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ST. ANTHONY FALLS LABORATORY
Engineering, Environmental and Geophysical Fluid Dynamics

Project Report No. 542

Stormwater Treatment: Assessment and Maintenance

Project Summary

By

By: Andrew J. Erickson, Peter T. Weiss, and John S. Gulliver

of the

University of Minnesota
Stormwater Assessment Project
<http://stormwater.safl.umn.edu/>

St. Anthony Falls Laboratory
University of Minnesota
2 Third Avenue SE Minneapolis, MN 55455
<http://www.safl.umn.edu/>



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Collaborating Individuals and Organizations

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Technical Advisory Panel Members

The Technical Advisory Panel (TAP) for this project provided feedback at various stages and in various formats. The authors would like to thank the technical advisory panel for their commitment to this project:

- Cliff Aichinger - Ramsey Washington Watershed District
- Erik Anderson - Washington Conservation District
- Scott Anderson - City of Bloomington, MN
- Sara Aplikowski - Minneapolis Park and Recreation Board
- Roger Bannerman - Wisconsin Department of Natural Resources
- John Barten - Three Rivers Park District
- Phil Belfiori - City of St. Paul Water Resource Coordinator
- Mike Borst - U.S. Environmental Protection Agency
- Roger Clay - Earthtech, Inc.
- Matt Crawford - City of Rochester Public Works
- Mark Doneux - Capitol Region Watershed District
- Mike Eastling - City of Richfield, MN
- Bruce Elder - City of St. Paul
- Michael Findorff - Minnesota Pollution Control Agency
- Bob Fossum - Capitol Region Watershed District
- Jack Frost - Metropolitan Council

- Tera Guetter - Pelican River Watershed District
- Jim Hafner - City of Blaine, MN
- John Harlow - City of Brooklyn Center (representing Shingle Creek Watershed District)
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- Bruce Holdhusen - Minnesota Department of Transportation
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- Chris Kleist - City of Duluth, MN
- Randy Lehr - Three Rivers Park District
- Brian Livingston - Minnesota Pollution Control Agency
- Jennifer Molloy - U.S. Environmental Protection Agency
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- Bob Newport - U.S. Environmental Protection Agency Region 5
- Steve Pedersen - BAE Systems, Inc.
- Jodi Polzin - CDM
- Jay Riggs - Washington Conservation District
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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 the Manual, “Assessment of Stormwater Best Management Practices,” (Gulliver and Anderson, 2007). Funding for this work was continued in the 2007 – 2009 biennium with Phase II of the project, titled “Assessment and Maintenance of Stormwater Best Management Practices” which culminated in the publication of the on-line manual, “Stormwater Treatment: Assessment and Maintenance” at <http://stormwaterbook.safl.umn.edu/> in 2010.

1.2 Faculty and Staff

The project team consisted of a diverse group of faculty, staff, and students, including:

Principal Investigators

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

Faculty

- Dr. Randal Barnes, UMN Department of Civil Engineering
- Dr. Raymond Hozalski, UMN Department of Civil Engineering
- Dr. Omid Mohseni, UMN Department of Civil Engineering
- Dr. John Nieber, UMN Department of Bioproducts and Biosystems Engineering
- Dr. Heinz Stefan, UMN Department of Civil Engineering
- Dr. Peter Weiss, Valparaiso University

Post-Graduate

- Andy Erickson, St. Anthony Falls Laboratory
- Tim Erickson, St. Anthony Falls Laboratory
- Dr. William Herb, St. Anthony Falls Laboratory
- Dr. Joohyon Kang, St. Anthony Falls Laboratory

Graduate Students

- Farzana Ahmed
- Greg DeGroot
- Greg LeFevre
- Eric Hettler
- Adam Howard
- Ben Janke
- Scott Kyser
- Eric Novotny
- Nicholas Olson

- David Saddoris
- Craig Taylor

Undergraduate assistants

- Bonnie Ausk
- Pat Brockamp
- Missy Gettel
- Teigan Gulliver
- Kurt McIntire
- Greta Schmalle

High school assistants

- Lanre Adekola
- Monica He

1.3 Tasks

The project consisted of several tasks:

- 1) Quarterly Progress Reports
- 2) Establish Dialog and Collaboration and Incorporate into Education Program
- 3) Further Develop On-Line Assessment Methodology
 - a) Select Technical Advisory Panel
 - b) Expand testing methodology to other types of BMPs
 - c) Incorporate maintenance procedures into on-line assessment document
- 4) Investigations required to demonstrate the assessment of stormwater BMPs
 - a) Groundwater pollution caused by infiltration.
 - b) Method for stormwater suspended solids size distribution.
 - c) Composting as a method of remediating stormwater pond sediments contaminated by Polycyclic Aromatic Hydrocarbons (PAHs)
- 5) Development and Implementation of a Hydrothermal Simulation Tool (MINUHET) for Assessing the Impact of Stormwater Runoff on Trout Streams
 - a) Incorporating new mitigation measures to MINUHET (Minnesota Urban Heat Export Tool)
 - b) Validation of the hydrothermal simulation tool
 - c) MINUHET training workshops and technical support
 - d) Support Data for the JPO Trading Project of the Vermillion River
 - e) Groundwater thermal model
 - f) Phase I of the Miller Creek temperature TMDL study

2 Project Completion and Deliverables

The project tasks were completed and deliverables were submitted to the MPCA project manager as describing in the sections below.

2.1 Quarterly Progress Reports

Quarterly reports were submitted to the MPCA project manager throughout the project.

2.2 Establish Dialog and Collaboration and Incorporate into Education Program

2.2.1 Technical Advisory Panel

A Technical Advisory Panel (TAP) for the 2005-2007 project was developed and the first meeting was held on June 30, 2005 at St. Anthony Falls Laboratory. The TAP met every 3 – 6 months throughout the project to review and provide feedback on the progress and deliverables of the project.

2.2.2 Workshops and Courses

For the 2005-2007 project, Assessment of Stormwater BMPs, three Input Sessions (Duluth, St. Paul, and Rochester, MN) were conducted to gather information on assessment considerations that are important to staff of watershed districts, soil and water conservation districts, counties, municipalities, consulting firms, state agencies and other stakeholder groups. The input sessions revealed that assessment of rain gardens/ bioretention, grassed swales, and porous pavements are key concerns. These input sessions also created partnerships and relationships that lasted throughout and after the project. In addition, training and outreach for this project included three training workshops in Rochester (3/19/2007), Duluth, (3/28/2007), and Farmington (4/24/2007), MN.

A formal MINUHET thermal trout stream model 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).

The project team regularly participated in, and collaborated with Stormwater U, an education program funded by the University of Minnesota Extension Service. The results and deliverables from this project were incorporated into Stormwater U professional workshops on stormwater pond management: outfalls and inventory (March 18, 2008), inspection (July 31, 2008), and maintenance (November 5, 2008).

The research experience developed through the project also resulted in developing new courses for the University of Minnesota, including CE 5515: Urban Hydrology and Landscape Development and BBE 5535: Assessment and Diagnosis of Impaired Waters. A number of existing courses were enhanced by the research performed on this project, including capstone design courses in both the Departments of Civil Engineering and Bioproducts and Biosystems Engineering.

2.2.3 Presentations

The project team travelled to various local, national, and international conferences, meetings, workshops, and seminars to present and discuss potential collaboration with other stormwater professionals of national recognition. Seventy presentations were given during the 48 months of the 2005-07 and 2007-09 biennia. This amounts to 1.5 presentations per month for the 48 month period.

The presentations were:

1. “Stormwater thermal loading study.” William Herb, *Minnesota Water Conference*, October 2005, Brooklyn Park, MN
2. “Stormwater thermal loading study.” William Herb, *NALMS Conference*, November 2005, Madison, WI.
3. “The Cost and Effectiveness of Stormwater Management Practices,” Weiss, P.T., J.S. Gulliver, A.J. Erickson (Presentation by P.T. Weiss), *2005 Water Resources Conference, American Water Resources Association*, November 11 – 16, 2005, Seattle, WA.
4. “Stormwater thermal loading study.” William Herb, Regional Stormwater Protection Team January 2006, Minneapolis, MN.
5. “Stormwater thermal loading study.” William Herb, MPCA Air, Water and Waste Environmental Conference, February 2006, St. Paul, MN.
6. “Cost Effectiveness of Stormwater BMPs,” Minnesota Air Water and Waste Environmental Conference, Bloomington, MN, February 2006.
7. “Cost Effectiveness of Stormwater BMPs,” Weiss, P.T., A.J. Erickson and J.S. Gulliver, *Minnesota Air, Water and Waste Conference*, February 9-11, 2006, Bloomington, MN.
8. “Assessing Rain Garden Effectiveness,” (with Brooke Asleson, Raymond Hozalski and John Nieber), 14th National Nonpoint Monitoring Workshop, Minneapolis, MN September 24-28, 2006.
9. “Assessing the Effectiveness of Proprietary Stormwater Treatment Devices,” (with Matt Wilson, Omid Mohseni, and Raymond Hozalski), 14th National Nonpoint Monitoring Workshop, Minneapolis, MN September 24-28, 2006.
10. “Stormwater thermal loading study.” William Herb, 14th National Nonpoint Source Monitoring Workshop, September 24-28, 2006, Minneapolis, MN. Poster
11. Ben Janke, “Impact of Urban Development on the Temperature of Cold-Water Streams.” *Environmental Protection Agency Fellows Conference*, Sep 24, 2006, Washington, DC. Poster.
12. “Four Levels of Infiltration Assessment,” (presentation by A. Erickson) Successful Infiltration-Designing to Meet Volume Control Requirements, Corcoran, Minnesota, October 2006.
13. ” Assessing Rain Garden Effectiveness,” Asleson, B.C., A. J. Erickson, J.S. Gulliver, and R. M. Hozalski (Presentation by B.C. Asleson), *Minnesota Water Resources Conference*, October 24 – 25, 2006, Brooklyn Park, MN.
14. “Assessing the Effectiveness of Proprietary Stormwater Treatment Devices,” Wilson, M.A., J.S. Gulliver, O. Mohseni and R. M. Hozalski (Presentation by M.A. Wilson), *Fifth National Monitoring Conference*, September 15 – 18, 2006, Minneapolis, MN.

