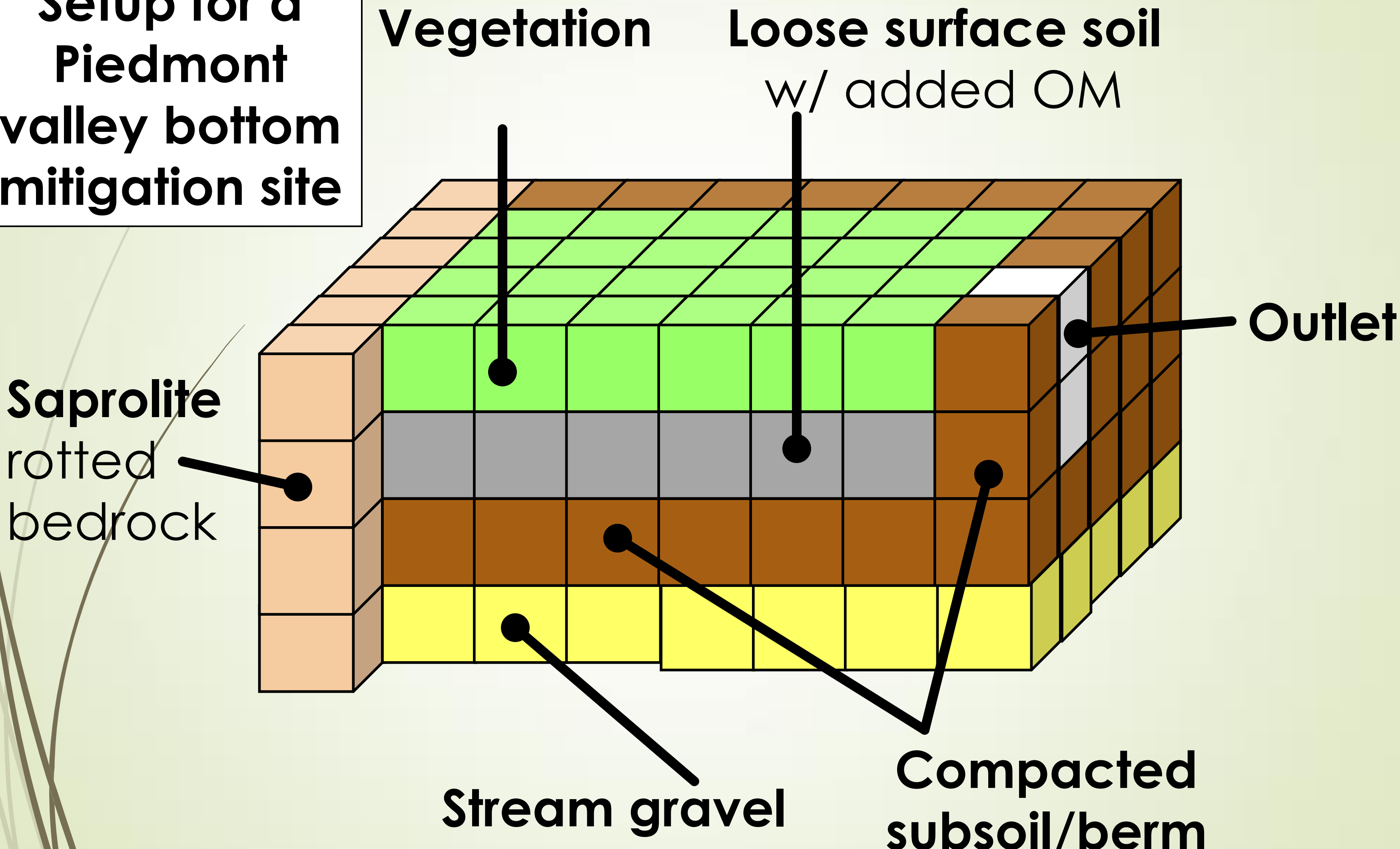


Wetbud Advanced Version: allows GWin, GWout, seepage down…

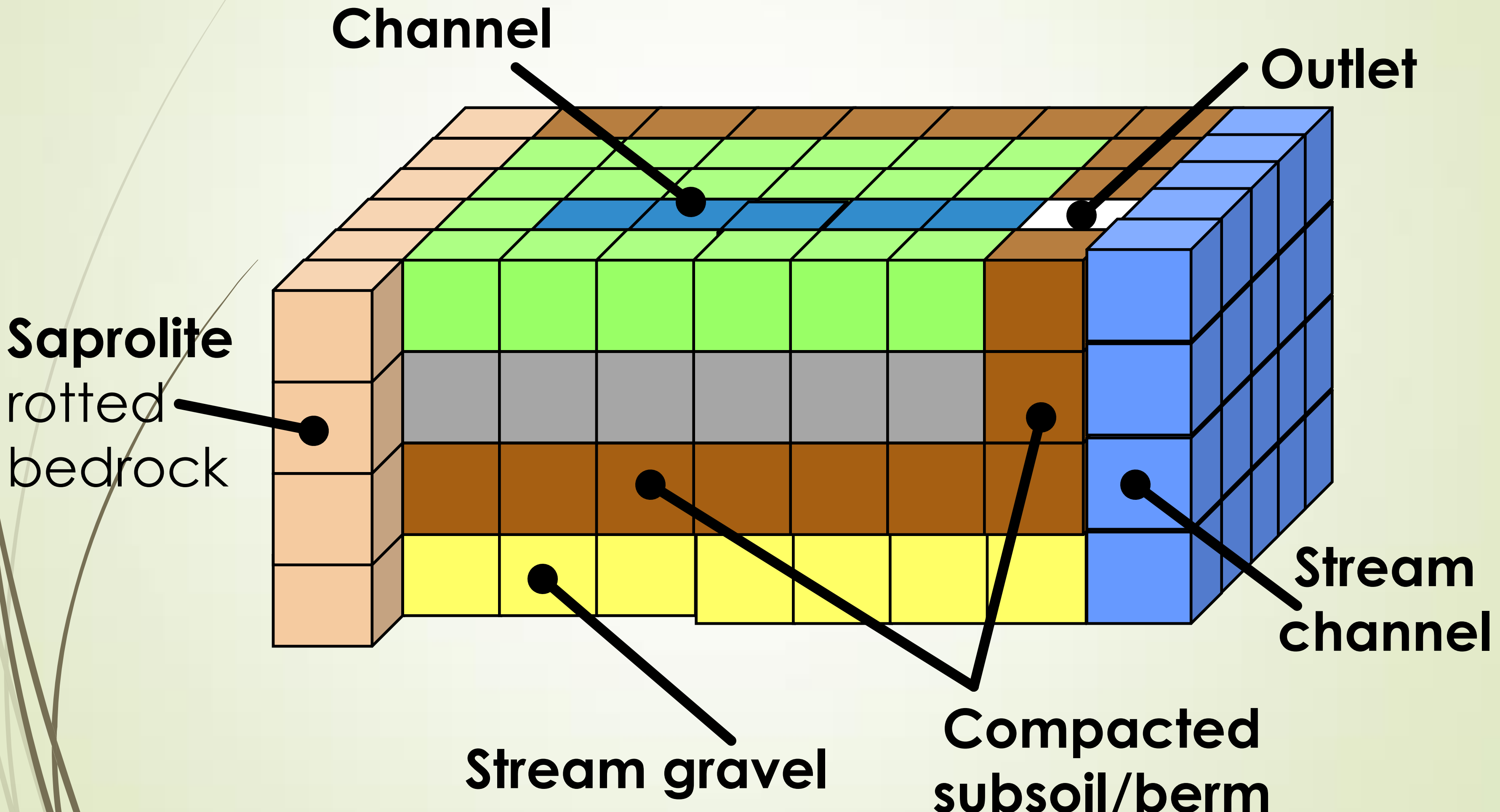


…plus complex geology, and…

Setup for a Piedmont valley bottom mitigation site



…surface slopes, internal channels, cells, streams, etc.



