A Hydrologic Study of Dune Wetland Interaction in Lake Station, IN

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Abstract:

The area of interest for this study was a recently restored wetland in Lake County, Indiana. The site was bounded by dunes on the north side and a drainage ditch on the south side. Formerly farmland, most of the area was sold to be restored to wetlands and a small area on the northern, dune edge was sold to an industrial recycling company. In 2009 the recycling company brought suit against the owners of the wetland complaining that the restoration caused flooding on the recycler's property. The purpose of this study was to model hydrologic activity in the area to determine if flooding of the recycler's property seemed plausible. The finite-difference method was used to model a two-dimensional cross section running from the northern dune boundary to the ditch in the south. Previously collected data from three monitoring wells along with a survey from the lawsuit were used to construct an average initial water table for the model. The model was run with daily potential evapotranspiration calculated from weather data for the 2000/2001 water year. Data from the monitoring wells was then used to check the accuracy of the model. By the end of the water year the water table under the wetland had dropped by about half of a meter. Even during the largest storm event of the year, although the water table under the wetland was raised by about a meter, the water was not high enough to flood the recycler's property. Water flows from areas of high hydraulic head to low hydraulic head. A colorimetric graph of hydraulic heads over the cross section show that the water in the model flowed from both the dune and wetland into the southern drainage ditch. Future work on this project could include finer calibration and running the model with more current weather data.

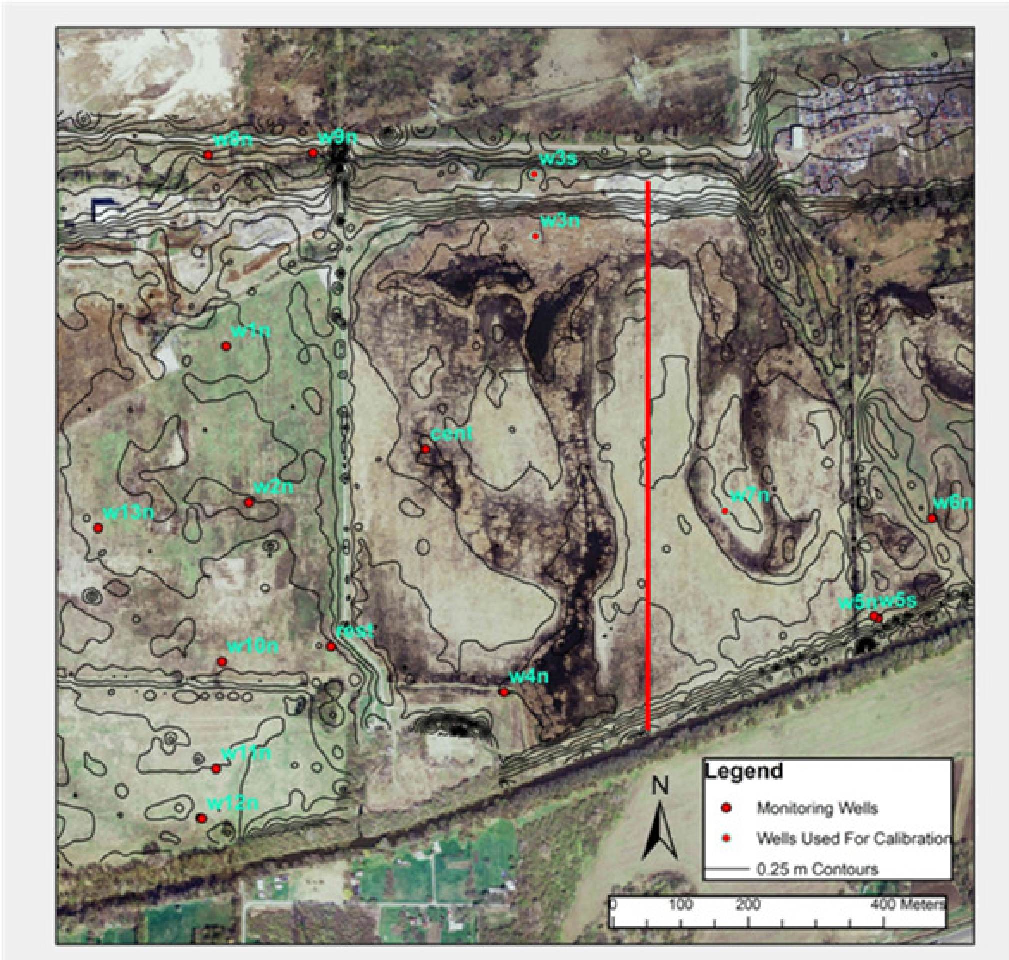


Figure 1. Map of study site. The red line represents the cross section modeled. The industrial recycling operation is located along the northern edge, just south of the road. A large pile of scrap was located on top of a dune at the northern tip of the cross section. A drainage ditch runs along the southern boundary of the wetland and is the southern end of the cross section. Monitoring wells are located throughout the wetland. Wells w3s, w3n, and w7n were used in model construction and calibration.

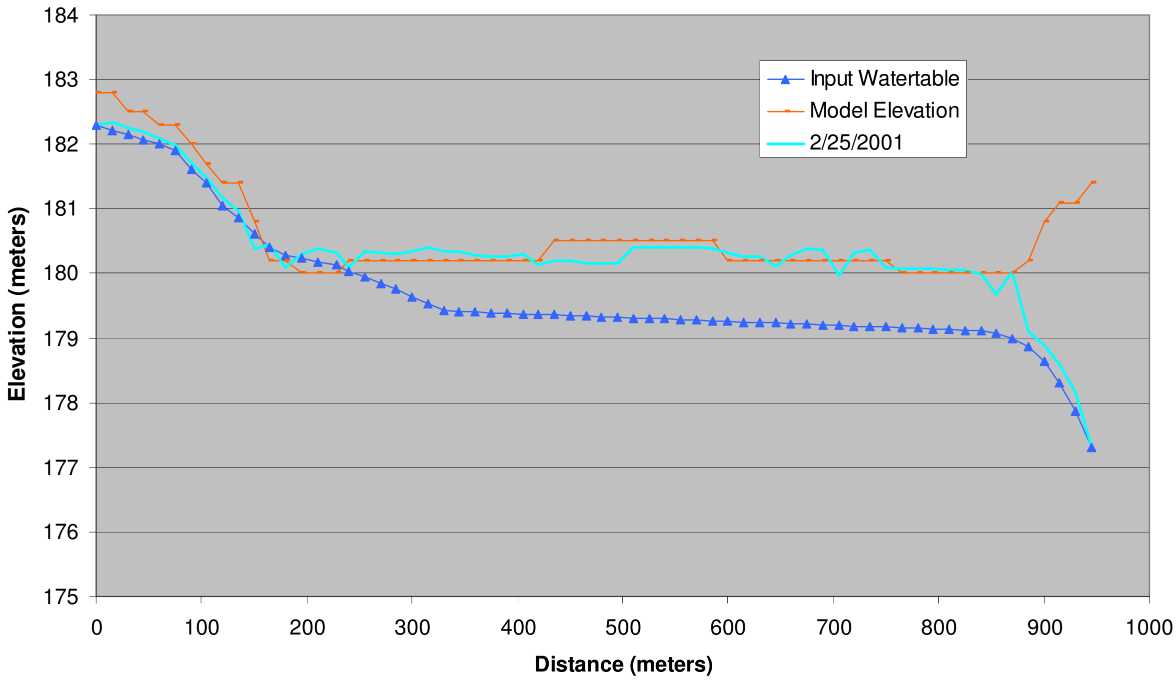


Figure 2. Graph of modeled cross section. The left side of the graph is the northern, dune boundary. The graph ends on the right at the drainage ditch at the southern boundary. Shown are the ground elevation in orange, the initial water table in blue with triangles, and the modeled water table elevation following the water year's largest storm even on February 25th in teal. The water table has increased by about one meter from initial conditions but still not enough to flood the recycling operation located on the dune.

