Stormwater Research Roadmap for Minnesota

Prepared for the Minnesota Pollution Control Agency and
the Clean Water Legacy Program

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The views expressed within this document do not necessarily reflect the views or policies of the MPCA.

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INTRODUCTION

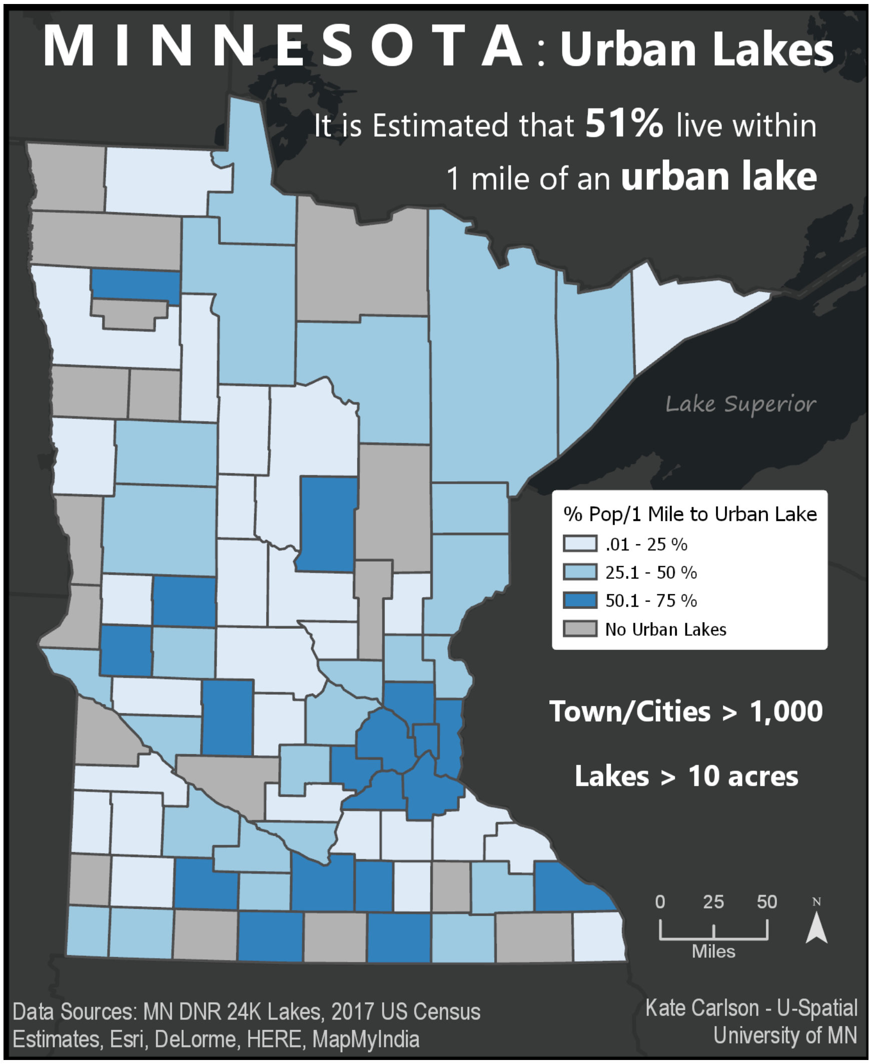
The importance of stormwater management

Urban stormwater - runoff from lawns, streets, parking lots and other urban surfaces - is important because Minnesotans value their water resources. Urban stormwater is a major source of pollutants to highly valued urban waters and contributes to downstream pollution of rivers that flow through cities. As urban stormwater flows across the landscape it picks up pollutants. Nutrients such as phosphorus and nitrogen are leached or eroded from vegetated surfaces, contributing to excessive algal growth in lakes and streams. Erosion of soil particles reduces water clarity and contributes to the filling of stormwater ponds, stream channels, and lakes. Chloride from winter de-icing of roads and parking lots has become a major polluter of both surface waters and groundwater. Various toxins such as pesticides and other compounds also enter stormwater. For example, contaminants from asphalt sealers have contaminated sediments in many stormwater ponds, increasing the cost of safely disposing dredged sediment.

Despite our rural image, 75% of Minnesotans live in cities larger than 2,500. Lakes are focal points for Minnesota cities; some examples include Como Lake (St. Paul) the Minneapolis Chain of Lakes; Albert Lea and Fountain Lakes (Albert Lea); the lake districts of Alexandria and Brainard; Shagawa Lake (Ely); and the mill ponds located in many cities with small rivers flowing through them.

Como Lake in St. Paul is a popular attraction for families, walkers and joggers.

Remarkably, 51% of Minnesotan's live within a mile of an urban lake and many people identify *closeness to home* as a major factor for recreation on the lakes they use most (Anderson et al. 1998).



Percentage of Minnesotans living within one mile of an urban lake. Map developed by Kate Carlson, U-Spatial, Office of the Vice President for Research.

Yet many urban waters are polluted. MPCA's list of impaired waters for the seven-county Metro region includes 369 water quality *impairments*, which means that these water bodies do not meet water quality standards, and generally requires cleanup. The pollutants that cause most water quality impairments for Metro region waters are nutrients (184 waters), mercury in fish (140 waters), and chloride (22 waters). Urban runoff is a major contributor of nutrients and chloride, but most mercury enters lakes by atmospheric deposition.

Urban runoff also potential affects 1.4 million Minnesotans who get their community water supplies (including drinking water) from rivers. For example, surface water supplies for St. Paul, Minneapolis and St. Cloud are affected by urban runoff from 64 upstream cities. In addition to surface water impairment, infiltration of urban runoff may transport soluble pollutants to groundwater. A particular concern is rising levels of chloride in shallow groundwater in the Metro Region, probably caused by road de-icing operations.

The need for urban stormwater research

There are five key reasons that developing a coordinated stormwater research strategy could reduce urban stormwater pollution.

