Examination of Thermal Impacts from Stormwater BMPs

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Project Team: The UNH Stormwater Center

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**Stormwater BMP**

Heat Transfer: Function of the mass of the system.

Heat Transfer: Function of the depth of the system.

Heat Transfer: Function of the time of day.

Input: Solar Radiation

Output: Heat

Thermal Energy

Ground

Air

Thermal Energy

Thermal Energy

Thermal Energy
Introduction

➢ Project Objective

- To quantify the effect of Best Management Practices (BMPs, n=8) on the temperature of stormwater runoff in relation to established environmental indicators and lethality indices for fisheries and aquatic ecosystems.

➢ Hypothesis

- Larger surface systems will see greater thermal variations.
- Larger subsurface systems will see greater thermal buffering.

\[ C_{th} = m \times C_P \]

- \( C_{th} \) = heat capacity of a system (J/°C)
- \( m \) = mass of a system (kg)
- \( C_P \) = specific heat (J/kg°C)
Experimental Design

- Experimental Design
- 40 Million Data Points

Examination of Storms

- Stormwater BMP
- CB
- $T_{in}$
- $T_{out}$
- 40 Million Data Points

Event Mean Temperature (°F)

- Runoff
- Retention Pond
- Detention Pond
- Gravel Wetland
- Bioretention
- Vegetated Swale
- HDS
- ADS
- STIR

Event Mean Temperature, EMT (°F)

- Cumulative Probability (%)

Δ $T$ in °F (approximate change in stream temp)

- Even Mean Temperature (°F)
- Even Mean Temperature, EMT (°F)

- Date
Performance Metric

- Event Mean Temperature, EMT (°F)
  - Flow or Volume weighted temperature
  - Calculated for each storm and each system
    - 120 Influent EMTs

Mathematical Formula:

$$
EMT = \frac{\int_0^T t(t)q(t)dt}{\int_0^T q(t)dt}
$$

$$
EMT = \frac{\sum Volume \times Temperature}{\sum Volume}
$$

Graph showing flow, temperature, and EMT over time, with dates from 3/10/07 to 3/11/07.
Qualitative Analyses

- Annual and Seasonal
  - Summer → April through September
  - Winter → November through March
- Time Series (EMT)
- Quartile Assessment (EMT)
- Cumulative Distribution Function (EMT)
- Histogram (Temperature)
- Thermal Loading
- Stream Mixing
Environmental Indicators

Temperature Indices
- Lower Optimum Limit (LOL) = 45°F
- Upper Optimum Limit (UOL) = 65°F
- Lethal Limit (LL) = 80°F

Thermal Regimes
- Vary by stream
- Range and frequency of temperatures

Mean July Temperatures
- Warmest month

Groundwater Temperature
- As a base flow condition
- New Hampshire = 47°F
Annual Cumulative Distribution Function

![Distribution Function](chart)

- **LOL**
- **GW**
- **UOL**
- **LL**

**Event Mean Temperature, EMT (°F)**

**Cumulative Probability (%)**

- Runoff
- Retention Pond
- Detention Pond
- Gravel Wetland
- Bioretention
- Vegetated Swale
- HDS
- ADS
- STIR
Winter Quartile Assessment

The graph shows the distribution of event mean temperature (°F) across different runoff management techniques during the winter quartile assessment. The box plots represent various techniques including Runoff, Retention Pond, Detention Pond, Gravel Wetland, Bioretention, Vegetated Swale, Hydrodynamic Separator, ADS Infiltration System, and StormTech Isolator Row. Each technique has a range of temperatures with outliers indicated by individual points. The data suggests a wide range of temperatures across different techniques, with some techniques showing more variability than others.
Annual Temperature Histogram

Normalized Frequency (Count/Total)

Stormwater Temperature (°F)