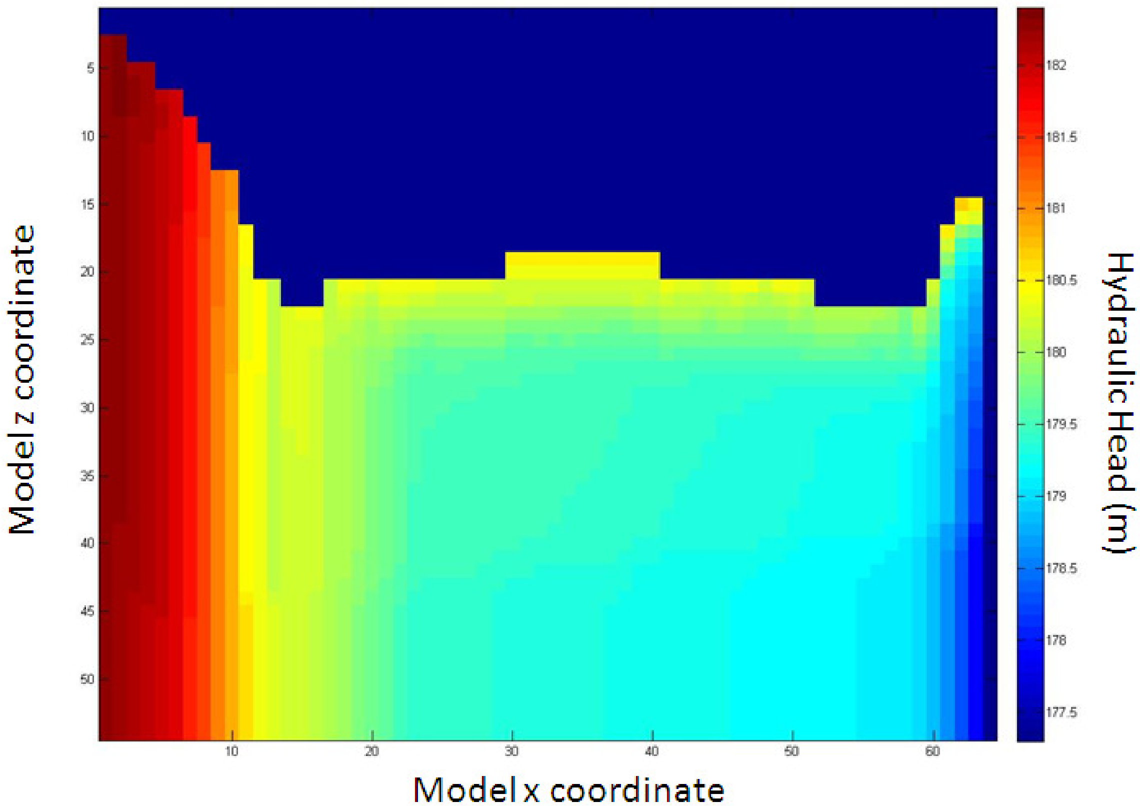
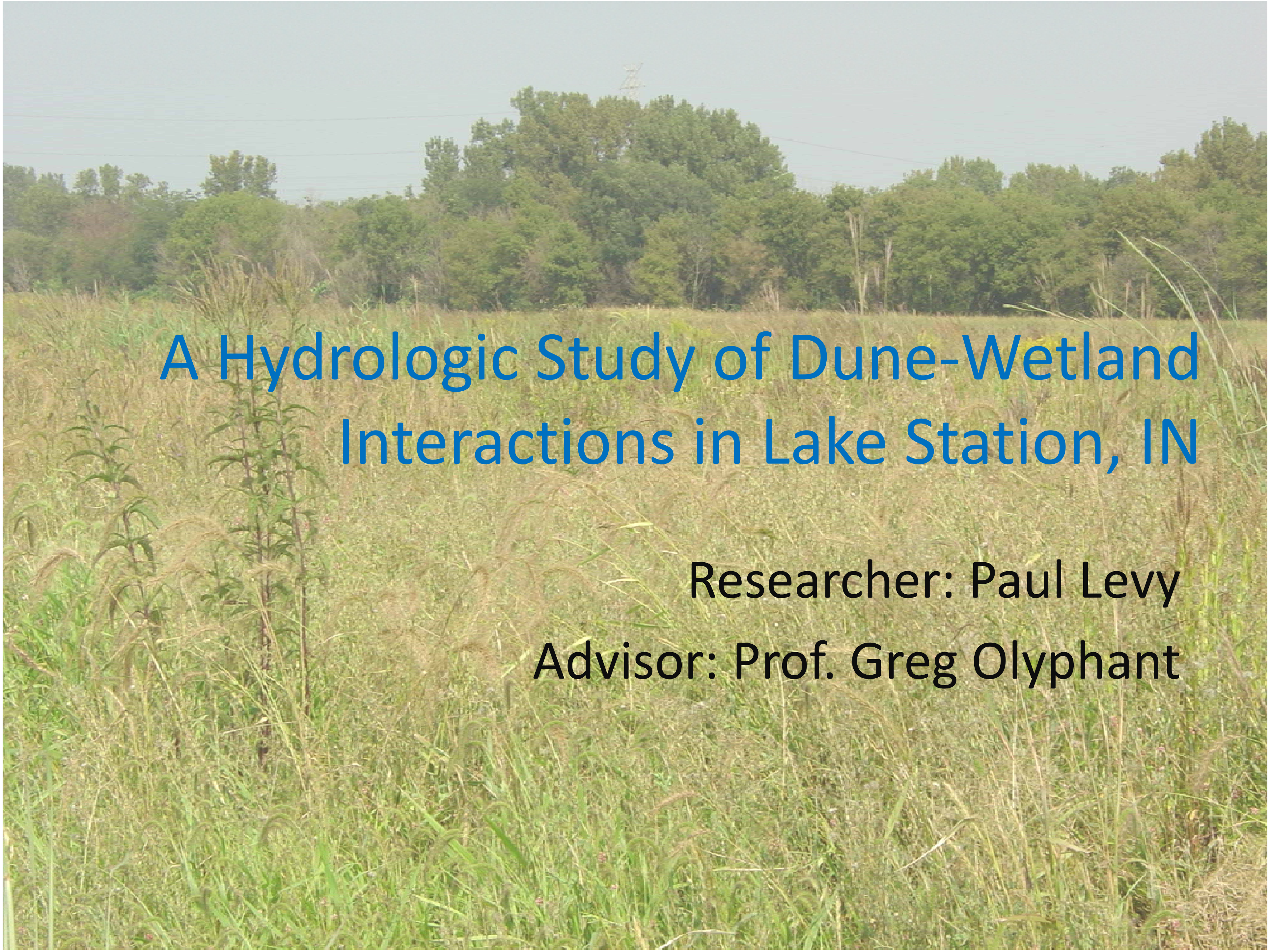


Figure 3. Colorimetric graph of hydraulic heads throughout the cross section following the 2/25/2001 storm event. This graph is of the same cross section as figure 2. The blue area on the top of the graph is open air. The left side of the graph is the dune at the northern boundary, the right side is a drainage ditch at the southern boundary. Water will flow from areas of higher head to areas of lower head. In this cross section the water will flow from the dune and the wetland into the ground underneath the wetland and south to the drainage ditch.



