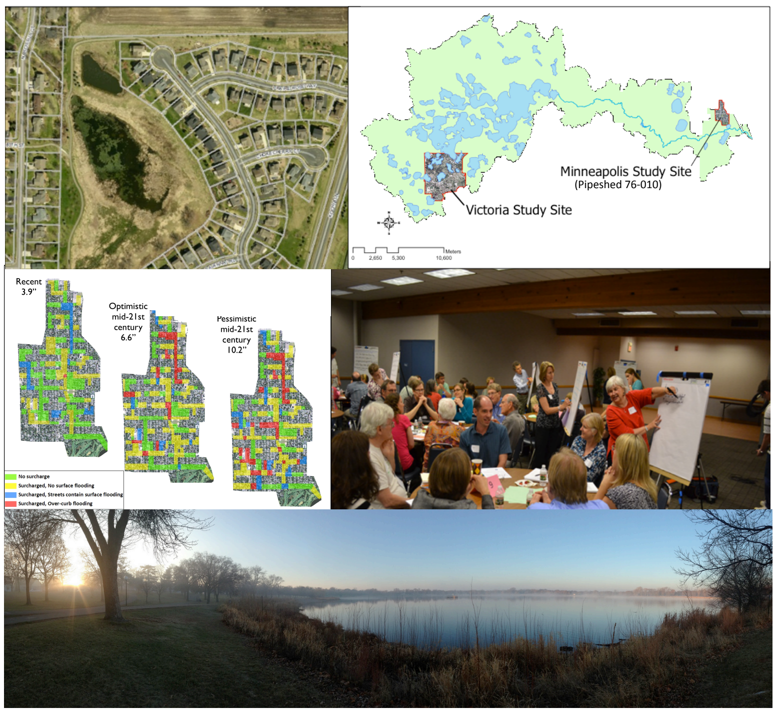
Weather: Extreme Trends

Final Project Report
Long-term climate information and forecasts supporting stakeholder-driven adaptation decisions for urban water resources:

Stormwater drainage system vulnerability, capacity, and cost, under population growth and climate change



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Stormwater drainage system vulnerability, capacity, and cost, under population growth and climate change

Minnehaha Creek Watershed District, Minnesota
January 31, 2014

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Foggy morning on Lake Hiawatha, Kyle Matteson

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Final Report: Long-term climate information and forecasts supporting stakeholder-driven adaptation decisions for urban water resources: Stormwater drainage system vulnerability, capacity, and cost: Response to climate change and population growth
Minnehaha Creek Watershed District, Minnesota

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Abstract from the proposal

The proposed study will be the fourth in an ongoing program to investigate unresolved issues pertaining to stormwater adaptation. The overarching purpose of this program is to promote stakeholder-driven adaptation of vulnerable stormwater management systems and related water resources, by demonstrating, implementing, and disseminating a quantified, local-scale, and actionable protocol for maintaining historical risk levels in communities facing significant impacts from climate change. The proposed project will utilize an interdisciplinary team of investigators and stakeholders, to transfer coupled-climate model projections to the sub-watershed scale, in a form understandable to planners, resource managers and decision-makers. On a planning scale, the study will Model capacities required for the existing infrastructure to convey peak flows from projected mid-21st century climate-changed precipitation and population growth; Model water quality impacts from projected mid-21st century climate-changed precipitation and population growth; Manage uncertainty in coupled-climate model output and associated downscaling; Provide a risk-based, prioritized schedule for adaptation of subcatchments and the stormwater management system; Estimate the cost of adapting the infrastructure to required capacities; Assess the potential for BMPs and Low Impact Development methods to provide more economical management of peak flows than drainage system upsizing. Through stakeholder participation, and community education and outreach efforts, the project will provide a forum and participative decision-making process to empower communities to implement the adaptation plan.

Project activities will include:

As necessary, limited fieldwork to validate existing hydrological and hydraulic models; Statistical downscaling of coupled-climate model output for a robust range of models and emissions scenarios; Development build-out to current zoning regulations, under standard and Low-Impact-Development methods; Model of required stormwater system capacity to accommodate climate change and population growth; Costs to upgrade the existing stormwater system, under replacement-cost, cost-avoidance, and substitution cost assumptions; Production of video, graphics, photographs, and a webcast to support communication of results; Implementation of a targeted program of community and stakeholder outreach, education, and participative decision-making; Dissemination of results through conference presentations and peer-reviewed publications.

The proposed analyses and associated outreach program provide both new and synthesized science-based knowledge; identify impacts and societal vulnerability; and provide a practical template to support stakeholder-driven implementation of adaptation programs. This study will make a significant contribution toward the generation of reliable and specific local-scale estimates of impacts from climate change, in support of programs to adapt civil infrastructures.

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Schedule of key findings:

Background

- The quantity of published adaptation studies lags a decade behind the quantity of published impacts assessments on which adaptation is predicated (Wilby et al., 2009)
- Detection of a climate change signal in extreme precipitation may not occur for 30-50 years. As a result, benefits from forestalling adaptation are not apparent (Fowler and Wilby, 2010).
- Infrastructure adaptation may be more urgent than generally assumed:
  - √ All SRES emissions scenarios understate already-observed warming (Rahmstorf et al., 2007);
  - √ Precipitation appears to be increasing at a rate of 7% per °C, rather than the 1-3% per °C modeled by coupled-climate models (Wentz et al., 2007);
  - √ Measured increases in daily extreme precipitation are exceeding coupled-climate model simulations (Allan and Soden, 2008; Lenderlink and van Meijgaard, 2008)
- Therefore, benefits from forestalling adaptation are not apparent;
- Dessai et al. (2009), concluded that "society can, and indeed must, make adaptation decisions in the absence of accurate and precise climate predictions...[furthermore,] the limits to accurate and precise foreknowledge of future climate has been falsely constructed as an absolute limit to adaptation."
- There is a need, in hydrological impacts research, to move away from comparison studies into the provision of decision-making tools for planning and management that are robust to future uncertainties (Fowler et al., 2007a); Grove et al., 2008)

Purpose and aims

- The purpose of the project was to promote implementation of local-scale stormwater infrastructure adaptation;
- To achieve this purpose, projects aims were to:
  - √ Gain popular support (Lowe et al., 2009), and stakeholder confidence in the decision to implement infrastructure adaptation;
  - √ Promote visionary leadership and organizational learning (Wilby and Mengelt, 2010);
  - √ Provide science that is "actionable", i.e. that includes "...data, analysis and forecasts that are sufficiently predictive, accepted, and understandable to support decision making…" (Lowe et al., 2009);
  - √ Promote an adaptation plan that can be implemented through existing policies and regulations (Lowe et al., 2009); and provide guidance for practitioners, (Wilby and Mengelt, 2010);
  - √ Clarify research issues pertaining to the budgeting, scheduling, and sizing of stormwater adaptation in the context of uncertain in long-term climate information;
  - √ Add to the corpus of expertise in the implementation of adaptation, that is currently insufficient (Yohe and Mengelt 2010; Sanchez-Rodriguez, 2009), but indispensible for efficient, economical, and effective adaptation;

Overarching findings

- Foundational premises of this project were that: information and methods are available today to support adequately-reliable infrastructure adaptation; the resolution of certain key issues in infrastructure adaptation will be attained most efficiently through learning-by-doing; and these issues can be studied concurrently with providing actionable adaptation guidance to communities;
- Findings of this study have broad application nationally and internationally, as communities transition civil infrastructures to accommodate already-occurring and projected change, in order to maintain historically accepted risk-levels. Though focusing on stormwater management systems, the principles and methods developed provide a template for other local, regional, and national infrastructure systems. These findings significantly improve national and international capacities to respond to climate variability and change;
- Required stormwater management system capacity and adaptation costs to achieve this capacity can be determined for a given combination of climate model, emissions trajectory, and landuse;
- A program of education and outreach can significantly increase a community's motivation to protect itself from more extreme climate impacts;
- As a result of factors that include an already changed precipitation climate, portions of stormwater systems are already undersized for current conditions (Table ST.1). Therefore, communities are already assuming a higher level of risk than intended under historical design standards. This contradicts the belief that a "wait and see" strategy is a valid response to changing climate conditions;
- A significant percentage of pipes remain adequately sized even for pessimistic climate change impacts (Figures ST.2, ST.4). As a result, it should not be necessary for communities to adapt 100% of their existing stormwater systems in order to maintain historically tolerable risk levels;
- Recent extreme rainfall amount in the region approximate, or exceed, pessimistic climate change projections (Figure ST.3). Previous studies in New Hampshire found similar reults, and supports a recommendation that communities adapt conservatively, providing a safety margin equivalent to adapting for pessimistic future conditions;
- Required capacity is insensitive to changes in precipitation intensity, and thus insensitive to uncertainty. An approximately 150% increase in the design precipitation results in an approximately 30% increase in the number of undersized components (Figure ST.4);
- The vulnerability of stormwater systems to more extreme precipitation varies according to region, topography, engineering design standards, and the type of drainage system (Figure St.4);
- Application of LID methods provides a significant reduction in adaptation costs, lowers the impact of uncertainty, and is more beneficial for more pessimistic climate change scenarios; and (6) a program of education and outreach can significantly increase a community's motivation to protect itself from more extreme climate impacts. This motivation has persisted past the completion of the project, and over the near- and mid-term can be expected to significantly reduce the community's exposure to losses from flooding;

- The ability to quantify required capacity and related construction costs for specific climate change scenarios, the insensitivity of capacity and costs to uncertainty, and the percentage of pipes and culverts that never require upsizing, all serve to limit the impact of uncertainty inherent in climate change projections. By constructing systems to more extreme scenarios and to the upper limit of confidence intervals, a safety factor is incorporated to adaptation programs to buffer uncertainty. Moreover, the insensitivity of construction cost to increased precipitation intensity provides incentive to incorporate even a very large safety factor. Thus, the ability to manage uncertainty supports a conclusion that adaptation is viable under current levels of uncertainty regarding the severity of future climate impacts.

Uncertainty: significance and management

- As recognition widens that no significant decreases in uncertainty is expected in the foreseeable future, and as impacts from climate change increasingly manifest, communities need to understand the significance of uncertainty and the size and affordability of safety factors that accommodate uncertainty;
- This study demonstrated the ability to develop specific capacities and costs for a given climate scenario using established civil engineering design methods and standard construction cost compilations;
- The combination of the number of drainage system components, and the number of landuse and climate-change scenarios modeled, resulted in a large dataset from which to establish the relationship between system capacity and cost, and precipitation and landuse;
- The use of established methods, and the size of this study's dataset, provide capacity and cost estimates that are reliable, and limit uncertainty to that which is inherent in hydrologic modeling and long-term climate forecasts;
- This study examined the effect of a high degree of uncertainty in long-term climate projections, by selecting precipitation scenarios that span a wide range of design storm intensities. For the design storm, projected increases from the recent climate for the A1b and A1fi scenarios for the GFDL 2.1 CCM, are 18% and 153%, respectively (Figure ST.4). This is a span of 135%, and can be compared with the range of uncertainty in hydrological modeling, to assess the validity of assumptions that the degree of uncertainty in long-term climate projections is unprecedented and a major impediment to adaptation;
- For this study, the calibrated Victoria and Pipeshed 76-010 hydrological models were found to vary up to 40% from measured flows at the watershed outlet (Table H.1). This range of uncertainty falls within the median variability between the current 10-year design storm and 10-year, mid-21st century precipitation projections. This overlap begs the question: if planner and engineers deal with this uncertainty in hydrologic analyses on a regular basis through accepted stormwater design practices, why should a similar degree of uncertainty in precipitation projections warrant paralysis?
- A survey of hydrological calibration studies found 205 datapoints from which the range of variation between simulated and gauge measurements was obtained. This range exceeded the range of precipitation estimates downscaled for the present study (Table

ST.3, Figures ST.5, ST.6). For the difference between simulated and gauge-measured flows from the hydrological studies, the differences between the 10th and 90th percentiles of measurements ranged from -61% to +73%, a range of 134%. For the 28 *most likely* and *+95% conf. limit* projections of mid-21st century 10-year 24-hour precipitation, the range between the 10th and 90th percentile was 94%. Thus, the range of uncertainty in long-term precipitation projections is comparable to the range of error that engineers, planners, and hydrologists have historically accommodated;

- The National Weather Service recently updated the intensity-frequency isofluvial maps for the Midwestern United States, including the study sites (Atlas 14, Volume 8). This work provides the 95% confidence limits for estimates. For the NCDC site used for the present study, the Minneapolis-St. Paul International Airport, for the 10-year 24-hour precipitation, Atlas 14 notes a 95% confidence range of 28% (Table ST.2). As shown in Figure ST.8, isoplubial contours for the 24-hour, 25-year event, as published in 1961 for *TP-40* (Hershfield, 1961) generally are 25% greater than similar contours published twenty-five years earlier by Yarnell (Yarnell, 1935);
- The assumption that *TP-40* itself was accurate and precise is fallacious (Wilson, 2008). Standard intensity-duration-frequency modeling of rainfall asserts that a minimum thirty year record is required to accurately estimate lower frequency events such as the twenty-five year storm. However, *TP-40* utilized historical datasets that, on average, were only fifteen years. In addition, *TP-40* provided only point estimates for precipitation levels, omitting confidence intervals and thus portraying a false degree of precision;
- In published literature, “soft” adaptations such as general resilience and capacity building remain the standard prescription for potential civil infrastructure vulnerability due to uncertainty in GCM output (e.g. Rosenberg, 2010). Yet “soft” adaptations are likely insufficient by themselves, requiring eventual supplement from “hard” adaptation methods (White House Climate Change Adaptation Task Force, 2010; Miller et al., 2010), presumably when anticipated reductions in uncertainty occur;
- In a rational decision framework, adaptation proceeds when the cost of damages from failure to adapt, exceeds the cost resulting from adapting to uncertain conditions (Figure ST.7). We believe that the point of equilibrium has already been reached for much of the continental United States, so that adaptation should proceed;
- The development of climate change-cognizant design specifications is possible under conditions of non-stationarity. European practice has applied *change factors* to increase design standards according to the useful life of the infrastructure being designed. For example, see Figure 9 in Hennegriff et al., 2006.

Outreach program

- Overall, the project resulted in a significant increase in awareness, at the watershed and municipal level, of the risk and response associated with the impacts from increases in extreme storms expected from long-term climate projections;
- The stakeholder outreach program utilized the Collaborative Planning Approach (Figure O.1);

• A broad cross-section of governing bodies were represented in the stakeholder group of 59 people (Figure O.2);
• As a result of the first public forum, stakeholders felt more knowledgeable about issues and possible actions related to stormwater management in the Minneapolis-St. Paul metropolitan area (Figure O.3);
• The project earned significant visibility in local news media (Table O.1);
• Stakeholders expected that the project would result in increased collaboration among stakeholder organizations (Figure O.4);
• Stakeholders felt that, as a result of the project, as a group they developed a shared vision for stormwater management (Figure O.5);

Precipitation downscaling model

• Current stormwater design practice in the Minneapolis-St. Paul metropolitan area is to specify components to accommodate peak flow from the historical once-in-ten-year (10-year) precipitation event (i.e. 10% annual probability), with a twenty-four (24) hour duration. The study projected a mid-21st century range of values for this intensity/duration;
• Fourteen (14) combinations of climate model, emissions scenarios, gridpoints, were downscaled to the local scale for the Minneapolis-St. Paul International Airport. Descriptive statistics were computed for the *most likely* and *upper-95% confidence limit* estimators from these fourteen combinations, a sample size of twenty-eight (14 x 2). The mean precipitation for this sample was 5.7", with an *upper-95% confidence limit* of 6.6" and a maximum of 10.1";
• From the sample of 28, five (5) values representing a range of results were selected for use in certain hydrologic and cost modeling, for others the three values labeled "Optimistic", "Moderate", and "Pessimistic" were used. The basis for selection: 5.66" was selected for being close to the mean value for all *most likely* and *+95% c.l.* estimators; 6.56" was selected for being at the upper 95% confidence limit for the sample of 28 estimators; 8.07" was selected for being approximately 100% greater than TP-40; 10.13" was selected for being the most pessimistic of all results and for being the closest to recent extreme events for eastern Minnesota.;
• Data from an ensemble of fourteen combinations of model generation (CMIP3 and CMIP5), model group (NCAR and GFDL), *coupled climate models* (PCM, CCCM4, CM2.1, and CM3), and future climate trajectories (for CMIP3, greenhouse gas emissions from the SRES: A1b, A1fi; for CMIP5, greenhouse gas *Representative Concentration Pathways* RCP 4.5, 6.0, 8.5), and gridpoint size, provided a range of climate realizations to assess impacts and uncertainty;
• National Climate Data Center (NCDC) historical records for weather stations proximate to the study sites, and sets of *CCM* gridpoints encompassing these NCDC stations, provided data for downscaling. Thirty-year records of precipitation were downloaded for each station, and for each gridpoint/model/scenario combination. Time periods obtained were 1926-1955 for model validation, 1971-2000 for validation and baseline from which future projections were made, and 2046-75 for *CCM* data to establish

percentages of changer from the recent climate. This resulted in almost 1,000 sets of historical or simulated precipitation data;
- A *point process, peaks-over-threshold* statistical method was used to derive the 10-year 24-hour rainfall event for each thirty-year dataset;
- A variation of the Change Factor, or Perturbation method, was used to statistically apply percentages of change, from the recent to projected future climates downscale long-term precipitation projections to the local scale.

Hydrologic/hydraulic, buildout, and low impact development (LID) models

- The EPA's Stormwater Management Model (SWMM; Rossman, 2010) was used to simulate rainfall-runoff processes and stormwater system hydraulics for both study sites. Existing SWMM models were available for both the Pipeshed 76-010 and Victoria pipesheds and were utilized as the basis in this study;
- The average impervious surface for Minneapolis Pipeshed 76-010 was 50%, and for Victoria was 14% for existing landuse and 29% with buildout (Table H-2);
- Mid-21st century landuse scenarios were developed for the study sites based on current zoning policies and projected population growth;
- Several adaptation tactics were examined for ability to accommodate increased runoff from climate change. These included upsizing existing infrastructure and implementing *low impact development* (LID) practices. In Pipeshed 76-010, three additional tactics were reviewed: over-curb surface storage in areas where structures would not be impacted, above-ground dry storage basins, underground storage.
- For pipe upsizing scenarios, the diameter of surcharged pipes downstream of flooded model nodes was increased incrementally until flooding was reduced to zero for all mid-21st century 10-year design storm scenarios.
- The adaptive capacity of LID was simulated by defining an LID unit sized to capture the first 25 mm (1 in) of runoff from all impervious surfaces within a given model subcatchment. In Pipeshed 76-010, we tested five rates of incorporation of LID: 100% of subcatchments; and, to simulate a more realistic extent to which LID might be retrofitted, randomly selected 10%, 15%, 20%, and 25% of subcatchments to in the pipeshed. In Victoria, LID scenarios included: (1) LID units sized to capture the first 25 mm of runoff from all impervious area; and (2) LID units designed to capture runoff only from impervious surfaces added as part of new construction;
- In both study sites, pipe upsizing was by far the most effective means of adapting the stormwater system to manage flooding associated with projected changes in climate. However, in the case of Minneapolis Pipeshed 76-010, the effectiveness of pipe upsizing was limited to a design storm depth of about 6 inches. This depth is 50% greater than the current 10-year design storm and within the range of increase expected under a moderate climate change scenario;
- The inability to mitigate flooding through pipe upsizing beyond the 6 inch depth reflects a system in which backwater effects are dominant, and surface storage and other detention opportunities are limited. Such a condition is not uncommon in urban areas, particularly where surface storage and infiltration capacity have been lost to accommodate dense development;

- In both Victoria and Pipeshed 76-010, pipe upsizing led to an increase in predicted peak flows at the watershed outlet. This demonstrates that downstream impacts such as channel stability, water quality, and flooding of downstream communities should also be considered in assessing the effectiveness of adaptation approaches toward creating more climate-resilient communities;
- Projected increases in flooding were not mitigated through LID at either study site for even the most optimistic mid-century precipitation scenario. This is not surprising, however, as LID practices – as modeled here and in their typical application – are designed to capture runoff associated with relatively frequent, small storms (e.g. 25 mm) rather than the 10-year storm modeled in this study;
- The relative resiliency of Victoria's existing network of stormwater ponds, wetlands, and lakes suggests that climate change resilience in Victoria (or in other communities with infiltration-limited native soils) can still be achieved through preserving (and/or creating systems that mimic) the hydrologic functions of naturally-occurring ecosystems, in this case wetlands and lakes, even apart from enhance infiltration;
- In an already built-out community such as Minneapolis, infiltration-based adaptation practices come with a different set of challenges, including retrofitting around existing foundations, utilities, and, in brownfield applications, the potential to mobilize contaminant plumes. Despite these challenges, LID practices have been applied more widely in the City of Minneapolis and neighboring urban communities. Coupling a moderate (e.g. 10%) rate of adoption of LID, with pipe upsizing, may be a viable strategy to adapt stormwater systems for future climate, even in a built-out community such as Minneapolis;
- A viable adaptation option for Victoria would be to allow flooding in streets and open spaces (e.g., a ball field and golf course) rather than upsizing pipes or adding additional capacity for infiltration. Victoria's relative climate resiliency is not by accident. Through its development policies of buffer setbacks and restricting floodplain development, Victoria has retained much of the landscape's capacity to provide hydrologic ecosystem services;