15. "Assessing Rain Garden Effectiveness for Runoff Volume Control," Asleson, B.C., J.S. Gulliver, R.M. Hozalski and J.L. Nieber, *Fifth National Monitoring Conference*, September 15 – 18, 2006, Minneapolis, MN.
16. "Testing versus Monitoring in the Assessment of Stormwater BMPs," Erickson, A.J. and J.S. Gulliver (Presentation by A.J. Erickson), *Minnesota Water Resources Conference*, October 25 – 26, 2006, Brooklyn Park, MN.
17. "Assessing the Effectiveness of Proprietary Stormwater Treatment Devices," Wilson, M.A., J.S. Gulliver, O. Mohseni and R. M. Hozalski (Presentation by M.A. Wilson), *Minnesota Water Resources Conference*, October 25 – 26, 2006, Brooklyn Park, MN.
18. "Testing Versus Monitoring in the Assessment of Stormwater BMPs," (presentation by A. Erickson), Minnesota Water 2006 and Annual Water Resources Joint Conference, October 2006.
19. "Assessing the Effectiveness of Proprietary Stormwater Treatment Devices," (presentation by M. Wilson), Minnesota Water 2006 and Annual Water Resources Joint Conference, October 2006.
20. "Technique for Evaluating Rain Gardens as a Stormwater BMP," (presentation by B. Asleson), Minnesota Water 2006 and Annual Water Resources Joint Conference, October 2006.
21. "Developing a Stormwater Assessment Manual for the State of Minnesota: Pros and Cons of Extensive Engagement," Water Resources Science Seminar Series, University of Minnesota, November 2006.
22. "Four Levels to Assess the Performance of Stormwater BMPs," (presentation by Andrew Erickson) 2007 Minnesota Air Water Waste Environment Conference, March 2007.
23. "Assessment of stormwater BMPs," EPA Region 5 TMDL Workshop, (Presentation by Andrew Erickson) Kalamazoo, MI. October 16-19, 2006.
24. "Techniques for evaluating the effectiveness of rain gardens as a stormwater BMP," (Presentation by Brooke Asleson), Erosion and Sediment Control Program, U of M Successful Infiltration Seminar - Designing to Meet Volume Control Requirements, Corcoran, MN. October 11, 2006.
25. "Assessment of stormwater infiltration. Erosion and Sediment Control Program," (Presentation by Andrew Erickson), U of M Successful Infiltration Seminar - Designing to Meet Volume Control Requirements, Corcoran, MN. October 11, 2006.
26. "Assessment of stormwater management practices on the water quality of runoff," presentation before Area Managers, Minnesota Pollution Control Agency, St. Paul, MN, May 15, 2006.
27. "Four Levels to Assess the Performance of Stormwater BMPs," Erickson, A.J. and J.S. Gulliver (Presentation by A.J. Erickson), *Minnesota Air, Water and Waste Conference*, February 7-9, 2007, Bloomington, MN.
28. "Developing a stormwater assessment program," presentation before Wisconsin DNR, USGS, and University of Wisconsin managers and researchers, U. S. Geological Survey, Madison WI, June 14, 2007.
29. "A model for runoff and thermal pollution from paved surfaces." William Herb, Ben Janke, Omid Mohseni, Heinz Stefan, ASCE/EWRI Conference, August 2007.
30. "Application of an Urban Storm Water Model to a Housing Development in Plymouth, MN." Ben Janke, *Minnesota Water Conference*, October 23, 2007, Brooklyn Park, MN.

31. "Groundwater recharge on a changing landscape." Timothy Erickson, *Minnesota Water Conference*, October 23, 2007, Brooklyn Park, MN.
32. "Developing an assessment program for stormwater best management practices," Building a Great Lake Superior, Duluth, MN, October 20, 2007.
33. Impacts of Urban Development on Flow and Temperature Regimes in Miller Creek, Duluth, MN," William Herb, Timothy Erickson, Heinz Stefan, "*Minnesota Water Conference*, October 2010, St. Paul, MN.
34. "Investigation of Sediment Sampling Effectiveness," M. Gettel, J. Brand and J.S. Gulliver (Presentation by M. Gettel), *Minnesota Water Resources Conference*, October 26 – 27, 2007, Brooklyn Park, MN.
35. "Sampling of Suspended Solids in Storm Water Conduits," DeGroot G., O. Mohseni and J.S. Gulliver (Presentation by G. DeGroot), *2007 Water Resources Conference, American Water Resources Association*, November 13 – 17, 2007, Albuquerque, NM.
36. "Developing a stormwater assessment program," Presentation before the Minnesota Stormwater Steering Committee, Roseville, MN, December 5, 2007.
37. "A Simulation Tool for Predicting Thermal Impacts of Stormwater Runoff on Trout Streams." Ben Janke, *American Geophysical Union Fall Meeting*, December 14, 2007, San Francisco, CA.
38. "Four level assessment of infiltration practices," Presentation to the Low Impact Development Workgroup, Little Canada, MN, February 21, 2008.
39. "The four levels of assessing infiltration rates," Presentation at the 19th Annual Erosion Control and Stormwater Management Conference and Trade Show, Minnesota Erosion Control Association, St. Louis Park, MN, March 7, 2008.
40. "Trout stream Thermal Impact Assessment," Omid Mohseni, William Herb, Ben Janke, Heinz Stefan, Trout Unlimited Midwest Fly Fishing Expo., March 2008, Minneapolis, MN. Poster.
41. "LID Performance Assessment," Presentation at the Build Smart Summit, Region Five Development Commission, Bemidji, MN, April 30 – May 1, 2008.
42. "A Statewide Survey on the Maintenance of Stormwater Best Management Practices," Kang, J., J.S. Gulliver, and P.T. Weiss (Presentation by J. Kang), *2008 Transportation Research Conference*, Center for Transportation Studies, May 20- 21, 2008, St. Paul, MN.
43. "Thermal impact of pavement runoff." Omid Mohseni, William Herb, Heinz Stefan, World Environmental and Water Resources Congress, ASCE/EWRI, August 2008.
44. "How to Evaluate Hydrodynamic Separators for Stormwater Treatment?" Mohseni, O., M. Wilson, D. Saddoris, J.S. Gulliver and R.M. Hozalski (Presentation by O. Mohseni), *International Conference on Underground Devices*, August 31 - September 5, 2008, Edinburgh, Scotland.
45. "Assessing Hydrodynamic Separators under High Water Flow Conditions," Saddoris, D., O. Mohseni, and J.S. Gulliver (Presentation by D. Saddoris), *2008 Minnesota Water Resources Conference*, October 27 – 28, 2008, St. Paul, MN.
46. "Tillage and Compost: Do they Improve Infiltration Rates of Compacted Soil?" Olsen, N., and J.S. Gulliver (Presentation by N. Olson), *2008 Minnesota Water Resources Conference*, October 27 – 28, 2008, St. Paul, MN.
47. "Stormwater Particle Size Distribution and Composition," DeGroot, G. and J.S. Gulliver (Presentation by G. DeGroot), *2008 Minnesota Water Resources Conference*, October 27 – 28, 2008, St. Paul, MN.

48. "Assessing Hydrodynamic Separators under High Water Flow Conditions," Saddoris, D., O. Mohseni, and J.S. Gulliver (Presentation by D. Saddoris), AWRA Annual Water Resources Conference, November 17-20, 2008, New Orleans, LA.
49. "Thermal pollution of trout streams from stormwater runoff," William Herb, Ben Janke, Omid Mohseni and Heinz Stefan, Trout Unlimited, September 2008, Minneapolis, MN. Poster.
50. "Groundwater Modeling" Ben Janke, Lakes and Rivers Conf., Rochester, MN, Sep 2008.
51. "Maintenance of Stormwater BMPs," by John S. Gulliver, Joohyon Kang and Peter T. Weiss, Keynote for Stormwater Initiative of Research and Outreach Needs meeting, Great Lakes Regional Water Leadership Team, Columbus, Ohio, September 17, 2008.
52. "Stream flow and temperature analysis of the Vermillion River." William Herb, *Minnesota Water Conference*, October 27-28, 2008, St. Paul, MN
53. Gulliver, J.S., "The Rain Falls and the Rain Runs Off, Should I be Concerned?" Presentation at the Minnesota Section, American Society of Civil Engineers, St. Paul, MN, October 27, 2008.
54. "Composting Stormwater Pond Sediments to Remove PAHs," Kyser, S.M.I., R.M. Hozalski and J.S. Gulliver, (Presentation by S.M.I. Kyser), Minnesota Erosion Control Association 2009 Conference, Bloomington, MN, March 4-5, 2009.
55. "Thermal Impacts of Urban Development on Trout Streams: What Have We Learned?" William Herb, Minnesota Pollution Control Agency, March 17, 2009, St. Paul, MN.
56. "Maintenance of Stormwater BMPs," A.J. Erickson, J.S. Gulliver, P.T. Weiss, and C.B. Wilson (Presentation by A.J. Erickson), Universities Council on Water Resources (UCOWR)/National Institutes for Water Resources (NIWR) Annual Conference. Chicago, IL. July 7, 2009.
57. "Survey of Stormwater BMP Maintenance Practices," Andrew J. Erickson, John S. Gulliver, Peter T. Weiss, and C. Bruce Wilson (Presentation by A.J. Erickson), Green Infrastructure Workshop-U. S. EPA Region 7, Kansas City, MO, Sept. 11, 2009.
58. "Cost and Effectiveness of Stormwater Treatment Practices," Andrew J. Erickson, John S. Gulliver and Peter T. Weiss (Presentation by A.J. Erickson), Regional Science Workshop on Stormwater-U.S. EPA Region 1, 2 and 3, Edison, NJ, October, 2009.
59. "The Four Levels," Andrew J. Erickson and John S. Gulliver (Presentation by A.J. Erickson), Regional Science Workshop on Stormwater -U.S. EPA Region 1, 2 and 3, Edison, NJ, October, 2009.
60. "Groundwater Recharge in a Coldwater Stream Watershed during Urbanization." Timothy Erickson, *Minnesota Water Conference*, October 26, 2009, St. Paul, MN.
61. "Iron-Enhanced Sand Filtration for Stormwater Phosphorus Removal," Erickson, A.J., B.J. Huser and J.S. Gulliver (Presentation by A.J. Erickson), *2009 Minnesota Water Resources Conference*, St. Paul, MN, October 26-27, 2009.
62. "Particle Settling Velocity and the Impact on Stormwater BMP Performance," Hettler, E., J.S. Gulliver, A.J. Erickson, and P.T. Weiss (Presentation by E. Hettler), *2009 Minnesota Water Resources Conference*, St. Paul, MN, October 26-27, 2009.
63. "Standard Sumps as a Stormwater Best Management Practice," Howard, A., O. Mohseni, J.S. Gulliver, H.G. Stefan (Presentation by A. Howard), *2009 Minnesota Water Resources Conference*, St. Paul, MN, October 26-27, 2009.

64. "Operation and Maintenance for Stormwater Management," Andrew J. Erickson and John S. Gulliver (Presentation by A.J. Erickson), Minnesota Association of Watershed Districts, Alexandria, MN, December 3, 2009.
65. "Testing of Underground Devices for Stormwater Treatment," Auckland Regional Council, Auckland, New Zealand, December 22, 2010.
66. "Iron-Enhanced Sand Filtration for Stormwater Phosphorus Removal." Andrew J. Erickson, John S. Gulliver, Peter T. Weiss and Brian J. Huser, 2010 Meeting of the Transportation Research Board, Washington, D.C., January 11 – 14, 2010.
67. "The Why and How of Treating Urban Runoff," Engineers Society of St. Paul, St. Paul, MN, March 9, 2010.
68. "Miller Creek temperature impact assessment," William Herb, Timothy Erickson. Heinz Stefan, William Herb, Timothy Erickson, Heinz Stefan, Annual Flyfishing Conf. and Expo, April 2010, Edina, MN. Poster.
69. "SAFL Baffle Improves Standard Sump as a Stormwater Treatment BMP," Howard, A., O. Mohseni, J.S. Gulliver, H.G. Stefan (Presentation by A. Howard), *21st Annual Transportation Research Conference*, St. Paul, MN April 27 -28, 2010.
70. "Improved Standard Sumps as Best Management Practice for Stormwater," Howard, A., O. Mohseni, J.S. Gulliver, H.G. Stefan (Presentation by A. Howard), *2010 National Hydraulic Engineering Conference*, Salt Lake City, UT, September 1 – 3, 2010.

2.2.4 Written Dialog and Dissemination

The project began producing a quarterly email newsletter in August 2005 that was expanded and distributed to many subscribers. This newsletter continues and is currently distributed to over 2,400 subscribers. A copy of the printed version is provided in Appendix A.