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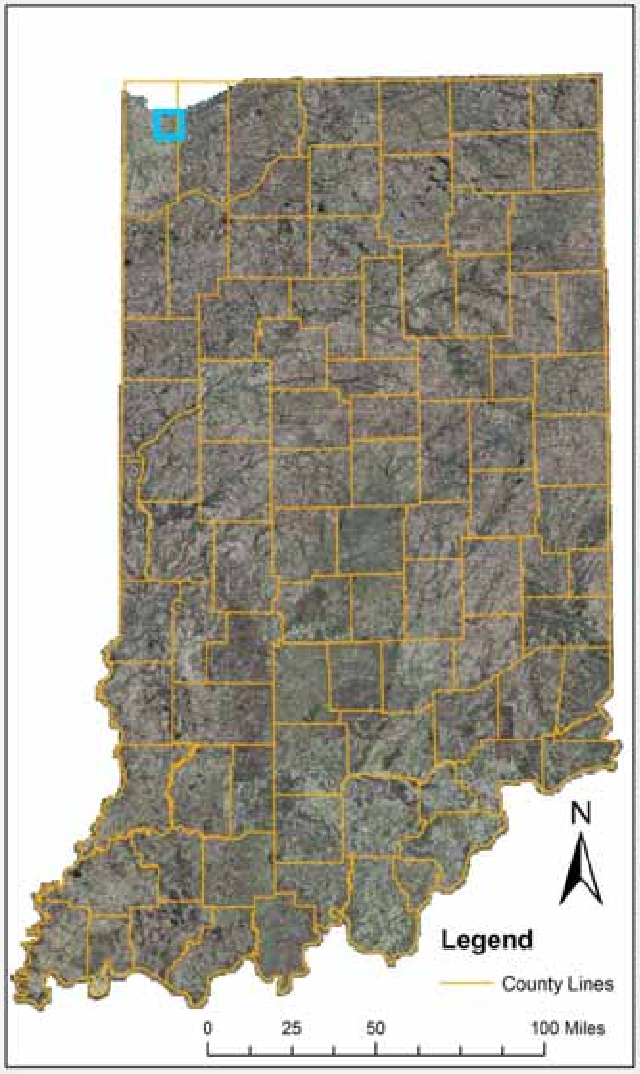
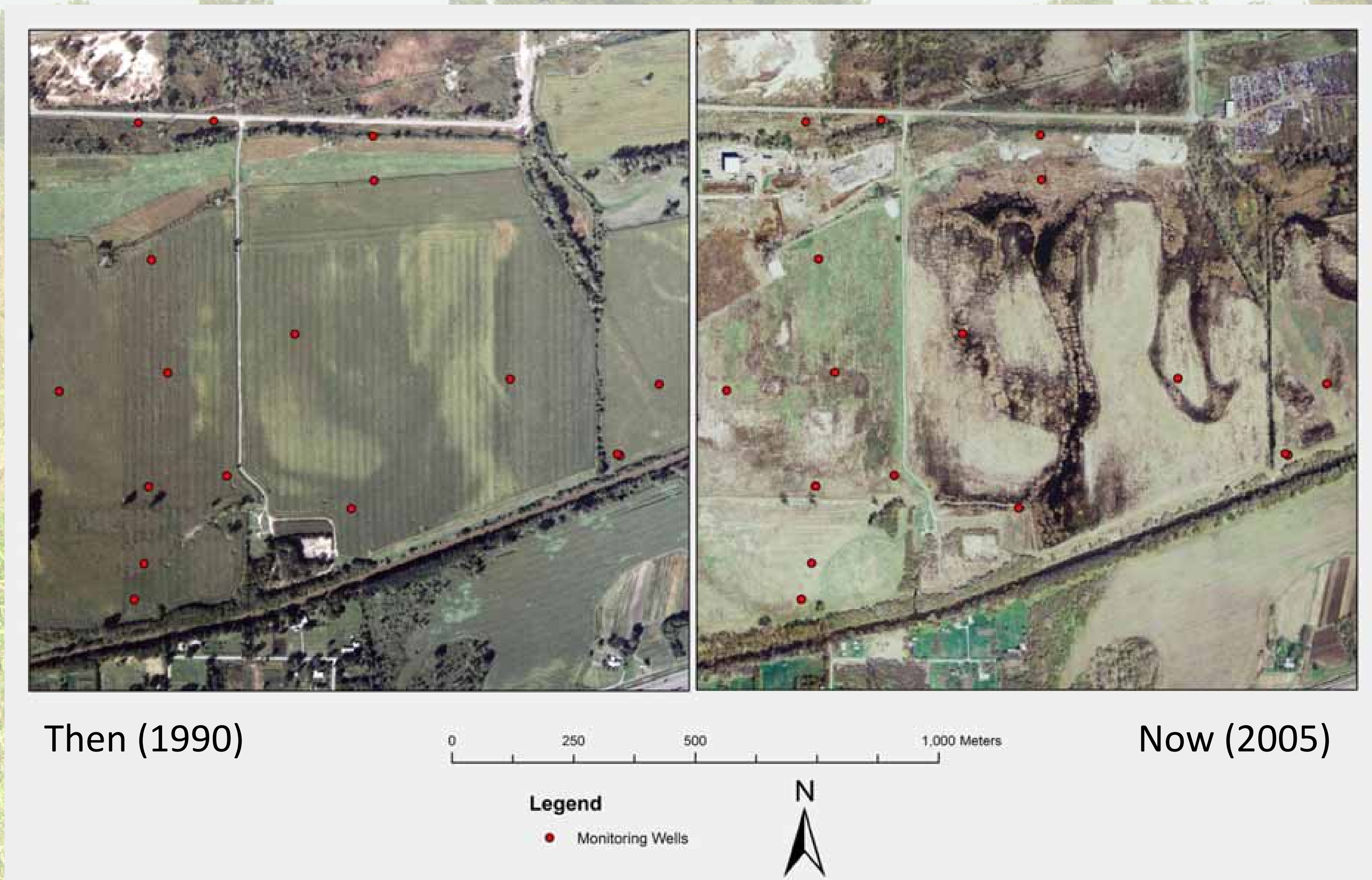
Study Site


