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Trout Stream Thermal Impact Assessment Study

Project Summary

by

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Abstract

Mechanisms by which urbanization in Minnesota leads to temperature increases in coldwater streams and subsequent loss of trout habitat were investigated and quantified. Hydrologic and thermal computer models for surface and groundwater systems were developed, calibrated, and applied to the Vermillion River in Dakota County and to Miller Creek in Duluth. Surface runoff from impervious surfaces can have significant impact on stream temperatures in small tributary coldwater streams. Runoff from pavements and commercial rooftops creates more thermal pollution than runoff from residential rooftops. Runoff from afternoon or evening rainfall events with rapid onset tends to produce the most thermal pollution. Storms with high dewpoint temperatures can also produce high levels of thermal pollution from both pervious and impervious surfaces. Wet stormwater detention ponds tend to increase total heat input to receiving streams compared to untreated runoff, but do reduce the rate of heat release, and thus create smaller but longer-lasting temperature changes in streams. Pond designs with subsurface outlets reduce heat loadings for smaller rainfall events. Infiltration practices are generally a highly effective stormwater management practice for mitigation of thermal pollution. Loss of riparian shading causes more frequent high stream temperatures than does surface runoff. Efforts to mitigate temperature impacts of land development need to consider both mitigation of surface runoff and maintaining or restoration of riparian shading. Since tree growth is a slow process long-term watershed planning is important. Coldwater streams in Minnesota rely on inputs of cold water from groundwater or wetlands to maintain moderate summer temperatures. Urbanization has the potential to impact stream temperature by reducing groundwater recharge and stream baseflow. Shallow groundwater aquifers, e.g. in the Vermillion River, can be heated by paved surfaces leading to local stream temperature increases. Establishing buffer distances between pavements and stream channels is advisable. Although not a focus of this study, changing climate will be a significant cause of temperature changes in coldwater streams. Long term planning to maintain coldwater streams in Minnesota needs to consider both land development and climate change. Additional study is needed to assess agricultural impacts, particularly on coldwater streams in southeastern Minnesota. The results of this and previous work should be condensed into a management document, similar to the Minnesota Stormwater Manual.

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Executive Summary

In this project, we quantified the mechanisms by which watershed urbanization in Minnesota leads to temperature increases in coldwater streams and subsequent loss of trout habitat. Hydrologic and thermal computer models for surface and groundwater systems were developed, calibrated, and applied to the Vermillion River in Dakota County and to Miller Creek in Duluth. The MINUHET model can simulate runoff hydrographs and runoff temperature time series from urban watersheds composed of impervious and pervious surfaces and drained by storm sewer systems including detention ponds.

The lessons learned in this project can be summarized as follows:

1. Surface runoff from impervious surfaces can have significant impact on stream temperatures, particularly in smaller tributary coldwater streams that may be important habitat for juvenile trout. Runoff from pavement and commercial rooftops generally creates the most thermal pollution and change in stream temperature. Typical residential rooftops were found to add runoff volume, but not additional heat energy, to surface runoff from residential developments.

2. Analyses of multiple years of precipitation data led to the conclusion that runoff from afternoon or evening storm events with rapid onset tend to produce the most thermal pollution, because surface temperatures are high prior to the onset of rainfall. More infrequent, large volume storms with high dewpoint temperatures can also produce high levels of thermal pollution from both pervious and impervious surfaces.

3. Typical stormwater wet detention ponds tend to increase thermal pollution to receiving streams compared to direct runoff. However, ponds do reduce the rate at which water and heat are released, and thus create a smaller but longer-lasting temperature change in streams compared to direct runoff. Pond designs with subsurface outlets reduce heat loadings for smaller rainfall events.

4. Infiltration is a highly effective stormwater management practice for mitigation of thermal pollution, but local surficial geology may limit the extent that infiltration practices can be used. Infiltration can therefore not be universally prescribed as a management practice in watersheds with coldwater streams.

5. In both the Vermillion River and the Miller Creek study streams, the loss of riparian shading from either urbanization or agriculture causes more frequent high stream temperatures than does surface runoff. Efforts to mitigate temperature impacts of land development need to consider both surface runoff mitigation and restoration of riparian shading. Since tree growth is a slow process maintaining riparian shading in buffer areas around coldwater streams needs to be considered in long term watershed planning,.