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

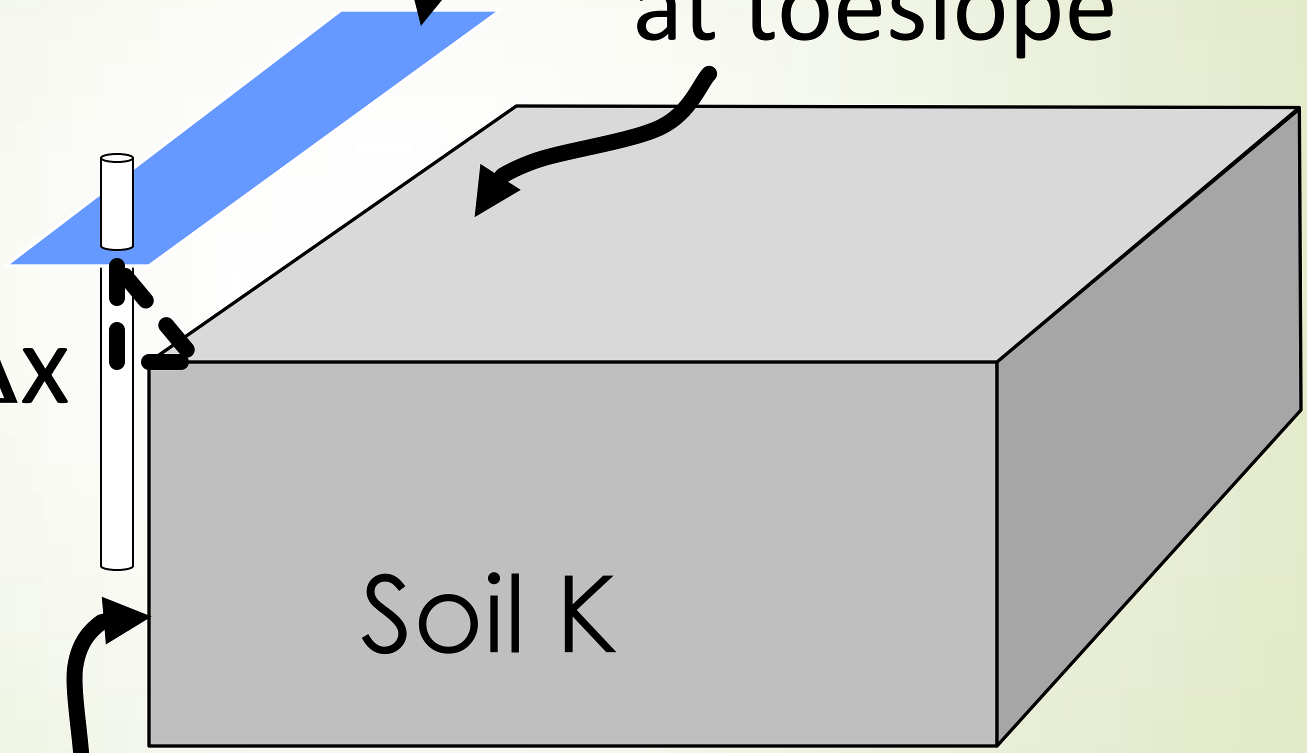
$$GW_{in} = K \; A \; \Delta h/\Delta x$$

(for Month B)

Water level in aquifer estimated by W_{em} calc'ns

Ground level at toeslope

$\Delta h/\Delta x$



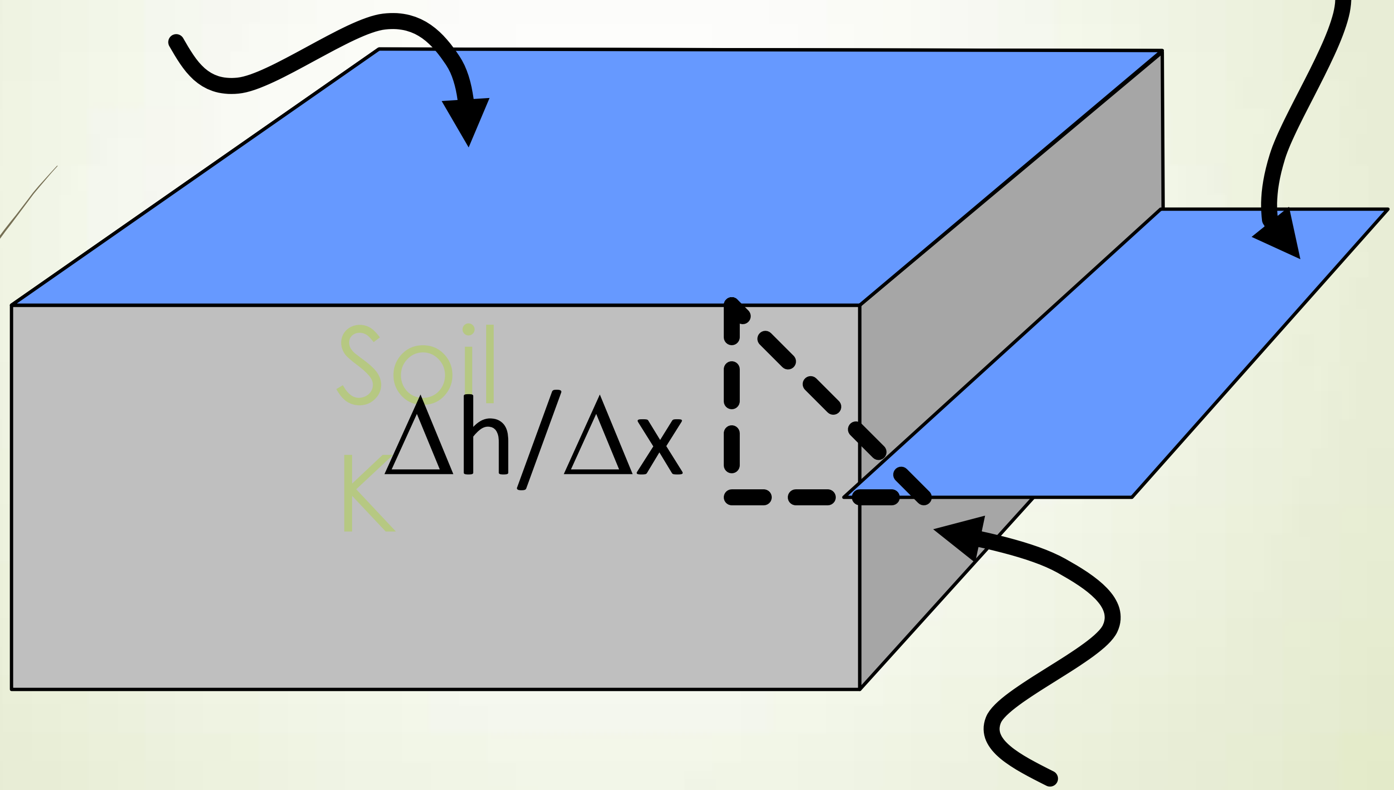
A: cross-section of uphill end

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

(for Month B)

Water level at end of Month A

Water level below outlet



A: cross-section of downhill end

Groundwater Considerations

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Is a specific **month** WET, NORM, or DRY ?

30%	40%	30%

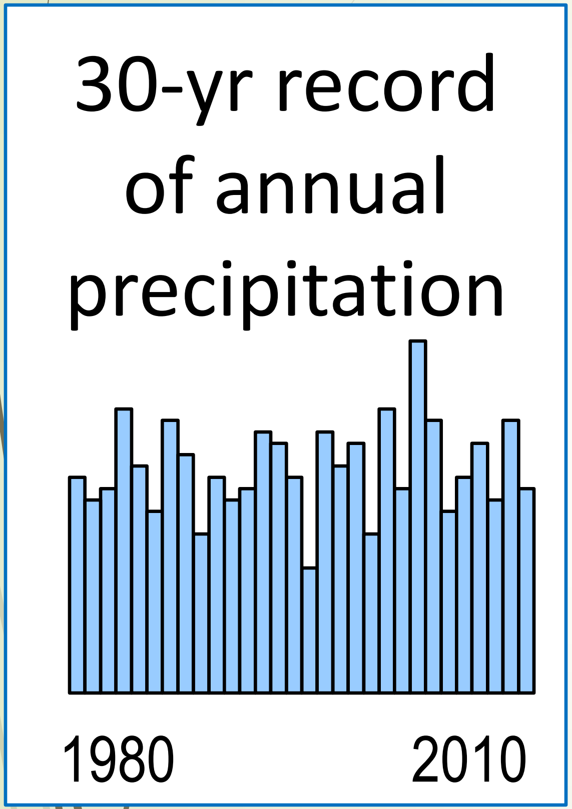
30 years of precipitation data at representative station

Determined for each month

Data available on a WETS table

Determine WND **years** w/ WETS tables:

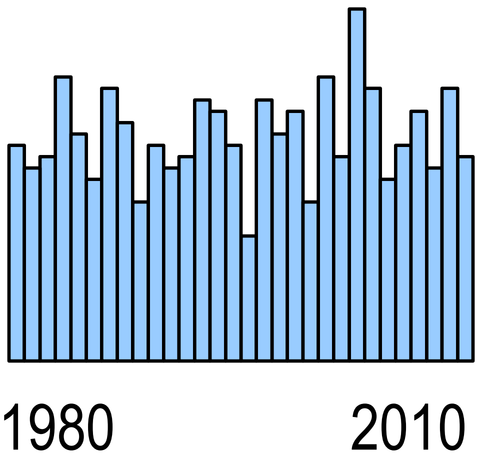
#1: Which years have WET (or DRY or NORM) total ppt?



