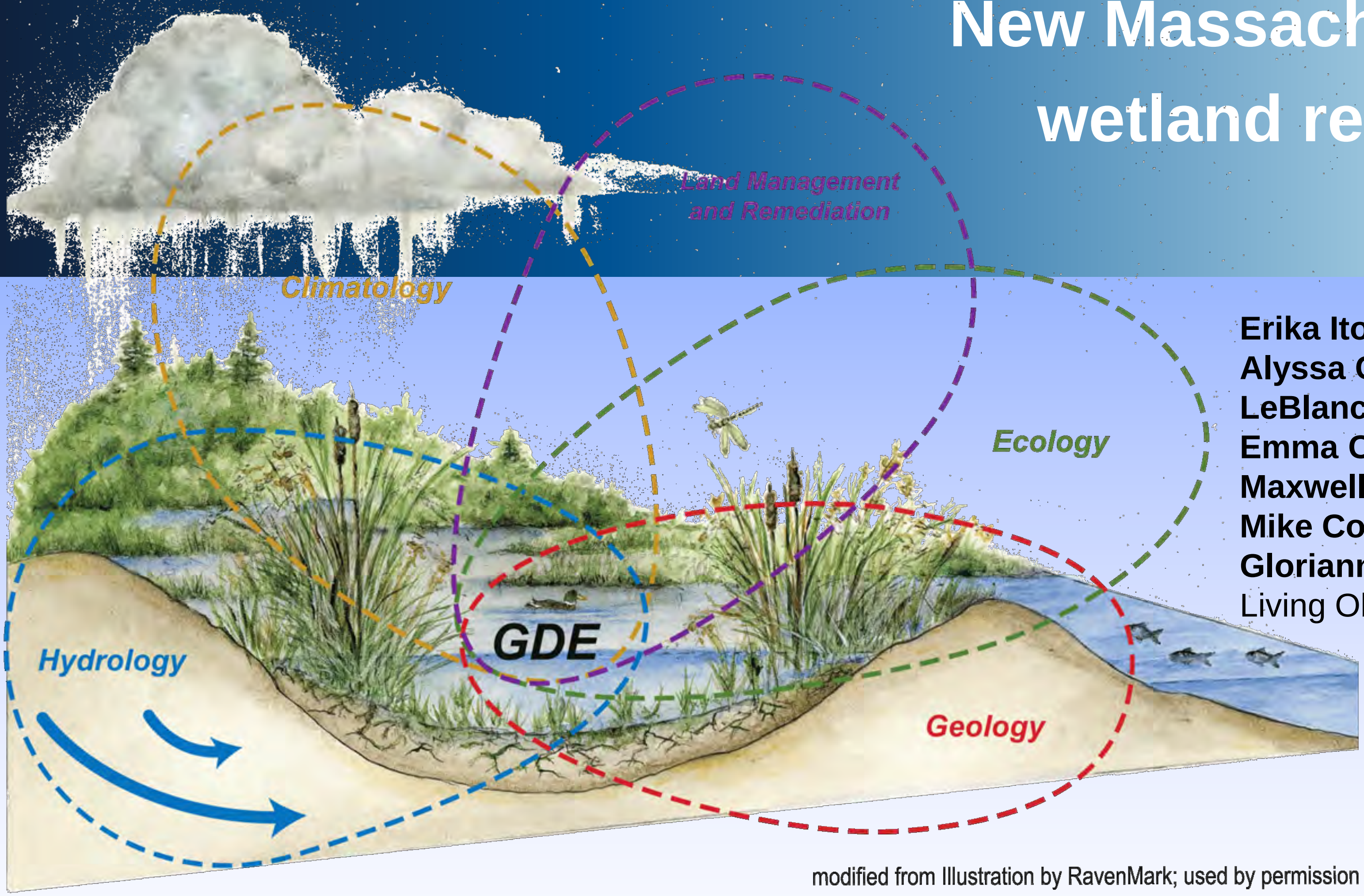
Groundwater Dependent Ecosystems: New Massachusetts wetland research



modified from Illustration by RavenMark; used by permission

Erika Ito, Luke McInnis, Alyssa Chase, Jeron LeBlanc, Julia Casey, Emma Cady, Marie Maxwell & more,
Mike Cosh, USDA-ARS,
Glorianna Davenport, Living Observatory

Christine E. Hatch
Lyn Watts
Earth, Geographic, and Climate Sciences

UMASS AMHERST

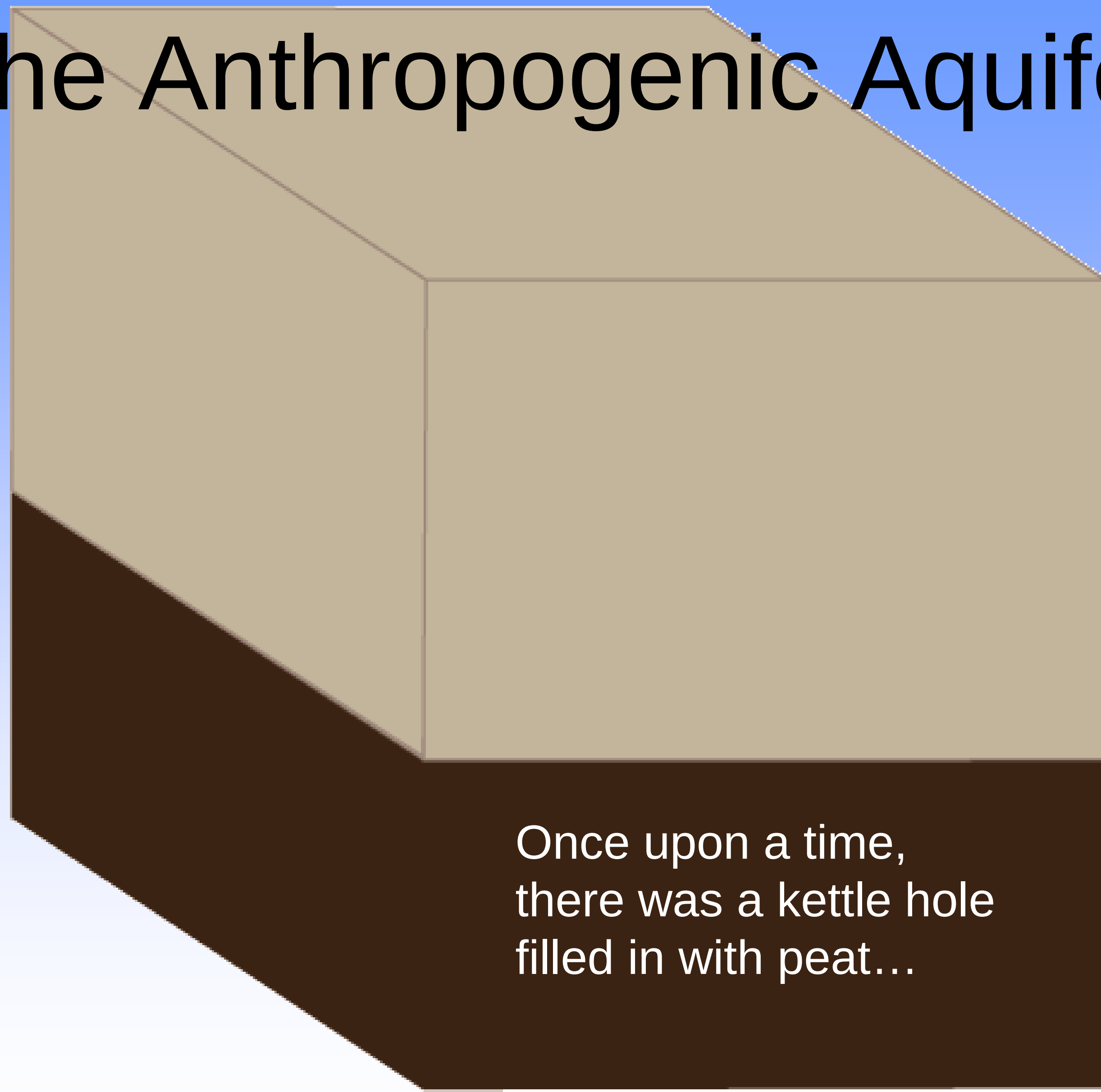
LIVING OBSERVATORY

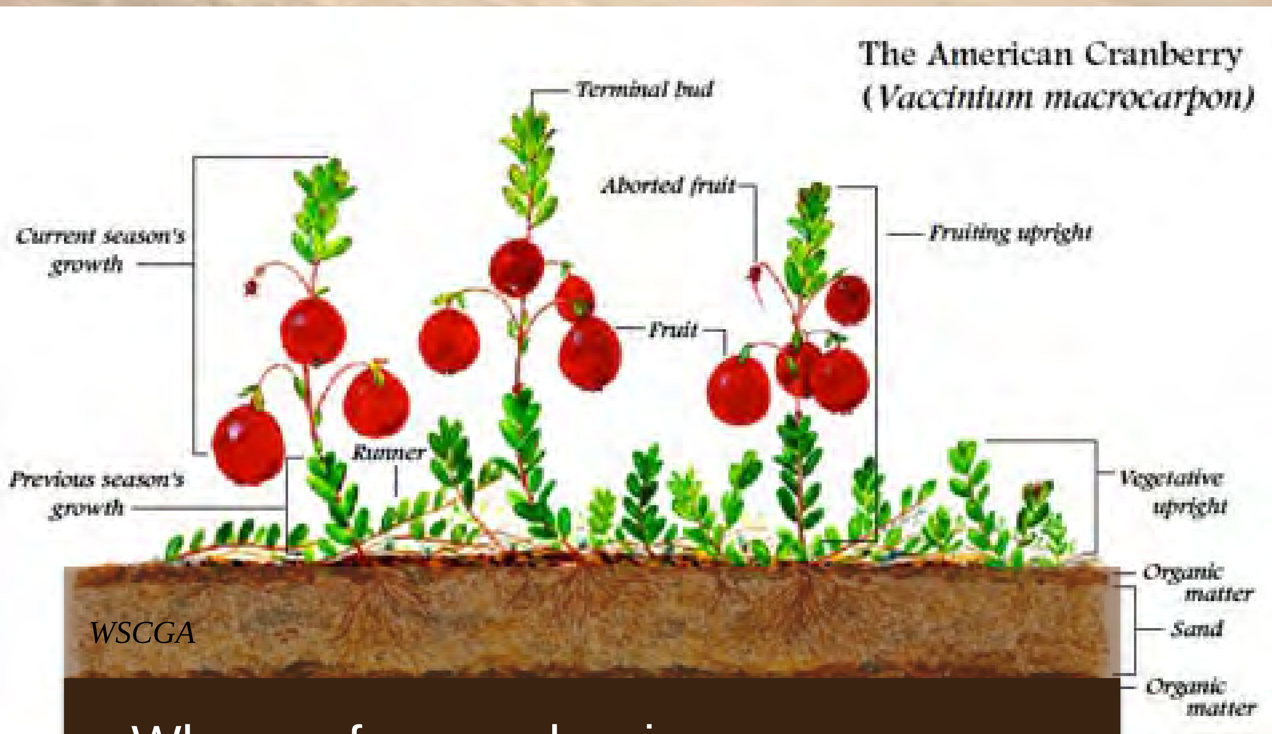
The Center *for* Agriculture, Food and the Environment

The Anthropogenic Aquifer

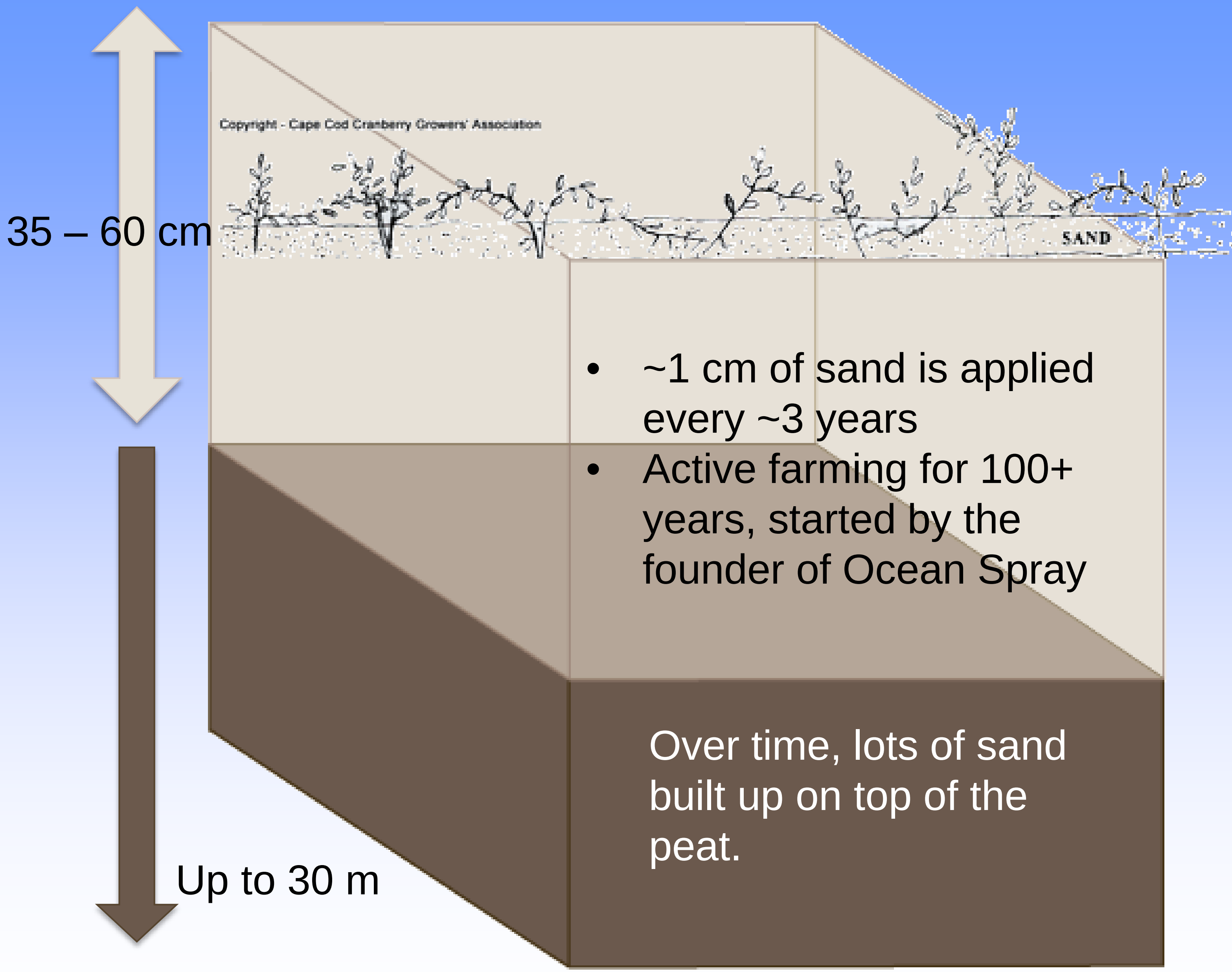
Once upon a time,
there was a kettle hole
filled in with peat…

The Anthropogenic Aquifer



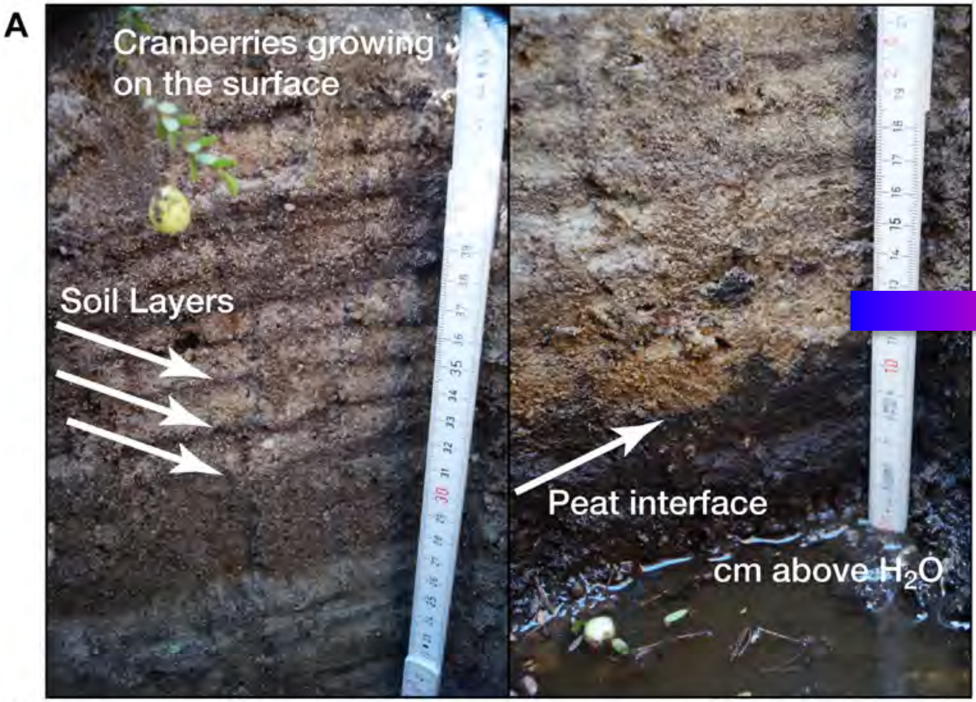


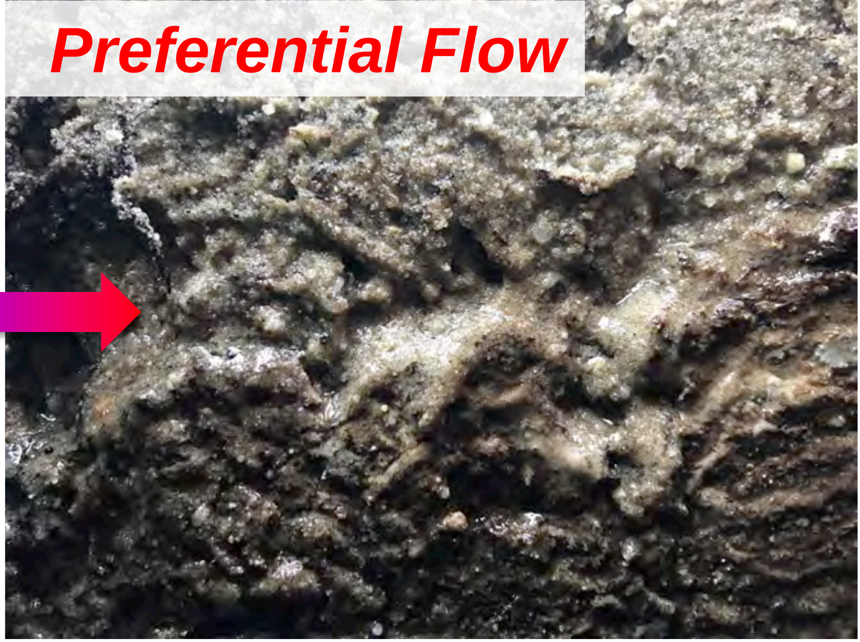
Where a few cranberries grew, we planted more. The happiest plants were next to some sand dunes…