N
Legend
County Lines
0
25
50
100 Miles


I-90
I-94
I-80
I-65
N
Legend
Interstates
0
0.5
1
2
3
4
5 Miles

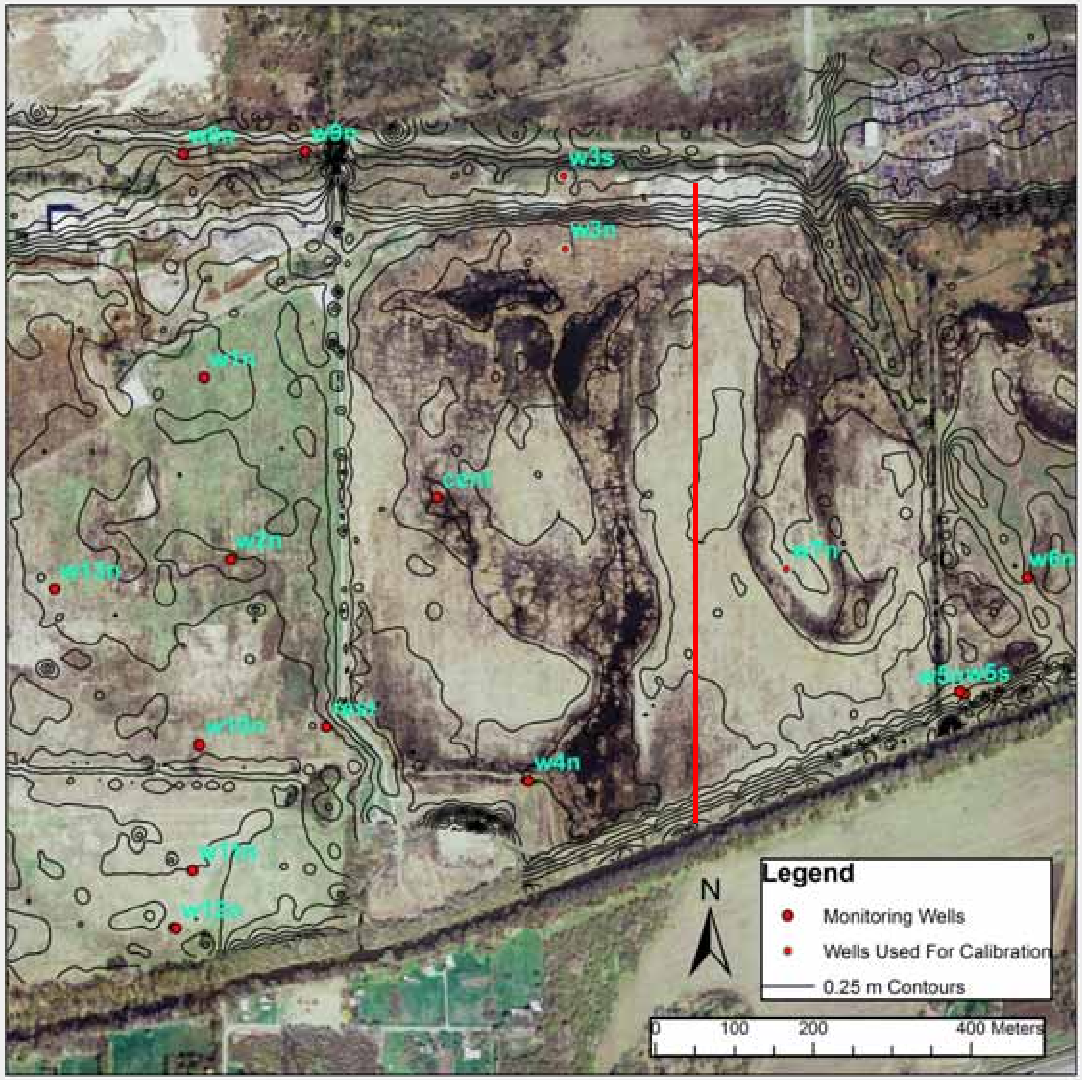
Study Site


Then (1990)
Now (2005)
0
250
500
1,000 Meters
Legend
Monitoring Wells
N

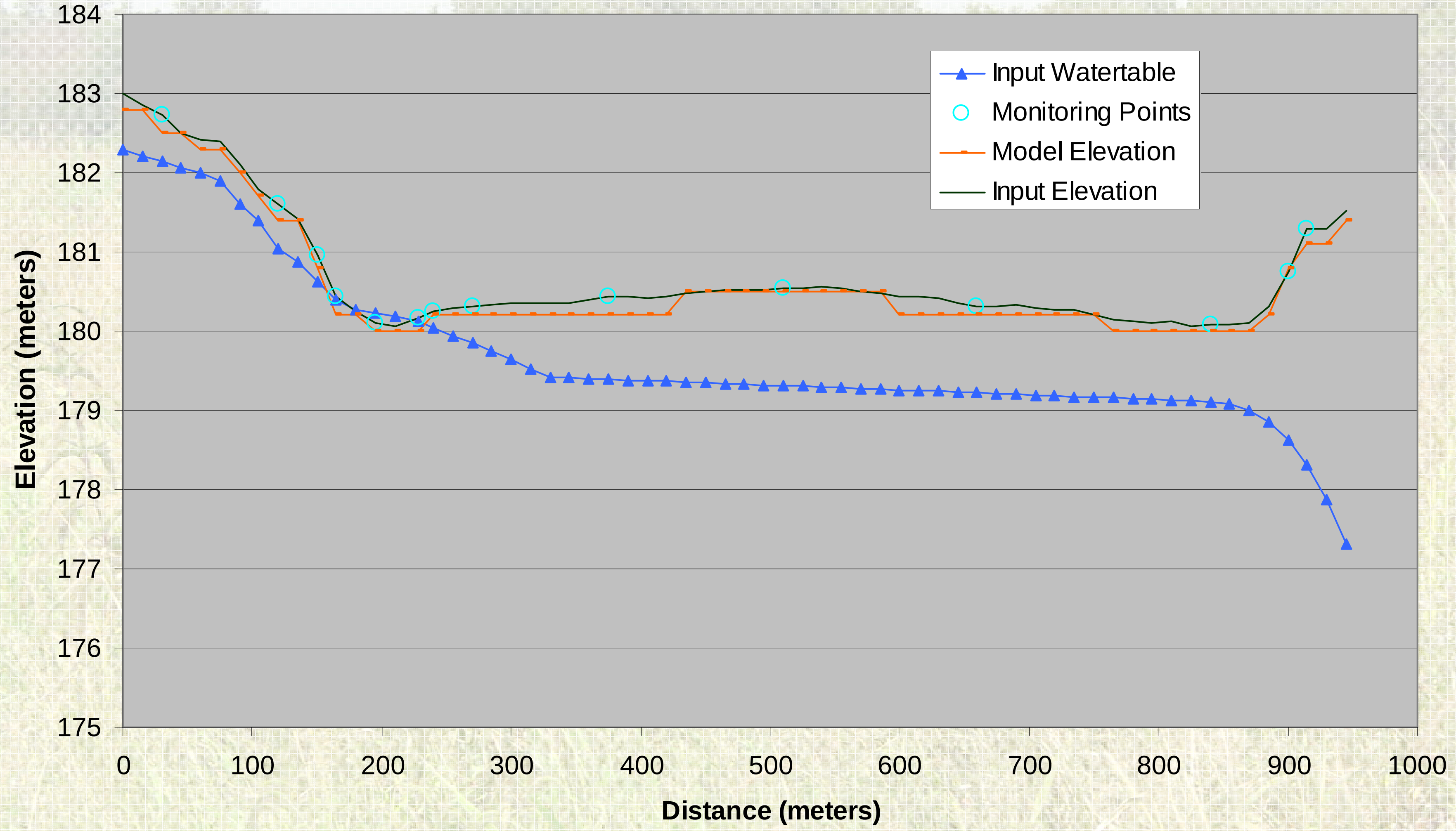
Research Questions

- Could restoration of the wetland area cause flooding of the neighboring industrial recycling facility?
- Which direction is ground water flowing?

