John K. Jackson, Ph.D.
Senior Research Scientist
Aquatic Entomologist & Stream Ecologist
Why is Water Temperature Important?

- Temperature varies temporally and spatially
  - Day versus night
  - Winter versus summer
  - Mountain versus valley

- Thermal pollution – controlled releases
  - Power plants and factories
  - Big dams – top release – hot – bottom release – cold

- Habitat modifications – deforestation, small dams, urbanization – hard surfaces, stormwater ponds, pipes

- Climate Change
Water Is Thermally Stable

**High Specific Heat**
- Temperature goes up 1°C

**Low Specific Heat**
- Temperature goes up 20°C

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>SPECIFIC HEAT (Joules/gram • °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid water</td>
<td>4.18</td>
</tr>
<tr>
<td>Solid water (ice)</td>
<td>2.11</td>
</tr>
<tr>
<td>Water vapor</td>
<td>2.00</td>
</tr>
<tr>
<td>Dry air</td>
<td>1.01</td>
</tr>
<tr>
<td>Basalt</td>
<td>0.84</td>
</tr>
<tr>
<td>Granite</td>
<td>0.79</td>
</tr>
<tr>
<td>Iron</td>
<td>0.45</td>
</tr>
<tr>
<td>Copper</td>
<td>0.38</td>
</tr>
<tr>
<td>Lead</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Water: High Heat Capacity**
1. Heat (energy) from the sun disrupts some of the hydrogen bonds between water molecules.
2. New hydrogen bonds are formed almost as quickly as they are disrupted.
3. While the sun’s energy may make sand very hot, when the same energy hits water, much of that energy breaks hydrogen bonds (which may later re-form), rather than increasing the water’s temperature.
Stream Temperature Starts with Ground Water Temperature
Colder in the North

Vannote and Sweeney 1980

http://waterheatertimer.org/Average-temperature-of-shallow-ground-water.html
Water Temperature Varies Within a Day

Small lake (red) versus Large lake (blue)

Fig. 3.—Maximum diurnal change in temperature as a function of stream order in temperate North America. Data are from unpublished White Clay Creek studies and water resource reports of the United States Geological Survey (U.S.G.S.).
Water Temperature Varies – Lake Size

Small lake (red) versus Large lake (blue)

Figure 2.—Distribution of monthly degree-day accumulations at various recording stations along White Clay Creek. Total degree-days are the annual sum of monthly records for each station. A, outflow of groundwater; B, woodland spring seeps; C, first order spring brooks; D, second order streams; E, third order stream (upstream segment); F, third order stream (downstream segment).
Large streams vary more than small streams (more sun versus more groundwater influence).

Fig. 2.—Distribution of monthly degree-day accumulations at various recording stations along White Clay Creek. Total degree-days are the annual sum of monthly records for each station. A, outflow of groundwater; B, woodland spring seeps; C, first order spring brooks; D, second order streams; E, third order stream (upstream segment); F, third order stream (downstream segment).
Seasonal Temperature & Stratification

- **Summer**: Epilimnion, Metalimnion, Hypolimnion. Wind mixing.
- **Autumn**: Overturn. Temperature gradient forming.
- **Spring**: Overturn. Water mixing.
- **Winter**: Ice formation, surface cooling to 0 °C, 4 °C to bottom, little effective circulation.

Seasonal Temperature & Stratification

Warm lake

Cold lake
People Change Thermal Regimes

- Forests thinned, fragmented, or removed
- Running water turned to standing water – ponds and reservoirs
- Urban area become heat sinks
- Municipal and industrial effluents discharged to streams
Deforestation Warms Thermal Regime

Appalachian headwater streams in summer 2008

Fig. 3 Cumulative temperature change as water flowed through unlogged and logged sections of headwater streams. Differences were calculated from daily high temperatures over a one-month period during summer.

Difference = + 2 or 4 °C
            + 3.6 or 7.2 °F

Deforestation affects a thermal regime

Fig. 4 Frequencies of hourly temperature observations of reference and treatment sections (50 and 90% basal area harvest) in Appalachian headwater streams. Data were gathered during two sampling events in summer 2008.

Deforestation Warms Thermal Regime

Dams Warm or Cool Thermal Regime

- Cooler than normal at some times
- Warmer than normal at some times
- Depends on reservoir size and operation

SOUTH FORK McKENZIE RIVER

TEMPERATURE (°C)

2011
Hydroelectric Dam Operation Affects the Thermal Regime

“Hydropeaking”

Difference =
+ 5.0 °C
+ 9.0 °F

Withdrawal Depth Affects Thermal Regime

Cooling Effect Reduced Downstream

Small Dams/Ponds Increase Stream Temperature

Bennett’s Run at Brandywine Creek
7.5 km²
6 km of stream
Upstream Ponds at Bennett’s Run

Bennetts K-C Upstream

Bennetts K-C Downstream

Crosslands

Kendal
Cheslen Preserve
-----
Wild trout

Additional Sites for Perspective

Bennetts Run

Bennetts Run Upstream
Bennetts Run Downstream
Small Dams/Ponds Increase Stream Temperature

The graph shows the mean temperature (°C) over a period from June 1, 2018, to December 1, 2018, for Bennetts Run. The temperature readings are compared for different locations:

- **Upstream** (red line)
- **Downstream** (blue line)
- **Cheslen** (green line)

The highest temperatures are observed in the late summer and early fall, with a notable increase in the downstream section. By December, there is a significant drop in temperature across all locations.
Small Dams/Ponds Increase Stream Temperature

Bennetts Run

Pond Effect =
+ 7.5 ° C
+ 13.5 ° F

900 m Forest Difference =
- 4.9 ° C
- 8.8 ° F
Small Dams/Ponds Increase Stream Temperature

Stream temperature changes due to small (<15 m) dams in Massachusetts

Fig. 4. Change in mean monthly temperature from upstream to downstream at each dam.