Case studies written by individuals and organizations that have done actual assessment and maintenance of stormwater treatment practices were solicited, received, and included in the on-line manual in an effort to provide field-proven practical application of these techniques described in the on-line manual. These case studies include:

- Monitoring a dry detention pond with under-drains
- Assessment of a proprietary underground structure for stormwater treatment
- Assessment of infiltration at a rain garden
- Monitoring a regional infiltration system
- Water quality benefits of surface stormwater drainage and treatment of parking lot runoff using multi-cell wetlands in parking lot median strips
- Assessing vegetated buffers using synthetic residential runoff
- Monitoring to test the P8 model at Bass Creek Business Park
- Monitoring and modeling to improve the management of Eagle Lake golf course
- Assessment of source reduction due to phosphorus-free fertilizers
- Lawn care impacts on phosphorus load
- Stormwater Retention Ponds: Maintenance vs. Efficiency

The results of this work have been disseminated in journal publications, including:

1. Asleson, B.C., R.S. Nestingen, J.S. Gulliver, R.M. Hozalski, and J.L. Nieber, "Assessment of Rain Gardens by Visual Inspection and Controlled Testing," *Journal of the American Water Resources Association*, 45(4), 1019-1031, 2009.
2. Erickson, A.J., Gulliver, J.S., Kang, J.H., Weiss, P.T., and Wilson, C.B. (2010). "Maintenance for Stormwater Treatment Practices." Universities Council on Water Resources (UCOWR)/National Institutes for Water Resources (NIWR) Stormwater Special Edition.
3. Erickson, A.J., J.H. Kang, P.T. Weiss, C.B. Wilson and J.S. Gulliver (2009). "Maintenance of Stormwater BMPs." Proceedings of the ASCE/EWRI World Environmental and Water Resources Congress. May 17-21, Kansas City, MO.
4. Erickson, A.J., J.S. Gulliver, P.T. Weiss, and C.B. Wilson (2009). "Survey of Stormwater BMP Maintenance Practices." Proceedings of the Universities Council on Water Resources (UCOWR)/National Institutes for Water Resources (NIWR) Annual Conference. July 7-9, Chicago, IL.
5. 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).
6. Erickson T.O. and H. G. Stefan. Shallow groundwater recharge in an urban watershed: effects of water distribution, sewer and storm water management systems, *Journal of Hydrology*, June 2009 (rev. subm. July 2010)
7. Flynn, L., T. Smith, A. Erickson, and M. Wenzel. 2010. "Industrial Stormwater Best Management Practices Guidebook." Published on-line by the Minnesota Pollution Control Agency.
8. Gulliver , J.S. and J.L. Anderson. 2007. "Assessment and Maintenance of Stormwater Best Management Practices" *University of Minnesota*.
9. Gulliver, J.S., A.J. Erickson, and P.T. Weiss (editors). 2010. "Stormwater Treatment: Assessment and Maintenance." University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN. <http://stormwaterbook.safl.umn.edu/>
10. Herb, W.R., B. Janke, O. Mohseni, and H.G. Stefan, "A model for runoff and thermal pollution from paved surfaces," *Journal of Hydrologic Engineering*, in press, 2009.
11. Herb, W.R., O. Mohseni and H.G. Stefan, "Simulation of temperature mitigation by a stormwater detention pond," *Journal of the American Water Resources Association*, in press, 2009.
12. 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*).
13. 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*).
14. 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*).
15. 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*).

16. Hettler, E., Gulliver, J.S., Erickson, A., and Weiss, P.T. (2009). "Stormwater Sediment Particle Size Distribution and the Impact on BMP Performance." Proceedings of the 8th Annual StormCon. August 16-19, Anaheim, CA.
 17. Hozalski, R. M., Erickson, A., and Gulliver, J.S. (2007). "A New Approach for Assessing the Performance of Stormwater Best Management Practices." Proceedings of the ASCE/EWRI World Environmental and Water Resources Congress. May 15-19, Tampa, FL.
 18. 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*).
 19. 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*).
 20. 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.).
 21. Kang J, P. T. Weiss, J.S. Gulliver, and C. Bruce Wilson. "Maintenance of Stormwater BMPs" *Stormwater Magazine*, Vol. 9, No. 8 (Nov/Dec 2008).
 22. Kang, J. and J.S. Gulliver. "Frequency, Effort and Cost of Stormwater Practice Maintenance." Proceedings of 2009 Environmental and Water Resources Institute (EWRI) of ASCE.
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-

Our work has also been cited in:

- "Urban Stormwater Management in the United States" Water Science and Technology Board (WSTB) and Earth and Life Studies (DELS). National Academic Press.

The dialog, collaboration, training, and outreach from this project have generated interest in the stormwater community. The results are evident in the number of non-affiliated websites that link to our project website, including the following (top 100 Google search results for Minnesota Stormwater Assessment, 8/3/2009):

- Federal Highway Administration:
<http://www.fhwa.dot.gov/environment/workshop/minnesota.htm>
- University of Vermont: Vermont Water Resources and Lake Studies Center:
www.uvm.edu/envnr/vtwater/announcements/Stormwater_Mgmt_Practice_Assessment_Project_2008_Univ_Minnesota.pdf

- Rutgers University: Water Technology Website:
[http://watertech.rutgers.edu/Publications/Member-Submitted\(Not-Peer-Reviewed\)/John_Gulliver/Mar_2008_Newsletter.pdf](http://watertech.rutgers.edu/Publications/Member-Submitted(Not-Peer-Reviewed)/John_Gulliver/Mar_2008_Newsletter.pdf)
- Stormwater Magazine: <http://www.stormh2o.com/november-december-2007/references-3085.aspx>
- Great Lakes Regional Water Program - Minnesota Initiatives:
www.uwex.edu/ces/regionalwaterquality/FocusAreas/states/minnesota.htm
- Lake Superior Streams:
http://www.lakesuperiorstreams.org/stormwater/duluth/stormwater_plan.html,
<http://www.duluthstreams.org/stormwater/toolkit/resources.html>
- Local Road Research Board, Minnesota Stormwater Roadmap:
<http://www.lrrb.org/pdf/LRRB%20Stormwater%20Roadmap%20PP.pdf>
<http://www.lrrb.org/pdf/LRRB%20Stormwater%20Roadmap%20Analysis.pdf>
- Lake Ozark Watershed Alliance, LOWA Inc.:
http://www.soslowa.org/LID_BMP_Stormwater_2009%20Feb%20Newsletter.pdf
- Better Roads: <http://obr.gcnpublishing.com/articles/jun06d.htm>
- Center for Transportation Studies Newsletter:
<http://tzd.state.mn.us/Publications/ResearchENews/2008/02/index.html>
- University of Arizona NEMO Program:
<http://www.srn.arizona.edu/nemo/index.php?page=bmpstormwater>
- National Institute for Water Resources (hosted by University of Nebraska-Lincoln):
<http://snr.unl.edu/niwr/docs/states/MN07.pdf>, <http://water.unl.edu/objectives>
- Kentucky Transportation Cabinet:
http://www.stormwater.kytc.ky.gov/MCM1/mcm1_targetaudiences_citycounty.html
- Minnesota Department of Employment and Economic Development:
http://www.deed.state.mn.us/bizdev/ShovelReady/application_examples/16_StormwaterProgramMPCA_MS4_SWPPP.pdf
- Water Resource Coordinators Group of Minnesota: <http://www.metrowater.org/2957.html>
- Izaak Walton League of America: Alternative Practices to Manage Highway Runoff,
<http://www.iwla.org/index.php?id=223>
- Minnesota Legislative Reference Library:
<http://www.leg.state.mn.us/lrl/resource/justin.asp?issue=1/1/2008&p=p>

In addition, several related projects provided key collaboration to this project:

- City of Bloomington – Monitoring various BMPs
- Dakota Soil and Water Conservation District – WERF grant has been awarded to DSWCD to evaluate rain garden performance during winter months. We are partnering with them to evaluate performance of the same sites during the spring/summer/fall months to provide continuous data
- Legislative-Citizen Commission on Minnesota Resources (LCCMR) – Precipitation intensity data updating by NOAA
- Metropolitan Council Environmental Services – Funds provided to examine the effectiveness of rain gardens and one proprietary device
- Minnehaha Creek Watershed District/Lower Mississippi Watershed Management Organization – Application of method for stormwater suspended solids size distribution
- Minnesota Department of Transportation – Performance of dry detention ponds with underdrains
- Minnesota Department of Transportation – Scour from underground devices at high flow rates and solids separation by MN/DOT manholes
- Minnesota Local Road Research Board – Cost and effectiveness of BMPs
- Minnesota Local Road Research Board – Effect of BMPs (swales and rain gardens) on infrastructure
- Minnesota Local Road Research Board – Enhanced sand filters
- Minnesota Local Road Research Board – Funds provided to examine the effectiveness of proprietary devices
- Minnesota Local Road Research Board – Method for stormwater suspended solids size distribution and Scour from underground devices at high flow rates
- Proprietary Device Manufacturers – Grants on testing proprietary devices from three manufacturers
- Three Rivers Park District – Tilling and composting compacted soils to decrease urban runoff
- University of Minnesota: Center for Urban and Regional Affairs – Tilling and composting compacted soils to decrease urban runoff
- University of MN Duluth – Monitoring program being developed and installed at a Duluth Campus bioretention facility
- US EPA/CWP 319 – Performance of Low Impact Development Practices on Stormwater Pollutant Load Abatement
- US EPA: Vermillion Trout Stream Thermal Trading Program – Support data and Heat transport model for the Vermillion River
- U. S. National Science Foundation - Degradation and remediation of PAHs in rain gardens
- Joint Water Research Grant Program – Estimating Size Distribution of Suspended Solids in Minnesota Stormwater

2.3 Further Develop On-Line Assessment Methodology

The project team developed and calibrated methods for assessment for use in field assessment). These methods were developed using well-established monitoring and testing criteria from

existing knowledge such as the U.S. EPA's guide, "Urban Stormwater BMP Performance Monitoring" (U.S. EPA. 2002). In addition to monitoring techniques, three levels of assessment were developed from existing and established visual inspection and testing criteria. This resulted in the four levels of assessment for measuring performance of stormwater treatment practices:

1. **Visual Inspection:** A rapid assessment procedure that qualitatively evaluates and documents the functionality of a stormwater treatment practice. The primary purpose of visual inspection is to identify, diagnose, and schedule maintenance for stormwater treatment practices. The results can be used to select and schedule maintenance.
2. **Capacity Testing:** An assessment method that determines the capacity of a stormwater treatment practice through a series of spatially distributed, relatively rapid, and simple point measurements. Specifically, capacity testing can be used to determine the hydraulic conductivity and total infiltration flow rate in volume per time or the sediment removal capacity (remaining sediment storage volume) of a stormwater treatment practice. The results can be used to select and schedule maintenance.
3. **Synthetic Runoff Testing:** An assessment method in which a prescribed amount of synthetic stormwater is applied to a stormwater treatment practice under controlled conditions to assess the effectiveness. Synthetic runoff testing can be used to assess the performance of a stormwater treatment practice for runoff volume reduction (e.g., through infiltration) and pollutant removal efficiency with measurements such as drain time and mass of pollutant capture. Results from synthetic runoff testing can also be used to calibrate watershed models for simulation of performance during natural rainfall events.
4. **Monitoring:** An assessment method which measures performance of a practice during natural rainfall or snowmelt events by measuring influent and effluent flow rates, collecting influent and effluent stormwater samples for analysis, and comparing influent and effluent volume, pollutant concentration, or pollutant load. Monitoring is the most comprehensive form of assessment and can assess multiple aspects of stormwater treatment practice performance (e.g., peak flow reduction and pollutant removal). It also requires a significant amount of data to calculate reliable results because the number and range of variables is large. The results from monitoring can be used to describe the runoff and pollutant load characteristics of a watershed and the associated response of stormwater treatment practice.