- Runoff
- Retention Pond
- Gravel Wetland
## Results

### Annual Assessments

<table>
<thead>
<tr>
<th>EMT (°F)</th>
<th>Runoff</th>
<th>Retention Pond</th>
<th>Detention Pond</th>
<th>Gravel Wetland</th>
<th>Bioretention</th>
<th>Vegetated Swale</th>
<th>HDS</th>
<th>ADS</th>
<th>STIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>52.4</td>
<td>48.1</td>
<td>52.8</td>
<td>47.3</td>
<td>51.8</td>
<td>57.3</td>
<td>56.6</td>
<td>49.2</td>
<td>47.6</td>
</tr>
<tr>
<td>Mean</td>
<td>53.5</td>
<td>50.9</td>
<td>52.3</td>
<td>48.7</td>
<td>51.9</td>
<td>54.8</td>
<td>54.1</td>
<td>51.5</td>
<td>49.0</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>12.7</td>
<td>14.6</td>
<td>15.1</td>
<td>12.0</td>
<td>13.1</td>
<td>12.6</td>
<td>13.6</td>
<td>9.7</td>
<td>9.2</td>
</tr>
<tr>
<td>Maximum</td>
<td>75.4</td>
<td>81.3</td>
<td>79.4</td>
<td>70.0</td>
<td>73.7</td>
<td>75.0</td>
<td>75.0</td>
<td>66.4</td>
<td>67.8</td>
</tr>
<tr>
<td>% Non-Exceedance UOL (65°F)</td>
<td>72.5%</td>
<td>79.0%</td>
<td>71.5%</td>
<td>87.0%</td>
<td>78.0%</td>
<td>72.5%</td>
<td>65.0%</td>
<td>95.0%</td>
<td>98.5%</td>
</tr>
</tbody>
</table>

### Summer Assessments

<table>
<thead>
<tr>
<th>EMT (°F)</th>
<th>Runoff</th>
<th>Retention Pond</th>
<th>Detention Pond</th>
<th>Gravel Wetland</th>
<th>Bioretention</th>
<th>Vegetated Swale</th>
<th>HDS</th>
<th>ADS</th>
<th>STIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>66.2</td>
<td>64.6</td>
<td>68.6</td>
<td>60.9</td>
<td>63.9</td>
<td>68.6</td>
<td>66.3</td>
<td>60.3</td>
<td>53.7</td>
</tr>
<tr>
<td>Mean</td>
<td>62.5</td>
<td>61.8</td>
<td>66.3</td>
<td>57.3</td>
<td>61.2</td>
<td>65.6</td>
<td>63.8</td>
<td>56.3</td>
<td>53.2</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>9.8</td>
<td>11.8</td>
<td>7.8</td>
<td>10.1</td>
<td>8.7</td>
<td>7.3</td>
<td>9.1</td>
<td>9.3</td>
<td>7.9</td>
</tr>
<tr>
<td>Mean July Temperatures (°F)</td>
<td>67.1</td>
<td>77.9</td>
<td>72.2</td>
<td>66.0</td>
<td>67.7</td>
<td>70.3</td>
<td>69.0</td>
<td>63.4</td>
<td>58.5</td>
</tr>
<tr>
<td>% Non-Exceedance UOL (65°F)</td>
<td>42.0%</td>
<td>56.0%</td>
<td>37.0%</td>
<td>73.0%</td>
<td>58.5%</td>
<td>35.0%</td>
<td>34.0%</td>
<td>91.0%</td>
<td>96.0%</td>
</tr>
</tbody>
</table>
Summer Natural Streams

![Graph showing temperature vs. non-exceedance probability for different streams and detention areas.](image)
Thermal Performance

% Non-Exceedance Upper Optimum Limit 65°F

Mean July Temperature°F

100

75

50

25

100

75

50

25

Mean July Temperature°F
Conclusions

➤ Infiltration practices allow greater buffering of stormwater temperature.
  - The longer subsurface flow paths and mass, the greater the buffering.
    • Bioretention → Gravel Wetland → ADS Infiltration System

➤ Conventional stormwater management designs that include ponding as a control measure, allow for additional increase in temperature.
  - Permanent pools of water act as heat sinks during the warmer summer months.
    • Vegetated Swale → Detention Pond →Retention Pond

➤ This data could be used to estimate the mixing of temperatures from the BMPs and receiving streams

➤ A predictive model could be developed based on mass and surface expression to determine required BMP characteristics (ie type and size) to be protective
While experts remain at odds over the issue of when life begins, most agree it’s sometime after work.
Future Research

- Porous Asphalt
  - Verify temperature readings
- System Size vs. Performance
  - Expand data to include off-site systems
- Stream Mixing
  - Determine thermal regimes for a variety of streams
  - Model mixing behavior of temperature