Terminology

Bog

- A peat-accumulating wetland that has no significant inflows or outflows and supports acidophilic mosses, particularly Sphagnum
Fen

- A peat-accumulating wetland that receives some drainage from surrounding mineral soil and usually supports marsh-like vegetation.
- This differs from bogs because they are less acidic and have higher nutrient levels. They are therefore able to support a much more diverse plant and animal community. These systems are often covered by grasses, sedges, rushes, and wildflowers.

*Cypripedium reginae*, an example of a unique plant that thrives in this.
Peatland

• A generic term of any wetland that accumulates partially decayed plant matter (peat)
• What is ‘peat’?
  – Partially carbonized vegetable matter, usually mosses, found in bogs and used as fertilizer and fuel
Marsh

- A frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions
Pothole

- Shallow marshlike pond, particularly as found in the Dakotas and central Canadian provinces.

Prairie Potholes

- These are depressional wetlands found most of ten in the Upper Midwest, especially North Dakota, South Dakota, Wisconsin, and Minnesota. This formerly glaciated landscape is pockmarked with an immense number of potholes, which fill with snowmelt and rain in the spring.
• Ombrotrophic peatland
  – Precipitation dominated
  – These are the true raised bogs that have developed peat layers higher than their surroundings and that receive nutrients and other minerals exclusively by precipitation
- **Minerotrophic peatland**
  - These are true fens that receive water that has passed through mineral soil. These peatlands generally have a high groundwater level and occupy a low point of relief in a basin. They are also referred to as rheotrophic peatlands.

- **Mesotrophic peatland**
Three Different Types of Wetlands
(as they are related to groundwater flow)

• Wetlands may
  – Receive inputs from groundwater
  – Recharge local groundwater by generating groundwater outflow
  – Be part of a flow-through system, receiving groundwater discharge along an up-gradient boundary and recharging groundwater along a down-gradient margin
Influence of Topographic Settings

Aquatic Body
(Lake or Wetland)

Soil-Moisture Zone

Tension held capillary water
Simulating vertical flow in large peatlands

A.S. Reeve, D.I. Siegel, P.H. Glaser
Introduction

• Peatland Hydrology
  – The hydrology of peatlands influences landform development by regulating interactions among vegetation, nutrient dynamics and carbon fluxes
  – Two conceptualizations of peatland hydrology
    • Shallow flow
    • Groundwater flow

Shallow Flow Model

• The deeper, more decomposed peat (catotelm) is relatively impermeable, isolating the uppermost peat (acrotelm) from the mineral soil or bedrock.
• Bogs are supplied with nutrients only by precipitation because they are topographically high areas isolated from runoff and groundwater. Fens, in contrast, receive solute-laden runoff from the surrounding uplands.
Groundwater Flow Model

- Water-table mounds sustained by precipitation from under bog domes and drive local ground-water flow cells.
- Dilute water derived from precipitation moves downward under the bog dome flushing solutes from the deeper bog peat. Fens are groundwater discharge zones for local flow cells and receive upwelling minerotrophic groundwater.

Peat Landforms

- Acrotelm
  - Upper peat layer
  - Less than 50cm thick
  - Undecomposed peat
  - Varying oxidation states due to water table fluctuation
  - High hydraulic conductivity (K)
    - 0.01m/s (~gravel or coarse sand)
    - Rapid water movement
• Catotelm
  – Lies below the acrotelm and above the mineral soil
  – Composed of more humified plant material
  – Lower hydraulic conductivity
    • $10^{-5}$–$10^{-8}$ m/s
    • ~ fine sand or silt
  – Continuously saturated and anoxic
    • anoxic $\rightarrow$ lacking of oxygen

**Governing Equation**

• Darcy’s Law?

$$Q = -KA \frac{dh}{dl}$$

• Possible reason for deviations from the Darcy’s law
  – Elastic storativity of the peat
  – Trapped biogenic gases in the peat column that affect pore
    -water flow by occluding pores and lowering hydraulic co
    nductivity
Governing Equation

\[ K_{xx} \frac{\partial^2 h}{\partial x^2} + K_{yy} \frac{\partial^2 h}{\partial y^2} + K_{zz} \frac{\partial^2 h}{\partial z^2} - W = S_s \frac{\partial h}{\partial t} \]

Grid Discretization and B.C.

Fig. 2: Boundary conditions and grid discretization for groundwater flow simulations. MODFLOW's drain package was used to remove surface runoff from the top of the model. Recharge and evapotranspiration (ET) were also applied across the top layer of the model at rates of $3.8 \times 10^{-8}$ and $2.9 \times 10^{-8} \text{ m}^3 \text{ s}^{-1}$.
System’s behavior to $K_{ms}$

When the $K_{ms}$ is small $\rightarrow$ small vertical gradient $\rightarrow$ vertical flow not significant

When the $K_{ms}$ is large $\rightarrow$ high vertical gradient $\rightarrow$ vertical flow significant

System’s sensitivity to $K_{ms}$

- Compare result 1-4 and 2-5
  - In both cases, regional slope was decreased from 0.0012 to 0.0006 (every other factor was fixed)
  - However, change of gradient value for the first case was larger than that for the second case.
• Compare result 1-3 and 2-4
  – In both cases, height of the bog dome was decreased from 1.80 to 0.90
  – However, change of gradient value for the first case was larger than that for the second case.