6. Coldwater streams in Minnesota rely on inputs of cold water from groundwater or wetlands to maintain moderate summer temperatures. Urbanization of a watershed has the potential to impact stream temperature by reducing groundwater recharge and hence stream baseflow. We

found that groundwater recharge and baseflow in the Vermillion River have not been affected by land development, because reductions in natural recharge have been offset by increases in artificial recharge. However, it is quite likely that urbanization has reduced baseflow in Miller Creek, which largely relies on wetlands for hydrologic storage. Management strategies for maintaining coldwater streams along the Lake Superior Northshore may need to be different from other regions of the state. The hydrological uniqueness of each region is crucial.

8. Watershed urbanization also has the potential to impact stream temperature via changes in groundwater temperature. Shallow groundwater aquifers, e.g. in the Vermillion River, can be heated by paved surfaces, which may lead to local stream temperature increases. It is appropriate to establish buffer distances between pavement and stream channels for this reason.

9. Although it was not a focus of this study, changing climate can and will be a very significant cause of temperature changes to coldwater streams. Long term-planning to maintain coldwater streams in Minnesota needs to consider both land development and climate change.

10. While we made significant progress in this project on quantifying the mechanisms by which watershed urbanization in Minnesota leads to temperature increases, additional work is needed on agricultural impacts, particularly for coldwater streams in southeastern Minnesota. The results of this and previous work should be enhanced and condensed into a management document, similar to the Minnesota Stormwater Manual.

Acknowledgements

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Collaborating Individuals and Organizations

For providing data, comments and suggestions for the project, the authors thank Dr. Kim Chapman and Theresa Nelson of Applied Ecological Services (AES), Brian Nerbonne, Jason Moeckel and Deserae Hendrickson of the Minnesota Department of Natural Resources, Paul Nelson of the Vermillion River Joint Powers Organization and Scott County, Travis Bistodeau Laura Jester of the Dakota County Soil and Water Conservation District, Nathan Schroeder and R.C. Boheim of the South St. Louis Soil and Water Conservation District, Kent Johnson of Metropolitan Council Environmental Services, Dr. John Nieber of the University of Minnesota, Department of Bioproducts and Biosystems, Dr. Marvin Bauer of the University of Minnesota Remote Sensing Laboratory, James Johnson, formerly of the Three Rivers Park District, Erik J. Larson, of the UMD Facilities Management, Tom Estabrooks of the MPCA in Duluth, Michael Findorf, James Stockinger, Mike Trojan and Nick Gervino of the Minnesota Pollution Control Agency, Ben Worel and Tim Clyne of the Minnesota Department of Transportation, and Jon Beatty for contributing to the computer program MINUHET and the publications that resulted from this project.

Technical Advisory Panel Members

The Technical Advisory Panel (TAP) provided feedback at several meetings. The authors would like to thank the panel members for their input to this project. Members were

- Brian Nerbonne – Minnesota Department of Natural Resources, St. Paul
- Jason Moeckel – Minnesota Department of Natural Resources, St. Paul
- Dawn Gibas – formerly of Scott County, Soil and Water Conservation District
- Kent Johnson – Metropolitan council environmental Services, St. Paul
- Marcel Jouseau – Metropolitan council environmental Services, St. Paul
- Roger Bannerman – Wisconsin Department of Natural Resources, Madison
- Nick Gervino – Minnesota Pollution Control Agency, St. Paul
- John Edinger
- Harvey E. Jobson (formerly of the U.S. Geological Survey, Reston VA)
- Lee Ganske – Minnesota Pollution Control Agency, St. Paul
- Cliff Aichinger - Ramsey Washington Watershed District, St. Paul

The involvement of the project manager from the MPCA, C. Bruce Wilson, is greatly appreciated.

1. Project Description

1.1 Introduction

During the 2005 – 2007 biennium, the Minnesota Pollution Control Agency (MPCA) provided funding to the University of Minnesota for "Assessment of Stormwater Management Practices on the Water Quality of Runoff." One of the primary deliverables of the project was a simulation tool (computer program) later called MINUHET (MINnesota Urban Heat Export Tool). Funding for additional work was continued in the 2007 – 2009 biennium (Phase II) under a project, titled "Assessment and Maintenance of Stormwater Best Management Practices".

1.2 Personnel

The Principal Investigators of the Stormwater Management project were:

- Dr. John Gulliver, UMN St. Anthony Falls Laboratory, Department of Civil Engineering,
- Dr. James Anderson, UMN Water Resources Center,
- Dr. Deb Swackhammer, UMN Water Resources Center.

The sub-project team for the **"Trout Stream Thermal Impact Assessment Study"** consisted of faculty, staff, and students, including:

Principal Investigators

- Dr. Heinz Stefan, UMN, St. Anthony Falls Laboratory, Department of Civil Engineering,
- Dr. Omid Mohseni, UMN, St. Anthony Falls Laboratory, Department of Civil Engineering.