1. There are many impaired urban waters in Minnesota that receive much of their pollution from stormwater.
2. The cost of meeting Clean Water goals is very high - estimated to be $317 million per year (Barr Engineering, 2017).
3. There is a perception among stormwater professionals (documented later in this report) that current stormwater management is not as efficacious as it could be.
4. Past research in Minnesota to improve urban stormwater management has resulted in the implementation of improved stormwater management practices.
5. Future research would be even more productive because it would be informed by our constantly improving capacity to acquire, store, and process information and because it will build upon lessons learned from previous research and implementation.

The Minnesota Cities Stormwater Coalition summarized these thoughts in a letter to the Minnesota Clean Water Council in 2018:

> "*Urban stormwater is still a relatively new field and we have huge and important gaps in our knowledge and understanding."*

Goal of this report

With this background, the goal of the *Stormwater Research Roadmap* is to articulate major research needs to improve stormwater management in Minnesota.

APPROACHES USED TO DISCOVER MINNESOTA's STORMWATER RESEARCH NEEDS

Multiple sources and approaches were used to identify stormwater research needs for Minnesota, including a review of relevant stormwater-related documents, and state-wide survey of stormwater managers, focus groups, and policy actor interviews.

Report and literature review

Numerous reports and publications provided a foundation for the inquiry:

- Stormwater Research in Minnesota (interim report, 2017) - this included interpretations and summaries of multiple surveys and published literature
- Governor's Water Summit Report (2016)
- 2015 Minnesota EQB Water Policy Report
- Minnesota Water Sustainability Framework (2010)
- Rainfall-to-Runoff: The Future of Stormwater - Water Environmental Foundation (2015)
- Water Reuse Workshop Proceedings Report - Freshwater Society (2016)
- And many others

State-wide survey of stormwater professionals and policy administrators

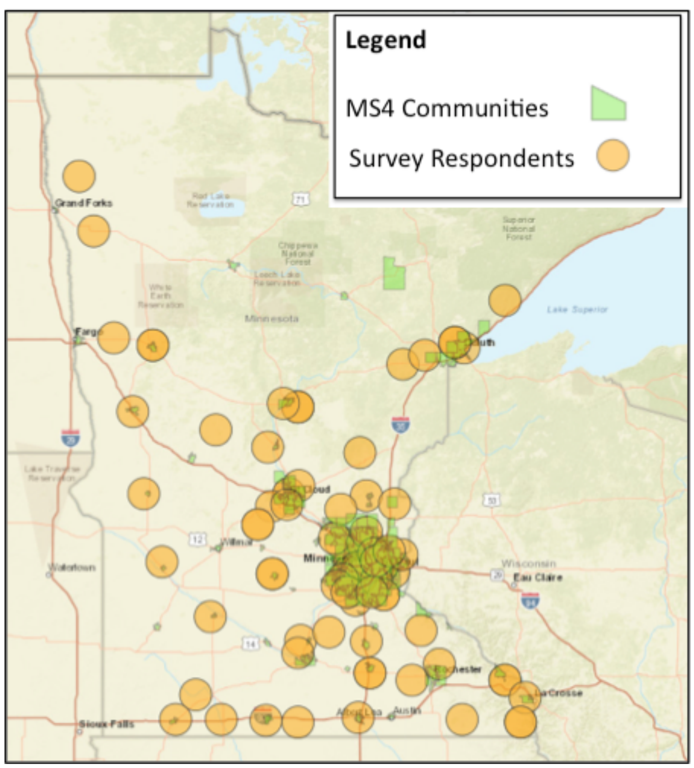
A survey was administered to 480 stormwater practitioners, professionals, and policy administrators across Minnesota. The survey list included the main contacts for the following:

- Municipal Separate Storm Sewer Systems (MS4) permittees
- Watershed Management Organizations
- Watershed Districts
- Soil Water Conservation Districts
- County Water Planners

The survey included a series of multiple-choice questions with opportunities for additional written responses and comments. Questions were developed around seven themes previously used in the 2017 interim report:

- Source Reduction and Pollution Prevention
- Characterization of Stormwater Runoff
- Impacts of Surface and Groundwater
- Treatment Practice Effectiveness
- Maintenance, Longevity, and Cost/Benefit
- Public Policy and Education
- Emerging Concerns

The survey included a series of questions of increasing specificity to triangulate research needs in each major topic area. For example, we asked questions about specific pollutants, barriers and opportunities regarding stormwater management, sources of stormwater, and the extent of development in the jurisdictions of respondents, as well as specific questions regarding research needs. The survey was web-based and administered by the Minnesota Center for Survey Research. 150 responses (31% response rate) came from all parts of the state, as shown in the graphic below. More survey details are presented in Appendix A1 and tabulated responses are presented in Appendix A2.



Distribution of survey respondents throughout Minnesota.

Policy actor interviews

Five interviews with experienced stormwater professionals from across Minnesota provided clearer understanding of research needs expressed in the surveys, focus groups and prior research publications. The stormwater managers interviewed routinely establish policy, fund research, and rely on research to plan, design, and implement stormwater management at a local or state level. They included:

- An administrator from a watershed joint powers organization
- An administrator from a not-for-profit organization
- Two MS4 city stormwater engineers
- A stormwater engineer from a private consulting firm

Semi-structured interviews used a series of questions provided to participants in advance. The questions centered on the following:

- Asking how new research or information could be useful to them or the communities they work with to prevent, minimize, or optimize mitigation from urban stormwater runoff
- Discussions of both structural and non-structural practices and their need for more research or new information
- Gathering opinions to prioritize criteria for research

The semi-structured format allowed for flexible conversation about stormwater research needs using the pre-determined questions as a foundation. The interviews and conversations provided an opportunity to gather additional details about specific needs or topics raised in the survey and focus groups.

The interviews were transcribed into electronic documents for *qualitative analysis* by researchers. The analysis sorted and coded conversations, looking for themes of frequent responses, multiple citations of priorities, and other ideas about research or information needed to advance stormwater management. A report articulating the interview methods, information obtained, analysis and findings are presented in Appendix 2.

