Potential hydrogeological controls on soil health and cropland productivity

This pdf version is annotated with additional thoughts from the author in these white boxes with dark red text.

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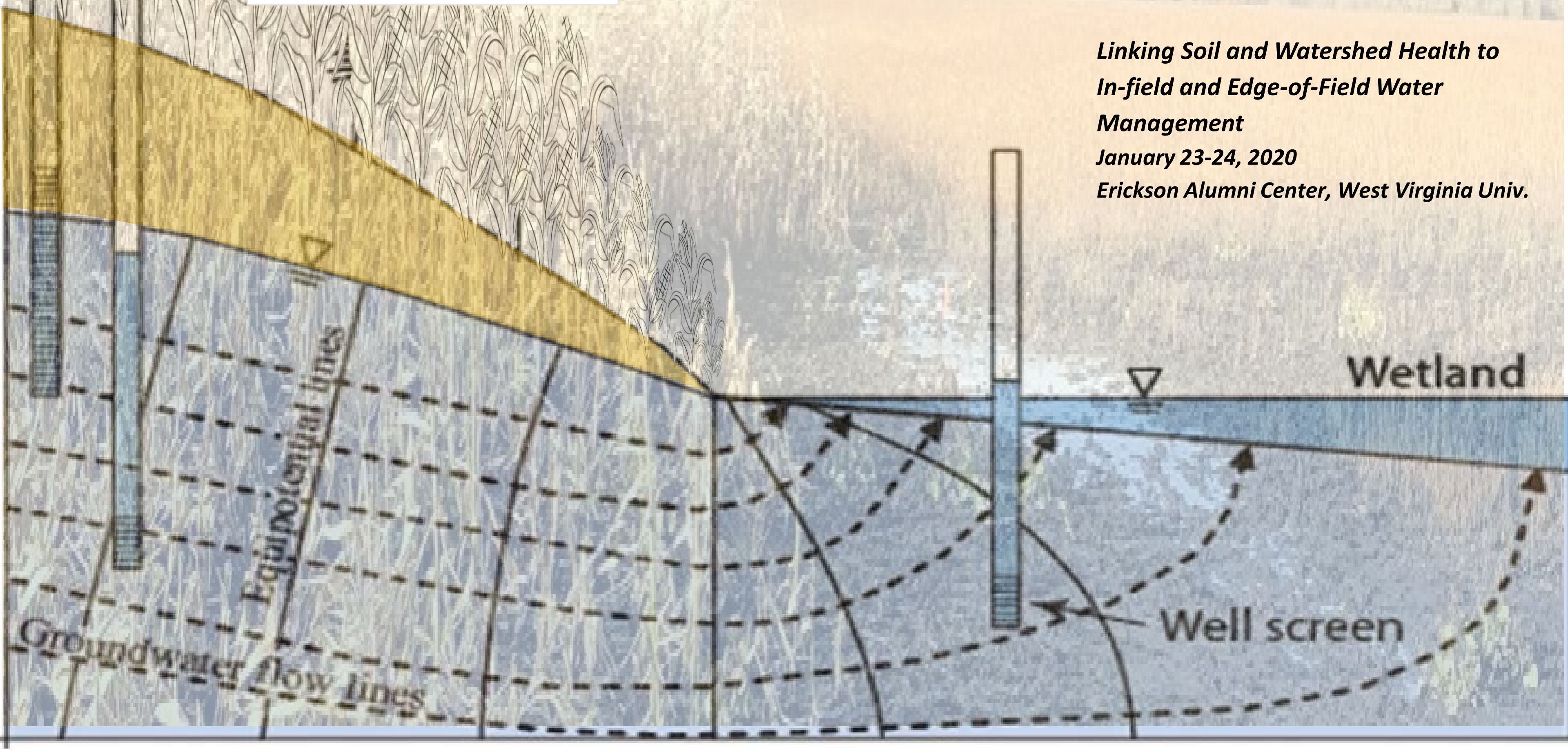
Linking Soil and Watershed Health to In-field and Edge-of-Field Water Management
January 23-24, 2020
Erickson Alumni Center, West Virginia Univ.



Some thoughts about groundwater relevant to this workshop

- Preventing waterlogging was main topic (top down more than bottom up)
- Not much about GW flow (*K* and *i*)
- Water-quality (nutrients yes, salinization not much)
- Not much on elevation of downstream receiver

These are all interrelated, which makes the GW influence complex

Not only does groundwater affect many of these concerns, many of these concerns also affect the volume and distribution of recharge to groundwater, which then affects the way that groundwater flows within a watershed and where and to what extent it discharges to streams and rivers.

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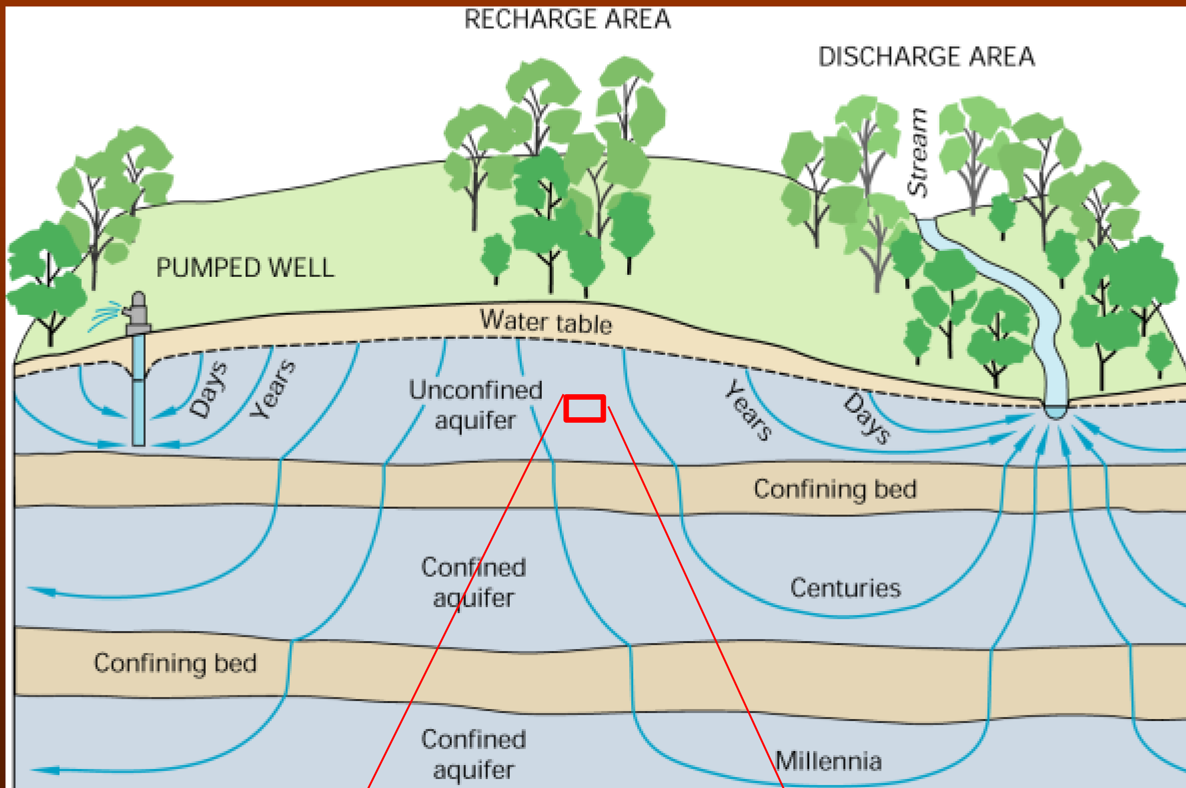
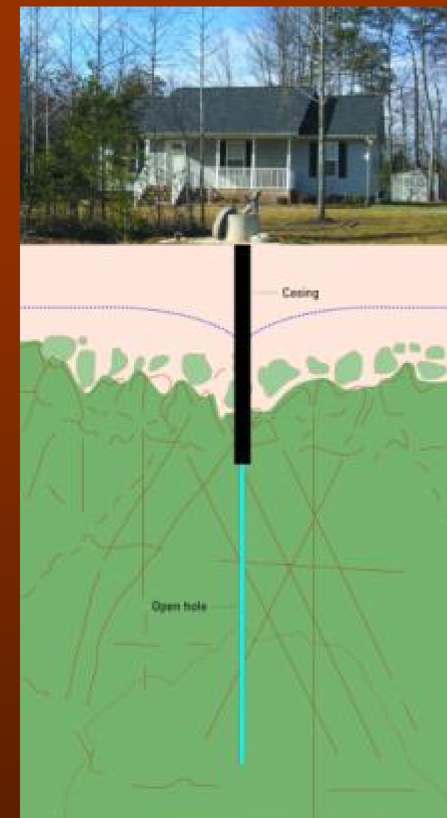
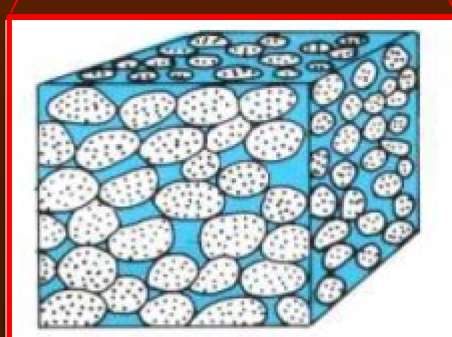
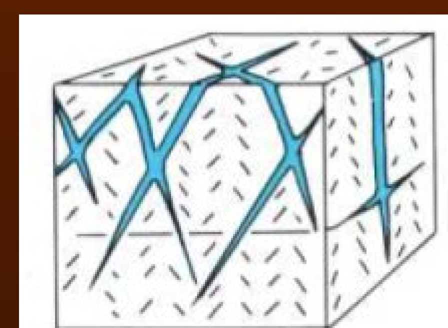
Typical view of groundwater





We commonly view groundwater (GW) with relatively simple flowpaths and with relatively homogeneous porous media.





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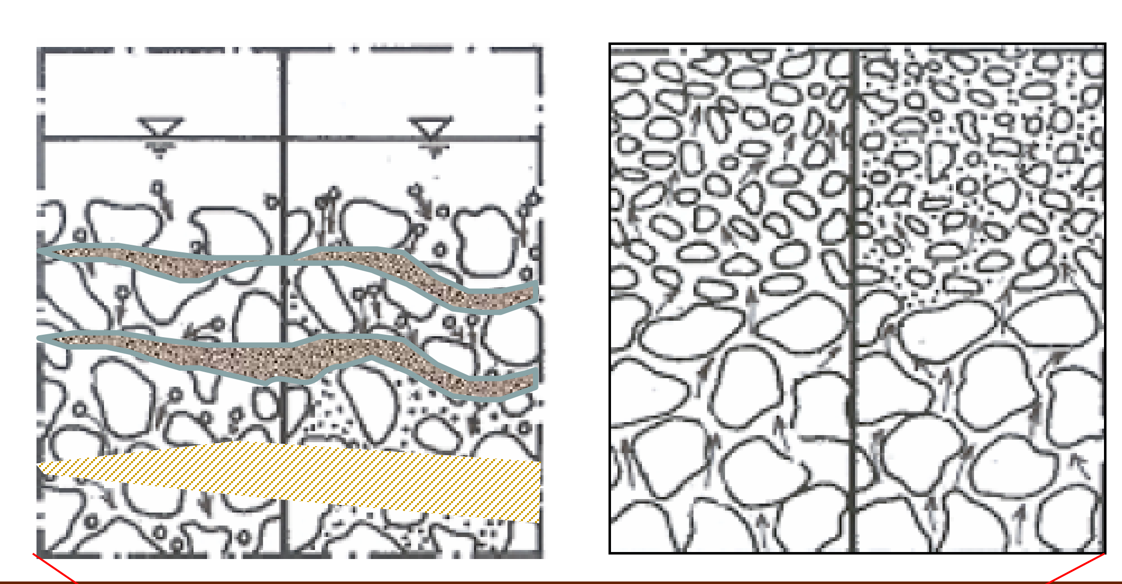
But geology usually is much more complex



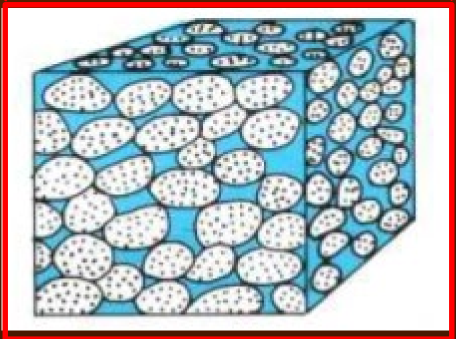
Velickovic, 2005, *Arch&Civil Eng.*

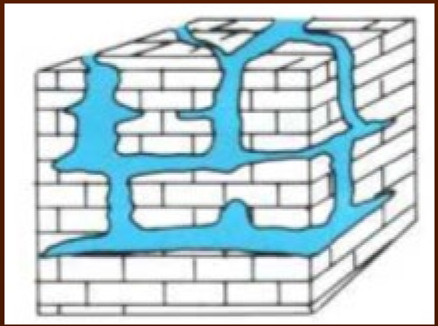
The percent and size of the finest sediment is what largely controls hydraulic conductivity (*K*)

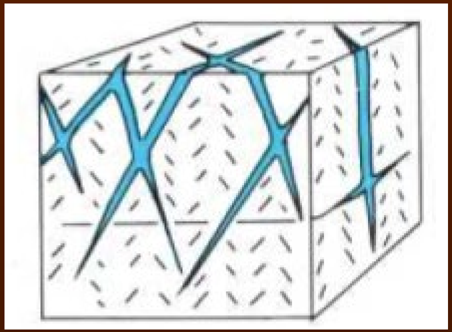
GW rise typically is ~ 3-10 times recharge amount due to specific yield around ~ 0.3-0.1

GW flow is typically very slow in low-gradient settings

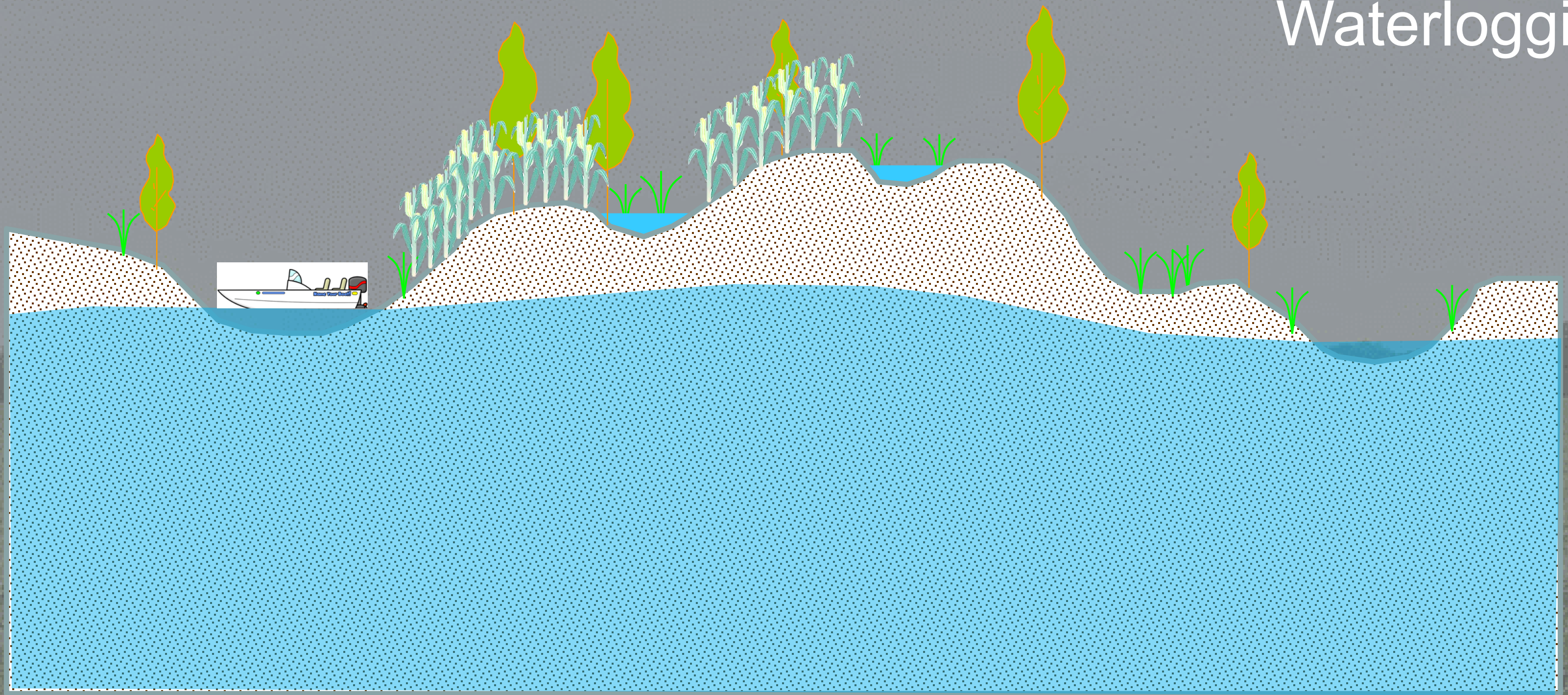
This is closer to what I typically see; lots of heterogeneity, plenty of fine-grained sediments, and thin, horizontal bands of fines and organic sediments.







Waterlogging



Groundwater is everywhere beneath land surface (May farmers don't realize this)

It is astonishing how resistant people are to this concept. I think the idea that groundwater is discontinuous comes from well drillers not being able to create a usable well in some places. The sediments may not be permeable enough to provide sufficient water for a well, but there still almost certainly is groundwater at that location. It just can't flow fast enough to a well when the well is pumped.