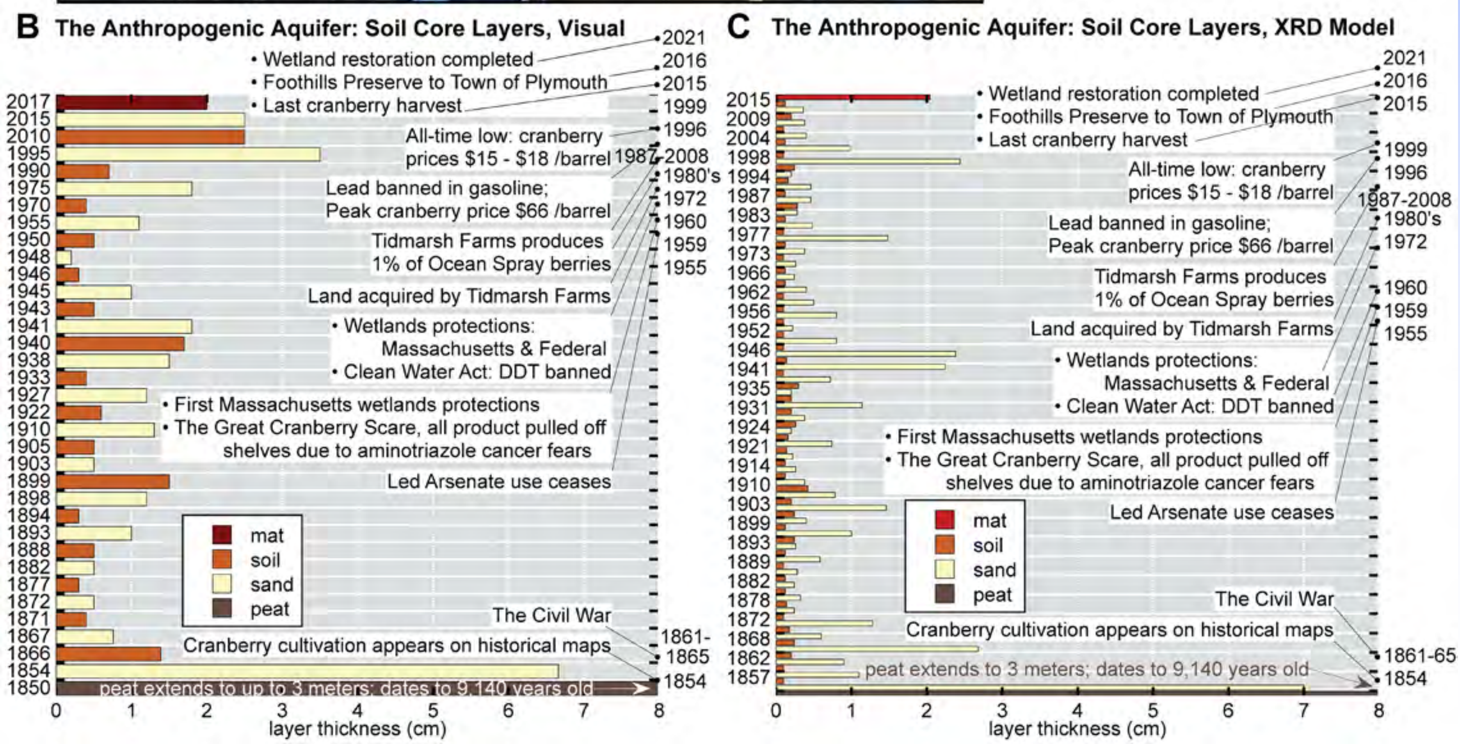

35 – 60 cm
Copyright - Cape Cod Cranberry Growers' Association
SAND
• ~1 cm of sand is applied every ~3 years
• Active farming for 100+ years, started by the founder of Ocean Spray
Over time, lots of sand built up on top of the peat.
Up to 30 m

Recovering groundwater for wetlands from an anthropogenic aquifer

Over time, a layered aquifer was established


A
Cranberries growing on the surface
Soil Layers
Peat interface
cm above H_2O


Preferential Flow


B The Anthropogenic Aquifer: Soil Core Layers, Visual
• Wetland restoration completed
• Foothills Preserve to Town of Plymouth
• Last cranberry harvest
All-time low: cranberry prices $15 - $18 /barrel
Lead banned in gasoline; Peak cranberry price $66 /barrel
Tidmarsh Farms produces 1% of Ocean Spray berries
Land acquired by Tidmarsh Farms
• Wetlands protections: Massachusetts & Federal
• Clean Water Act: DDT banned
• First Massachusetts wetlands protections
• The Great Cranberry Scare, all product pulled off shelves due to aminotriazole cancer fears
Led Arsenate use ceases
The Civil War
Cranberry cultivation appears on historical maps
peat extends to up to 3 meters; dates to 9,140 years old
2021
2016
2015
1999
1996
1987-2008
1980's
1972
1960
1959
1955
1861-1865
1854
2017
2015
2010
1995
1990
1975
1970
1955
1950
1948
1946
1945
1943
1941
1940
1938
1933
1927
1922
1910
1905
1903
1899
1898
1894
1893
1888
1882
1877
1872
1871
1867
1866
1854
1850
mat
soil
sand
peat
0 1 2 3 4 5 6 7 8
layer thickness (cm)
C The Anthropogenic Aquifer: Soil Core Layers, XRD Model
• Wetland restoration completed
• Foothills Preserve to Town of Plymouth
• Last cranberry harvest
All-time low: cranberry prices $15 - $18 /barrel
Lead banned in gasoline; Peak cranberry price $66 /barrel
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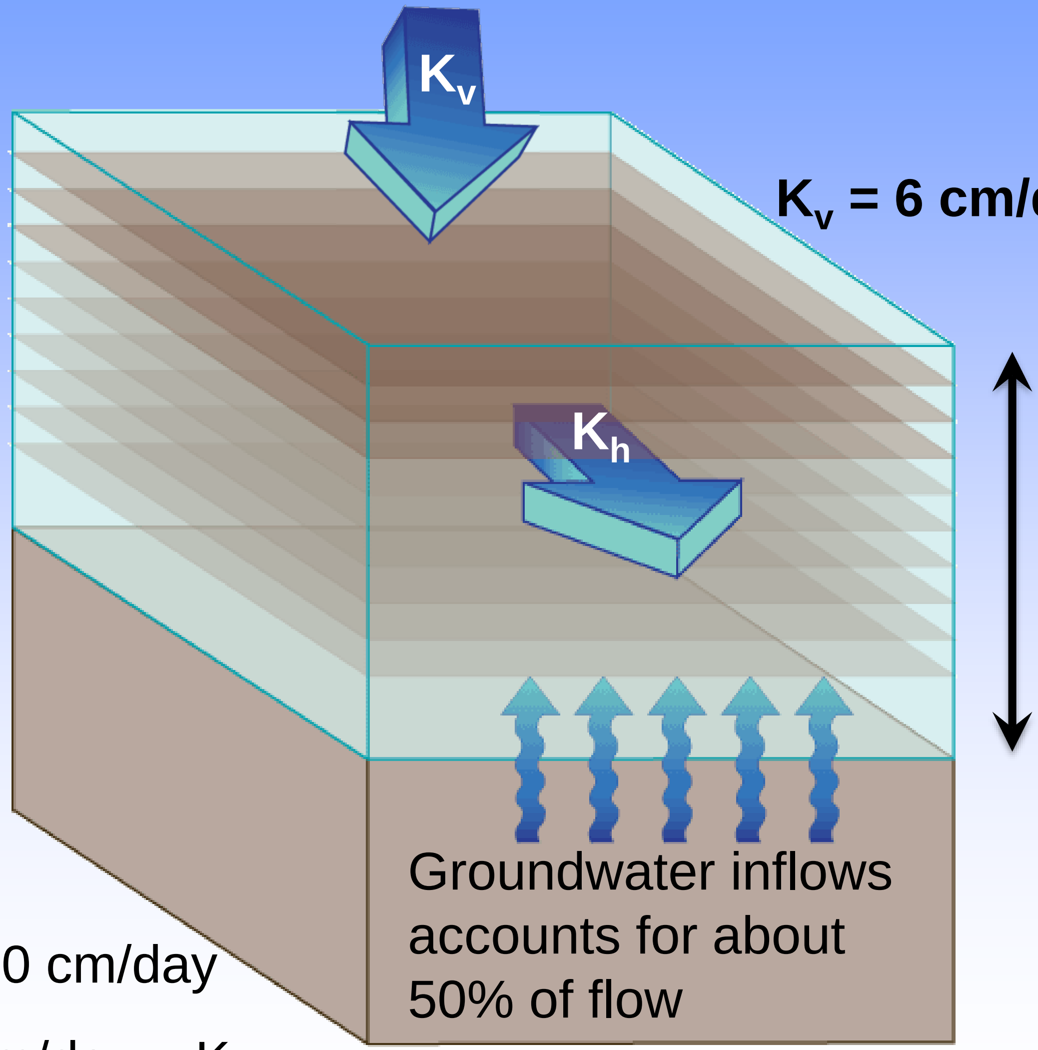
2021
2016
2015
1999
1996
1987-2008
1980's
1972
1960
1959
1955
1861-65
1854
2015
2009
2004
1998
1994
1987
1983
1977
1973
1966
1962
1956
1952
1946
1941
1935
1931
1924
1921
1914
1910
1903
1899
1893
1889
1882
1878
1872
1868
1862
1857
mat
soil
sand
peat
0 1 2 3 4 5 6 7 8
layer thickness (cm)

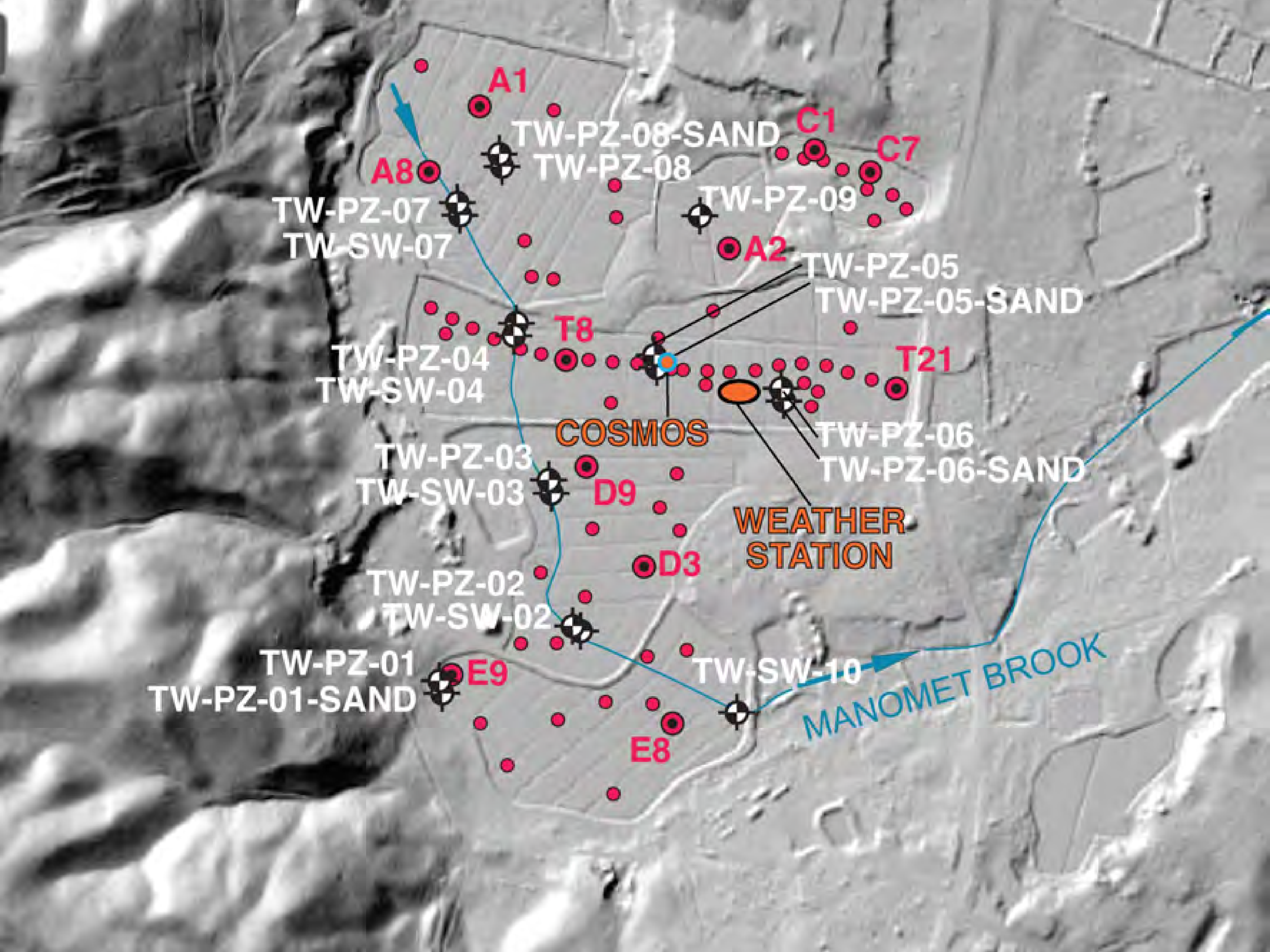
The anthropogenic aquifer creates anisotropic preferential flow