Pipeshed 76-010

- Curves were fit to establish the relationship between change in design storm depth and the number of undersized components in the existing storm sewer network (Figure H.3). A given conduit was only considered to be undersized if it was (1) surcharged *and* (2) upstream of a flooded node;
- Based on the practicalities of managing surface flooding in a built-out environment, the City of Minneapolis generally prioritizes flooding as either acceptable or unacceptable. Acceptable flooding pertains to flooding that is stored in streets or over curbs up to the elevation of structures. Unacceptable flooding includes any flooding that exceeds the elevation of structures, thereby posing a risk to property;
- In its existing condition, approximately 10% of pipes in Pipeshed 76-010 are too small to convey runoff associated with the recent 10-year storm (Figure H.3). This result likely stems from changes in design standards that have occurred over the life of the storm sewer system. The proportion of undersized pipes increases by approximately 150% and 350% for the moderate and pessimistic mid-century precipitation scenarios;

- The volume of flooding predicted for the range of mid-century precipitation scenarios also increases, up to a factor of 40 (Table H.4, Figure H.4);
- In order to identify points in the system most vulnerable to flooding, a series of "stoplight" maps were developed (Figure H.5). The elevation of flood waters relative to structures was determined outside of SWMM in ArcGIS using 1-meter resolution surface elevation data;
- Upsizing pipes to reduce flood volumes for the 4.15" to 5.65" precipitation scenarios required increasing the diameter of 3,439 to 12,272 linear feet of pipes in the system (Figure H.7);
- Pipe upsizing has limited ability to mitigate flooding. Storms of 6.56" and larger resulted in an increase in the total flood volume to that of the existing condition (Figures H.6, H.7). This is due to backwater effects of the receiving water body which, under high flows serves to: (1) restrict free discharge of runoff from the pipe network to the lake and (2) contribute to negative (up-gradient) pipe flows as runoff unable to exit the system at Pipeshed 76-010 backs up into the pipe network and is ejected as surface flooding at low-lying areas of the system. Figure H.8 provides an example of a location in the system in which upstream pipe upsizing resulted in a transfer of the flood volume downstream.
- Unacceptable flooding was not completely eliminated through any LID scenario, even for the most optimistic climate change projections (Table H.4, Figures H.6, H.7). Increasing the rate of utilization of LID reduced the volume of unacceptable flooding, but with diminishing results;
- However, unacceptable flooding was reduced by LID for all precipitation scenarios, even when only applied to 10% of the total pipeshed impervious area. Substantial reductions in flood volume can be achieved with a relatively modest reduction in impervious surface runoff through LID;

Victoria

- The hydraulic response of Victoria's stormwater system contrasts sharply with that of Pipeshed 76-010 (Figure H.8), due to a lower percentage of land having been developed, and to the incorporation of runoff management methods. Fewer than 1% of components in Victoria's stormwater system are undersized for the current design storm, and up to a precipitation depth of about 5.6 inches. Thus, the system is adequately sized for up to a 40% increase beyond the current design storm;
- Beyond a 40% increase in the design storm, Victoria's system displays a similar rate of increase in the number of undersized components for a given increase in precipitation as observed for Pipeshed 76-010 (Figure H.8);
- In a developing community such as Victoria, changes in climate are expected to act in concert with land use change upon hydrological processes (Figure H.9);
- Constructed storage ponds, a prominent feature in the City's stormwater management system, have sufficient storage capacity up to the 6.56-in scenario, at which point 8 of the 31 ponds overtopped (Figure H.10b). Thirteen ponds, representing 40% of the total, overtopped in the most pessimistic scenario;
- Even for the most pessimistic climate scenario, 10.1 inches, all surface flooding in Victoria was contained within streets and public open spaces. However, if the

objective were to maintain the current level of service, i.e. no surface flooding, adaptation methods would be necessary;

- Three adaptation scenarios were considered for Victoria: (1) allow flooding up to a level that would be confined to streets and public spaces, i.e. "do nothing"; (2) upsize pipes to convey projected peak flows and eliminate flooding completely; and (3) implement LID at various intensities to reduce flood volumes by increasing infiltration (Figure H.11);
- In contrast to the Pipeshed 76-010 pipeshed, flooding associated with climate change projections could be completely mitigated through pipe upsizing. The total length of upsized pipes ranged from 577 ft. for the 4.15- and 4.77-in precipitation scenarios, up to 14,132 ft. for the pessimistic 10.13-in scenario (Figure H.12);
- Increasing pipe diameters increased the peak flow at the watershed outlet (Figure H.11a); however, the increase was nominal (1-5% across all Mid-century precipitation scenarios). This is likely due to the buffering effect of the watershed's network of stormwater ponds and natural lakes and wetlands;
- As was the case in the Pipeshed 76-010 pipeshed, projected flooding was not fully mitigated by LID practices (Figure H.11a);
- The reduction in flood volume was greatest for the 6.56-in precipitation scenario (26% as applied to all impervious surfaces; 13% for new construction only). Flood volume reductions were generally less than 10% for all other climate scenarios;
- The addition of LID to manage runoff from the landscape is not expected to have a substantial effect on the length of pipe that would need to be upsized to completely eliminate surface flooding for all mid-century precipitation scenarios. This likely reflects some limitation to infiltration by clay-like soils in the Victoria study area;

Cost model

- This analysis provides planning-scale cost estimates for several stormwater management alternatives, to adapt existing systems for conveying projected mid-21st century design runoff in Minneapolis and Victoria;
- Adaptation plans typically consist of a variety of tactics that can be combined in various ways (Hasnoot et al., 2013). A community selects a set of adaptation pathways that provide sufficient adaptive capacity and flexibility for accommodating uncertainty; and that are achievable within its tolerance for risk, political environment, and economic resources;
- Adaptation pathways consist of a combination of tactics that might include: creating barriers to the impact; changing infrastructure to assimilate the impact; changing expectations through policies, so to accommodate the impact; moving away from the impacted areas; and doing nothing, which implies accepting a higher-than historical risk. All have both quantifiable and intangible costs and benefits.
- For this study, cost analyses were performed for five adaptation actions:
  - √ Replacing the existing system with larger pipes;
  - √ Diversion of excess waters to detention basins;
  - √ Diversion of excess waters to underground storage;
  - √ Cost mitigation from instituting Low Impact Development;
  - √ Damage costs for waters exceeding curb-height;

- There are differences between the two cities in the conditions that determine the rate of undersized components (Figure C.1), and therefore the costs to adapt that each will face. Costs will not be comparable, and the optimal mix of tactics will differ between the cities (Figures C.1, C.2);
- The cost analysis derived typical cost-per-linear-foot of pipe replacement, from actual costs of eight (8) recent stormwater pipe replacement projects provided by the City of Minneapolis (Table C.1). Data from these projects was fit to a power function (r^2 = 0.73) to derive cost-per-foot date, *most likely* estimator was \$890/LF, with the *95% confidence interval* \$490-1,290/LF). (Figure C.3, Table C.2);
- Cost-per-linear-foot information was applied to the length of pipe that the hydrologic/hydraulic modeling indicated as undersized for a scenario, to derive estimated total cost for a given scenario (Table C.3, Figure C.4);
- For Pipeshed 76-010, pipe upsizing can mitigate flooding caused by precipitation scenarios through 6.56”. The *most likely* estimated costs range from \$2.9m through \$17.0m across this range of precipitation events (Table C.3);
- For Pipeshed 76-010, the estimated cost per million gallons (MG) of flood water that was mitigated by pipe upsizing, for the 4.15”, 4.77”, and 5.67” precipitation events, is \$0.9m/MG, \$1.9m/MG, and \$2.5m/MG, respectively (Table C.4). For precipitation events of 6.56” and above, pipe upsizing is not viable due to increased flooding downstream;
- For Victoria, pipe upsizing can mitigate flooding caused by all precipitation scenarios. The *most likely* estimates range from \$0.46m to \$11.8m (Table C.5);
- The hydrology/hydraulic analysis determined that there was a limit to which pipes could be enlarged in one part of the pipeshed without increasing street flooding in another (Figure H.8). Thus, other options such dry storage basins or underground storage need to be considered for diverting excess water above 6.56 inches;
- The high-estimated cost of dry detention basins for the 6.56”, 8.07”, and 10.1” precipitation events are: for Pipeshed 76-010, \$2.6m, \$4.1m, and \$6.7m, respectively. For Victoria, costs are \$1.3m, \$2.7m, and \$5.4m, respectively (Tables C.9, C.10);
- The estimated cost of underground storage for the 6.56”, 8.07”, and 10.1” precipitation events are: for Pipeshed 76-010, \$23m, \$45m, and \$84m, respectively. For Victoria, costs are \$2m, \$7m, and \$18m, respectively (Table C.13);
- The least expensive means of mitigating flooding from increased precipitation is estimated to be dry detention basins, followed by pipe upsizing, and underground storage (Table C.14). On a per-million-gallons (MG) of mitigation basis, dry detention basins cost \$0.1m/MG, pipe upsizing \$1.8m/MG, and underground storage \$2.4m/MG. However, pipe upsizing has limited benefit;
- The adoption of achievable levels of Low Impact Development (LID) methods reduces the cost of all three structural adaptation methods examined: pipe upsizing, dry detention basins, and underground storage (Tables C.16, C.17, C.18; Figure C.10);
- The cost benefits of LID decline as precipitation increases beyond 6.56 inches, for all three structural adaptation methods examined: pipe upsizing, dry detention basins, and underground storage (Tables C.16, C.17, C.18; Figure C.10);

Project commitments from the funding proposal

Problem Statement, from Funding Proposal

For rainfall/runoff modeling, which informs design of stormwater drainage systems, similarities can be seen between conditions that designing engineers were confronted with in the mid-20th century, and contemporary issues derived from climate change adaptation. By the mid-20th century, the rational method equation posited by Mulvaney was a century old (1851); the recent 30 years had seen the development of runoff sub-models such as the Green-Ampt infiltration equation (1911), Ross' distributed hydrological model (1921), and Sherman's Unit Hydrograph (1932); yet significant uncertainty existed, and persists even today, between modeled runoff and runoff as measured by streamflow gauges. Similarly, the basic greenhouse gas law was posited a century ago by Arrhenius (1896-1908); the last 30 years have seen the development of general circulation models; yet uncertainty in the modeling of future rainfall/runoff persists and estimates of future rainfall intensity/return-period relationships are not codified to inform engineering design.

For rainfall-runoff modeling, design and construction of stormwater drainage systems proceeded throughout the 20th century, concurrent with the evolution of stormwater theory, and in spite of significant uncertainty. In contrast, Wilby et al. (2009), found that the quantity of published adaptation studies lags a decade behind the quantity of published impacts assessments on which adaptation is predicated. Although it is well-known that resource managers do not utilize climate forecasts (Rayner et al., 2005; Hartman et al., 2002), a rational basis for the lack of attention from the scientific and professional community is not evident. Sources of uncertainty in long-term climate forecasts are not expected to significantly resolve in the foreseeable future, for example Fowler and Wilby (2010) found that detection of a climate change signal in extreme precipitation may not occur for 30-50 years. As a result, benefits from forestalling adaptation are not apparent. In addition, the commencement of infrastructure adaptation may be more urgent than generally assumed: Rahmstorf et al., (2007) observed that all SRES emissions scenarios understate already-observed warming; Wentz et al., (2007) noted that precipitation appears to be increasing at a rate of 7% per °C, rather than the 1-3% per °C modeled by coupled-climate models; and measured increases in daily extreme precipitation are exceeding coupled-climate model simulations (Allan and Soden, 2008; Lenderlink and van Meijgaard, 2008). Near the site we propose to study, the recent 24-hour, 50-year design storm at the Minneapolis-St. Paul airport is approximately 53% greater than that computed for the TP-40 era ending around 1960 (Stack, 2008). For Minnesota, Fitzpatrick et al. (2009) anticipated climate change impacts that include wetter falls, winters, and springs, drier summer rainfall resulting in less groundwater recharge and lower lake levels, and a 66% increase in heavy rains, defined as more than two inches in one day.

Recently the scientific community has more fully engaged stormwater adaptation challenges, and issues raised therefrom may find relevant information from our ongoing research program. Evans et al. (2004) noted inadequate evidence for concluding whether LID methods alone can mitigate increased runoff/peak-flow from climate change, our work confirms that a realistically achievable LID scenario is able to significantly mitigate impacts from the more-optimistic A1b scenario, but is ineffective for the more pessimistic A1fi trajectory (Stack et al., 2010). White (2008) stated that the upgrade of stormwater systems as existing components reached the end of service life would require 50-100 years for complete adaptation. However, the majority of culverts in studied sites were found to be adequately sized even for pessimistic emissions trajectories, and a program that combines adaptation at the expiration of service life, with more immediate upgrade of high-risk components, achieves system-wide, and budgetable adaptation within 10-20 years (Stack et al., 2010).

Fowler et al. (2007b) observed that much consideration had been given to uncertainties in the modeling framework, but found few studies that examined impacts to hydrological systems. Fowler et al. (2007a), and Grove et al. (2008), noted the need, in hydrological impacts research, to move away from comparison studies into the provision of decision-making tools for planning and management that are robust to future uncertainties. The team's ongoing research program specifically addresses local-scale hydrological/hydraulic systems (Stack et al., 2009). These showed that significant opportunities for managing uncertainty may be available, and developed tools to explore this at the component scale via marginal cost studies, risk-analyses, design safety margins and rules-of-thumb, and probabilistic forecasts. However, drainage systems appear to have inherent capacity for accommodating uncertainty: 77% and 65% of culverts in the two completed studies were found to be adequately sized even for pessimistic impacts and population growth. For manufactured components, discrete size options result in a step-function for capacity, such that up-sizing for less-severe emissions trajectories appears to provide excess capacity sufficient for accommodating pessimistic trajectories.

As such, we concur with Dessai et al. (2009), who argued that "society can, and indeed must, make adaptation decisions in the absence of accurate and precise climate predictions...that the limits to accurate and precise foreknowledge of future climate has been falsely constructed as an absolute limit to adaptation." The core purpose of the proposed study is consistent with previous work, to promote implementation of stormwater infrastructure adaptation that protects communities from imminent or already-manifesting impacts, and in so doing: to clarify research issues pertaining to the budgeting, scheduling, and sizing of stormwater adaptation in the context of uncertain long-term climate information; to develop support tools that incorporate long-term forecasts in a manner sufficient for engendering stakeholder confidence in the decision to implement infrastructure adaptation; and to begin building the corpus of implementation expertise currently insufficient (Yohe and Mengelt 2010; Sanchez-Rodriguez, 2009), but indispensible for efficient, economical, and effective adaptation.

The proposed project is crucial because it addresses these objectives. However, it also leverages the project platform to examine a number of secondary research questions, improves the study design developed in prior work, and increases the relevance of results for supporting adaptation. As our research program has progressed, the team's capacity increases for incorporating more complex climate information, analytical methods, study sites, and decision-support features. The proposed project firstly responds to the most pressing of these: assist stakeholders to appropriately place drainage system upgrades within a nexus of available adaptation tactics. Stormwater adaptations are generally categorized into three or four groups: methods to increase resistance/threshold capacity, either by drainage system up-sizing or non-drainage alternatives such as BMPs, LID, or Smart Growth; methods to increase capacity to cope with flooding via land use planning, building codes, or the provision of exceedence flow pathways; and methods that increase capacity for recovering from floods (deGraaf, 2009). Up-sizing the drainage system is considered the most expensive accommodation for excess flows, so that an effective and efficient plan will combine a variety of tools tailored to unique conditions at a study site. Effective decision support facilitates the development of a multi-faceted plan, by organizing factors relevant to the decision at hand, and providing sufficient information for discriminating between options. These factors include financial resources; the availability of sites for placement of retention ponds or exceedence channels; the capacity of a given tool for accommodating increased flows; the correct ordering of tactics in the adaptation mix; and the values of the stakeholder community. The proposed study will utilize stakeholder feedback to evolve the threshold and cost analyses, and spatial mapping, already developed in previous and in-process studies. The study will utilize a GIS to search for candidate sites for retention ponds and exceedence corridors.

A framework for robust adaptation to climate change by searching the impacts-adaptation response surface for "low regret" adaptations, was proposed by Wilby and Dessai (2010). This framework synthesizes a number of adaptation approaches and will guide decision-support and adaptation development in the proposed study. Ashley et al. (2010) note that standard stormwater management systems are centralized, with well-defined ownership, designed using long-accepted civil engineering principles, and do not require broad stakeholder engagement. They conclude that adaptation plans incorporating decentralized methods such as LID, BMPs, and resilience policies, will require an effective stakeholder engagement process, the presentation of technical analyses results in forms that are understandable and relevant as decision-support to stakeholders; and management of ownership by multiple-entities.

Recent studies of factors influencing outreach program success have informed the study design. Foremost are the findings of Gruber (2010), who reviewed published results of 23 research teams to identify twelve principles that researchers or practitioners considered important for successful outreach programs. He recommends applying the Q-sort method as an evaluation of outreach programs, to associate perceptions of success factors with stakeholder and practitioner value systems. Tuler and Webler (2010) noted little guidance in the literature for selecting a stakeholder decision process well-matched for a specific situation. Over ten case studies, they determined that participants' perceptions of context and desired outcomes, and affiliations, experiences, and motivations, influenced their preferences for one type of outreach process over another. They concluded that process design should be based on a formal assessment of the factors unique to each outreach process, and offered guidance on conducting an assessment.

Wilby and Mengelt (2010) describe nine hallmarks of organizations that are "climate smart", defined as implementing specific, measurable, achievable, realistic, and time-bound activities to reduce exposure and sensitivity, and increase resilience. These traits are visionary leadership, setting objectives, risk and vulnerability assessments, guidance for practitioners, organizational learning, low-regret adaptive management, multi-partner programs, accountability for progress, and effective communication. Lowe et al. (2009) added several unique characteristics of successful urban adaptation plans, including: the presence of a "climate champion", a top-level political or municipal department leader who "enthusiastically promotes efforts to improve community resilience"; and science that is "actionable", i.e. that includes "...data, analysis and forecasts that are sufficiently predictive, accepted, and understandable to support decision making, including capital investment decision making". The authors recommend partnering with academic institutions, and implementing the plan through existing policy and regulatory mechanisms, gaining popular support, and obtaining financing.

Finally, evaluation measures in the proposed project will be informed by the assessment of adaptation planning guides performed by Preston et al. (2009). They observed that evidence-based measures for evaluating the success of adaptation policies, processes, and actions were inadequate. Dividing each adaptation plan into inputs, processes, and outputs, authors found inadequate consideration given to the sufficiency of natural and financial capital inputs, inadequate criteria against which to evaluate processes, and inadequately defined roles and responsibilities for plan implementation. Cognizant of these shortcomings, the proposed study will devote additional resources to ensure their sufficient consideration.

Research opportunities from prior projects

Certain methodological choices in previous studies by this research team, while not limiting the transferability of the study protocol and core findings, may have limited the ability to extrapolate quantitative results to dissimilar sites. For example, drainage systems in previous studies consisted almost universally of culverts crossing under roads in rural settings. Due to the novel study aims, the project team had selected culvert-based systems quite literally to keep methods visible, in order to control or exclude potential sources of error. Similar decisions were made with respect to rainfall/runoff and drainage system modeling, and downscaling of coupled climate model output.

Continuing the team's commitment to increasing complexity with successive studies, the proposed project incorporates changes that make results more universally relevant. For example, the Oyster River project found that 65% of culverts were adequately sized, even for the upper 95% confidence bounds of the A1fi design storm. Whether this finding indicates true robustness in civil engineering and TP-40 standards, or artifacts of a Road Agent's risk-averse decisions to take the largest pipe sitting in the yard, has major implications for the extent of required stormwater adaptations nationwide. In addition, rainfall/runoff and culvert capacity modeling was performed on a program created in-house, which may not have credibility for the majority of practitioners who use a standard retail software product.

By modeling a highly urbanized subcatchment, the proposed study tests whether previous findings are relevant outside of rural watersheds. The use of the existing runoff and drainage model, developed using XPSWMM, an off-the-shelf program, will promote the acceptance of results in a broader professional community. Together these increase the transferability of research program results to urban stormwater systems. The anticipated availability of fifth-generation Coupled Model Intercomparison Project (CMIP5) model output (Meehl and Hibbard, 2007), and the new approaches for generating emissions trajectories (Representative Concentration Pathways, or RCPs) will maintain the teams commitment to state-of-the-art methods, and promote the long-term relevance of study findings.