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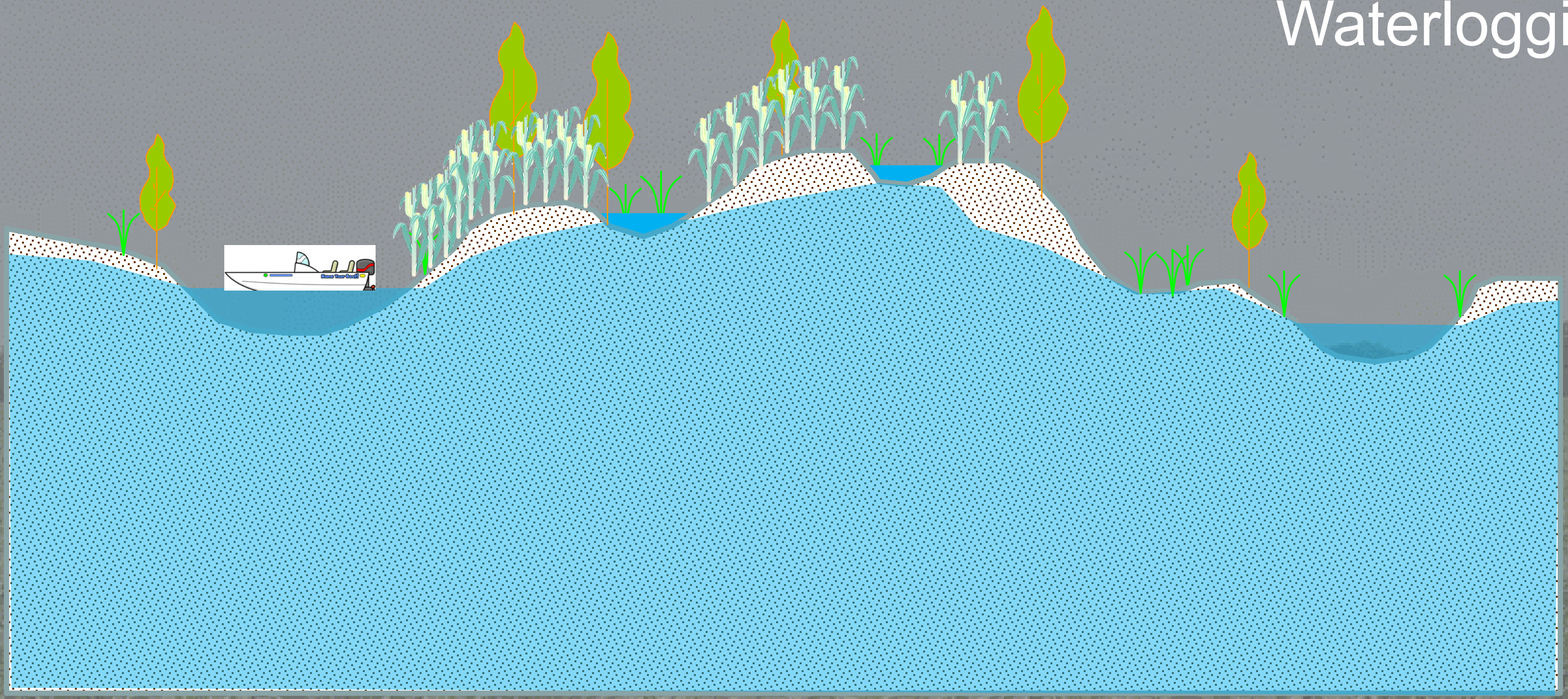
Waterlogging



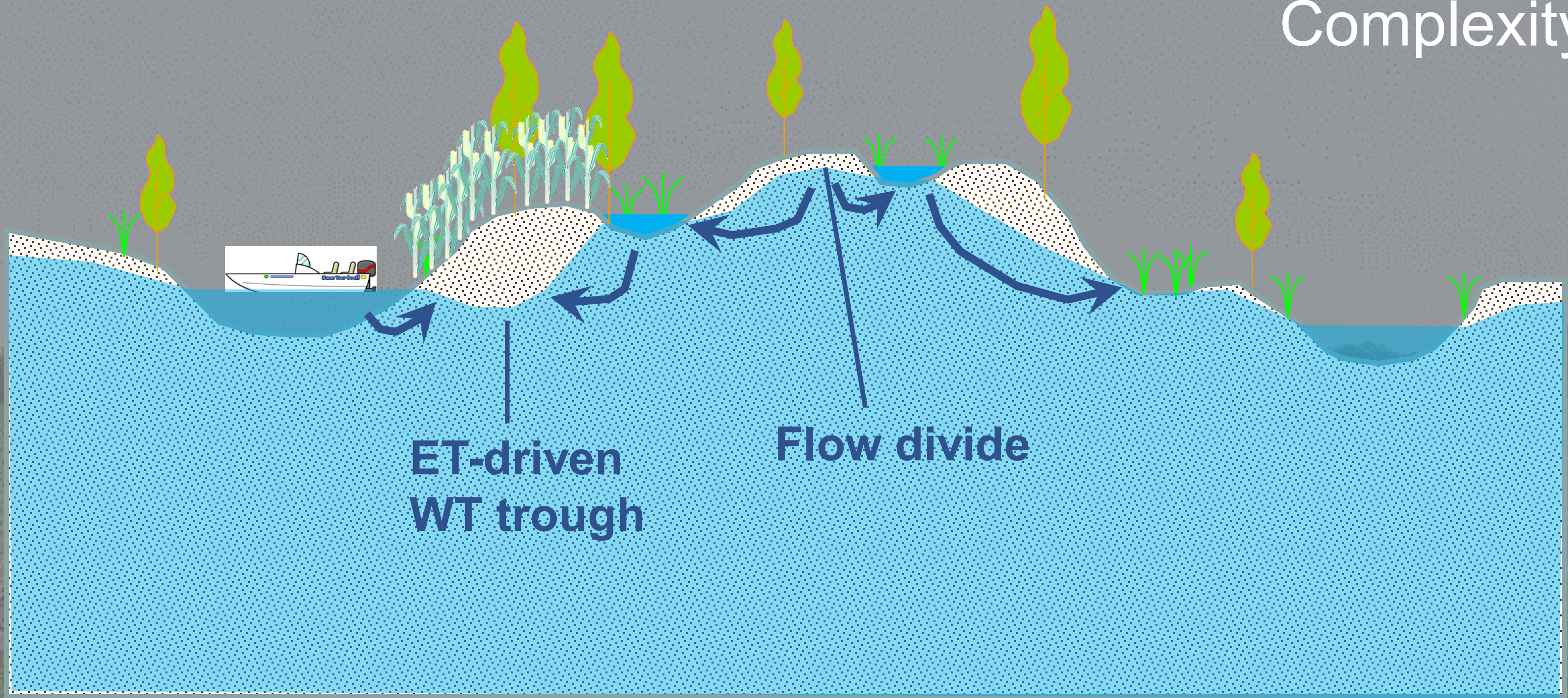
But when it's too close to land surface (I heard <1.5m) we have problems

Excess water is bad, but I didn't hear much about movement of solutes into the soil, which can be even worse (salinization in the arid regions)

Rise is not uniform due to varying recharge and specific yield

Not much was said about the quality of the groundwater that might rise into the rooting zone. In addition to salinity, which is a big problem in irrigated areas, other dissolved constituents could substantially reduce crop yields if the water table gets too high.

Complexity



And the water-table configuration often does not mimic the land surface

Groundwater hydraulics can play a huge role in whether and where groundwater flows. If a water-table mound is in place, it can serve as a hydraulic-head "dam" that can prevent water from flowing from one part of the GW flow domain to another. A water-table trough can serve the same purpose. In the cartoon, water from the pond just to the right of the crops can't flow to the right because of the higher groundwater that rises to a flow divide, and water from the pond can't get to the lake with the boat because the water-table trough in between will intercept the flow.

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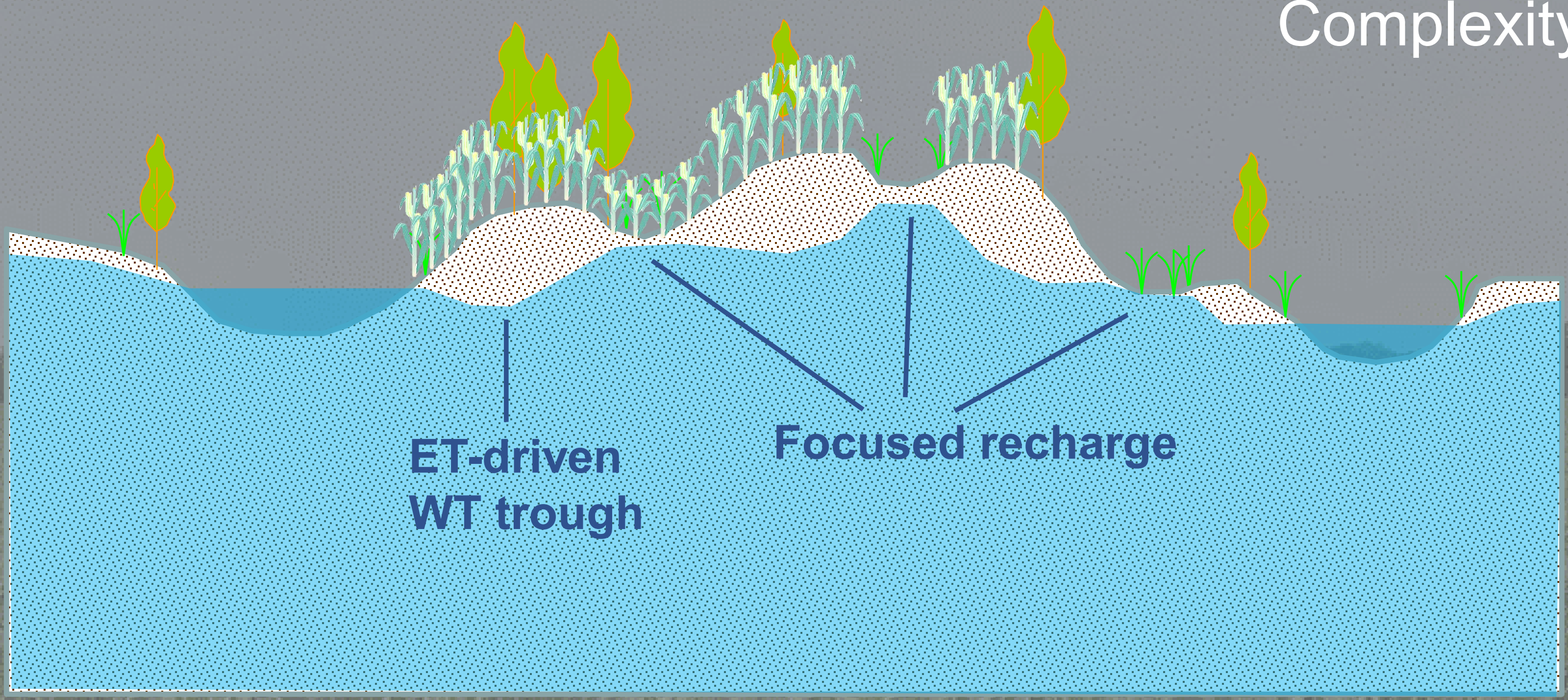
Complexity



For <u>naturally</u> well-drained settings, the depressions are the primary points of GW recharge and water-table rise

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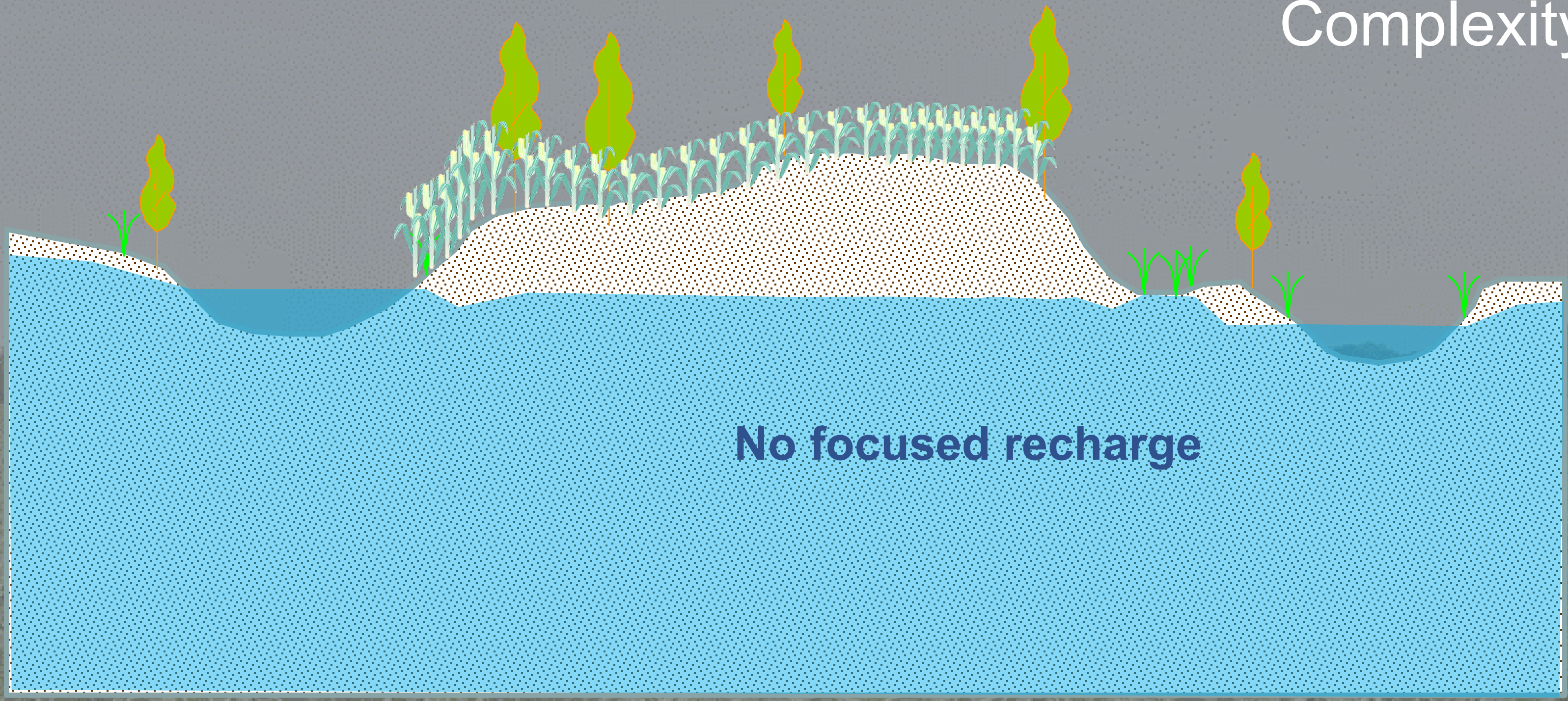
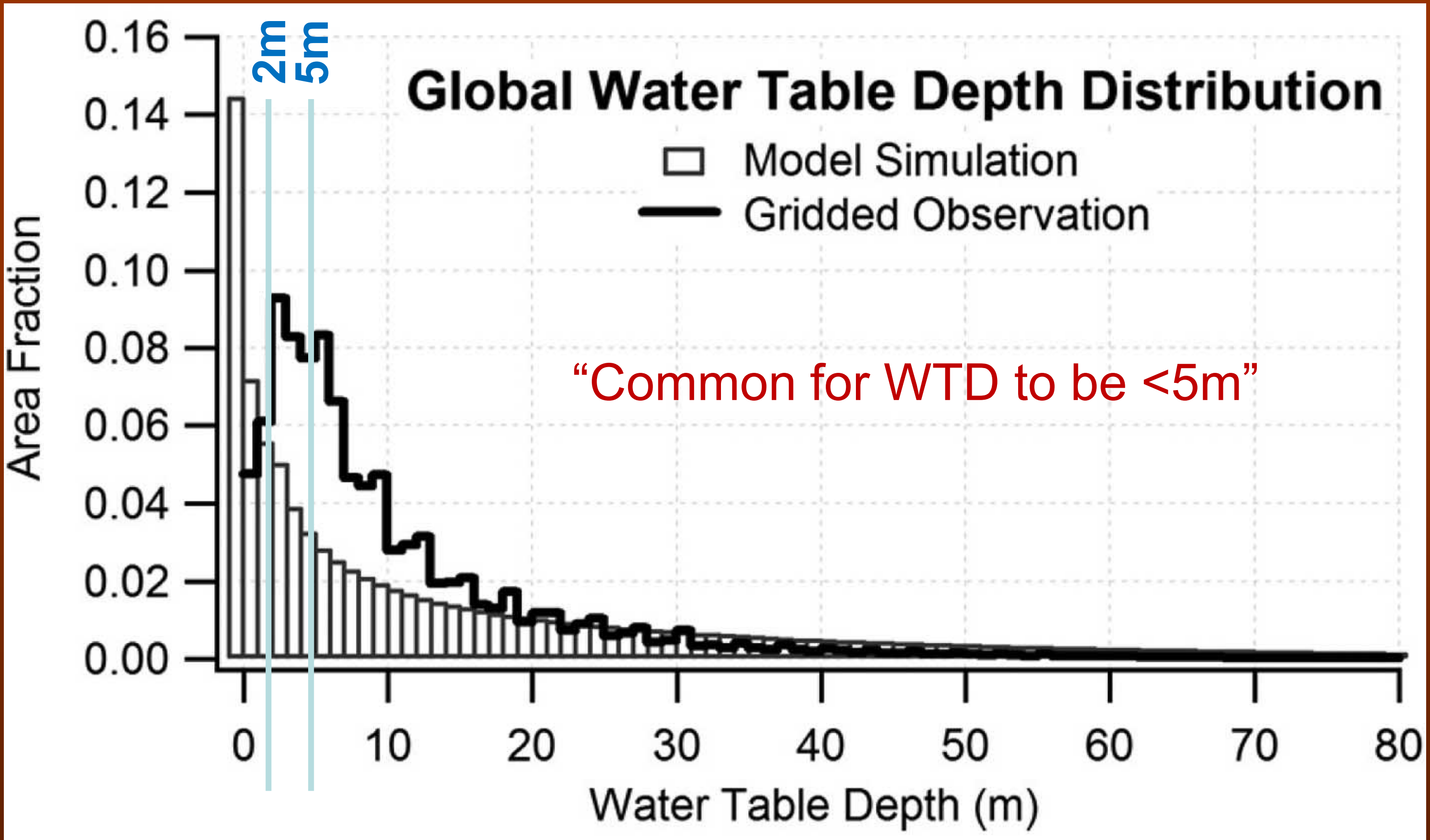
Complexity



Note the small water-table depressions next to the wetlands and the lake. They are created by ET from near-shore plants and are pretty common features.

Without the depressions to focus recharge, DTW will increase

There's no water-table mound if recharge is not greater than the rate at which it can flow to a drain

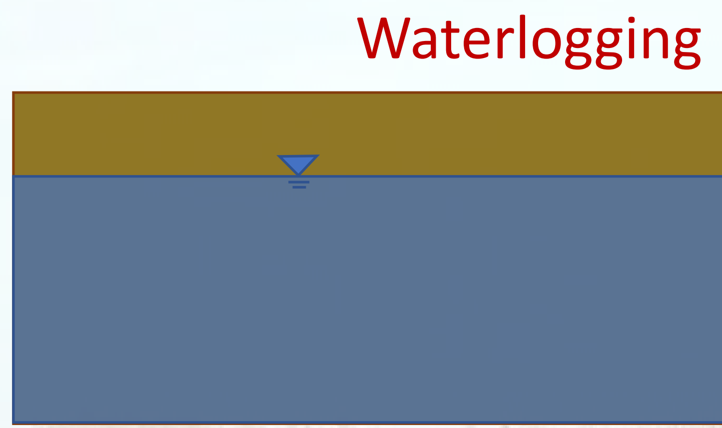


Fan et al., 2018, *Science*

Therefore, GW can easily and quickly rise beyond the "sweet spot," hence all the talk about drains

But that's not the case for terrain with greater local relief. I only heard a few talks about those types of settings.