Focus groups

Seven focus groups organized in three workshops provided information from specific stakeholder groups. The workshops and focus groups included:

- Workshop 1 included 27 staff and professionals from the Minnesota Pollution Control Agency working in the stormwater, water quality, and water policy program areas.
- Workshop 2 had four focus groups including representatives from Minnesota cities, watersheds, counties, not-for-profits, and private engineers. This workshop used the Minnesota Erosion Control Association and the Minnesota Cities Stormwater Coalition to solicit participation by 20 individuals.
- Workshop 3 included two focus groups with ten researchers and professionals involved in stormwater research and local stormwater management affiliated with the University of Minnesota-Duluth.

The focus groups generally centered conversation around a series of questions that included:

- Identifying existing barriers and opportunities for stormwater management
- Identification of specific research needs to advance stormwater management ideas regarding barriers and opportunities previously identified
- Included discussion, identification of and ranking of criteria to prioritize needs.

Information gleaned from these question and answer conversations was recorded on paper and then transcribed into electronic documents for qualitative analysis by researchers. Similar to the interviews, the analysis sorted and coded the written information from the focus group. Frequently repeated responses, multiple citations of priorities, and other ideas about research or information needed to advance stormwater management were noted (Appendix 2).

Interpretation of findings and identification of research needs

Identification of stormwater research needs was inferred from both quantitative data (survey responses) and qualitative data (focus groups and policy actor interviews). Each of the following eight research needs includes *supporting evidence* from our findings.

Research Need #1: Improve Characterization Of Urban Stormwater And Watersheds.

Managing urban stormwater effectively requires good characterization of both stormwater runoff and the watershed. Characterization of stormwater includes measurements of flow and chemical characteristics at multiple points in a watershed and at various times, from minutes (for analysis of individual runoff events) to years (to analyze trends in pollutants). Characterization of watersheds also includes analysis of landscape characteristics, such as mapping fine-scale land cover characteristics (trees, rooftops, and streets), and delineating the flowpaths of urban runoff as it moves toward storm drains. Research could also make characterization less expensive.

Supporting evidence:

1. Most (88%) of survey respondents perceived that *financial constraints* were a moderate or major barrier regarding stormwater characterization, suggesting that less expensive characterization tools would be an important research goal.

2. A variety of research topics were considered important or very important by survey respondents, with more than 50% of respondents rating them of *moderate* or *a great dea*l of importance:

- Sources and impacts of non-regulated contaminants (71%)
- Characterization of runoff from specific land uses (68%)
- Toxicity of pond sediments (68%)
- Identification of sources of conventional pollutants (53%).

3. When then asked for their top research priority, *characterization of runoff from specific land uses* was selected by 35%, followed by *toxicity of pond sediments* (28%).

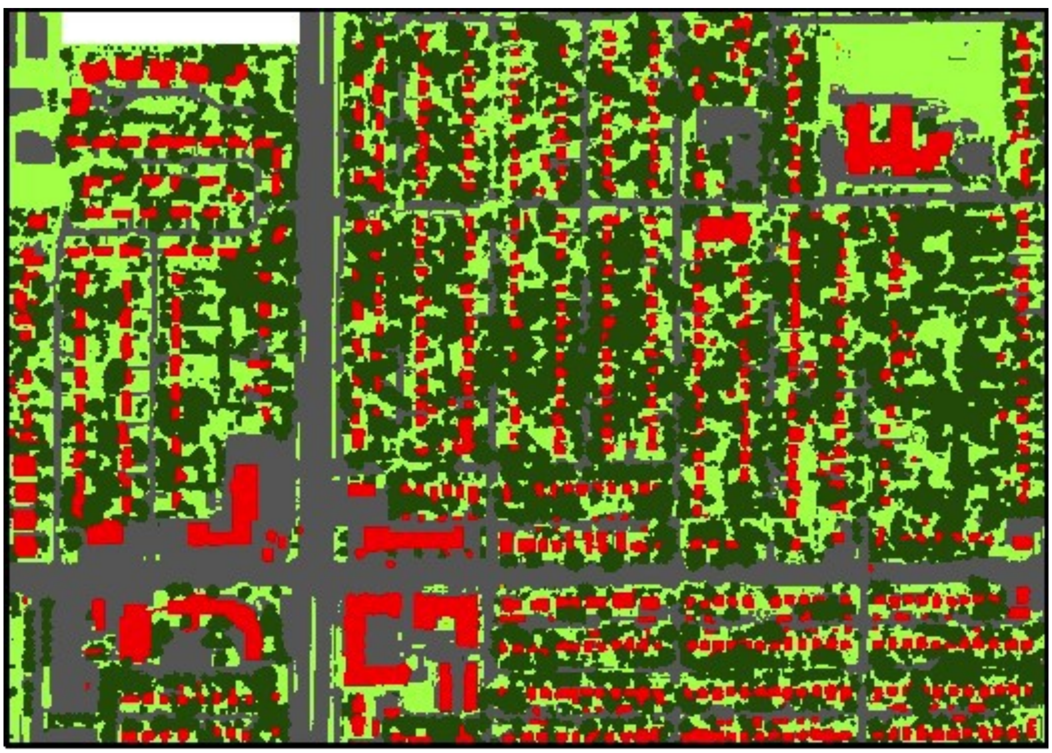
4. Research needs around characterization also included advanced monitoring methods stormwater runoff, such as real-time analysis.

As one watershed district manager noted:

> "*Some really good guidance about monitoring, methodology that could work better. That could be valuable, ... could extend resources. I think that has some appeal because then I feel better about where we're spending our time. Then perhaps the University could use some of our data.*"

Discussion:

Improved characterization of urban watersheds and stormwater quality could help stormwater managers improve the effectiveness of BMPs while also lowering the cost of characterization, especially stormwater monitoring. Our rapidly expanding technological capacity to acquire, store and analyze water quality data makes continuous improvement of characterization activities feasible. Advances in data acquisition technologies in Minnesota include state-wide LiDAR mapping (which provides very fine-scale elevation maps) and development of LiDAR-enabled fine-scale (0.6 m) land cover mapping. These new data tools enable researchers develop new tools for stormwater and watershed characterization that would have been impossible a decade ago. New characterization tools could collect water quality data at finely pinpointed times and places, enabling more precise targeting of stormwater management activities.