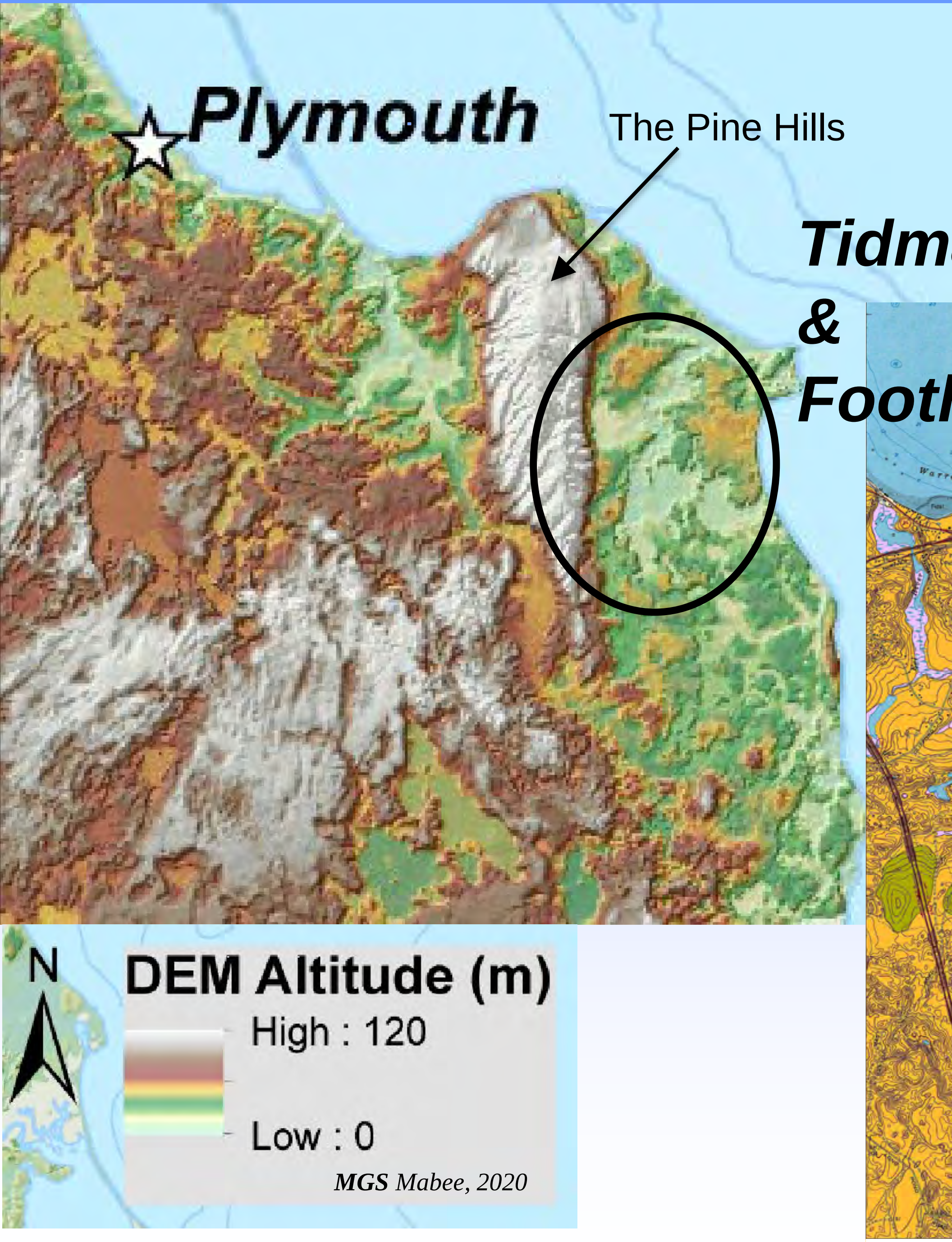
$$\frac{K_h}{K_v} = 22$$

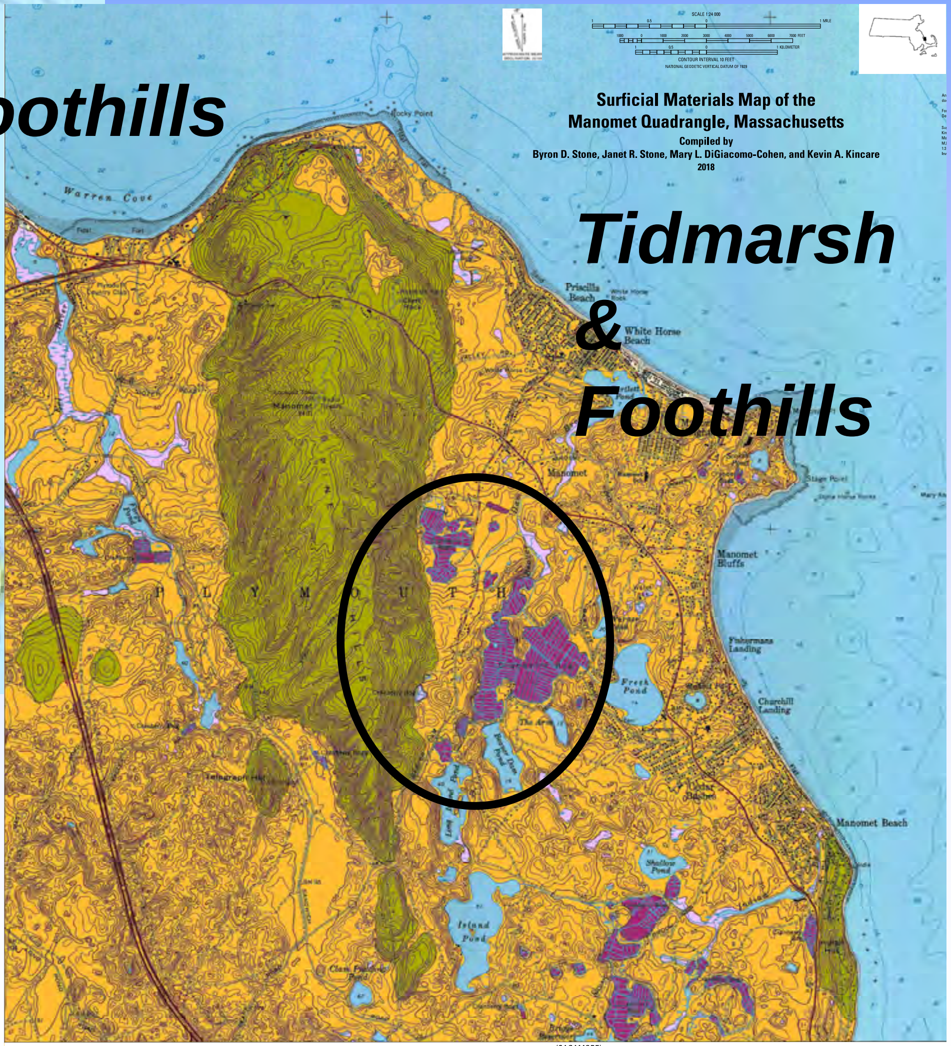
K_{sand} = 200 cm/day

K_{soil} = 2 cm/day ~ K_{peat}

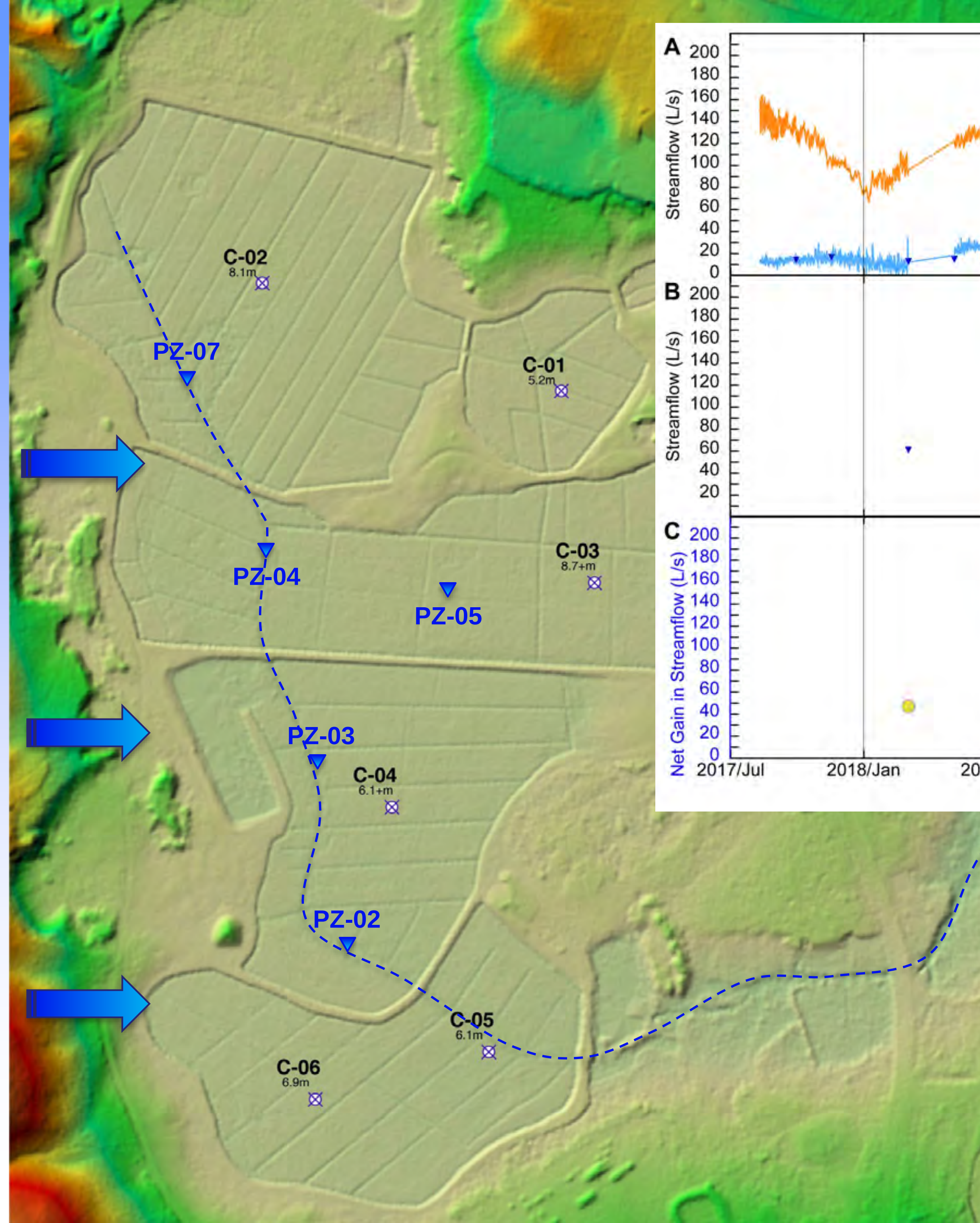


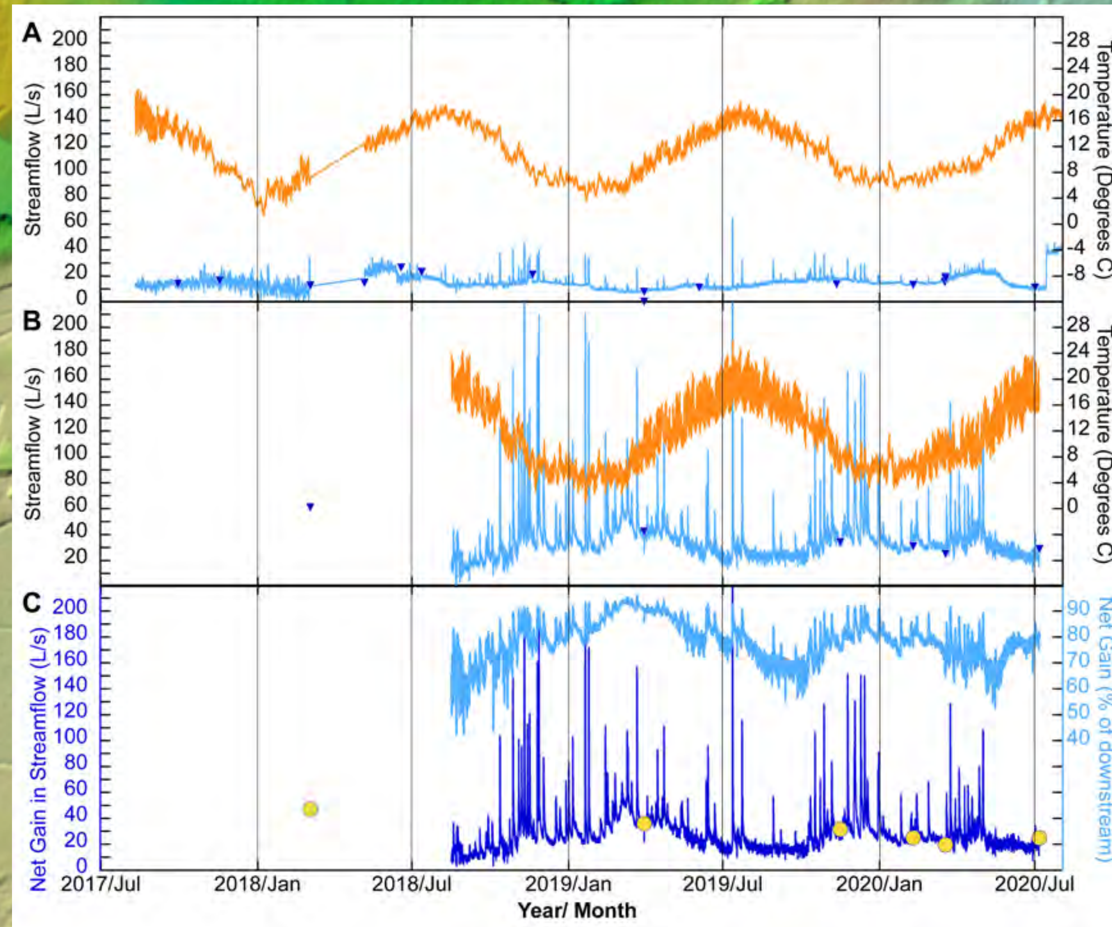
A1
TW-PZ-08-SAND
TW-PZ-08
C1
C7
A8
TW-PZ-07
TW-SW-07
TW-PZ-09
A2
TW-PZ-05
TW-PZ-05-SAND
T8
T21
TW-PZ-04
TW-SW-04
COSMOS
TW-PZ-06
TW-PZ-06-SAND
TW-PZ-03
TW-SW-03
D9
WEATHER STATION
D3
TW-PZ-02
TW-SW-02
TW-PZ-01
TW-PZ-01-SAND
E9
TW-SW-10
MANOMET BROOK
E8



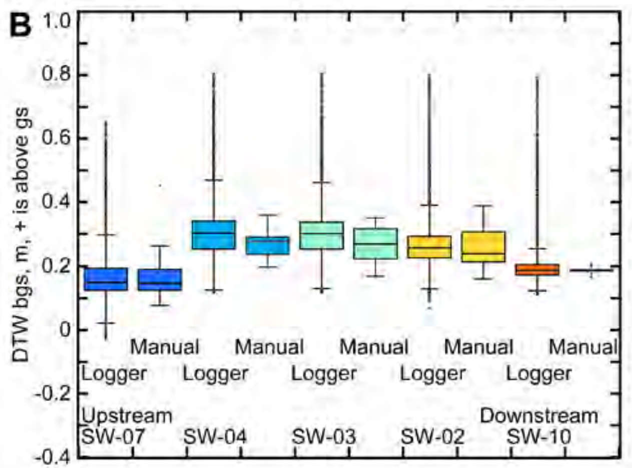


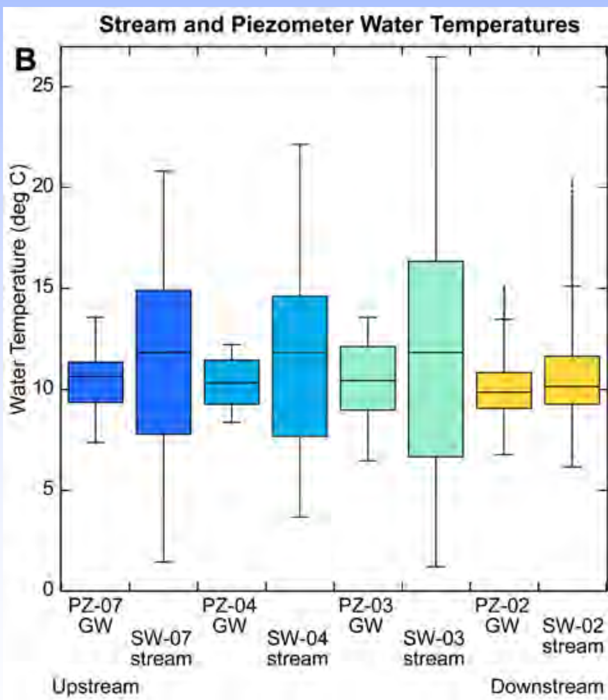
USGS Stone et al., 2018

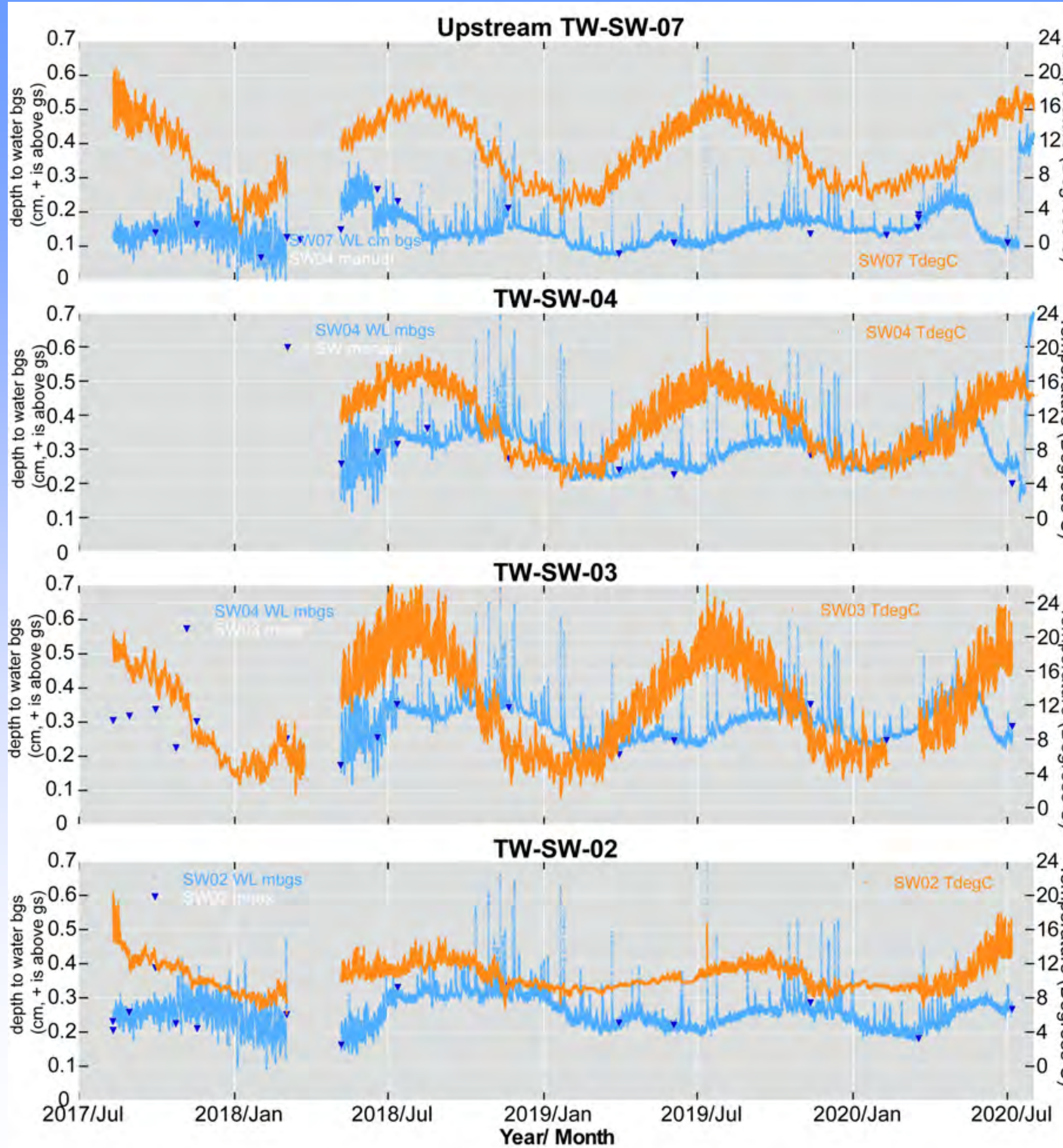


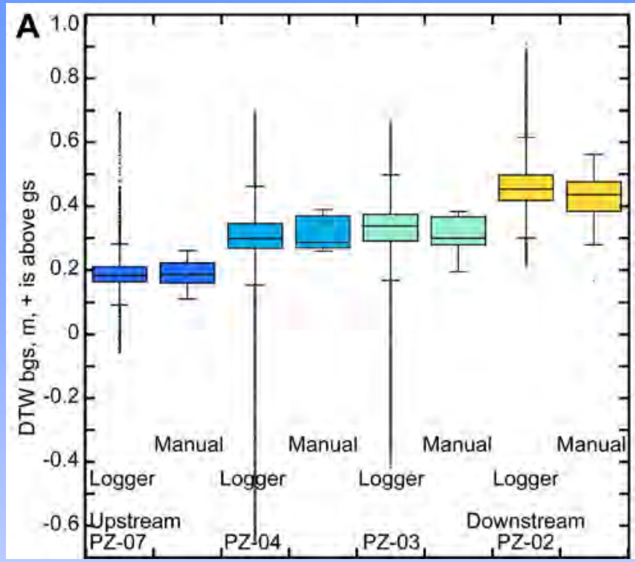


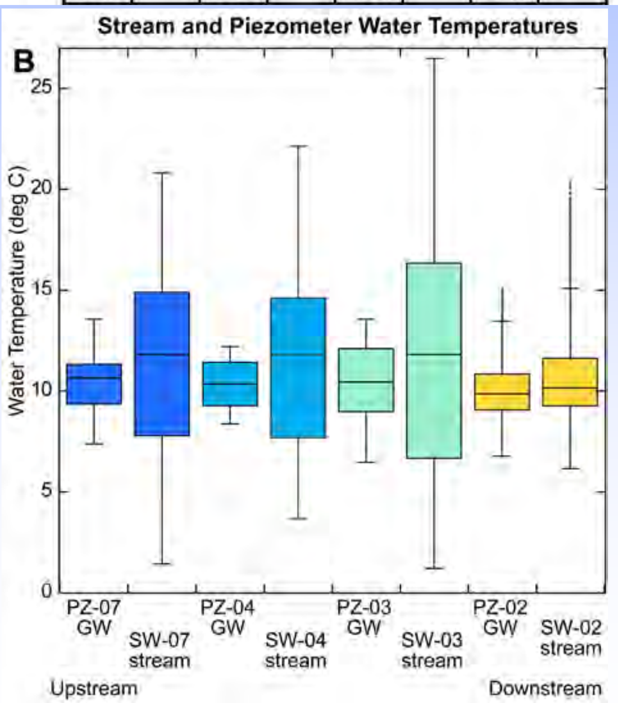
- streamflow indicates that groundwater inflows account for 50 - 80% of flow year round