I must have been channeling Keith Schilling and Kathy Boomer in my concept of settings where tile drains work; places with substantial local relief



High water tables reduce yields

The water table is a balance between recharge, rate of flow (*K* and *i*), and the drain elevation

This is the terrain that I am more familiar with, where GW is likely to be substantially more than 1.5 m below land surface beneath quite a bit of the watershed.

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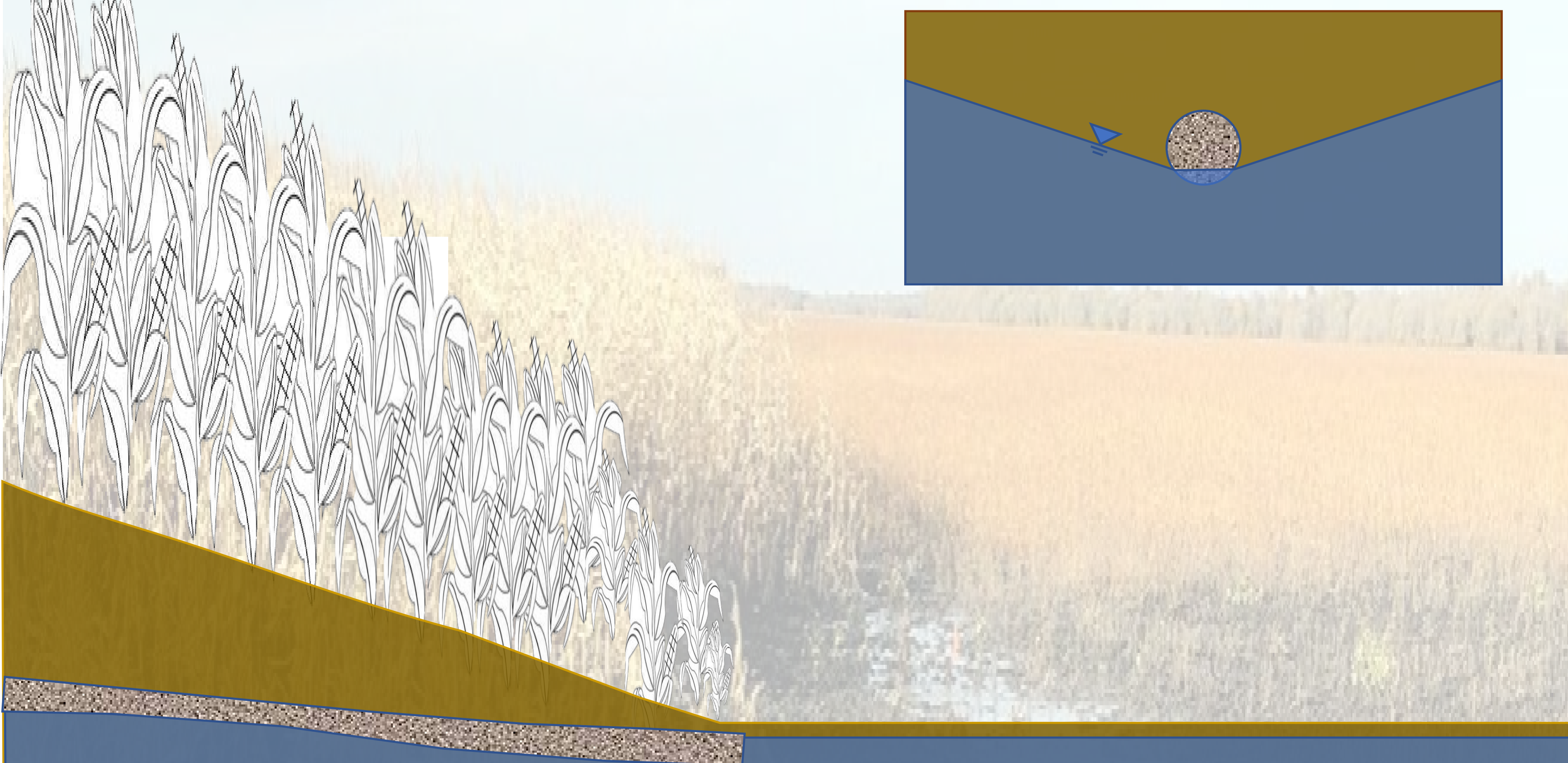
Waterlogging

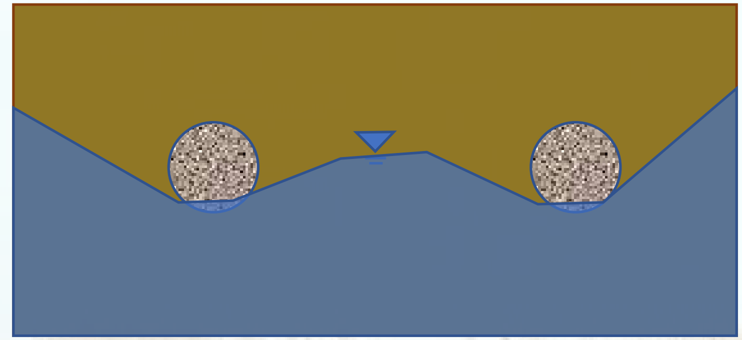


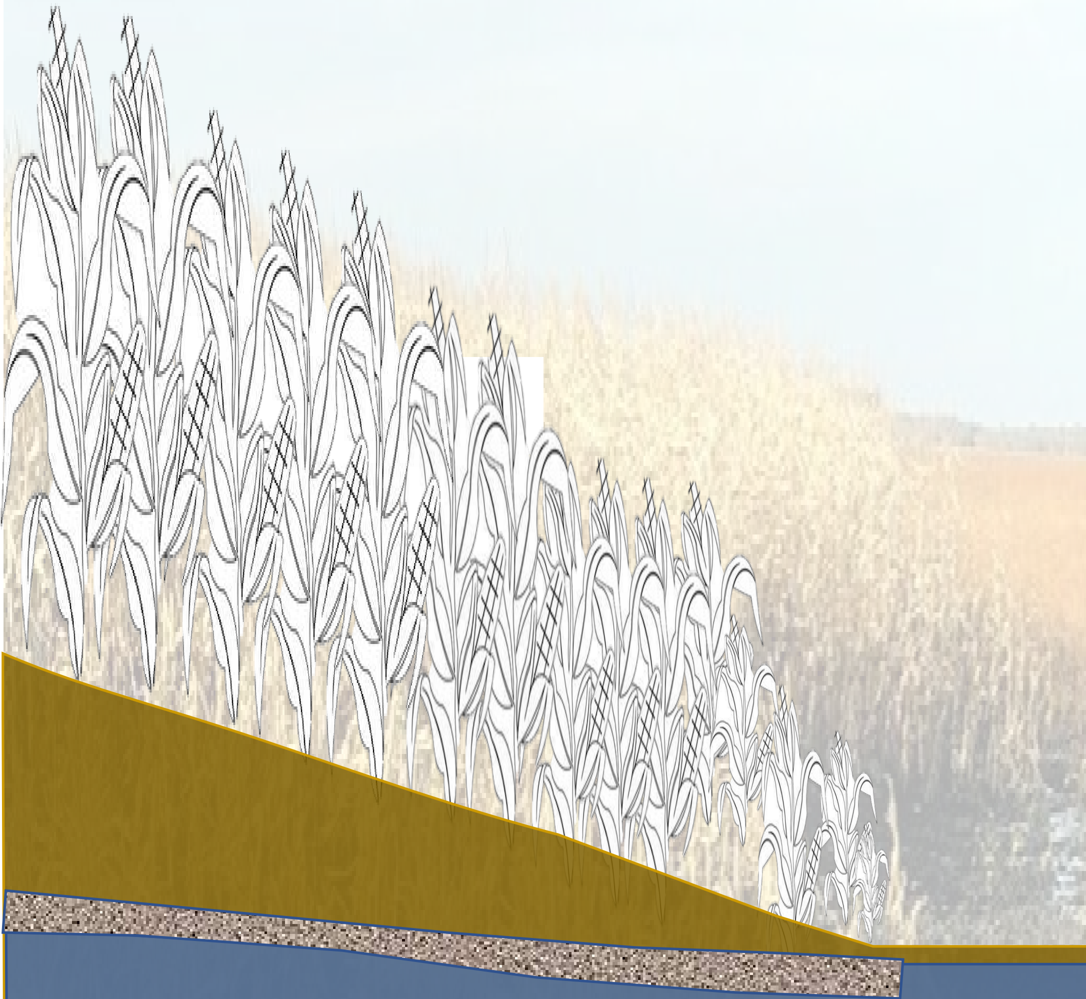
Tile drains can be effective

A tile is essentially a zone of high *K*

Although a drain tile is great at keeping water out of the rooting zone, it also diverts a fair bit of GW. Those areas of artificially low head serve to more rapidly remove GW from the watershed, which could be detrimental later in the season, or during a drought cycle.

Waterlogging





Tile drains can be effective

A tile is essentially a zone of high *K*

This technology is massively more prevalent than I knew. But when fields are fallow, shouldn't these drains be shut down?

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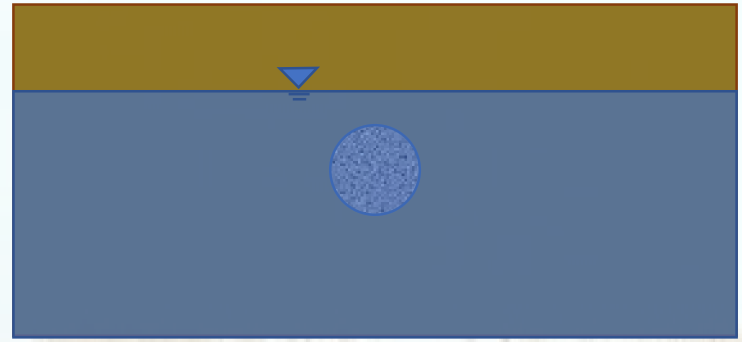
I didn't hear much about this yesterday.

Waterlogging



But what happens if the "drain-to" elevation increases?

The tile doesn't route any water if there is no gradient (i = 0) to drive flow

With greater temporal variability in precipitation, and wetter wet periods and bigger rain events, the likelihood that the elevation of water body to which the drain is routed could be substantially higher than the drain outlet.

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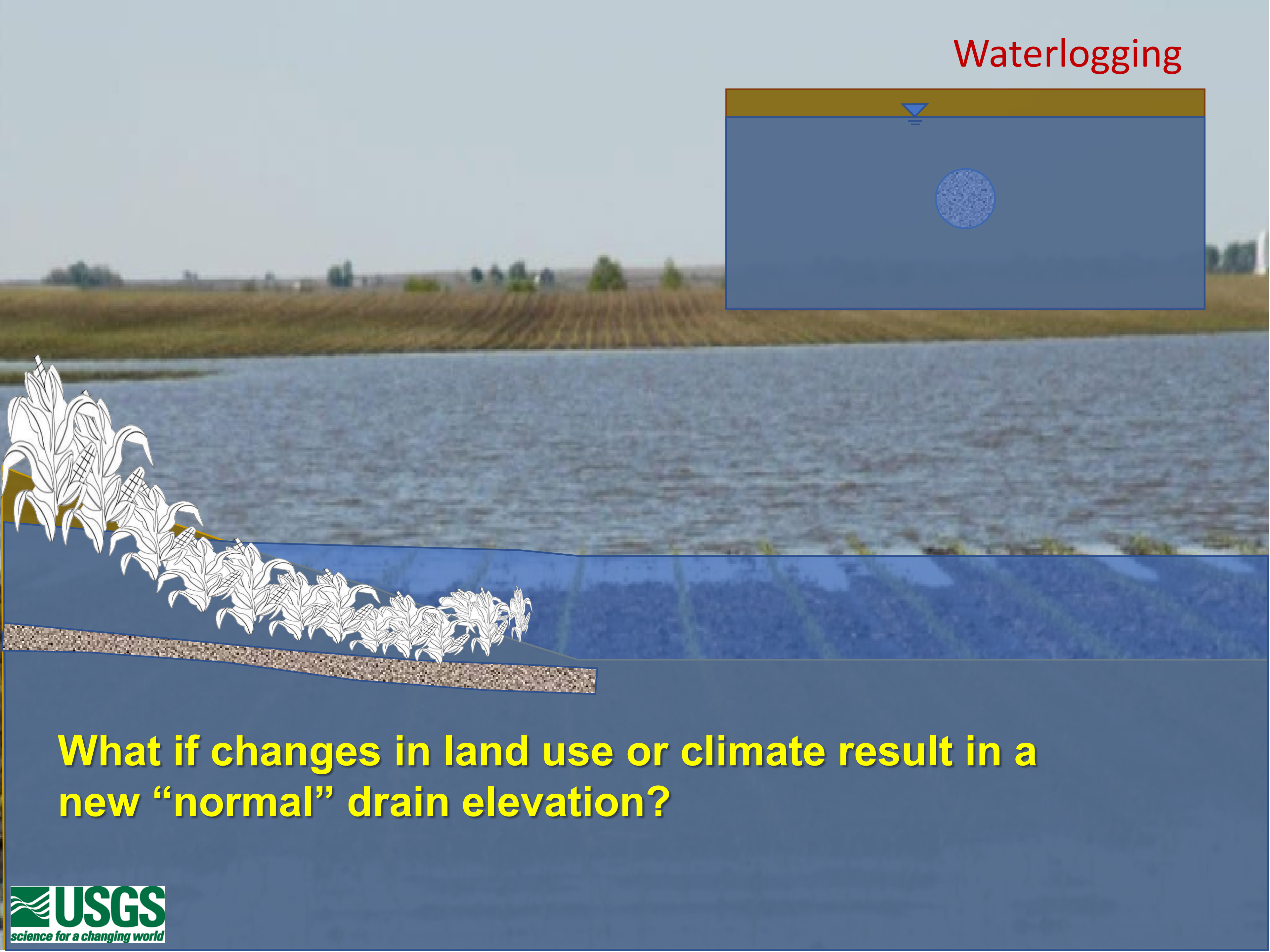
Waterlogging
What if changes in land use or climate result in a new "normal" drain elevation?
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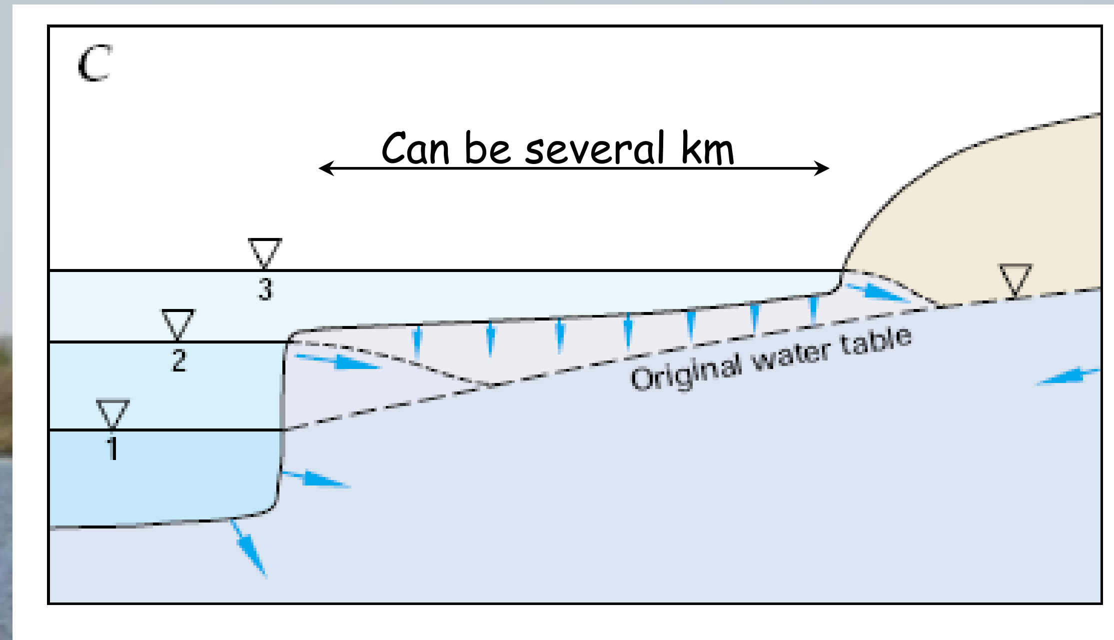

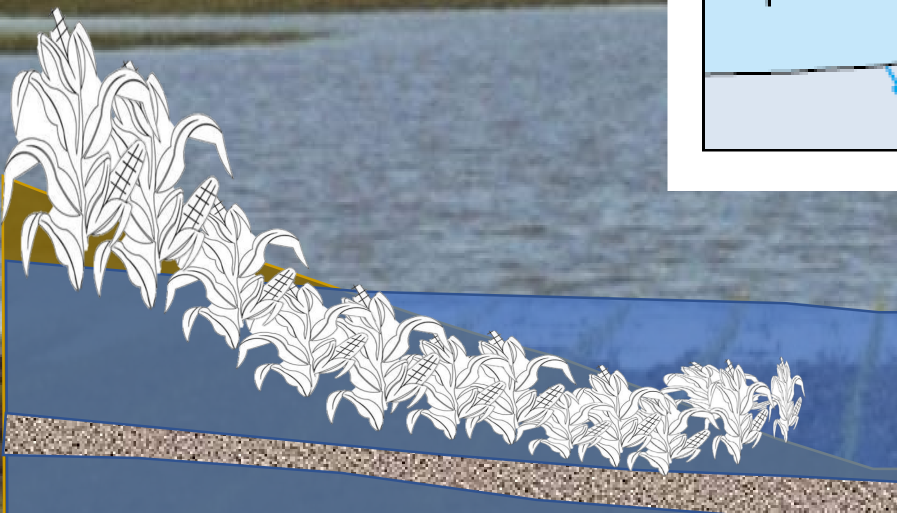

What if changes in land use or climate result in a new "normal" drain elevation?