Research Staff

- Dr. William R. Herb, UMN, St. Anthony Falls Laboratory,
- Timothy Erickson, UMN, St. Anthony Falls Laboratory
- Dr. John Nieber, UMN, Department of Bioproducts and Biosystems Engineering

Graduate Students

- Ben Janke, Department of Civil Engineering, St. Anthony Falls Laboratory
- Eric Novotny, Department of Civil Engineering, St. Anthony Falls Laboratory
- Craig Taylor, Department of Civil Engineering, St. Anthony Falls Laboratory

1.3 Tasks

The project consisted of several tasks:

Phase I:

1) Investigations required to

   a) analyze and quantify all significant runoff and heat transfer processes associated with surface runoff from rainfall before and after urban development

b) understand and quantify the recharge of groundwater to aquifers that feed coldwater trout streams before and after urban development
c) understand the heat transfer to shallow groundwater before and after urban development, as well as the impact of climate warming on shallow groundwater.

2) Development and Implementation of a Hydrothermal Simulation Tool (MINUHET) for Assessing the Impact of Stormwater Runoff on Trout Streams.

Phase II:

3) Development and Implementation of a Hydrothermal Simulation Tool (MINUHET) for Assessing the Impact of Stormwater Runoff on Trout Streams, added
   a) incorporating new mitigation measures to MINUHET (Minnesota Urban Heat Export Tool)
   b) validation of the hydrothermal simulation tool
   c) providing training workshops and technical support for the MINUHET

4) Providing support for the JPO Trading Project of the Vermillion River (sponsored by the USEPA), including
   a) providing support data and simulation results for the JPO Trading Project of the Vermillion River,
   b) developing and using a groundwater thermal model to project effects of urbanization and climate warming on groundwater that feeds trout streams,

5) Developing runoff and thermal models for Phase I of the Miller Creek temperature TMDL study.

2. Project Completion and Deliverables

Project tasks were completed and deliverables were submitted to the MPCA project manager as they became available.

2.1 TAP Meetings

Meetings of the Technical Advisory Panel (TAP) were held at which oral and visual progress reports were delivered to the panel and critiqued by panel members. The TAP for the 2005-2007 project held its first meeting on March 24, 2005 at St. Anthony Falls Laboratory. The TAP met several times throughout the project to review and provide feedback on the progress and deliverables of the project.

2.2 Presentations

The project team presented results of the study in sessions of the Annual Minnesota Water Resources Conferences in, 2007, 2008 and 2009. The conferences were typically attended by 600 professionals, and the audience of the sessions was on the order of 100 persons. The presentations were:

1) William Herb, “Stormwater thermal loading study.” *Minnesota Water Conference,* October 2005, Brooklyn Park, MN

2) William Herb, “Stormwater thermal loading study.” *NALMS Conference*, November 2005, Madison, WI.

3) William Herb, “Stormwater thermal loading study.” Regional Stormwater Protection Team January 2006, Minneapolis, MN.

4) William Herb, “Stormwater thermal loading study.” MPCA Air, Water and Waste Environmental Conference, February 2006, St. Paul, MN.

5) William Herb, “Stormwater thermal loading study.” 14th National Nonpoint Source Monitoring Workshop, September 24-28, 2006, Minneapolis, MN. Poster

6) Ben Janke, “Impact of Urban Development on the Temperature of Cold-Water Streams.” *Environmental Protection Agency Fellows Conference*, Sep 24, 2006, Washington, DC. Poster.

7) William Herb, Ben Janke, Omid Mohseni, Heinz Stefan, “A model for runoff and thermal pollution from paved surfaces.” ASCE/EWRI Conference, August 2007.

8) Ben Janke, “Application of an Urban Storm Water Model to a Housing Development in Plymouth, MN.” *Minnesota Water Conference*, October 23, 2007, Brooklyn Park, MN.

9) Timothy Erickson, “Groundwater recharge on a changing landscape.” *Minnesota Water Conference*, October 23, 2007, Brooklyn Park, MN.

10) Ben Janke, “A Simulation Tool for Predicting Thermal Impacts of Stormwater Runoff on Trout Streams.” *American Geophysical Union Fall Meeting*, December 14, 2007, San Francisco, CA.

11) Omid Mohseni, William Herb, Ben Janke, Heinz Stefan, “Trout stream Thermal Impact Assessment”. Trout Unlimited Midwest Fly Fishing Expo., March 2008, Minneapolis, MN. Poster.