Study Site

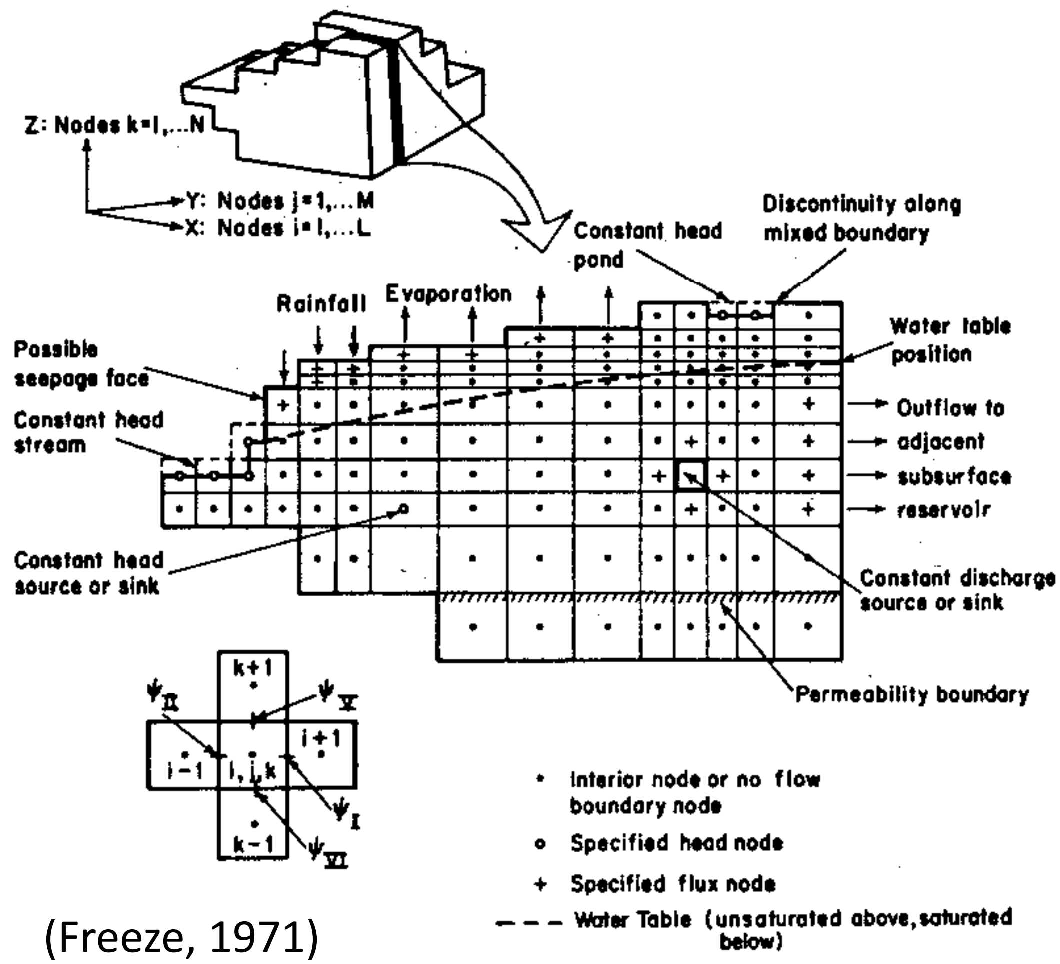

w9n
w3s
w3n
w1n
w2n
w4n
w6n
Legend
Monitoring Wells
Wells Used For Calibration
0.25 m Contours
N
0
100
200
400 Meters

Study Site



Input Watertable
Monitoring Points
Model Elevation
Input Elevation
Elevation (meters)
Distance (meters)
184
183
182
181
180
179
178
177
176
175
0
100
200
300
400
500
600
700
800
900
1000

The Model



(Freeze, 1971)

The Model

$$\frac{\rho^2 g}{\mu}\left(\frac{\partial}{\partial x}\left[K(\Psi)\frac{\partial \Psi}{\partial x}\right]+\frac{\partial}{\partial y}\left[K(\Psi)\frac{\partial \Psi}{\partial y}\right]+\frac{\partial}{\partial z}\left[K(\Psi)\left\{\frac{\partial \Psi}{\partial z}+1\right\}\right]\right)=\left[\frac{\rho\theta}{n}(\alpha+\beta n)+\rho C(\Psi)\right]\frac{\partial \Psi}{\partial t}$$

Where

x, y, z = coordinate directions, cm

t = time, s

Ψ = pressure head (tension in unsaturated zone), cm

ρ = density of water, g/cm^3

μ = viscosity of water, g/cm·s

g = acceleration due to gravity, cm/s^2

α = coefficient of vertical formation compressibility, cm^{-1}

β = coefficient of water compressibility, cm^{-1}

n = soil porosity, unit less

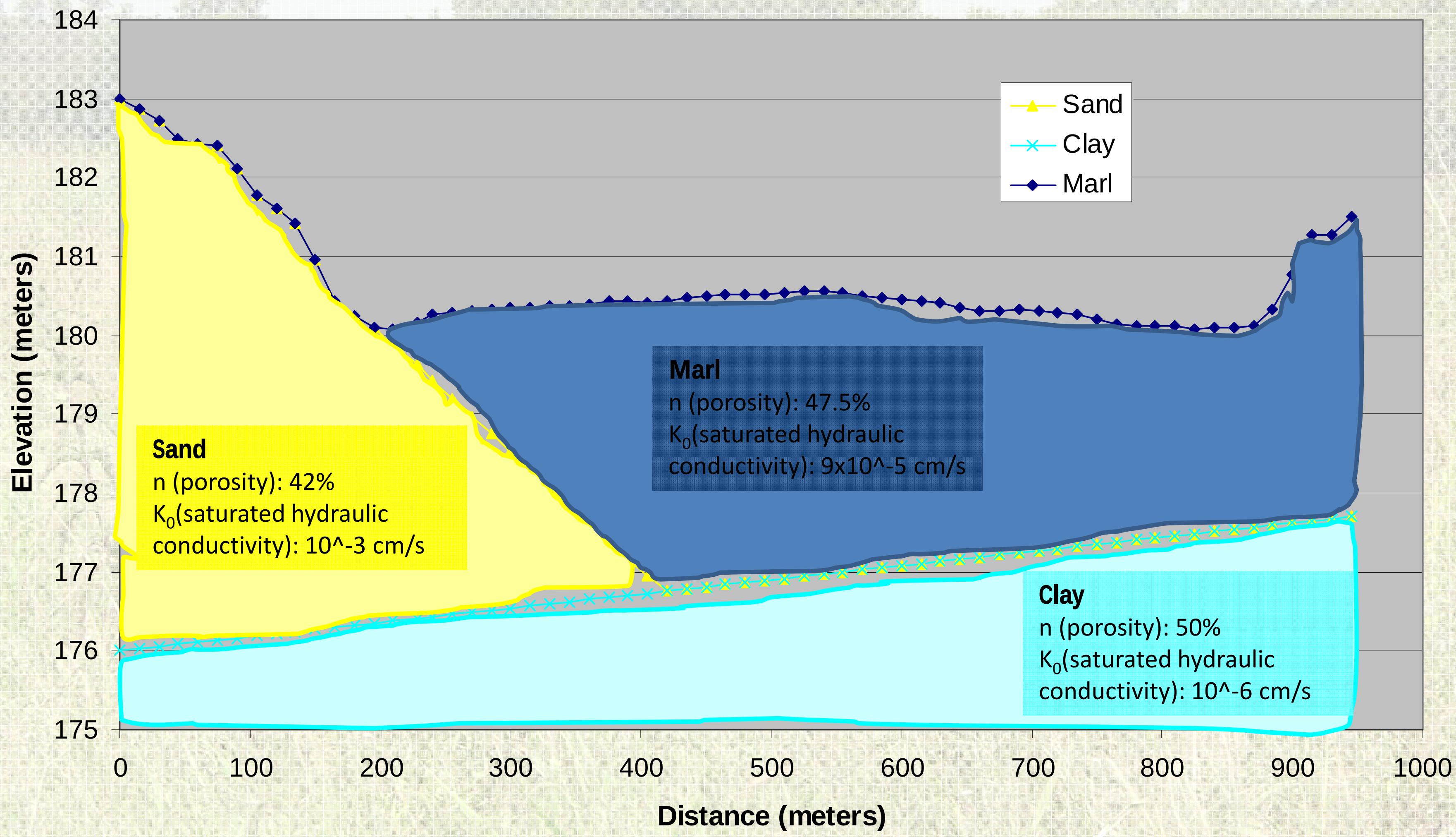
θ = volumetric soil moisture content, unit less