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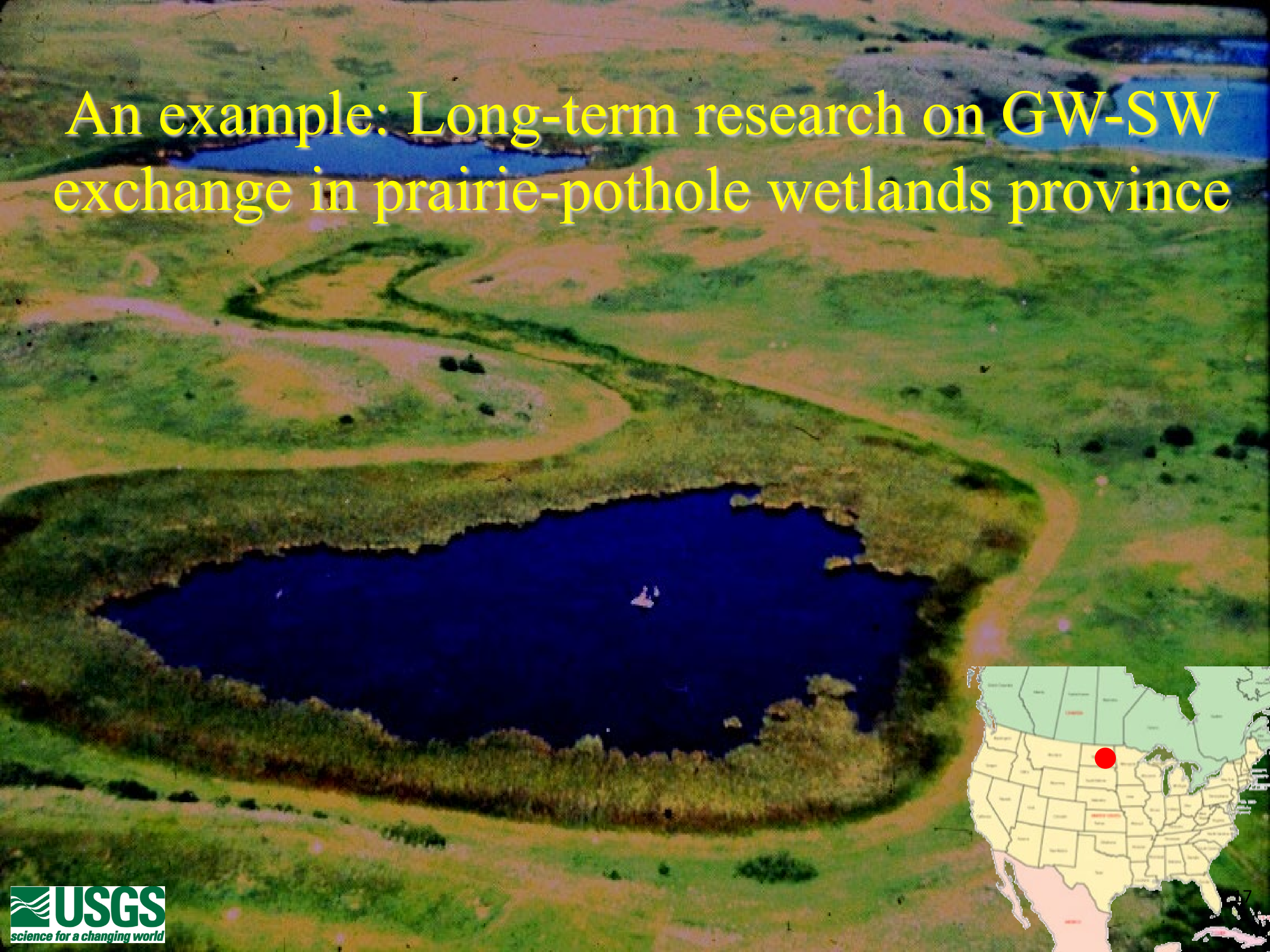
An example: Long-term research on GW-SW exchange in prairie-pothole wetlands province



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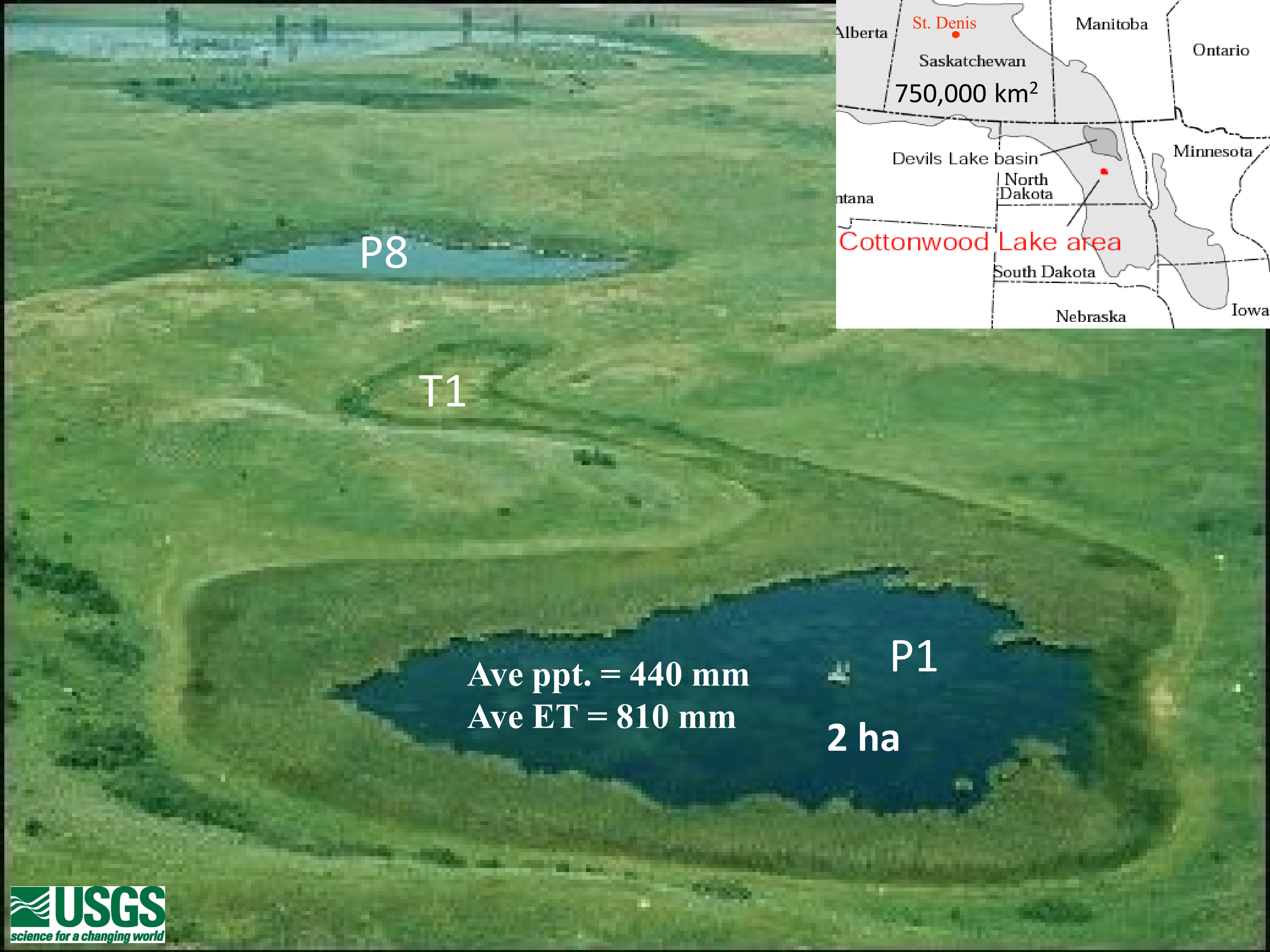
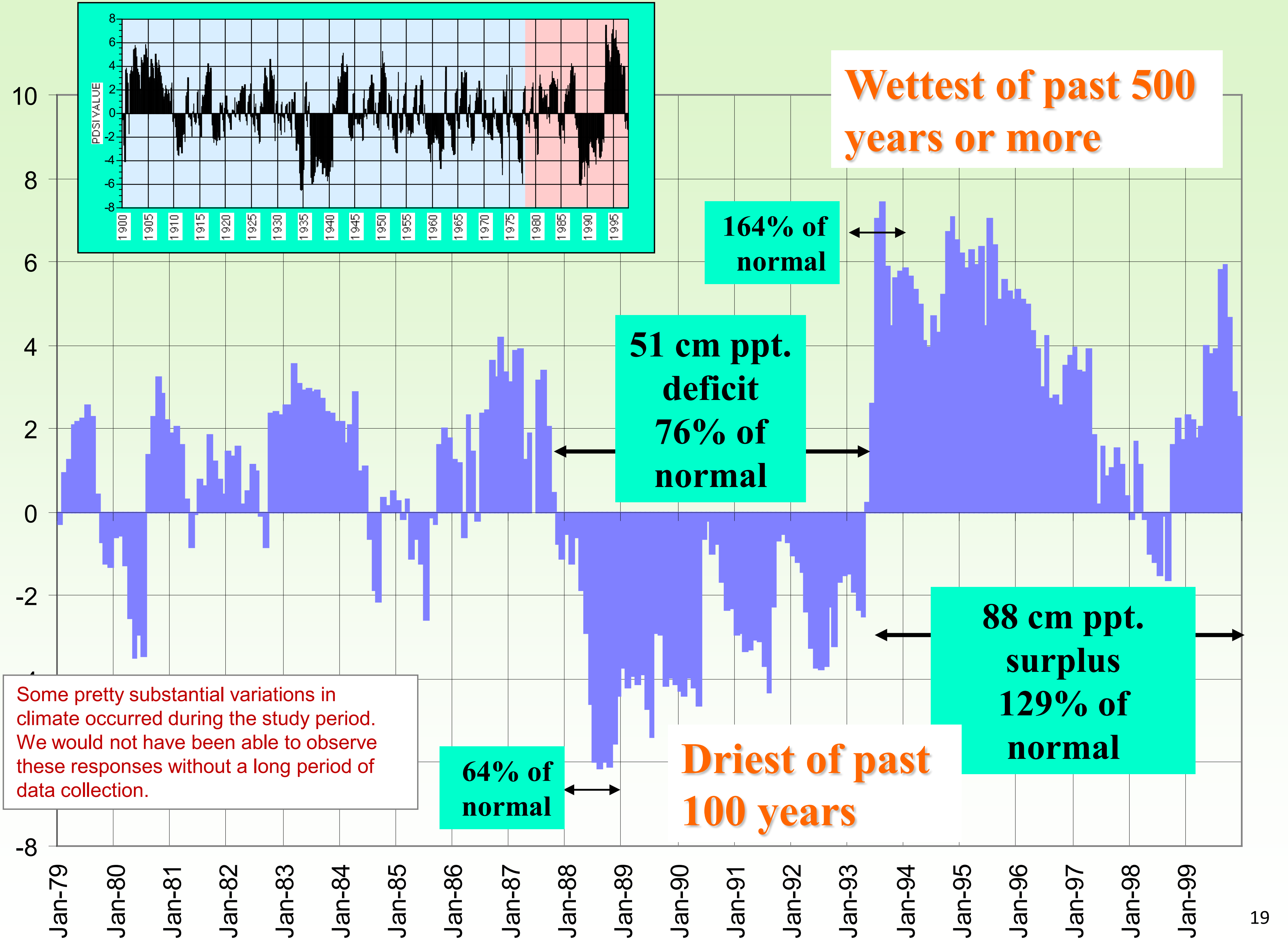
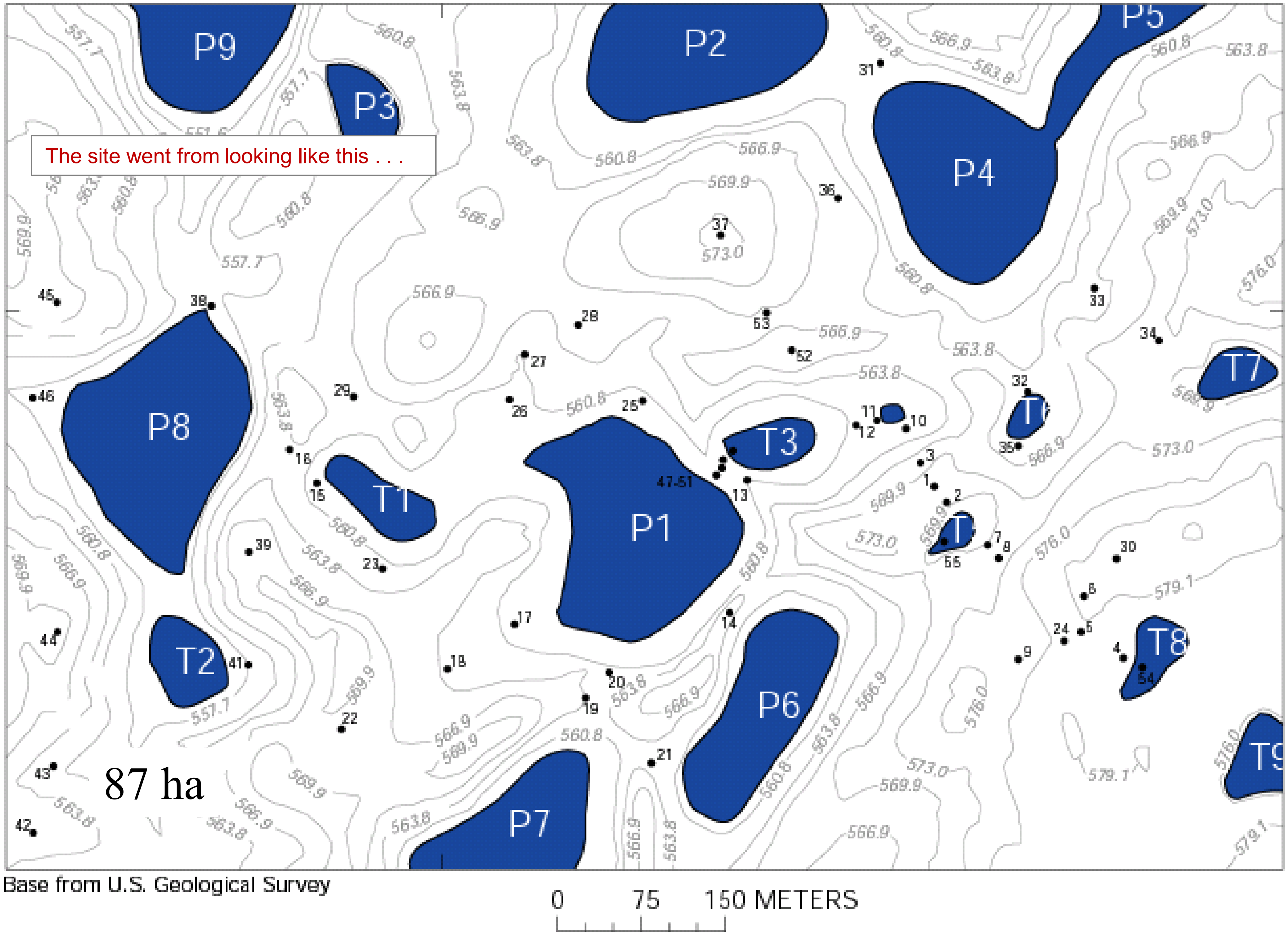

P8
T1
P1
Ave ppt. = 440 mm
Ave ET = 810 mm
2 ha
Alberta
St. Denis
Saskatchewan
750,000 km²
Manitoba
Ontario
Devils Lake basin
Minnesota
North Dakota
ntana
Cottonwood Lake area
South Dakota
Nebraska
Iowa



Winter and Rosenberry, 1998, *Climatic Change*


The site went from looking like this . . .
P9
P2
P5
P3
P4
P8
P1
P6
P7
T1
T2
T3
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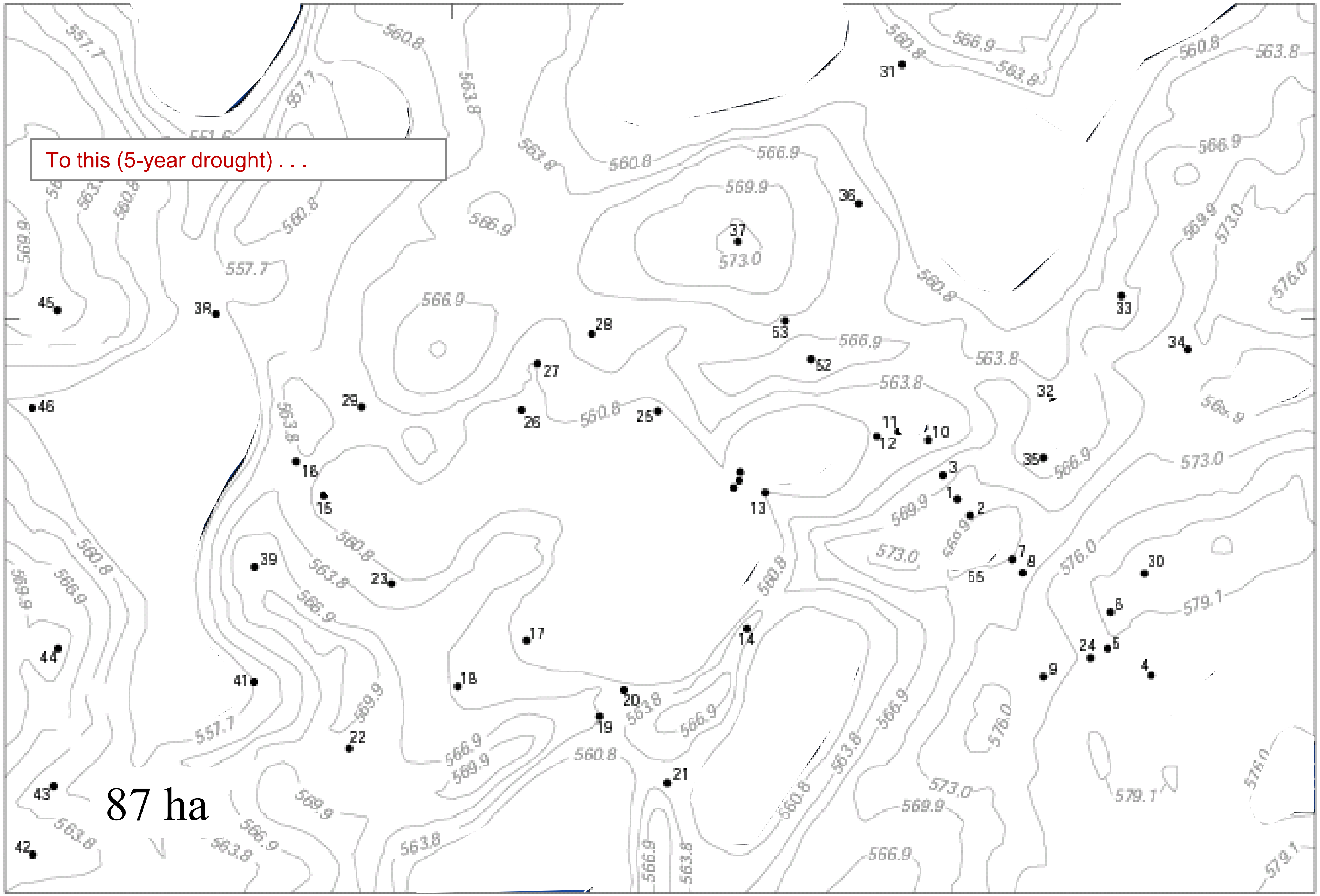
T8
87 ha
Base from U.S. Geological Survey
0 75 150 METERS