Finally, previous studies did not model the influence of climate driven changes to evapotranspiration rates which influence runoff calculations via their role in initial abstraction rates. Manning et al. (2009) found that in a changing climate the influence of potential evapotranspiration (PET) on rates of initial abstraction of rainfall is up to half of the impact on runoff rates. The proposed study will model climate change impacts to PET and initial abstraction.

Scientific Objectives (Study Aims):

Aim 1. Precipitation and land-use modeling, runoff and *peak flow* response

Develop reliable, quantified, best-available estimates of likely local-scale impacts on runoff, *peak flows*, streamflow, and water quality, resulting from mid-21st century climate change and population growth, utilizing probabilistic estimates of the climate-changed design storm downscaled from a range of emissions scenarios and coupled-climate models;

Aim 2. Stormwater management system response and adaptation

Model the required capacities, and associated upgrade costs, for existing and planned water-related infrastructures, including dams, to convey current and future *peak flow* from stormwater runoff;

Aim 3. Decision Support

Create, with input from stakeholders, charts, maps, tables, slides and interactive tools supporting stakeholder development of a risk-based strategy for economically adapting the stormwater management system, based on analyses of replacement-cost, cost-avoidance, and substitution cost;

Aim 4. Outreach and Dissemination

Catalyze local and national adaptation by developing and applying a program of citizen and stakeholder engagement; facilitate a participative decision-making process that implements local policies and actions that are founded on the technical analysis; disseminate results regionally and nationally.

Relevance to the goals of the CSI-Water program, Urban Water Resources track:

This urban water resources project is eminently relevant to the goals of the Urban Water Resources track of the CSI-Water program. The project applies a multidisciplinary team to support a major Midwestern city, and associated watershed district, faced with impacts from climate change and variability. In partnership with the Climate Program Office, the proposed project continues and significantly advances the team's established program of stakeholder engagement for decision-support of risk-cognizant adaptation of civil infrastructure. The study team devotes considerable project resources and expertise to developing an outreach program that promotes trust. communication, and sound stakeholder decision-making founded on clear, digestible, and relevant information. This includes representations of uncertainties and valuations of the costs and benefits to society from impacts and adaptation.

The founding premise of the team's research mission, that rigorous, quantified, local-scale, and actionable information to support urban stormwater adaptation is achievable, implicitly realizes many of the goals and objectives of the CSI-Water program. These studies extend adaptation research to understudied areas and questions (Yohe and Mengelt 2010; Sanchez-Rodriguez, 2009; Grove et al., 2008; Fowler et al., 2007a; Fowler et al., 2007b), and add important information to the scientific debate by joining with Dessai et al. (2009), in challenging the prevailing belief that uncertainty must paralyze infrastructure adaptation.

The proposed project will continue the Climate Program Office's national leadership in the research and dissemination of cutting-edge decision-support knowledge and tools, to achieve climate-adapted water sectors. The project:

• Supports leaders and stakeholders in responding to climate-related risks;

• Through a specific evaluation plan, increases the effectiveness and relevance of the Climate Service by improving understanding of needs of resource managers and planners, and obstacles faced in coping with climate change;

• Proposes a robust plan for disseminating findings, and transfers knowledge, tools, and products;

Benefits to general public:

Benefits to the study region:

The proposed study will seed, beyond the study site, adaptation-related assessments, planning, and eventually implementation. Although the study region is generally progressive on environmental issues, climate change appears to be a lower priority than found during previous studies in northern New England. Communication activities of this study will increase the visibility of this issue for the two-year duration of the project, promoting understanding and dialogue beyond those immediately involved as stakeholders. Although the two investigators on the project team who are from stakeholder organizations understand the need for impacts assessments and adaptation, demanding workloads have precluded development of ongoing climate change related outreach. This project will open space for them to focus on promoting adaptation and related awareness within their spheres of influence.

Marshall et al. (2010) found that a key factor in successful participative watershed management programs is adequate financial support. The important benefits that this study will provide to the community, and urban communities nationwide, would not occur without the support of the Climate Program Office. The need for state or federal funding of community-scale adaptation studies is a consistent finding as we work to identify communities to partner with, present results at conferences, and otherwise interact with community leaders. The crucial role that Climate Program Office funding plays in promoting awareness and adaptation must not be underestimated.

Benefits to the general public:

The proposed study advances the translation of important climate information from the research lab to practitioner communities. This operationalizes climate forecasts and information on uncertainty and risk, into the hands of those with the ability to influence societal systems toward adaptation. As such, this study is of practical benefit to the general public. In addition, through nationally distributed press releases the project will promote widespread public awareness of the need to adapt (EarthTimes, 2010; PhysOrg, 2005).

Benefits to the scientific community:

The proposed study identifies research questions from current literature and previous studies to advance the development of a corpus of adaptation practice expertise. The project will continue the objective of prior studies, to define and clarify the extent to which uncertainty may not be the obstacle to adaptation that it is generally assumed to be. This study asks this question in the context of an urbanized catchment, increasing the relevance of the research program. This series of studies constitute an innovative program that seeks to answer the numerous calls in the literature for moving beyond the repetition of comparison and vulnerability research.

Proposed Methodology:

Study Site:

The proposed study site is the area of the Minnehaha Creek Watershed District that lies within the city limits of Minneapolis. 36% of land area of Minneapolis lies within the MCWD. As of the 2000 census, the population of this area was 136,767, with expected growth between 2000 and 2030 of 14%. Land area is almost completely developed and dominant land use is single family residential with scattered commercial and industrial zones and corridors. Because so much of the subwatershed is already developed, future land use in the subwatershed is not expected to change dramatically by 2030. Strategies and policies for growth are for redevelopment, reclamation, and infill. Redevelopment and infill development will provide opportunities to retrofit with stormwater quantity and quality measures in areas that currently have no, or inadequate, measures.

Minnehaha Creek is the outlet for runoff from this subwatershed, conveying water to the Mississippi River. Hydrological/water-quality modeling performed in 2003 identified 14 locations with known or modeled flooding issues, and nine locations where high pipe flow velocities may cause erosion. Within the watershed, six lakes draining into Lake Minnehaha are designated as being impaired due to nutrient loading. Minnehaha Creek has been listed on the State of Minnesota's 303(d) list of Impaired Waters for its impaired biotic community, and aquatic habitat in the Creek is generally poor.

Scope of Work

Aim 1 <u>Precipitation and land-use modeling, runoff and *peak flow* response</u>

Activity 1.1: Climate information, downscaling of design storms

Summary: Apply next-generation CMIP5 coupled model output from multiple high-skill models bracketing a range of sensitivities from dry-to-wet, for two Representative Concentration Pathways bracketing likely emissions trajectories;

Activity 1.2: Modeling of climate-changed evapotranspiration rates
Summary: Utilize linear regression equations and CCM output to estimate changes in the evapotranspiration rate resulting from climate change.

Aim 1, Activity 3: Utilizing the existing hydrologic model, determine volumes of runoff and peak flow for design storms.

Aim 2. Stormwater management system response and adaptation

Aim 2, Activity 1: Stormwater drainage system modeling
Utilizing the calibrated model of the stormwater management system, determine adequacy for conveying peak flows from historical, recent and mid-21st century design storms.

Aim 2, Activity 2: Evaluate the capacity of LID and other practices to manage Q_P more economically than increasing the size of drainage system components under climate change scenarios.

Aim 3. Decision Support

Activity 3.1: Planning-scale analysis of replacement, upgrade, and marginal upgrade costs

Activity 3.2: Cost of non-drainage system stormwater management: implementation cost of LID, storage/retention
Activity 3.4: Synthesis of decision-support via Integrated Assessment Modeling

Aim 4. Outreach and Dissemination

Aim 4, Activity 1: Through a stakeholder-driven process, determine issues for future municipal planning as they relate to stormwater management and local land use policies. This process will assess stakeholder values to inform capacity-building efforts and determine the most effective way to communicate study results so that they best inform existing and future plans and policies. This stakeholder process will also contribute to the risk-analysis in Aim 3, Activity 2

Aim 4, Activity 2: Build stakeholder capacity to understand study results by continuing the engagement process and developing and distributing targeted educational materials. Promote incorporation of study results into innovative local government plans and polices for land use, infrastructure asset management master plans, and capital planning and budgeting processes.

Aim 4, Activity 3: Disseminate results to at least four regional and national conferences, two peer-reviewed publications, and on one internet site, in partnership with existing regional and national organizations.

Methodology as applied

The Study Sites: Physical Features

Two cities that have watersheds within the Minnehaha Creek Watershed District participated in this study. The City of Minneapolis supported the project with participation on the study team, advice and input to study design, data, and the hydrological/hydraulic model currently used by the City to model stormwater infrastructure. A sub-watershed within City boundaries was selected for this project. The City of Victoria also supported study aims, and served as a contrasting site.

The first of two sites selected was the Minneapolis pipeshed 76-010, a 445 Ha subwatershed within the City of Minneapolis and part of the Minnehaha Creek watershed District (MCWD; Figure SS.1). The pipeshed comprises approximately 3% of the area of the City. The Pipeshed 76-010 watershed is almost fully built-out, with moderate population density from the predominance of single-family residential zoning and scattered commercial and light-industrial zones. The average impervious area over the watershed is 50%, while the average slope is 5%. Future land use in the watershed is not expected to change dramatically through the study period. Policies for growth include redevelopment, reclamation, and infill, providing retrofit opportunities for runoff quantity and quality mitigations. Three detention basins built after previous flooding provide approximately 87,400 m^3 of stormwater volume storage across the pipeshed. The City also utilizes an additional 136,400 m^3 of storage in low points in streets and alleys as part of the management of the 10-year design storm. Runoff from the watershed is discharged to the 21-Ha Pipeshed 76-010 via a 27-km network of stormwater pipes. Both Pipeshed 76-010 and Minnehaha Creek, the outlet for the lake and watershed to the Mississippi River, are designated impaired. Minnehaha Creek and its attendant watersheds have areas susceptible to flooding.

To contrast with the built-out Pipeshed 76-010 pipeshed, the second site selected was the predominantly rural watershed of the City of Victoria. This site sits on the western boundary of the urban-rural fringe surrounding the Minneapolis metro area. The Victoria watershed is 670 Ha, with land uses dedicated to single family residential (29%), commercial/industrial (4%), parks and other open space (17%), agriculture (12%) and wetlands and open water (38%) (Figure SS.2). A 15% growth rate is projected for the area and, by current zoning policies, all existing agricultural land uses are expected to transition to single family residential (10-40% impervious area) by 2030. With the exception of a 55-Ha golf course, development has occurred primarily in upland areas, allowing for the preservation of wetlands and natural drainages. Runoff from impervious surfaces is piped to a network of 31 constructed stormwater ponds located throughout the study watershed, which discharge to existing lake and wetland systems. As in Pipeshed 76-010, stormwater pipes in Victoria are designed to convey peak flows associated with a 10-year design storm. The stormwater ponds, however, are designed to store up to the current 100-year design storm (150 mm; 6 inches) with an additional 0.3 m (12 inches) freeboard.

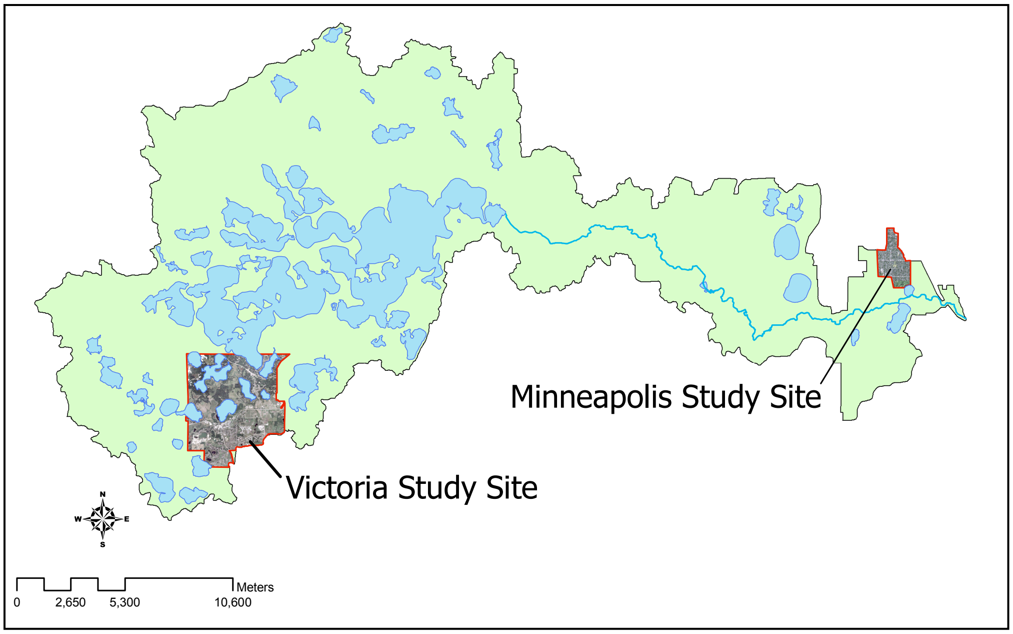


Figure SS.1. Map showing relative locations of the Pipeshed 76-010 and Victoria study sites. Both are part of the Minnehaha Creek Watershed District (MCWD).

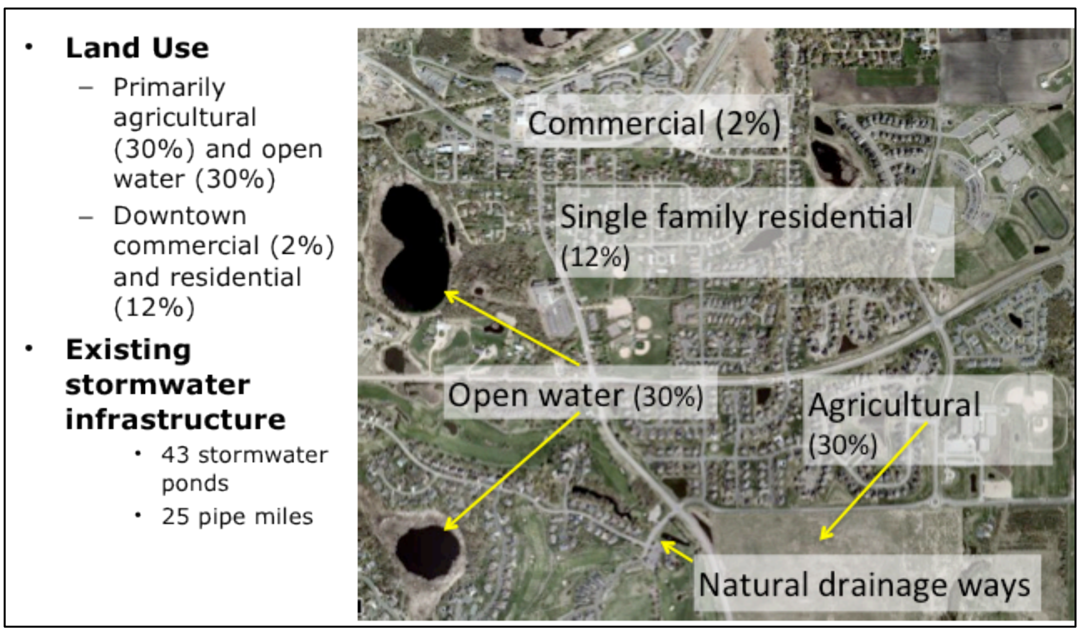


Figure SS.2. Land use in the Victoria watershed.

Precipitation model

(Also see Appendix "A")

In order to project mid-21st century design storm precipitation for the study sites, conservative statistical methods that are well-established in the published literature were applied to coupled climate model (CCM) output. Results of this analysis were used for the hydrological and cost modeling, to generate estimates that could be used by stakeholders to examine the risks and adaptation options available to the community.

Mid-21st century precipitation patterns were estimated by applying a percentage increase to the recent level of rainfall intensity that has served as the standard for drainage system design for the City of Minneapolis. This design-level of rainfall is unusually large and therefore historically has occurred on average every-ten years. In other words, historically it has a 10% probability of occurring in any one year. The percentage increase was derived from CCM output. A detailed description of precipitation downscaling methodology is provided in Appendix “A”. Salient features of this process include:

• Minneapolis practice is to design stormwater systems to accommodate peak flow from the historical once-in-ten-year precipitation event with a 24 hour duration. The percentage change in this design event, from recent to mid-21st century, was estimated by statistically applying percentages of change derived from daily CCM output;

• Based on standard hydrological practice, the 10-year 24-hour event was estimated using thirty-year periods from the recent historical record and from the CCM output;

• To measure the impact on study results from uncertainty in climate change projections, a range of CCMs and greenhouse gas scenarios were used.

• To establish the relationship between watershed hydrological characteristics and engineering hydraulic design methods, the response of the combined hydrologic/hydraulic system to arbitrary increases in precipitation of TP-40 was determined;

• A *point process, peaks-over-threshold* statistical method was used to derive the 10-year 24-hour value for each set of sample data.

Results

Results of precipitation downscaling are presented in Table P.1. In order to reduce the number of scenarios for the hydrologic, LID, flood damage, and cost analyses, we selected five (5) precipitation values from Table P.1, including single and averaged values. Table P.2 lists precipitation scenarios selected for hydrologic and cost modeling. Five values were used for certain analyses, for others the three values labeled “Optimistic”, “Moderate”, and “Pessimistic” were used. The basis for selection: 5.66” was selected for being close to the mean value for all *most likely* and *+95% c.l.* estimators; 6.56” was selected for being at the upper 95% confidence limit for the sample of 28 estimators; 8.07” was selected for being approximately 100% greater than TP-40; 10.13” was selected for being the most pessimistic of all results and for being the closest to recent extreme events for eastern Minnesota.

Table P.1. Downscaled precipitation estimates

				Precip (in)		%Δ_over _recent_NCDC:		% undersized components	
Generation:	Model:	Grid_size:	Scenario:	ML	+95%ci	ML	+95%ci	ML	+95%ci
Historical	NCDC	Station	Recent	3.93				11%	
CMIP3	CM2.1	9-grid	A1b	4.81	7.53	22.3%	91.6%	15%	30%
CMIP3	CM2.1	9-grid	A1fi	5.09	7.08	29.5%	80.2%	17%	27%
CMIP3	CM2.1	6-grid	A1b	5.13	6.16	30.5%	56.7%	17%	23%
CMIP3	CM2.1	6-grid	A1fi	4.94	7.10	25.7%	80.7%	16%	27%
CMIP3	CM2.1	4-grid	A1b	4.15	6.16	5.6%	56.8%	12%	23%
CMIP3	CM2.1	4-grid	A1fi	4.99	10.13	27.1%	157.8%	16%	43%
CMIP3	PCM	9-grid	A1b	3.97	6.69	1.1%	70.3%	11%	25%
CMIP5	CCSM4	9-grid	rcp45	3.83	5.82	-2.5%	48.1%	10%	21%
CMIP5	CCSM4	9-grid	rcp60	4.25	6.06	8.1%	54.2%	13%	22%
CMIP5	CCSM4	9-grid	rcp85	4.08	6.09	3.8%	54.9%	12%	22%
CMIP5	CM3	9-grid	rcp60	4.29	7.29	9.2%	85.5%	13%	28%
CMIP5	CM3	9-grid	rcp85	5.18	7.88	31.9%	100.6%	17%	32%
CMIP5	CM3	6-grid	rcp60	4.08	6.33	3.7%	61.1%	12%	23%
CMIP5	CM3	6-grid	rcp85	5.66	7.67	44.1%	95.2%	18%	30%
Average, all GCMs/Scenarios/Grids:			A1b	4.51	6.63	14.9%	68.9%	14%	25%
			A1fi	5.01	8.07	27.4%	105.4%	16%	33%
			rcp45	3.83	5.82	-2.5%	48.1%	10%	21%
			rcp60	4.20	6.56	7.0%	66.9%	12%	25%
			rcp85	4.97	7.21	26.6%	83.6%	16%	28%

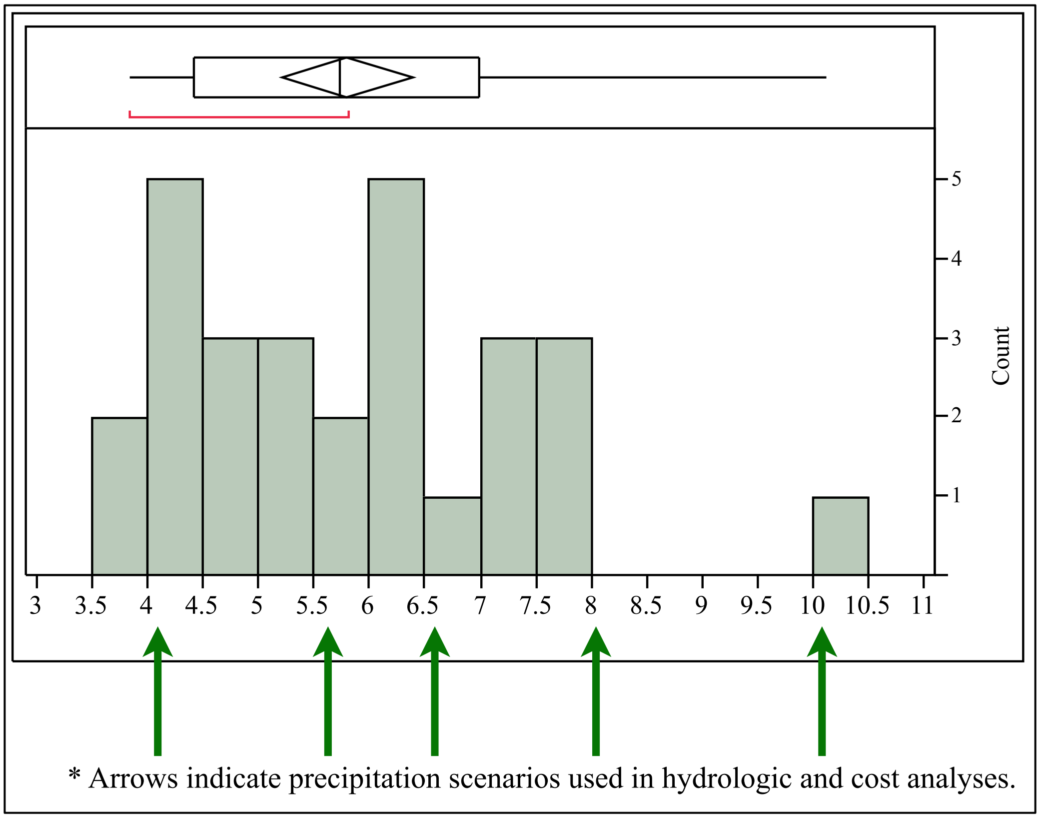


Figure P.3. For downscaled precipitation results, statistical distribution and five values selected for modeling.