A second, major goal for the 2007-2009 biennium was to develop and demonstrate maintenance procedures and provide recommendations for scheduling maintenance in the on-line assessment manual. A survey was distributed to 106 Municipal Separate Storm Sewer System (MS4) permit holders in Minnesota on the frequency, effort, and cost of maintenance for stormwater treatment practices. Of those, 28 responded and provided important information on municipal maintenance activities for stormwater treatment. This information was combined with published maintenance recommendations and including in the on-line manual.

2.4 Investigations required to demonstrate the assessment of stormwater BMPs

2.4.1 Groundwater pollution caused by infiltration

Existing literature was reviewed and summarized in a St. Anthony Falls Report titled, “Contamination of Soil and Groundwater Due to Stormwater Infiltration Practices” (Weiss et al. 2008). Members from the project team also met with the Minnesota Department of Health to discuss well-head protection practices and the potential impact of stormwater infiltration on groundwater. Infiltration measurements in rain gardens were used to estimate the amount of stormwater runoff that could typically be captured and infiltrated into the shallow groundwater.

2.4.2 Method for stormwater suspended solids size distribution

The goal was to improve the design, maintenance and assessment of all stormwater treatment devices that rely upon sedimentation to remove solids and associated chemicals from stormwater. In particular, a proprietary device testing protocol and settling pond design requires that the solids size distribution be known. Phase I of this research, funded by the Minnesota Local Road Research Board, improved the sampling technology to collect representative samples of the suspended sediment in stormwater runoff and conducted the preparations necessary to develop a methodology to determine the suspended sediment size distribution in stormwater. Phase II of this work, funded by the MPCA, was the development of the methodology to determine the suspended sediment size distribution in stormwater runoff. Phase III, funded jointly by the Mississippi Watershed Management Organization and the Minnehaha Creek Watershed District currently involves the measurement of size distribution at a number of selected locations. A report is currently in preparation for the Local Road Research Board, and will be forwarded to the MPCA when it is completed.

2.4.2 Composting as a method of remediating stormwater pond sediments contaminated with Polycyclic Aromatic Hydrocarbons (PAHs)

This task investigated composting as a method of remediating PAH-contaminated dredged sediments. A proof-of-concept bench-top laboratory study was performed on dredged pond sediments from ponds in the City of White Bear Lake with multiple compost reactors operated under controlled conditions. First, 48-305 ml bottles were operated in a temperature control room, with oxygen and humidity addition. These bottle experiments were designed to test the concept under close to ideal environmental conditions. Second, an incubator reactor study was undertaken with four-3L chambers with temperature feedback control. The purpose of the incubator reactors was to test the amount of sediment that can be mixed into the compost. The temperature feedback sets the outside temperature to be equal to the temperature in the center of the compost pile. This system simulates the temperature increase of a compost pile, in addition to the other parameters. Variables that were investigated in these bench-top experiments include: Ratio of sediment to compost, inoculums (no inoculums for the control and treatment options containing fungi or bacteria inoculums), temperature, mixing/aeration rates, and nutrient concentrations. The results from the laboratory studies indicated that composting will not remove a sufficient amount of PAHs to substantially reduce their concentrations in pond sediments. The

reason for this is believed to be the limited bio-availability of the PAHs, which are known to strongly bind to black carbon in the sediments. This issue should be considered in the assessment of pond sediment concentrations. If the PAHs are not bio-available, it is possible that the sediment concentrations are not truly at the toxic level.

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

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.

The efforts in trout stream impacts of stormwater runoff are further documented in a separate report (Stefan H.G. and W.R. Herb, 2010. "Trout Stream Thermal Impact Assessment Study: Project Summary," SAFL Project Report No. 541, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN).

3 Future Investigations

Stormwater Treatment remains an important applied research topic for the State of Minnesota. The pollution to our receiving waters is substantial, and there remains much to be done. Some of the most urgent are the following:

3.1 Urban Stormwater Inputs of Perfluorochemicals and Treatment Options

- Some lakes have been listed as contaminated with PFCs.
- Stormwater is hypothesized to be a source of PFCs to lakes.
- Will characterize the types of watersheds that have high PFC concentrations.
- Will supplement a project on the retention of PFCs in settling ponds funded by the University of Minnesota's Water Resources Center

Perfluorochemicals (PFCs) represent a state, national and global environmental concern due to their ubiquity and toxicity. PFCs have been used in several industrial polymers from Teflon to Scotchgard. Scotchgard is a trade name of a polymer produced by the 3M company of Minnesota and was used as a stain and water repellent for clothing and furniture. Despite their stability, low vapor pressure and hydrophobicity these polymers can enter the environment by several pathways. They can leach out of textiles during washing and directly enter the wastewater. They can be directly discharged as a residual waste from fluorochemical production and/or disposal. Once in the environment they are not easily degraded by physical or chemical mechanisms. As a result, the 3M corporation stopped producing PFCs of sufficient carbon chain-length that pose a significant environmental or human health hazard.

Despite this production phase-out, PFCs remain a concern. In 2007, several Twin Cities metropolitan lakes were labeled impaired for contamination with a suite of perfluorochemicals, primarily perfluorooctane sulfonate (PFOS) in fish. Most of the lakes listed as impaired have no connection to 3M's production or disposal. We hypothesize that a significant source of PFCs to surface waters is urban stormwater, which receives PFCs from commercial, industrial and residential sources within its watershed.

Research on the project funded by the Water Resources Center has shown that PFCs function similar to ultra-fine clay particles in the water. This identifies a potentially excellent treatment option, because we have spent a great deal of time learning how to treat water for turbidity: coagulation and flocculation with sedimentation removal. We would like to determine if this treatment will work to remove PFCs from water.

Preliminary cost estimate: \$280,000

3.2 Investigation of soil compaction on new construction

- Compaction of soil due to construction activities reduces infiltration potential of urban watersheds.
- MPCA and the McKnight Foundation have funded the project for the first year.
- Three sites with three test plots each have been established.
- Testing control, tillage and tillage with compost.
- Need funds to test other construction sites.

One important challenge with new construction is the compaction of soil in future landscape areas by the transport of construction equipment across these areas. Many regulators state that it is difficult for the infiltration capacity of the soil to recover from this compaction without remediation. Quantifying effects of reducing urban landscape soil compaction for new construction and in established areas upon runoff volumes can be performed with the infiltration measurement technology developed by the University of Minnesota storm water team, i.e. the Modified Phillip Dunne permeameter can be used to determine the infiltration capacity following construction, and the results can be compared to other locations with good infiltration. A research program is underway to investigate the impact of soil remediation techniques on infiltration. Three sites with three test plots each are currently being investigated for infiltration potential. The three test plots consider compact soil (control), remediation with tilling to 24 inches, and remediating by adding four inches of compost and tilling to 24 inches. The funding for this project will ended in 2010, and will require additional funding to fully investigate the impacts of remediating compact soil, because the deterioration of the improved infiltration needs to be documented. These efforts and the results could be used to develop soil compaction standards for the soils that will be landscaped at construction sites.

In order to verify hypotheses developed from field observations, experiments on the use of compost or other amendments will also be conducted under laboratory conditions. Soil columns will be collected from the field plots for the control treatment as well as for the amended treatments. The saturated hydraulic conductivity of these columns will be measured before subjecting them to cyclic moisture content variations. The cyclic variations in moisture content will be imposed on the columns to assess the stability of the amendments. Samples of these soil columns will also be subjected to moisture extraction experiments to determine the relationship between water content and water pressure. From these moisture extraction experiments we will be able to quantify the pore size distribution and thereby assess the effect of amendments and their long-term stability on the pore size distribution.

Preliminary cost estimate: \$120,000

3.3 Remediation of stormwater pond sediments contaminated with Polycyclic Aromatic Hydrocarbons (PAHs)

- PAHs have a high concentration in pond sediments.
- Must currently be disposed of in a lined facility, tripling the cost of dredging these sediments.
- Bio-availability of PAHs to organisms is also important to determining toxicity of PAHs in pond sediments.
- Addition of activated carbon may also be a viable treatment option if isolating PAHs onto black carbon is deemed an acceptable treatment.
- Composting is a promising technique to eliminate PAHs available to micro-organisms, if sufficient oxygen is made available.

Recent municipal sampling of stormwater pond sediments, in preparation for pond maintenance activities, have shown elevated polycyclic aromatic hydrocarbon (PAH) concentrations. As a result, dredged stormwater pond sediment evaluation (sampling and analytical) and disposal options may become more costly. Given the enormous number of sediment ponds in the Twin Cities Metropolitan Area, there will be significant volumes of pond sediments that may require special disposal requirements. Hence, the need for more cost-effective PAH-contaminated sediment remediation options is needed.

More specifically, the last bulleted item refers to windrow-composting, where the sediments are mixed with a bulking agent and possibly other additives (e.g., fertilizer), seeded with a degradation agent (i.e. bacteria, fungi), and laid out in rows. The rows are turned periodically to maintain the oxygen supply to the aerobic degraders and to avoid high temperatures that could limit fungal degradation. However, our PAH degradation studies were not as successful as hoped, likely because the PAHs were not bio-available to micro-organisms in the compost. Thus, bioavailability of these PAHs is a topic of interest to treatment options. We have identified a well-researched bioavailability analysis that can be used in conjunction with the PAH measurements, and will also perform this analysis. The bioavailable portion of the PAHs in sediments can then be identified for consideration in rule-making. Also a possible treatment option is isolation of PAHs through adsorption onto black carbon or powdered activated carbon.

Preliminary cost estimate: \$200,000

3.4. Techniques to Quantify Effective Impervious Cover

- The most important parameter in urban runoff is impervious cover.
- Past efforts of the MPCA have resulted in excellent satellite and air-based imagery analysis of impervious cover for the State of Minnesota.
- The effective impervious cover, subtracts unconnected from the total impervious cover.
- Techniques will be developed that result in a practitioner-based capability to estimate effective impervious cover for a given catchment by integrating the locations of inlets to the stormwater collection system.

With the most important parameter in urban runoff being impervious cover, the sensitivity of runoff to impervious cover is important for any model run on any water catchment. Past efforts of the MPCA have resulted in excellent satellite and air-based imagery analysis of impervious cover for the State of Minnesota. However, the effective impervious cover, indicating its true impact on runoff, needs to differentiate between disconnected and connected impervious cover. Techniques will be developed that result in a practitioner-based capability to estimate effective impervious cover for a given catchment by considering runoff discharge and verifying/calibrating impervious-cover runoff models.

The overall goal of the project is to develop and to evaluate a tool for determining the amount of disconnected impervious area (DCIA) in watersheds and its impact on the hydrologic response of watersheds. The specific objectives are to:

- (1) Use Han and Burian's (2009) GIS method to estimate DCIA for watersheds in Minnesota,
- (2) Estimate DCIA using observed runoff events from gauged urban watersheds,
- (3) Compare the estimate DCIA from observed events with those obtained with the Han and Burian's method and, if necessary, improve it, and
- (4) Develop a predictive runoff method using the GIS-derived DCIA.

Preliminary cost estimate: \$280,000

3.5 Assessment and Operation of Linear BMPs.

- Grassed drainage ditches and swales are utilized on many linear development projects.
- Research is needed on optimizing the operation of these practices for the removal of suspended solids and the chemicals associated with these solids.
- The potential of tall grasses and infiltration techniques as a simple removal mechanism will be assessed.

Linear BMPs used for many roadway projects need to be assessed and operated in an optimized fashion. The results will be employed to provide a more current tool that can be used to estimate future BMP operating and maintenance costs. Grassed swale (roadside ditch) locations with two treatments (mowed and un-mowed) at current or recent roadway projects will be selected for monitoring, for a total of four grassed swales. The effectiveness of the GRASSF model will be evaluated as a tool to potentially reduce the monitoring costs for this BMP. The project activities will apply the recommended monitoring techniques and begin to answer the question “How well is the practice performing?” The results of the project will allow regulatory agencies and municipalities to more optimally utilize limited resources when implementing stormwater management plans.