C(Ψ) = pressure head dependent specific moisture capacity, cm^{-1}

K(Ψ) = pressure head dependent hydraulic conductivity, cm/s

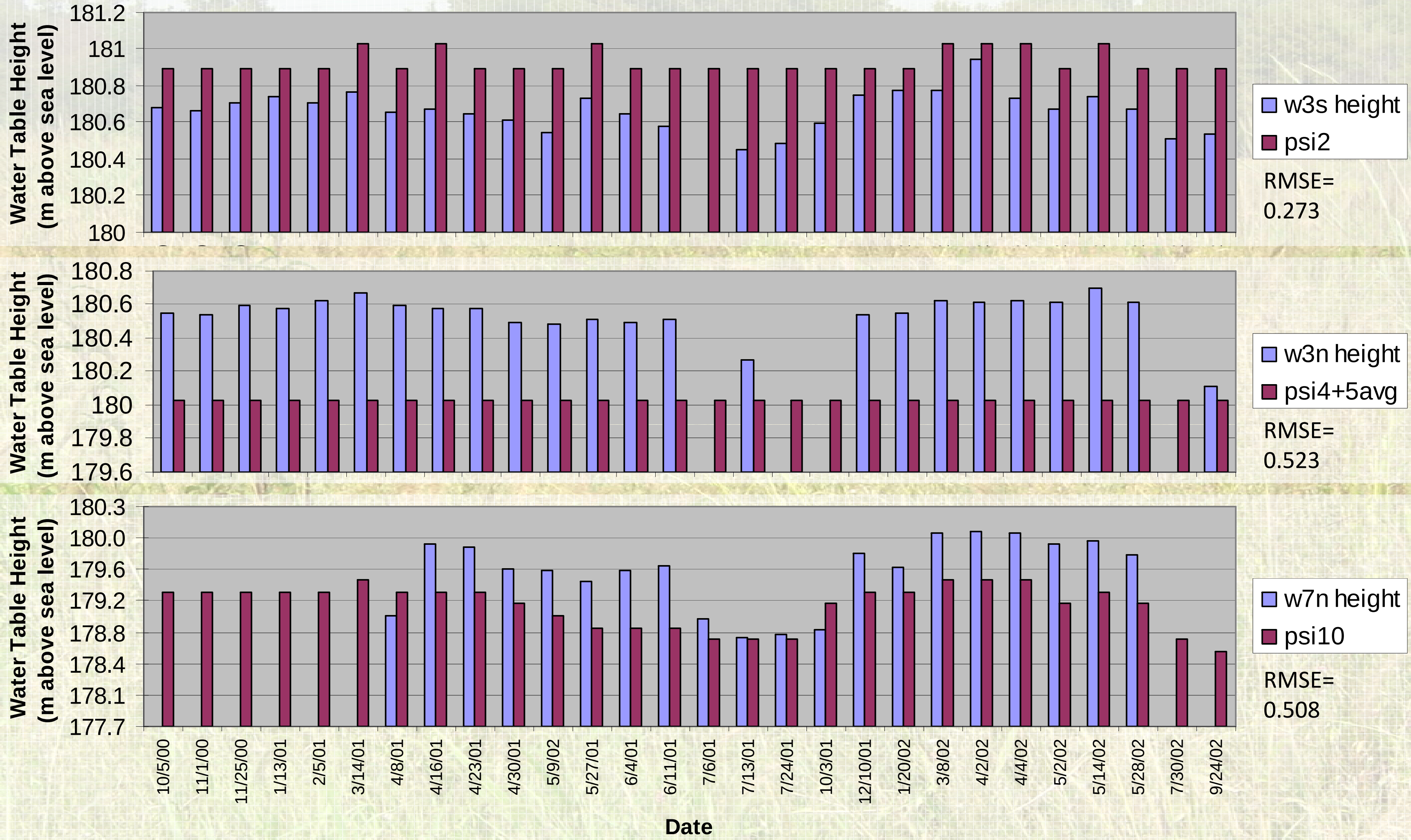
** Note that the storage coefficient C and hydraulic conductivity K are not constant, but depend on the pressure head (tension force) in the unsaturated zone

