Pilot Assessment of Stream Temperature for an Impaired Waterway

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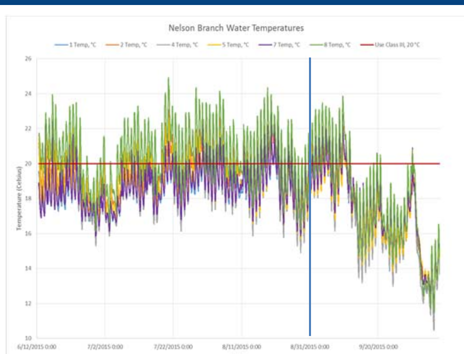
Nelson Branch Data Loggers

Temperature Records



Temperature Data from Nelson Branch

Logger Number*	% Exceeding 20C	% Forest	% Agriculture	% Urban	% Impervious	Drainage Area (acres)
1	8%	22.6%	65.9%	11.5%	3.4%	155.2
2	33%	27.2%	48.6%	24.2%	6.3%	152.4
4	15%	46.5%	45.9%	7.7%	3.1%	59.2
5	21%	28.9%	57.1%	14.0%	4.2%	762.6
7	14%	17.6%	73.7%	8.8%	1.4%	41.2
8	50%	28.6%	60.6%	10.9%	3.3%	1,109.5

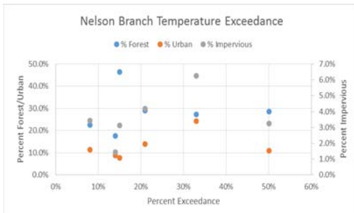
- Loggers 3 and 6 were air temperature loggers and are not displayed in this table
- WQ criteria allow up to 10% exceedance

Logger Number*	Maximum Recorded Water Temperature	Date of Maximum
1	21.3	9/9/2016
2	23.1	7/20/2016
4	22.5	6/16/2016
5	22.6	7/20/2016
7	22.9	8/19/2016
8	24.9	7/20/2016

24 to 27 is the upper lethal temperature for Brook Trout

Temperature – Causes?

- No apparent correlation between temperature exceedance and watershed land use
  - Forest
  - Urban
  - Impervious
- Other possible causes
  - Lack of stream shading
  - Low summer instream flows
  - Increased width to depth ratio of streams
  - Warm water from ponds
  - Heated run off during rain events



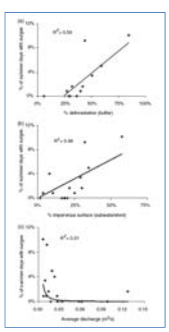
Land Cover Type	Slope	*p*-value	R^2
Forest	0.026	0.938	0.002
Urban	0.130	0.514	0.113
Impervious	0.035	0.504	0.119

Modeling Goals

- Relate watershed characteristics to stream temperature for both Nelson Branch and in the future for other County watersheds –
  - Determine and quantify causes of increased temperature
  - Forecast temperature reduction based on potential improvements

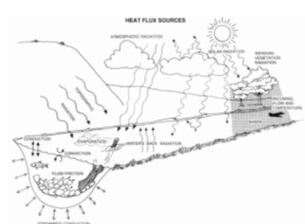
Types of Models

- Statistical / Stochastic
  - Correlation or regression analysis or modeling of random variables
  - Usually unique to the region where they were developed
  - May require a long time series of measurements in order to describe a wide range of conditions



Types of Models

- Deterministic
  - Physically-based with an energy budget approach
  - Heat transfer and fluid flow equations
  - Generally capable of simulating conditions that may not be present in the existing watershed
  - More complex and require more input data



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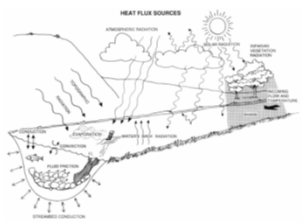

Selection Criteria

- Capability to assess of sources of impairments
- Types of management measures to be modeled
- Availability of input data
- Resources, complexity, and expertise required
- Model support