An example of new characterization tools: Fine scale land cover mapping, down to 2 x 2 foot pixels, enabled researchers to map tree cover canopy through the Capital Region Watershed District, making it possible to map inputs of phosphorus from vegetative debris for the entire watershed.

Advances in watershed landscape characterization would create opportunities to improve spatial targeting of stormwater management. For example, findings from two studies at the UMN - one resulting in a fine-scale map of land cover characteristics (including individual trees) and the other resulting in a model of nutrient removal by street sweeping - were combined to quantify inputs of nutrients from vegetative debris onto streets across watersheds in the Capital Region Watershed District.

Research Need #2: Evaluate The Efficacy Of Stormwater Management Practices At The Watershed Scale.

Ultimately, the goal of stormwater management is to improve the quality of receiving waters (lakes, streams, and groundwater) at reasonable cost. Although we know the pollutant removal for a given BMP, we need better knowledge regarding changes in water quality in larger urban watersheds, which may contain dozens of BMPs and also be affected by changing land use and other factors.

Supporting evidence:

1. Of those responding, 37% rated their MS4 programs effectiveness in improving surface water quality at as high or very high; 54% rated effectiveness as moderate, and 9% gave a low rating.

2. We asked survey respondents to rate four research topics regarding quality of receiving waters. All four topics - *trends in soluble pollutants (such as nitrate & chloride) in groundwater*, *trends in conventional pollutants in surface waters*, *trends in biological indicators*, and *development of new metrics, such as 'ecosystem benefits'*, expressed in economic terms, were rated as somewhat or very important by 81% to 94% of respondents.

3. When asked which single issue should be the *highest* research priority, 50% selected *trends in conventional pollutants,* and 9% to 24% selected one of the other three topics.

4. A new report estimates the cost of future stormwater management to be *$317 million per yea*r (Barr Engineering 2018). In the context of Research Need #2, the issue is *watershed-scale costs* in relation to watershed-scale water quality improvement. Cost efficiency is discussed later in the context of individual BMPs (Research Need #5).

5. A 2014 Met Council water quality study of Metro region streams concluded:

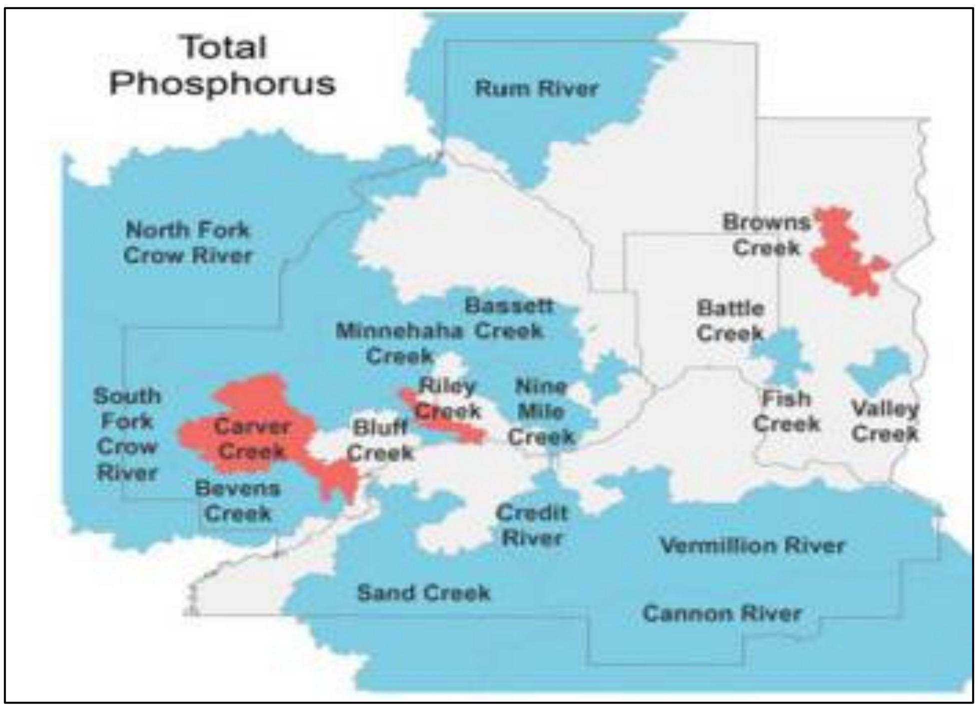
> "*Trend results indicate improvements in water quality in the majority of monitored streams during 2008-2012 based on reductions in sediment, phosphorus, and nitrate flow-adjusted concentrations. However, the trend analysis does not identify which actions, projects, structures, or practices have caused the improvements (or declines*)."

On the other hand, chloride trends have often been increasing in Metro region streams, lakes, and groundwater (MPCA 2017).

Discussion:

We now have a wealth of monitoring data on urban lakes and streams, especially in the Metro region that could be used to evaluate both trends in water quality and the multiple drivers that cause these changes, including specific stormwater management practices, land use/land cover changes, the lawn phosphorus fertilizer law, etc. Some urban streams have been monitored consistently for 20 years or more and we now have satellite-inferred lake clarity data dating back to 1975. However, analysis of these databases has been limited, especially with respect to assigning causes of water quality changes.

Research to evaluate *future* watershed-scale effectiveness of stormwater management will benefit from the implementation of "Internet of Things" – networks of inexpensive ground- based and remote sensing systems that will facilitate analysis of water quality trends and the underlying mechanisms that cause these trends, including stormwater management.



Map of total phosphorus levels in the Metro region. Most waters have shown slight declines, but the reason isn't well known. Source: MCES 2014.

Research Need #3. Inform Effective Pollution Reduction At The Source.