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

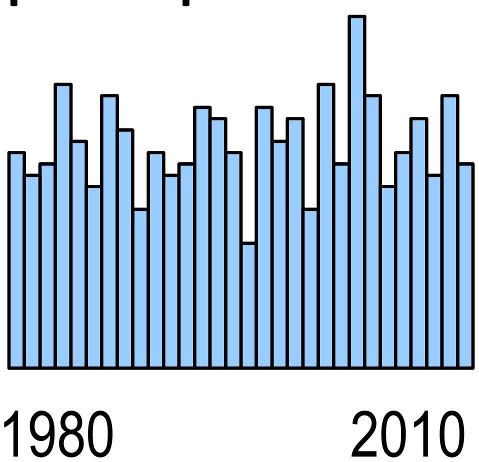
Rank order annual ppt. values

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	D	W
2	1	3
x1	x2	x3

2+2+9=

13

(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

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

Building Wetbud Model(s)

1. Create Project and Scenario

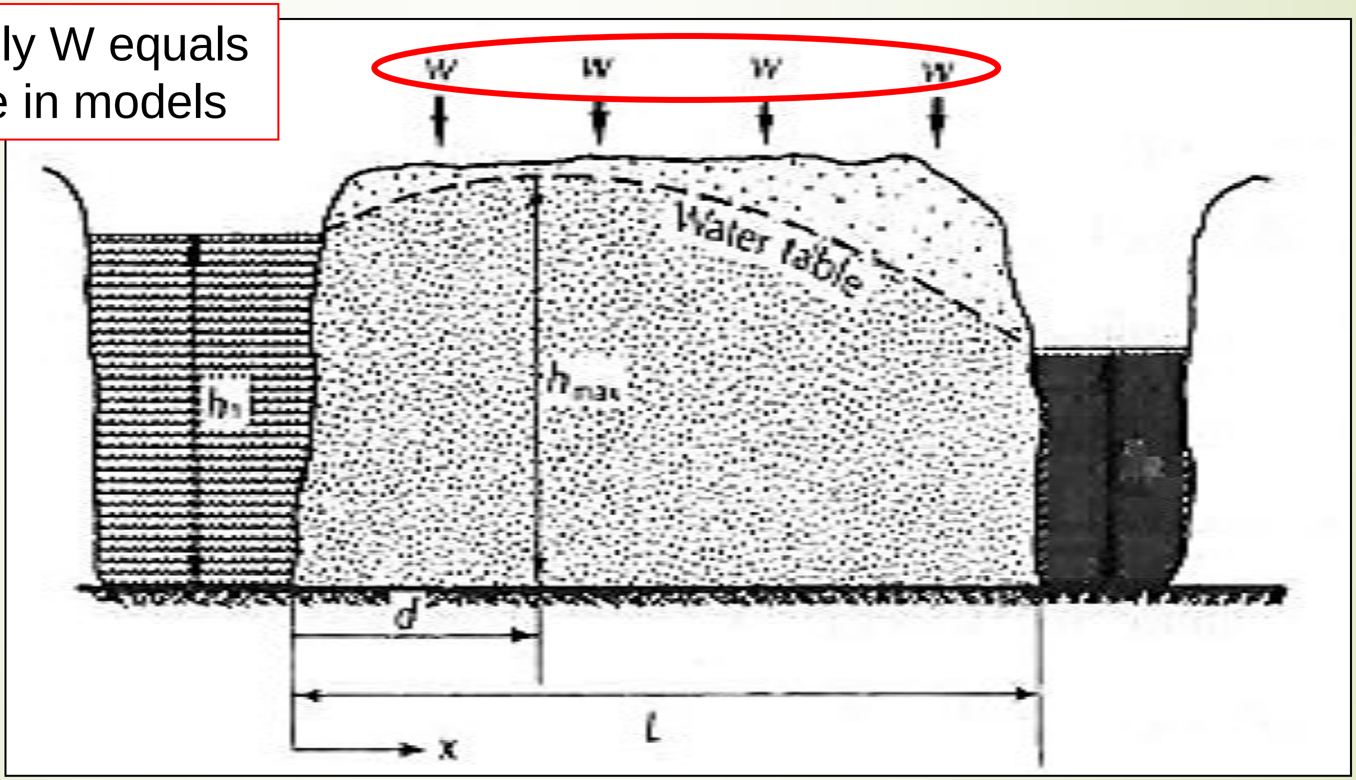
You need an estimate of the heads in the uphill aquifer for years long before you put in your monitoring wells. Wetbud uses the Effective Monthly Recharge procedure (W_{em}) to make those estimates.

3. Input GW_{in} or calculate using W_{em} (well data)
4. Input or calculate Gw_{out}
5. Input or calculate overbank flow

W_{em} = “Effective Monthly Recharge”

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

Traditionally W equals Recharge in models



Fetter, 1999

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 (D<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

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

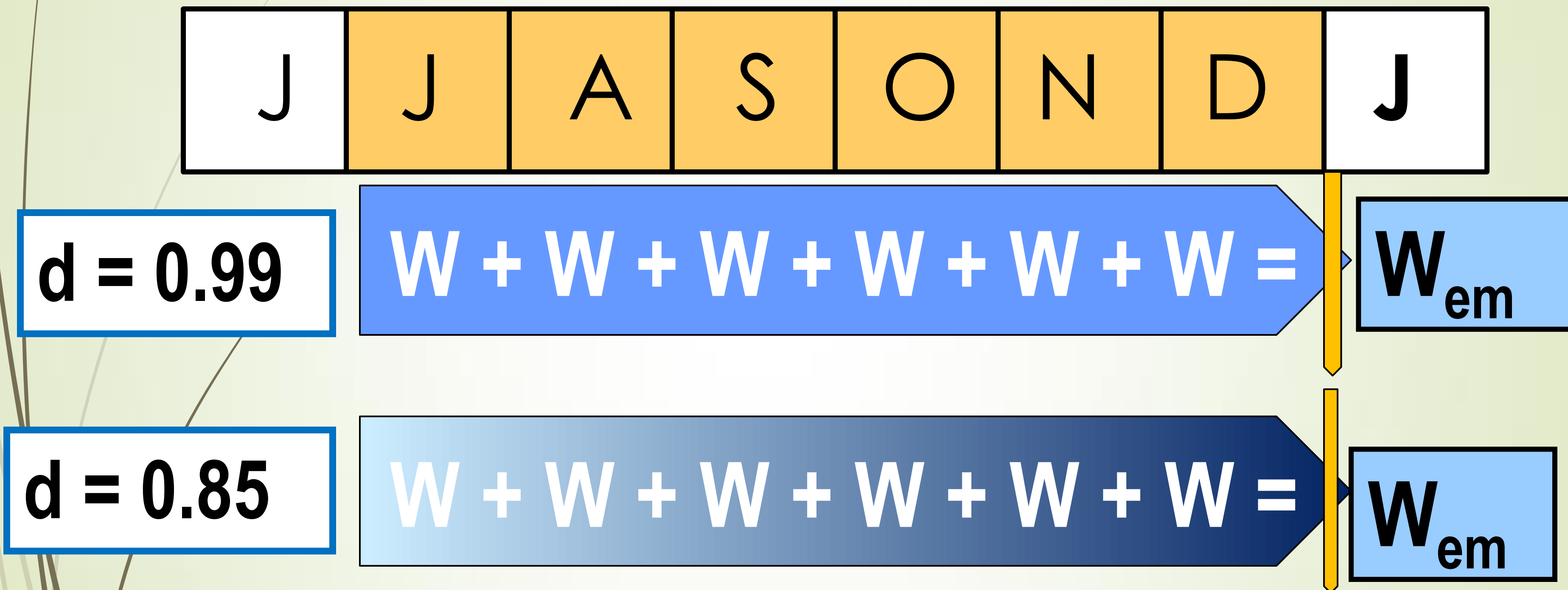
How much influence do past months have on water levels in Month A?

