Watersheds and the Hydrologic Cycle
Water Cycle in Florida
Florida Water Facts

- Surface Area = 170,452 km²
- Average Rainfall = 140 cm (55”)
  - Total Annual Rain = 238 billion m³ (62.6 trillion gallons)
- River and Stream = 84000 km
- Largest River = Apalachicola (Q = 22 km³/yr = 25,000 ft³/s)
- Lake Area = 12,100 km²
- Springs ~ 30 billion L/ day (8 billion gallons)
- Groundwater supplies 95% of water
  - 24 billion L/day; 80% in S. Florida
- Low relief – travel time for water (rainfall to sea) can be decades

Florida’s Average Annual Rainfall, 1961–90
Source: Fernald and Purdum, 1998
The Hydrologic Check-Book

- **Mass Balance**
  - Water mass is conserved
  - Therefore: Water In = Water Out

- **Sources**
  - Rain, Snow, Groundwater, Human Effluent

- **Sinks**
  - Ground, River, Atmosphere, Humans

- **Stores**
  - Wetlands, Lakes, Rivers, Soil, Aquifers
The Water Budget (Exam 1)

\[ P = Q + ET + G + \Delta S \]

**INFLOW**
- Precipitation
- Surface runoff
- Evapotranspiration

**OUTFLOW**
- Groundwater
- Storage
Annual Water Budget - Flatwoods

Rainfall (~ 140 cm)

Interception (~ 25 cm)

Transpiration (~ 85 cm)

Surface Runoff (~ 3 cm)

Infiltration to Deep Aquifer (~5 cm, though up to ~ 40 cm)

Subsurface Runoff (~ 22 cm)
Annual Water Budget – Ag Land

Rainfall (~ 140 cm) → Interception (~ 20 cm) → Transpiration (~ 100 cm)

Surface Runoff (~ 20 cm) ← Irrigation (~ 50 cm) ← Subsurface Runoff (~ 20 cm)

Infiltration to Deep Aquifer (~30 cm)
Annual Water Budget – Urban Land

- Rainfall (~ 140 cm)
- Infiltration to Deep Aquifer (~ 10 cm)
- Interception (~ 20 cm)
- Transpiration (~ 50 cm)
- Surface Runoff (~ 50 cm)
- Subsurface Runoff (~ 10 cm)
Changes in Internal Stores

• $\Delta$Storage = Inputs – Outputs

– Usually easy to measure (e.g., lake volume)

What if $In_{\text{measured}} > Out_{\text{measured}}$

AND water level is falling?
Rules of Water Balances

- Water balance terms must be in common units
  - (usually meters depth over the watershed area).
- Precipitation and ET measured in depth (m/yr)
- Water flows measured as volumes (m³/yr).
An Even Simpler Water Budget

- Budyko Curve shows annual catchment hydrology
  - Can neglect G and ΔS, focus on ET (P ~ ET + Q)
  - Aridity index on the x-axis (potential ET:rain)
  - Evaporative index on the y axis (actual ET:rain)
Catchment Water Balance

- Area = 1000 ha (10,000 m² per ha)

- **Annual** Measurements:
  - Rainfall = 2 m (tipping-bucket rain gage)
  - Surface outflow (Q) = 2,000,000 m³ (weir)
  - ET = 1.5 m (eddy correlation tower)
  - Groundwater flow = 1,000,000 m³ (wells)
  - Assume ΔS=0
Budget: \( P = Q + ET + G + \Delta S \)

- Area = 1000 ha; 1 ha = 10,000 m\(^2\)
- \( P = 2.0 \) m
- \( Q = 2,000,000 \) m\(^3\)/(1000 ha * 10,000 m\(^2\)/ha) = 0.2 m
- \( ET = 1.5 \) m
- \( G = 1,000,000 \) m\(^3\)/(1000 ha * 10,000 m\(^2\)/ha) = 0.1 m
- \( \Delta S = 0 \)

\[ 2.0 = 0.2 + 1.5 + 0.1 + 0 \ (?!?) \]
Explanations

• Rainfall is uneven
  – 1 rain gage may not reflect rainfall patterns

• Streamflow may be poorly gaged
  – Poor measurements are usually ± 10%

• ET measurements may be incomplete
  – Eddy correlation towers are usually accurate

• Groundwater flow is more complex
  – Network of shallow wells is hard to implement

• Storage change is NOT zero
  – Wetlands fill/drain, soils dry/wet, aquifers rise/fall
Watersheds