Table P.2. Precipitation modeling scenarios used for subsequent analyses.

Generation	GCM	GHG trajectory	Estimator	Precip (in)	%Δ over TP-40	Scenario
CMIP3	GFDL CM2.1	A1b	ML	4.15	4%	Optimistic
CMIP5	PCM CM3	RCP85	ML	5.66	42%	
CMIP5	Average	RCP60	+95%cl	6.56	64%	Moderate
CMIP3	Average	A1fi	+95%cl	8.07	102%	
CMIP3	GFDL CM2.1	A1fi	Worst-case	10.13	153%	Pessimistic

Hydrology/hydraulic, LID, and buildout models

The EPA's Stormwater Management Model (SWMM; Rossman, 2010) was used to simulate rainfall-runoff processes and stormwater system hydraulics for both study sites. Existing SWMM models were available for both the Pipeshed 76-010 and Victoria pipesheds and were utilized as the basis in this study. The Pipeshed 76-010 model was developed in 2005 for the City of Minneapolis, and included all stormwater conduits, surface flow pathways between catch basins via curb and gutter, and surface storage available at depressional areas in streets, alleys, and constructed stormwater dry basins.

The existing model for Victoria was developed as part of a broader pollutant loading study for the Minnehaha Creek Watershed District (EOR, 2003). However, individual components of the stormwater network were not discretely modeled as required for application in the present study. Using the calibrated hydrologic parameters from the existing model, a more detailed SWMM model was developed to include pipes 47 mm (12 in) in diameter and greater, surface flow pathways between catch basins via curb and gutter, and surface storages including constructed stormwater ponds and naturally-occurring lakes and wetlands for this study. As appropriate, flow between surface storages in natural channels and/or culverts was also modeled. This more spatially explicit model was calibrated to flow measurements collected at the watershed outlet during 3 storms (50, 25, and 30 mm) from May to June 2012 (Table H.1).

Precipitation data was obtained from a tipping-bucket rain gage with a 15-minute recording interval located within the watershed (7 km (4.3 miles) from the watershed outlet) and managed by the MCWD. A Solinst level logger (model 3001) was used to record stream depth at 5-minute increments. After correcting for atmospheric pressure as obtained from a nearby weather station, water depth measurements were converted to discharge based on a rating curve developed from weekly flow and depth measurements by the Minnehaha Creek Watershed District at the same transect. Measured and modeled discharge at the watershed outlet for the calibration period are displayed in **Figure H.1** and summarized in Table H.1. The goodness-of-fit between modeled and measured flow was evaluated by the Nash-Sutcliffe Efficiency (NSE) coefficient (Nash and Sutcliffe, 1970). Values of NSE greater than 0.5 are generally considered acceptable for hydrologic models such as this (Engel et al., 2007). Despite a relatively poor fit between observed and modeled flow data for storms less than 40 mm (1.6 in), overall model performance for the Victoria study site was deemed acceptable with an NSE of 0.83.

Although calibration and validation efforts were limited by a narrow range of precipitation events and availability of continuous flow data, model performance seems to improve for events greater than 50 mm (2 in), which, in the case of this study, are of greatest interest.

Parameters used to calibrate both SWMM models include percent subcatchment imperviousness and Green-Ampt infiltration parameters (soil initial moisture deficit, suction head at the wetting front, and saturated hydraulic conductivity). The average values for calibration parameters over the Pipeshed 76-010 and Victoria study areas, along with general stormwater network characteristics, are summarized in **Table H.2.** The final SWMM models used to represent the stormwater network of both study areas are depicted in Figure H.2.

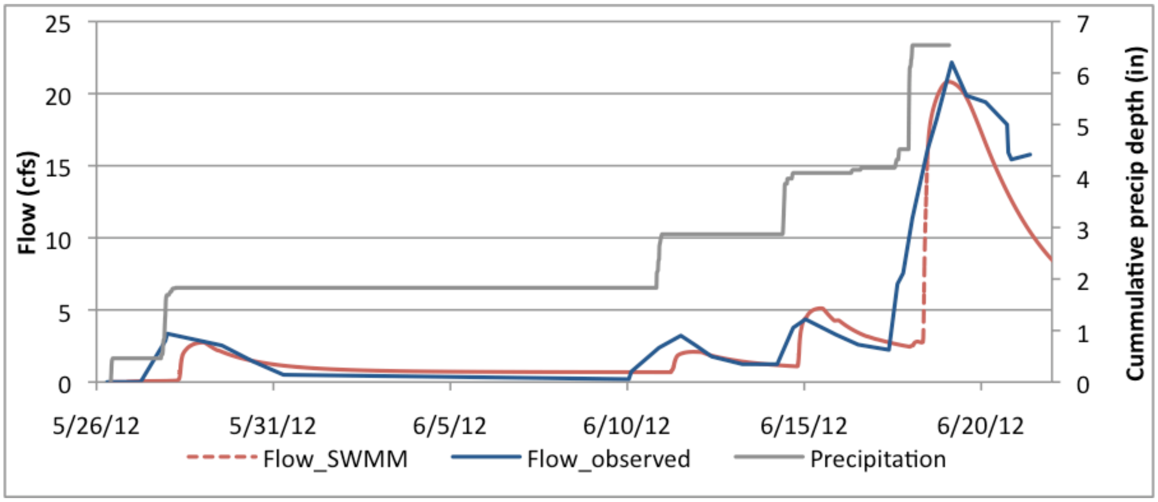


Figure H.1. Comparison of measured and modeled discharge at the outlet of the Victoria study area for the calibration period May to June 2012. The timing and magnitude of peaks during small storms is not represented well by the model; however, model seems to perform adequately for predicting the peak of larger storms such as those of interest to this study.

Table H.1. Summary of model performance, as evaluated by percentage difference between observed and predicted peak flows (individual events) and the Nash-Sutcliffe Efficiency (NSE) coefficient (overall calibration period).

Calibration					
Date	Precip depth	Precip duration	Peak flow (cfs)		% difference, Q_p
	(mm)	(hr)	Observed	Modeled	
5/26/2012	37	8.25	4.45	2.7	39.3%
6/10/2012	22	3.75	3.22	2.1	34.8%
6/14/2012	30	7	3.1	2.2	29.0%
6/17/2012	60	14	22.2	20.8	6.3%
Overall Calibration Period (5/26/12 – 6/17/2012)					NSE = 0.83

Table H.2. Summary of Pipeshed 76-010 and Victoria study area characteristics as modeled in SWMM. Percent subcatchment imperviousness and Green-Ampt infiltration parameters were the primary parameters used in the calibration of both models (SRF, 2005, EOR, 2003).

SWMM model characteristics	Lake Hiawatha (Minneapolis)	Victoria
Total pipeshed area (Ha)	1100 ac	1145 ac
Total model subcatchments	653	176
Avg. subcatchment Green Ampt-infiltration parameters:		
Initial soil moisture deficit	0.32	0.024
Suction wetting front head (m)	0.25	0.14
Sat. hydraulic conductivity (m s^{-1})	1.8×10^{-6}	1.34×10^{-6}
Avg. subcatchment imperviousness (%)	50%	14% Existing; 29% w/ Buildout
Total pipe length (m)	27,011	15,940
Total natural channel length (m)	0	2,733
Total storage, constructed stormwater wet/dry basins (m^3)	87,400	111,484
Total storage, other storage nodes	136,400[a]	6,800,857[b]

[a]includes allowed depression storage in streets and alleys
[b]includes storage in 3 naturally-occurring lakes and 4 wetland complexes

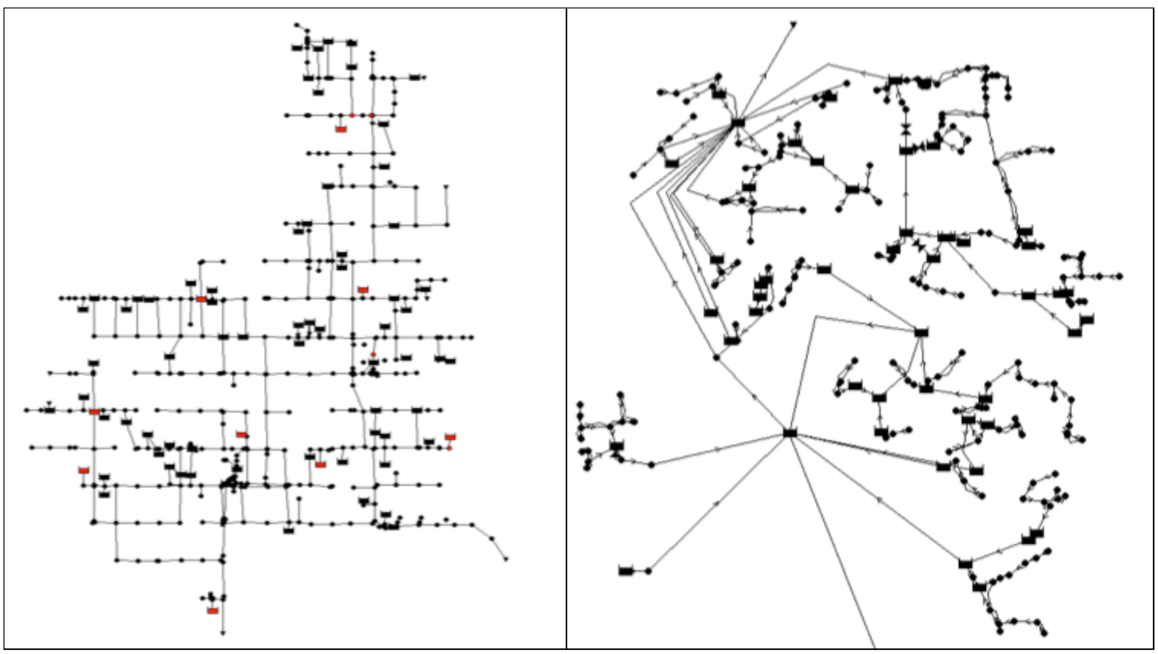


Figure H.2. Representation of the Pipeshed 76-010 (left) and Victoria (right) stormwater networks in EPA SWMM (not to scale). Stormwater components are generally classified as either nodes (circles and rectangles) or conduits (solid lines between nodes) in which stormwater is routed between nodes. Nodes are further classified as junctions (circles), through which stormwater runoff may enter the conduit network or be re-emitted as surface flooding when the conduit network is over capacity (e.g., manholes or catch basins) or storage units (rectangles), which represent physical features of the landscape in which a defined volume of runoff may be stored (e.g., constructed stormwater basins, depressions in streets, lakes, wetlands).

Precipitation scenarios

For application in SWMM, precipitation scenarios obtained through modeling must be distributed on a sub-daily time scale. The time scales most relevant for urban stormwater modeling are on the scale of minutes (Olsson et al., 2012). Given that such a fine resolution precipitation time series was not an outcome of the climate modeling undertaken, it was necessary to make some assumptions as to how future rainfall would be distributed. In keeping with the current design-storm approach, a 24-hour, SCS Type II rainfall distribution was assumed. In this distribution, 50% of the total rainfall depth is concentrated in the middle 6.25% of the 24-hour period, reflective of the short duration, high-intensity storms the Type II distribution was developed to represent (NRCS, 1986).

Land Use Change(Buildout) Scenarios

Mid-21st century land use scenarios were developed for the study sites based on current zoning policies and projected population growth. Projected changes in land use were modeled in SWMM by adjusting the percent watershed impervious parameter according established relationships between housing density and imperviousness (NRCS, 1986). For Pipeshed 76-010, a random sampling of impervious rates was completed within the study boundaries. Since the pipeshed is assumed to be fully built-out at the present time, land uses in Pipeshed 76-010 were not expected to change appreciably over the study period, so that impervious cover remained at an average value of 50% for all scenarios. For the Victoria study site, the percent impervious area of each model subcatchment was adjusted to reflect maximum development densities allowed under current zoning regulations (see Figure H.10 for depiction of areas of projected development). This resulted in an approximate doubling of average impervious surface cover over the entire watershed from 15% to 33%.

Adaptation Scenarios

At both study sites, adaptation strategies were modeled to explore the potential to maintain existing service levels (i.e., conveyance of stormwater runoff up to 10-year design storm) provided by stormwater infrastructure. Adaptation measures included upsizing existing infrastructure to manage projected increases in peak runoff, implementing low impact development practices to reduce surface runoff, and, in the Pipeshed 76-010 watershed, utilizing over-curb surface storage in areas where structures would not be impacted. For pipe upsizing scenarios, the diameter of surcharged pipes downstream of flooded model nodes was increased incrementally until flooding was reduced to zero for all mid-21st century 10-year design storm scenarios. The adaptive capacity of LID was simulated by defining an LID unit sized to capture the first 25 mm (1 in) of runoff from all impervious surfaces within a given model subcatchment. Exfiltration from the unit was controlled by the saturated hydraulic conductivity defined for the surrounding native soils (Table M2). In Pipeshed 76-010, five LID scenarios were tested. In the first scenario, LID units were designated in all (100%) subcatchments within the pipeshed to assess a maximum effect of LID. For the remaining 4 scenarios, LID units were designated in 10%, 15%, 20%, and 25% of randomly selected subcatchments to simulate a more realistic extent to which LID might be retrofitted in the pipeshed. In Victoria, LID scenarios included (1) LID units sized to capture the first 25 mm of runoff from all impervious area and (2) LID units designed to capture runoff only from impervious surfaces added as part of new construction. The total area and storage volume associated with LID scenarios is summarized in Table H.3. The final adaptation pathway, considered only for Pipeshed 76-010, was the storage of excess runoff in streets and over the curb up to (but not greater than) the elevation of existing structures. This option was modeled in SWMM by adjusting the stage-storage curves defined for model storage units representing street or alley detention storage areas up to the maximum height allowed without impacting structures.

Table H.3. Summary of the total area of LID (in acres) and storage volume (in million gallons) required to capture the first 25 mm (1 inch) of runoff from the given portion of impervious surface cover in the Pipeshed 76-010 and Victoria study sites.

Lake Hiawatha		
LID scenario	Total area (Ac)	Total Volume (MG)
10%	3.4	1.1
15%	5.2	1.7
20%	7.1	2.3
25%	8.9	2.9
100%	34.5	11.3
Victoria		
LID scenario	Total area (Ac)	Total Volume (MG)
New Construction	15.6	5.1
100%	26.5	8.6

Results

In the following sections, results pertaining to key hydrologic and hydraulic metrics, namely peak flow and flood volume, are presented for existing and mid-century precipitation and land use scenarios for both study sites. The efficacy of pipe upsizing and LID adaptation scenarios for mitigating increases in peak flow and flooding are also discussed.

Pipeshed 76-010: Existing conditions.

Prior to running mid-century climate projections in SWMM, a series of storms representing a 25% to 250% increase from the existing 10-year design storm (4 inches) were input to the Pipeshed 76-010 SWMM model to develop a curve depicting the relationship between the change in design storm depth and the number of undersized components in the existing storm sewer network (Figure H.3). Note that a given conduit was only considered to be undersized if it was (1) surcharged *and* (2) upstream of a flooded node. In SWMM, "flooding" is defined as any volume of water that exits the storm network as stormwater inflows exceed the capacity of the system. This curve may be related to the existing and future level of service provided by the system by overlaying the percent undersized components for the recent (3.93 in) and mid-century 10-year storm scenarios (4.15, 5.65, 6.56, 8.07, and 10.13 inches). Mid-century 10-year precipitation scenarios were selected to span the range in uncertainty indicated by downscaled climate models.

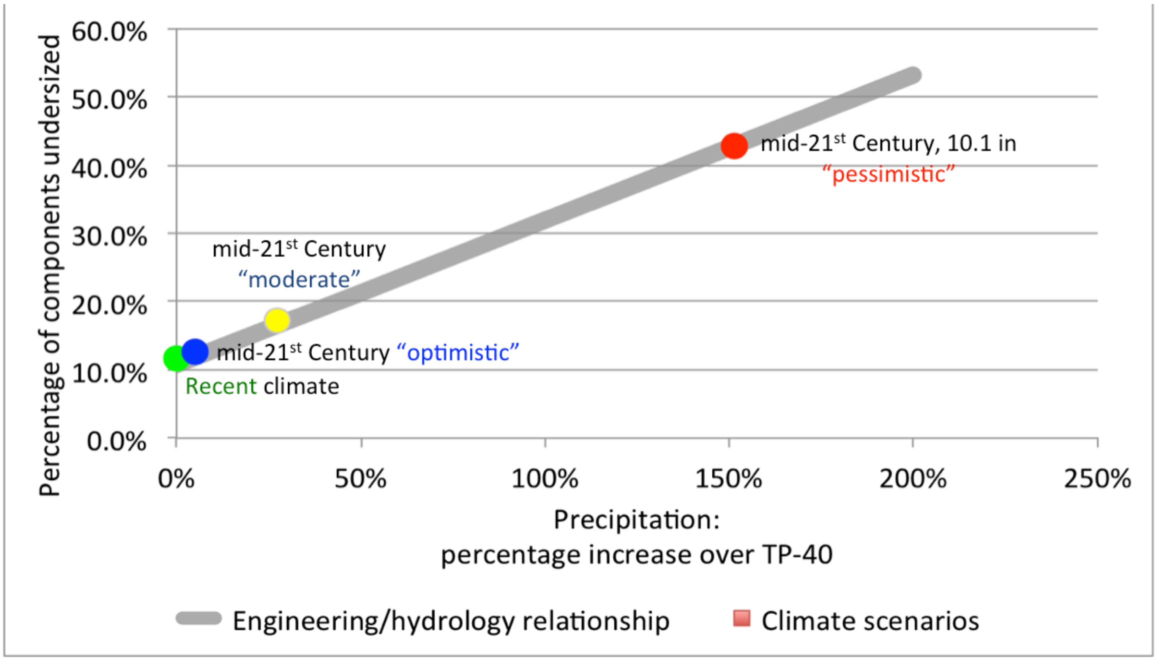


Figure H.3. Engineering-Hydraulic relationship between a given increase in the current 10-year design storm depth (4 inches) and the percent undersized components in the Pipeshed 76-010 storm sewer network. The percent components undersized for the recent (0% increase) and mid-century 10-year rainfall depths corresponding to optimistic (5% increase), moderate (28% increase), and pessimistic (150% increase) climate scenarios are overlain.

Other important hydrologic and hydraulic response metrics for recent and mid-century precipitation scenarios (average peak flow of runoff entering the stormwater network, peak flow at the pipeshed outlet, and the total system flood volume) are illustrated in Figure H.4. Based on the practicalities of managing surface flooding in a built-out environment, the City of Minneapolis generally prioritizes flooding as either acceptable or unacceptable. Acceptable flooding pertains to flooding that is stored in streets or over curbs up to the elevation of structures. Unacceptable flooding includes any flooding that exceeds the elevation of structures, thereby posing a risk to property. The terms "acceptable" and "unacceptable" will be used to define surface flooding in the Pipeshed 76-010 pipeshed in the following sections.