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

d = 0.99 W + W + W + W + W + W = W_{em}

d = 0.85 W + W + W + W + W + W = W_{em}

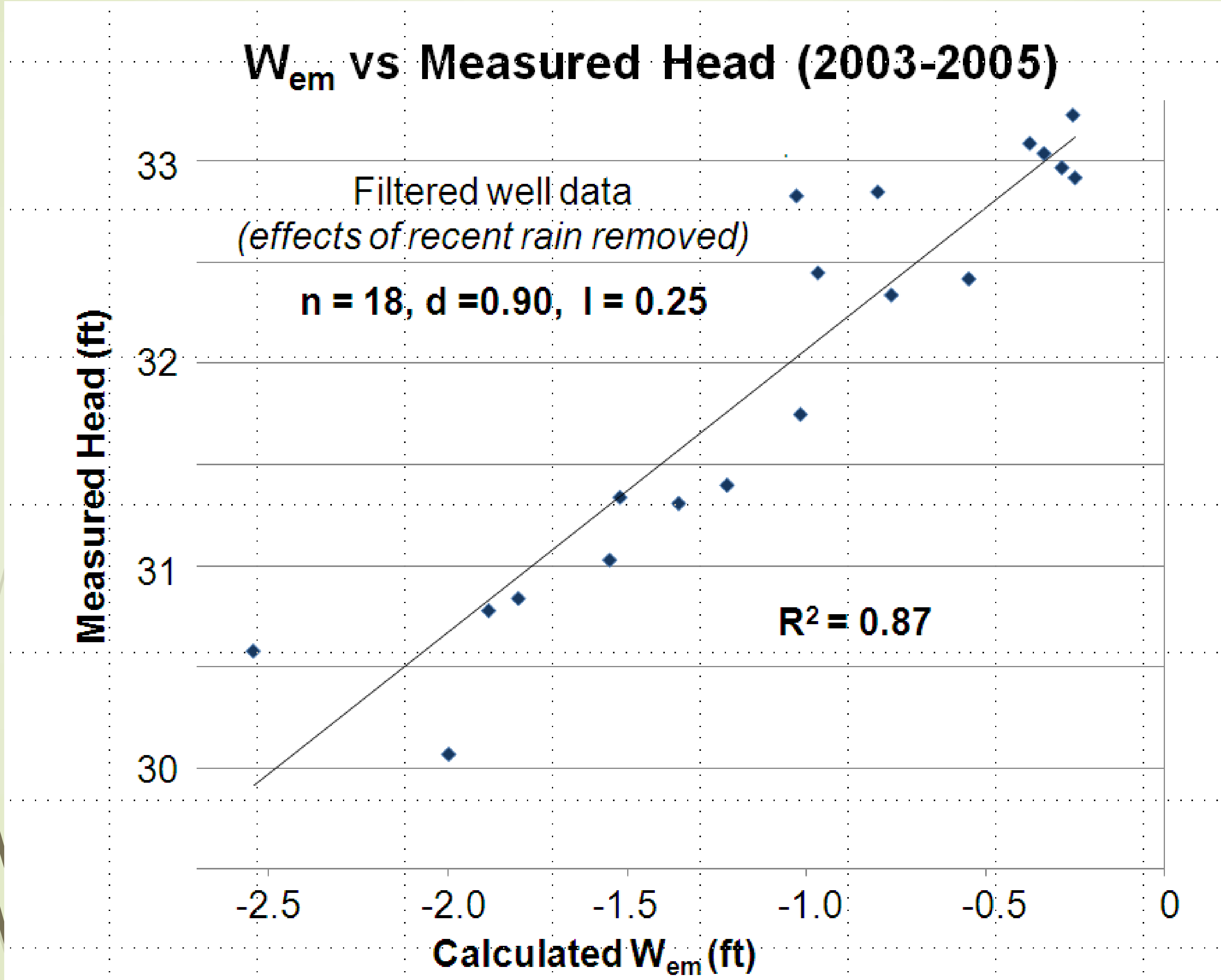
How much influence do past months have on water levels in Month A?



Must run every combination of N and D to find the best for prediction

The PATTERN over time of W_{em} values calculated for a series of months (using one N, one D) is compared to the PATTERN over time of first-of-the-month water levels (heads) measured during the same months.

For each N-and-D combination, the W_{em} values and heads for each month are compared with linear regressions…


W_em 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 W_em (ft)

Matrix of correlation coefficients (R^2)

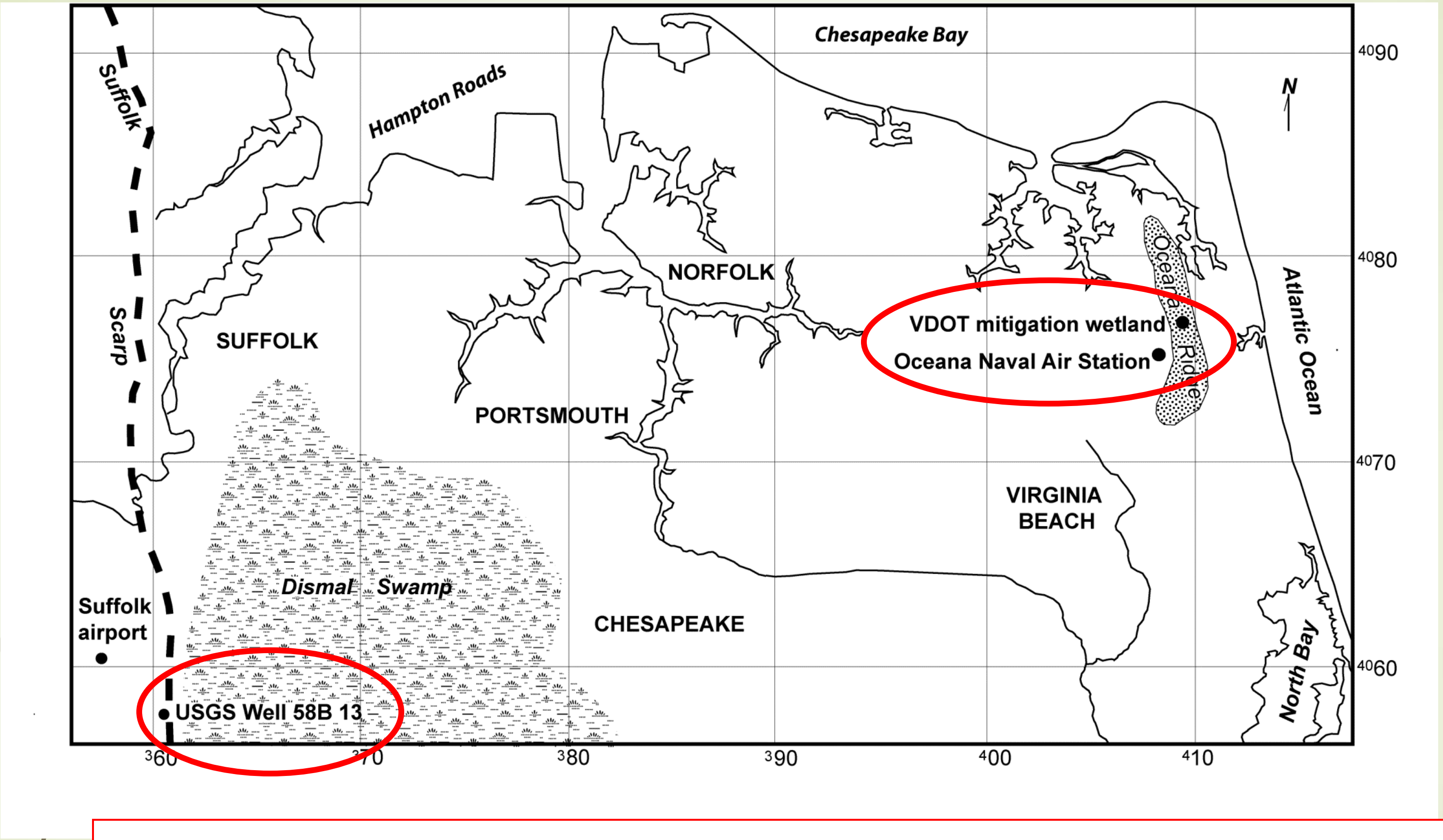
…and the combination of N-and-D with the highest R^2 values is used in the "calibrated W_{em} equation"