Preliminary cost estimate: \$200,000

3.6 Thermal Studies to Protect and Restore Trout Streams

Future research related to thermal impacts on trout streams in Minnesota 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.

Appendix A

Sample of quarterly newsletter (printed version) sent out quarterly to over 2400 subscribers.



UPDATES

Volume 4 - Issue 4

NOVEMBER 2009

inside:

SPOTLIGHT ARTICLES

Standard Sumps as Pollution

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SHSAM: Sizing Hydrodynamic Separators and Manholes 2

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Dissolved Phosphorus Capture

MINUHET: Minnesota Urban Heat Export Tool

Simulation of temperature mitigation by a stormwater detention pond

Settling Velocity Distribution

TURNING STANDARD SUMPS INTO A POLLUTION PREVENTION DEVICE WITH THE SAFL BAFFLE

Contributed by Adam Howard

(Contact: John Gulliver at gulli003@umn.edu)

Funded by Minnesota Department of Transportation

There are many standard sumps that may qualify as a best management practice to remove suspended sediment from the water column. However, no data on the effectiveness of sediment removal and maintenance schedule of the sumps exist. Such data could justify providing pollution prevention credit for the use of standard sumps for transportation departments, municipalities, counties and other local governments.

To determine whether the standard sumps remove suspended sediment from stormwater runoff, two standard sumps were tested in a laboratory setting. The removal efficiencies under flow conditions up to design flow as well as the effluent concentrations under greater flow conditions were determined for all configurations. The sumps did remove suspended sediment at the lower flows, but at greater flows the sediment exhibited substantial scour. This scour would negate the sumps as a sediment capture device.

A flow-through baffle was designed and tested as a possible retrofit to the sump. The idea is to use the head loss provided by the flow-through baffle to distribute the jet flowing from the inlet more evenly across the sump, and reduce the maximum velocity. Multiple configurations with varying percent open area and different angles of attack were evaluated in a scale model. An optimum configuration was then constructed at the prototype scale and evaluated for both capture efficiency and sediment retention (i.e., scour prevention). The final design (Figure 1) of the St. Anthony Falls Laboratory (SAFL) Baffle consists of a flow-through baffle which is oriented perpendicular to the flow and extends a distance above to a distance below the inlet pipe crown and invert. (cont'd on page 4)

FIGURE 1: SAFL BAFFLE inside a standard sump manhole (flow inlet shown). (Photo courtesy A. Howard)



WELCOME

Thank you for reading our newsletter! Our purpose is to create opportunities for partnerships which are crucial to our quest for improving the methods for assessment and maintenance of stormwater treatment practices.

UPDATES is a quarterly newsletter designed to share news, current stormwater research efforts, and contact information related to the development of assessment methods and maintenance education for stormwater treatment practices. It is an outreach effort of a project sponsored by the Minnesota Pollution Control Agency (MPCA) and in cooperation with other agencies and organizations. For information, contact Andy Erickson (eric0706@umn.edu).

STORMWATER ASSESSMENT AND MAINTENANCE PROJECT TEAM:

University of Minnesota

John Gulliver (PI), Civil Engineering
Deb Swackhamer (Co-PI), Water Resources Center
Randal Barnes, Civil Engineering
John Chapman, Bioproducts & Biosystems Engineering
Andy Erickson, St. Anthony Falls Laboratory
William Herb, St. Anthony Falls Laboratory
Raymond Hozalski, Civil Engineering
Omid Mohseni, St. Anthony Falls Lab/Barr Engineering Co.
John Nieber, Bioproducts and Biosystems Engineering
Heinz Stefan, Civil Engineering
Pete Weiss, Valparaiso University

PROJECT MANAGERS & TECHNICAL LIAISONS

C. Bruce Wilson, MPCA
Mike Eastling, City of Richfield
Marilyn Jordahl-Larson, Mn/DOT
Barbara Loida, Mn/DOT
Rhonda Rae, Donohue and Associates, Inc.
Doug Snyder, Mississippi Watershed Management Organization



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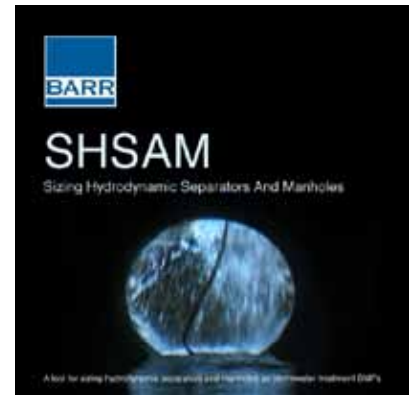
SHSAM: A TOOL FOR SIZING HYDRODYNAMIC SEPARATORS AND MANHOLES AS STORMWATER TREATMENT BMPS

Contributed by Omid Mohseni (omm@barr.com)

Funded by Barr Engineering Company, Inc.

Hydrodynamic separators are stormwater treatment devices with small footprints used for removing suspended sediments and floatables from stormwater runoff in urban areas. Numerous data have been published by research institutes as well as manufacturers regarding the performance of these devices in removing suspended sediments from stormwater runoff. Often the published results are site dependent or only address the specific type of tests conducted on these devices. The questions ahead of the primary users of these devices, (i.e., cities, counties and other local government agencies and large retailers) are: "How well do these devices remove suspended sediment from our stormwater runoff? How can we size them for our site?"

To address this question, Barr Engineering Company has developed a tool (SHSAM: Sizing Hydrodynamic Separators And Manholes) to simulate runoff and the removal of suspended sediments from stormwater runoff using the results of the studies conducted at St. Anthony Falls Laboratory. The runoff component is a continuous hydrologic model



for small drainage basins in urban areas. The hydrologic model utilizes the SCS curve number method to simulate excess rainfall, and the SCS unit hydrograph to simulate the runoff hydrograph. The suspended sediment removal is estimated using the performance functions developed by the St. Anthony Falls Laboratory for 6 hydrodynamic separators and also standard sumps. The input data into the model are 15-minute precipitation data, daily air temperature data to mimic stormwater temperature, the drainage basin characteristics, the particle size distribution in stormwater runoff, the specific weight of sediment particles, and the concentration of suspended sediments in stormwater runoff. The output is the removal efficiency of these devices over a period of time, (e.g., 15 years) and the total amount of sediments removed as well as the number of times a device has to be cleaned every year.

In the November of 2009, SHSAM will be posted on the Barr web site and will be available to the public at no charge. For more information, please contact Omid Mohseni at omm@barr.com.

SIMULATION OF STORMWATER TEMPERATURE AND HEAT LOADING FOR THE MILLER CREEK TEMPERATURE TMDL

Contributed by William Herb (herb0003@umn.edu)
 Funded by Minnesota Pollution Control Agency

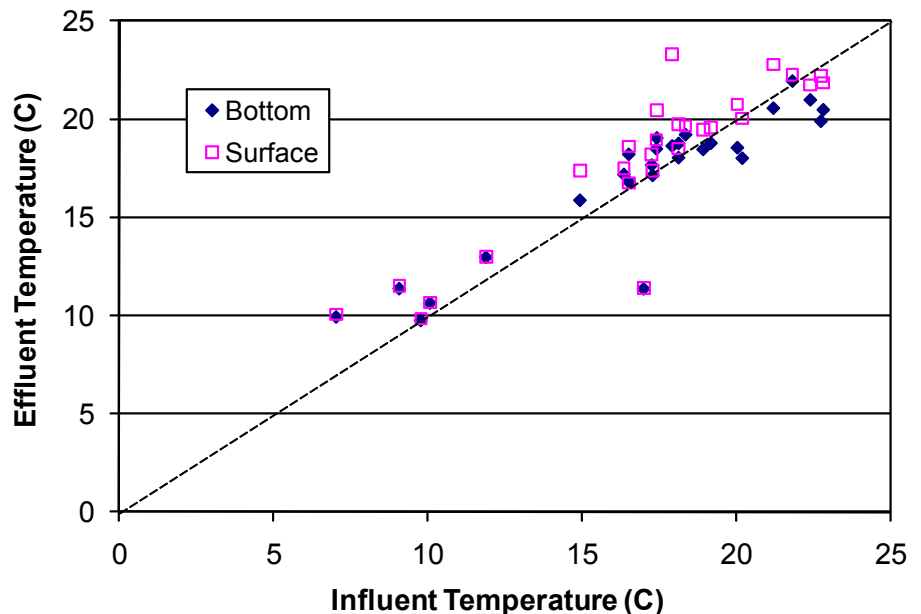
Miller Creek is a designated trout stream which originates near Duluth International Airport, flows through the cities of Hermantown and Duluth, MN and discharges into St. Louis Bay. Miller Creek was recently added to the list of impaired waters (for temperature) by the Minnesota Pollution Control Agency. The 9.4 square mile watershed is about 22% impervious, so that stormwater is a dominant source of flow for Miller Creek.

In support of the TMDL, the MINUHET surface runoff modeling tool was used to characterize stormwater runoff temperatures for typical residential and commercial sub-watersheds for June to September, 2008. Overall, runoff temperatures were simulated to an accuracy of 1.1 to 1.3 °C when compared to field observations. Runoff from the commercial site was, on average, 0.6 °C higher in temperature than the residential site due to higher fractions of impervious area and lower shading.

Models for wet detention ponds were then used to estimate changes in temperature and heat loading to Miller Creek from surface runoff, where heat loading depends on both runoff volume and temperature. A typical wet pond was found to increase, overall, water temperature (Figure 1) and total heat loading, but reduce peak heat loading rates by reducing flow rates. The use of a wet pond with a bottom withdrawal outlet structure gave some reductions in effluent temperature for smaller rainfall events (< 1 cm rainfall), but were of little benefit for larger events compared to standard surface outlets.

Underground stormwater vaults and infiltration practices are currently being studied as alternate practices to reduce heat loading. Further details on this study and the models used can be found in the reference section (Herb and Stefan 2009, Herb et al. 2009a and 2009b).

FIGURE 1: Simulated wet pond effluent temperature for surface and bottom outlets vs. influent temperature for 25 rainfall events in 2008. Points above the dashed line mean that the pond increased the water temperature. (Figure courtesy W. Herb)



EVENTS CALENDAR

NOTE: All travel paid for by the University of Minnesota

October 26-27, 2009: Minnesota Water Resources Conference (St. Paul, MN)

- *Iron-Enhanced Sand Filtration for Stormwater Phosphorus Removal*
- *Standard Sumps as A Stormwater Best Management Practice*
- *Particle Settling Velocity and the Impact on Stormwater BMP Performance*

December 3-4: Minnesota Association of Watershed Districts (Alexandria, MN)

- *Operation and Maintenance for Stormwater Management (December 3rd, 7 pm)*
- *Posters: Assessment and Maintenance of Stormwater Treatment Practices*

January 10-14, 2010: 89th Annual Transportation Research Board Meeting (Washington, D.C.)

- *Iron-Enhanced Sand Filtration for Stormwater Phosphorus Removal*

February 21-24, 2010: 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research (IAHR-APD 2010) (Auckland, NZ)

- *Dissolved Phosphorus Capture in Stormwater Filtration*
- *Settling Velocity Distribution in Urban Stormwater Runoff*

TURNING STANDARD SUMPS INTO A POLLUTION PREVENTION DEVICE WITH THE SAFL BAFFLE (cont'd)

(cont'd from page 1)

Tests were performed on sumps pre-loaded with sediment. The results shown in Figure 2 indicate that, with the right baffle dimensions and porosity, there can be nearly complete elimination of sediment scour for flows up to the 10-year design storm of 4.2 inches in 24 hours for the Minneapolis, MN area. A significant increase in removal efficiency at the low flows was also observed with the SAFL Baffle. The data collected show that standard sumps retrofitted with the flow-through SAFL Baffle can be successfully used as stormwater treatment BMPs.