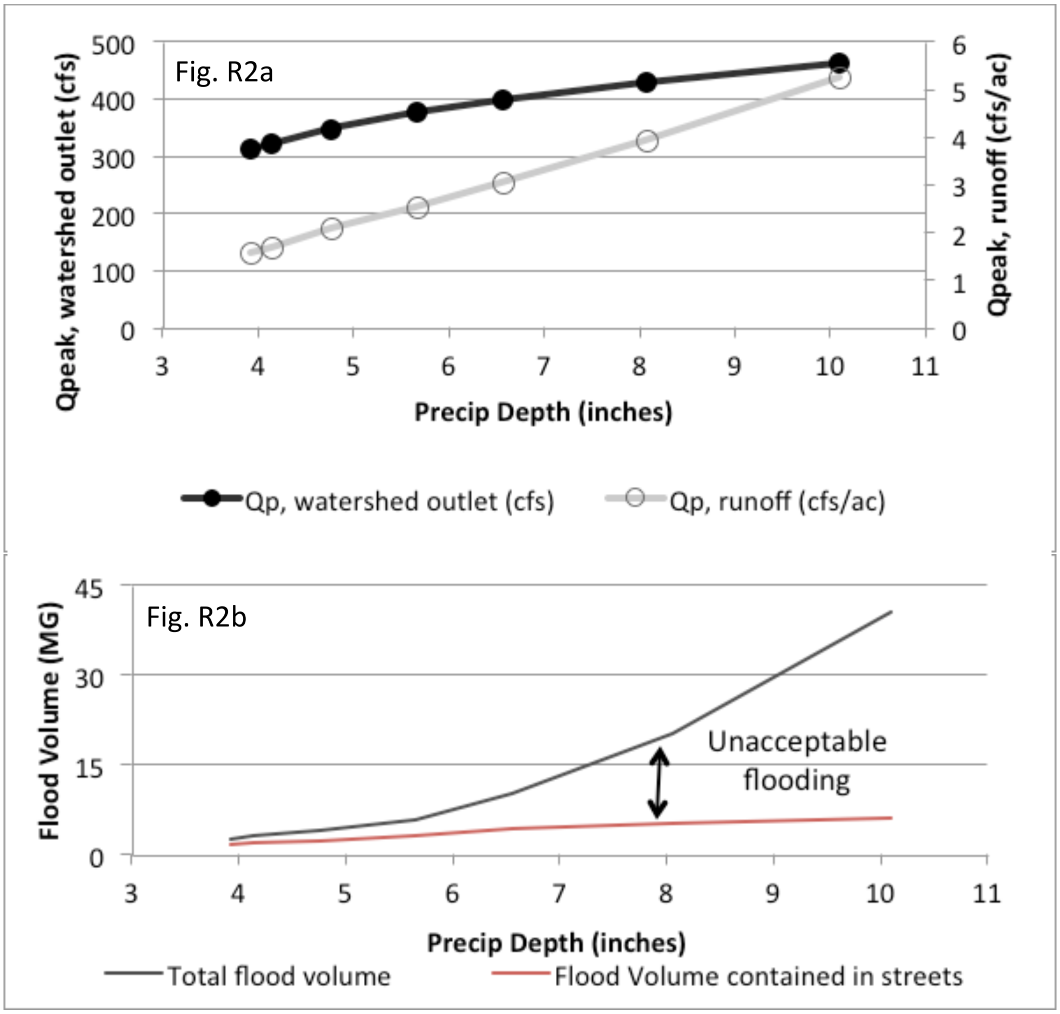


Figure H.4. Hydrologic/hydraulic response of the Pipeshed 76-010 pipeshed to mid-century 10-year storm projections: (a) average subcatchment peak flow delivered to the stormwater pipe network (open circles) and peak flow at the outlet of the pipeshed (closed circles); (b) Total flood volume (black line, representing total volume of water ponded on surface due to inadequately sized stormwater system components). Total flood volume is separated into allowable street-flooding (red line, represents flood volume contained in streets or over curbs up to elevation of structures) and unacceptable flooding (volume between total and allowable flooding; represents volume of flooding for which elevation exceeds that of structures).

In its existing condition, approximately 10% of pipes in the Pipeshed 76-010 pipeshed are too small to convey runoff associated with the 10-year storm (Figure H.3). This result likely stems from changes in design standards that have occurred over the life of the storm sewer system. For example, pipes installed prior to 1960 were designed only to convey flows associated with the 2- or 5-year storm (J. Polzin, personal communication, Dec. 19, 2011). The proportion of undersized pipes increases by approximately 150% and 350% for the moderate and pessimistic mid-century precipitation scenarios. Accordingly, the volume of flooding predicted for the range of mid-century precipitation scenarios also increases, up to a factor of 40 (Figure H.4). In order to identify points in the system most vulnerable to flooding, a series of “stoplight” maps were developed (Figure H.5). These maps classify individual pipes in the storm network as being either (1) adequately sized (i.e., the 10-year storm is conveyed without surcharge), (2) surcharged (i.e., flow in the pipe is under orifice control but is not associated with downstream flooding), (3) surcharged and associated with acceptable downstream street flooding, or (4) surcharged and associated with unacceptable downstream over-curb flooding.

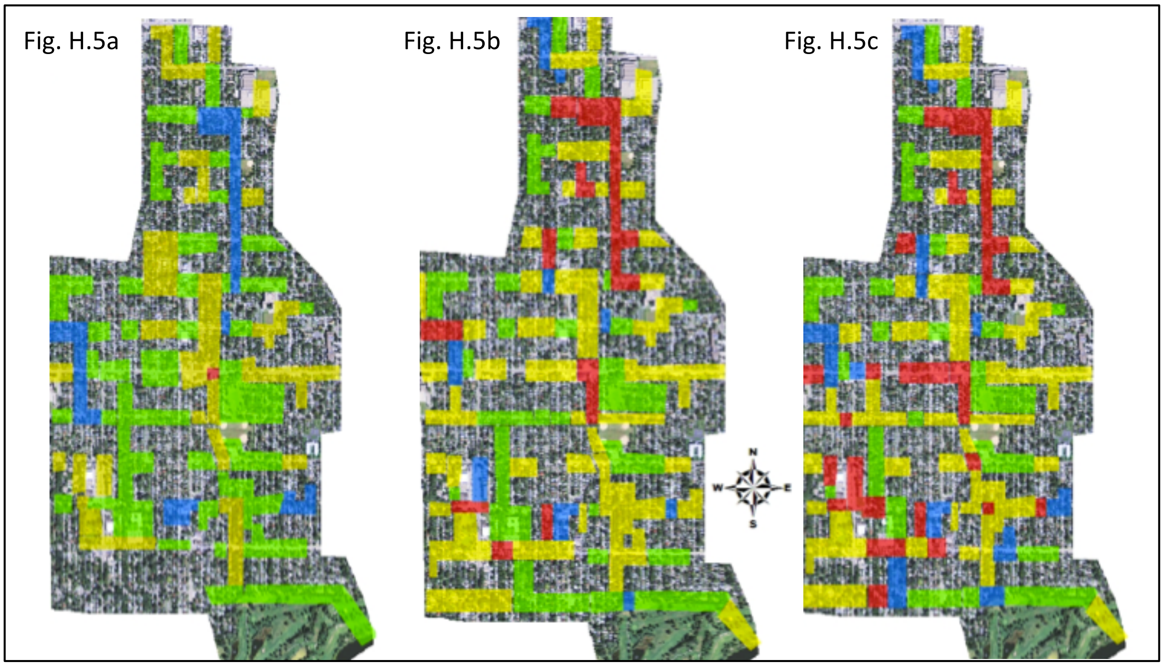


Figure H.5. Stoplight maps comparing system vulnerabilities for the (a) recent 3.93 in., (b) moderate 6.56 in., and (c) pessimistic 10.13 in., mid-century 10-year storm scenarios. Individual pipe segments are highlighted according to their classification as either: adequately sized (green), surcharged (yellow), surcharged with on-street storage (blue), or surcharged with downstream over-curb flooding (red).

Pipeshed 76-010: Adaptation options.

Three primary adaptation options were explored for the Pipeshed 76-010 pipeshed: (1) allowing street and over-curb flood storage up to (but not in excess of) the elevation of structures, (2) up-sizing pipes to convey projected peak flows and flood volume in excess of allowable flooding under option (1), and (3) implementing LID at various intensities to increase infiltration throughout the pipeshed. The first of these measures represents a "do-nothing" approach and serves as a baseline for comparison with active adaptation measures such as pipe-upsizing and LID. Over-curb flood volume resulting from these actions is shown in Table H.4.Of particular interest is the effect of pipe upsizing and LID on total peak flows at the watershed outlet to Pipeshed 76-010 and in reducing the volume of unacceptable flooding relative to the existing condition (do-nothing alternative; Figure H.6). The efficacy of adaptation options are discussed in more detail in the following sections. Note that the term "flood volume" throughout these sections refers to unacceptable flooding, that is, the volume of flooding *in excess* of that allowed over streets and curbs up to, but not in excess of, the elevation of residences, garages, or commercial structures. The elevation of flood waters relative to structures was determined outside of SWMM in ArcGIS using 1-meter resolution surface elevation data.

Table H.4. Flood (over-curb) volume under existing, pipe-upsized, and LID scenarios

	Over-curb flood volume (MG)	Over-curb flood volume (MG)	Over-curb flood volume (MG)	Over-curb flood volume (MG)	Over-curb flood volume (MG)	Over-curb flood volume (MG)	Over-curb flood volume (MG)
Precip	Existing	Over-curb flooding after pipe-upsizing	Over-curb + BRC 1-in 10%	Over-curb + BRC 1-in 15%	Over-curb + BRC 1-in 20%	Over-curb + BRC 1-in 25%	Over-curb + BRC 1-in 100%
3.93	0.86	0	0.37	0.35	0.3	0.28	0.07
4.15	1.03	0	0.46	0.44	0.39	0.37	0.07
4.77	1.62	0	0.74	0.71	0.66	0.64	0.26
5.66	2.61	0	1.37	1.18	1.13	1.11	0.75
6.56	5.91	8.7	3.81	3.67	3.47	3.26	1.73
8.07	14.80	17.4	12.03	11.83	11.6	11.39	9.20
10.1	34.49	35.3	31.77	31.67	31.89	31.81	31.45

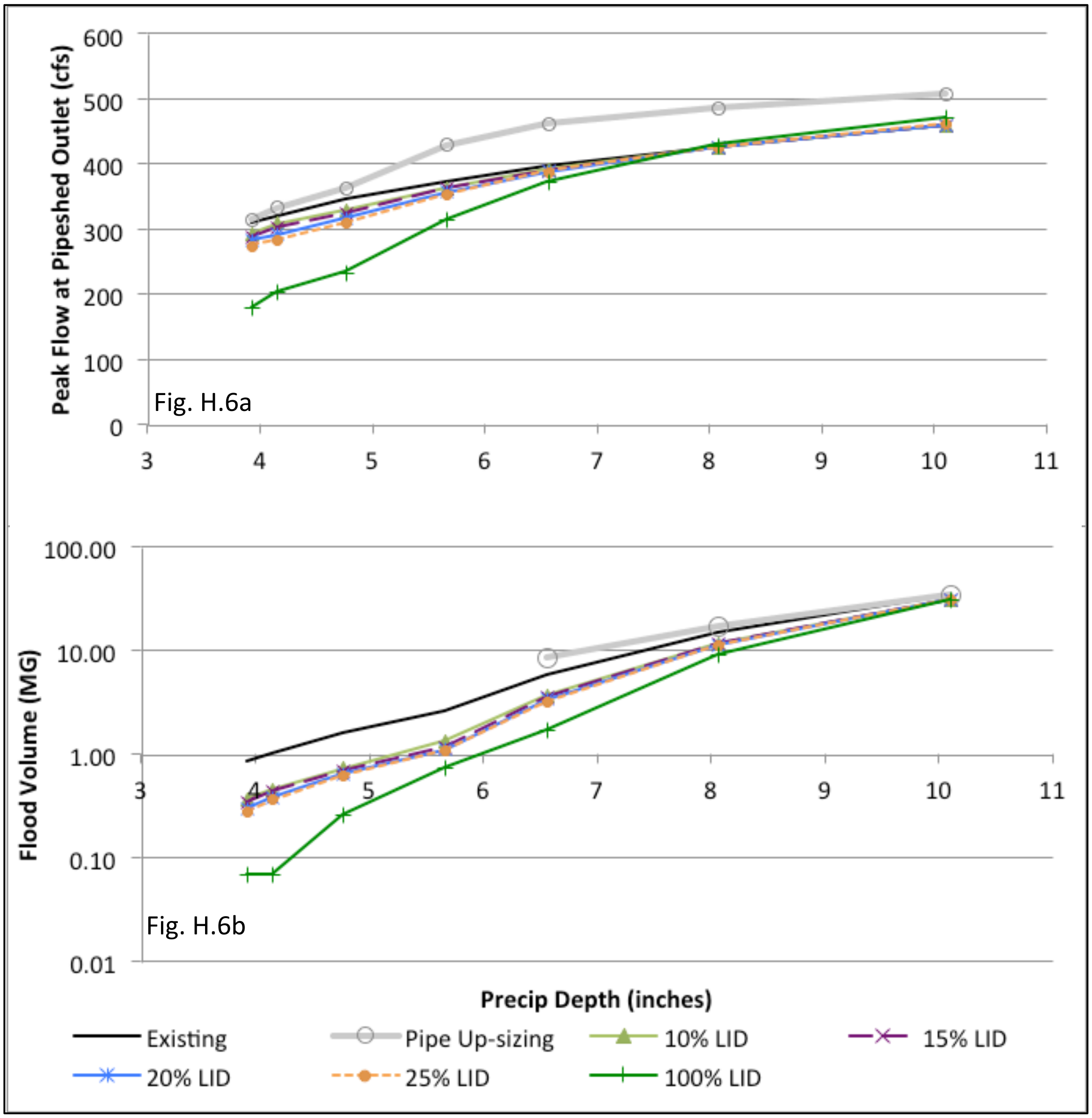


Figure H.6. Peak flow at the watershed outlet (a) and total flood volume (b) for existing conditions and adaptation options (pipe upsizing and LID implementation) under current and projected mid-century 10-year precipitation scenarios. Results reflect flood volume in excess of allowed surface storage (i.e., in constructed detention basins and over streets up to elevation of structures).

Pipe Upsizing

Flood volumes were effectively mitigated by increasing the diameter of pipes associated with downstream flooding up to a rainfall depth of 5.65 in. Achieving this reduction in flood volume for the 4.15- to 5.65-in precipitation scenario required increasing the diameter of 3,439 to 12,272 linear feet of pipes in the system (Figure H.7). As indicated in Figure H.6 and the bars in Figure H.7, continuing to increase pipe diameters for the 6.56-in and larger storms resulted in an increase in the total flood volume to that of the existing condition. This aberration can be explained by several factors, namely backwater effects of the receiving water body (Pipeshed 76-010), which, under high flows serves to (1) restrict free discharge of runoff from the pipe network to the lake and (2) contribute to negative (up-gradient) pipe flows as runoff unable to exit the system at Pipeshed 76-010 backs up into the pipe network and is ejected as surface flooding at low-lying areas of the system. Backwater flooding is exasperated by upstream pipe upsizing, through which the time of concentration at the pipeshed outlet decreases. Figure H.8 provides an example of a location in the system in which upstream pipe upsizing resulted in a transfer of the flood volume downstream.

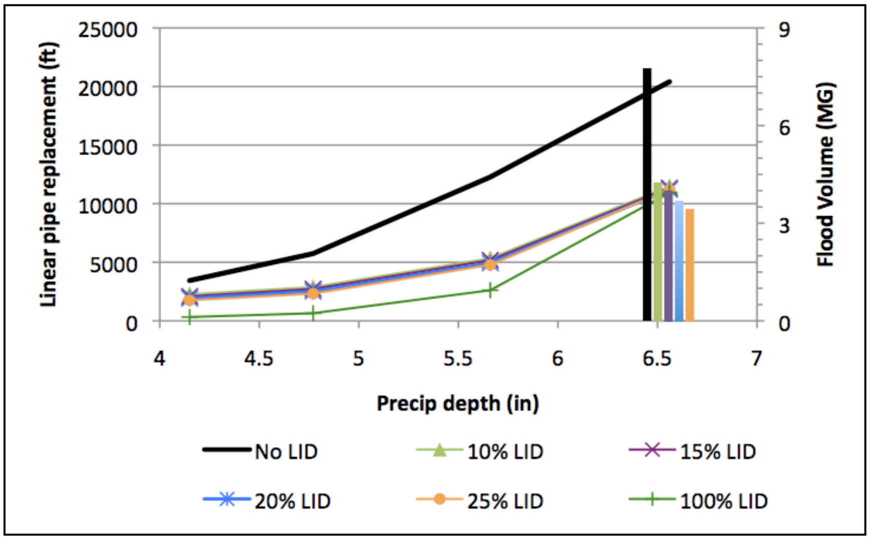


Figure H.7. Required length (linear feet) of pipes for which diameter must be upsized to eliminate flooding in excess of that allowed over streets and curbs up to the elevation of structures without (black solid line) and with various LID intensities. The bars on the chart specify the flood volume that remained even after pipe up-sizing for the 6.56-in precipitation scenario for (from left to right) no LID (black bar), 10% LID (green bar), 15% LID (purple bar), 20% LID (blue bar), 25% LID (orange bar). No flooding was predicted for the combination of pipe upsizing and 100% LID at the 6.56 in scenario.

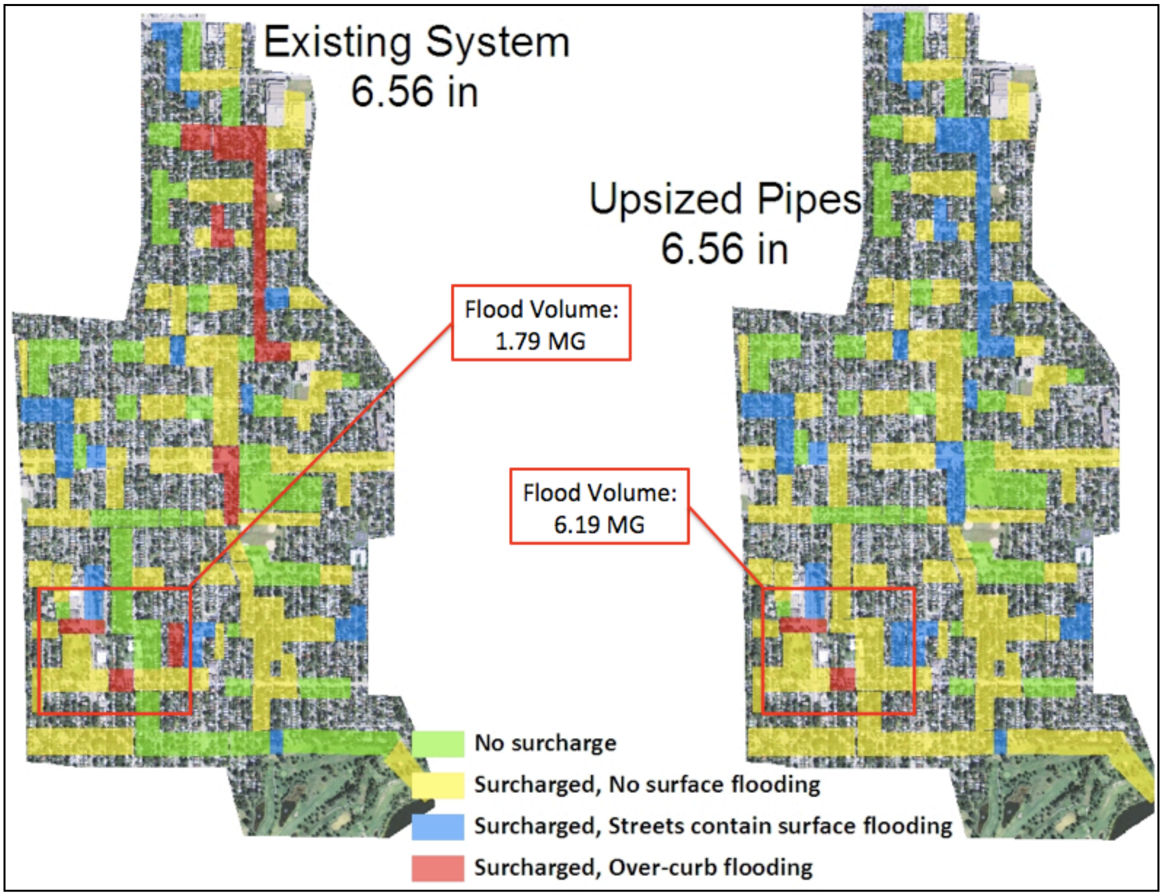


Figure H.8. Example of downstream flooding exasperation by upstream pipe up-sizing. While upsizing pipes in upper watershed eliminated unacceptable flooding (indicated by shift from red highlights in the left figure to blue highlights in the right), flood volumes were actually increased downstream. For the 6.56-in precipitation scenario, the volume of unacceptable flooding increased by about 4.5 MG within the area enclosed by the red box.