d: response-decay factor

n: # of antecedent months

n \ d	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

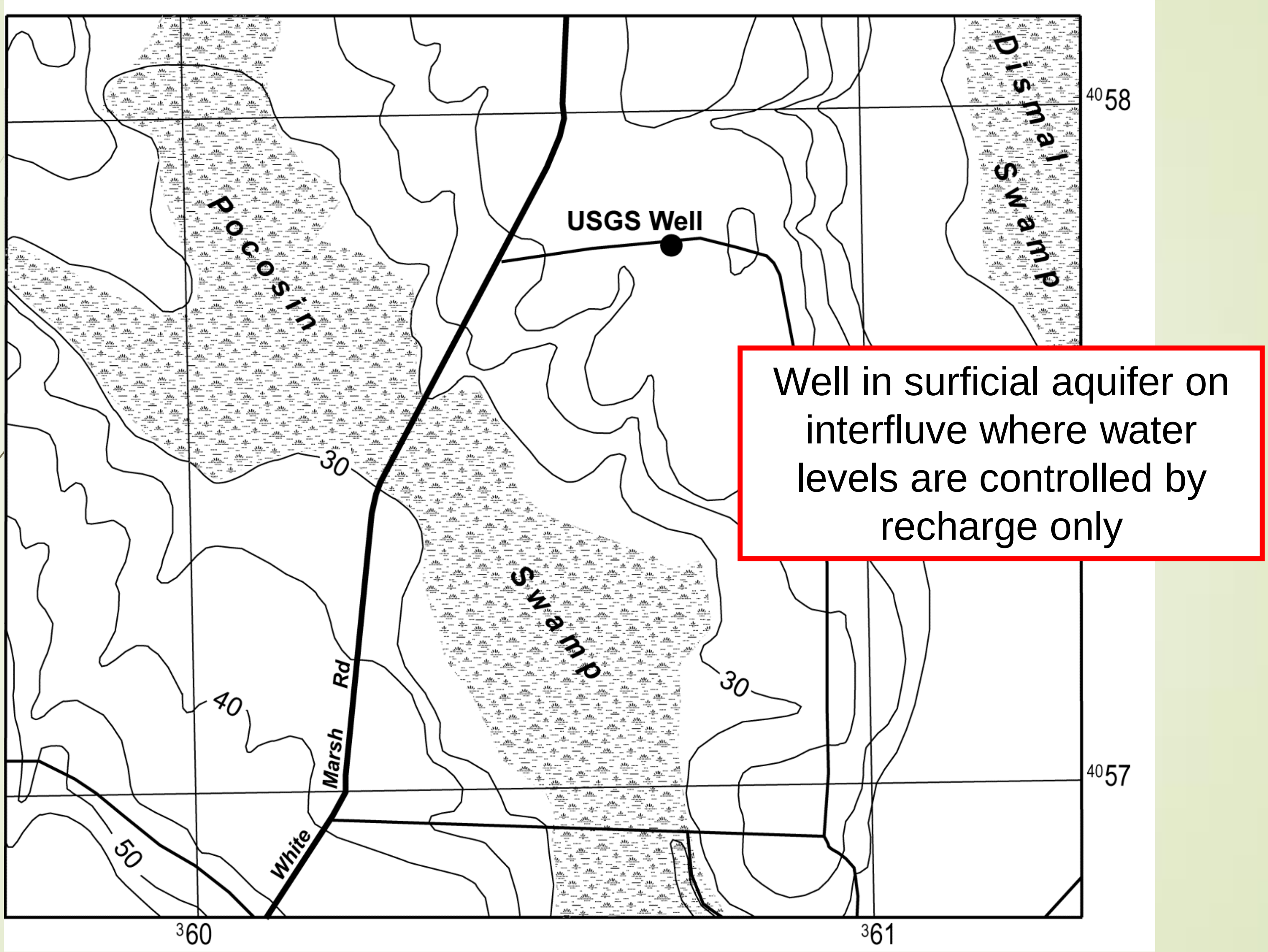
Verification of W_{em} Calculations



Locations of two studies with data used to verify that the W_{em} procedure can accurately predict monthly water levels from weather data

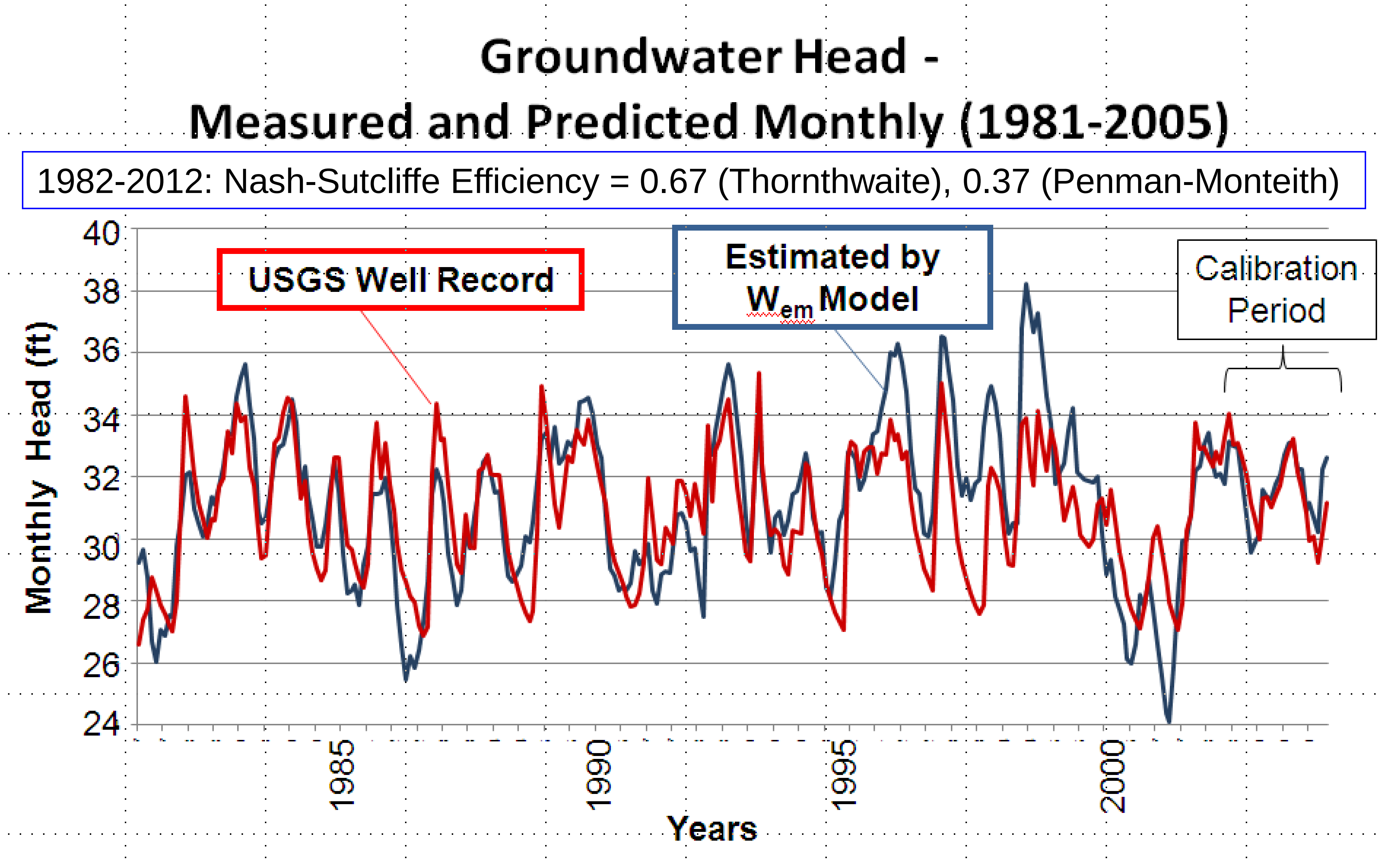
Whittecar and others (in review)

Verification of W_{em} Calculations



Whittecar and others (in review)

Verification of W_{em} Calculations



Whittecar and others (in review)

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

Get readings from the widest possible range of WT levels (dry to wet)

Whittecar and others (in review)

W_{em} = "Effective Monthly Recharge"

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

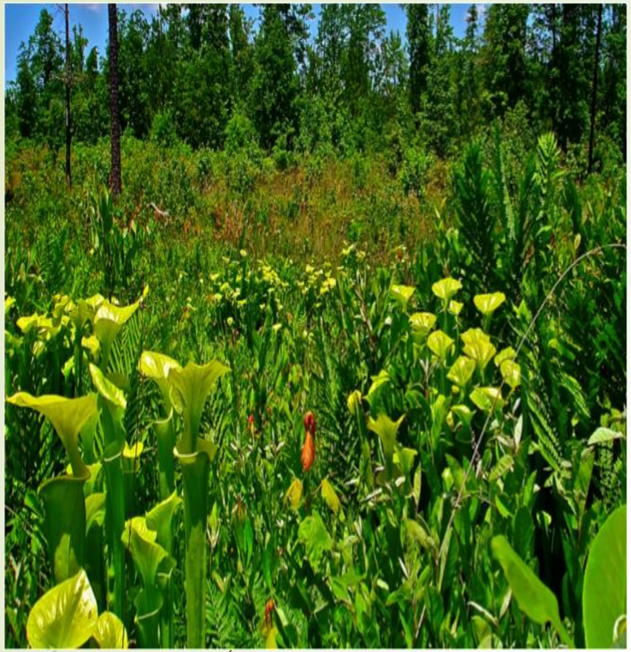
Routinely use both Thornthwaite and Penman-Monteith ET methods

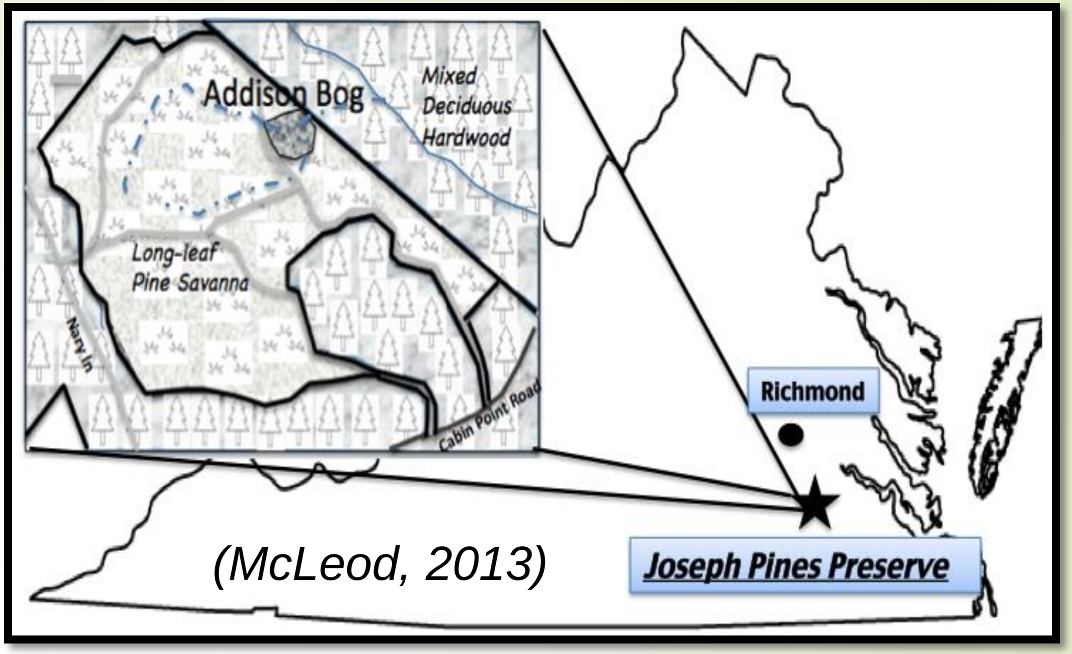
Can reconstruct GW levels using weather data for times with no well data