Source reduction, also called pollution prevention, means reducing the production of pollutants from the watershed before they become part of the stormwater runoff stream. Source reduction also includes reducing the volume and rate of stormwater runoff.

Tree leaves accumulating in a catch basin.

Supporting evidence:

1. When survey respondents were asked about potential opportunities for improving stormwater management, 75% rated *wider use of pollution prevention/source reduction* as a *moderate* or *major* opportunity.

2. *Inability to reduce sources of TMDL pollutants* was identified as a moderate or major barrier towards improved stormwater management by 64% of survey respondents.

3. More than 60% of respondents identified suspended solids, phosphorus, chloride, and nitrogen as having *moderate* or *major* opportunity for reduction by source reduction/pollution prevention.

4. When asked specifically about barriers to pollution prevention/source reduction BMPs, ratings of *somewhat* or *very* important were:

- Practical barriers for implementation (94%)
- Perceived low potential for improving water quality (78%)
- Low public acceptance (69%)
- Lack of technical knowledge (74%)
- Regulatory requirements (69%)
- Low administrative support (62%)

5. Focus groups and policy actor interviews also expressed a need for more information and research related to pollution prevention and source reduction practices. Research needs centered around the desire for more information about the effectiveness of pollution prevention practices, how much credit for reduction should be given to these practices, and how cost-effective pollution prevention is compared with other types of practices.

One policy actor expressed the need for additional research in this area by saying:

> *"Before it is the storm sewer. I mean source reduction. What are the sources of pollutants that we can knock out. That sort of thing. We have spent a lot of time on what we can put on the end of the stormwater pipe to make it better ... but I'd like to know more about what we can do before it enters the pipe."*

Discussion

Source reduction has been successful for reducing inputs of pollutants to stormwater, which should motivate future research. Some examples include:

- An estimated 90% reduction in stormwater lead concentrations, accomplished by reductions of lead in gasoline and paint (Baker et al. 2008).
- Evidence suggesting that Minnesota's lawn P fertilizer law has reduced phosphorus in lakes (Halbach 2016).
- A product ban on coal tar-derived asphalt sealants, which will probably reduce PAHs in stormwater pond sediments (Mahler et al. 2012)
- Elimination of various organochlorine chemicals in the 1970s, resulting in major reductions of these compounds in fish tissues (Schmidtt et al. 1990)

Recent research demonstrates properly timed street sweeping may be a very cost-efficient way to remove nutrients from streets with substantial tree canopy (Kalinosky et al. 2013). Source reduction is the only feasible way to reduce chloride contamination, and research may yield ways to do this very efficiently. Reducing inputs of coarse solids to stormwater catch basins may also be an effective way to improve pond maintenance, which is an important barrier to stormwater management in Minnesota (see Research Need #5).

Research Need #4. Improve Performance And Reduce Maintenance On Structural BMPs.

Structural BMPs include stormwater ponds, dry detention basins, infiltration basins, wetlands, rain gardens, swales and related practices that trap and filter sediments and sediment-bound pollutants and may reduce the rate and/or volume of stormwater runoff.

Dredged pond sediments being de-watered in large filter bags make it easier to transport the sediments to a landfill.

Supporting evidence:

1. In our survey, *financial constraints* and *long-term maintenance* were identified as moderate or major barriers regarding the effectiveness of structural BMPs by 83% and 82% of respondents, much higher than other barriers. The two issues are related, because maintenance can be expensive.

2. When asked specifically about research needs for BMPs, *long-term maintenance* and *performance of widely used BMPs* were rated as somewhat or very important by 89% and 95% of respondents, respectively. (Other BMP research needs are discussed in Research Needs #5 and #6). Survey responses create a strong case for additional research of operation and maintenance stormwater practices. In many cases, multiple focus groups and interview participants elevated these concerns especially related to specific practices.

3. We observed strong impressions in focus groups and policy actor interviews that *pond maintenance* is important. As one city engineer noted***:***

> *"…we have to be cleaning our ponds out. I know it's very, very expensive. That's another good one. Research need. How can we make pond dredging cheaper? Can we get volume down? Is it about strategic dredging?*
>
> *…There are ponds that haven't been maintained for 40 years and we're counting on these."*

4. Others commented on long-term maintenance of the relatively new practice of using underground filtration systems and on bioretention systems. One engineer commented:

> *"This underground system I have is completely clogged even though I maintained it. It would not drain. What do I do now?"*

A policy actor from a nongovernmental organization commented:

> *"I don't know how long a well maintained rain garden lasts. I don't know how long a crappy maintained rain garden lasts. What happens if we let it go to crap and suddenly it's taken over by undesirable plants. There are variations of those questions we don't know the outcome for."*

And a watershed organization administrator commented:

> *"What is the typical lifespan of a bioretention basin before you have to dig it up? Can you really leave it alone for 10 years or is there stuff you have to be doing."*

Vacuum trucks remove sediment from a catch basin.