• This implies that the system becomes more sensitive with higher values of $K_{ms}$

**Vertical Flow is more active with**

• Lower regional slope
  – This can not be obtained from simply reading and analyzing the table, but can be known from the modeling result figures.

• Higher bog mounds
Fig. 6. Simulation 3 with regional slope of 0.0012 and a post-mound height of 6.05 m. Hydraulic conductivity of the mineral soil is 10^{-5} m/s. Solid vertical lines are equipotentials plotted at a 2 m contour interval. Minimum head = 0.06 m, c = 0.06, k = 0.06, and i = 0.06 m. Diagonal solid lines indicate neat surface, contact between post and mineral soil, and boundaries for flow towards the boundary. Dashed lines are streamlines with arrows indicating the direction of flow.

Fig. 7. Simulation 4 with regional slope of 0.0012 and a post-mound height of 6.04 m. Hydraulic conductivity of the mineral soil is 10^{-5} m/s. Solid vertical lines are equipotentials plotted at a 2 m contour interval. Minimum head = 0.06 m, c = 0.06, k = 0.06, and i = 0.06 m. Diagonal solid lines indicate neat surface, contact between post and mineral soil, and boundaries for flow towards the boundary. Dashed lines are streamlines with arrows indicating the direction of flow.
Conclusion

- Vertical flow is significant when the difference in hydraulic conductivity between mineral soil and overlying peatland is higher
  - Lateral flow dominant when K_{ms} is very low.
- System is sensitive with higher value of mineral soil’s hydraulic conductivity
- Vertical flow in peatland is more active with
  - Lower regional slope
  - Higher bog mound
Discussion

• Is the domain size of this model appropriate?

Is boundary condition appropriate?
Interaction between Groundwater and Wetlands, Southern Shore of Lake Michigan, USA

Robert J. Shedlock, Douglas A. Wilcox, Todd A. Thompson and David A. Cohen

Introduction
Fig. 1. Simplified surficial geology map of south shore of Lake Michigan, northwest Indiana.
Northern White Cedar

Sedge Meadow

Sedge Grass & Centipede Meadow
Shrub Zones

Cowles Bog
Hydrogeologic Settings

Fig. 1. Simplified surficial geology map of south shore of Lake Michigan, northwest Indiana.

Fig. 4. Geologic section through Cedar Bog. See Fig. 3 for location.
Field Measurement
Hydrochemistry of the aquifers:

**Class I**: water in the subaquifer below the Cowles Bog peat mound.
Ca$^{2+}$, Mg$^{2+}$, HCO$_3^-$
Higher in SO$_4^{2-}$ and low in Na$^+$ than subtill aquifer.

**Class II**: water from surficial aquifer, but not on the peat mound.
Similar in composition to water below the mound. Proportionally lower Mg$^{2+}$ and SO$_4^{2-}$ concentrations.

**Class III**: water from the surficial aquifer in the dunes.
More variable, less alkaline.

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Hydrochemistry of the aquifers:

**Peat vs. Sand below Peat**

- There is less difference in chemical composition in the peat mound and sand below it.

- There is more difference beyond the mound.
Fig. 6. Chemical composition of ground waters in the study area.

Fig. 7. Chemical composition of surface waters in the study area.
**Tritium composition:**

Pre-radiation levels < 15 pCi/l

- Water below the subtill aquifer : 1-5 pCi/l
- Water in sand below dune : 2-13 pCi/l
- Water in peat at mound : 19-40 pCi/l
- Water elsewhere : 1-153 pCi/l

1 pCi = 1x10^{-12} Curies

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**Ground-flow patterns:**

- Regional groundwater flow
- Intermediate groundwater flow
- Local groundwater flow
Fig. 5. Vertical ground-water flow patterns for section through Couple Bog in Fig. 4

Fig. 9. Schematic section showing geometric relations between subglacial and sublunae aquifers. See Fig. 3 for approximate line of section.
Much less mineralized calcium sulfate bicarbonate type (high tritium, lower hardness, alkalinity, and dissolved solids concentration)

calcium magnesium bicarbonate type (low tritium, high hardness, alkalinity and dissolved solids concentration)

Much less mineralized calcium sulfate bicarbonate type (high tritium, lower hardness, alkalinity, and dissolved solids concentration)

calcium magnesium bicarbonate type (low tritium, high hardness, alkalinity and dissolved solids concentration)
Discussion

- What to do next?
  - Are there any additional data which would be helpful?
  - Is modeling the next step?
  - What kind of model?
  - Do the authors miss some opportunities to resolve some of the puzzles?

Conclusion

- The nature of groundwater-wetland interaction underscores the importance of understanding the hydrogeologic setting of an area much larger than that of the wetlands of concern
Fig. 2. Map of study area showing surficial geology, drainage, and location of Cowles Bog.