LID scenarios

In contrast to pipe upsizing, unacceptable flooding was not completely eliminated through any LID scenario, even for the most optimistic climate change projections (Figure R4). However, this result does not preclude the applicability of LID to stormwater adaptation planning; as indicated in Figure R4, unacceptable flooding was reduced by LID for all precipitation scenarios, even when only applied to 10% of the total pipeshed impervious area. Relative to the existing system, increasing the intensity of LID application from 10% to 25% of the watershed's impervious area resulted in a 7% reduction (from 39% to 46%) in flood volume as averaged across all mid-century precipitation scenarios. Capturing the first 25 mm of runoff from 100% of the impervious surfaces in the watershed resulted in an additional 20% reduction in flood volume relative to flooding predicted for the existing system. While greater reductions in the volume of unacceptable flooding were achieved by increasing the intensity of LID, these results indicate the return was diminishing. For example, though the 100% LID application represented a 10-fold increase in the volume of runoff stored over the 10% LID scenario, it only resulted in a 1.5-fold decrease in flood volume under a moderate climate change scenario (5.66-in 10-yr storm). Still, these results indicate that substantial reductions in flood volume can be achieved with a relatively modest reduction in impervious surface runoff through LID.

Although flooding was not completely eliminated through LID alone, the combination of LID and pipe upsizing may achieve this goal. By reducing the volume of runoff entering the storm sewer system, LID serves to reduce the total length of pipe that must be upsized were a combination of the two adaptation measures to be pursued (Figure H.7). Even with the combination of approaches, SWMM results indicate that the capacity to completely absorb excess flooding impacts is limited up to about a 6.5-in storm, which represents a 62% increase in the current 10-year design storm. Beyond this, backwater-related flooding limited the effectiveness of further pipe upsizing.

Victoria: Existing conditions.

As for Pipeshed 76-010, the relationship between precipitation (as a percentage increase in the existing 10-year design value of 4 inches) and hydraulic response of the stormwater network (as the percentage of components that are undersized) was examined. The hydraulic response of Victoria's stormwater system contrasts sharply with that of Pipeshed 76-010 (Figure H.8). Fewer than 1% of components in Victoria's stormwater system are undersized, that is, too small to pass the design storm scenario without resulting in surface flooding, up to a precipitation depth of about 5.6 inches. Thus, the system is adequately sized for up to a 40% increase in the existing design storm. Beyond this, Victoria's system displays a similar rate of increase in the number of undersized components for a given increase in precipitation as observed for Pipeshed 76-010, though the data follow a more logarithmic curve.

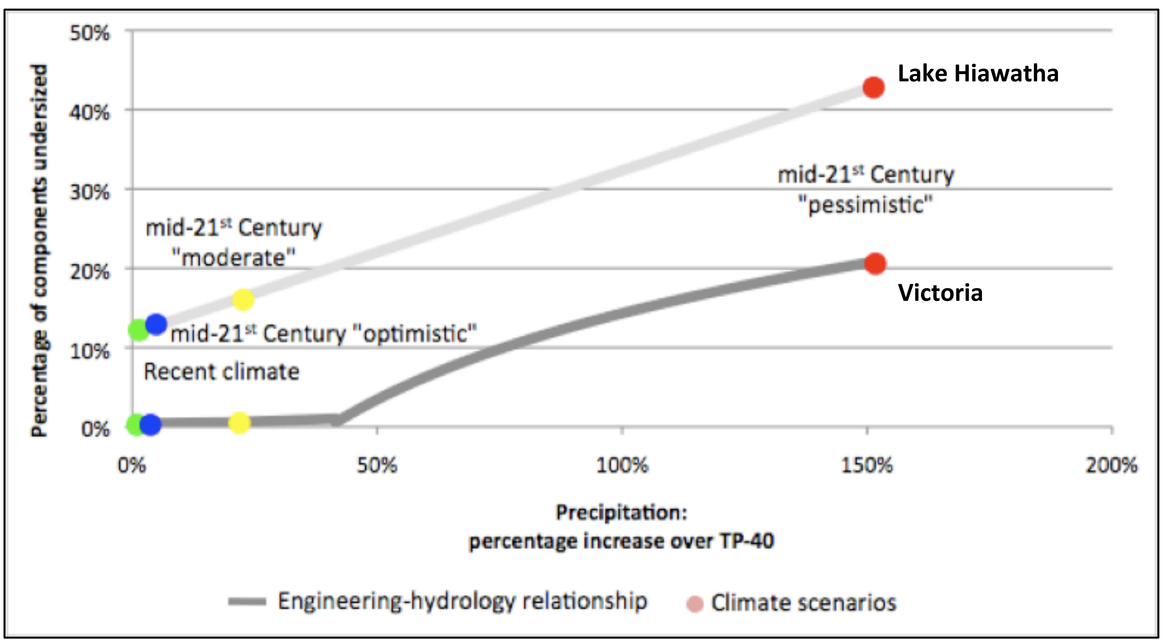


Figure H.8. Engineering – Hydraulic relationship between a given increase in the current 10-year design storm depth (4 inches) and the percent undersized components in the Victoria (dark gray line) and Pipeshed 76-010 (light gray line) stormwater networks. The percent components undersized for the recent (0% increase) and mid-century 10-year rainfall depths corresponding to optimistic (5% increase), moderate (28% increase), and pessimistic (150% increase) climate scenarios are overlain.

In a developing community such as Victoria, changes in climate are expected to act in concert with land use change upon hydrological processes. The influence of projected increases in impervious surface cover on peak flows and flood volume across a range of mid-century climate scenarios is presented in Figure H.9. In terms of both peak flow and flood volume, future climate is expected to exert a disproportionately greater effect on the hydrology of the Victoria study area relative to projected increases in impervious surface cover, particularly for moderate to pessimistic climate scenarios. Projected flood volumes from individual components of the Victoria SWMM model were combined with 1-meter resolution elevation data to identify areas that were most vulnerable to flooding. Areas where surface flooding is expected to accumulate are highlighted in Figure H.10. The status of constructed stormwater ponds, which are a prominent feature of Victoria's stormwater management network, is also displayed. The storage volume available in all ponds was sufficient up to the 6.56-in scenario, at which point 8 of the 31 ponds overtopped (Figure H.10b). Thirteen ponds, representing 40% of the total, overtopped in the most pessimistic scenario. It should be noted that even for the most pessimistic climate scenario examined (10.1 inches), all surface flooding in Victoria was contained within streets and public open spaces. In the context of the Pipeshed 76-010 pipeshed, this level of flooding, since it is not expected to pose any hazard to structures or life, would be deemed acceptable. However, if the objective were to uphold a similar level of service (i.e., no surface flooding), other adaptation methods would be necessary.

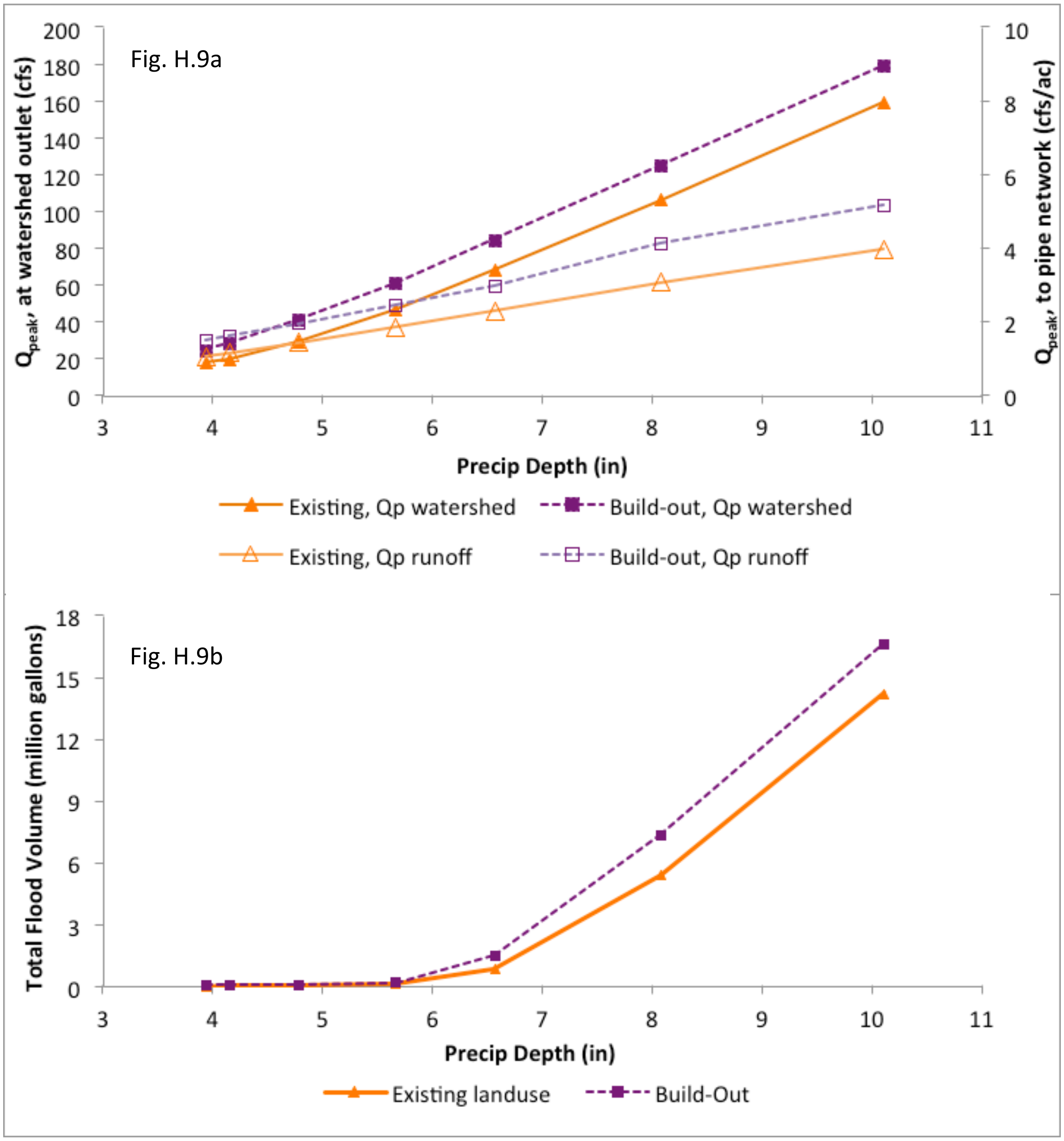


Figure H.9. Hydrologic/hydraulic response of the Victoria study area to mid-century 10-year storm projections for existing landuse (solid lines) and projected build-out (dashed lines): (a) peak flow at the watershed outlet (closed symbols) and average subcatchment peak flow delivered to the stormwater pipe network (open symbols) and (b) total surface flood volume.

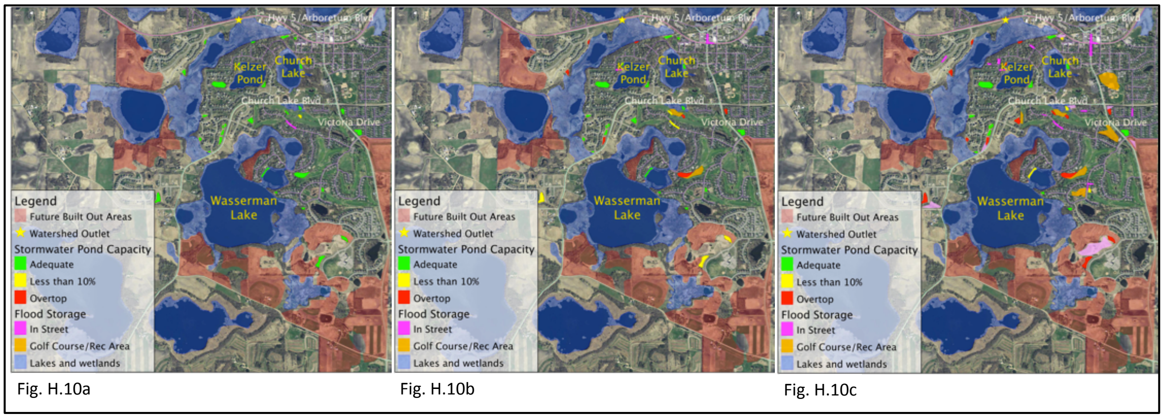


Figure H.10. Vulnerability mapping of Victoria's stormwater system under future climate and landuse changes for the (a) 3.93-inch, (b) 6.56-inch, and (c) 10.1-inch precipitation scenarios. Constructed stormwater ponds are highlighted according to remaining volume for stormwater storage: adequate (green), less than 10% storage volume remaining (yellow), or volume exceeded such that pond overtops (red). Areas of the landscape where flooding is expected to accumulate include streets (pink) and public open spaces (orange), and naturally occurring lakes, wetlands, and stream (blue).

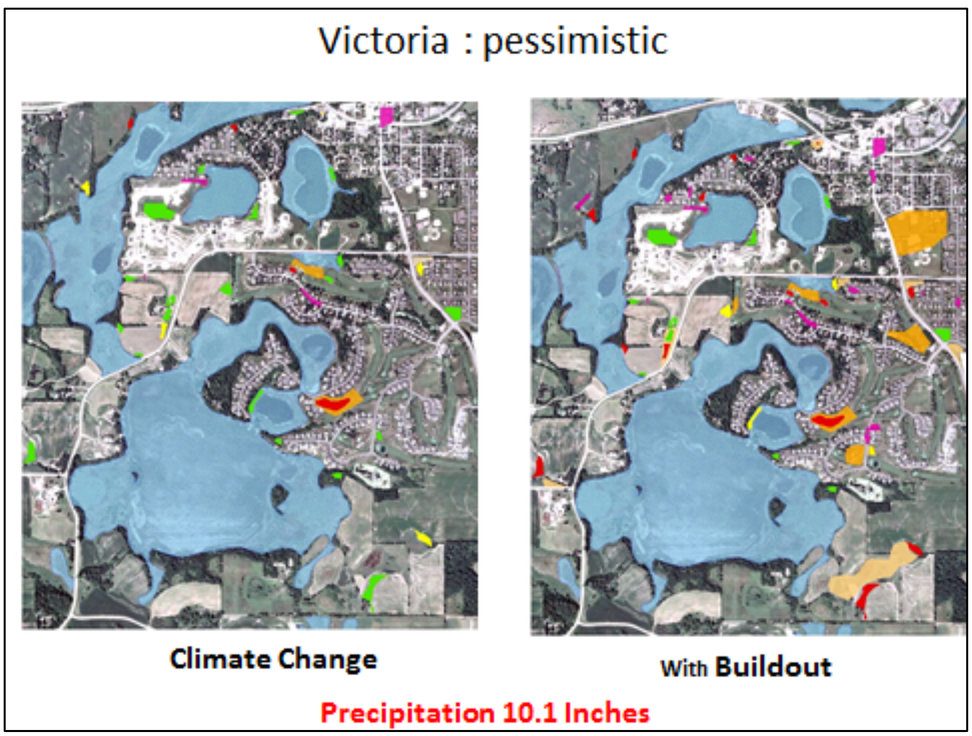


Figure H.11. Impact of population growth on surface flooding.

Victoria: Adaptation options

The following adaptation options were considered for the Victoria study area: (1) allow flooding confined to streets and public spaces (i.e., "do nothing"), (2) up-size pipes to convey projected peak flows and eliminate flooding completely, and (3) implement LID at various intensities to reduce flood volumes by increasing infiltration. The effect of pipe-upsizing and LID on flood volume and peak flow relative to the "do-nothing" approach is illustrated in Figure H.12 and is discussed further in the following sections.

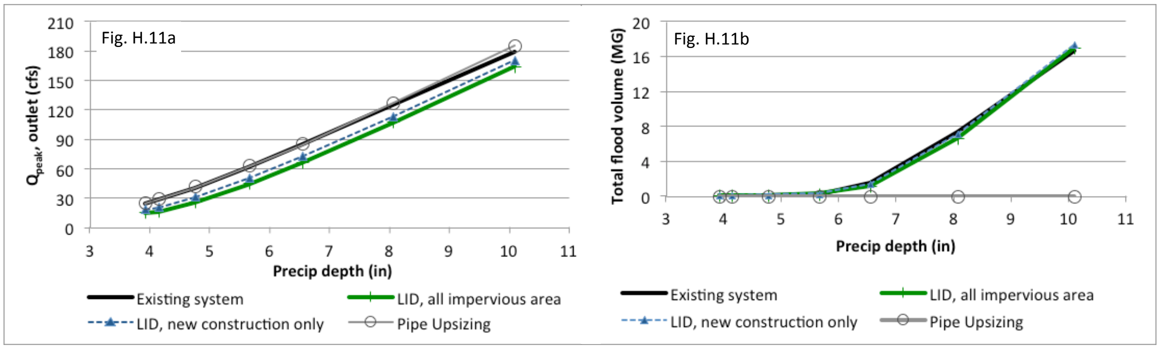


Figure H.12. Comparison of (Left) total peak flow at the watershed outlet and (Right) total volume of surface flooding for the Victoria study site, as modeled with (1) the existing stormwater network and projected build-out conditions (solid black line), (2) pipes upsized as necessary to completely eliminate all surface flooding (gray line with open circles), (3) LID applied to capture the first 25 mm (1 in) of runoff from new construction associated with projected build-out (blue dashed line with closed triangles) and (4) LID applied to capture the first 25 mm (1 in) of runoff from all impervious surfaces in the watershed (green solid line with vertical hashes). The depth of rain associated with the range of climate scenarios examined is on the x-axis of both charts.

Pipe Upsizing

After determining the volume of flooding for Victoria's existing stormwater system under projected climate and land use changes, the diameter of individual pipes was increased in SWMM to eliminate surface flooding from streets and public open spaces. In contrast to the Pipeshed 76-010 pipeshed, flooding associated with climate change projections could be completely mitigated through pipe upsizing. The total length of upsized pipes ranged from 577 ft. for the 4.15- and 4.77-in precipitation scenarios, up to 14,132 ft. for the pessimistic 10.13-in scenario (Figure H.13). As expected, increasing pipe diameters increased the peak flow at the watershed outlet (Figure H.12a); however, the increase was nominal (1-5% across all mid-21st century precipitation scenarios). This is likely due to the buffering effect of the watershed's network of stormwater ponds and natural lakes and wetlands.

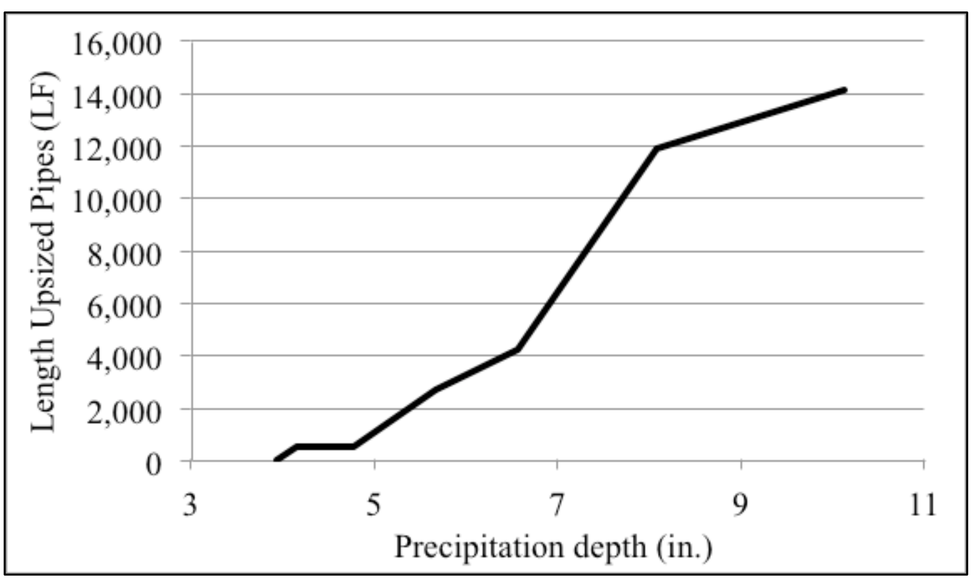


Figure H.13. Required length (linear feet) of pipes for which diameter must be upsized to eliminate surface flooding in streets and public open spaces in the Victoria study area for the range of mid-century precipitation scenarios examined.

