Biogeochemistry of Wetlands: Wetland hydrology
Science and Applications

Outline

- Learning objectives
- Hydrologic Cycle
- Water Budget
  - Components of wetland inflow/outflow
  - How are these measured?
  - Examples of relative contribution of components in different wetland types
- Key points learned
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Learning Objectives

- What are the components of the hydrologic cycle?
- What about for wetlands?
- What are the components of a wetland water budget?
- How are each of these components measured?
- How significant are each of these components in water budgets for different types of wetlands?

Wetlands definitions

- U.S. Army Corps of Engineers
  - those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (33 CFR328.3(b); 1984)

- State of Florida
  - those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils. Soils present in wetlands generally are classified as hydric or alluvial, or possess characteristics that are associated with reducing soil conditions. The prevalent vegetation in wetlands generally consists of facultative or obligate hydrophytic macrophytes that are typically adapted to areas having soil conditions described above. These species, due to morphological, physiological, or reproductive adaptations, have the ability to grow, reproduce, or persist in aquatic environments or anaerobic soil conditions. Florida wetlands generally include swamps, marshes, bayheads, bogs, cypress domes and strands, sloughs, wet prairies, riverine swamps and marshes, hydric seepage slopes, tidal marshes, mangrove swamps and other similar areas. Florida wetlands generally do not include longleaf or slash pine flatwoods with an understory dominated by saw palmetto. (Florida Statutes 373.019, 25)
Earth’s Water Resources

• All water in the atmosphere, soil, rivers, lakes, and wetlands: **0.03% of total** on Earth.

• **2/3 of freshwater** in polar ice caps
  – Antarctic ice sheet: 80% of the world’s ice
  – Covers an area almost 1.5 times the U.S.
  – Sea level would rise about 300 feet if the ice melted

• Groundwater represents **95% of available** freshwater
Hydrologic Cycle

[Diagram showing the hydrologic cycle, including processes such as evaporation, precipitation, and flow through different water bodies like oceans, groundwater, and surface water.]
Hydrologic Cycle

Wetland Water Budget

- Conservation of mass (mass in minus mass out equals...?)
- Inflow – Outflow = Change in Storage
  \[ Q_i - Q_o = \Delta S \]

<table>
<thead>
<tr>
<th>Inflows:</th>
<th>Outflows:</th>
<th>Storage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Precipitation</td>
<td>- Evapotranspiration</td>
<td>- Open Water</td>
</tr>
<tr>
<td>- Overland flow</td>
<td>- Downstream flow</td>
<td>- In Porous Media</td>
</tr>
<tr>
<td>- Upstream flow</td>
<td>- Infiltration to Groundwater</td>
<td></td>
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<tr>
<td>- Groundwater influx</td>
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</table>
Wetland Water Budget

\[ \Delta V/\Delta t = Q_i - Q_o + S_i - G_o + G_i + P_nA - EA \]

Where does the water in different wetland types come from?

(and where does the water go...?)
Precipitation

\[ P = I + TF + SF \]

I - interception
TF - through fall
SF - stem flow

Interception 8 - 35%
(13% deciduous; 28% coniferous)
Time of year...

Mitsch and Gosselink, 2000
Net Precipitation ($P_n$)

$$P_n = P - I = TF + SF$$

- Precipitation ($P$)
- Throughfall ($TF$)
- Interception ($I$)
- Stemflow ($SF$)

• How do we measure? (where do the numbers come from)
Evapotranspiration

Evapotranspiration = Evaporation + Transpiration

• Evaporation is the water that vaporizes from the water or soil directly to the atmosphere.
• Transpiration is the water that moves from the soil or water into vegetation and then is released to the atmosphere, typically through stomata within leaves.

Factors Regulating Evapotranspiration

• Vapor pressure (the driving force)
• Temperature
• Wind
• Solar radiation
• Vegetation
• Elevation
• Humidity
• Water table depth
Evaporation Rate

\[ E = c f(u) (e_w - e_a) \]

- \( E \) = rate of evaporation
- \( c \) = mass transfer coefficient
- \( f(u) \) = function of wind speed, \( u \)
- \( e_w \) = vapor pressure at surface, or saturation vapor pressure at wet surface
- \( e_a \) = vapor pressure in surrounding air

- First-order expression where vapor pressure difference is the driving force
- Increased evaporation from
  - increased vapor pressure at water surface (e.g., more solar radiation)
  - decreased vapor pressure of surrounding air (e.g., low humidity)

Evapotranspiration

- Estimation methods for ET
  - Pan evaporation
    - potential ET (not likely correlated to actual ET from vegetated areas)
  - Diurnal Method
    - requires soil properties
- Empirical approximations
  - Thornthwaite
  - Penman-Monteith
    - Standard method for many agencies
    - Requires daily mean temperature, wind speed, relative humidity, and solar radiation