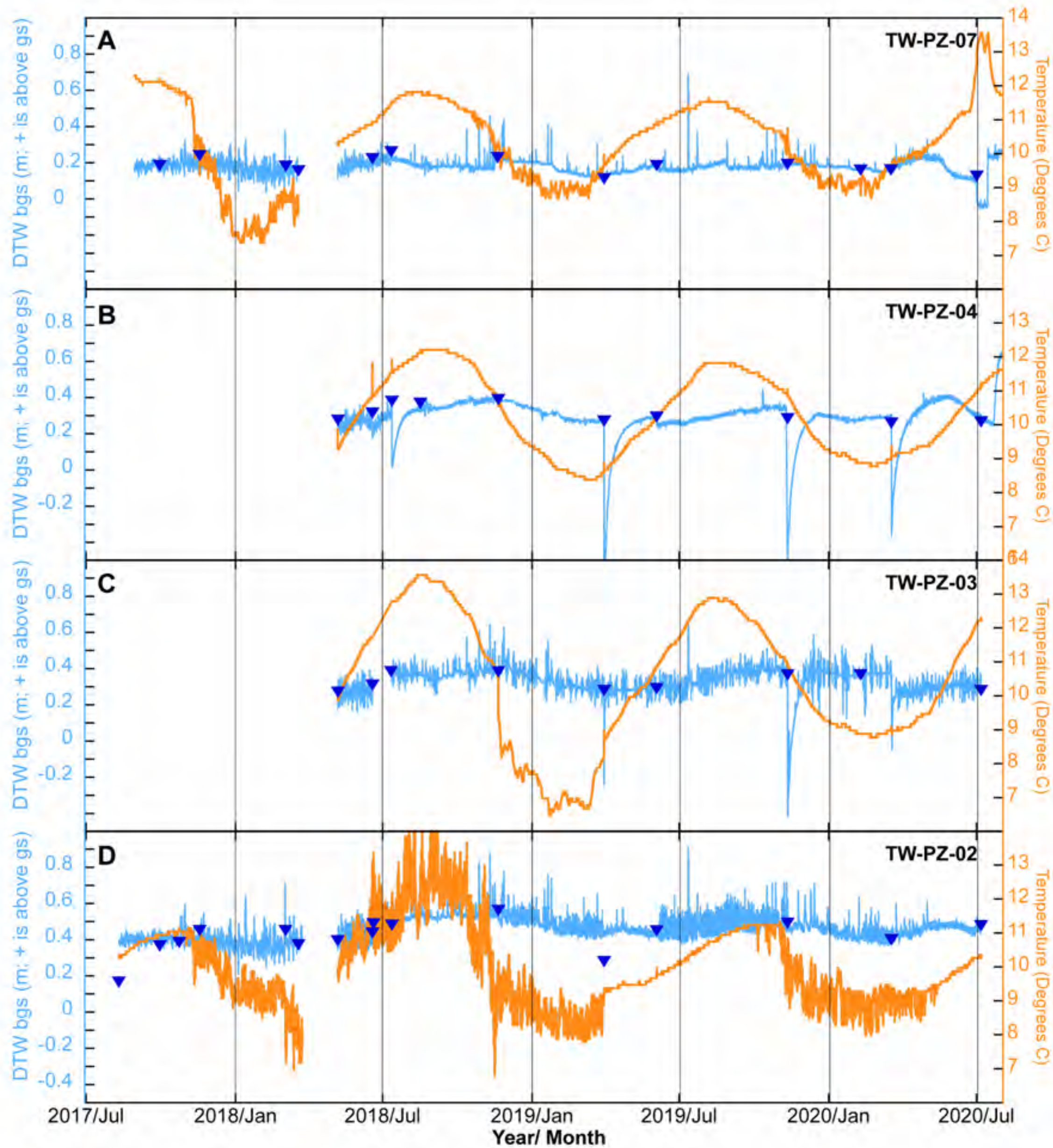

B
DTW bgs, m, + is above gs
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Manual
Manual
Manual
Manual
Manual
Logger
Logger
Logger
Logger
Logger
Upstream
SW-07
SW-04
SW-03
SW-02
Downstream
SW-10

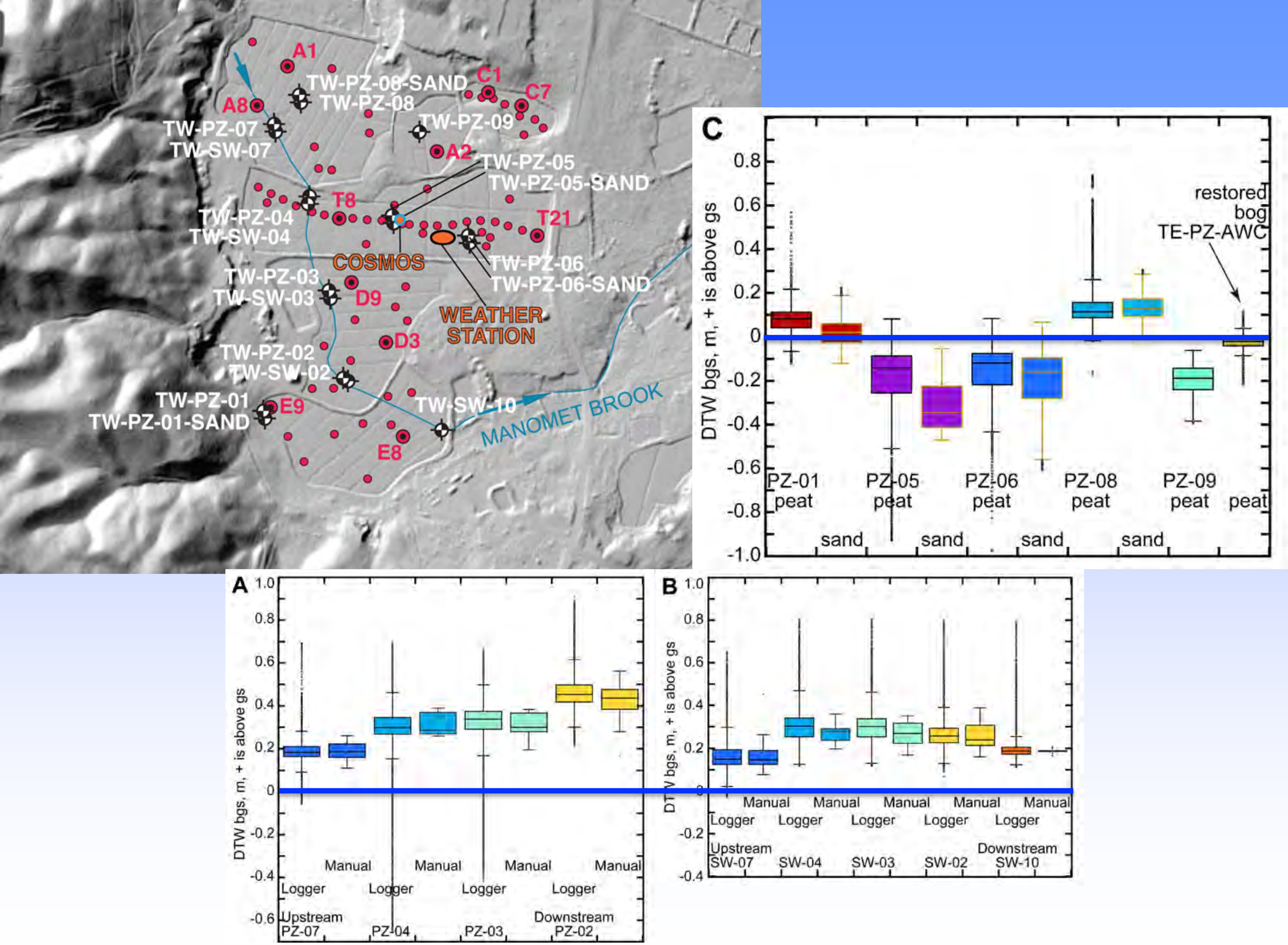

Stream and Piezometer Water Temperatures
B
Water Temperature (deg C)
25
20
15
10
5
0
PZ-07 GW
SW-07 stream
PZ-04 GW
SW-04 stream
PZ-03 GW
SW-03 stream
PZ-02 GW
SW-02 stream
Upstream
Downstream

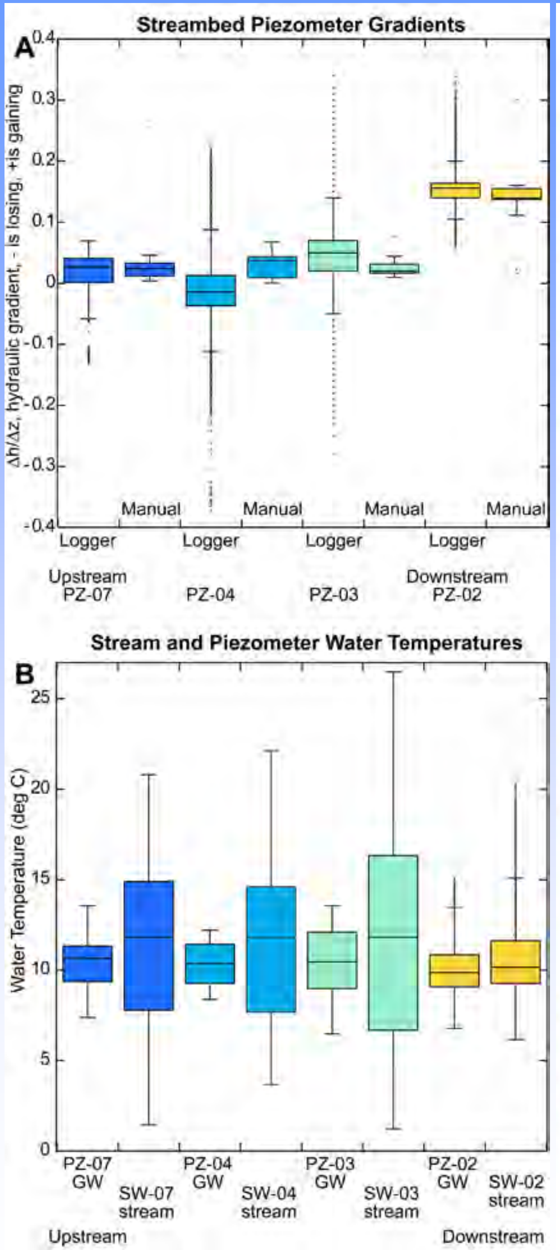

Upstream TW-SW-07
SW07 WL cm bgs
SW07 TdegC
TW-SW-04
SW04 WL mbgs
SW04 TdegC
TW-SW-03
SW04 WL mbgs
SW03 TdegC
TW-SW-02
SW02 WL mbgs
SW02 TdegC
depth to water bgs (cm, + is above gs)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Temperature (Degrees C)
24
20
16
12
8
4
0
2017/Jul
2018/Jan
2018/Jul
2019/Jan
2019/Jul
2020/Jan
2020/Jul
Year/ Month

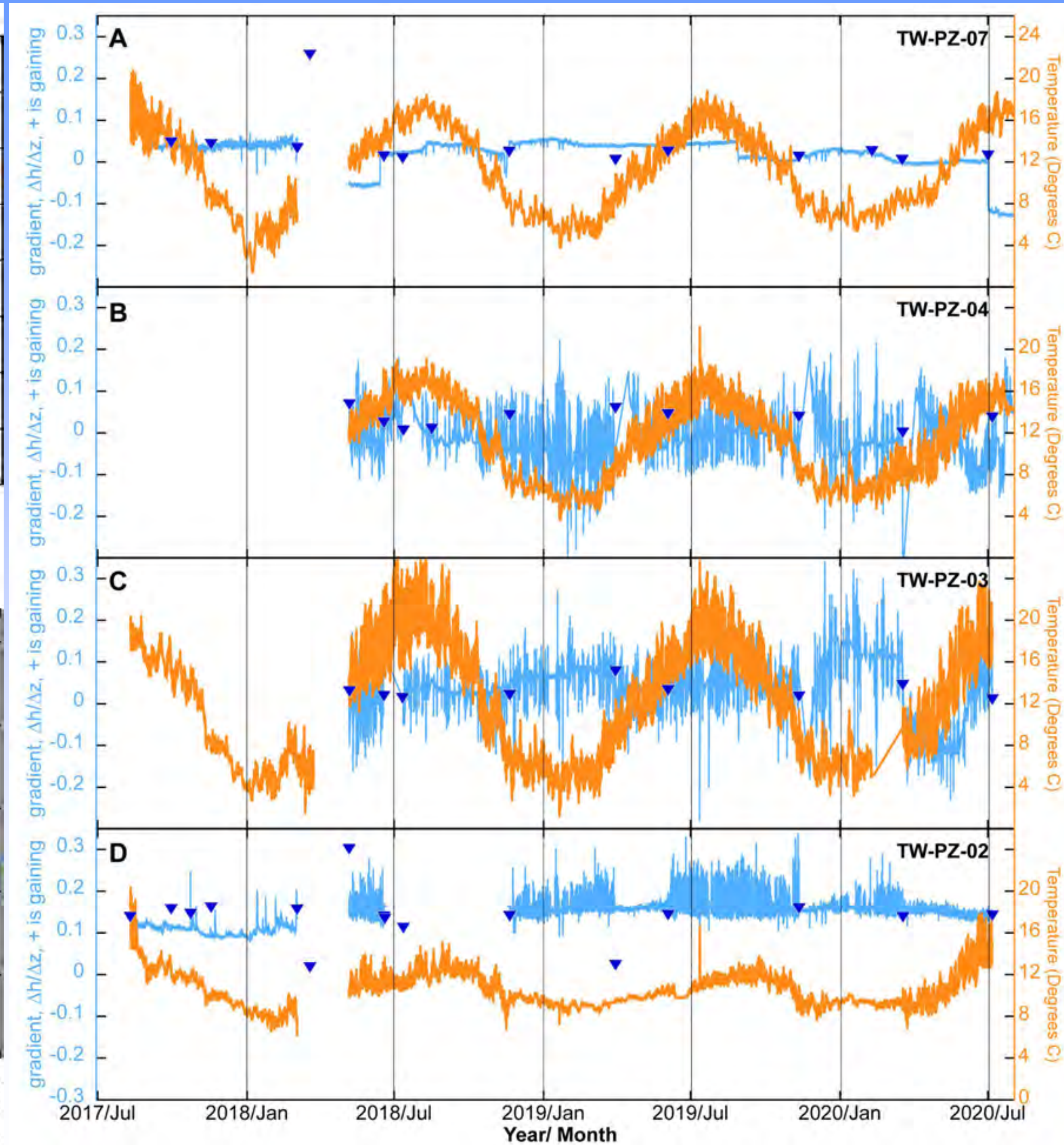

A
DTW bgs, m, + is above gs
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Manual
Manual
Manual
Manual
Logger
Logger
Logger
Logger
Upstream
PZ-07
PZ-04
PZ-03
Downstream
PZ-02

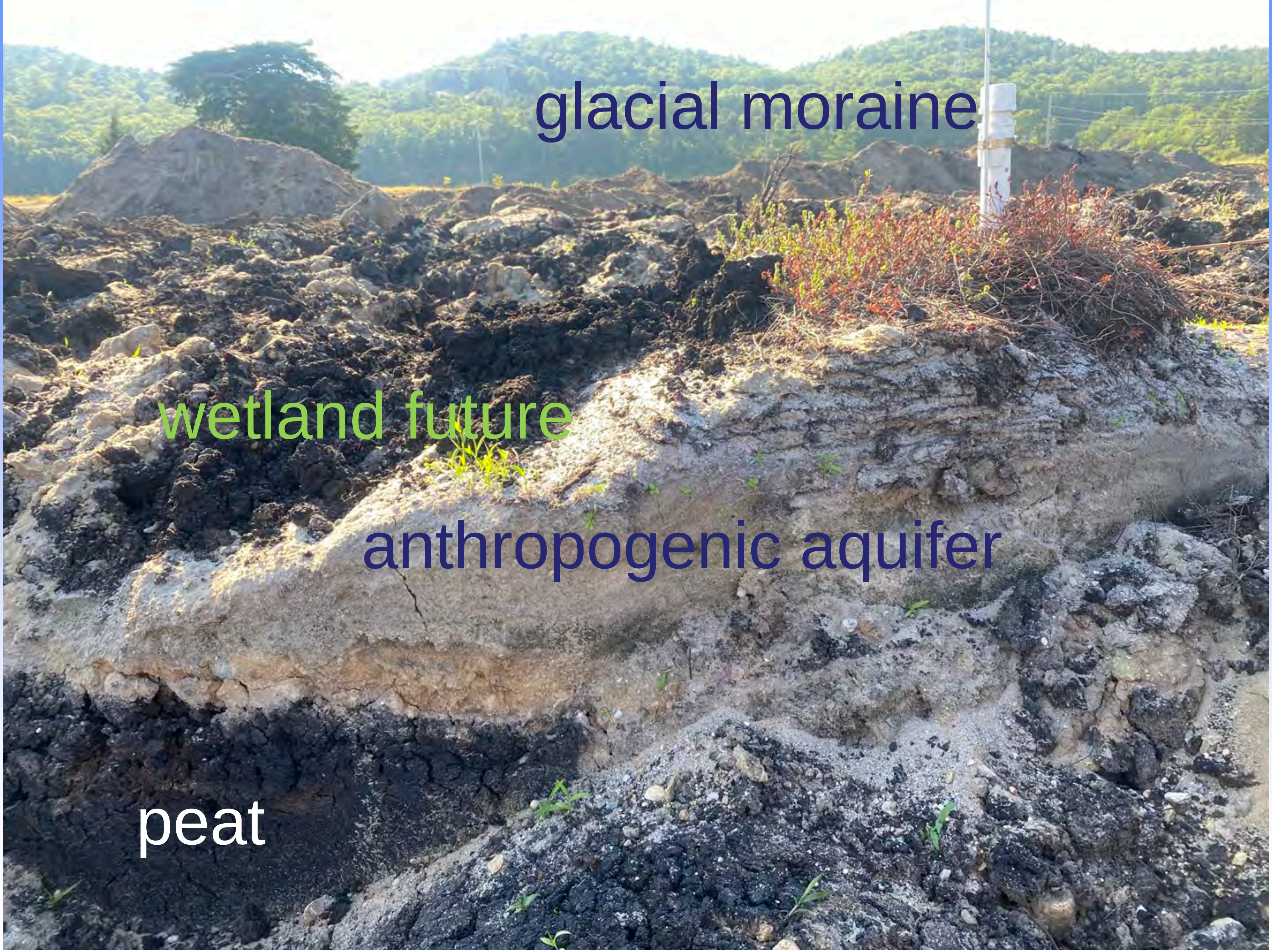

Stream and Piezometer Water Temperatures
B
Water Temperature (deg C)
25
20
15
10
5
0
PZ-07 GW
SW-07 stream
PZ-04 GW
SW-04 stream
PZ-03 GW
SW-03 stream
PZ-02 GW
SW-02 stream
Upstream
Downstream


A
TW-PZ-07
B
TW-PZ-04
C
TW-PZ-03
D
TW-PZ-02
DTW bgs (m; + is above gs)
Temperature (Degrees C)
2017/Jul
2018/Jan
2018/Jul
2019/Jan
2019/Jul
2020/Jan
2020/Jul
Year/ Month


A1
A8
TW-PZ-08-SAND
TW-PZ-08
C1
C7
TW-PZ-07
TW-SW-07
TW-PZ-09
A2
TW-PZ-05
TW-PZ-05-SAND
T8
TW-PZ-04
TW-SW-04
T21
COSMOS
TW-PZ-06
TW-PZ-06-SAND
TW-PZ-03
TW-SW-03
D9
WEATHER STATION
D3
TW-PZ-02
TW-SW-02
TW-PZ-01
TW-PZ-01-SAND
E9
TW-SW-10
MANOMET BROOK
E8
C
DTW bgs, m, + is above gs
restored bog
TE-PZ-AWC
PZ-01 peat
sand
PZ-05 peat
sand
PZ-06 peat
sand
PZ-08 peat
sand
PZ-09 peat
peat
A
DTW bgs, m, + is above gs
Upstream PZ-07
Logger
Manual
PZ-04
PZ-03
Downstream PZ-02
B
DTW bgs, m, + is above gs
Upstream SW-07
SW-04
SW-03
SW-02
Downstream SW-10
Logger
Manual


Streambed Piezometer Gradients
A
Δh/Δz, hydraulic gradient, - is losing, +is gaining
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Manual
Manual
Manual
Manual
Logger
Logger
Logger
Logger
Upstream
PZ-07
PZ-04
PZ-03
Downstream
PZ-02
Stream and Piezometer Water Temperatures
B
Water Temperature (deg C)
25
20
15
10
5
0
PZ-07
GW
SW-07
stream
PZ-04
GW
SW-04
stream
PZ-03
GW
SW-03
stream
PZ-02
GW
SW-02
stream
Upstream
Downstream