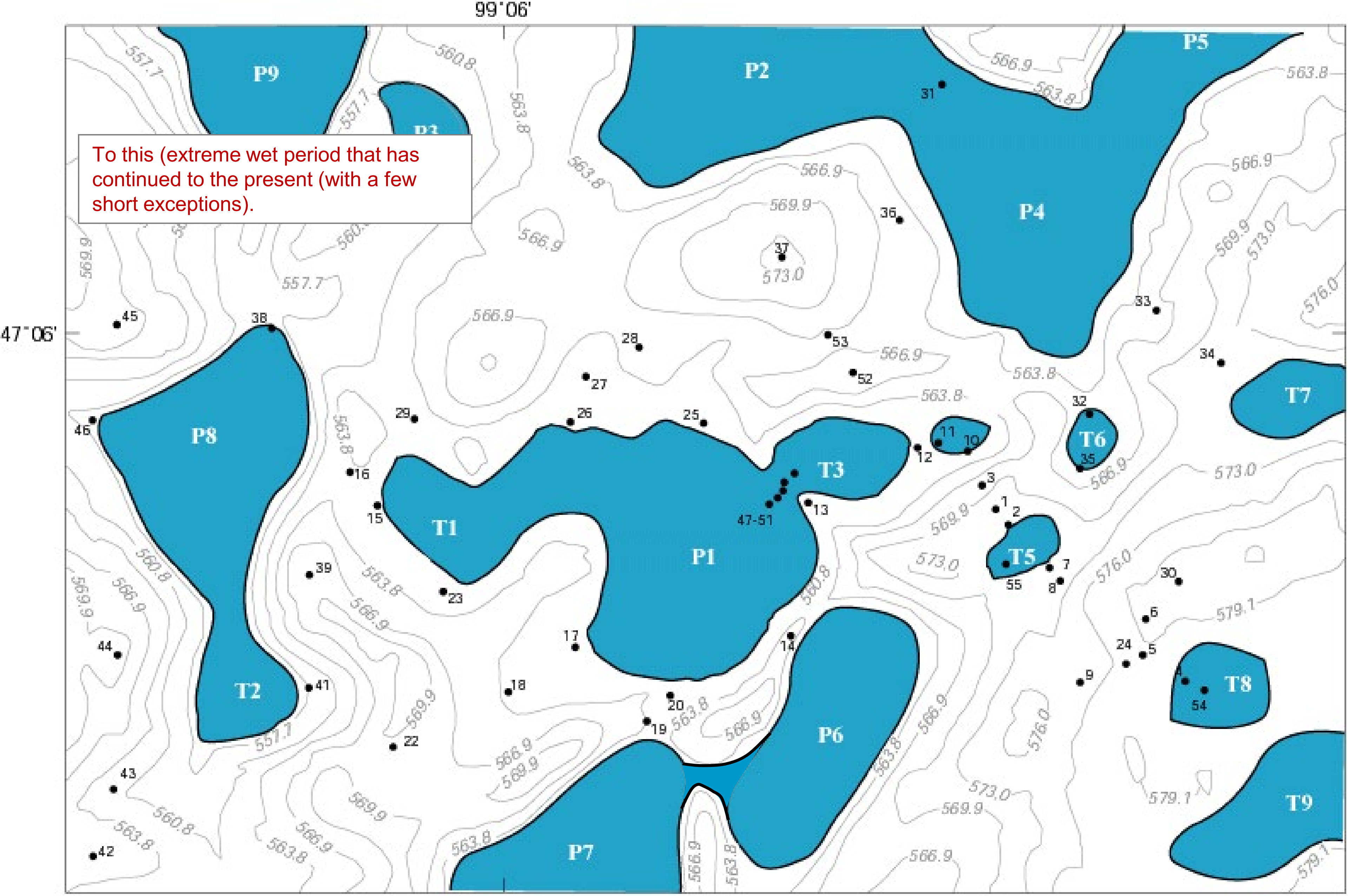


Base from U.S. Geological Survey

0 75 150 METERS

Every one of these wetlands dried up during the drought

To this (extreme wet period that has continued to the present (with a few short exceptions).



Base from U.S. Geological Survey

0 75 150 METERS

SCALE

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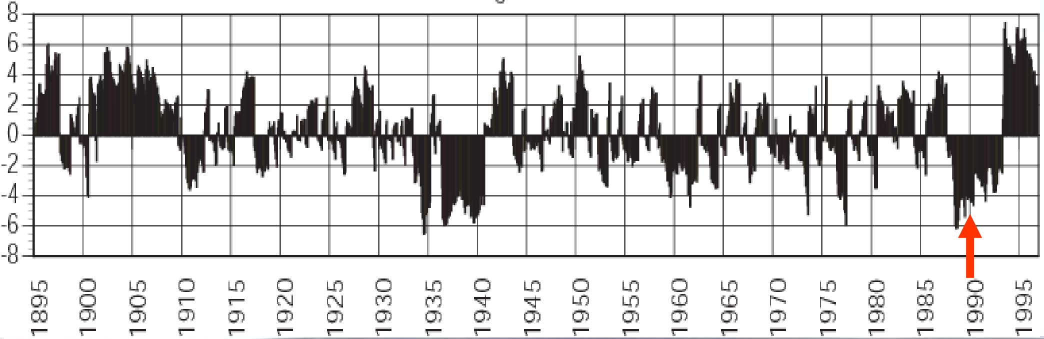
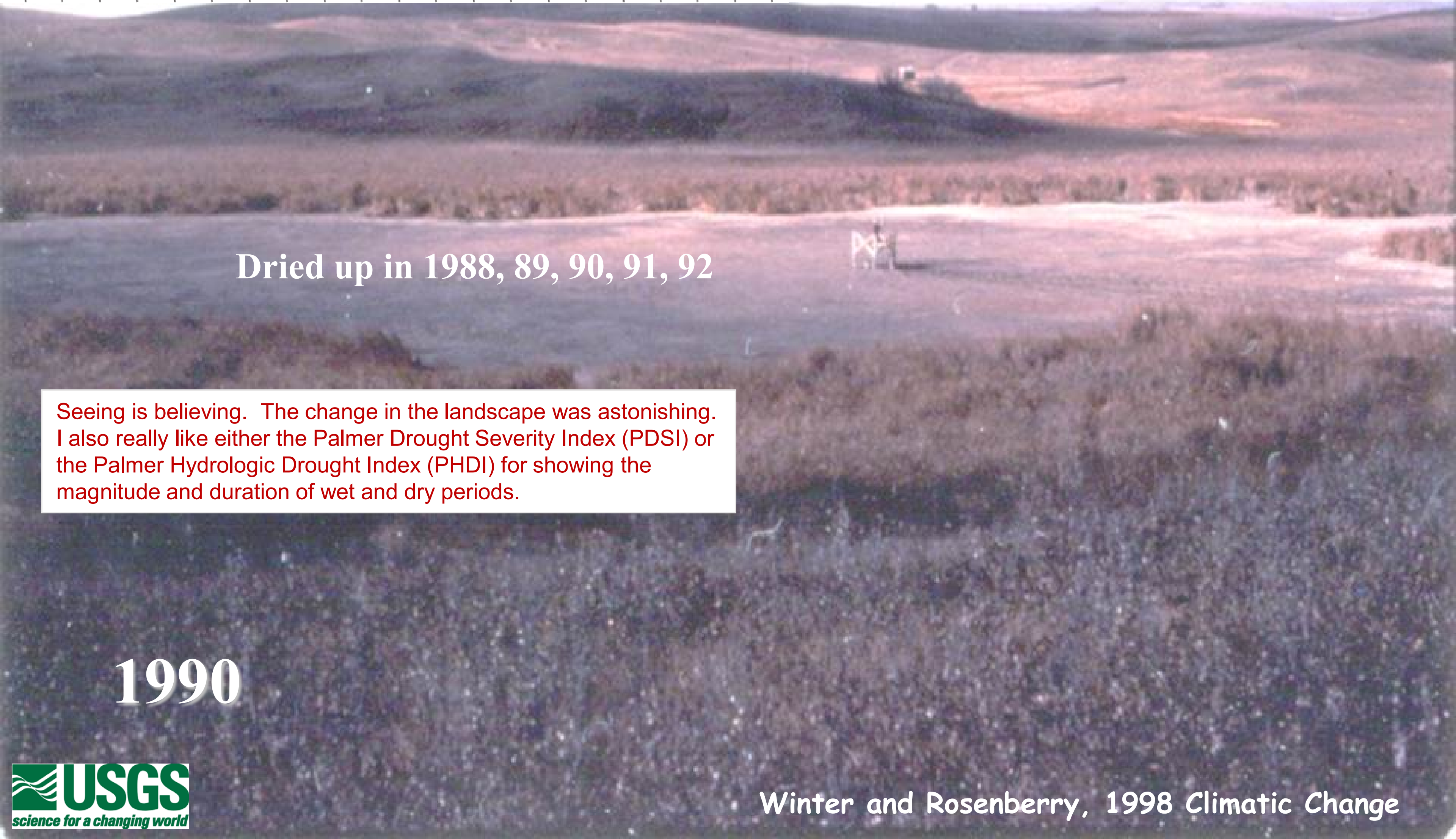


Driest period of the last century



Seeing is believing. The change in the landscape was astonishing. I also really like either the Palmer Drought Severity Index (PDSI) or the Palmer Hydrologic Drought Index (PHDI) for showing the magnitude and duration of wet and dry periods.

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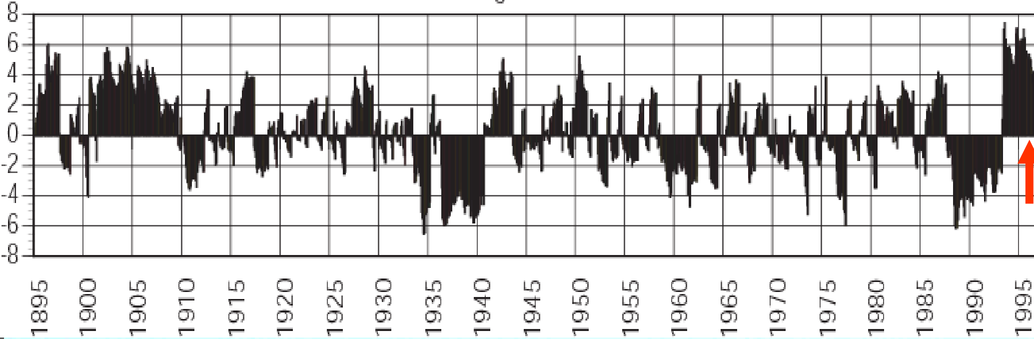
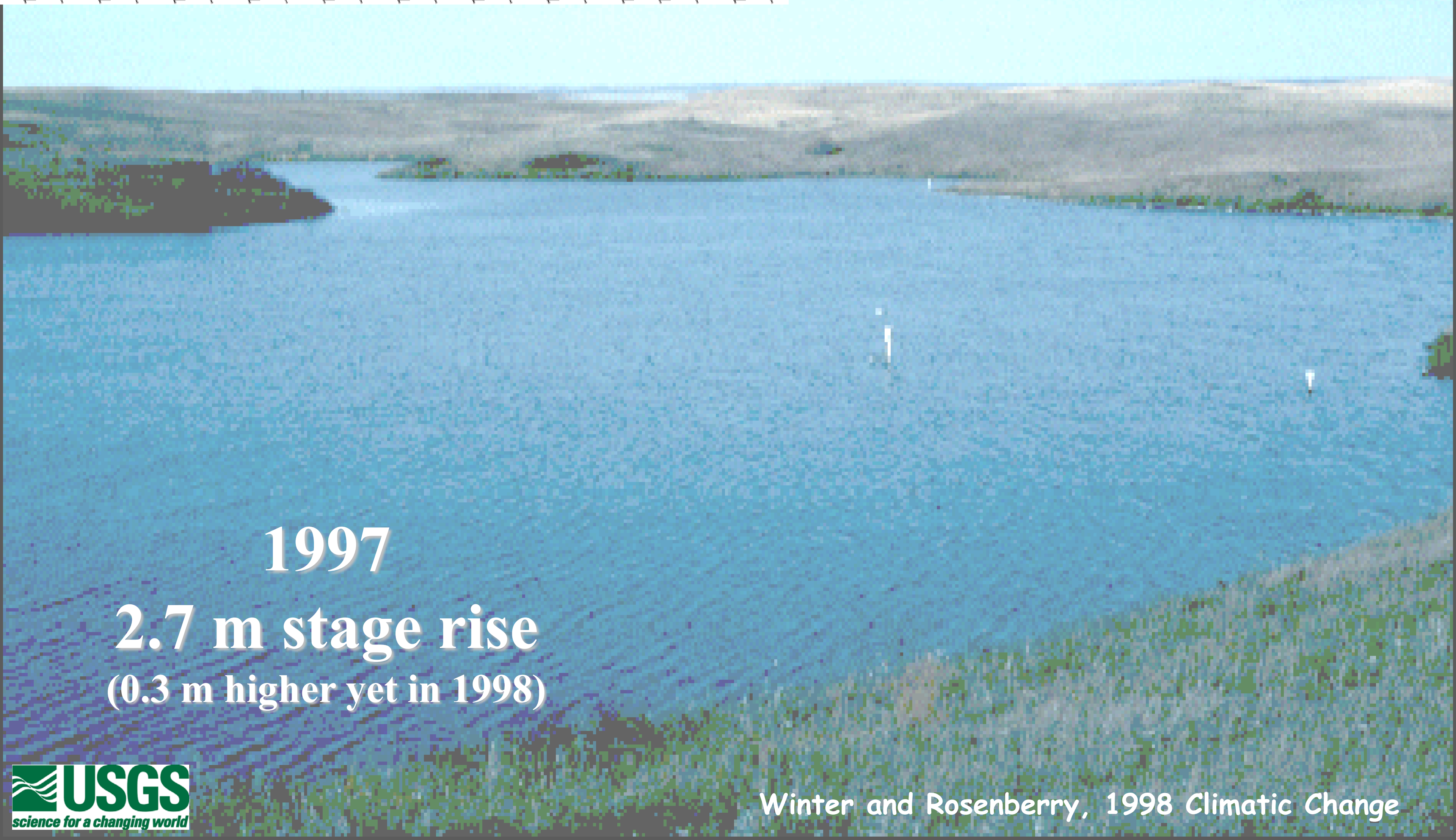
Winter and Rosenberry, 1998 Climatic Change

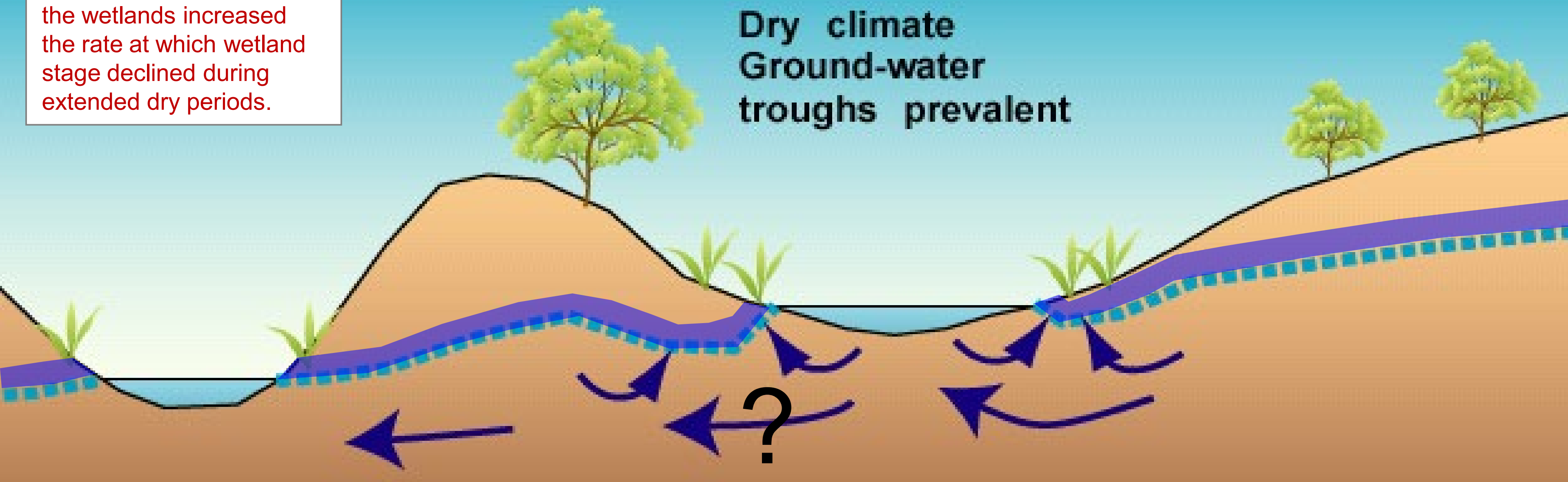




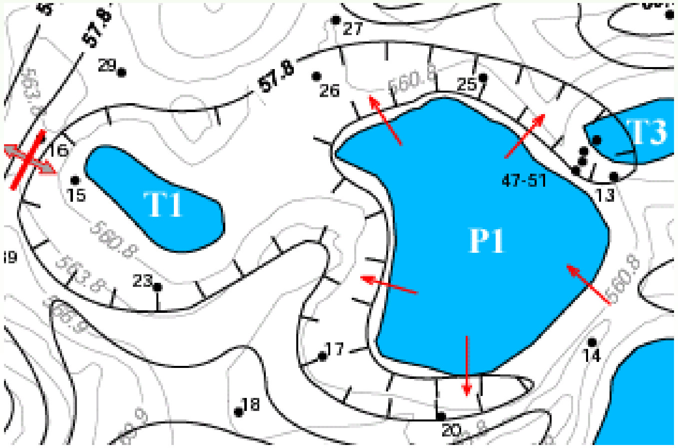
1997
2.7 m stage rise
(0.3 m higher yet in 1998)

Winter and Rosenberry, 1998 Climatic Change

The water-table troughs that formed adjacent to the wetlands increased the rate at which wetland stage declined during extended dry periods.