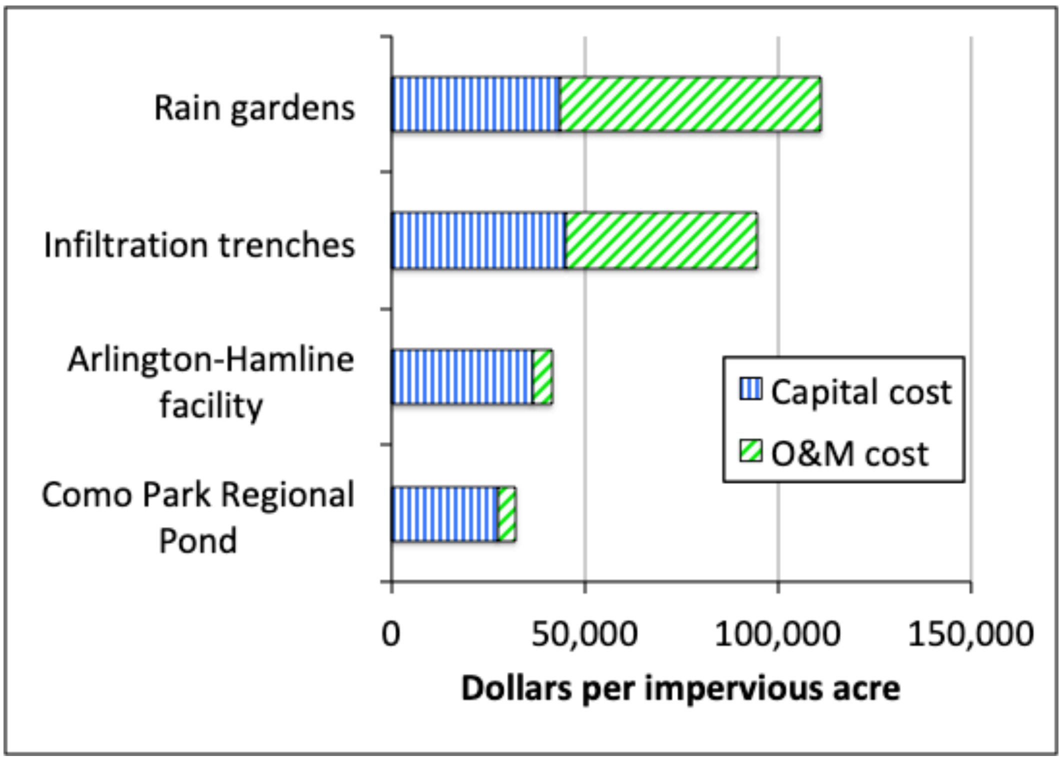
Discussion:

Pollutant removal rates for common BMPs are well-documented but removal rates are often low and variable (Weiss et al. 2008). New research to improve pollutant removal performance might include studies of stormwater solids characteristics, the processes by which pollutants are removed, and winter performance, which is poorly understood.

In addition, research to reduce maintenance requirements of BMPs might include studies of forebays to trap coarse material, improved dredging and dewatering, and source reduction of solids.

Research Need #5. Determine The Cost Efficiency Of Stormwater Practices.

The cost of stormwater management includes both capital costs (for example, the construction of structural BMPs) and operation and maintenance (O&M). Examples of O&M costs are removal of accumulated sediments and debris and other actions to maintain the effectiveness of BMPs. For some BMPs, the O&M costs can exceed 50% of capital costs.



Comparison of capital costs and operations and maintenance (O&M) costs for several BMPs in the Capital Region Watershed District (CRWSD 2012). Costs are sometimes calculated as dollars per pound of pollutant removed.

Supporting evidence:

1. Ninety-six percent of survey respondents rated *costs and benefits of individual BMPs* as being a *moderate* or *major* research need.

2. When asked to rank 13 research needs related to both commonly used and innovative

practices, *costs and benefits of individual BMPs* were ranked as the top priority by 19% of respondents, just below *new, innovative BMPs.* (Research Need #6).

4. The recent estimation of stormwater management statewide costs of $317 million per year (Barr Engineering 2017) highlights the need for improved cost efficiency.

5. Research on cost efficiency, normalized to universal metrics like $/lb pollutant removed for each BMP or $/acre of drainage area, would enable stormwater managers to make more cost efficient choices.

6. Participants in focus groups and policy actor interviews expressed their need for information using a variety of terms including *cost-benefit*, *cost-effectiveness*, *life-cycle costs* and *pollutant removal efficiency*. Often, they used these terms interchangeably.

"I think there is a definite need for someone to do some legitimate life cycle costs analysis." … "What is the true cost when we are building it now versus the way we could build it? But nobody has really pulled that stuff [economic data] together really well and the city engineers and public works directors out there would love to have that so would the watershed districts." said a NGO policy actor, a sentiment echoed repeatedly in the focus groups and policy leader interviews.

Discussion:

Research on stormwater management practice costs and benefits should therefore have two thrusts. First, there was considerable interest in reducing-term operations and maintenance (O&M) costs, especially for stormwater ponds, which need to be periodically dredged to remove sediments. Research topics might include improved P8 modeling, source reduction BMPs to reduce solids inputs to ponds, better design of forebays to trap coarse sediments, and methods to manage dredged sediment, especially when they are contaminated with toxins such as PAHs (polyaromatic hydrocarbons, which come from asphalt sealers, combustion, and other sources).

A second research thrust might be side-by-side comparisons of the costs and benefits of individual structural and non-structural BMPs and non-structural practices such as source reduction. Findings would enable stormwater managers to select the most cost efficient BMPs.

Research Need #6. Develop New And Innovative Stormwater Management Practices.

Current BMPs often have limitations such as high costs, variable treatment effectiveness, large land requirements, and accumulation of pollutants. Because of this, there is considerable interest in emerging BMPs that reduce these problems. New knowledge on source reduction and innovative pollution treatment can quickly create opportunities to improve stormwater management.

Supporting evidence:

1. Sixty-five percent of survey respondents rated *improved design and maintenance of structural Best Management Practices* as being moderate or major opportunities in water quality improvement.

2. Forty-nine percent of survey respondents rated *availability of suitable sites for structural BMPs* as a moderate or major barrier.

3. When asked specifically about research on BMPs, *design and performance of new, innovative BMPs* rated as somewhat or very important by 90% of respondents. On the same question, *design and performance of BMPs for constrained spaces* rated as somewhat or very important by 88% of respondents.

4. When the question was narrowed further, asking respondents to rank research needs for emerging practices (high or very high importance), the four top rankings were:

- Stormwater reuse (59%)
- Enhanced filtration systems (49%)
- Trees for hydrologic control (43%)
- Enhanced street sweeping for nutrient removal (42%)

5. When asked to pick the single *most important* topic for BMP research among both emerging and common practices, *design and performance of new innovative BMPs* ranked first, selected 20% of the time.

6. Focus group and policy actor interview participants most frequently expressed the following areas for new research on emerging BMPs:

- Stormwater reuse systems
- Iron-enhanced sand filter practices

- Practices that use trees
- Alternatives to the use of chloride for winter deicing

Some comments from focus groups:

"Research on the different types of systems used to treat reuse water is needed."