A
TW-PZ-07
B
TW-PZ-04
C
TW-PZ-03
D
TW-PZ-02
gradient, Δh/Δz, + is gaining
Temperature (Degrees C)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
24
20
16
12
8
4
0
2017/Jul
2018/Jan
2018/Jul
2019/Jan
2019/Jul
2020/Jan
2020/Jul
Year/ Month

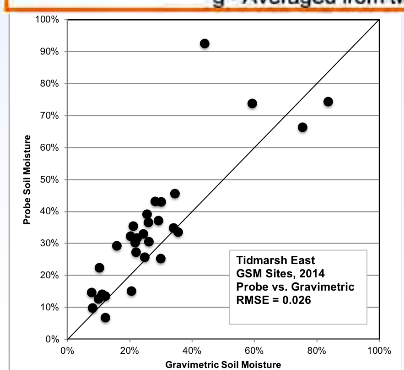

glacial moraine
wetland future
anthropogenic aquifer
peat

Change in Soil Moisture Pre- to Post-Restoration

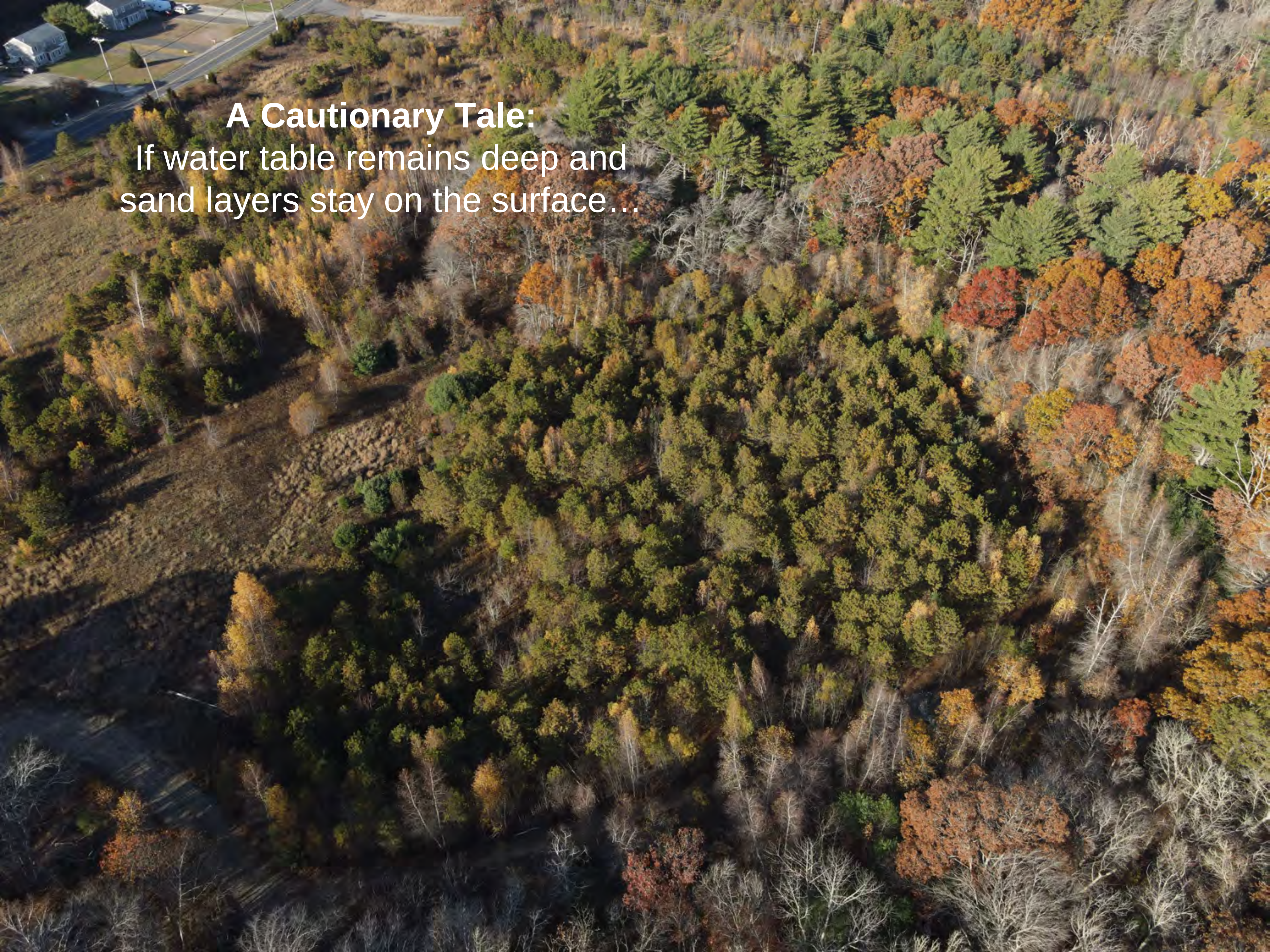
Foothills Preserve and Tidmarsh Soil Moisture

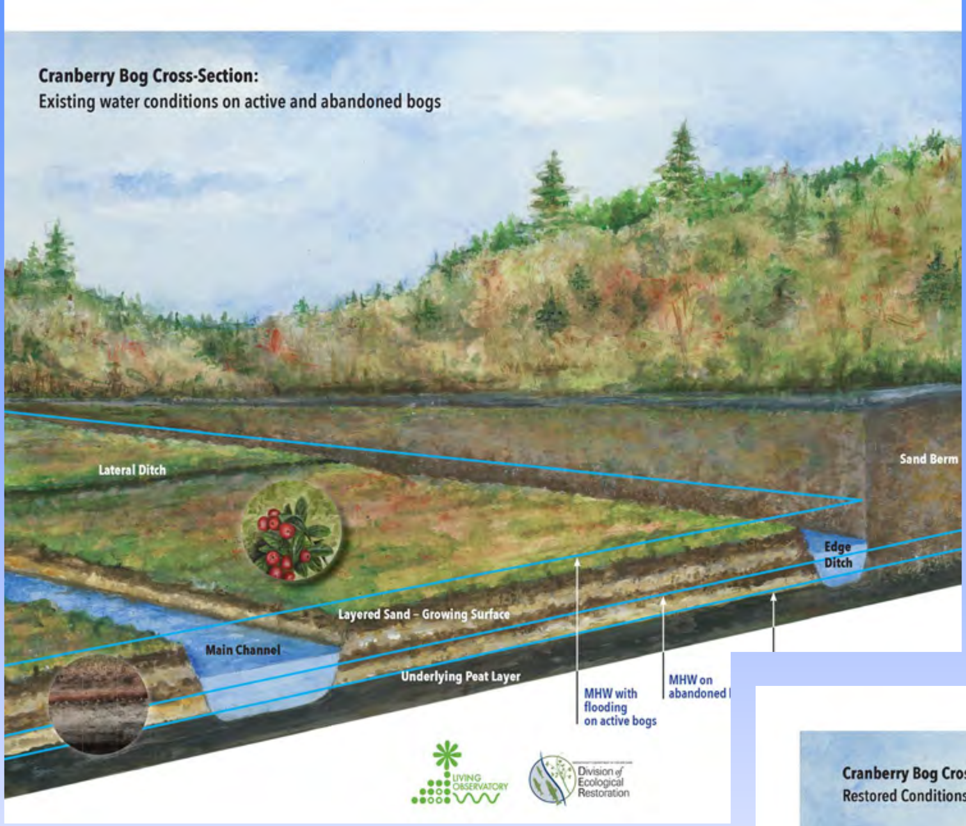
	2017 Foothills: E BOG, Cable path [c, d] (10 cm scale)	**2020** Foothills: E BOG, Cable path [c, d] (20 cm scale)	**2014 Pre-Restoration,** Tidmarsh [e, f] (points)	**2017** Tidmarsh [e] (points)	**2018** Tidmarsh [e] (points)	**2019** Tidmarsh [e] (20 cm scale)	**2020,** Tidmarsh [e, g] (20 cm scale)
Mean Soil Moisture [a, b]	19%	11%	41%	54%	58%	58.5%	59.2%
Standard Deviation	9%	9%	28%	28%	27.0%	15%	15%
Variance	0.9%	0.9%	7.9%	8.0%	7%	2%	2%
Minimum	4%	0%	7%	2%	4%	25%	14%
Maximum	100%	85%	100%	100%	100%	100%	100%
No. Measurements	504	671	32	33	30	270	290
Total Length (cm)	50,400	13,400	0.026			5,400	5,800

Notes: a - Surveys conducted with a Dynamax TH2O electrical permittivity moisture probe and converted from millivolt data to % saturation by volume.
b - Survey dates covered similar moisture conditions throughout, July-Aug, 2017, 2019 and 2020; and Mar 2019
c - Foothills Preserve is a fallow cranberry bog, last harvest 2015; restoration in 2019-2020.
d - Three fiber optic cables were installed at Tidmarsh West to monitor soil moisture. Data were collected on 7/26, 7/31, 8/1 (2017) and 7/28 (2020).
e - Tidmarsh Nature Sanctuary underwent restoration in 2016-2017. Data were collected on 8/2, 8/3 (2017), 3/31 (2019) and 8/2, 8/3 (2020).
f - Point measurements with probe vs. gravimetric; RMSE instead of total length
g - Averaged from two transects across an experimental microtopography technique and an area left essentially undisturbed from the farmed state.



$\theta = 41\% \rightarrow 54\% \rightarrow 58\% \rightarrow 59\%$


A Cautionary Tale:
If water table remains deep and
sand layers stay on the surface…

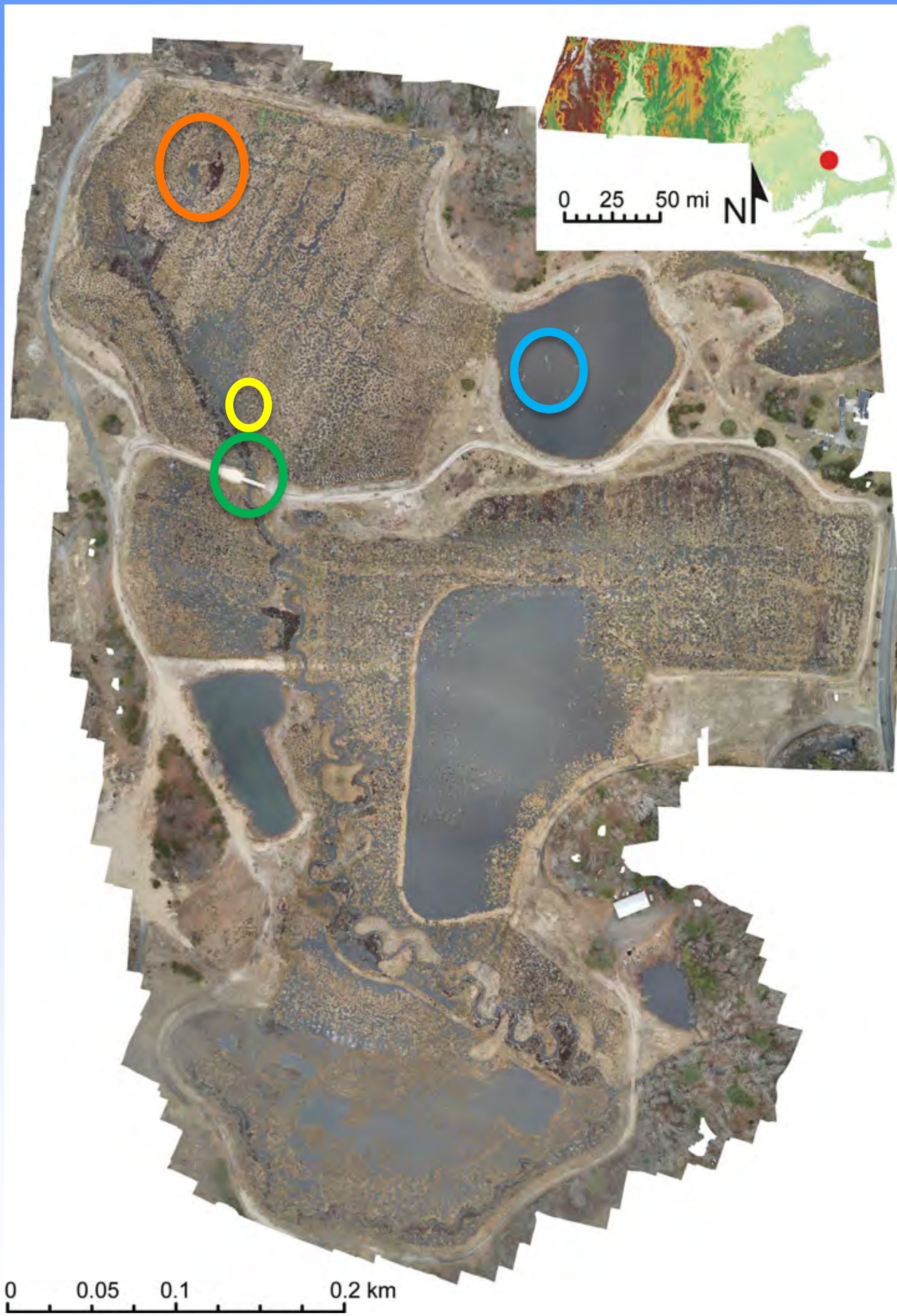


Special sauce:

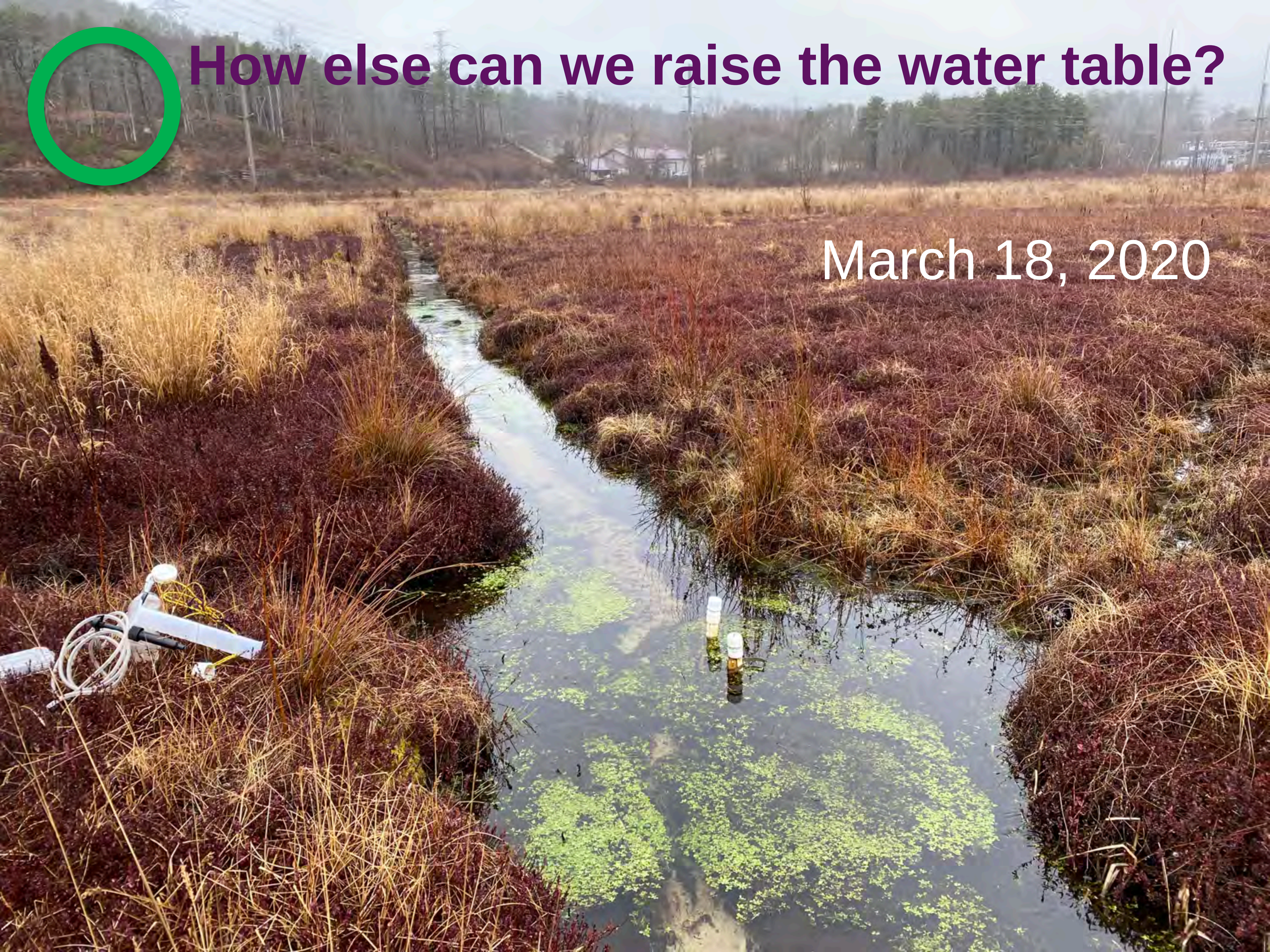
…to turn cranberry bogs back into wetlands…

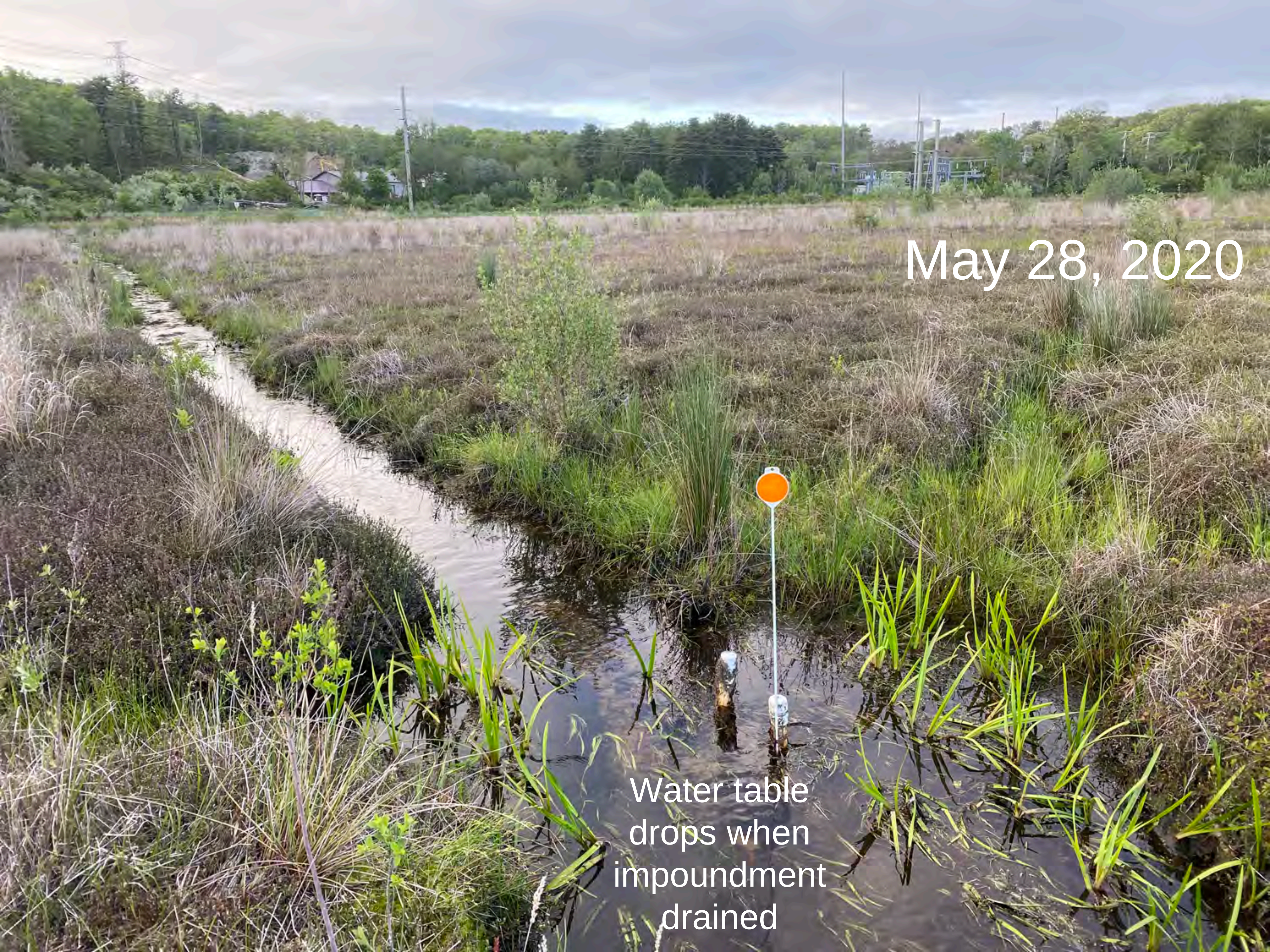
- ***Glacial geology,***
- ***lots of water,***
- ***remove legacy of farming practice,***
- ***and time***

Illustrations by RavenMark, LLC.