GW provides a <u>positive feedback</u> to wetland response to climate change during <u>both dry and wet times</u>



ET-induced water-table trough

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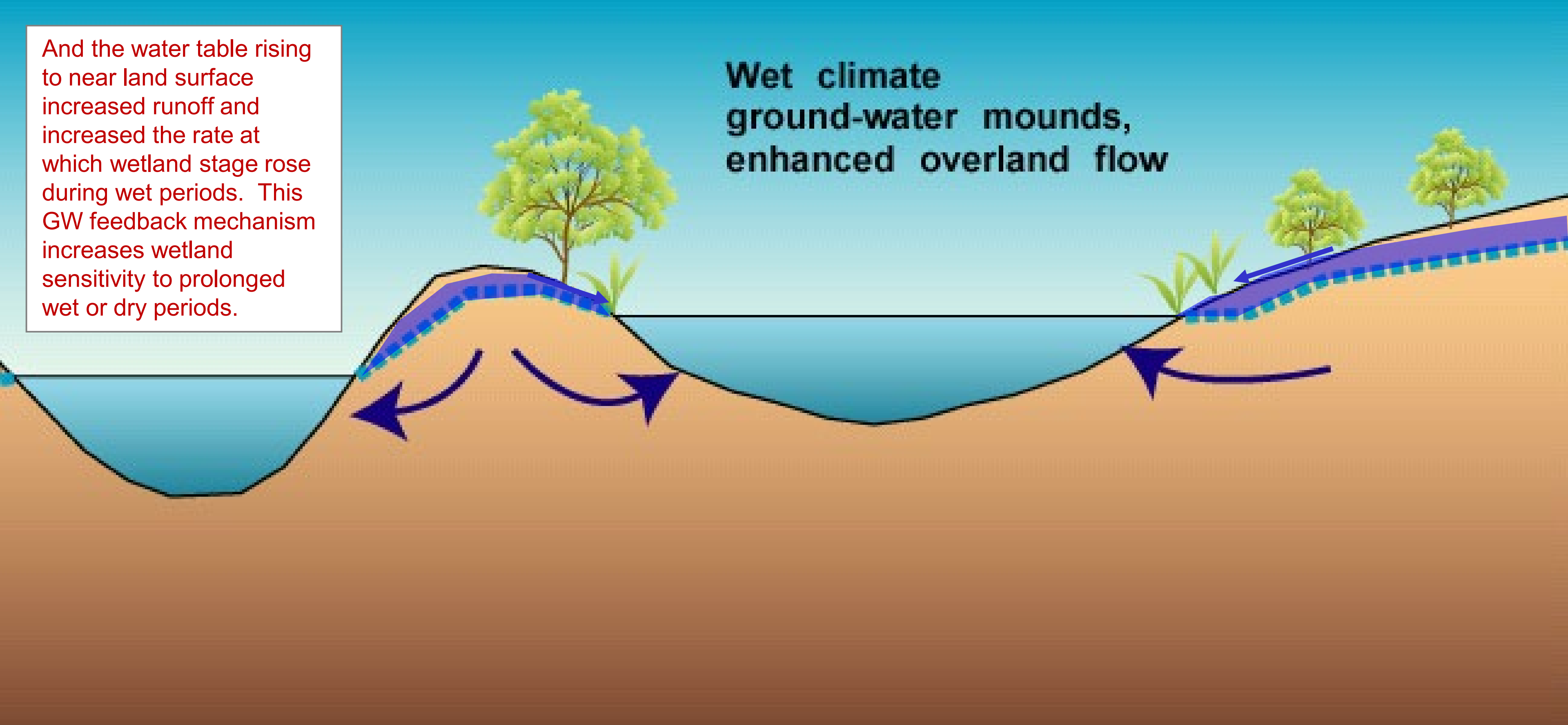
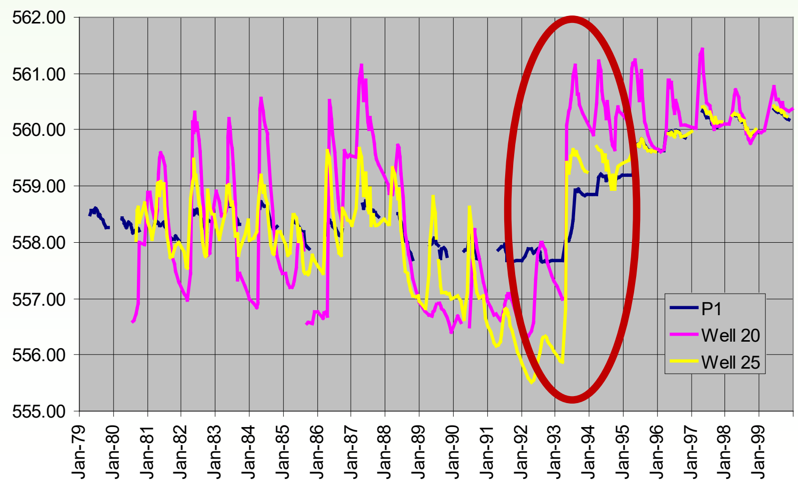
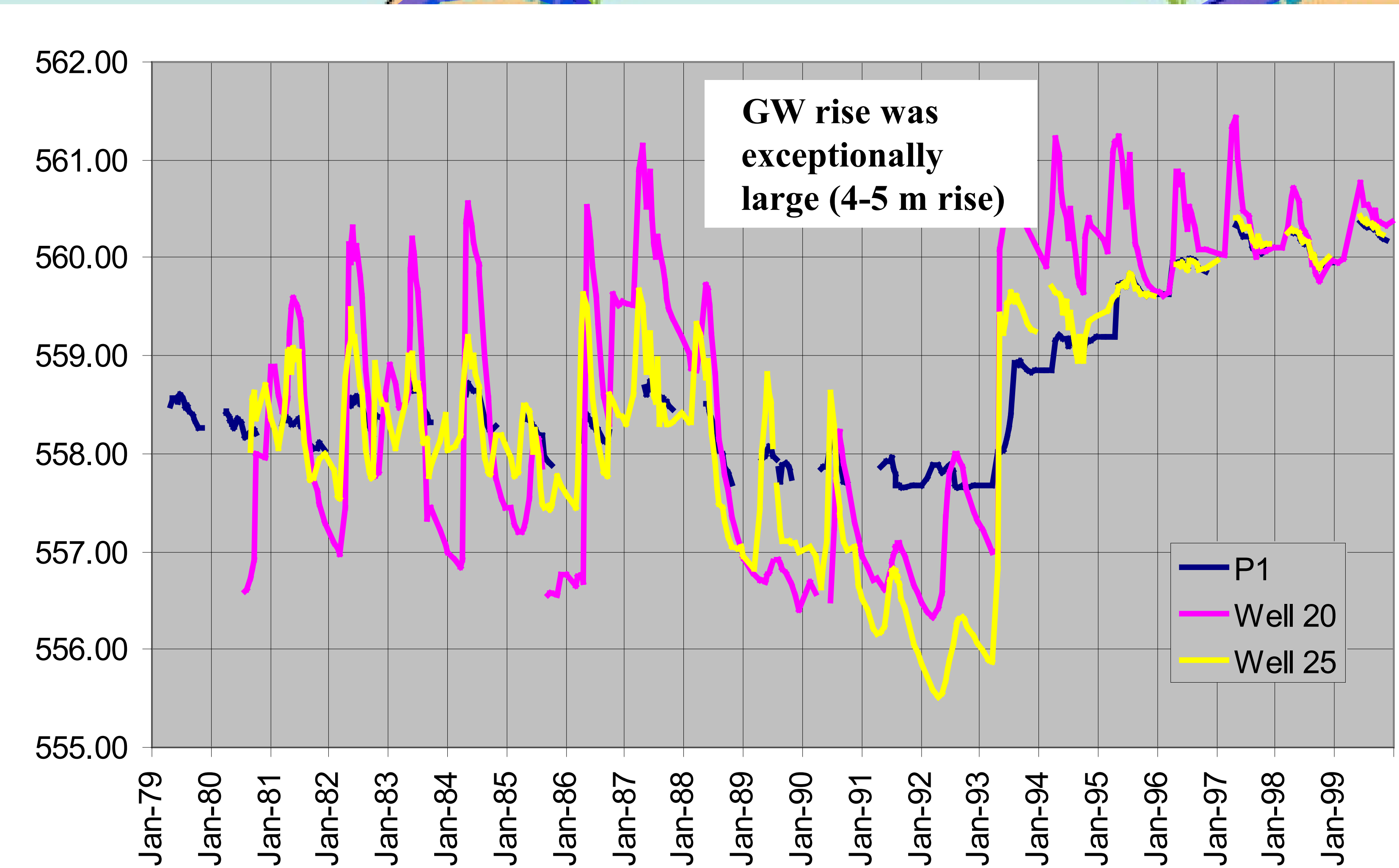
And the water table rising to near land surface increased runoff and increased the rate at which wetland stage rose during wet periods. This GW feedback mechanism increases wetland sensitivity to prolonged wet or dry periods.

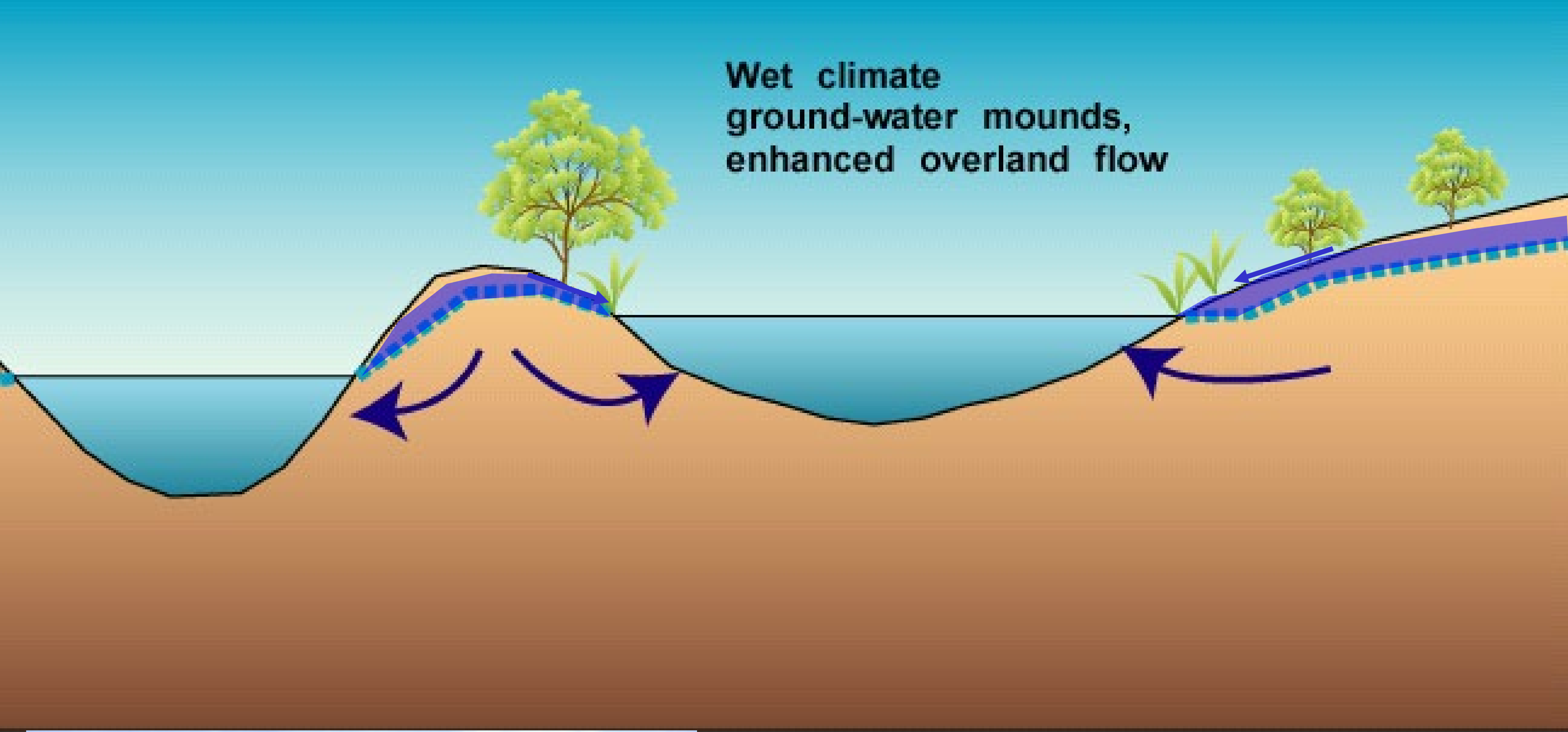




The large GW rise was due primarily to small values of specific yield.

Wet climate ground-water mounds, enhanced overland flow





Ground-water mounds surrounds wetland P1 during deluge

- Water table rose to or near land surface during wet period. No storage left. Virtually all precip. Falling on the basin ended up in the wetland (the local drain).

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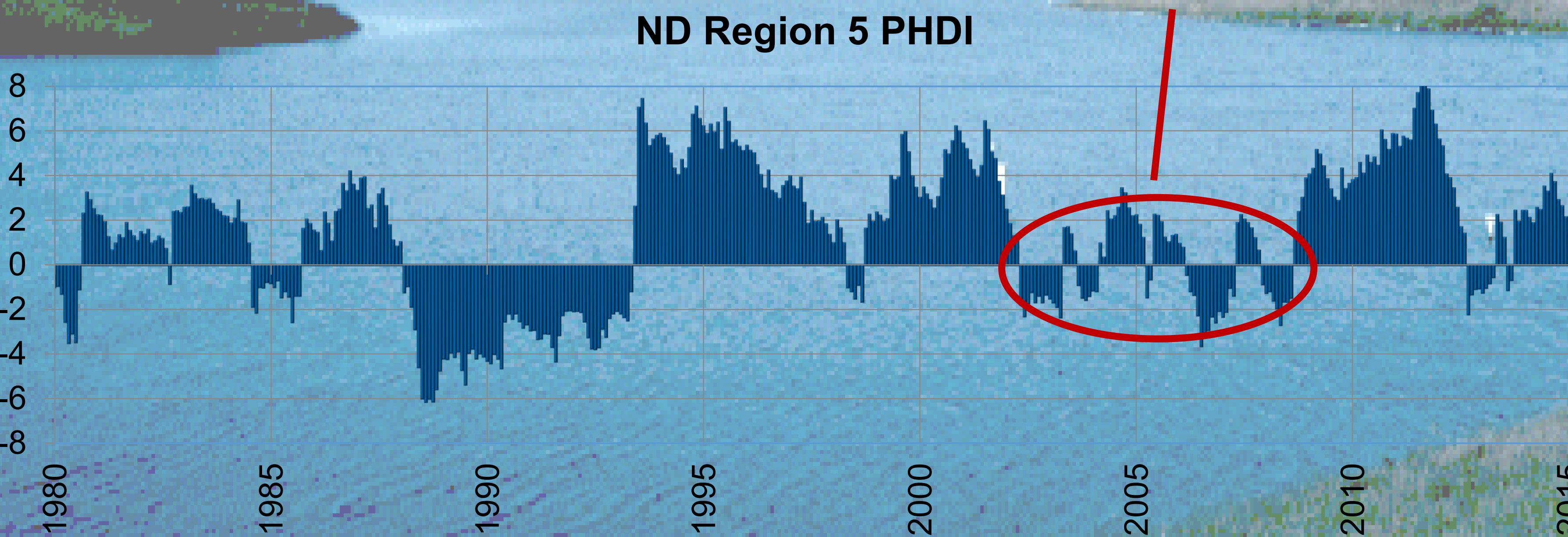
Is this a new high-stage normal?

"Normal" conditions returned
P1 declined ~ 0.7 m

Upland wells declined 1.2 m; mid-basin wells declined 0.5 m

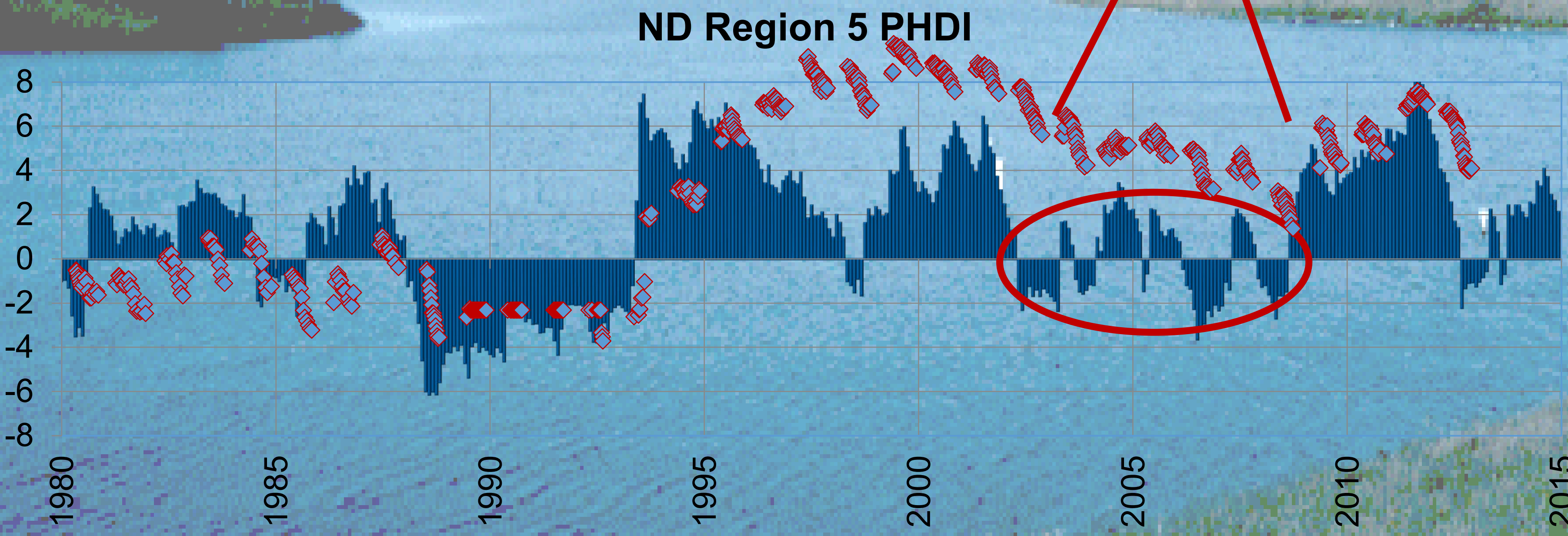
But those same wells rose 4 to 4.5 m in 1993.



For years, we were asked if this period of very high wetland stage was going to be the new normal. Being cautious scientists, we were hesitant to say or write that. However, GW and wetland stages declined only slightly during the 5 to 6 years of normal conditions circled in red, demonstrating substantial resiliency of this physical setting.

Is this a new high-stage normal?