A city stormwater engineer:

"Tree trenches. They're becoming more popular, but I don't think we really know exactly how much value they are adding….There could be some real value in research on this. It will need to be long term. Compare and contrast these systems that are supporting trees."

A private engineer:

"Oh here's another research need, take some of these iron enhanced filters that aren't working. It would be interesting to have a playbook. It's a very hot topic right now. A lot of people are working on these. Why are there some iron enhanced filters working and some that are failing. How to design them for optimal conditions. A filter that has been designed by you or someone else, how do you fix it? Do you really just have to rebuild it? Or is there a way to replenish the systems. How do you fix them? How to retrofit the retrofit?"

Rainwater from the roof of the Metro Transit Operation and Maintenance Facility for the Green Line LRT is collected in a 27,000- gallon cistern for use in CHS Field irrigation and toilet flushing, saving 450,000 gallons of water and $1,600 per year.

Discussion:

There was strong interest in research to develop and understand emerging BMPs. No one emerging practice stood out, but the topic of stormwater reuse has attracted wide attention and is being implemented at dozens of sites throughout Minnesota. The concern here is the impact of reused water on human health.

The issue of BMPs for built-up areas may become more important because densification of inner urban areas will continue, limiting space available for structural BMPs.

Research Need #7. Education To Improve Public Perception Of Stormwater Management And To Improve Effectiveness Of Citizens' Actions To Improve Water Quality.

Stormwater education brings public awareness and behavioral changes that reduce water contamination and minimize negative environmental impacts of excessive stormwater runoff. Stormwater education is offered to stormwater professionals (training), the public (school education, citizen education), and public officials. Stormwater education research areas include investigating the needs and the efficacy of stormwater education (principles, concepts, and methods).

Stormwater professionals conducting a water quality pond inspection field exercise as part of the 2018 SWU: Stormwater Practices Maintenance Certification Workshop.

Supporting Evidence:

1. Minnesota stormwater professionals and policy actors rated stormwater education and training as the second highest stormwater research need and the third highest barrier to improving water quality.

2. Survey respondents ranked *education and training* as the third highest opportunity toward improving water quality, with 70% rating this topic as a moderate or major opportunity.

3. Public cooperation and support identified as the third highest barrier towards improving water quality in their jurisdictions, with 62% of respondents rating this topic as a moderate or major opportunity.

4. Conversely, three topics were rated as moderate or major barriers toward stormwater education by more than half of respondents:

- Insufficient funds (64%)
- Lack of interest (63%)
- Lack of measurement for education effectiveness (62%)

5. With regard to *research* on stormwater education, all six topics presented ranked were considered helpful or very helpful by large majorities:

- Effectiveness of education to elicit behavior change (89%)
- Effectiveness of education about improving water quality (87%)
- Evaluation methods for education and communication tools (87%)
- Effectiveness of education efforts to increase knowledge (85%
- Effectiveness of education to improve water quality (87%)
- Methods to increase public or administrative support for education efforts (81%)

The *most important* topic identified by survey respondents was *effectiveness of education to elicit behavior change*, selected by 43% (each of the other topics were ranked most important by less than 20% of respondents).

6. Finally, when asked about value of new information and research to various audiences, each choice was rated as very or somewhat important by more than 90% of respondents:

- Local elected and appointed leaders (92%)
- Homeowners and renters (92%)
- Business owners and employees (93%)
- Stormwater professionals (93%)
- Youth (in both K-12 and informal environments) (90%)
- Social organizations (garden clubs, lake associations, etc.) (90%)

Two topics were most commonly rated as the top priority for education research: *education to elicit behavior* change (selected by 43% of survey respondents) and *effectiveness to improve water quality* (selected by 19%)

7. Focus group participants identified stormwater education and training as the second highest stormwater research need. Similar to the survey findings, the focus group participants identified *educating audiences with specific priorities*, the *most effective education practices to reach those audiences*, and *measuring the effectiveness of education efforts* as research needs.

A city stormwater engineer stated:

> **"***Research is needed on what activates people. What motivates people including what would motivate city staff to do more education? What motivates residents to do something in their yards? What will make a lake cabin owner quit mowing to the edge?***"**

The second research need in stormwater education was *better knowledge of the effectiveness of various education and behavior change strategies* and *where it can help us to show that...hours spent on education relates to phosphorus removal.* The research needs to investigate the efficacy of stormwater education was reiterated during the NGO policy actor interviews by statements such as:

> "*I can tell you how much phosphorus a grass swale can remove, but how many pounds of phosphorus will talking to three cabin owners remove?*"

Discussion:

One common theme all focus groups and the survey found was the need for research on how best to motivate all Minnesotans to be better clean water stewards. Minnesota has a diverse population of people who may not share the same vocabulary to articulate their hopes, expectations, and intended use of their natural resources. Research is needed on how to expand the audience of stormwater education, include voices of all people, and engage all Minnesotans. This research might have two veins. First, education could focus on changing attitudes toward stormwater management and increasing public support, which is often lacking. This may lead to public acceptance of increased funding for stormwater management activities, or strengthened local stormwater ordinances.

Second, education can inform *direct action* by citizens. Of particular value would be quantification of the relationship between behavior change and water quality. Education foci might include de-icing practices on private property, lawn management practices, tree leaf management, and removal of pet waste from landscapes.

Research Need #8: Improve Stormwater Management Policies.

Beyond engineering research, *policy research* could strengthen stormwater management. Policy research examines issues such as effectiveness, economics, equity, and accountability of existing and alternative policies.

Supporting evidence:

1. Several moderate to major policy-related barriers that might be reduced by research include *insufficient funding to fully implement BMPs identified in Total Maximum Daily Load (TMDL) plans* (79% of respondents), *level of public cooperation and support* (62%), and *ineffective regulations* (45%).

2. *Improved Clean Water policy beyond the MS4 program* was identified as a moderate or major opportunity by 62% of survey respondents.