0 25 50 mi
N
0 0.05 0.1 0.2 km

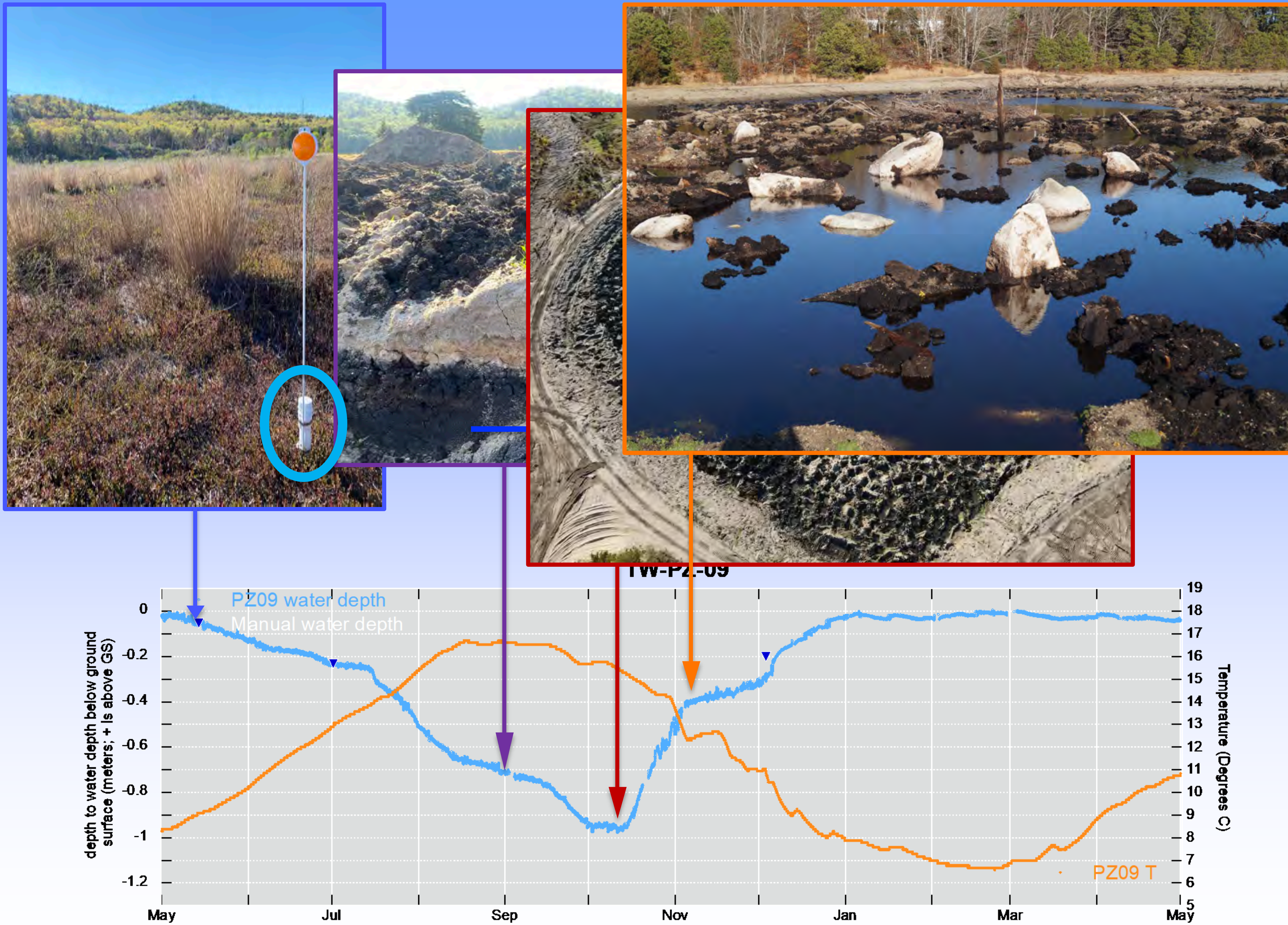
How else can we raise the water table?




May 28, 2020
Water table drops when impoundment drained

September 3, 2020


Plugs raise water table and trap sediment



PZ09 water depth
Manual water depth
depth to water depth below ground surface (meters; + is above GS)
Temperature (Degrees C)
PZ09 T
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
May
Jul
Sep
Nov
Jan
Mar
May

Mapping Groundwater and Mapping Restoration Success

Dr. Christine Hatch, Associate Extension Professor, UMass Amherst
Lyn Watts, M.S. Candidate, UMass Amherst
Ryan Wicks, Data Analyst, and Lead Equipment Technician, UMass Air

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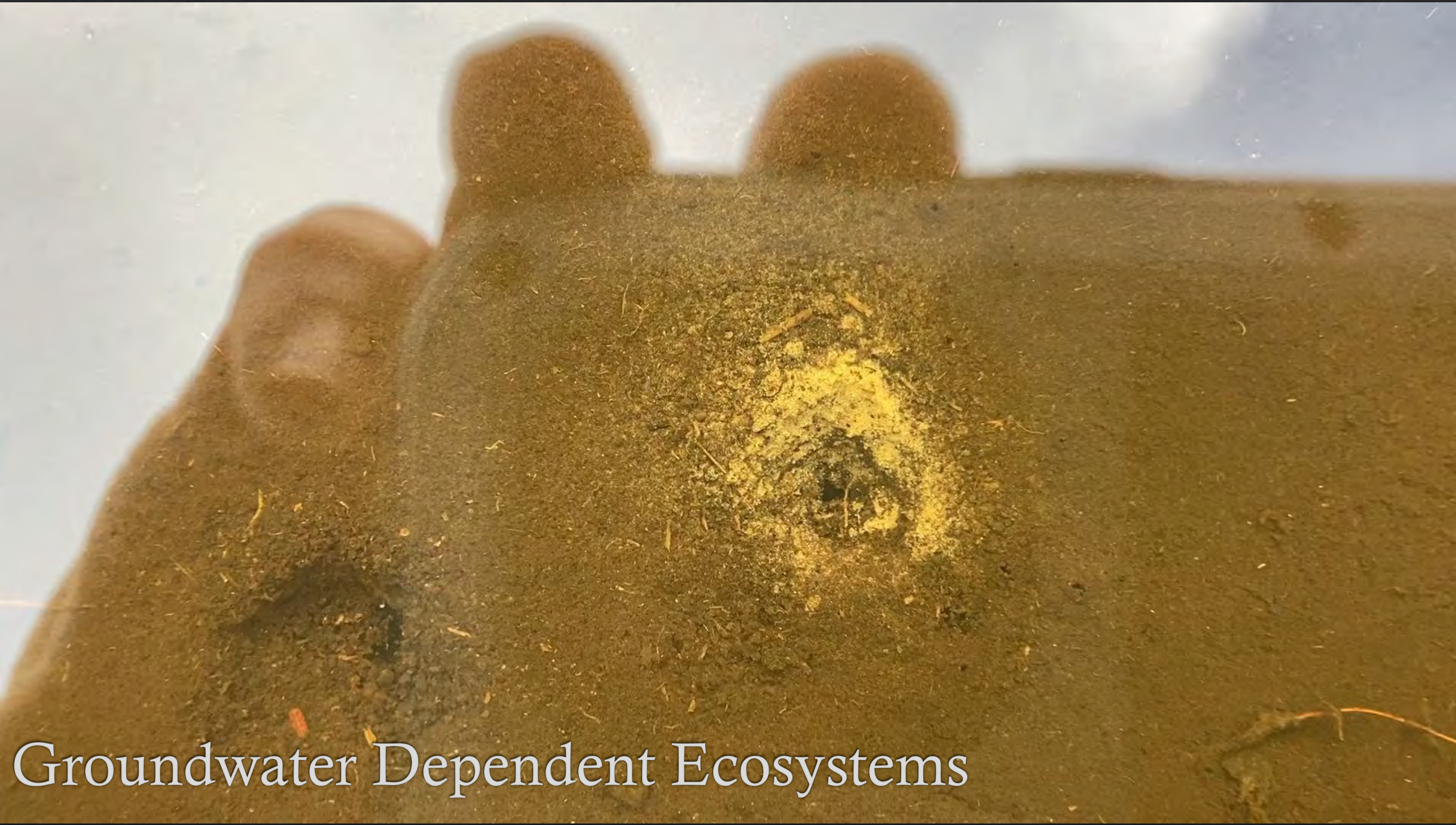
geosciences

Tidmarsh: Former Cranberry Bog Growing Freshwater Wetland

From This:

To This:

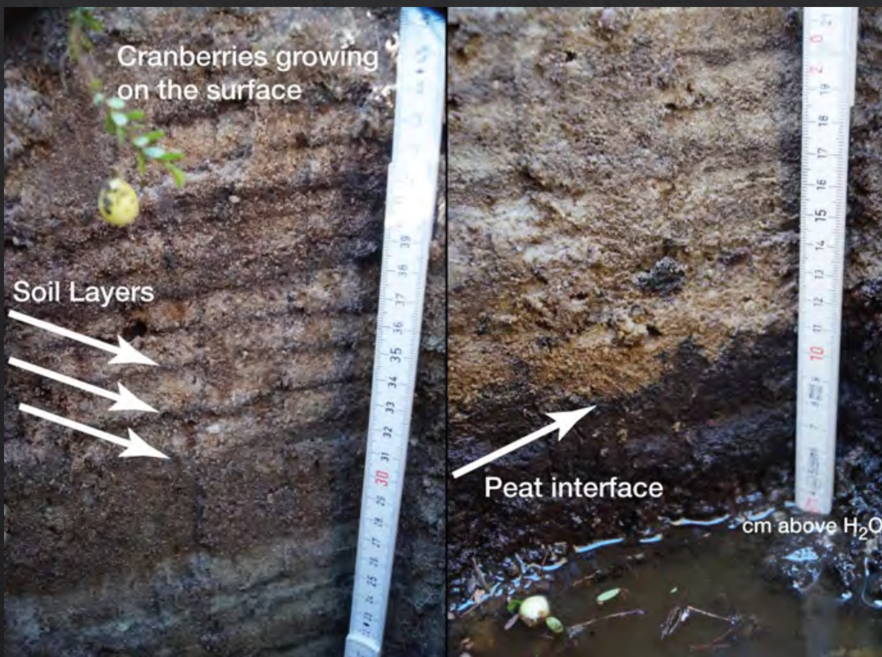

Groundwater Dependent Ecosystems

Groundwater provides consistent moisture and temperatures to freshwater species:

Amphibians

Anadromous coldwater fish

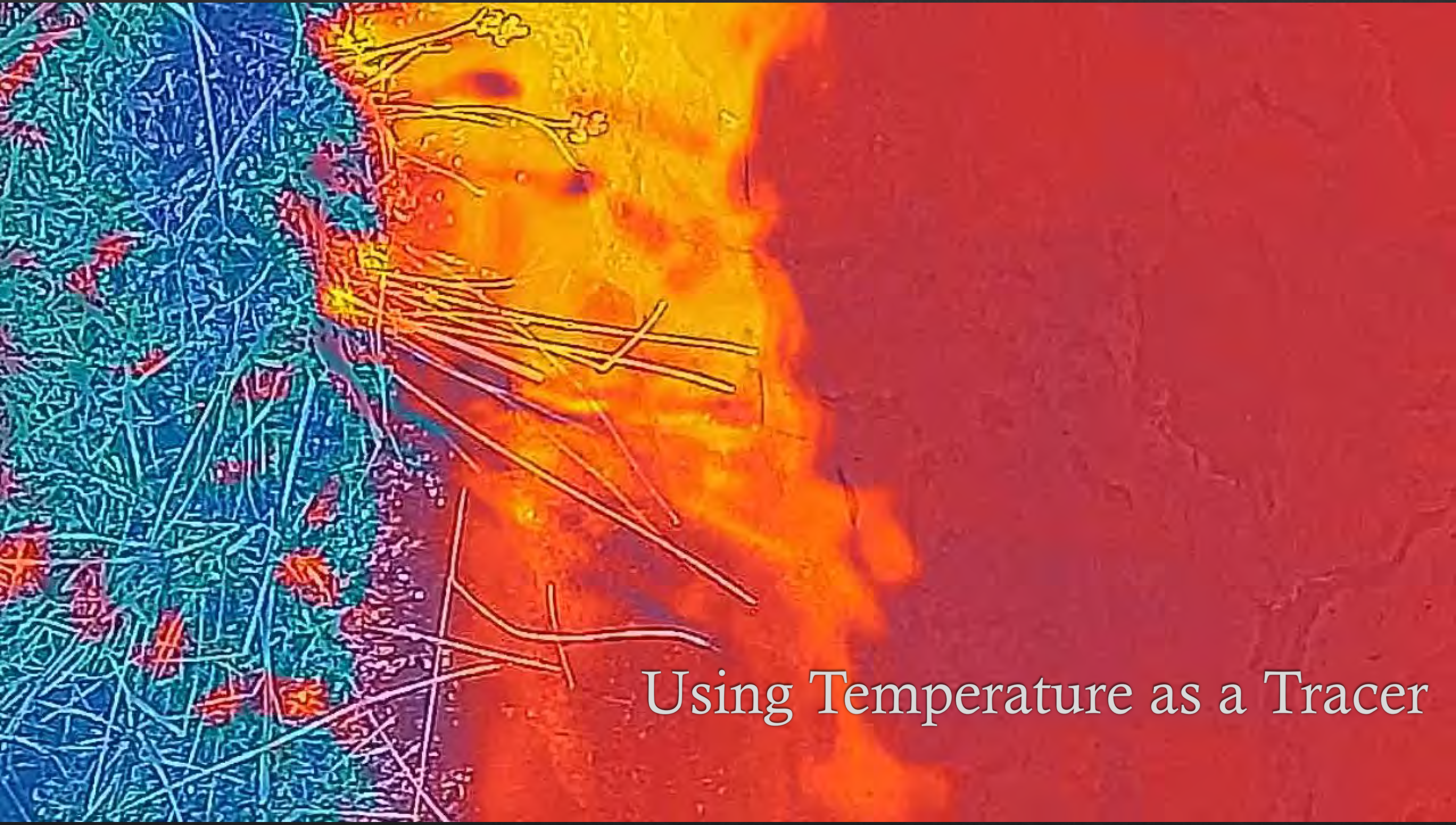
Restoration Techniques:



Mixing soil layers

Microtopography

How do we find groundwater seeps?



Using Temperature as a Tracer

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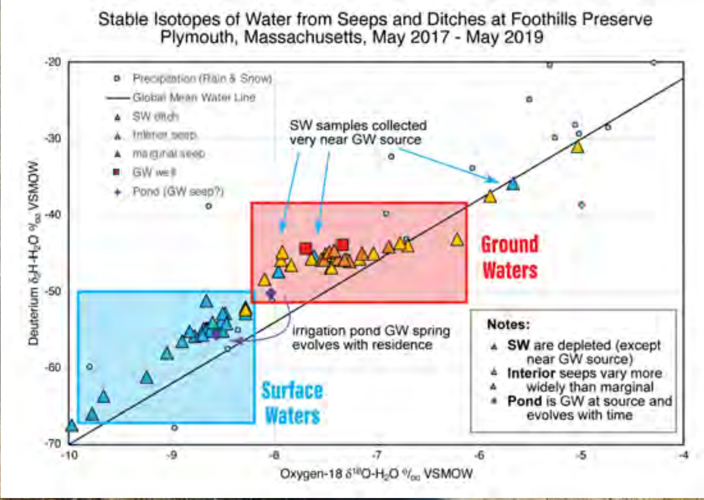
The picture can't be displayed.