Source of Impairment	Possible Remediation
Lack of stream shading	Restore native riparian vegetation; increase canopy cover and forest height to cast longer and denser shadows.
	Protect riparian area from unnatural disturbances; remove non-native vegetation
	Control livestock access to the stream via fencing and restoring native riparian vegetation
Low summer instream flows	Restore headwater watershed features that retain moisture and allow increased infiltration; e.g. wetlands, wide riparian buffers.
	Implement storm water and agricultural BMPs to promote infiltration of runoff.
Increased width to depth ratio of streams	Stabilize stream morphology to reduce incision and widening.
	Implement stream restoration projects to create deeper, wider baseflow channels and connect streams with floodplains.
Warm water from ponds	Convert ponds into wetlands
	Remove inline pond connection
	Where feasible retrofit pond with bottom release structure to allow for cooler bottom water to reach the stream
Heated run off during rain events	Implement storm water BMPs such as infiltration, bioretention, swales, and rain gardens to promote infiltration.
	Disconnect runoff by redirecting it away from impervious areas to turf or forested land cover.

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	Input data element	Nelson Branch data loggers	County GIS layers	LGF WQMP	SHA RWIS data	County rain gages	NOAA climate data
Meteorology	Air temperature	x			x		
	Cloud cover						x
	Wind speed				x		
	Humidity				x		
	Precipitation					x	
Hydrology	Flow volume	x					
	Ponds / reservoirs		x				
	Water temperature	x					
Channel Morphology	Reach length		x	x			
	Width / depth			x			
	Slope		x	x			
	Gradient / sinuosity		x				
	Substrate			x			
	Elevation		x				
Topography	Stream aspect		x				
	Latitude		x				
	Elevation		x				
Shading	Riparian vegetation		x	x			
Watershed	Impervious cover		x				
	Forest cover		x				

Deterministic Models

Model	Sponsor	Hydrodynamics / Time Step	Description	Info Source
CEQUAL-RIV1	USACE	Continuous, Sub-Daily	Hydrodynamic and water quality model for nutrients, sediment, metals, bacteria, effects of algae and macrophytes in addition to temperature.	Deas and Lowney (2000)
HSPF	USGS	Continuous, Sub-Daily	Hydrologic and water quality model; simulates watershed processes on pervious and impervious surfaces. Along with temperature, output includes water budget, and pollutant loading. Reach and reservoir nutrient cycle and biological transformations are also modeled.	Deas and Lowney (2000)
QUAL2E	USEPA	Sub-Daily	Receiving water quality model intended for TMDL development. Hydrologic, temperature, and pollutant mass balance is calculated for each subreach.	Deas and Lowney (2000)
SNTEMP	USGS	Steady state, Daily to monthly	Heat transport model that predicts daily mean and maximum temperature based on stream distance and heat flux from radiation, convection, conduction, shading, and groundwater inflow.	Deas and Lowney (2000)
SSTEMP	USGS/ FWS	Steady state, Daily to monthly	Scaled down version of SNTEMP which handles single stream reaches for a single time period per run. Predicts mean and maximum temperatures based on heat flux processes: convection, conduction, evaporation, air temperature, solar radiation, and shading.	User Manual
HEATSOURCE	Oregon DEQ	Continuous, Sub-Daily	The model simulates dynamic open channel hydraulics, flow routing, heat transfer, effective shade and stream temperature. Processes include mass transfers, groundwater inflows, landscape radiation, adiabatic cooling, radiation modeling, evaporation, hydrodynamic routing with hyporheic exchange within the substrate.	User Manual

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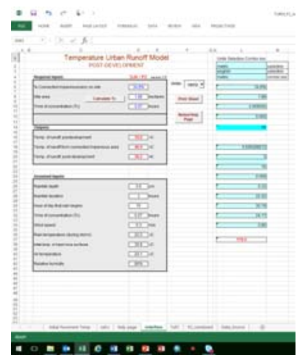
Model	Description	Selection
CEQUAL-RIV1 HSPF QUAL2E	Developed primarily for water quality modeling. Temperature modeling is an element of water quality.	• More data intensive. • Pollutant loading input required. • More complex.
HEATSOURCE	Developed solely for modeling stream temperature.	• Data intensive • Required GIS analysis of remote sensing data • Could be considered for a future modeling
SNTEMP		• Stream network temperature model • Could be considered for future modeling with a hydrologic flow model
SSTEMP		• **Single reach model** • **Less complex version of SNTEMP** • **Input data were available**

Runoff Modeling

- One model identified through literature search:
  - Thermal Urban Runoff Model (TURM)
  - Dane County, WI
  - Based on Excel spreadsheet
  - Site-level model rather than a watershed model
- Predicts temperature changes in runoff from new development that adds impervious cover