The Model

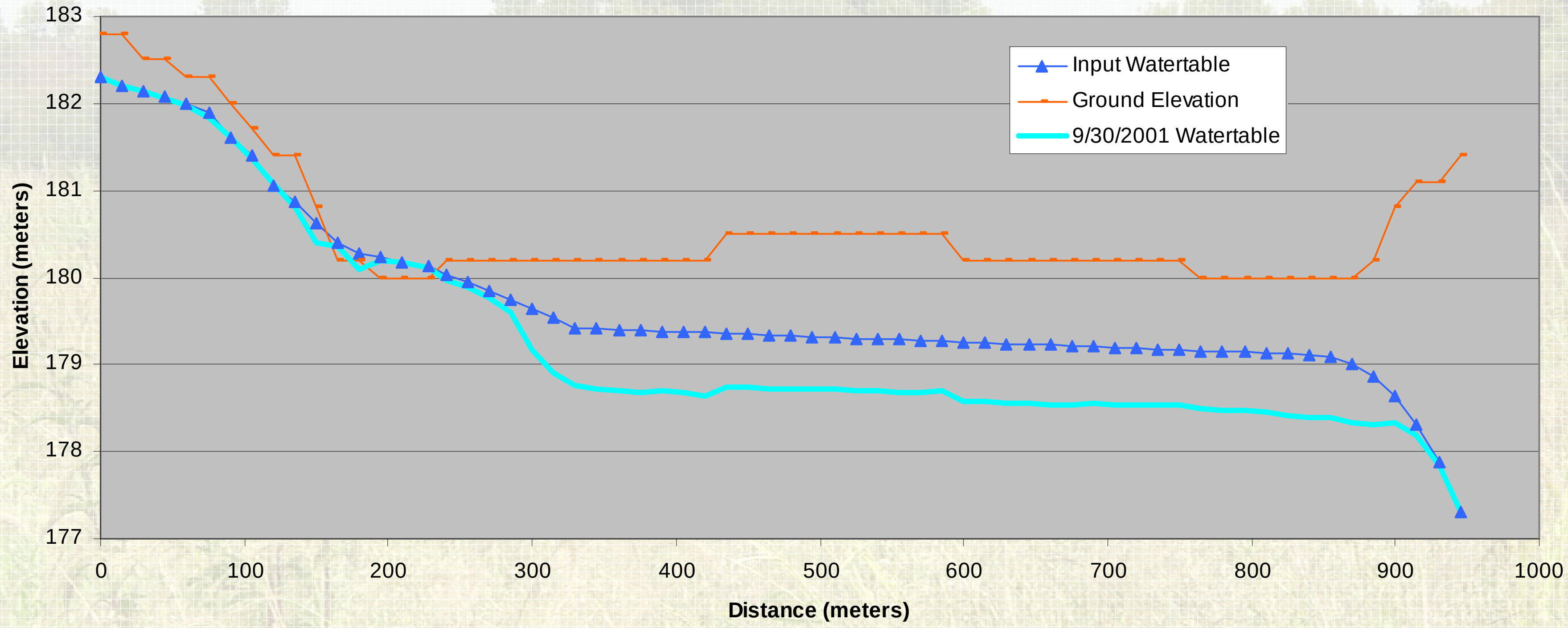


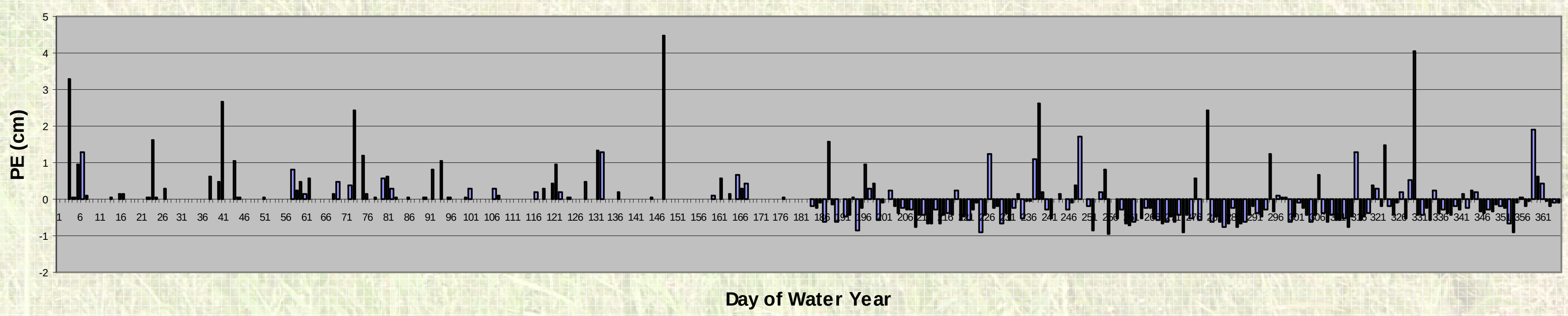
184
183
182
181
180
179
178
177
176
175
Elevation (meters)
0
100
200
300
400
500
600
700
800
900
1000
Distance (meters)
Sand
Clay
Marl
Marl
n (porosity): 47.5%
K_0(saturated hydraulic
conductivity): 9x10^-5 cm/s
Sand
n (porosity): 42%
K_0(saturated hydraulic
conductivity): 10^-3 cm/s
Clay
n (porosity): 50%
K_0(saturated hydraulic
conductivity): 10^-6 cm/s