In SWMM, LID elements were created to simulate two LID scenarios in which the first 25 mm (1-in) of runoff from impervious surfaces was captured and infiltrated for (1) all impervious surfaces in the study area and (2) only those impervious surfaces associated with new construction due to projected build-out. As was the case in the Pipeshed 76-010 pipeshed, projected flooding was not fully mitigated by LID practices (Figure H.12). The reduction in flood volume was greatest for the 6.56-in precipitation scenario (26% as applied to all impervious surfaces; 13% for new construction only). However, flood volume reductions were generally less than 10% from the existing system for either LID treatment for all other climate scenarios. The nominal decrease in flooding achieved by LID likely reflects some limitation to infiltration by clay-like soils ($K_{sat} = 1.34x10^{-6}$ m/s; Table H.2) in the Victoria study area. For this reason, the addition of LID to manage runoff from the landscape is not expected to have a substantial effect on the length of pipe that would need to be upsized to completely eliminate surface flooding for all mid-century precipitation scenarios.

Cost analysis for selected structural adaptation tactics

This analysis provides planning-scale cost estimates for several stormwater management alternatives, to adapt existing systems for conveying projected mid-21st century design runoff in Minneapolis and Victoria. The stormwater management projects from which costs were derived are not engineered designs, as would be found in a typical project bid document. Rather these are projections made at a planning-scale for the comparing costs and benefits of particular tactics, to support the cities and stakeholders in planning.

Adaptation plans typically consist of a variety of tactics that can be combined in various ways (Hasnoot et al., 2013). A community selects a set of adaptation pathways that provide sufficient adaptive capacity and flexibility for accommodating uncertainty; and that are achievable within its tolerance for risk, political environment, and economic resources.

Adaptation pathways consist of a combination of tactics that might include: creating barriers to the impact; changing infrastructure to assimilate the impact; changing expectations through policies, so to accommodate the impact; moving away from the impacted areas; and doing nothing, which implies accepting a higher-than historical risk. All have both quantifiable and intangible costs and benefits. For this study, cost analyses were performed for five adaptation actions:

- Replacing the existing system with larger pipes
- Diversion of excess waters to detention basins
- Diversion of excess waters to underground storage
- Cost mitigation from instituting Low Impact Development
- Damage costs for waters exceeding curb-height

There are differences between the two cities in the conditions that determine the rate of undersized components (Figure C.1), and therefore the costs to adapt that each will face. Costs will not be comparable, and the optimal mix of tactics will differ between the cities. The images in Figure C.2 reflect current land use. Pipeshed 76-010 site is fully built-out, while Victoria has a more recent history of urban development and build-out and retains significant areas of undeveloped land. Minneapolis has greater challenges in accommodating increased runoff, Victoria is better positioned to pro-actively implement plans such that future development supports rather than hinders management of more extreme events.

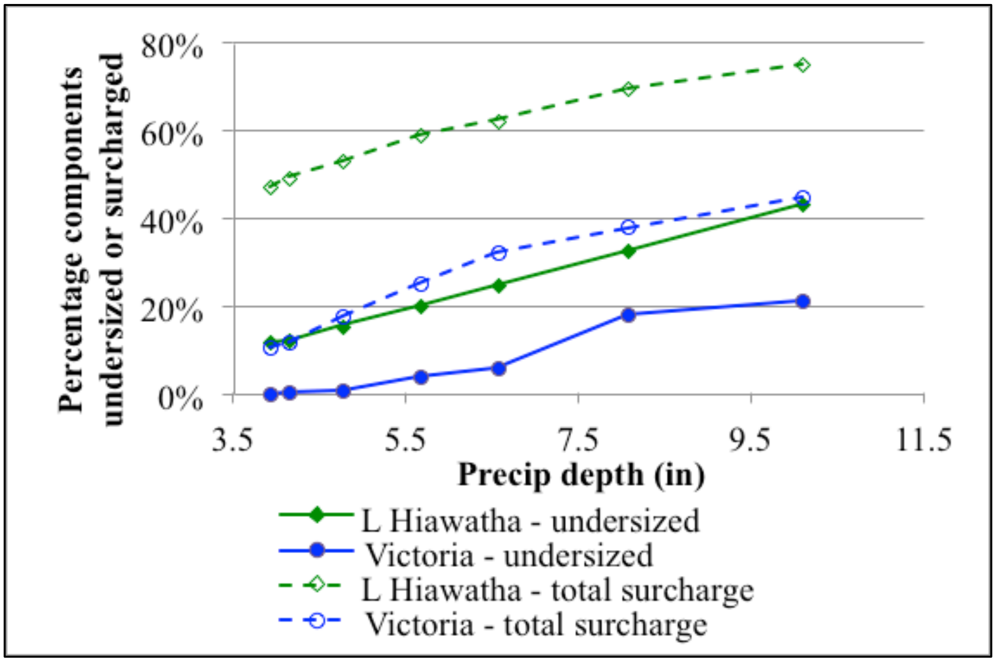
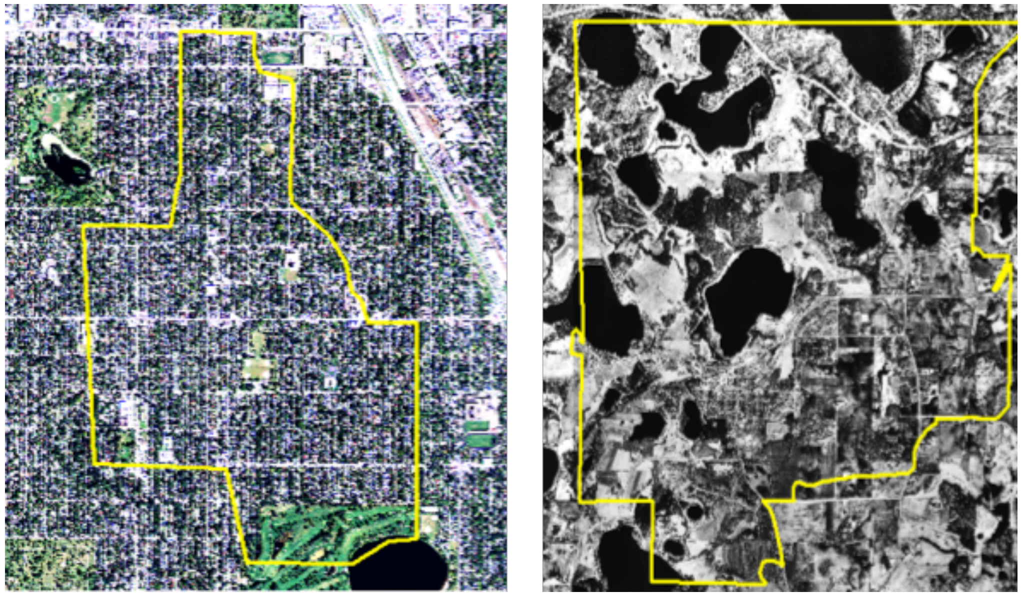


Figure C.1. Performance of the existing systems differ between the two cities.



Lake Hiawatha **Victoria**

Figure C.2. Landuse and population density vary between the two cities.

Pipe upsizing

Minneapolis pipeshed 76-010

Previous water conveyance vulnerability studies, which primarily focused on rural/peri-urban systems costs, analyzed the marginal costs of upgrading culvert diameter for road crossings (Simpson et al., 2010, Stack et al., 2012). But within an urban integrated drainage system the cost impact of increasing the diameter of a pipe is a small incremental cost compared to the overall scale of a typical project. Such a project may require street removal, utilities by-pass, and possible mitigation of historically contaminated soils. Our analysis used the actual costs of recent stormwater pipe replacement projects, provided by the City of Minneapolis, that implicitly included managing conditions encountered in urban sites. This data provided a typical cost per linear foot of pipe replacement, which was then applied to the length of pipe that the hydrologic/hydraulic modeling indicated as undersized for a scenario.

Eight projects formed the basis for this replacement piping cost analysis (Table C.1). The projects varied in scale and scope, with most having multiple infrastructure replacement/creation objectives beyond just repairing or upgrading.

Table C.1 shows the results of culling out activities from each of the projects that could be attributed to replacing the storm water pipes. These are divided into two sets of activities, that part of the project associated specifically with excavation and replacement of the street and associated utilities, and that part of the project associated specifically with replacement of the storm water pipes. All costs are in 2013 dollars. The cost per linear foot of pipe is based on the total estimated cost.

Table C.1. Projects serving as sources for the pipe-upsizing cost analysis

Project	Project 1	Project 2	Project 3	Project 4
Street ($)	3,540,000	3,070,000	3,350,000	400,000
Stormwater ($)	1,020,000	450,000	570,000	260,000
Total ($)	4,550,000	3,510,000	3,920,000	660,000
Piping (ft)	6,100	2,300	2,600	1,200
Piping (S/ft)	750	1,540	1,530	570

Project	Project 5	Project 6	Project 7	Project 8
Street ($)	860,000	670,000	440,000	1,330,000
Stormwater ($)	1,800,000	590,000	510,000	570,000
Total ($)	2,670,000	1,260,000	950,000	1,900,000
Piping (ft)	2,100	2,800	2,500	3,100
Piping (S/ft)	1,280	450	380	620

The per-foot cost of piping has a high range, and is not highly correlated with total project costs (Figure C.3). This would be expected with a City that has existed as an urban center for well over a century. Multiple development/redevelopment efforts happened in different parts of the urban boundary, at different times, and under different regulatory and design parameters. These factors result in a variety of street and below-ground city infrastructure that impacts the variability in costs.

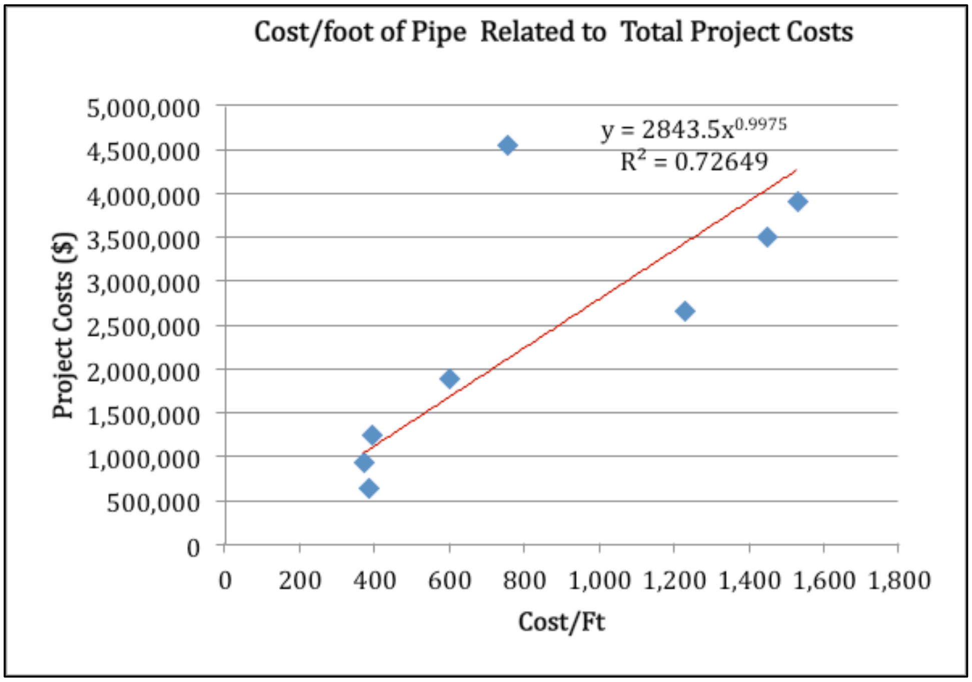


Figure C.3. Fit of total costs for actual projects to a power function.

On average the storm water piping replacement costs were 36% of total project costs. Average cost per linear foot was $890. Because the cost per linear foot were normally distributed (CV <1), a normal Student t-test yielded an upper and lower 95% confidence interval (Table C.2). These costs per foot were used to derive a range of pipe replacement costs for each precipitation scenario (Table C.3, Figure C.4), based on the results of the hydrologic analysis.

Table C.2. Minneapolis pipe replacement cost per linear foot

Cost per linear foot		
Low (- 95% CI)	**Mid (mean)**	**High (+ 95% CI)**
490	890	1,290

Table C.3. Pipeshed 76-010, estimated cost to increase pipe capacity for various design events.

Precipitation (in)	Pipe Replacement (linear ft)	Cost		
		low	**mid**	**high**
4.15	3400	1,800,000	2,900,000	4,000,000
4.77	5700	3,000,000	4,800,000	6,600,000
5.66	12300	6,300,000	10,300,000	14,200,000
6.56	20400	10,600,000	17,000,000	23,500,000
8.07	20400	10,600,000	17,000,000	23,500,000
10.1	20400	10,600,000	17,000,000	23,500,000

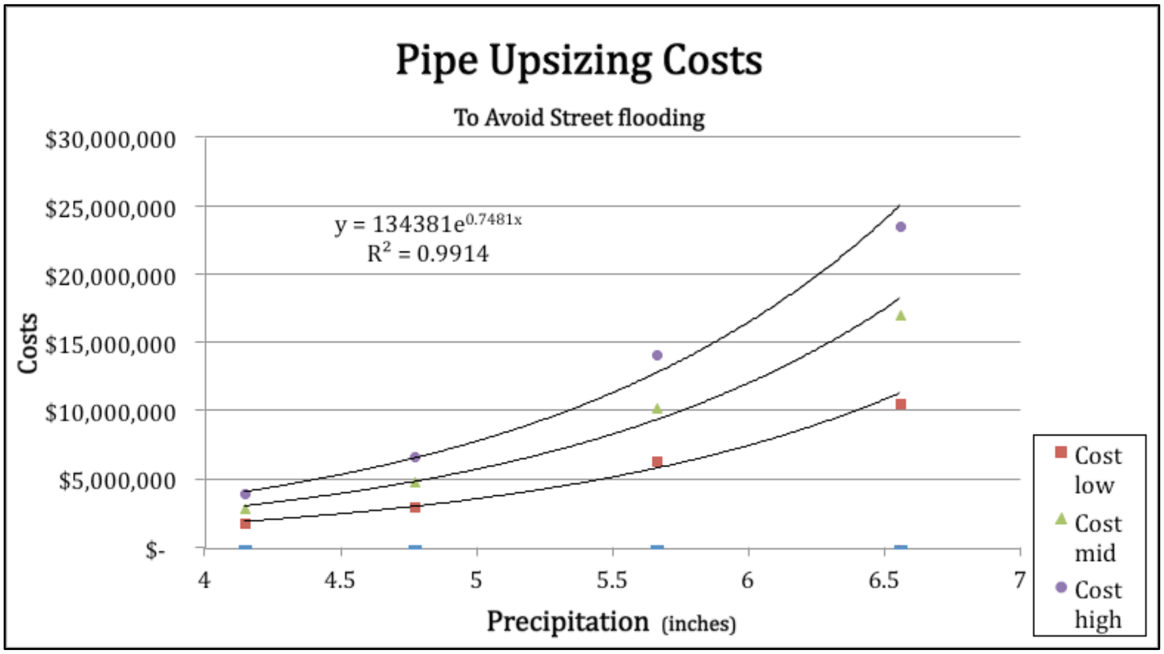


Figure C.4. Range of estimated pipe upsizing costs for a given precipitation depth. For precipitation depths greater than 6.56", pipe sizing is not possible due to down-pipe constraints.

From the linear-foot cost coefficient for pipe upsizing, a cost-per-volume was derived. For Pipeshed 76-010, the volume difference between pre- and post-upsized pipe flooding was divided by *most likely* cost estimators ("mid" estimates on Table C.3), to estimate a cost-per-volume ($/MG) coefficient (Table C.4). Although somewhat artificial, the cost-per-volume coefficient provides a basis for comparing pipe upsizing with other adaptation tactics such as dry detention basin costs and underground storage costs.

Figure Table C.4. Pipeshed 76-010, cost-per-MG of mitigated flood volume.

Precip. (in)	Pipe replacement (LF)	Costs for upsizing piping ($)	Flood volume, pre-pipe upsizing (MG)	Flood volume, post-pipe upsizing (MG)	Volume mitigated by upsizing (MG)	Cost per MG
4.15	3,400	2,873,000	3.95	1.46	2.49	900,000
4.77	5,700	4,796,000	5.57	1.46	4.11	1,900,000
5.66	12,300	10,253,000	8.43	3.38	5.05	2,500,000

The hydrology/hydraulic analysis determined that there was a limit to which pipes could be enlarged in one part of the pipeshed without increasing street flooding in another (Figure H.8). Thus, other options such dry storage basins or underground storage need to be considered for diverting excess water above 6.56 inches.

Victoria

Victoria's urban infrastructure is more recent and undoubtedly has less historic variability in their street and underground infrastructure as one would see in a much older urban area such as Pipeshed 76-010 study location. In addition, currently Victoria has the capacity to in-fill, and also expand, its urban area. Thus, the cost analysis for Victoria required determining not only undersized stormwater pipes for current conditions, but also conditions if the community was built-out (Figure H.11).

For the current drainage system and landuse, Victoria has the capacity to manage, without flooding, rainfall events up to the 5.6 inch, 24-hr precipitation event. Above this amount, pockets of street and associate property flooding are observed. With the build-out scenario one can see impacts to the system, even at the historical (TP-40) 10-yr, 24-hr precipitation event. Figure H.13 shows the linear feet estimated to require upsizing for the built-out scenario.

The same cost per linear foot coefficient utilized in Minneapolis was applied to estimate the piping system upgrade costs for undersized components in Victoria Table C.5. For different precipitations depths, the table reflects the required length of pipe in order to avoid street flooding in Victoria.

Table C.5. Estimated Pipe Upsized Costs: Victoria

Precipitation (in)	Pipe Replacement (linear ft)	Cost		
		low	mid	high
4.15	550	280,000	460,000	630,000
4.77	550	280,000	460,000	630,000
5.66	2,700	1,400,000	2,200,000	3,100,000
6.56	4,200	2,200,000	3,500,000	4,800,000
8.07	11,900	6,100,000	9,900,000	13,700,000
10.1	14,100	7,300,000	11,800,000	16,300,000

Dry Basins

Minneapolis pipeshed 76-010

Because pipe upsizing for this pipeshed was not viable for precipitation events greater than 6.56”, we estimated the cost for diverting runoff to dry detention basin storage and underground storage. Both would allow capacity to hold and gradually release water through infiltration between storm events.

Detention basins have been incorporated within both Minneapolis’ and Victoria’s approach to storm water management. Within the Pipeshed 76-010 study site, three detention basins built after previous flood events were located (Figure C.5).

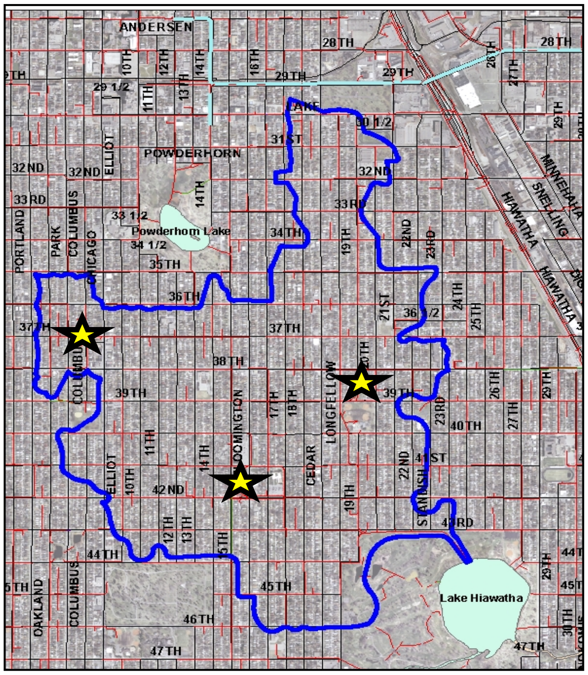


Figure C.5. Location of Existing Detention Basins in pipeshed 76-010

An example of these is the Bancroft Meadows flood basin built in 1989, at Bloomington and 42nd streets, in Minneapolis (Figure C.6).


Figure C.6. Dry-Detention Basin: pipeshed 76-010

Victoria has historically looked to wet detention basins for new development, usually with a two tier approach. This consists of an initial holding pond, with a headboard height designed for the historic (TP 40, 24-hr) 100 year storm event, and followed by a wetland infiltration system (Figure C.7).

Figure C.7. Detention Pons & Associate Wetland: Victoria

For different precipitation depths, Table C.6 reflects the volume of water that would flood streets after upgrading pipes. Dry basin costs were calculated based on the volume of over-curb flooding. For the Victoria numbers, an assumption was made that by mid-century that Victoria would be built-out.

Table C.6. Estimated flooding after pipe upsizing

Precipitation (in)	Flooding (MG)	Street Flooding (storage) (MG)	Over-Curb Flooding (MG)	Over-Curb Flooding (acre-feet)
Pipeshed 76-010				
6.56	10.1	1.4	8.7	26.0
8.07	20.0	2.6	17.4	58.0
10.1	40.1	4.8	35.3	107.0
Victoria				
6.56	1.6	0.7	0.9	2.8
8.07	7.4	4.4	3.0	9.2
10.1	16.7	9.2	7.5	22.9

Two methods were used to estimate costs for dry storage extended detention basins. The first was to utilize the approach developed by Weiss et al., (2007). The second utilized empirical data supplied by the City of Minneapolis for actual construction costs of three dry detention basins that were created within the study area.