Whittecar and others (in review)

Groundwater Considerations

1. Landscape and Geology
2. How and where GW used
3. New calcs: WND and W_{em}
4. **Example applications**

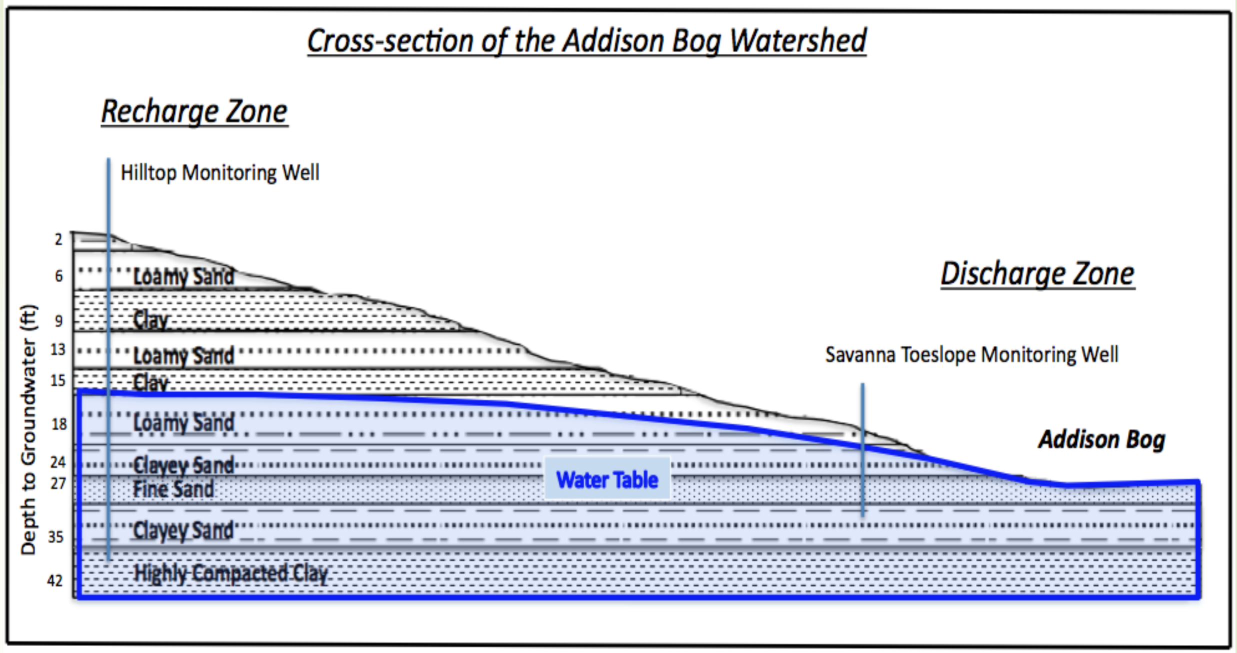



Addison Bog
Mixed Deciduous Hardwood
Long-leaf Pine Savanna
Cabin Point Road
Richmond
Joseph Pines Preserve
(McLeod, 2013)

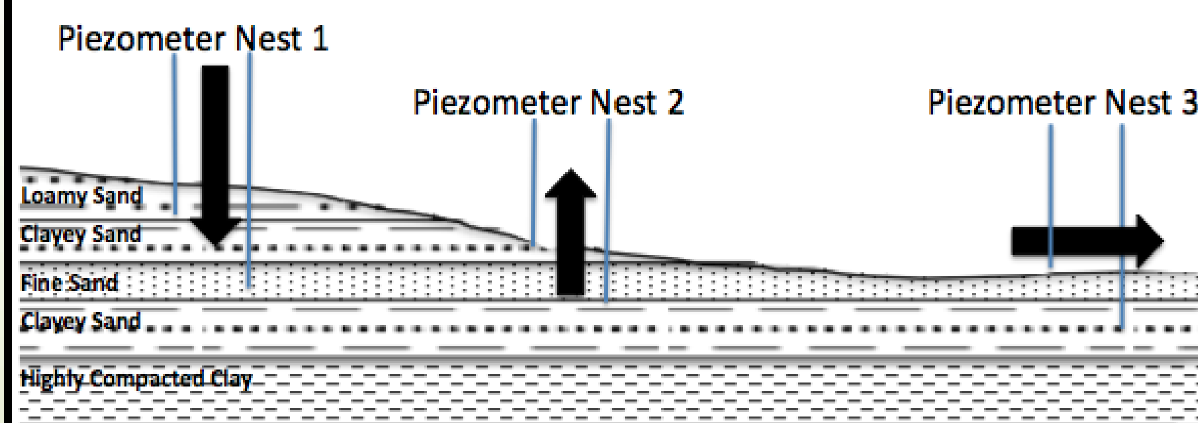
Joseph Pines Preserve

(McLeod, 2013)

Site of restored long-leaf pine savanna and pitcher-plant habitats



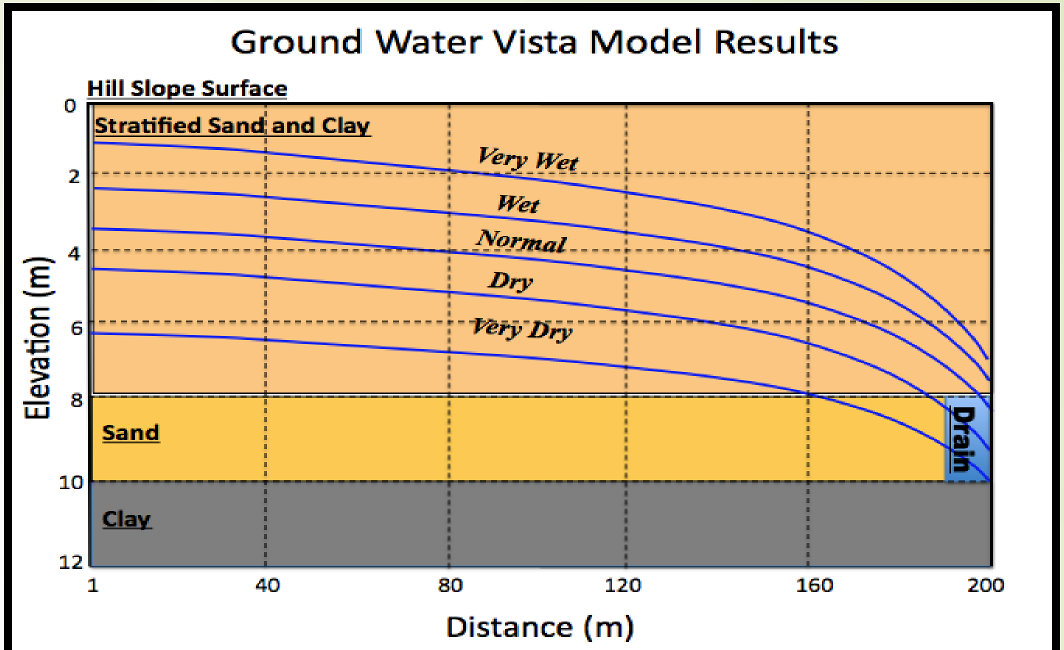
Head Elevations						
	Piezometer Nest 1		Piezometer Nest 2		Piezometer Nest 3	
Date	*Short*	*Deep*	*Short*	*Deep*	*Short*	*Deep*
4/21/11	1040.49 m	1040.47 m	1040.20 m	1040.22 m	1040.13 m	1040.13 m
5/1/11	1040.58 m	1040.55 m	1040.27 m	1040.29 m	1040.17 m	1040.17 m
10/12/11	1040.23 m	1040.27 m	1040.16 m	1040.19 m	1040.03 m	1040.03 m