Matrice 210 UAS with FLIR Thermal Infrared Camera



Water isotopes

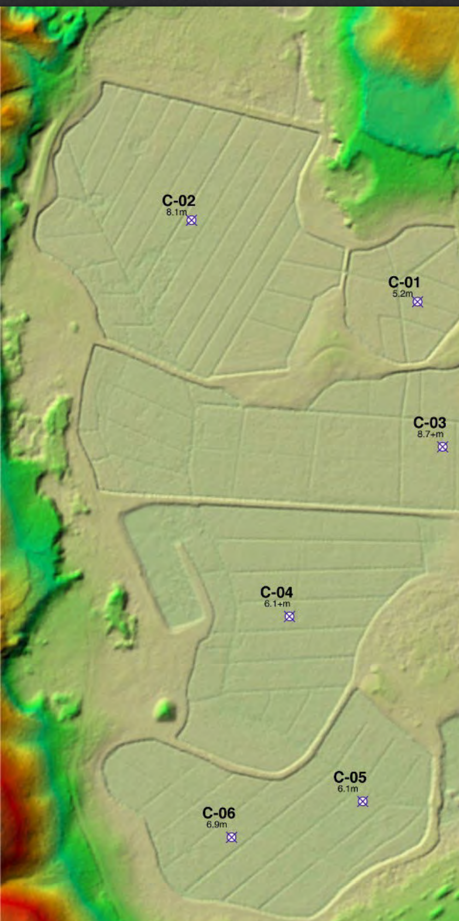
Ground Control Points have low emissivity

Post Processing: Resetting greyscale ranges for each flight

Lidar Map

RGB Map

TIR Map



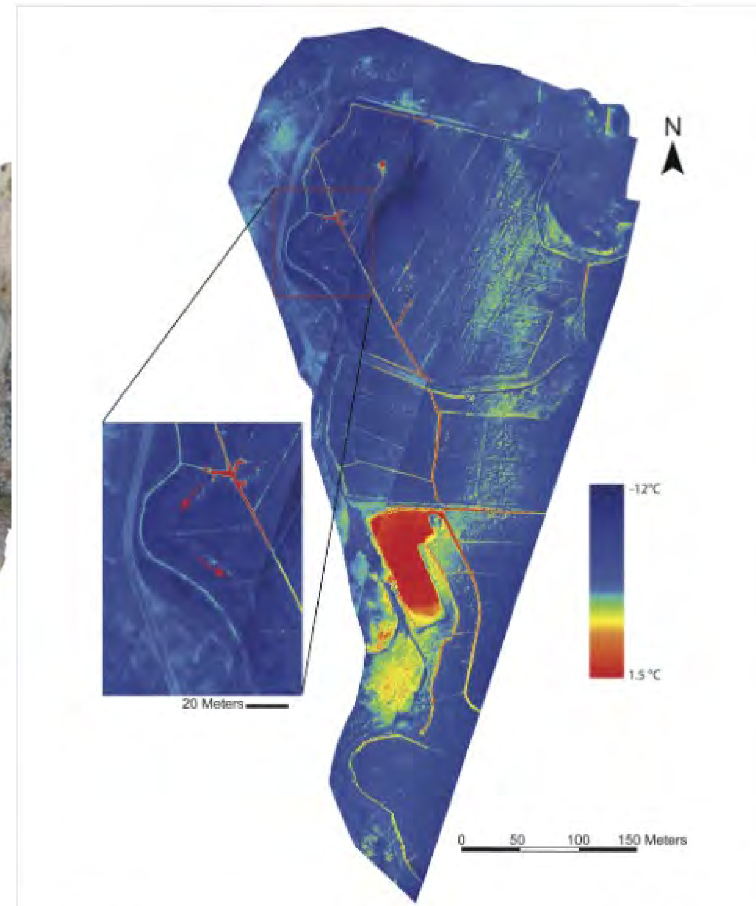
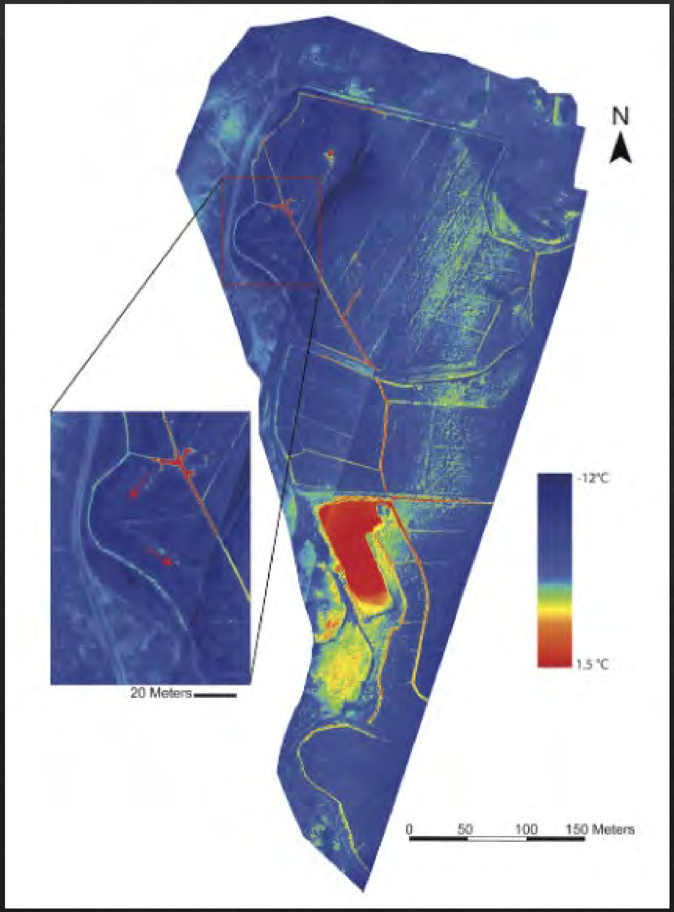
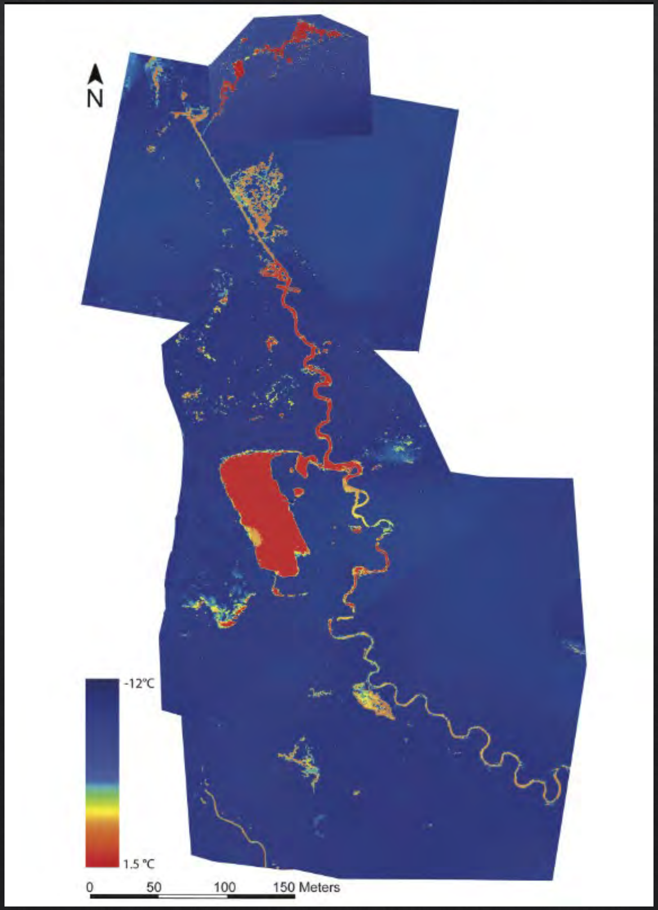


FIGURE 3
Orthomosaic image of pre-restoration UAS-derived thermal infrared imagery 8 February 2020. Ground surface is cold (blue), and discrete warmer groundwater springs show up as warm (red) dots and flow into surface ditches. The inset image shows the hypothesized location of the original stream channel, with red arrows indicating flow direction.

TIR Pre - Restoration

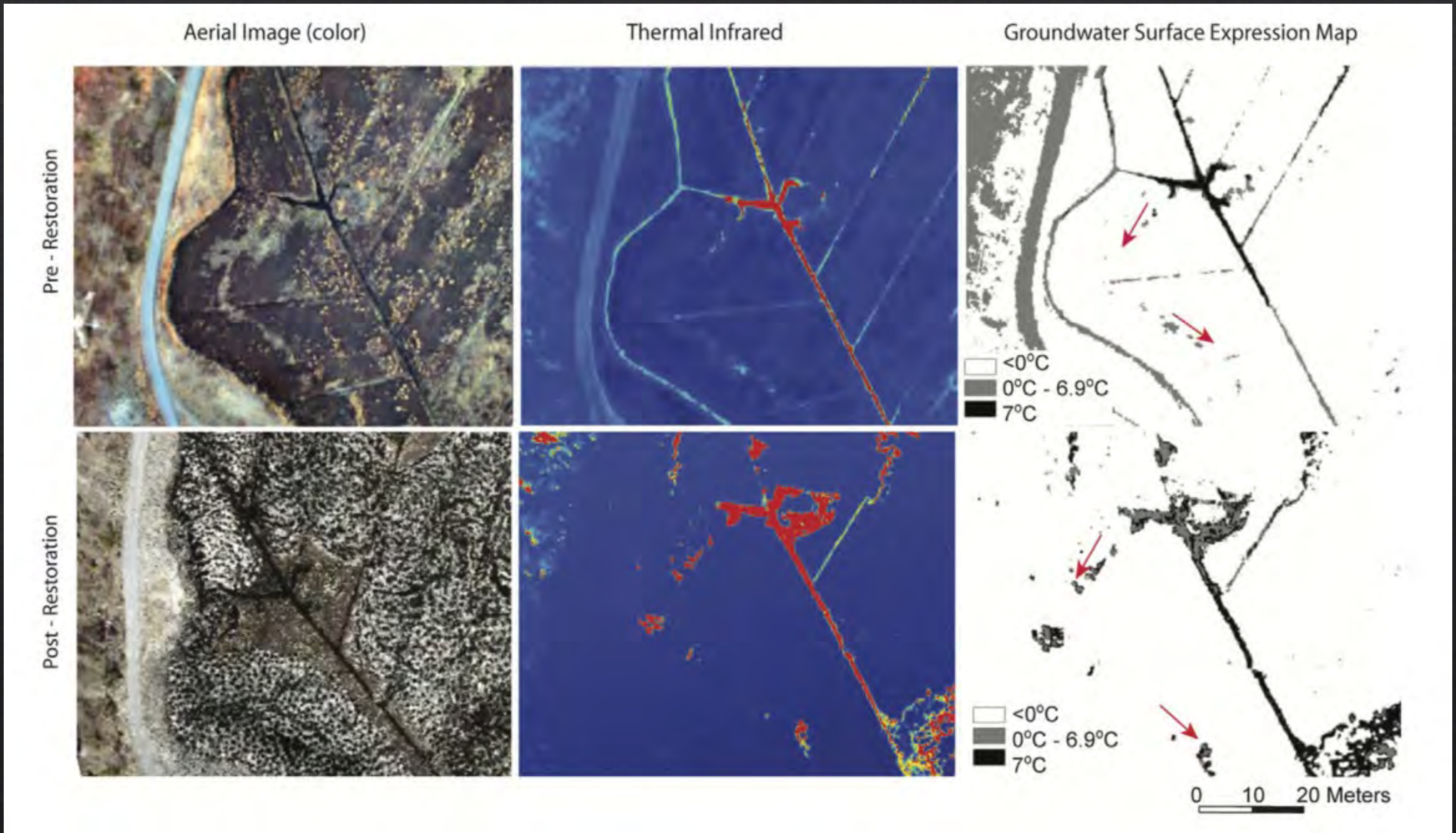


TIR Post - Restoration



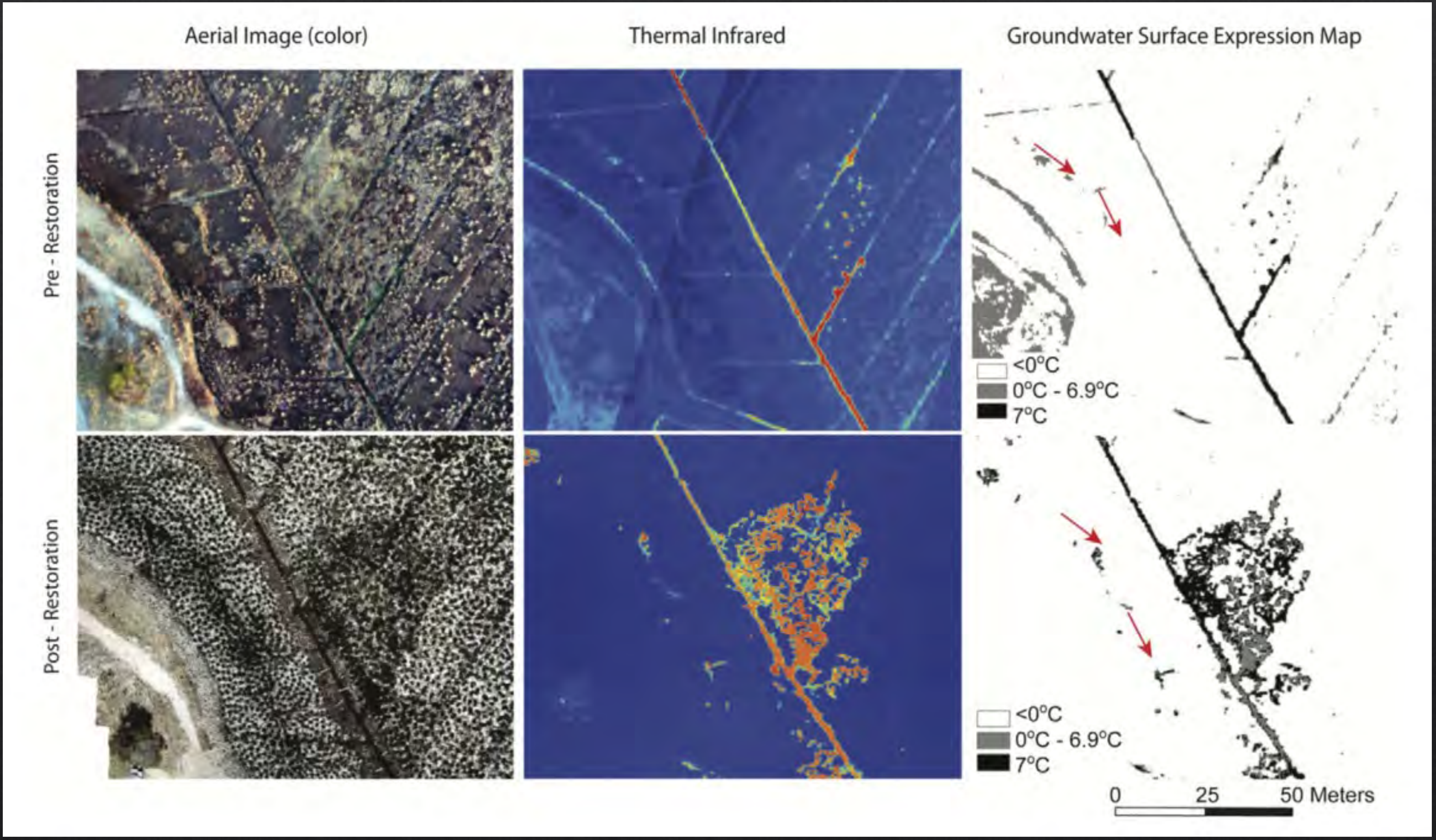
Restoration Takeaways

Seep locations are not significantly impacted by restoration



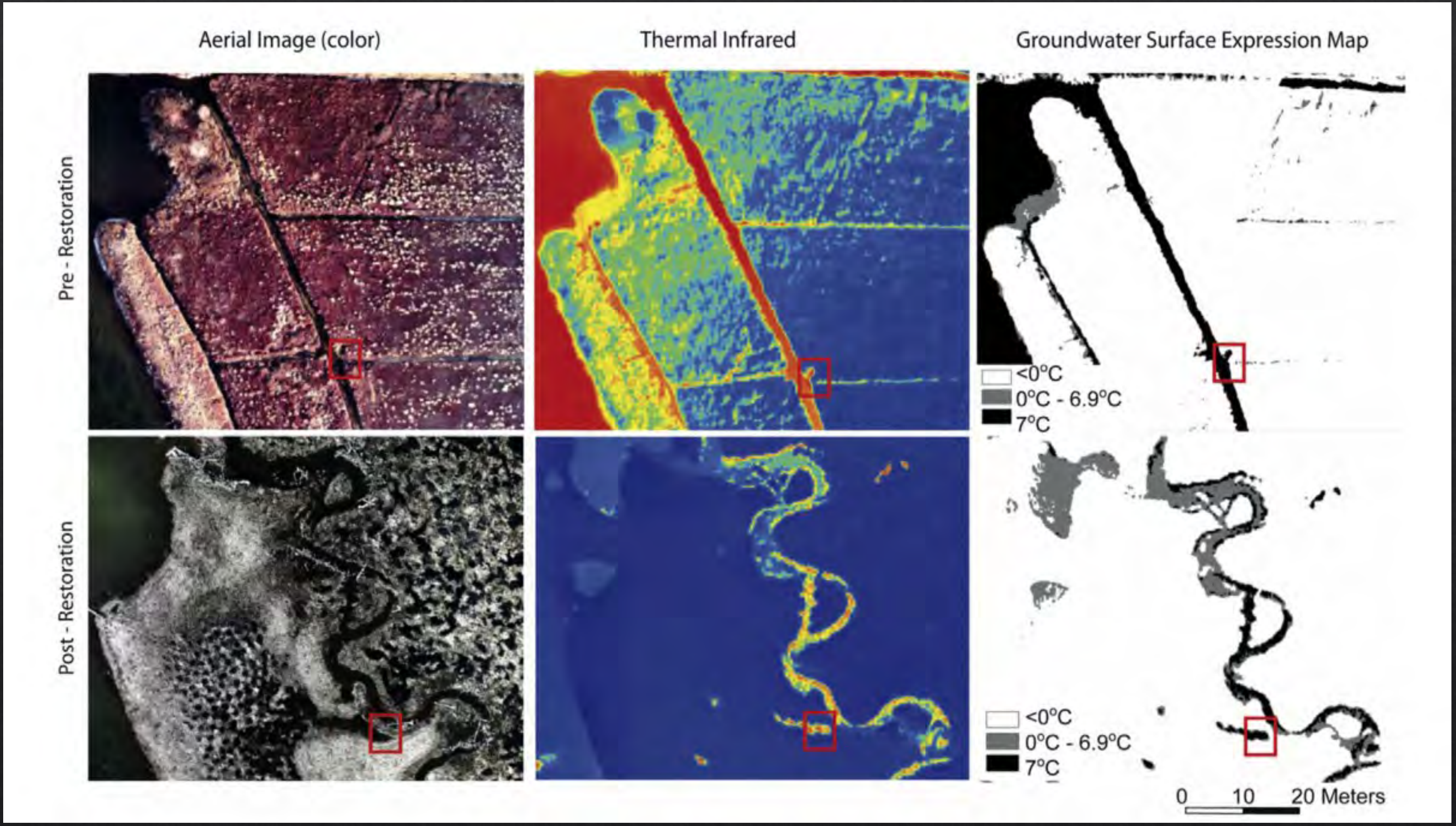
Restoration Takeaways

Total area saturated by groundwater grows



Restoration Takeaways

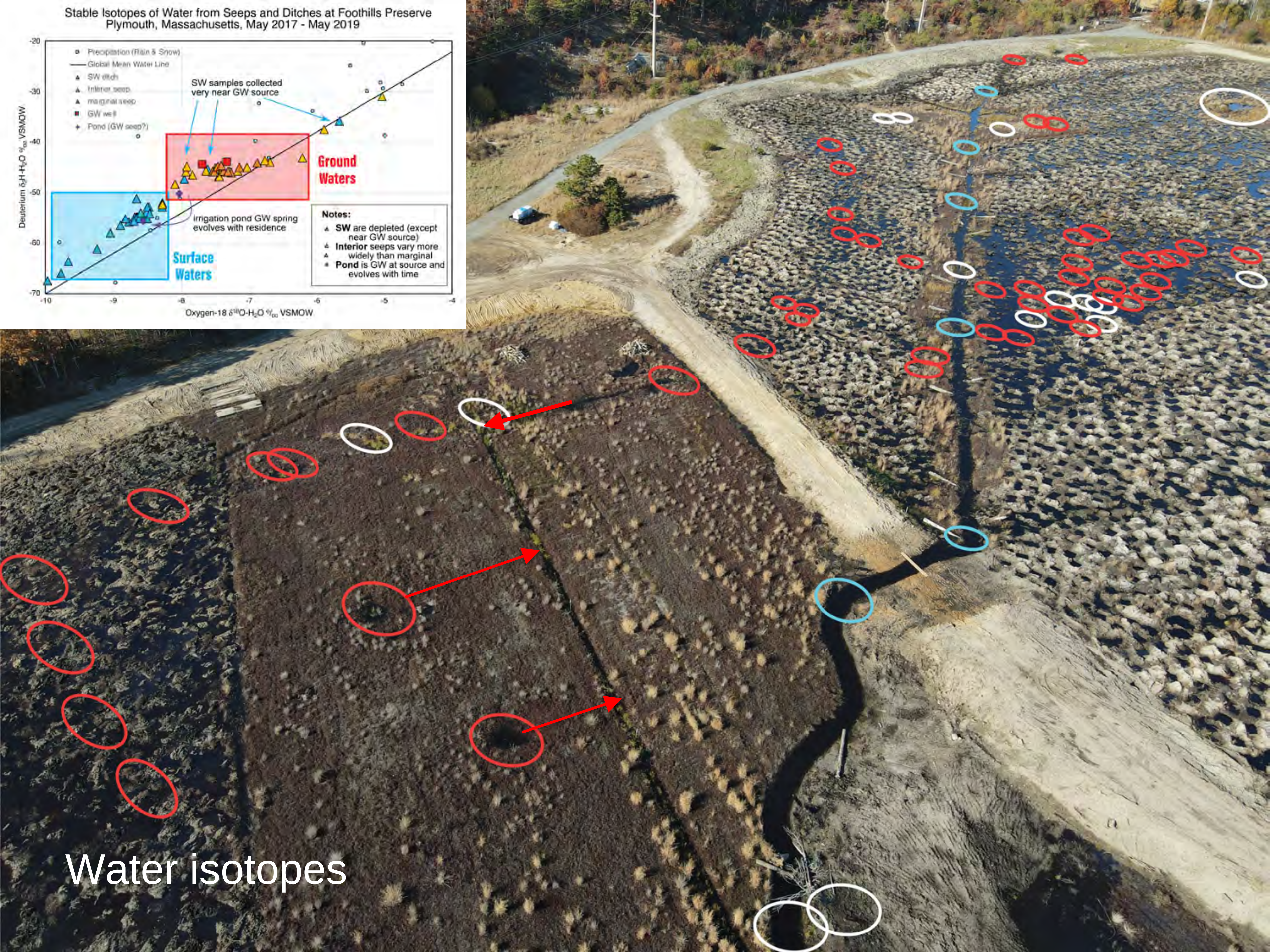
Groundwater takes longer to reach channel