12) Omid Mohseni, William Herb, Heinz Stefan, “Thermal impact of pavement runoff.” World Environmental and Water Resources Congress, ASCE/EWRI, August 2008.

13) William Herb, Ben Janke, Omid Mohseni and Heinz Stefan, “Thermal pollution of trout streams from stormwater runoff. Trout Unlimited, September 2008, Minneapolis, MN. Poster.

14) Ben Janke, “Groundwater Modeling” Lakes and Rivers Conf., Rochester, MN, Sep 2008.

15) William Herb, “Stream flow and temperature analysis of the Vermillion River.” *Minnesota Water Conference*, October 27-28, 2008, St. Paul, MN

16) William Herb, “Thermal Impacts of Urban Development on Trout Streams: What Have We

Learned?" Minnesota Pollution control Agency, March 17, 2009, St. Paul, MN.

17) William Herb, Timothy Erickson and Heinz Stefan,"Miller Creek temperature impact assessment". Annual Flyfishing Conf. and Expo, April 2010, Edina, MN. Poster.

18) Timothy Erickson, "Groundwater Recharge in a Coldwater Stream Watershed during Urbanization." *Minnesota Water Conference*, October 26, 2009, St. Paul, MN.

19) William Herb, Timothy Erickson, Heinz Stefan, "Impacts of Urban Development on Flow and Temperature Regimes in Miller Creek, Duluth, MN". *Minnesota Water Conference,* October 2010, St. Paul, MN.

2.3 Journal Publications

Information on the project has also been disseminated in several peer reviewed journal articles, including:

1) Janke, B.D., W. R. Herb, O. Mohseni and H. G. Stefan, 2008. Simulation of heat export by rainfall-runoff from a paved surface. *Journal of Hydrology*, 365 (2009):195-212 (Technical Paper No. 2008-017-A, SAFL*).

2) Herb, W.R., B. Janke, O. Mohseni and H.G. Stefan, 2008. Thermal pollution of streams by runoff from paved surfaces. *Hydrological Processes* 22(7): 987-999. Special EGU/AGU Issue (Technical Paper No. 2008-024-A, SAFL*).

3) Herb, W.R., B.D. Janke, O. Mohseni, and H. G. Stefan, 2008. Ground surface temperature simulation for different land covers. *Journal of Hydrology*, 356(3): 327-343 (Technical Paper No. 2008-025-A, SAFL*).

4) Herb, W.R., B.D. Janke, O. Mohseni, and H. G. Stefan, 2009. Runoff temperature model for paved surfaces, *Journal of Hydrologic Engineering* 14(10):1146-1155.
DOI: 10.1061/(ASCE)HE.1943-5584.0000108 (Technical Paper No. 2009-011-A, SAFL*).

5) Herb, W.R., O. Mohseni and H. G. Stefan, 2009. Simulation of temperature mitigation by a storm water detention pond, *Journal of the American Water Resources Association*, 45(5):1164-1178. DOI:10.1111/j.1752-1688.2009.00354. (Technical Paper No. 2009-012-A, SAFL*).

6) Taylor, C.A. and H. G. Stefan, 2009. Shallow groundwater temperature response to climate change and urbanization. *Journal of Hydrology* 375 (2009): 601-612.
doi:10.1016/j.hydrol.2009.07.009 (Technical Paper No. 2009-025-A, SAFL*).

7) Erickson, T.O and H. Stefan, 2009. Projecting natural groundwater recharge response to urbanization in the Vermillion River watershed, Minnesota. *Journal of Water Resources Management,* 135(6):512-520, Nov/Dec 2009. DOI: 10.1061/(ASCE)0733-9496(2009)135: 6(512).

8) Erickson T.O. and H. G. Stefan. Shallow groundwater recharge in an urban

watershed: effects of water distribution, sewer and storm water management systems, J*ournal of Hydrology*, June 2009 (rev. subm. July 2010)

9) Taylor, C.A. and H. G. Stefan, Heating of shallow groundwater flow by conduction from a paved surface: Requirements for coldwater stream protection", *Water Resources Research*, Sep. 2009 (rev. subm. July 2010).

10) Janke, B., O. Mohseni, W.R. Herb and H.G. Stefan, Heating of Rainfall Runoff on Residential and Commercial Rooftops, *Water Resources Research*, February 2010 (subm.).