![Image](image.png)

![Graph](graph.png)
Surface Inflow:

- **Surface overland flow ($S_i$)**
  - Non-channelized sheet flow
  - Estimating $S$ from rainfall?
- **Channelized flow ($Q_l$ or $Q_o$)**
  - Streams, channels, ditches, canals, control structures flowing into/out of wetland
Surface Overland Flow $S_i$
(total volume estimate)

$$S_i = R_p \cdot P \cdot A_w$$

- $S_i =$ surface runoff to wetland, m$^3$/event
- $R_p =$ hydrologic response coefficient, represents fraction of precipitation that becomes surface runoff (estimated 4-18% for small watersheds in Eastern US)
  - not usually a constant in time!
  - depends on antecedent conditions (soil moisture from previous rain events)
- $P =$ average precipitation in watershed, m
- $A_w =$ area of watershed draining into wetland m$^2$

Channelized Water Flow: $Q$

$$Q_i \text{ or } Q_o = vA_x$$

- $Q_i =$ channelized flow into the wetland, m$^3$/sec
- $Q_o =$ channelized flow out of the wetland, m$^3$/sec
- $A_x =$ cross sectional area of the channel m$^2$
- $v =$ average velocity, m/sec

- Measure flow by stream gaging (flow meters), weirs (or other control structures), hydrologic model of the watershed (P input and Q/S output), Manning equation
Stream gaging; $Q = vA$; $Q = \Sigma v_j A_j \ (n \sim 10)$

**Weir for measuring surface flow**

- Generic weir equation
  
  $Q_o = a L^b$

  $a$ and $b$ = constants based on the weir geometry
  $L$ = height of the water behind (upstream of) the weir

- Derived from Conservation of Energy
Manning Equation

\[ Q = \frac{k}{n} AR_H^{2/3} S^{1/2} \]

- \( Q \) = surface flow
- \( n \) = roughness coefficient
- \( A_x \) = cross section area of the stream
- \( R_H \) = Hydraulic radius (cross sectional area of flow divided by wetted perimeter)
- \( S \) = bed slope

- Summary? (Consider direct vs inverse proportionality of factors in equation)

Groundwater-Surface Water Exchange in Wetlands

- Recharge - Discharge Relationships
  - Wetland drainage

- Darcy's Law
Vadose zone = between ground surface and water table

- Water pressure is less than atmospheric
- ‘vadosus’

Wetlands and Groundwater

Riparian

Fen

Bog
Groundwater “Recharge” Wetland

- Water moves from the wetland towards the water table which is lower in the surrounding landscape.
- Leaching environment, tends to lower nutrient and carbonate concentrations
- Wetland recharges the groundwater

Groundwater “Discharge” Wetlands

- Water moves from the groundwater into the wetland
- Tends to be an enriching environment with accumulation of carbonates, higher nutrients
- Fluctuating water tables can cause wetland to shift back and forth between discharging and recharging wetlands
Groundwater “Flow-through” Wetlands

- Water moves through wetland at surface of exposed water table
- Flow-through wetlands are often connected with outflows of one becoming the inflow of the next.
- Water supply to the lower wetland is often delayed until the upper one fills

Groundwater “Perched” Wetlands

- Low conductivity soils below wetland reduce infiltration and can cause water within the wetland to become disconnected “perched” from the groundwater.
- Often a transient condition during the beginning of a wet season or shortly after a rain event.
Darcy’s Law - flow through porous media

\[ G = -A_x K \frac{dH}{dL} \]

- \( G_{i,o} \) = ground water flow into/out of the wetland
- \( K \) = hydraulic conductivity of the porous media
- \( A_x \) = cross sectional area of flow
- \( dH \) = head difference between wetland and groundwater
- \( dL \) = distance over which head difference is measured

- Vertical flow
  - Darcy’s Law with thickness of peat or clayey sediment often used for \( dL \)
- Lateral flow (e.g., discharge from GW to wetland)
  - Darcy’s Law integrated in space (Dupuit equation)

Hydraulic Conductivity, \( K \) [L/T]

- Flow through pores
- May vary over orders of magnitude for different materials
- Sand = 10,000 times higher than clay
  - Sand \( \sim 3 \) m/day (10 ft/day)
  - Clay \( \sim 3 \times 10^{-4} \) m/day
- Poorly decomposed peat = 1000 times higher than clay; well decomposed (and well compressed) \( \sim 10 – 100 \) times clay (large variability)
Groundwater/surface water exchange: Okeechobee isolated wetlands

\[ \Delta V/\Delta t = Q_i - Q_o + S - G_o + G_i + P_n A - EA +/- T \]

- \( P = \) rain gage
- \( ET = \) pan; meteorological data; diurnal water table
- \( Q_i = \) stream gaging (flow meters); weirs (or other control structures); hydrologic model of the watershed; Manning equation
- \( GW = \) Darcy’s Law, seepage meters; or mass balance
Total Water Budget

- Depending upon the degree of confidence in the measurement, quantifying each of these components of a water budget can be a complex, technologically intensive and costly. However, even ballpark numbers allow us to estimate the relative contribution of each hydrologic component.
- In the next few slides several water budget from different wetlands are presented.

