Methods

- Hydraulics
- Seepage meters
- Water balance
- Environmental tracers
  - radon
  - oxygen-18, deuterium
  - ion chemistry
**Approach**

Tracers will be useful for identifying groundwater inflow to surface water if:

1. Concentrations of the tracers in surface runoff and groundwater are distinct
2. Tracers are conservative (do not undergo chemical reactions once in the wetland)

The proportion of groundwater is determined by comparing surface water, groundwater and wetland concentrations.
Environmental Tracers

Radon
- unreactive gas, only source is from decay of uranium (and radium) in aquifer materials
- negligible concentrations in atmosphere
- radioactive, half-life 3.8 days
- zero concentration in rainfall (runoff), high concentration in groundwater

Chloride
- relatively unreactive
- low concentrations in rainfall, higher concentrations in groundwater
Radon

Increased Groundwater Inflow

Increased Residence Time

radioactive decay
gas exchange

evaporation

Increased Residence Time

Increased Groundwater Inflow

Chloride
Radon

Chloride

Groundwater

Rainfall

Surface Water,
Short Residence Time

Groundwater,
Short Residence Time

Surface Water,
Long Residence Time

Groundwater,
Long Residence Time
• Radon and chloride concentration measured in 37 wetlands and 25 bores.

• Runoff chemistry not measured, although rainfall data is available for chloride. Runoff concentrations of radon assumed to be zero.

• Sampling took place in November 2004 and February 2005.

• Duplicate samples collected from 3 wetlands.
Radon

Groundwater, Short Residence Time
Surface Water, Short Residence Time
Surface Water, Long Residence Time
Ground Water, Long Residence Time

(a)

Chloride

\[ \text{Cl}^- \text{(mg/L)} \]

\[ \text{Rn (Bq/L)} \]

Surface Water, Long Residence Time
Groundwater, Short Residence Time
Tracer Mass Balance

Steady state, advective model:

\[
\frac{\partial V}{\partial t} = I_s + I_g - Q - EA = 0
\]

\[
\frac{\partial cV}{\partial t} = I_sc_s + I_gc_g - Qc - kAc - \lambda Vc = 0
\]

\[
c = \frac{I_sc_s + I_gc_g}{I_s + I_g - EA + kV + \lambda V}
\]

\[
t_r = \frac{I_s + I_g}{V}
\]
Ionic Tracers

• if we choose conservative, unreactive ionic tracers (e.g., chloride), then \( \lambda = 0, k = 0 \)

\[
\begin{align*}
\frac{I_s c_s + I_g c_g}{I_s + I_g - EA + kV + \lambda V}
\end{align*}
\]

• unknowns \( I_s, I_g \)
Radon

• unreactive gas, only source is from decay of uranium (and radium) in aquifer materials

• negligible concentrations in atmosphere

• $c_s = 0$

\[
c = \frac{I_g c_g}{I_s + I_g - EA + kV + \lambda V}
\]

• unknowns $I_s, I_g$
Simultaneous Solution

- requires two tracers
- measure $c_I, c_2, c_{s1}, c_{s2}, c_{g1}, c_{g2}$
- estimate $E, k, z$
- $\lambda$ is known
- solve for $I_g$ and $I_s$
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<th>Moderate Dependence</th>
<th>Low Dependence</th>
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<td>Border Swamp</td>
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<td>Woolwash Z2</td>
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Is this too good to be true?
Uncertainties in Model

• spatial variability of groundwater chemistry

Further Uncertainties in Model

• spatial variability of wetland water chemistry
• radon diffusion from sediments
Radon Diffusion from Sediments
Radon Production in Sediments

Radon Emanation Measurements

[Diagram of mineral oil and water with a device for measurement]
\[ c = \frac{\gamma}{\lambda \epsilon} \left( 1 - \left( 1 + \frac{\sqrt{\lambda \epsilon D}}{k + \lambda b} \right)^{-1} \exp \left( - \frac{\lambda \epsilon z}{D} \right) \right) \]

\( \gamma = 0.003 \text{ Bq/cm}^3/\text{day} \)
EC (μS/cm) in Honan South surface water, 25/07/06
Conclusions

• radon and chloride provide a valuable tool for determining groundwater input to wetlands
• diffusional input is relatively small, and can be corrected for or measured
• limited mixing poses problems in very shallow lakes
• radon cannot distinguish between different groundwater sources (e.g., perched versus regional groundwater)