11) Janke, B., W. R. Herb, O. Mohseni, and H. G. Stefan, "Estimation of groundwater input to a trout stream from stream temperature observations. *Journal of Hydrology*, (subm. 2010)

2.4 Project Reports

The results of the entire project have been presented in 27 project reports from the St. Anthony Falls Laboratory. These reports are archived and available to the public, either through the main SAFL publications web page (http://www.safl.umn.edu/publications/publications.html) or through the web page created for this project (http://troutstreamresearch.safl.umn.edu/). Requests can be made through the SAFL website www.safl.umn.edu. The list of reports is as follows:

Phase 1 (2005-2007):

1) Janke, B., W. Herb, O. Mohseni, and H. Stefan, "Quasi 2-D Model for Runoff Temperature from a Paved Surface", St. Anthony Falls Laboratory Report 477, August 2006, 78 pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr477.pdf

2) Herb, W., B. Janke, B., O. Mohseni, and H. Stefan, "All-Weather Ground Surface Temperature Simulation", St. Anthony Falls Laboratory Report 478, September 2006, 57 pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr478.pdf

3) Herb, W., M. Weiss, O. Mohseni, and H. Stefan, "Hydrothermal Simulation of a Storm Water Detention Pond or Infiltration Basin", St. Anthony Falls Laboratory Report 479, September 2006, 34 pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr479.pdf

4) Herb, W.R., H. G. Stefan, and O. Mohseni, "Heat Export and Runoff Temperature Analysis for Rainfall Event Selection", St. Anthony Falls Laboratory Report 483, April 2007, 65 pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr483.pdf

5) Herb, W.R., B. Janke, O. Mohseni and H. G. Stefan, "An Analytic Model for Runoff and Runoff Temperature from a Paved Surface", St. Anthony Falls Laboratory Report 484, October 2006, 19 pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr484.pdf

6) Shaw, J.V. and H. G. Stefan, "Analysis of Surface Recharge Effect on 2-D Shallow Groundwater Flow into a Stream", St. Anthony Falls Laboratory Report 487, December 2006, xx pp.
http://home.safl.umn.edu/bmackay/pub/pr/pr487.pdf

7) Herb, W.R., B. Janke, O. Mohseni and H. G. Stefan, "Estimation of Runoff Temperatures and Heat Export from Different Land and Water Surfaces", St. Anthony Falls Laboratory Report 488, February 2007, 34 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr488.pdf

8) Erickson, T. and H. G. Stefan, "Groundwater Recharge from a Changing Landscape", St. Anthony Falls Laboratory Report 490, May 2007, 112 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr490.pdf

9) Janke, B, W. R. Herb, O. Mohseni and H. G. Stefan, "Application of a Runoff Temperature Model (MINUHET) to a Residential Development in Plymouth, MN". St. Anthony Falls Laboratory Report 497, June 2007, 34 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr497.pdf

10) Herb, W.R., O. Mohseni and H.G. Stefan, "A Model for Mitigation of Surface Runoff Temperatures by a Wetland Basin and a Wetland Complex", St. Anthony Falls Laboratory Report 499, July 2007, 34 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr499.pdf

Phase 2 (2007-2009):

11) Taylor, C. A. and H. G. Stefan, "Shallow Groundwater Temperature Response to Urbanization and Climate Change in the Twin Cities Metropolitan Area: Analysis of vertical heat convection effects from the ground surface", St. Anthony Falls Laboratory Report 504, May 2008, 68 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr504.pdf

12) Erickson, T. O. and H. G. Stefan, "Baseflow Analysis for the Upper Vermillion River, Dakota County, Minnesota", St. Anthony Falls Laboratory Report 507, June 2008, 55 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr507.pdf

13) Herb, W. and H. Stefan, "Analysis of Vermillion River Stream Flow Data (Dakota and Scott Counties, Minnesota)", St. Anthony Falls Laboratory Report 514, July 2008, 28 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr514.pdf

14) Herb, W. and H. Stefan, "A Flow and Temperature Model for the Vermillion River, Part I: Model Development and Baseflow Conditions", St. Anthony Falls Laboratory Report 517, August 2008, 30 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr517.pdf

15) Herb, W., "Analysis of the Effect of Storm Water Runoff Volume Regulations on Thermal Loading to the Vermillion River". St. Anthony Falls Laboratory Report 520, September 2008, 34pp. http://home.safl.umn.edu/bmackay/pub/pr/pr520.pdf

16) Herb, W. and H. Stefan, "Analysis of Flow Data from Miller Creek, Duluth, Minnesota", St. Anthony Falls Laboratory Report 522, November 2008 (revised Sept 2009), 23 pp. pp. http://home.safl.umn.edu/bmackay/pub/pr/pr522.pdf