Small Dams/Ponds Increase Stream Temperature

Factors affecting temperature change: dam height, impoundment volume, impoundment widening, impoundment residence time, impoundment area:watershed area, and watershed forest cover.

Fig. 4. Change in mean July temperature from upstream to downstream at each dam, with the direction and length of each arrow representing the direction and magnitude of change, respectively.

**Table 2**
Predicted thermal footprint (distance to recovery of upstream temperatures given observed downstream decay rates) for seven sites with both significant warming and subsequent cooling patterns with distance downstream of the dam.

<table>
<thead>
<tr>
<th>Site</th>
<th>Warming (°C)</th>
<th>Decay rate (°C/km)</th>
<th>Footprint (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.54</td>
<td>−1.93</td>
<td>0.28</td>
</tr>
<tr>
<td>5</td>
<td>1.18</td>
<td>−3.72</td>
<td>0.33</td>
</tr>
<tr>
<td>23</td>
<td>1.31</td>
<td>−3.75</td>
<td>0.34</td>
</tr>
<tr>
<td>2</td>
<td>1.49</td>
<td>−4.32</td>
<td>0.35</td>
</tr>
<tr>
<td>3</td>
<td>5.25</td>
<td>−4.10</td>
<td>1.35</td>
</tr>
<tr>
<td>9</td>
<td>4.72</td>
<td>−2.65</td>
<td>2.04</td>
</tr>
<tr>
<td>29</td>
<td>2.76</td>
<td>−0.64</td>
<td>4.47</td>
</tr>
<tr>
<td>Mean</td>
<td>2.46</td>
<td>−3.02</td>
<td>1.31</td>
</tr>
</tbody>
</table>

Footprint due to heat loss depends (in part) on water volume, velocity, shade.
Urbanization Increases Stream Temperature

Urban areas tend to be warmer (heat island)

Urban streams tend to be warmer than normal

Delta-t is the difference in mean or max stream temperature from a developed stream, compared to an undisturbed stream.
Urbanization = Roads, Pipes and Ponds

Hard surfaces = warmer (deforested)
Standing water ponds = warmer (dams)
Pipes = cooler (groundwater)
Old Urbanization = Streams in Pipes

https://www.hiddenhydrology.org/philly-h20/
Old Urbanization = Streams in Pipes
Summer storms bring in warm water as temperature surges
Urban Wastewater Increases Stream Temperature

Wastewater can warm the stream throughout the year (due to heated household water)

Climate Change Will Increase Temperature

High Emissions Difference =
  + 5.0 °C
  + 9.0 °F

Low Emissions Difference =
  + 3.1 °C
  + 5.5 °F
Climate Change Will Increase Temperature


Climate Change Will Increase Temperature

Projected maximum daily water temperatures for the year 2090 under four scenarios:
- urbanization plus climate change (U+C)
- climate change only (C)
- urbanization only (U)
- baseline (B).

In addition to existing thermal pollution: deforestation, dams/ponds, urbanization, wastewater

High Emissions Difference =
+ 5.0 °C
+ 9.0 °F

Low Emissions Difference =
+ 3.1 °C
+ 5.5 °F

Solutions to Thermal Pollution

- Protect cold water – protect existing shade.
- Reduce warm-water production – drain or disconnect ponds, remove existing dams where possible, increase shade by planting trees/restoring forests
- Prevent future warm-water production – don’t promote new ponds with standing water – infiltrate stormwater to recharge ground water
Stream Functions Pyramid – A Tool for Assessing and Restoring Stream Functions

Functions & Parameters

1. Hydrology
   - Function: Transport of water from the watershed to the channel
   - Parameters: Channel-Forming Discharge, Precipitation/Runoff Relationship, Flood Frequency, Flow Duration

2. Hydraulic
   - Function: Transport of water in the channel, on the floodplain, and through sediments
   - Parameters: Floodplain Connectivity, Flow Dynamics, Groundwater/Surface Water Exchange

3. Geomorphology
   - Function: Transport of wood and sediment to create diverse bed forms and dynamic equilibrium
   - Parameters: Sediment Transport Capacity, Sediment Transport Celerity, Large Woody Debris, Transport and Storage, Channel Evolution, Bank Migration/Lateral Stability, Riparian Vegetation, Bed Form Diversity, Bed Material Characterization

4. Physicochemical
   - Function: Temperature and oxygen regulation; processing of organic matter and nutrients
   - Parameters: Water Quality, Nutrients, Organic Carbon

5. Biology
   - Function: Biodiversity and the life histories of aquatic and riparian life
   - Parameters: Microbial Communities, Macrophyte Communities, Benthic Macrowebruary Communities, Fish Communities, Landscape Connectivity

Toxins?
Points to Remember

- Temperature is important to life in water
- Temperature varies naturally – diel, seasonal, annual – within a watershed, among watersheds
- Humans have already modified stream temperature, and climate change will make streams warmer
Questions?
ADVANCING KNOWLEDGE AND STEWARDSHIP OF FRESH WATER SYSTEMS THROUGH RESEARCH, EDUCATION, AND RESTORATION

WWW.STROUDCENTER.ORG