Restoration Success

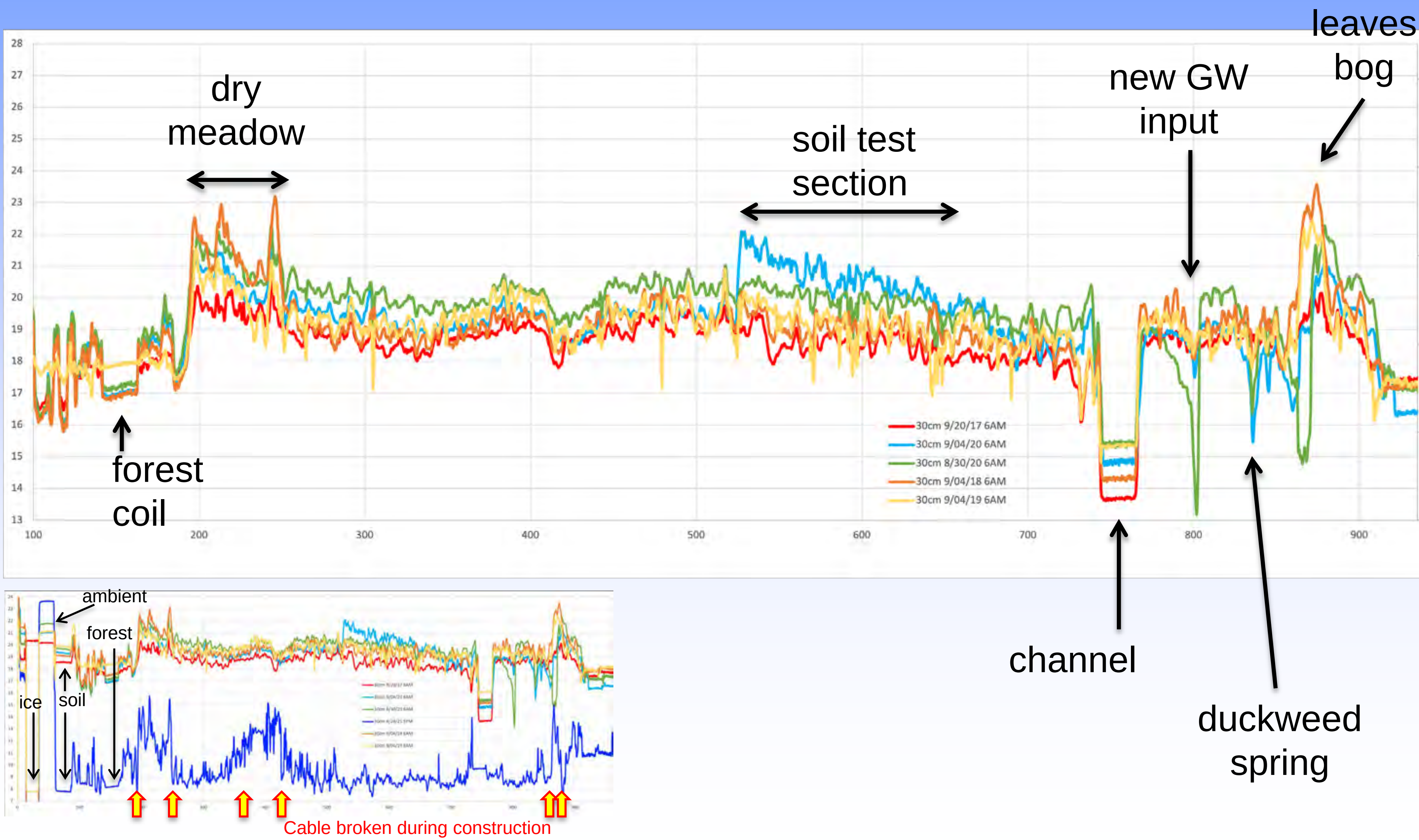
Restoration increases the land surface saturated by groundwater

TIR is a useful tool for mapping small groundwater seeps, and quantifying change


Stable Isotopes of Water from Seeps and Ditches at Foothills Preserve
Plymouth, Massachusetts, May 2017 - May 2019
Precipitation (Rain & Snow)
Global Mean Water Line
SW ditch
Interior seep
marginal seep
GW well
Pond (GW seep?)
SW samples collected very near GW source
Ground Waters
Surface Waters
Irrigation pond GW spring evolves with residence
Notes:
SW are depleted (except near GW source)
Interior seeps vary more widely than marginal
Pond is GW at source and evolves with time
Deuterium δ2H-H2O ‰ VSMOW
Oxygen-18 δ18O-H2O ‰ VSMOW
-20
-30
-40
-50
-60
-70
-10
-9
-8
-7
-6
-5
-4
Water isotopes

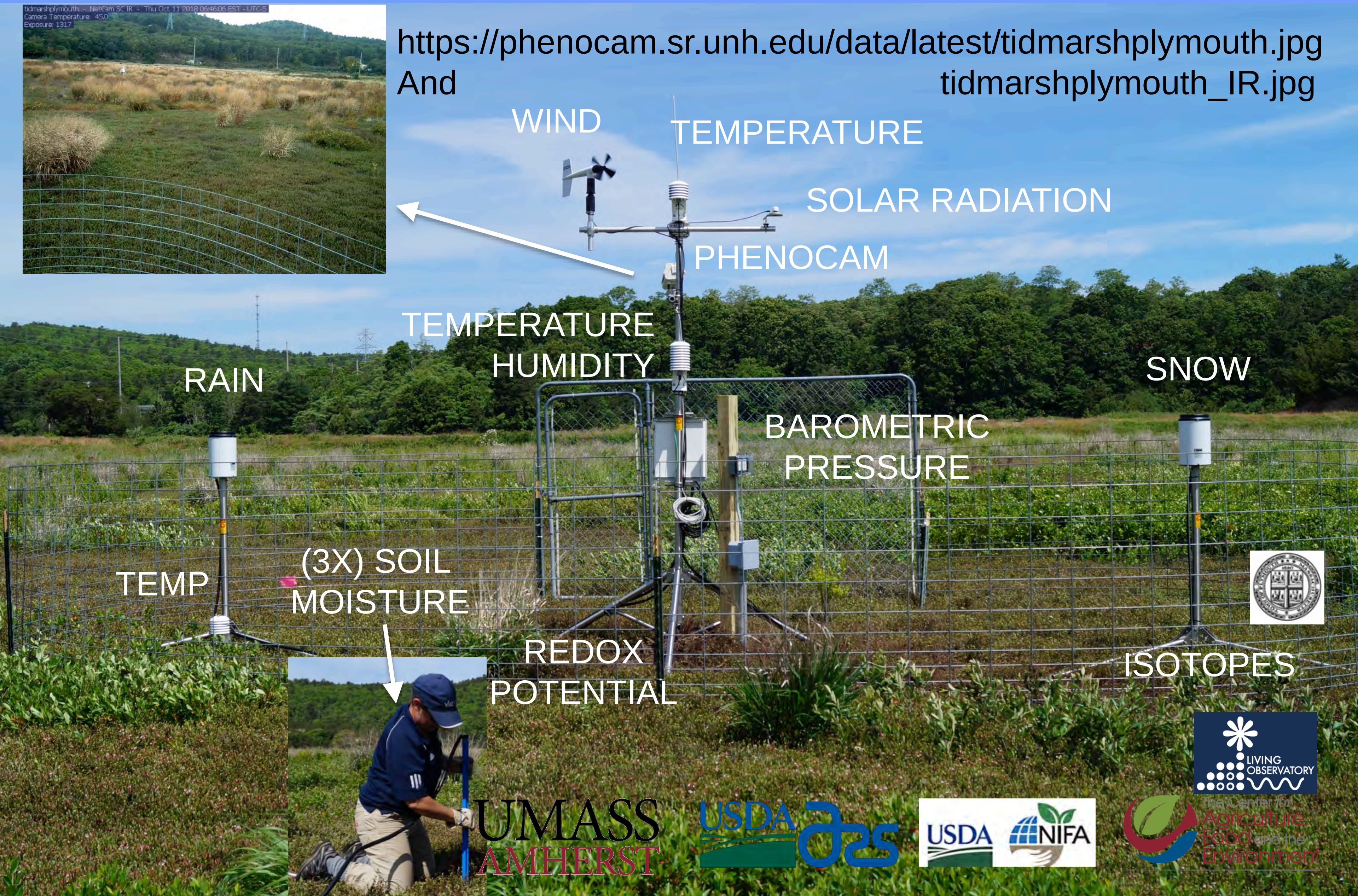
Thermal Underground

DTS 30cm September 2017-2020

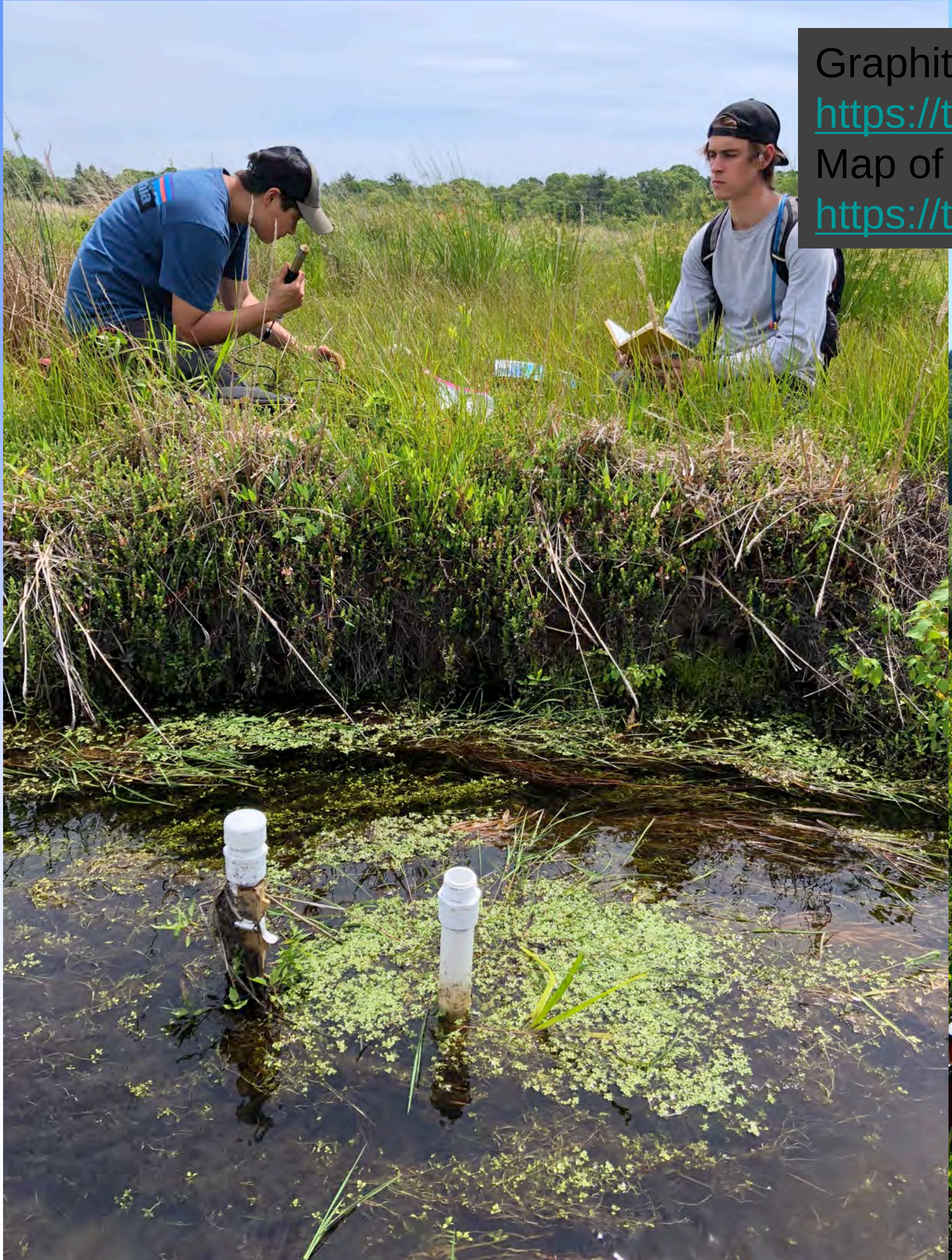


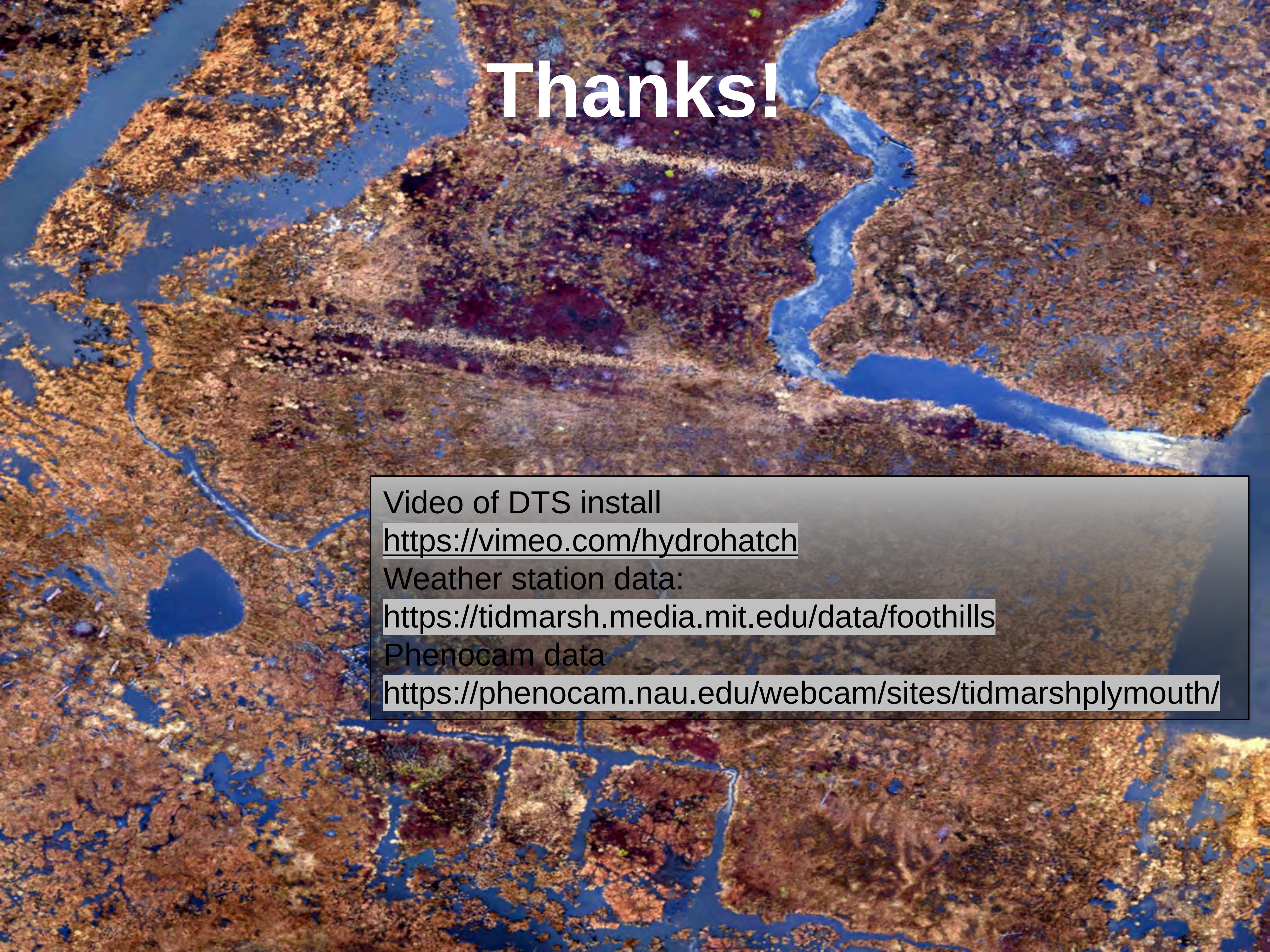
Real time weather station data

https://phenocam.sr.unh.edu/data/latest/tidmarshplymouth.jpg
And tidmarshplymouth_IR.jpg



Graphite (easily plot data from the sensors):
https://tidmarsh.media.mit.edu/graphite/
Map of sensor locations:
https://tidmarsh.media.mit.edu/~bmayton/map/





Thanks!

Video of DTS install
https://vimeo.com/hydrohatch
Weather station data:
https://tidmarsh.media.mit.edu/data/foothills
Phenocam data
https://phenocam.nau.edu/webcam/sites/tidmarshplymouth/

Questions?