17) Janke, B., W. R. Herb, O. Mohseni, and H. G. Stefan, "Estimation of Groundwater Inflow to the Vermillion River from Observations of Stream Flow and Stream Temperature". St. Anthony Falls Laboratory Report 523, December 2008 (updated Feb. 2010), 61 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr523.pdf

18) Erickson, T. O. and H. G. Stefan, "Groundwater Recharge in a Coldwater Stream Watershed during Urbanization", St. Anthony Falls Laboratory Report 524, January 2009, 74 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr524.pdf

19) Herb, W. and H. Stefan, "A Flow and Temperature Model for the Vermillion River, Part II: Response to Surface Runoff Inputs". St. Anthony Falls Laboratory Report 525, December 2008, 61 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr525.pdf

20) Herb, W., O. Mohseni, B. Janke and H. Stefan, "MINUHET (Minnesota Urban Heat Export Tool): A Software Tool for the Analysis of Stream Thermal Loading by Storm Water Runoff". St. Anthony Falls Laboratory Report 526, March 2009, revised January 2010, 44 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr526.pdf

21) Herb, W. and H. Stefan, "Analysis of Stream Temperature Data from Miller Creek, Duluth, Minnesota", St. Anthony Falls Laboratory Report 529, October 2009 (updated), 57 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr529.pdf

22) Herb, W., O. Mohseni, B. Janke and H. Stefan, "MINUHET (Minnesota Urban Heat Export Tool) USER MANUAL". St. Anthony Falls Laboratory Report 530, revised January 2010, 60 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr530.pdf

23) Taylor, C. A. and H. G. Stefan, "Heating of shallow groundwater flow by conduction from a paved surface: Requirements for coldwater stream protection", St. Anthony Falls Laboratory Report 531, May 2009, 33 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr531.pdf

24) Janke, B., O. Mohseni, W. R. Herb and H. G. Stefan, "Heating of Rainfall Runoff on Residential and Commercial Rooftops", St. Anthony Falls Laboratory Report 533, January 2010, 59 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr533.pdf

25) Herb, W.R., T. Erickson and H. G. Stefan, "Stream Temperature Modeling of Miller Creek, Duluth, Minnesota", St. Anthony Falls Laboratory Report 535, October 2009, 78 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr535.pdf

26) Erickson, T. O., W. R. Herb and H. G. Stefan, "Streamflow Modeling of Miller Creek, Duluth, Minnesota", St. Anthony Falls Laboratory Report 536, January 2010, 57 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr536.pdf

27) Weiss, M., W.R. Herb and H. G. Stefan, "Storm water Detention Pond Water Temperature and Salinity Data Collection", St. Anthony Falls Laboratory Report 537, May 2010, 61 pp. http://home.safl.umn.edu/bmackay/pub/pr/pr537.pdf

2.5 MINUHET Model

To address the need for the assessment of temperature impacts of stormwater runoff on trout streams, the MINUHET tool was developed at the University of Minnesota St. Anthony Falls Laboratory. MINUHET is a stand-alone software tool used to simulate the flow of stormwater surface runoff and its associated heat content through a small watershed for one or several rainfall events. The tool includes sophisticated hydrologic and thermal models for surface runoff, natural and man-made drainage networks, and stormwater management practices. A user friendly, Windows-based, graphical user interface is used to define the land cover information of each sub-watershed, define the drainage network, and specify treatment ponds and other stormwater management practices. The tool includes a database of storm events that have the potential to produce high thermal loading in receiving streams. The user interface also includes a post-processor that can be used to graph flow, temperature, and heat outputs from the watershed and create summary tables for each storm event that is analyzed.

A common application of MINUHET is to predict the thermal loading of stormwater runoff from an area of land slated for development, both prior to and after development. The simulation results of MINUHET (runoff volume, temperature, heat) can be used, as is, to assess changes in heat loading from an area of land, or used as input to a stream temperature model to predict dynamic changes in stream temperature due to the runoff. MINUHET will allow agency personnel and consulting engineers to assess the impacts of proposed or existing developments on coldwater streams, and to design effective temperature mitigation practices. MINUHET has been used to assess the effectiveness of stormwater infiltration standards (including LID practices) as temperature mitigation practices in the Vermillion River watershed.

A formal MINUHET training workshop was held at the St. Paul MPCA office (6/2007). Informal training presentations were given at the Rochester MPCA office (12/2009) and the Duluth MPCA office (1/2010).