P1 stage declined, but it is still ~2 m higher than pre-1993 stage



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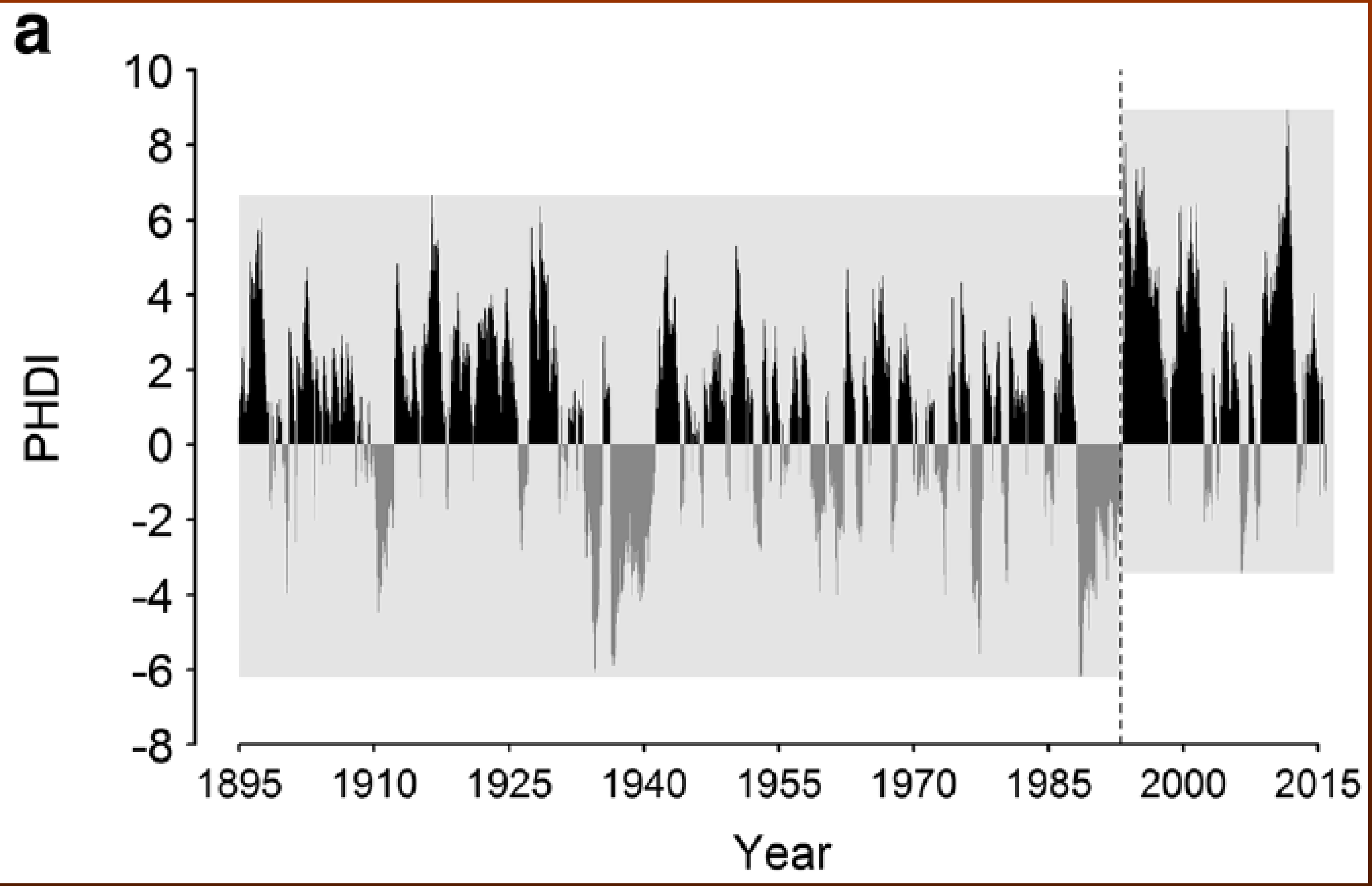
Substantial evidence for a "state shift"



Eventually, the evidence became overwhelming and we published the "state-shift" paper.

McKenna et al., 2017, Evidence for a **climate-induced ecohydrological state shift** in wetland ecosystems of the southern Prairie Pothole Region: *Climatic Change*.

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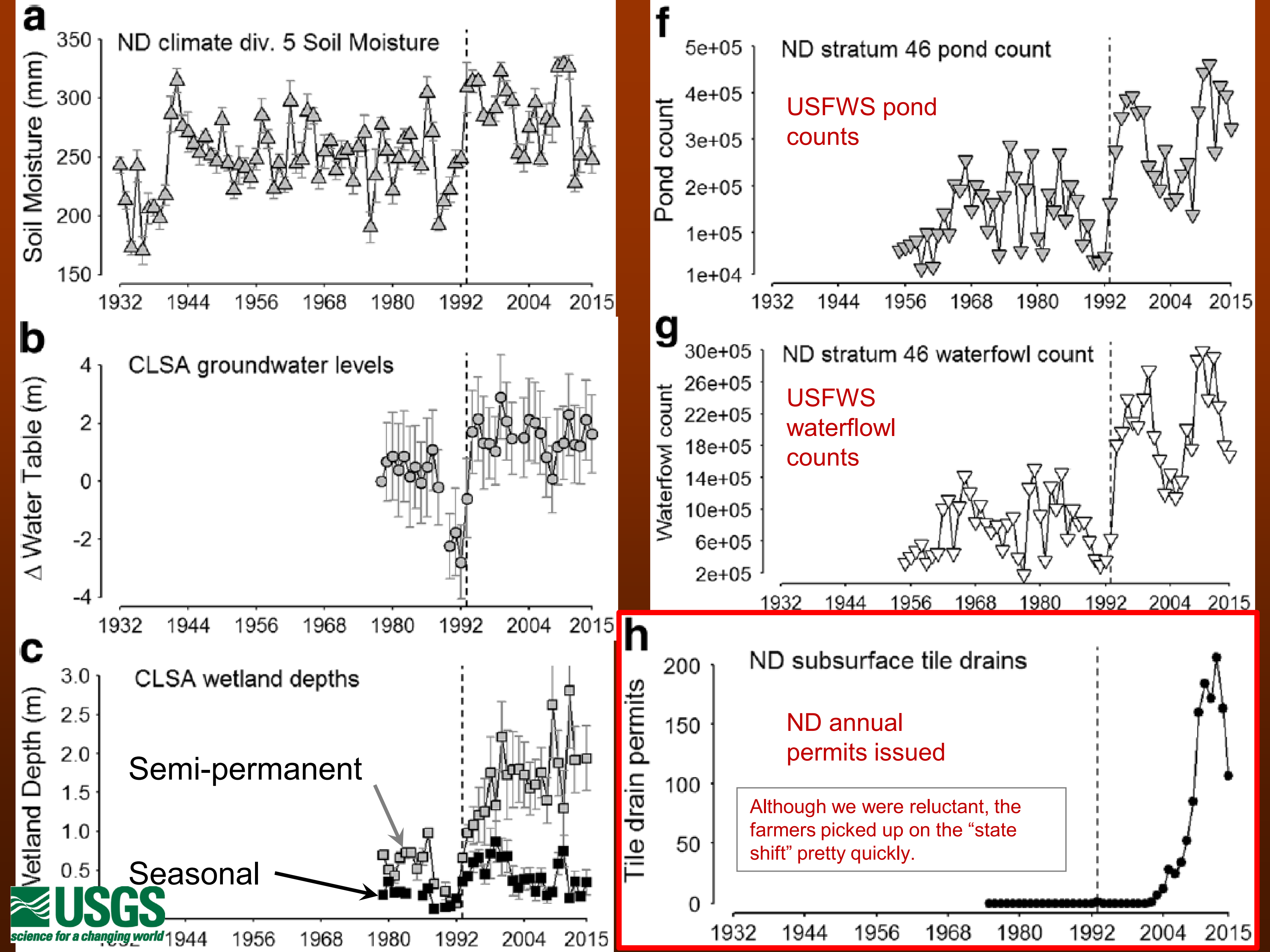
a
ND climate div. 5 Soil Moisture
Soil Moisture (mm)
350
300
250
200
150
1932
1944
1956
1968
1980
1992
2004
2015
b
CLSA groundwater levels
Δ Water Table (m)
4
2
0
-2
-4
c
CLSA wetland depths
Wetland Depth (m)
3.0
2.5
2.0
1.5
1.0
0.5
Semi-permanent
Seasonal
f
ND stratum 46 pond count
Pond count
5e+05
4e+05
3e+05
2e+05
1e+05
1e+04
USFWS pond
counts
g
ND stratum 46 waterfowl count
Waterfowl count
30e+05
26e+05
22e+05
18e+05
14e+05
10e+05
6e+05
2e+05
USFWS
waterflowl
counts
h
ND subsurface tile drains
Tile drain permits
200
150
100
50
0
ND annual
permits issued
Although we were reluctant, the
farmers picked up on the "state
shift" pretty quickly.
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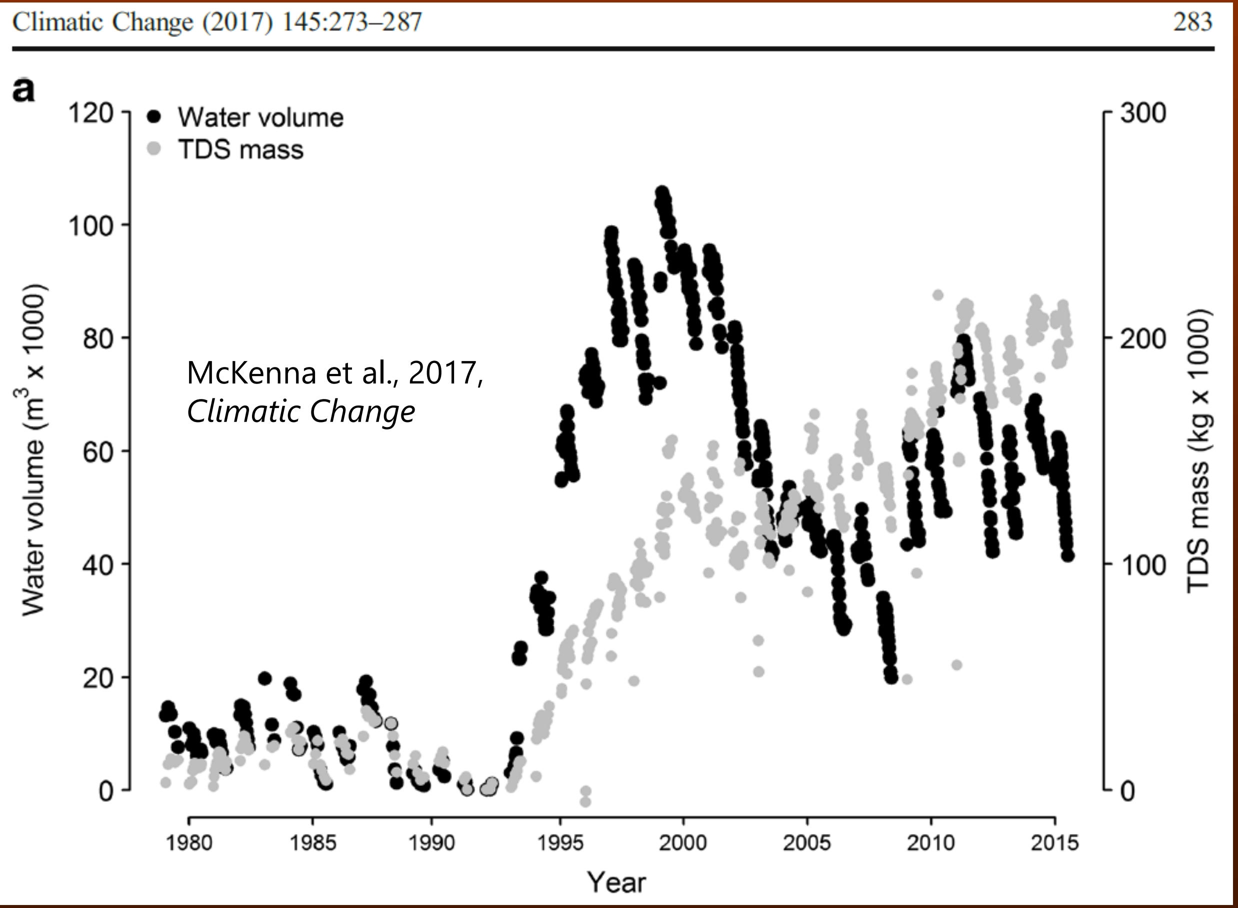
And this long-term change is even affecting wetland salinity



We wondered if this would happen. During dry periods, the water-table troughs surrounding the wetlands were creating troughs of salty GW surrounding the wetlands that allowed the wetlands to be fresher than they otherwise would be. Now, with a persistent wet period that allows the wetlands to extend over those salt stores, the salt is leaching back into the wetlands.

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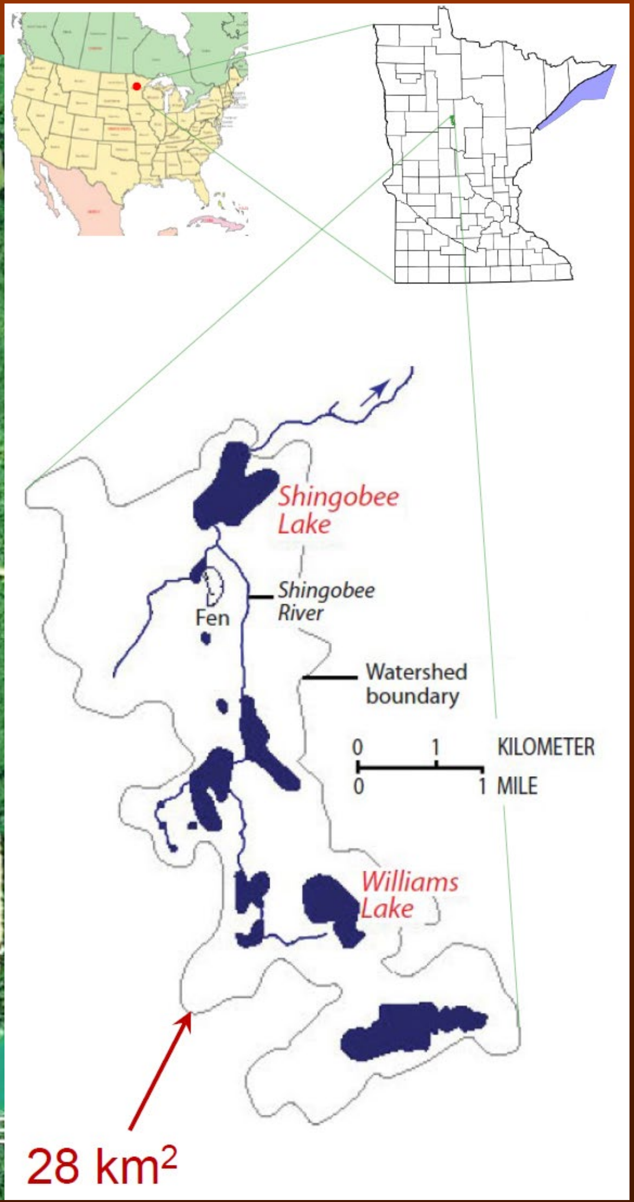
The groundwater response could also be opposite of what is expected



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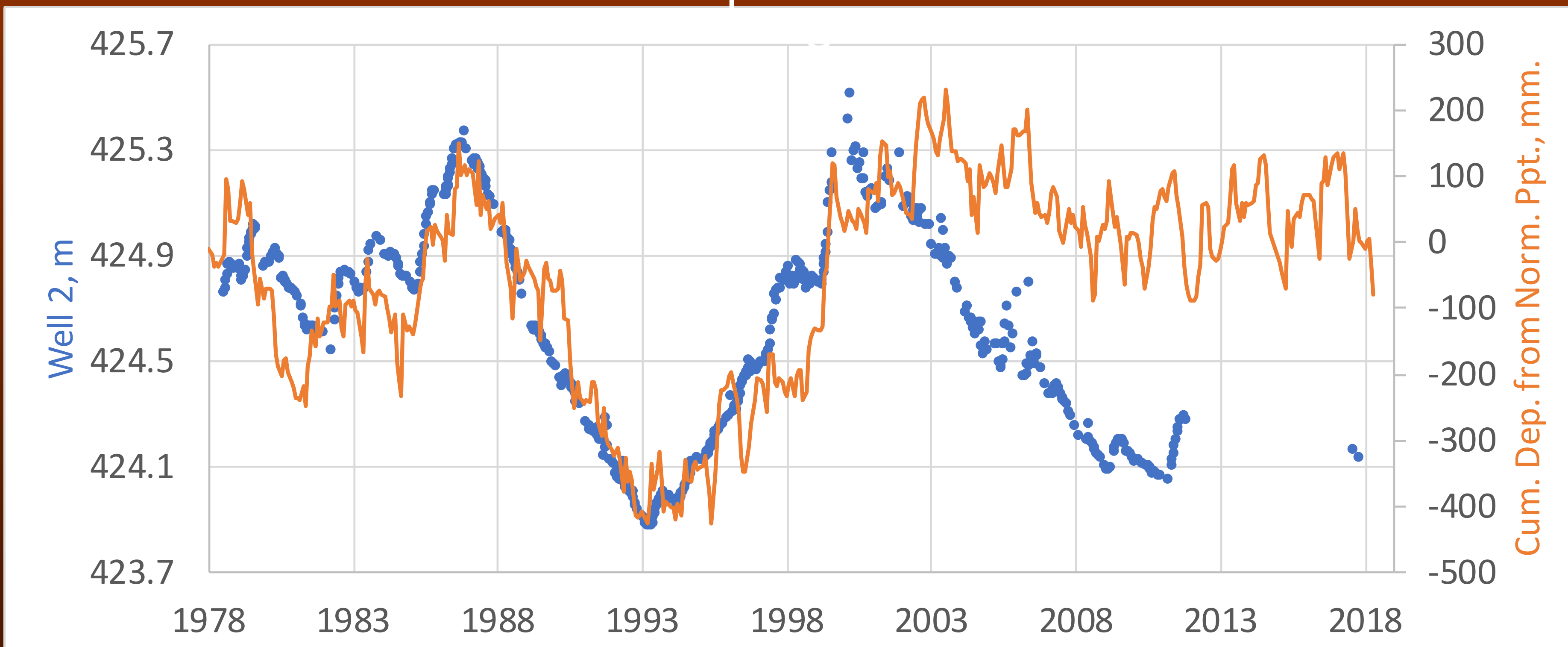
The groundwater response could also be opposite of what is expected

We still have more to do to test this hypothesis, but something clearly changed around 2001 that seems to have reduced GW recharge.

Distribution of ppt. can result in more runoff and less GW



Rosenberry et al., 2019, *AGU Fall conf.*

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But what about connectivity of water and chemicals to downstream receivers?