• A land area from which all rainfall drains to the same point.
  – The “watershed” is technically the divide between two such areas (called basins)

<table>
<thead>
<tr>
<th>Term</th>
<th>Area (mi²)</th>
<th>Stream Order</th>
<th>Planning Authority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment</td>
<td>0.5</td>
<td>1</td>
<td>Land owner</td>
</tr>
<tr>
<td>Sub Watershed</td>
<td>1-10</td>
<td>1-2</td>
<td>Local government</td>
</tr>
<tr>
<td>Watershed</td>
<td>10-100</td>
<td>3-4</td>
<td>Multi-local governments</td>
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<tr>
<td>Sub Basin</td>
<td>100-1,000</td>
<td>&gt;4</td>
<td>Regional or state</td>
</tr>
<tr>
<td>Basin</td>
<td>1,000-10,000</td>
<td>&gt;4</td>
<td>State, Federal</td>
</tr>
</tbody>
</table>

Bradford experimental forest catchment> New River watershed> Santa Fe River sub basin> Suwannee River Basin
Delineating Watersheds

1. Identify outlet point
2. Identify high points
3. Link high pts crossing contour lines at right-angles
High-Relief Watersheds

Digitized from 1:100,000 Topographic Map

Automated Delineation from 1:24,000 DEM
Why Watersheds?

• Control boundaries
  – Water that falls either comes out the bottom or is abstracted

• Imagine a water budget if you weren’t sure where the water was going...

\[ P + Q_{in1} + Q_{in2} = Q_{out1} + Q_{out2} + ET + G_1 + G_1 + \Delta S \]
Experimentation – Paired Watersheds

• What is the effect of forest management on:
  – Water yield
  – Sediment yield
  – Nutrient export
  – Water temperature
  – Time of transport
Paired Watershed Response

![Paired Watershed Response Diagram]

- **Watershed 2 Flow** vs. **Watershed 1 Flow**
- **Pre-Treatment** line
- **Post-Treatment** dashed line
Paired Watershed Study of Forest Harvest Effects on Peakflows

Beschta et al. 2000 – H.J. Andrews Experimental Forest (OR)
Does watershed delineation work in Florida?

- Low-relief
  - Delineation of boundaries hard
  - In parts of Florida, water flows depend on:
    - where it rained,
    - where the wind is blowing and
    - where people put the canals and roads

- National contour maps too coarse (5 ft)
- Roads act as flow delineators
“Delineating” Watersheds in Florida
Paired Watersheds in Florida

- Shown that (Riekerk 1983):
  - High intensity logging increased water yields by 250%
  - Low intensity logging increased water yields 150%
  - Clear cutting altered nutrient export rates
  - All forest operations (fire?) were less than urbanization (much more on this later)
Stream Patterns

- Dendritic patterns follow Strahler Order
  - 1\textsuperscript{st} order is unbranched
  - 2\textsuperscript{nd} order occurs when two 1\textsuperscript{st} order reaches converge
  - Increased order requires convergence of two reaches of the same order
  - What are springs?
Network Forms

- Regional landform dictates shape
- Regional geology dictates drainage density
- Regional climate (rainfall) dictates density and maturation rate
### Stream Order Distribution

<table>
<thead>
<tr>
<th>Order</th>
<th>Number</th>
<th>Average length (mi)</th>
<th>Total length (mi)</th>
<th>Average watershed area (mi²)</th>
<th>Example</th>
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<tr>
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<td>1</td>
<td>1,570,000</td>
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<td>1,250,000</td>
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</table>
Watershed Networks

- Mass transport is optimal at minimum work
  - Reach and network scales at the SAME time
- Necessary conditions for dendritic drainage
  - Minimal energy expenditure at any link in the network
  - Equal Energy Expenditure per unit area
  - Minimum Energy Expenditure in the Network as a whole

Rodriguez-Iturbe et al. (1992) - WRR
Water Convergence Across Scales

- St Johns River Basin
- Ocklawaha River Basin
  - Orange Creek Sub-Basin
    - Newnans Lake Watershed
      - Hatchett Creek Watershed
        - ACMF “Hillslope”
          - Lake Mize catchment
Lake Mize
hillslope
Austin Cary
Forest
Hatchet Creek Catchment
Newnans Lake Watershed
Ocklawaha River Basin
St. Johns River Basin (and Water Management District)
Next Time...

- Precipitation
  - Where it falls
  - When it falls
  - How it’s made
  - How we measure it