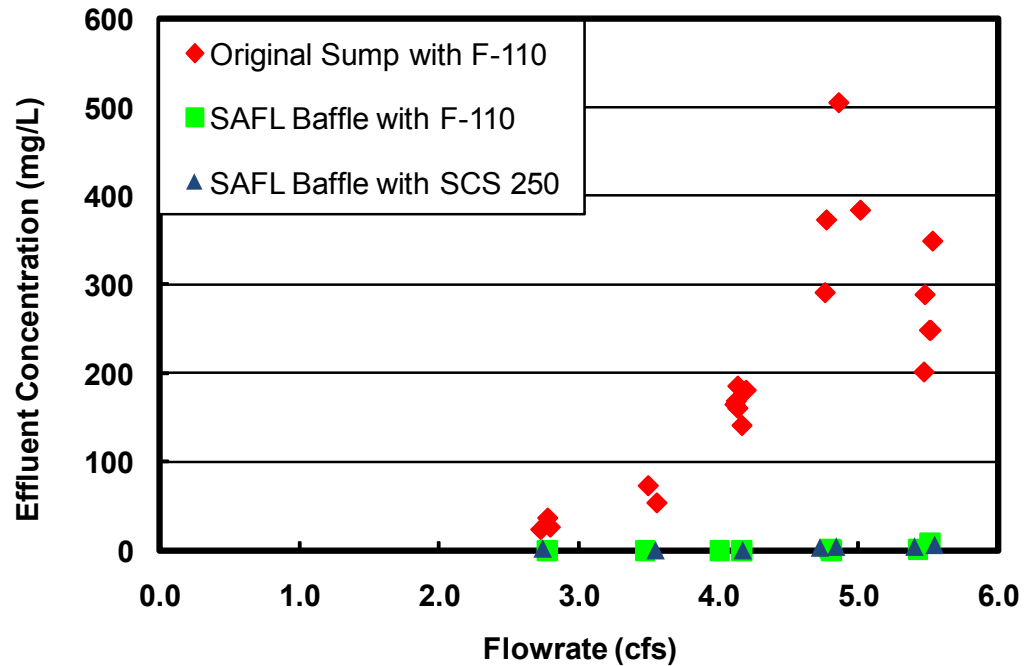


FIGURE 2. A large effluent concentration from the sump pre-loaded with sediment indicates substantial scour at flows above 4 cfs. Almost complete elimination of scour occurs with the SAFL Baffle for sediment loading with F-110 (median diameter of 110 microns) and SCS-250 (median diameter of 44 microns). (Figure courtesy A. Howard).

PUBLICATIONS

1. Erickson, A.J., Gulliver, J.S., Weiss, P.T., and B.J. Huser. (2010). Dissolved Phosphorus Capture in Stormwater Filtration. Proceedings of the 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research (IAHR-APD 2010). February 21-24, 2010, Auckland, NZ.
2. Erickson, A.J., Gulliver, J.S., Weiss, P.T., and B.J. Huser. (2010). Iron-Enhanced Sand Filtration for Stormwater Phosphorus Removal. Proceedings of the 89th Annual Transportation Research Board Meeting. January 10-14, 2010, Washington, D.C.
3. Herb, W.R., B. Janke, O. Mohseni and H.G. Stefan. (2009a). MINUHET (Minnesota Urban Heat Export Tool): A software tool for the analysis of stream thermal loading by urban stormwater runoff. St. Anthony Falls Project Report 526.
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6. Hettler, E. and J.S. Gulliver (2010). *Settling Velocity Distribution in Urban Stormwater Runoff*. Proceedings of the 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research (IAHR-APD 2010). February 21-24, 2010, Auckland, NZ.



UPDATES

Volume 5 - Issue 1

MARCH 2010

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SPOTLIGHT ARTICLES

- Groundwater recharge in an urbanizing watershed: A case study 1
- Stormwater Treatment: Assessment and Maintenance Online Manual 2

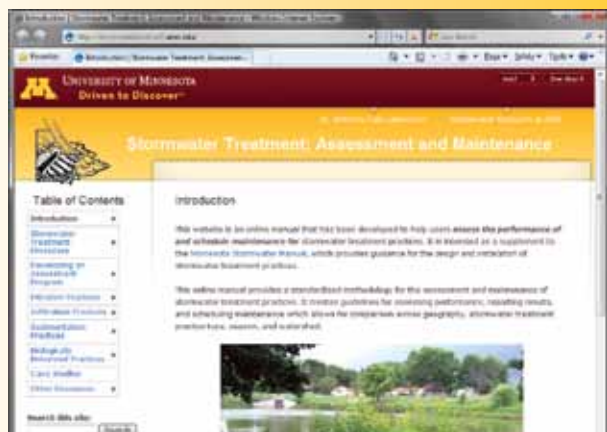
EVENTS CALENDAR 4

PUBLICATIONS 4

- Streamflow analysis on the Upper Vermillion River in Dakota County, Minnesota*
- Groundwater recharge in a coldwater stream watershed during urbanization*
- Projecting natural groundwater recharge response to urbanization in the Vermillion River watershed, Minnesota*

ONLINE MANUAL LAUNCHED!

See page 2



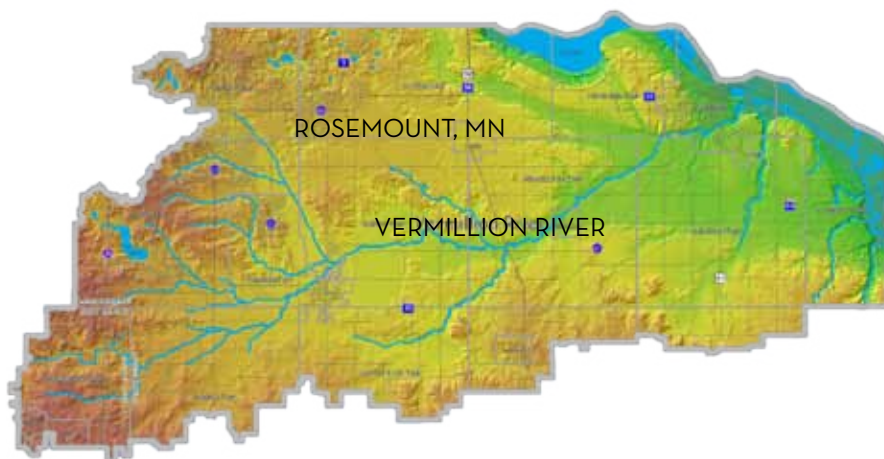
GROUNDWATER RECHARGE IN AN URBANIZING WATERSHED: A CASE STUDY

Contributed by Tim Erickson (eric1003@umn.edu)
Funded by Minnesota Pollution Control Agency

General hydrologic theory states that urbanization reduces groundwater recharge due to increased imperviousness. A case study in the Vermillion River watershed (VRW) shows that this might not always be the case. The Vermillion River is a naturally producing trout stream located in the southern metro area (Scott and Dakota counties) with a large portion (~80%) of its annual streamflow coming from groundwater sources. Due to that high percentage, the Vermillion River should be susceptible and responsive to urbanization.

A recent streamflow analysis suggests that urbanization in the VRW has lead to no significant reduction in shallow groundwater recharge so far, and the trends may actually be towards a slight increase in groundwater recharge. The case study showed recharge from artificial sources, such as leakage for water distribution networks, excess crop and lawn irrigation, and septic system drainage, has replaced projected decreases in natural recharge from increased imperviousness.

(cont'd on page 4)



VERMILLION RIVER WATERSHED, MN. (Courtesy Vermillion River Watershed Joint Powers Organization).

WELCOME

Thank you for reading our newsletter! Our purpose is to create opportunities for partnerships which are crucial to our quest for improving the methods for assessment and maintenance of stormwater treatment practices.

UPDATES is a quarterly newsletter designed to share news, current stormwater research efforts, and contact information related to the development of assessment methods and maintenance education for stormwater treatment practices. It is an outreach effort of a project sponsored by the Minnesota Pollution Control Agency (MPCA) and in cooperation with other agencies and organizations. For information, contact Andy Erickson (eric0706@umn.edu).

STORMWATER ASSESSMENT AND MAINTENANCE PROJECT TEAM:

University of Minnesota

John Gulliver (PI), Civil Engineering
Deb Swackhamer (Co-PI), Water Resources Center
Randal Barnes, Civil Engineering
John Chapman, Bioproducts & Biosystems Engineering
Andy Erickson, St. Anthony Falls Laboratory
William Herb, St. Anthony Falls Laboratory
Raymond Hozalski, Civil Engineering
Omid Mohseni, St. Anthony Falls Lab/Barr Engineering Co.
John Nieber, Bioproducts and Biosystems Engineering
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Pete Weiss, Valparaiso University

PROJECT MANAGERS & TECHNICAL LIAISONS

C. Bruce Wilson, MPCA
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STORMWATER TREATMENT: ASSESSMENT AND MAINTENANCE ONLINE MANUAL

Contributed by Andy Erickson (eric0706@umn.edu)
Funded by Minnesota Pollution Control Agency

The University of Minnesota and St. Anthony Falls Laboratory are proud to announce the launch of a NEW online manual for the assessment and maintenance of stormwater treatment practices! The manual, “**Stormwater Treatment: Assessment and Maintenance**” builds on the knowledge and experience of engineers, researchers, faculty, consultants, watershed districts and many others. The purpose is to provide guidance and recommendations for measuring performance (i.e., assessment) and maintaining stormwater treatment practices.

The online manual provides methodology for assessment and maintenance through discussion, equations, examples, figures, and tables. The manual’s organization is centered around the four levels of assessment:

1. Visual Inspection
2. Capacity Testing
3. Synthetic Runoff Testing
4. Monitoring

Example 10.2: Tracer Study of a wet pond (data)

Alan, the director of the county environmental services, conducted a study that was performed on a stormwater wet pond to determine the hydraulic residence time of the pond. In the study, a perfectly mixed wet pond was modeled (represented by a rectangular tank), and the following data were obtained:

Equation 9.3: Equation for Saturated hydraulic conductivity for synthetic runoff testing of infiltration

$$K_{sat} = \frac{f(t)}{\left[\frac{\psi \Delta \theta}{F(t)} + 1 \right]}$$

The online manual explains when to use each of the four levels and also provides detailed guidance on how to apply the four levels to many types of stormwater treatment practices.

One of the most powerful tools in the online manual is the guidance and supporting documents for visual inspection (level 1 assessment).

(cont'd on page 3)

Biologically Enhanced Practices



UNIVERSITY OF MINNESOTA
**Stormwater Treatment:
Assessment and Maintenance**

Field Data Sheet for Level 1 Assessment: Visual Inspection of Bioretention Practices (including Rain Gardens)

Inspector's Name(s): _____
Date of Inspection: _____
Location of the bioretention practice: _____

STORMWATER TREATMENT: ASSESSMENT AND MAINTENANCE ONLINE MANUAL (cont'd)

Checklists for visual inspection have been developed from interactions with practitioners for many stormwater treatment practices. These standard checklists can be used to develop or augment an inspection program, document performance, and significantly reduce maintenance costs. In addition, capacity testing (level 2) can also be used to select and schedule specific maintenance tasks.