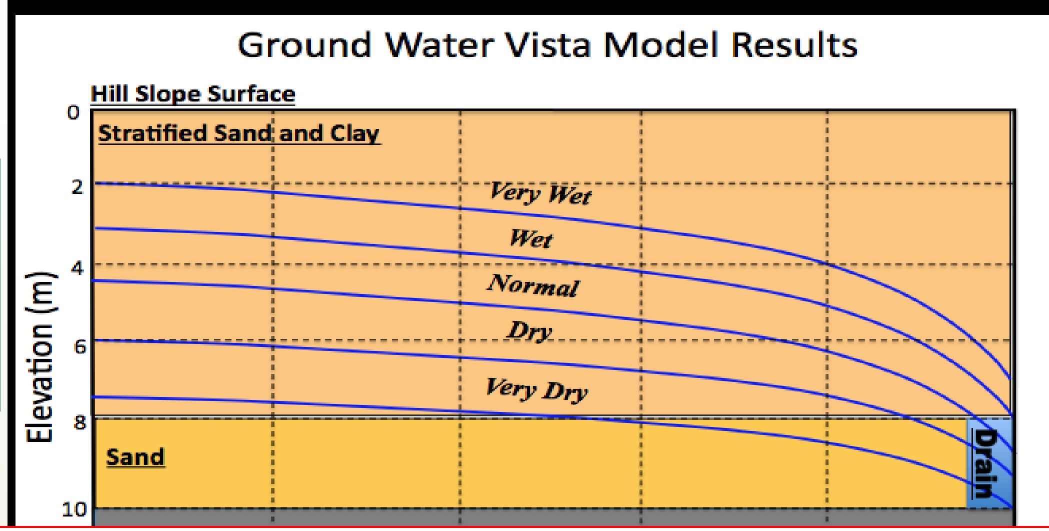
Joseph Pines Preserve

(McLeod, 2013)

Simulation for Longleaf Pine Savanna



Simulation for Loblolly-Hardwood Forest

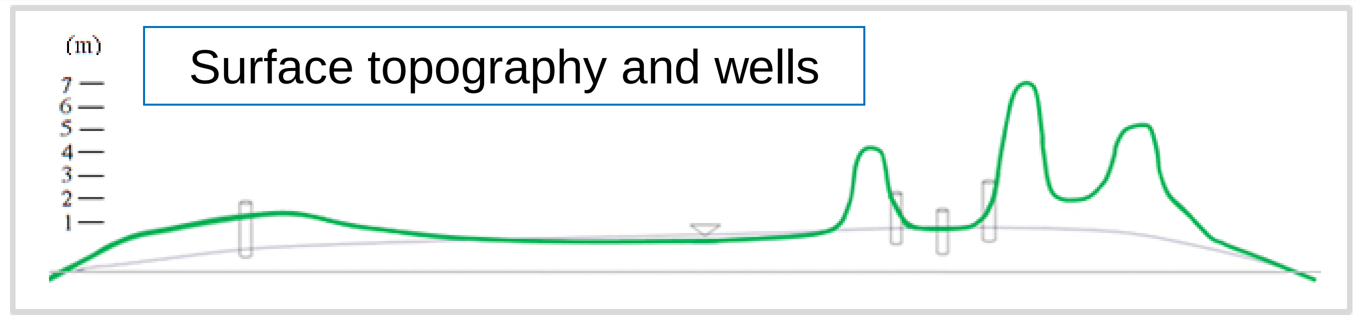


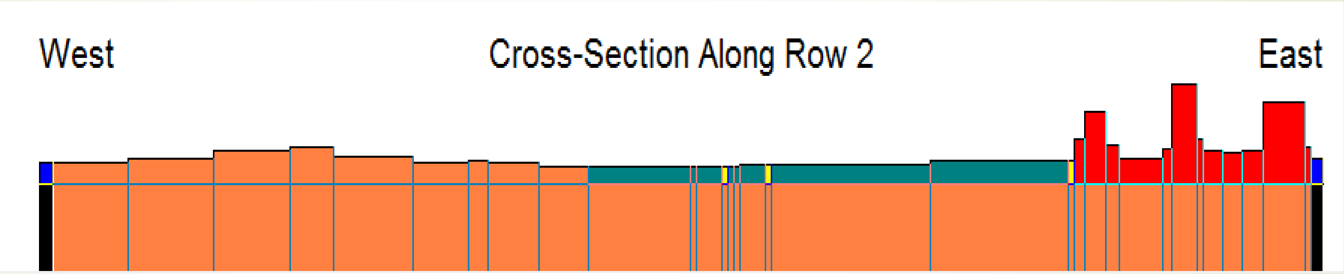
Study used WND procedure to select years of weather data to use in steady-state flow model of GW flow to wetland

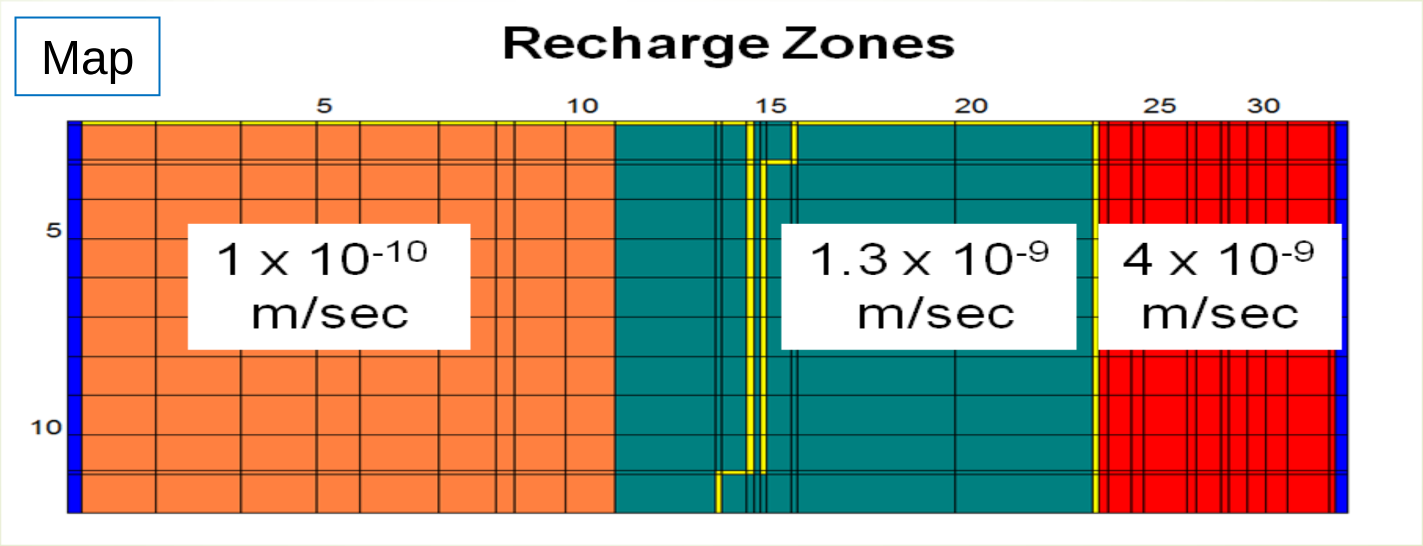
False Cape State Park
(Richardson, 2013)

Interdune swale on barrier island

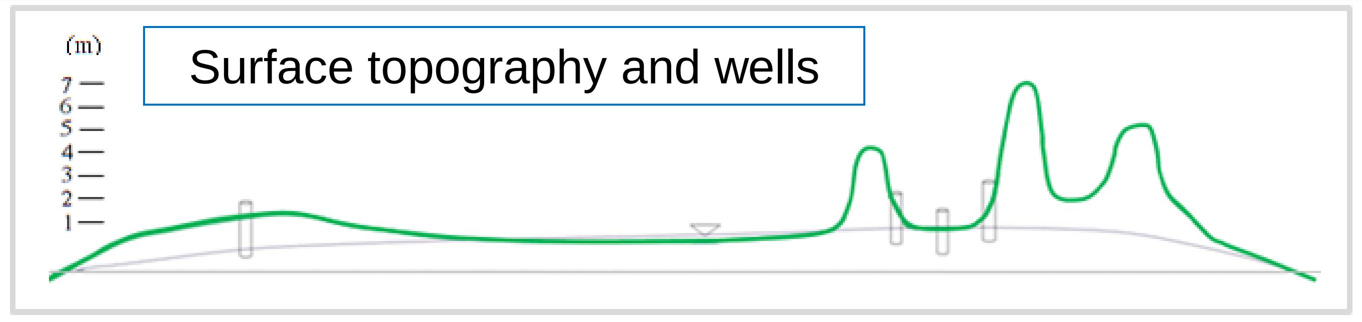
Barrier Island Model Design *(Richardson, 2013)*