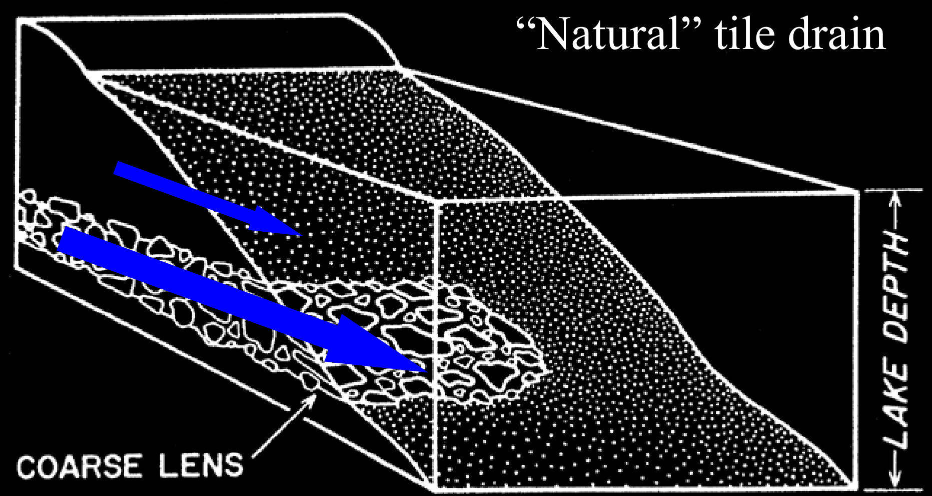

Fig. 5. Three-dimensional schematic drawing of the hypothesized situation at Trout Lake showing a coarse lens intersecting the lakebed.

I have long cited this paper demonstrating preferential flow into a lake, but it never occurred to me that it is very similar to a flooded drain tile situation.

Krabbenhoft and Anderson, 1986, *Ground Water*

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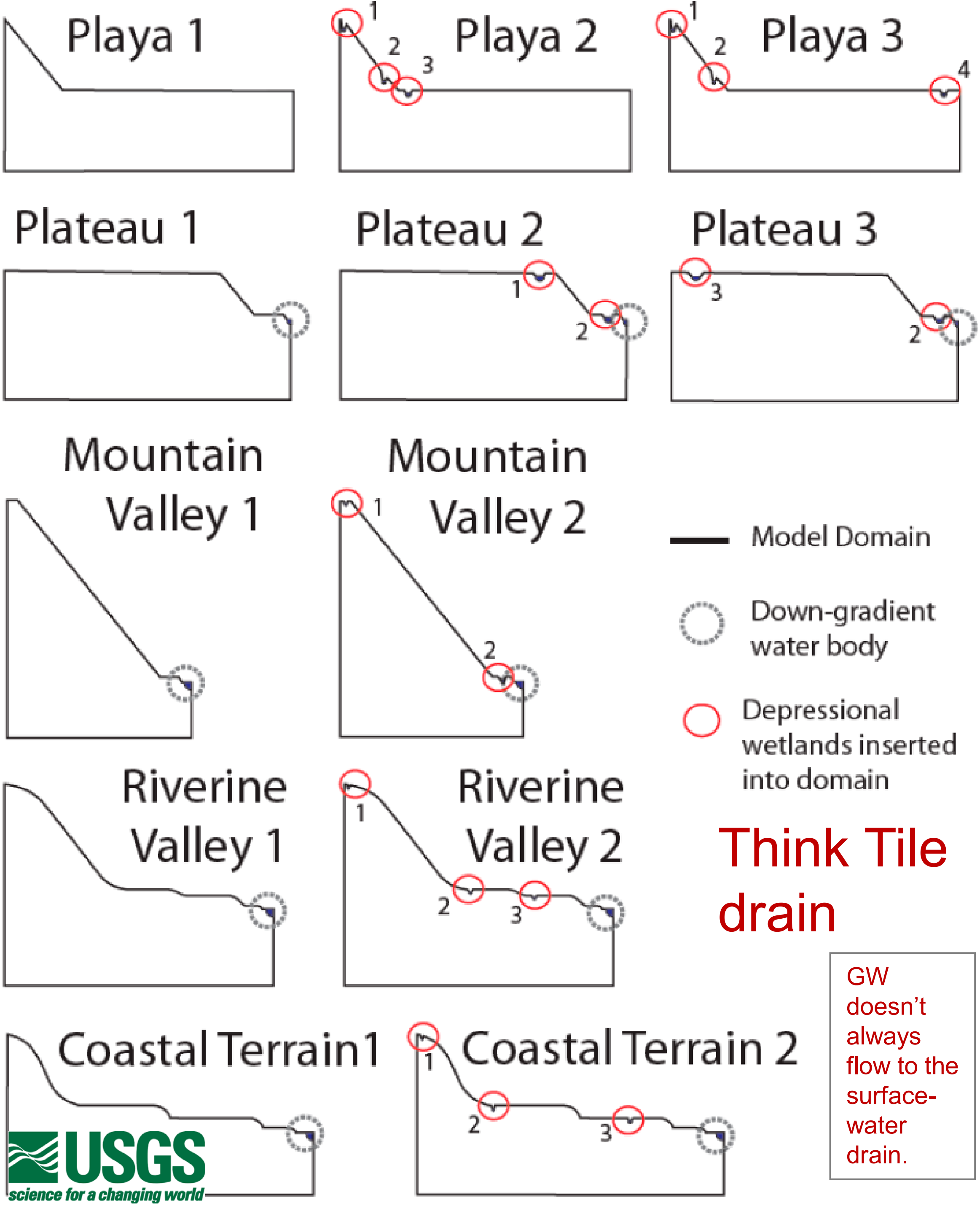


Think Tile drain

GW doesn't always flow to the surface-water drain.

Modeling of connectivity to downstream waters

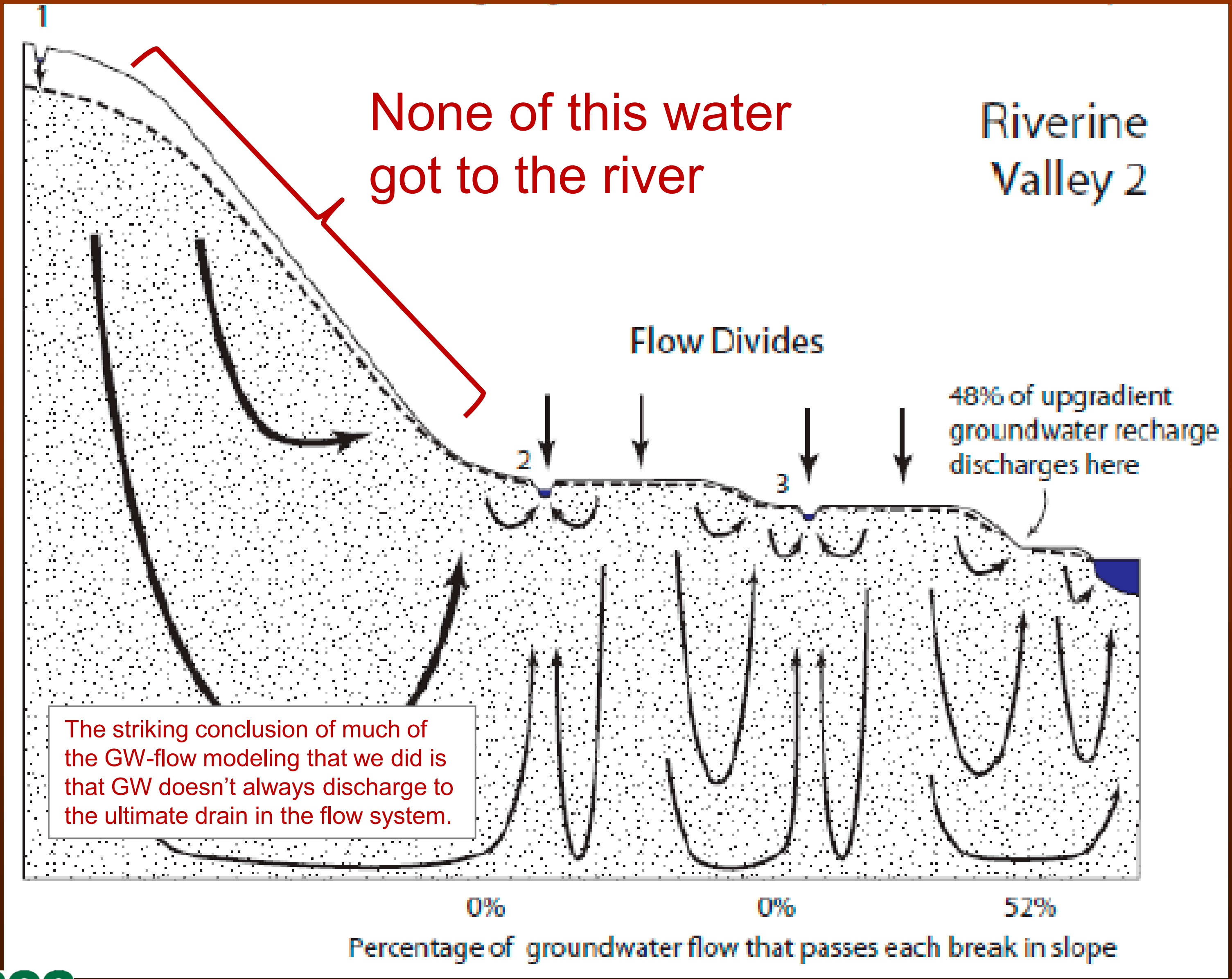
Based on Tom Winter's hydrologic landscapes perspective

Keith Schilling used Hydrogeosphere. We used a simpler 2-d model

Neff & Rosenberry, 2018, *Wetlands*

Neff et al., 2020, *Water*

Connections can be complex in some settings



The striking conclusion of much of the GW-flow modeling that we did is that GW doesn't always discharge to the ultimate drain in the flow system.

Neff et al., 2020, *Water*

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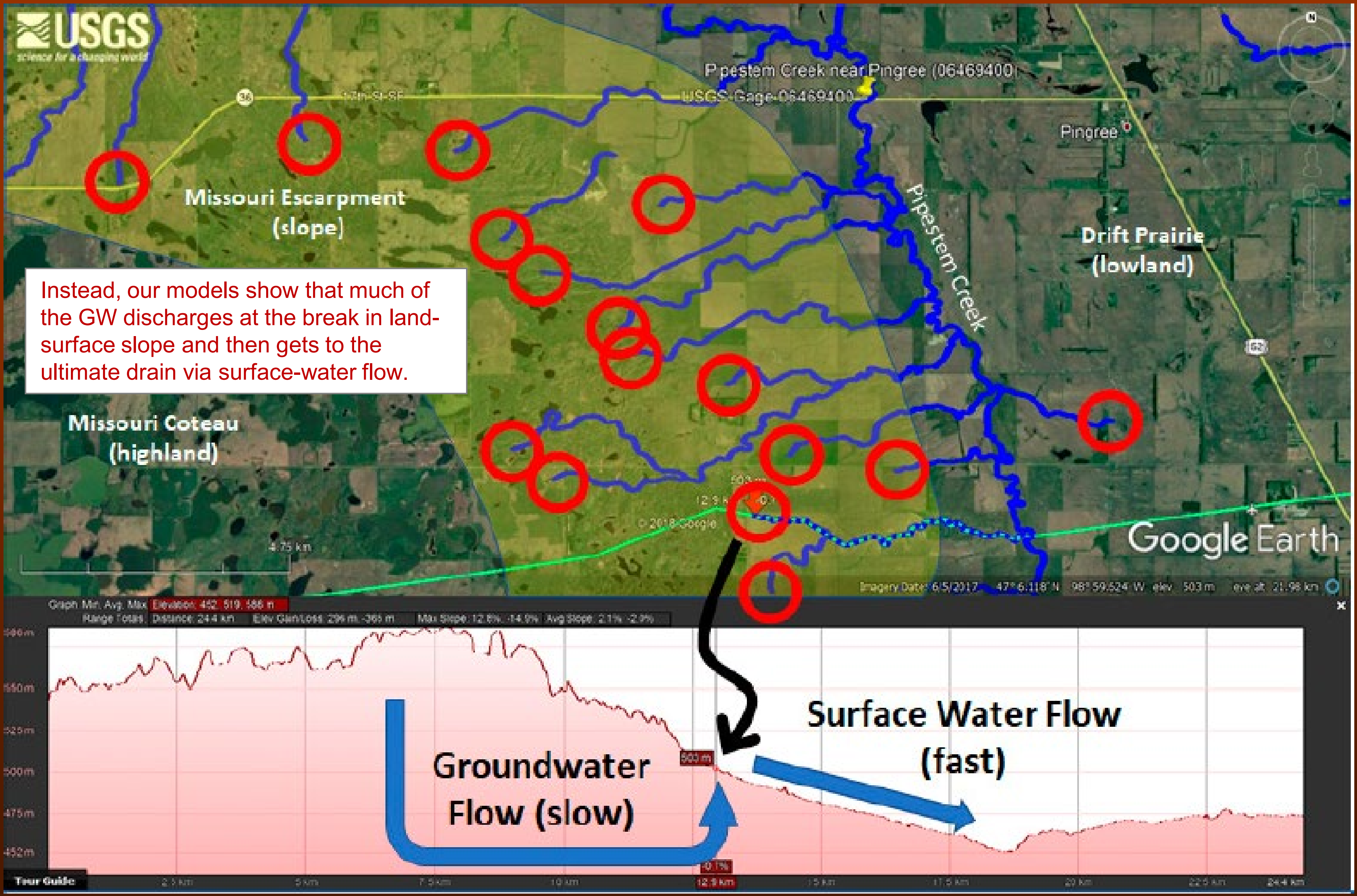
Water logging could be more likely in some settings



Neff et al., 2020, *Water*

So what to do? *Some thoughts from a novice*

- Nobody wants hypoxia in the Gulf
  - Nutrients and water both have value
  - Why not keep both on the landscape?

I was encouraged to learn that letting the water level in shallow monitoring wells turn valves in tile drains on and off is already being done in some areas.

- There is a “sweet spot” of depth to groundwater (1 to 1.5 m) that is most beneficial to crop yield. We seem to manage well for this.

1. Farmers manage well for top-down recharge but not so well for bottom-up (rising water table)
   - Install shallow GW monitoring wells in known wet areas that can alert farmers when the depth to water (DTW) is getting dangerously small (close to the drains)
   - Install valves on drains to shut them down when they’re not really needed, and to automatically turn them on when DTW gets too small
     - Shutting down drains when not needed will allow greater recharge to GW, a higher water table in general, which will slow drying of soils overall

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So what to do? *Some ideas from a novice*

2. Manage the outlet. Run drains to low, closed basins (likely former wetlands) for ponding rather than to a streamflow network
   - This provides temporary storage and keeps nutrients and pesticides from entering rivers
   - Pump water from those ponds for irrigation during dry times
   - Pumping could be timed to coincide with excess supply in the grid
3. Allow money to flow uphill as well
   - Provide credits to farmers who “re-use” the drained water (from savings related to reduced need for hypoxia mitigation)

Keeping water in the watershed may not seem smart during wet periods, but it could be of substantial value during times when crops, either higher on the landscape or during prolonged dry periods, are stressed due to dry soils. Re-use of ponded water could also serve to recycle nutrients to some extent.

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So what to do? *Some ideas from a novice*

Companies already send well-level data via bluetooth

Could even install stock ponds like we do in more arid regions

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Additional discussion and ideas!

I mentioned the idea of creating artificial water-table mounds parallel to streams that could prevent nutrient-rich tile drainage or GW flow from getting to the stream or river. Evidently that is already being done in some places. Another idea, where storage of excess water in a pond is not an option, could be to install a vastly increased density of tile drains. Those drains could be closed and then serve as underground water storage that could be pumped to the surface during dry times.

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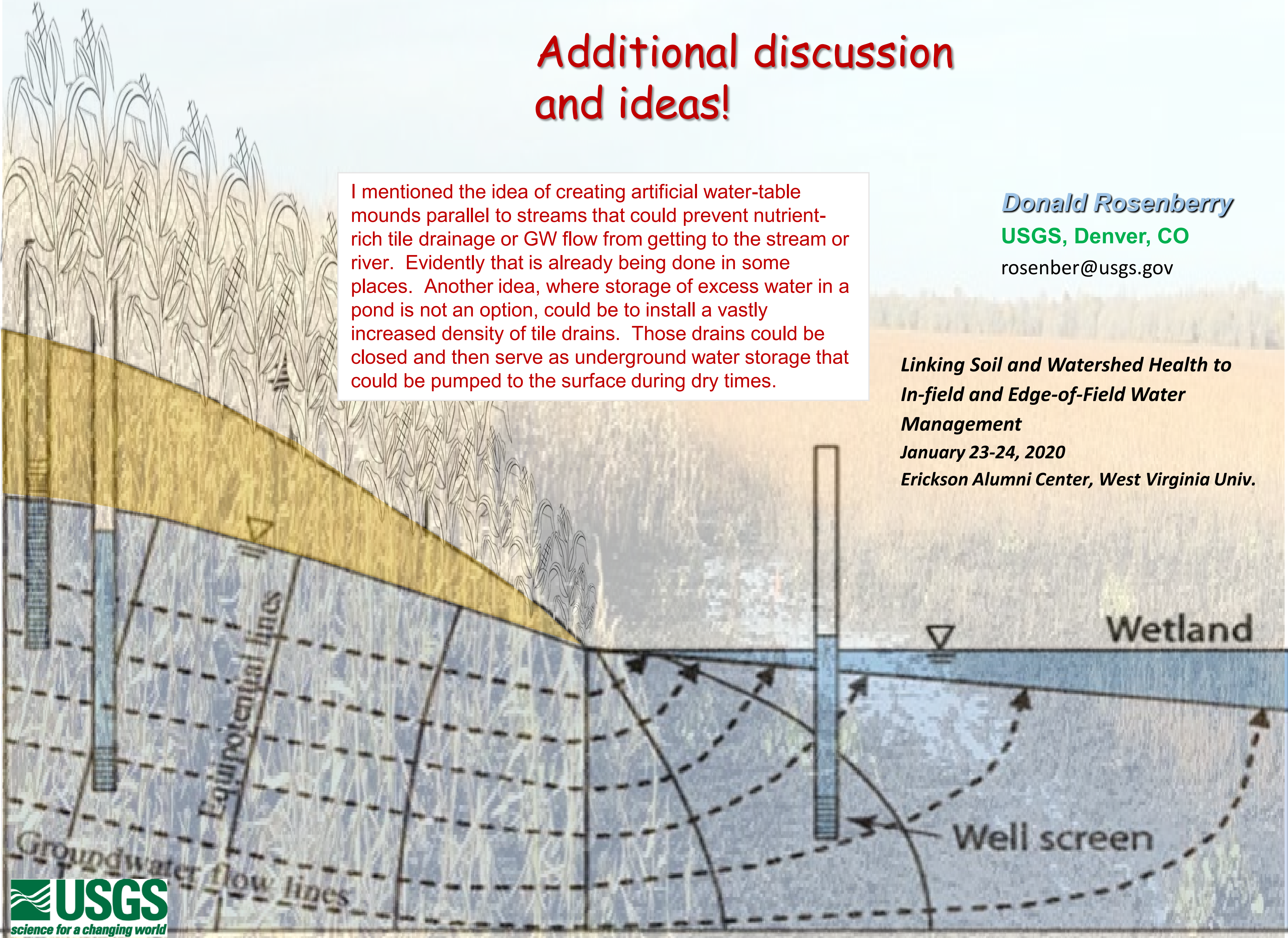

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