2.6 Information for the JPO Vermillion River Trading Project

The Joint Powers Organization (JPO) of the Vermillion River in Apple Valley, MN, received an EPA grant to explore the feasibility of establishing a thermal pollution trading system. Under the MPCA contract, SAFL provided input on several topics in close cooperation with Applied Ecological Services, Inc., the science lead for the EPA project. Substantial information was provided on surface runoff temperatures for different land covers, including pavement, rooftops, crops, forest, and bare soil. Runoff temperatures were simulated over 6 years of observed climate data, and detailed information on runoff for 20 storm events giving the most heat export was provided to Applied Ecological (AES) (SAFL project report #488). In addition to land surface runoff, information was also provided on the temperature of effluent from stormwater ponds, lakes, and wetlands for the same 6 years of climate data. A hydrothermal model for a wetland complex was developed as part of this effort (SAFL project report #499). The runoff and effluent temperatures were used in the watershed scale, AES land surface heat contribution model.

The second SAFL contribution to the EPA thermal trading project was to create a stream flow and temperature model for the Vermillion River (SAFL project reports #517 and 525). The model included the main stem from Dodd Avenue to Goodwin Avenue and a number of tributaries, including South Branch, South Creek, North Creek, and Middle Creek. The EPD-riv1 package was used to simulate stream flow. A stream temperature model was assembled based on previous work at SAFL. The stream temperature model uses flow and flow area from the flow solver, along with observed climate data to calculate surface heat transfer. The models were calibrated both for baseflow conditions (SAFL project report #517) and for a surface runoff event (SAFL project report #525). Substantial analysis of stream flow observations preceded the model calibration process (SAFL project report #514).

The model was then used to predict the flow and temperature response of the Vermillion River to a ½" design storm event for present and future conditions (SAFL project report #525). Surface runoff inputs to the Vermillion River were simulated using a GIS-based land heat contribution model, which was developed and run by Applied Ecological Services. Simulated runoff volumes and temperatures from the 35 sub-watersheds were used as input to the stream flow and temperature model, to simulate the hydraulic and thermal response of the Vermillion to runoff from the ½" rainfall event. Several future land development and mitigation scenarios were run to help guide the thermal trading program.

SAFL also provided substantial information on groundwater in the Vermillion River watershed. This effort included a substantial analysis of the water budget in the Vermillion River, including precipitation, groundwater recharge, and stream baseflow (SAFL project reports #507, 524). An analysis of baseflow in the Vermillion River using baseflow separation techniques revealed that about 80% of the flow in the Vermillion comes from groundwater. Trend analysis of precipitation and streamflow data found the interesting result that land development in the Vermillion River watershed has not reduced groundwater recharge and baseflow, mainly due to an increase in artificial recharge. Possible increases in shallow groundwater temperature due to land development and climate change were also investigated. Overall increases in groundwater temperature in the watershed due to land use changes and climate change were estimated (SAFL project report #531), and local effects of pavement on groundwater temperature were also analyzed (SAFL project report #531). Finally, a stream reach thermal budget model was used to estimate groundwater input rates to a number of reaches in the Vermillion River (project report #523). Groundwater inputs were found to be highly variable both spatially and temporally.

2.7 Information for the Miller Creek TMDL

Miller Creek in Duluth is identified as a temperature impaired stream on the MPCA's list of impaired waters in Minnesota. The MPCA in cooperation with the South St. Louis Soil and Water Conservation District and NRRI (UMD) is preparing a TMDL study. In support of this effort, we supplied analyses of stream flow and temperature observations, assembled coupled models for runoff, stream flow, and stream temperature for Miller Creek, and used the models to characterize flow sources, heat inputs, and stream temperatures.

An analysis of streamflow data found that only the lower gaging station at 26th Avenue gives reliable data, and that reliable flow data is well correlated to precipitation at daily time scales and longer (SAFL project report # 522). An analysis of stream temperature data found that stream temperatures are strongly correlated to air temperature but only weakly correlated to flow condition. An analysis of stream temperature exceedance found that only 10-15% of exceedances are associated with storm runoff events, with the remaining majority due to warm sunny days.

A SWMM model of the Miller Creek watershed was assembled and calibrated (SAFL project report #536) based on previous work at NRRI. The model was used to help characterize baseflow sources in Miller Creek and to investigate possible methods for augmenting baseflow in the future. Simulations of surface runoff were used in conjunction with runoff temperature simulations to estimate surface runoff heat loadings to Miller Creek. The MINHET model was used to characterize surface runoff temperatures for typical commercial and residential developments in Miller Creek, and to assess the impact of different stormwater management practices on temperature and heat loading (SAFL report #535). A stream temperature model based on the USGS SNTEMP model was assembled and calibrated for Miller Creek. The stream temperature model was used to assess current shading conditions in Miller Creek, assess the impacts of surface runoff and atmospheric heat loadings on stream temperature, and assess possible reductions in stream temperature using augmented riparian shading (SAFL report #535).