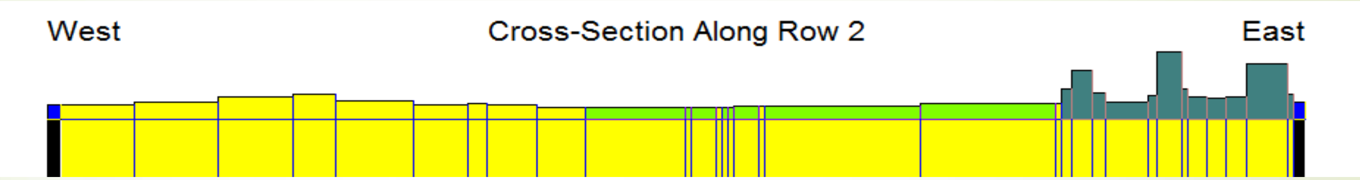




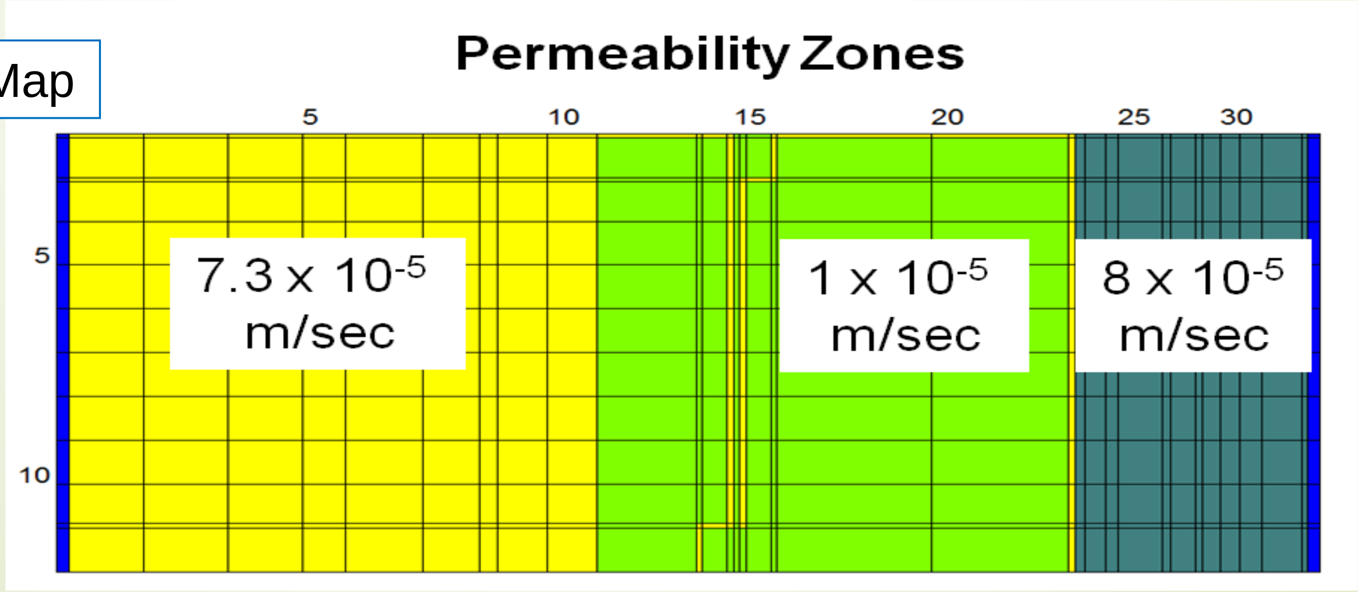


Barrier Island Model Design *(Richardson, 2013)*



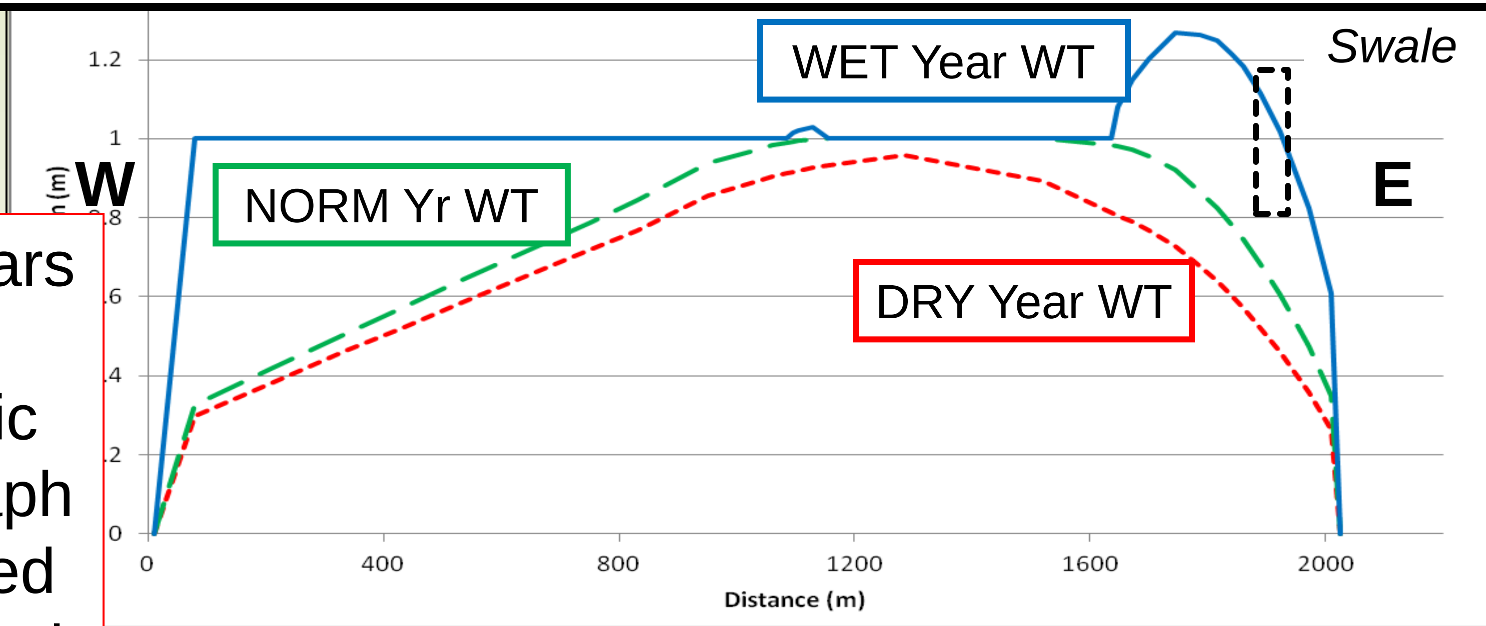


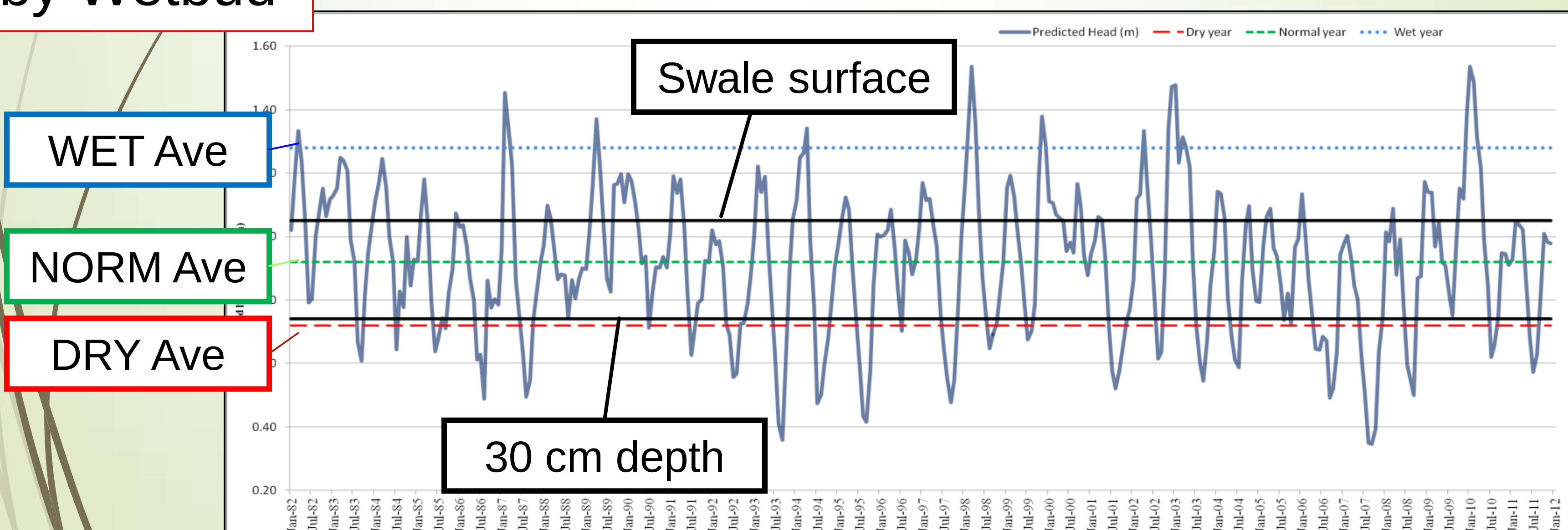
Map



Barrier Island Model Results *(Richardson, 2013)*

WND years and synthetic hydrograph generated by Wetbud





Summary of Conclusions:

Groundwater Considerations

1. Landscape and Geology:

   Wetbud was designed for TOESLOPES; it can work elsewhere, but be careful if you do

2. How and where GW used:

   Drill those uphill monitoring wells!

3. New calcs: WND and W_{em}:

   Congrats – you stayed awake through the formulas!

4. Example applications:

   These new procedures work in many situations