SSTEMP – Sensitivity and Calibration

- Sensitivity
  - Which variables would have the greatest effect on temperature
- Calibration
  - Varying input data so model results match field measurements
  - Results for four reaches
    - Changed Total Shade input
    - Three of four could be calibrated

Description	Calibration Change
Mainstem between Loggers 1 and 5	Shade from 65.5 to 77
Mainstem between Loggers 5 and 8	Shade from 50.7 to 45
Tributary to Logger 4	Shade from 67.6 to 100
Tributary to Logger 2	Shade from 65 to 87

SSTEMP – Instream Results

- Instream Improvements
  - Taking ponds offline
    - Trials were made varying the assumption that upstream ponds were present. There was no effect on the mean temperature.
  - Stream restoration
    - Trials were made varying the width parameters. Mean temperatures varied by less than one percent, indicating that this is not a significant factor in this watershed, or that SSTEMP's algorithms do not model variations in stream width or overwidening well.
  - Adding riparian buffer / shade
    - Increasing buffer shading had a positive effect on temperature.

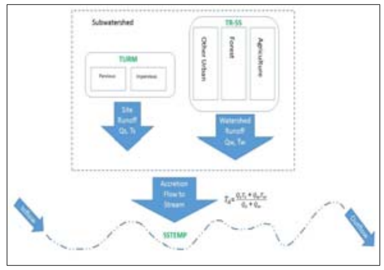
SSTEMP – Riparian Buffer Results

- Modeling
  - Possible sun was increased to 100% to show the worst case scenario for unshaded streams.
  - Percent of shade was increased with the goal of meeting a mean temperature of 20°C
- Cost
  - King and Hagan (2011) estimated $33,000 / ac, or approximately $150 per tree if planted at 200 trees per acre.

Reach	Measured	100% Sun	Shaded	Change in Shading	Ac.	Cost
Mainstem between Loggers 1 and 5	19.98	20.26	19.98	77% to 81%	1.1	$36,300
Mainstem between Loggers 5 and 8	21.80	22.41	19.97	45% to 80%	8.3	$273,900
Tributary to Logger 2	21.02	21.26	20.06	87% to 100%	1.7	$56,100

TURM – Procedure

- Modeling
  - TURM was run for one subwatershed of Nelson Branch.
  - Headwaters of the stream draining to Logger #2 - the only area with concentrated impervious cover at St. James Academy
- Procedure
  - Run TURM to find the temperature from the urbanized site.
  - Run TR-55 to find the volume of flow for the site and the remainder of the watershed, then calculate a weighted average for runoff temperature.
  - Calculate a weighted accretion temperature for the stream.
  - Calculate change in stream temperature using SSTEMP.



TURM – Results

- Site
  - 22.0 °C Rainfall
  - 46.4 °C Runoff from connected impervious area
  - 36.2 °C Runoff from site
- Subwatershed
  - 22.0 °C Undisturbed watershed (assumed same as rainfall)
  - 36.2 °C Runoff from site
  - 24.8 °C Subwatershed weighted by flow volume
- Stream
  - 21.0 °C Without site runoff
  - 24.8 °C With site runoff

Temperature increase: Approximately 10%

Model Summary

- Both models were relatively easy to use and did not have extensive data requirements.
  - Use of the two models was feasible for runoff heating but limited by the lack of a good linkage between the watershed and stream.
- TURM did not provide a module to test improvements from urban BMPs such as infiltration, impervious disconnection, grass channels, or level spreaders.
- SSTEMP did not model changes well from stream widening or shallow water depth.
- Neither model could successfully estimate temperature changes from heated water in ponds.

Future Work

- For future analyses using SSTEMP:
  - Weather data
    - Instream and air temperature
    - Dew point temperature or relative humidity
    - Cloud cover, at least daily
  - Stream data
    - Frequent flow measurements at every data logger
    - Average reach width and depth
    - Additional temperature readings at upstream pond discharges
  - Detailed Riparian Vegetation Data
    - Height
    - Crown
    - Offset
    - Density
- Test other models:
  - Statistical / Stochastic
    - Maryland-based empirical model including seasonal and urbanization effects (Nelson and Palmer, 2007)
  - Deterministic
    - SNTEMP stream network with watershed hydrologic model (Krause et al, 2004)
    - HEATSOURCE with or without Thermal Infrared Imagery

Questions and Comments

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