Some assessment programs will require accurate measurement or estimation of water budget components such as open channel flow, infiltration, and rainfall. The online manual provides recommendations for many measurement devices and techniques such as flow meters, weirs, rain gauges, infiltrometers, and permeameters.



Figure 4.6: H-flume (<http://www.>)

Measuring performance for impacts on water quality will often require sampling and often analysis. The online manual provides detailed discussion and recommendations for sampling methods (e.g., *in situ*, grab, automatic) and analysis of water and soils, including quality assurance.

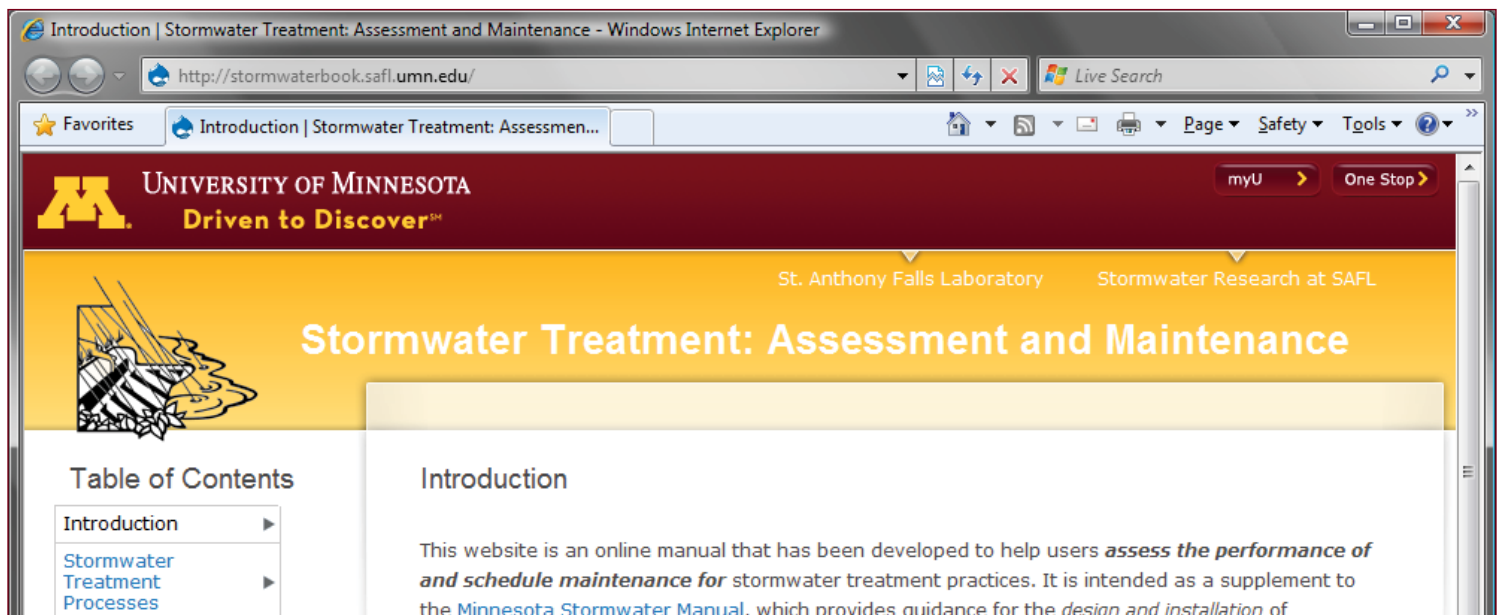
The online manual also provides detailed instructions with examples that illustrate how to calculate performance for a stormwater treatment practice based on load, event mean concentration (EMC), effluent probability, and percent exceedance. In addition, techniques and guidance for estimating uncertainty is also provided.

The manual also includes information on maintenance collected from public works departments and reports to provide guidance on expected maintenance schedules, level of effort, and expected costs.

Table 9.6: Percent of respondents who indicated the listed factors caused deterioration of stormwater treatment practice performance

	Dry Ponds	Wet Ponds	Unconsolidated Sediment
Sediment Buildup	24%	26%	
Litter/Debris	31%	19%	

The online manual includes case studies submitted by practitioners illustrating examples of assessment and maintenance using all four levels of assessment for various stormwater treatment practices. The manual is available online now at <http://stormwaterbook.safl.umn.edu/>



The online manual, "Stormwater Treatment: Assessment and Maintenance" is designed to provide guidance and recommendations for measuring performance (i.e., assessment) and maintaining stormwater treatment practices. The online manual makes this information available in a clear, concise, and easy-to-navigate format. Find it now at <http://stormwaterbook.safl.umn.edu/>

GROUNDWATER RECHARGE IN AN URBANIZING WATERSHED: A CASE STUDY (cont'd)

Figure 1 shows a projected decrease in natural recharge of about 0.5 inches/yr over the period 1988 to 2005 due to increased imperviousness, yet artificial recharge has increased over the period, leaving the net recharge unchanged.

Evidence of the additional recharge from man-made sources can be seen in the seasonal distribution of baseflow. Irrigation occurs only during the growing season. The distribution of baseflow shows increases from June through October, while precipitation actually increased only during June. Base flow is increasing during irrigation months, suggesting that groundwater recharge from irrigation is occurring.

Groundwater recharge has changed in the VRW, yet contrary to common assumption, total groundwater recharge in the VRW has not decreased. Natural recharge has been reduced, but has been replaced by recharge from “artificial” water sources. Further details of this study can be found in the reference section (Erickson and Stefan 2008, 2009a, and 2009b)

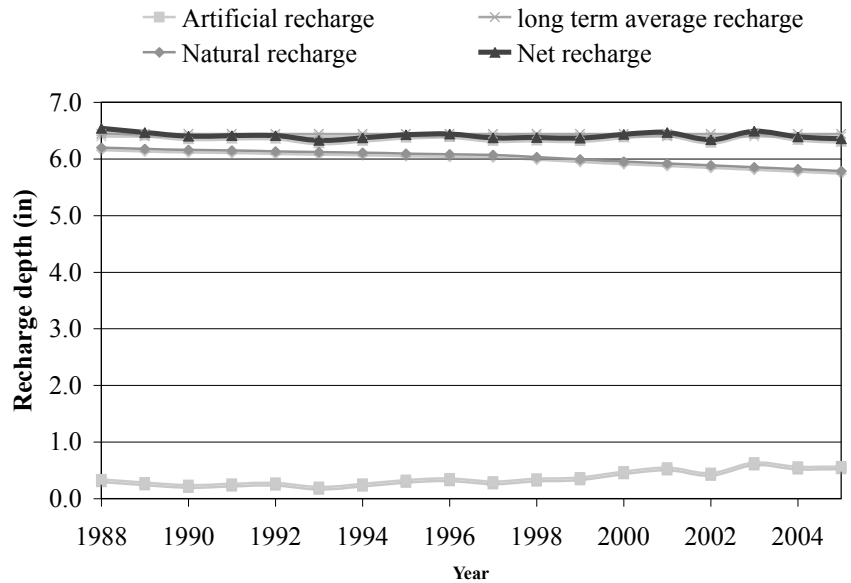


FIGURE 1. Annual groundwater recharge in the Vermillion River watershed (Erickson and Stefan, 2009a). (Figure courtesy T. Erickson).

PUBLICATIONS

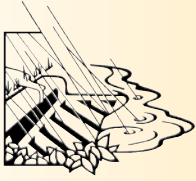
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2. Erickson, T.O., Stefan, H.G. 2009a Groundwater recharge in a coldwater stream watershed during urbanization. Saint Anthony Falls Laboratory Project Report no. 524. University of Minnesota, Minneapolis, Minnesota
3. Erickson T.O., Stefan, H.G. 2009b. Projecting natural groundwater recharge response to urbanization in the Vermillion River watershed, Minnesota. Journal of Water Resources Planning and Management 135(6) 512-520

EVENTS CALENDAR

NOTE: All travel paid for by the University of Minnesota

February 21-24, 2010: 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research (IAHR-APD 2010) (Auckland, NZ)

- *Dissolved phosphorus capture in stormwater filtration*
- *Settling velocity distribution in urban stormwater runoff*



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- Soil Remediation as a Stormwater Best Management Practice 3

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PUBLICATIONS 4

- Maintenance of Stormwater Treatment Practices*

IMPORTANCE OF PARTICLE SETTLING VELOCITY IN BMP DESIGN

Contributed by Eric Hettler (hettl001@umn.edu)
 Funded by Minnesota Pollution Control Agency

Urban runoff contains particles that vary in size from small clays to coarse sands. Some best management practices (BMPs) such as ponds and hydrodynamic separators rely on sedimentation as the primary mechanism to remove these particles. Sedimentation is a function of the settling velocity of particles depends on the particle size and density. In order to ensure accurate design and estimates of performance, it is important to have an accurate measure of the particle settling velocity distribution for particles entering BMPs.

Previous studies have attempted to characterize particle size distribution (PSD) in urban runoff (USEPA 1986, Sansalone et al. 1998, Li et al. 2005), and the reported PSD varies widely. The PSD found by Sansalone et al. is coarser (i.e., larger particles) than the PSD found by Li et al., and the PSD found by Li et al. is coarser than the distribution found by the USEPA (NURP distribution). Nonetheless, practitioners and regulators generally use the NURP distribution for the design of BMPs. Assuming these particles have the same density, the settling velocity will increase as particle size increases.

Figure 1 displays expected solids removal from an underground hydrodynamic separator receiving runoff from a hypothetical impervious watershed assuming the PSD reported by Sansalone et al., Li et al., and the USEPA (NURP distribution). Predicted removal for the coarser distributions (Sansalone et al., Li et al.) is substantially greater than for the commonly used USEPA/NURP distribution. Clearly, an accurate assumption of particle size distribution is essential to the proper design and evaluation of many BMPs.

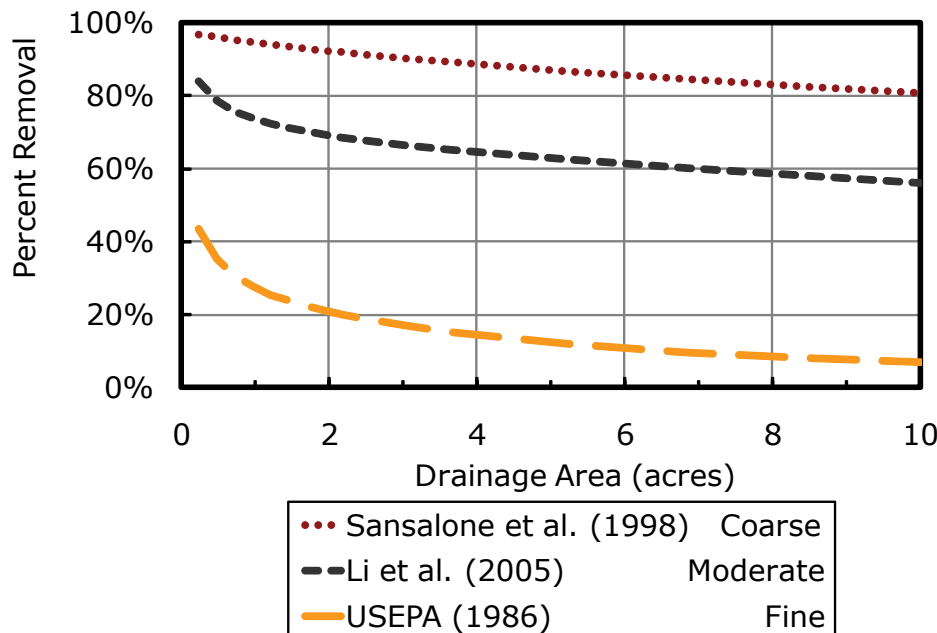


FIGURE 1: Predicted removal from a hydrodynamic separator for a range of particle size distributions. (Courtesy E. Hettler)

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MEASURING AND ESTIMATING INFILTRATION RATE WITH THE MPD INFILTROMETER

Contributed by Farzana Ahmed (ahmed262@umn.edu)
Funded by Minnesota Pollution Control Agency

Infiltration is an essential process of many stormwater best management practices (BMPs). However, infiltration rates have great spatial variation, making quantification of infiltration rates challenging. In addition, accumulation of fine particles at the surface can limit the infiltration rate of these practices. Therefore, measurements of the infiltration rate are needed to determine performance, schedule maintenance, and meet regulatory requirements. The Modified Philip Dunne (MPD) Infiltrrometer has been developed as a fast, simple, and inexpensive device to measure the infiltration rate of water into the soil at a number of locations in rain gardens, infiltration basins and trenches, swales, and filter strips. A person with minimal training can obtain the saturated hydraulic conductivity at a number of locations in an infiltration practice, and ultimately calculate the infiltration rates for a variety of storms.