2.8 Curriculum

The methods and results from this project were also incorporated into the engineering curriculum at the University of Minnesota in courses such as CE 8561 Analysis and Modeling of Aquatic Environments and CE 5515: Urban Hydrology and Land Development.

3. Highlights of Accomplishments

The first goal of this study was to develop an understanding of the hydrologic and heat transport processes that pose a threat to coldwater (i.e. trout) streams in Minnesota. We have assembled physics-based relationships and simulation models to estimate the temperature and the heat export of runoff from paved surfaces (SAFL Reps. 477, 484), building roofs (533), land with various vegetation cover (478,483,488), and pond/wetland/lake surfaces (479,499,537). We have also developed and assembled relationships to quantify groundwater recharge (SAFL Rep. 487,490,507,524) and seasonal heat transfer cycles (504, 531) to shallow groundwater under different (urbanized) land surface conditions. Using this information we can now estimate water temperature changes in inflows to coldwater streams in response to surface runoff and groundwater inputs. To simulate water temperatures and flow rates in the surface runoff from an urban sub-watershed including roads, buildings, lawns etc. we have developed the simulation tool MINUHET described in SAFL Reps. 497, 526 and 530. For subsurface and groundwater heating we have developed a separate 2-D heat transfer model.

Typical (sloping) residential building roofs were found to add insignificant amounts of heat to surface runoff because their heat capacity is small, and water residence times are short. Typical (horizontal) roofs of commercial buildings can add significant amounts of heat to surface runoff.

Natural groundwater recharge is reduced by impervious surface areas in urbanized areas, but water import for urban water supply, lawn watering, and rain gardens etc. can make up for the loss. Paved (asphalt or concrete) surfaces increase heat transfer to shallow groundwater considerably, and can therefore raise source water temperatures to coldwater streams substantially. Rising mean annual air temperatures under different global warming scenarios will raise groundwater temperatures as well. This is a serious threat to the source water of many coldwater streams in Minnesota.

In Phase II of the study, mitigation measures were added to MINUHET. These include underground storage and stormwater detention ponds. A separate model was developed for temperature stratified ponds, and an extensive field study was conducted to validate the pond model. It was found that while a stormwater detention pond usually acts as solar collector and adds heat to runoff water, the slow release of the water provides for a net reduction in thermal impact on coldwater streams.

A deterministic stream temperature model that includes heat exchange with the atmosphere, streambed heating and cooling, tributary and groundwater input, was developed for the

Vermillion River (SAFL Rep. 514,517,520 and 525). This model was used to assess the sensitivity of the Vermillion River to the different heat input, including the effect of shading. The model was also used to estimate the amount of groundwater inflow (cfs/mile) based on stream temperature measurements in different stream reaches. Values as high as 3.9 cfs/mile were found.

The JPO staff was provided with information on the attenuation of thermal signals as a function of distance or travel time in tributaries or the mainstem of the Vermillion.

The Miller Creek study produced a SWMM model for runoff and a hydrothermal model for stream temperatures. The SWMM modeling framework does not fit Miller Creek well because only a fraction of the watershed has storm sewers. The presence of wetlands, the absence of major aquifers, ill-defined groundwater pockets and small stream channels with variable geometry suggest that a different modeling framework be developed. The source water is mainly from wetlands, but storage is not sufficient to sustain a baseflow of desirable proportion. Additional upland water storage, e.g. by wetland expansion seems very desirable.

4. Future Investigations

Future research related to thermal impacts on trout streams in Minnesota is necessary and under consideration. Research subjects include (1) an assessment of thermal impacts of agricultural practices on coldwater streams, (2) temperature effects of current urban stormwater BMPs (e.g. rain gardens, grassed drainage ditches and swales, buffer strips, filters and small detention ponds on groundwater sources of coldwater streams, (3) design of shading and storage measures for water temperature management of coldwater streams, and (4) the thermal response of Minnesota's trout streams in the southeastern Karst region (driftless area) of Minnesota.

Potential climate change impact on cold water streams that receive their source water from shallow groundwater or wetlands needs to be investigated, because climate warming is a big threat to coldwater streams in Minnesota. A manual on "Stream temperature management and mitigation measures" that summarizes knowledge acquired in the recent decade needs to be written for planners and environmental resource managers.

5. References

The publications listed in Sections 2.3 and 2.4 can serve as a reference list for the work accomplished.