Calibration

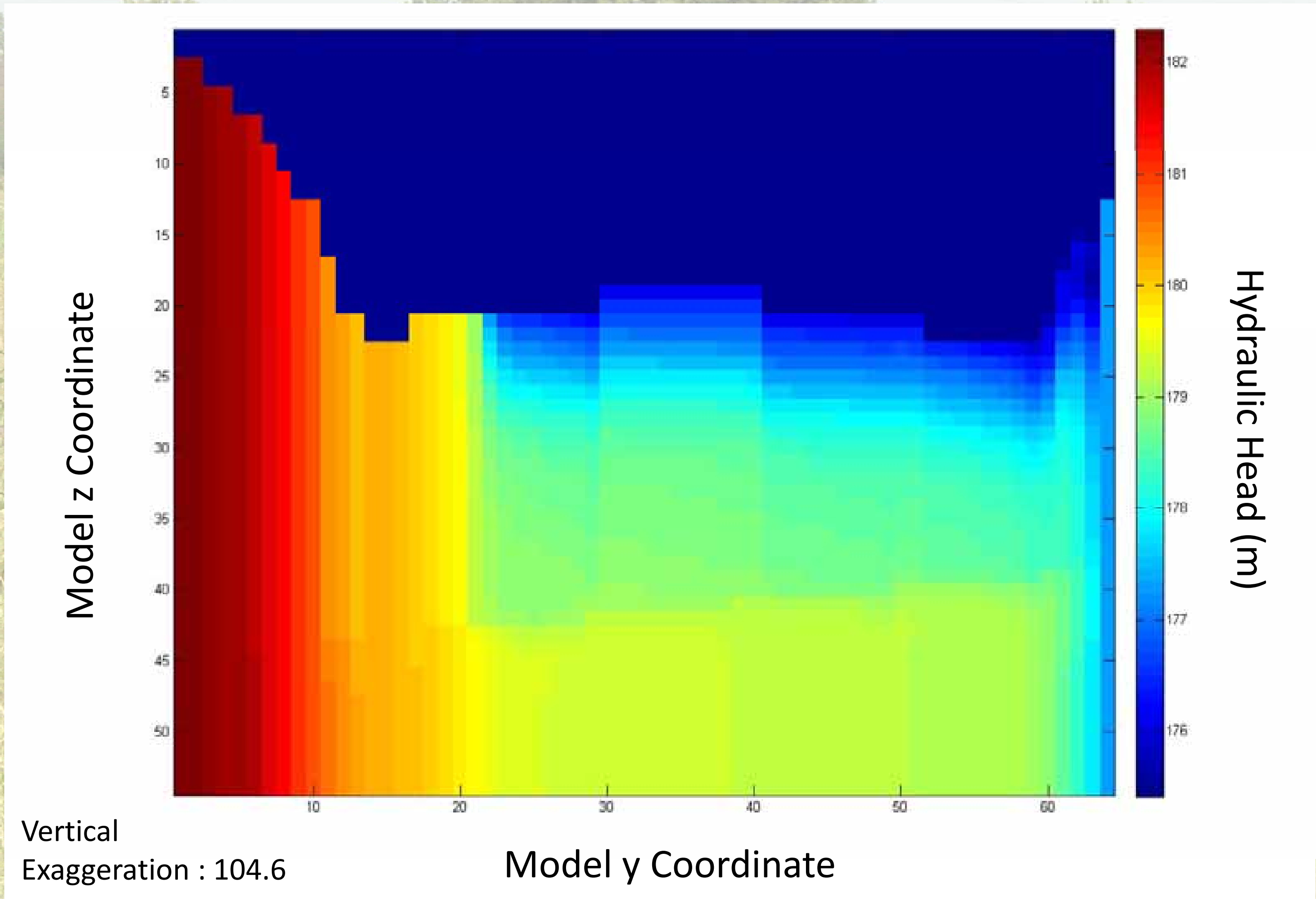


End of Year Results

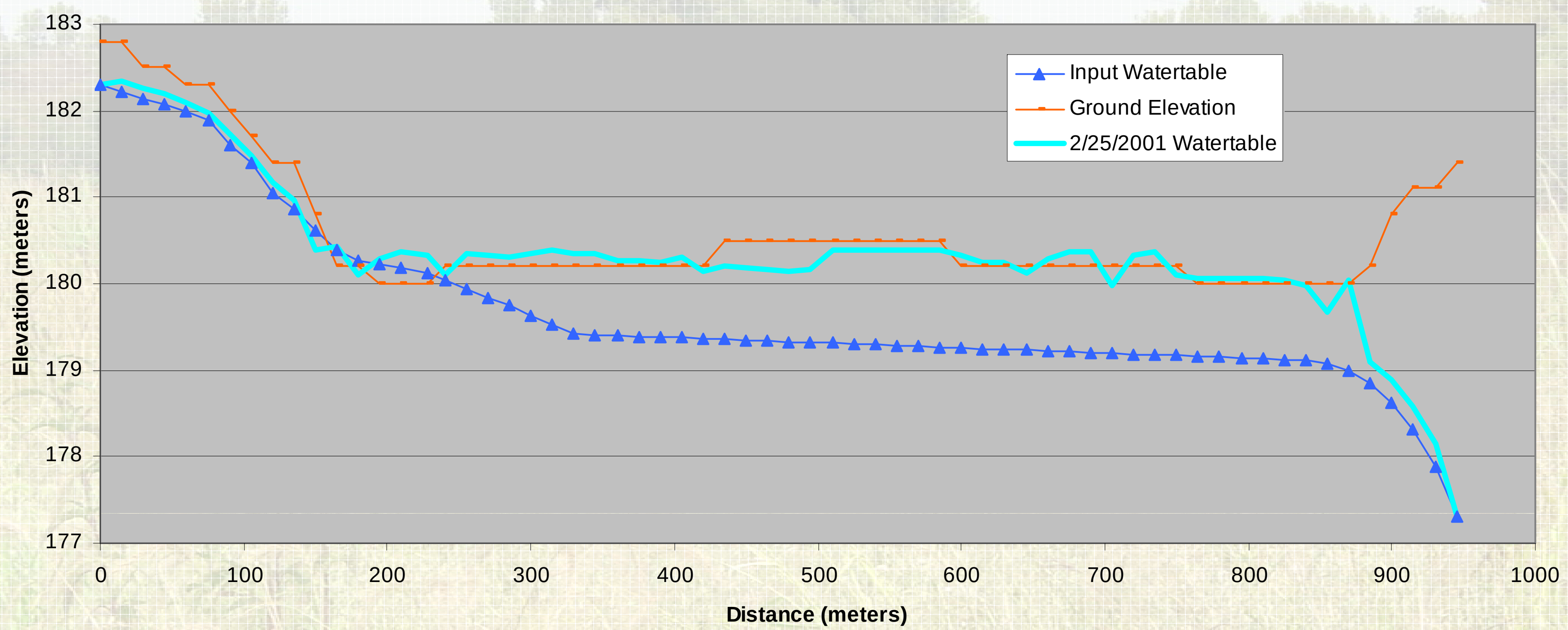


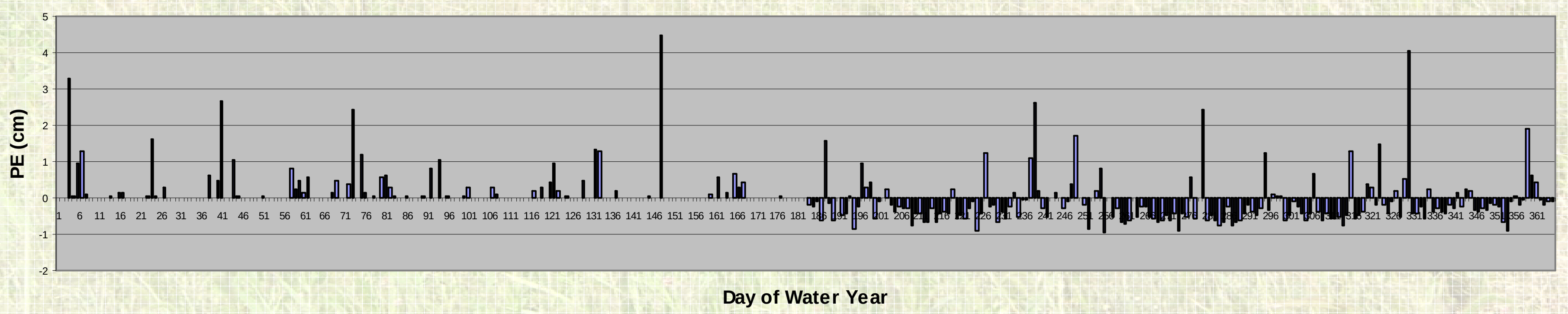


End of Year Results

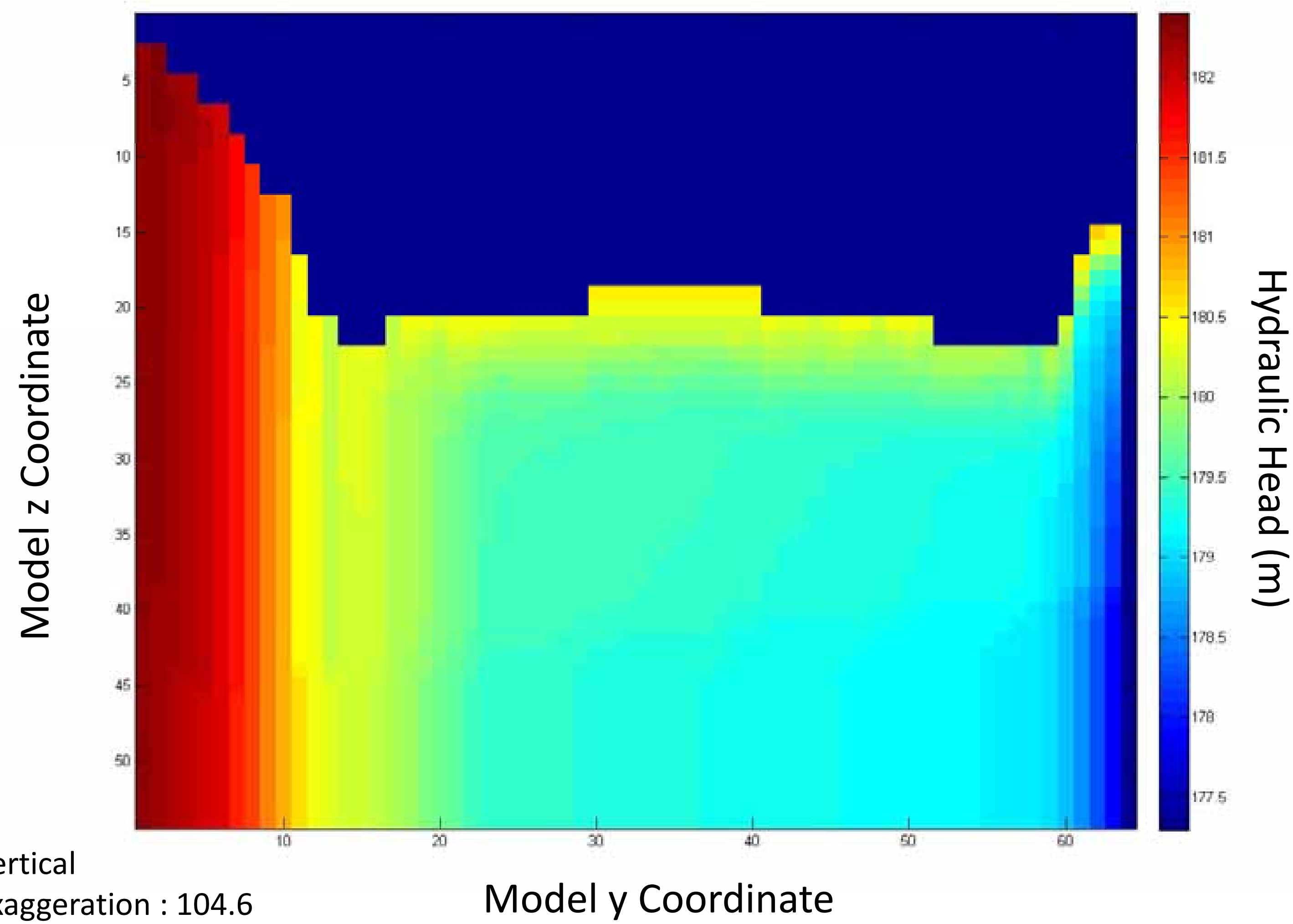


Storm Event Results





Storm Event Results



Vertical Exaggeration : 104.6

Conclusions

- Even the year’s largest storm even did not flood the dune.
- Water is flowing from the dune into the wetland and drainage ditch.

Questions?

Van Genuchten's Equations

$$K(\Psi) = K_o S_e^{1/2}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$

Where
K_o = saturated hydraulic conductivity, cm/s
S_e = effective saturation

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(\frac{1}{1 + |\alpha\Psi|^n}\right)^m$$

Where
θ_s = saturated moisture content
(which is equal to porosity)
θ_r = residual moisture content
m, n, and α = empirical parameters
θ = volumetric moisture content

$$\mathrm{C}(\Psi) = \frac{\partial\theta}{\partial\Psi} = \frac{mn\alpha^n \cdot (\theta_s - \theta_r) \cdot |\Psi|^{n-1}}{\left[1 + \alpha|\Psi|^n\right]^2}\left(\frac{1}{1 + \alpha|\Psi|^n}\right)^{m-1}$$