The MPD Infiltrrometer is a falling head device. This infiltrrometer is made of a hollow open-ended cylinder that is pounded two inches deep into the soil. Next, the device is filled with water to a predetermined height; a stopwatch is started when the water level starts to drop, and the water level is recorded over time. An MPD spreadsheet, developed for application in EXCEL, is then used to determine the saturated hydraulic conductivity (K_{sat}) and soil suction (C) based on the water level vs. time data, dimensions of the MPD, and the initial and final moisture conditions.

The spreadsheet minimizes the root mean square (RMS) of the difference between the observed and predicted time increment (Δt), as well as the observed and predicted head increment (ΔH), by adjusting the saturated hydraulic conductivity (K_{sat}) and soil suction (C). The MPD spreadsheet and a set of MPD infiltrrometers will be available for purchase from St. Anthony Falls Laboratory in the summer of 2010.

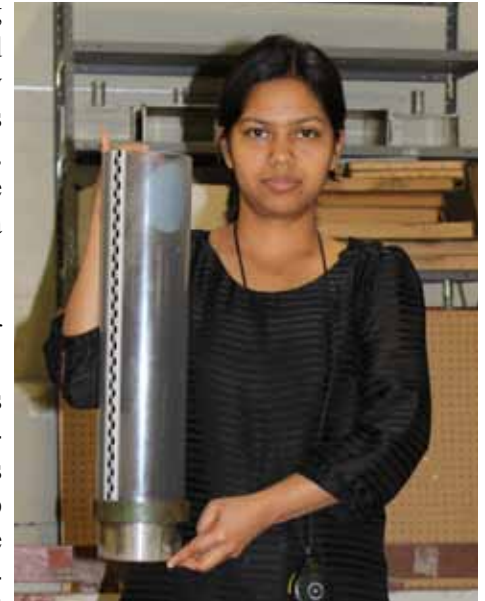


FIGURE 1: Modified Philip Dunne Infiltrrometer (Courtesy F. Ahmed)

SOIL REMEDIATION AS A STORMWATER BMP

Contributed by Nick Olson

(Contact: John Gulliver at gulli003@umn.edu)

Funded by Minnesota Pollution Control Agency, Three Rivers Park District, and The Center for Urban and Regional Affairs.

Soils in residential developments typically have lower stormwater infiltration rates than the soils they replace. This is due to reduced topsoil depth and increased subsoil compaction as land is reshaped and worked with heavy equipment during development. Loss of infiltration leads to increased stormwater runoff and associated downstream problems of flooding, pollutant transport, and warming stream temperatures.

Field studies were conducted to measure the practical application and performance of amending soil with tillage and compost under actual conditions. Three different sites (Maple Lakes Park, Lake Minnetonka Regional Park, and French Regional Park) were divided into three plots for comparison:

- **Control:** No remediation was performed
- **Tilled:** Tilled to 24" depth and spaded to a depth of 16" to smooth furrows
- **Compost:** Tilled to 24" depth and spaded with 3" of compost incorporated to a depth of 16"

Each plot has been tested to assess compaction before and after soil remediation with three indicators: saturated hydraulic conductivity, soil bulk density, and soil strength. Saturated hydraulic conductivity (K_{sat}) measures the permeability of the soil under saturated conditions and in general K_{sat} decreases as compaction increases. Soil (dry) bulk density is a measure of the density of the soil which increases as compaction increases. Soil strength is a measure of the resistance to penetration in the soil column, and penetration resistance increases as compaction increases.

Comparison of each site before and after remediation revealed that compost amended plots at all sites had the largest K_{sat} values and were 3.4 to 6.1 times greater than pre-remediation plots (e.g., see figures 1 and 2). Tilled plots had K_{sat} values 1.3 to 2.4 times greater than pre-remediation plots, but were not statistically different from the control plot averages at Lake Minnetonka Regional Park and French Regional Park (not shown).

Bulk densities before and after remediation were similar for the control and tilled plots at all sites. Bulk densities in the compost plots, however, ranged from 0.93 to 1.15 g/cm³, which is a significant improvement compared to the pre-remediation average of 1.4 g/cm³. *(cont'd on page 4)*

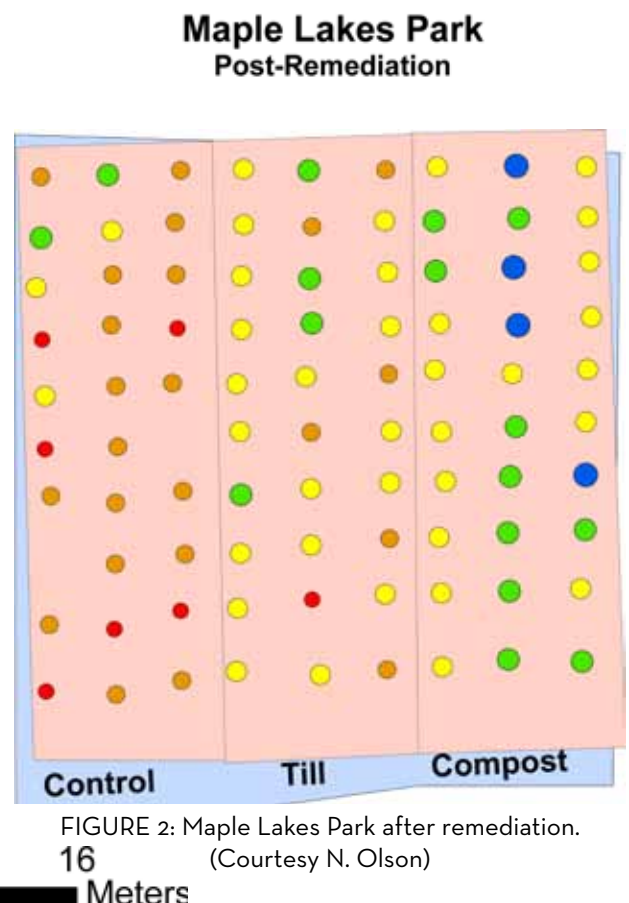
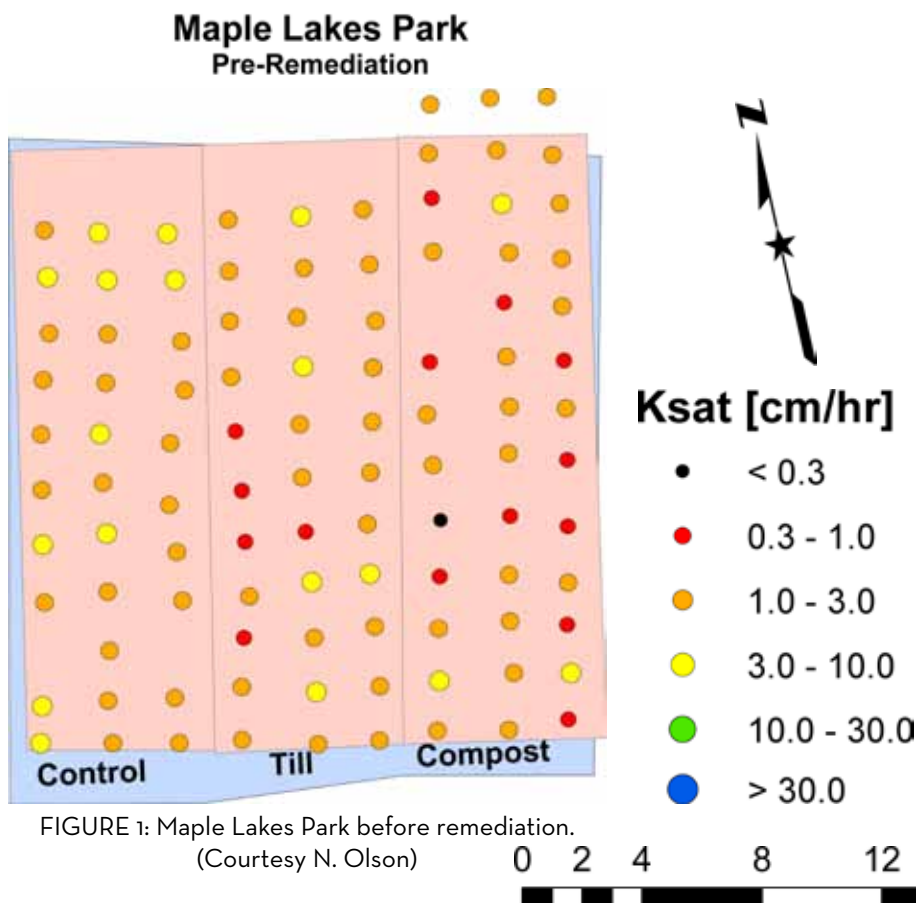


FIGURE 1: Maple Lakes Park before remediation. (Courtesy N. Olson)

FIGURE 2: Maple Lakes Park after remediation. (Courtesy N. Olson)

SOIL REMEDIATION... (cont'd)

Remediation substantially reduced the soil strength at the surface and significantly reduced soil strength to depths near 12 inches in both the tilled and compost plots. This is a significant improvement when compared to the control plot.

Remediation by tillage alone was ineffective in improving the saturated hydraulic conductivity, even though soil strength was reduced. Spading in compost after a soil has been tilled resulted in increased K_{sat} and reductions in bulk density, both of which improved the soil condition. This is likely due to the ability of the compost to increase the porosity and connected pathways in the soil. The next step in this study will be to assess permeability at French Regional Park and Maple Lakes Park to determine if the compost plots continue to improve (or maintain) the soil permeability.

FIGURE 3: High school research assistant Lanre Adekola takes measurements with a Modified Philip-Dunne Permeameter. (Courtesy N. Olson)



EVENTS CALENDAR

NOTE: Participant travel paid for by the University of Minnesota

May 17-21, 2010: World Environmental & Water Resources Congress (EWRI) (Providence, RI).

- *Enhanced Filtration for Stormwater Phosphorus Removal*

June 9-10, 2010: Stormwater U Education Program (St. Paul, MN) <http://www.extension.umn.edu/stormwater/>.

- *P8 Modeling for Reviewers and Modelers*

August 1-5, 2010: StormCon (San Antonio, TX) -

- *Capturing Dissolved Phosphorus With Iron-Enhanced Sand Filtration*
- *When Do We Need to Replace a Bioretention Practice?*
- *Field Measurement of Particle Settling Velocity*

PUBLICATIONS

1. Erickson, A.J., J.S. Gulliver, J.H. Kang, P.T. Weiss, and C.B. Wilson. (In Press). "Maintenance of Stormwater Treatment Practices," *Journal of Contemporary Water Research and Education*. Accepted 2009.