3. Several questions regarding policy issues for the MS4 programs *in their jurisdiction* also suggests several policy-related opportunities.

- *Effectiveness of their local MS4 programs at improving surface water quality* was rated moderate, low, or very low by 54% of respondents
- *Cost efficiency of their MS4 programs* was rated as moderate, low, or very low by 72%
- *Sense of unnecessary regulatory burden of the MS4 program* was rated as high or very high by 59%

4. When asked to rank a list of potential policy-related research issues, all were highly ranked as somewhat or very important, with rankings from 78% (*pollution trading*) to 95% (*cost effectiveness of BMPs*).

- Evaluation of costs and benefits of specific BMPs (95%)
- Evaluation of state-wide effectiveness of the MS4 program for achieving improved water quality (89%)
- Adaptive management (for example, greater flexibility, use of nonconventional BMPs, success based on measured water quality improvement) within the MS4 program (85%)
- Improved integration of stormwater management and flood control policies (83%)
- Efficacy of stormwater education (83%)

- A study of pollution trading for nutrient removal across cities and farmland (78%).

5. When asked to identify the *highest priority* for policy research, *evaluation of costs and benefits of specific BMPs* was most common (38% of respondents). Among other topics, the top priority choice was fairly evenly distributed:

- Evaluation of statewide effectiveness of the MS4 program for achieving improved water quality (18%)
- Adaptive management (for example, greater flexibility, use of nonconventional BMPs, success based on measured water quality improvement) within the MS4 program (15%)
- A study of pollution trading for nutrient removal across cities and farmland (12%)
- Improved integration of stormwater management and flood control policies (9%)
- Efficacy of stormwater education (8%)

Several policy actor comments highlight policy research questions:

> ***"****Are the rules that we adopted, for example MIDS or use of underground devices, leading us to a place where these things are going to be a real pain in the future? Did the policy work out in the way that we had thought?"* (Private stormwater engineer)

Participants in focus groups and interviews also expressed the need for research on policy issues related to structural BMPs. Additional research could address concerns for some of the more recent practices such as the fate of pollutants and the below-ground operations of reuse systems. **"***Research on rules and regulations for reuse would be critical,"* cited one private engineer.

Discussion:

Supporting evidence reveals a perception among stormwater professionals that stormwater management is too expensive and the public does not understand benefits.

One of the top research issues identified is the *economics* of stormwater management at the level of MS4 jurisdictions and at the watershed scale, and at least implicitly, at the state level.

Economics research might evaluate *pollution trading* between urban runoff and agricultural runoff, as streams entering cities (especially in rural Minnesota) often contain runoff from agricultural land, which may contribute substantially to urban water pollution. In this situation, the regulated entities (cities, through the MS4 programs) might be willing to pay for reduction of agricultural pollution (which is not similarly regulated), if the overall cost of meeting a regulatory goal was lower than relying solely on management of urban runoff.

Urban lakes like Albert Lea Lake can be at risk from water entering from agricultural area streams carrying sediment and fertilizers.

PRIORITIZATION OF RESEARCH NEEDS

We asked stormwater professionals to prioritize urban water research needs through surveys, focus groups, and policy actor interviews. Across research topics, we found the four most important criteria for ranking research needs were:

- *Effectiveness and reliability*
- *Number of people affected*
- *Applicability*
- *Cost*

The *applicability* criteria were expressed as *more places*, or *more practices*, or *more people*. *Cost* included both the cost of the research and the cost savings resulting from research findings. When applied to research on behavior change, applicability may consider the number of people and the range of population affected. For research on new treatment technology, applicability may consider the number of different places or situations where the technology could be implemented.

Criteria that were not as highly ranked across topics were *depth of understanding*, *urgency*, and *actionability.*

We suggest that funding sponsors use the four highest ranked criteria to inform priorities for research and in the evaluation of research proposals.

FROM RESEARCH ROADMAP TO STORMWATER RESEARCH STRATEGY

The previous sections outlined a rationale for additional research on stormwater management, eight specific research needs, and evaluation criteria for research ideas. Here we elucidate tenets to complete a Stormwater Research Roadmap:

Focus on clean water goals. The central framing statement that emerges from stakeholders is that a *stormwater research strategy should focus on improving the effectiveness of stormwater management toward the goal of achieving clean water, with greater cost efficiency*.

An adaptive research strategy. A viable Stormwater Research Roadmap must be adaptive. We suggest that this Research Roadmap be updated every five years, in concert with the Clean Water Legacy's five-year planning cycle. A goal might be to integrate research findings from the past five years into the CWL new policy and practices for the next five years, while incorporating an updated Research Roadmap to meet knowledge needs for the new planning period.

Convergence of water quality programs. Increasingly, water quality programs, such as the MS4, TMDL, and One Water programs are converging. New research could synergize this convergence.

Coordination of resources. The formation of the Stormwater Research Council (SRC) at the University of Minnesota's Water Resources Center provides a coordinating body for potential research sponsors. Funneling funds into one unit is administratively efficient and the composition of the SRC (including stormwater experts *outside* the University) assures thorough and unbiased recommendations for funding stormwater projects.

Need for partners. Partnerships between researchers and cities, watershed districts, individuals, companies, non-profits, and other organizations are important. These partnerships are also important to direct research funding. Local partnering with university researchers results in shared data, access to field sites, and direct participation by a jurisdiction's staff.

Translation to practice. Stormwater practitioners often feel that university research findings do not get translated into practice. Solutions might include longer grant cycles (typically two-three years now) that include a translational phase (e.g., the development and testing of models developed in research) and expanded outreach and education components, such as informing the MIDS calculator and the MPCA Stormwater Manual.

Expanded vision. Improved engineered BMPs alone will not clean up urban waters.

Research is needed for non-structural practices, including source reduction practices and education, and bringing management of non-regulated pollution sources in line with urban stormwater goals.

The Minnesota Stormwater Research Council, Clean Water Council, the University of Minnesota Water Resources Center, and MPCA are well positioned to create a formal research strategy following the framework above.

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