Wetland Water Budget
Example Water Budgets  alluvial swamp, Illinois

\[ \Delta V / \Delta t = 0 \]

- \( P = 105 \)
- \( I = 31 \)
- \( ET = 72 \)
- \( P_n = 74 \)
- \( S_o = 232 \)
- \( S_i = 229 \)
- \( G_i = 22 \)
- \( G_o = 21 \)

Flood = 5300

Annual water budget, units = cm/yr

Example Water Budgets  bog, Massachusetts

\[ \Delta V / \Delta t = +19 \]

- \( P_n = 145 \)
- \( ET = 102 \)
- \( S_o + G_o = 24 \)

Annual water budget, units = cm/yr
Example Water Budgets  
**rich fen, North Wales**

\[ \Delta V/\Delta t = -9 \]

\[ S_i + G_i = 38 \quad S_o = 100 \]

\[ P = 102 \quad ET = 49 \]

Annual water budget, units = cm/yr

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Example Water Budgets  
**mangrove swamp, Florida**

\[ \Delta V/\Delta t = -54 \]

\[ S_o = 90 \]

\[ T_{in} = 1228 \quad T_{out} = 1177 \]

\[ G_o = 28 \]

\[ P = 121 \quad ET = 108 \]

Annual water budget, units = cm/yr
Example Water Budget  treatment wetland, Florida

\[ P = 11 \quad ET = 8.9 \]

\[ Q_i = 86 \quad \Delta V/\Delta t \quad G_i = 2.6 (?) \quad G_o = 6 (?) \]

Guardo, 1999 (ENR 1994-1996, percent of inflows/outflows)

Relative contributions of in/out flows in constructed/natural wetlands

<table>
<thead>
<tr>
<th>Wetland type</th>
<th>No</th>
<th>Qi (%)</th>
<th>Io (%)</th>
<th>P (%)</th>
<th>Δ V/Δ t (%)</th>
<th>Gi (%)</th>
<th>Go (%)</th>
<th>ET (%)</th>
<th>Δ S (%)</th>
<th>References</th>
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<td>ENR</td>
<td>1</td>
<td>82</td>
<td>9</td>
<td>9</td>
<td>69</td>
<td>24</td>
<td>7</td>
<td>-</td>
<td>0</td>
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<tr>
<td>ENR</td>
<td>4</td>
<td>77</td>
<td>&lt;1</td>
<td>23</td>
<td>54</td>
<td>19</td>
<td>27</td>
<td>1</td>
<td>1</td>
<td>Siefert and Harvey (2000)</td>
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<tr>
<td>Treatment (natural &amp;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heinburg (1984), Nienau and</td>
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<tr>
<td>constructed)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tschierski (2006), Mountast et al.</td>
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<tr>
<td>Natural</td>
<td>35</td>
<td>30</td>
<td>17</td>
<td>53</td>
<td>33</td>
<td>19</td>
<td>49</td>
<td>36</td>
<td>6</td>
<td>Chip (1966), O’Heller (1968), O’Brien (1975), Mostets (1975), Linz (1980), Lipp and</td>
</tr>
</tbody>
</table>

- Constructed/natural
- Qi vs P
- Why difference in ET?

Nungesser and Chimney, 2006 (ENR)
Summary for wetland hydrologic processes

- Hydrologic conditions help define what is a wetland
- Exchange with groundwater is the hardest water budget component to measure, and often is very important for understanding leakage
- Water budgets are intrinsically useful for understanding ecological function and are the first step in understanding chemical (e.g., nutrient) budgets

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Upon completion of this course, participants should be able to:

- Recognize that hydrologic conditions help define what is a wetland
- Describe the components of the hydrologic cycle
- Explain the components of a wetland water budget
- Understand how are each of these components measured
- Recognize that exchange with groundwater is the hardest water budget component to measure, and often is very important for understanding leakage
- Understand why water budgets are intrinsically useful for understanding ecological function and are the first step in understanding chemical (e.g., nutrient) budgets