Weiss et al., (2007) analyzed the costs of both construction and annualized operations and maintenance (O&M), for dry extended detention basins across the United States from the published literature (Figure C.8). They defined these systems as having the capability to typically detain storm water for at least 48 hours.

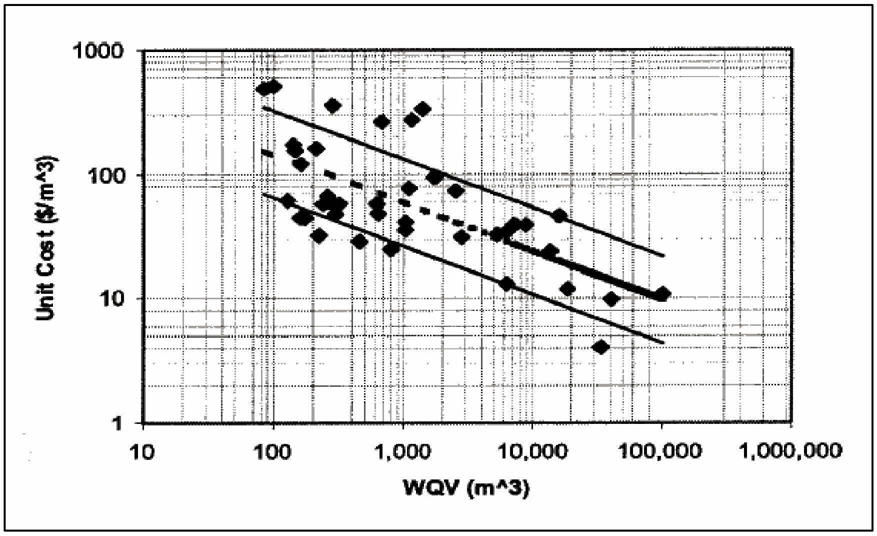


Figure C.8. Dry Basin Construction Costs (after Weiss et al., 2007)

From this data, unit construction costs were calculated and graphically presented. Added to the construction costs was an annualized O&M cost, applied over a 20-year lifetime calculated for net-present-value. O&M costs were typically less than 1% of construction costs. From this, constants were developed for total costs (within a 67% confidence interval). The resulting total present-value cost, excluding land costs, for the dry detention basin can be represented by a best fit equation, with constants shown in the following Table C.7:

$$TPC = \beta_0 (WQV)^{\beta_1}$$

where:

TPC = total costs, at present value
WQV = water volume (m^3)
and β_0 and β_1 are constants

Table C.7 Range of values for factors in dry basin costing, after Weiss et al., 2007.

Low (-67% CI)		Mid (mean)		High (+67% CI)	
β_0	β_1	β_0	β_1	β_0	β_1
1,055	0.585	1,281	0.634	2,024	0.671

This formula was applied to the over-curb flooding volumes developed through the hydrology/hydraulic analysis of the piping systems for both the Pipeshed 76-010 and Victoria study sites.

An additional method was used to estimate the cost per volume of dry detention basins. The City of Minneapolis provided costs and storage capacity design for five dry-detention basins they have built (Eberhart, 2014, Table C.8). The mean and then a 95% CI was developed for this small data set to estimate the high and low projections for a cost per volume. Table C.7 shows the cost per volume based on information provided by Minneapolis, with a mean of $121,000 per million gallons (2013 dollars).

Table C.8. Historical dry basin installed cost for recent projects, Minneapolis

Project cost (2005 dollars)	Volume (acre-ft)	Volume (MG)	Cost/volume (MG)
4,600,000	15	46.05	99,891
6,300,000	15	46.05	136,808
7,100,000	30	92.10	77,090
10,000,000	50	153.50	65,147
10,800,000	27	82.89	130,293

Tables C.9, C.10, C.11 summarize the range of projected costs (in 2013 dollars) for installing dry detention basins just for the over-curb flooding after pipes have been upsized to their effective maximum. Tables C.9, C.10 use the Weiss et al., (2007) methodology for developing cost coefficients, Table C.11 is based on actual Minneapolis project costs.

Table C.9. Pipeshed 76-010: dry basin costs, post pipe-upsizing, Weiss et al., 2007 methodology

Precipitation (in)	Over-Curb Flooding (MG)	Over-Curb Flooding (m^3)	Costs (low estimate)	Costs (high estimate)
6.56	8.7	33,000	554,000	2,602,000
8.07	17.4	66,000	832,000	4,143,000
10.1	35.3	134,000	1,258,000	6,659,000

Table C.10. Pipeshed 76-010: dry basin costs, post pipe-upsizing, regression from Minneapolis actual project costs.

Precipitation (in)	Over-Curb Flooding (MG)	Over-Curb Flooding (m^3)	Costs (low estimate)	Costs (high estimate)
6.56	8.7	33,000	777,000	1,337,000
8.07	17.4	66,000	1,554,000	2,673,000
10.1	35.3	134,000	3,154,000	5,423,000

Table C.11. Victoria: dry basin costs, post pipe-upsizing, Weiss et al., 2007 methodology

Precipitation (in)	Over-Curb Flooding (MG)	Over-Curb Flooding (m^3)	Costs (low estimate)	Costs (high estimate)
6.56	0.91	3,000	148,000	570,000
8.07	2.9	11,000	296,000	1,267,000
10.1	7.47	28,000	1,015,000	2,342,000

Underground Storage

For in-filled urban areas with little available open space, an additional stormwater management tactic is the construction of underground storage, with holding tanks that allow a gradual infiltration of captured run-off. Minneapolis has been progressive in considering these, especially in areas that topographically and historically has seen repeated street flooding. An example for this was the construction of the 37th Avenue Greenway flood project constructed in 2011 (Figure C.9). This project was designed to store stormwater in large underground storage chambers, combined with on-surface low impact development installations to mitigate storm water quality.

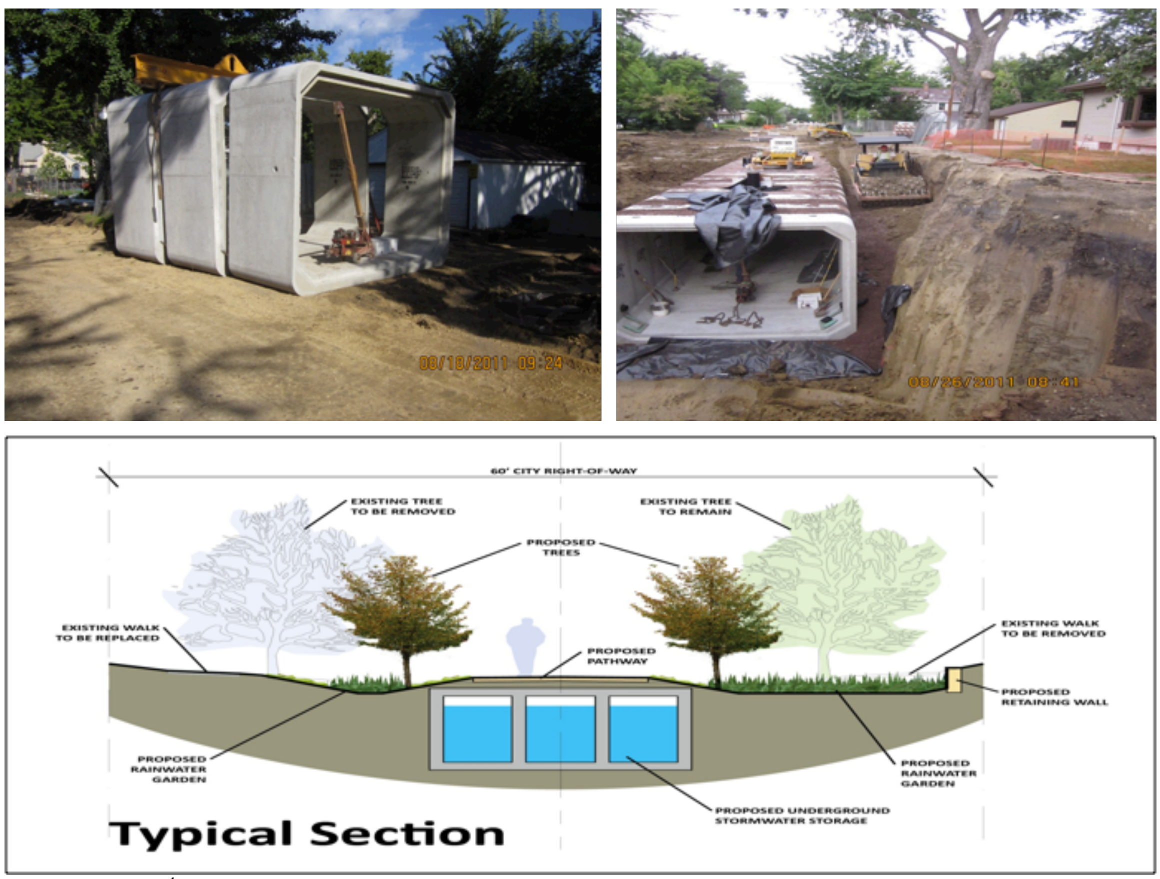


Figure C.9. 37th Avenue Greenway Flood Project (2011)

Similar to the dry detention basin cost estimate, this analysis targeted the same over-curb flooding volumes found at precipitation depths above the effectiveness of pipe upsizing

(Table C.6). From actual project budget sheets for the 37th Avenue Greenway flood project, the volume of underground storage provided by that project, excluding storage within pipes and on-surface basins, was 152,000 cu feet, which translates to 1,136,000 gallons, or 3.48 acre-feet (Table C.12).

Table C.12. 37th Avenue Greenway Flood Project: Underground Storage

Cement storage components	Square feet	Linear feet	Cubic feet
12x5	60	118	7,080
12x8	96	534	51,264
12x10	120	304	36,480
18x6	108	154	16,632
18x8	144	281	40,464
sum:			151,920

With a project cost of \$ 2,631,189, this translates to \$2.40 per gallon, or \$783,000 per acre-foot of underground storage (in 2013 dollars). This coefficient was rounded to \$780,000 and applied to the project over-curb gallons estimated at different rainfall depths. Table C.13 summarizes the estimated costs for underground basin storage for the over-curb flooding after pipe upsizing is no longer deemed an effective stormwater mitigation strategy.

Table C.13. Estimated cost of underground storage, and number of projects required.

Precipitation (in)	Over-curb flooding (MG)	Over-curb flooding (acre-feet)	Underground storage cost estimate (\$)	Required # of projects comparable to 37th Ave.
Lake Hiawatha				
6.56	8.7	26.0	20,300,000	8
8.07	17.4	58.0	45,200,000	15
10.1	35.3	107.0	83,500,000	31
Victoria				
6.56	0.9	2.8	2,200,000	1
8.07	3.0	9.2	7,200,000	3
10.1	7.5	22.9	17,900,000	7

Unit cost factors that were developed for the various runoff management scenarios are summarized in Table C.14.

Table C.14. Cost coefficients for different adaptation strategies

Upsizing Pipes cost/foot[1]	Upsizing Pipes cost/MG[2]	Dry Detention Basin cost/MG	Underground Storage cost/MG[3]
$835	$1,772,000	$93,000[4] - $121,000[5]	$2,400,000

[1] Used mid value

[2] Used the mean of the three values developed at different precipitation depths of

[3] Only one value created from the 37th Ave project found in Minneapolis, the cos

[4] For the three precipitation depths of 6.56", 8.07 , 10.1" the cost/MG ranged fro

[5] Derived from five dry detention basin projects in Minneapolis with a range fror

Impact of LID on structural adaptation cost

One approach to mitigating future impacts to stormwater flooding is to consider instituting low impact development (LID) strategies for new construction, and provide incentives for existing residents and businesses to consider incorporating LID alternatives on-site. Minneapolis has been progressive in looking at LID alternatives for both transportation and commercial development. Through their stormwater fee system they provide an economic incentive for residents to incorporate LID approaches on their property that both mitigate stormwater volumes and quality impacts.

The LID standard used in this study provided a realistically achievable specification of one inch (1") of effective storage, for both Pipeshed 76-010 and Victoria. This specification was established for previous installations, and was found to have a less-than 5% impact on construction costs for new construction (Roseen, 2013).

The reduction in both linear feet of required pipe upsizing and in over-curb flooding was determined, and cost savings were estimated for pipe upsizing, dry detention basins, and underground storage, using the previously derived unit cost rates.

The total length of pipe to be upsized did not change in the Victoria study site because the LID scenarios only minimally reduced runoff peak flows and pipe surcharge. This may be due to the K_{sat} of soils in the Victoria study area.

For Pipeshed 76-010, the mitigation to upsizing pipes as the result of LID can be seen in Table C.15.

Table C.15. For Pipeshed 76-010, reduction in pipe upsizing costs due to LID.

Precipitation (inches)	Feet of Pipe Replacement (no LID)	Feet of Pipe Replacement (10% LID)	Feet of Pipe Replacement (25% LID)	Mid Cost (no LID)	Mid Cost (10% LID)	Mid Cost (25% LID)
4.15	3,000	2,000	2,000	2,900,000	1,900,000	1,500,000
4.77	6,000	3,000	2,000	4,800,000	2,400,000	1,900,000
5.66	12,000	5,000	5,000	10,300,000	4,500,000	4,000,000
6.56	20,000	11,000	11,000	17,000,000	9,600,000	9,400,000
8.07	20,000	20,000	20,000	17,000,000	17,000,000	17,000,000

Note in Table C.15 that a reduction in piping upsizing costs occurred until a precipitation depth 6.56 inches, however no reduction in the quantity or cost of pipe replacement was achieved for precipitation of 8.07 inches. Figure C.10 shows that the marginal value of LID decreases for precipitation above 6.56 inches.

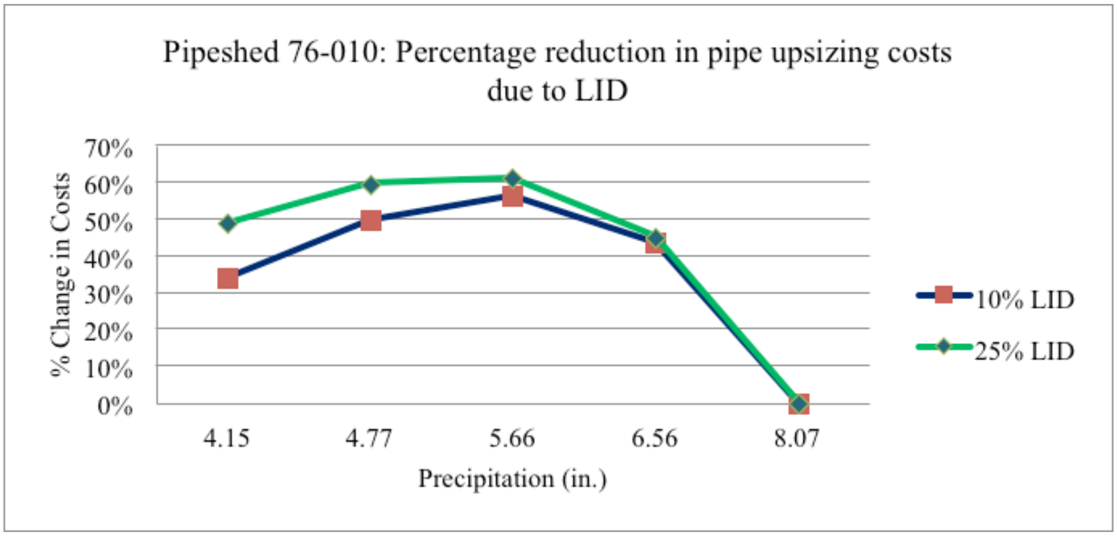


Figure C.10. Limits of cost benefit from LID, as precipitation increases.

The rise and drop in cost reduction due to implementing LID that is seen in Figure C.10 can be attributed to the diminishing impact of the fixed 1" storage capacity assumption that drove the model. At some point this storage capacity is reached, and any continued precipitation contributes to street and over-curb flooding. The efficacy of LID for reducing over-curb flooding without pipe upsizing can be seen in Table C.16.

Table C.16. Pipeshed 76-010: Over-curb Floodwater Storage Reduction Due to LID

Precipitation	Over-curb Flooding (MG)	Over-curb Flooding (MG) w/ 10% LID	% Reduction of Volume for 10% LID	Over-curb Flooding (MG) w/ 25% LID	% Reduction of Volume for 25% LID
3.93	0.9	0.4	57%	0.3	67%
4.15	1.0	0.5	55%	0.4	64%
4.77	1.6	0.7	54%	0.6	60%
5.66	2.6	1.4	48%	1.1	57%
6.56	5.9	3.8	36%	3.3	45%
8.07	14.8	12.0	19%	11.4	23%
10.1	34.5	31.8	8%	31.8	8%

If we were to just look at the cost impact of over-curb flooding from instituting LID without piping being upsized, one sees some avoided costs realized. However, above an 8.07 inch precipitation event, the mitigation of over-curb flooding from a LID strategy drop off significantly (Table C.16).

Table C.17, C.18, shows the reduction in costs achieved by LID, for dry detention basins and underground storage. As with pipe upsizing, the rate of cost savings declines as precipitation increases beyond 6.56 inches.

Table C.16. Pipeshed 76-010: Over-curb Floodwater Storage Cost Reduction Due to LID.

Precipitation (inches)	Dry Detention Basin Costs (without LID)	Underground Storage Costs (without LID)	Dry Detention Basin Costs 10% LID	Dry Detention Basin Costs 25% LID	Underground Storage Costs 10% LID	Underground Storage Costs 25% LID
6.56	900,000	13,700,000	700,000	600,000	8,800,000	7,600,000
8.07	1,600,000	34,400,000	1,400,000	1,300,000	27,900,000	26,400,000
10.1	2,700,000	80,100,000	2,500,000	2,500,000	73,900,000	73,900,000

As seen in Tables C.17 and C.18, the percentage reduction of costs for both dry-detention basins and underground storage cost reduction is incrementally greater than the percentage of LID implemented across the watershed.

Table C.17. Pipeshed 76-010: % Reduction in Dry Detention Basin Costs Due to LID

Precipitation (inches)	Dry Detention Basin Costs (without LID)	Dry Detention Basin Costs 10% LID	% Reduction in Costs	Dry Detention Basin Costs 25% LID	% Reduction in Costs
6.56	880,000	660,000	25%	600,000	32%
8.07	1,570,000	1,370,000	13%	1,330,000	15%
10.1	2,680,000	2,540,000	5%	2,540,000	5%

Table C.17. Pipeshed 76-010: % Reduction in Underground Storage Costs Due to LID

Precipitation (inches)	Underground Storage Costs (without LID)	Underground Storage Costs 10% LID	% Reduction in Costs	Underground Storage Costs 25% LID	% Reduction in Costs
6.56	13,700,000	8,800,000	36%	7,600,000	45%
8.07	34,400,000	27,900,000	19%	26,400,000	23%
10.1	80,000,000	73,900,000	8%	73,900,000	8%

Outreach

(Also refer to Appendix "B", Outreach)

The abstract of the proposal for this project entitled "Long-term climate forecasts and information supporting adaptation decisions" that was submitted to the Climate Program Office for Urban Water Resources of NOAA stated that:

"The overarching purpose of this program is to promote stakeholder-driven adaptation of vulnerable stormwater management systems and related water resources, by demonstrating, implementing, and disseminating a quantified, local- scale, and actionable protocol for maintaining historical risk levels in communities facing significant impacts from climate change. The proposed project will utilize an interdisciplinary team of investigators and stakeholders, to transfer coupled-climate model projections to the sub- watershed scale, in a form understandable to planners,

resource managers and decision-makers."

The public process team under this project, working closely with the science team, planned and implemented a collaborative stakeholder-driven planning process that engaged a wide range of constituency groups. These stakeholders, through this public process, completed strategic planning efforts that resulted in specific and prioritized adaptation strategies for addressing growing stormwater intensive events. The disseminated results of this collaborative process are in a form that is understandable to planners, resource managers and decision-makers. This following sections describe this process, the outcomes, and provides an evaluation of its effectiveness.

Outreach process overview

In a 2008 report, the National Research Council identified three main goals for stakeholders in assessment and decision-making: (1) improve quality; (2) improve legitimacy; and (3) improve capacity of environmental assessment and decisions. First, quality of the outcomes is enhanced by incorporating social values, interests, concerns of all those that are affected, including best available knowledge/science, into the decision-making process. Second, recommended actions or solutions, no matter how brilliant, are of little value if the process is not legitimate. The process must inherently be, and be perceived as, fair, competent and follow due process of law. Finally, building the overall capacity of the system to make needed changes includes raising awareness of the present situations, building networks and partners, and developing a shared understanding of both the challenges that need to be addressed and how to move forward.

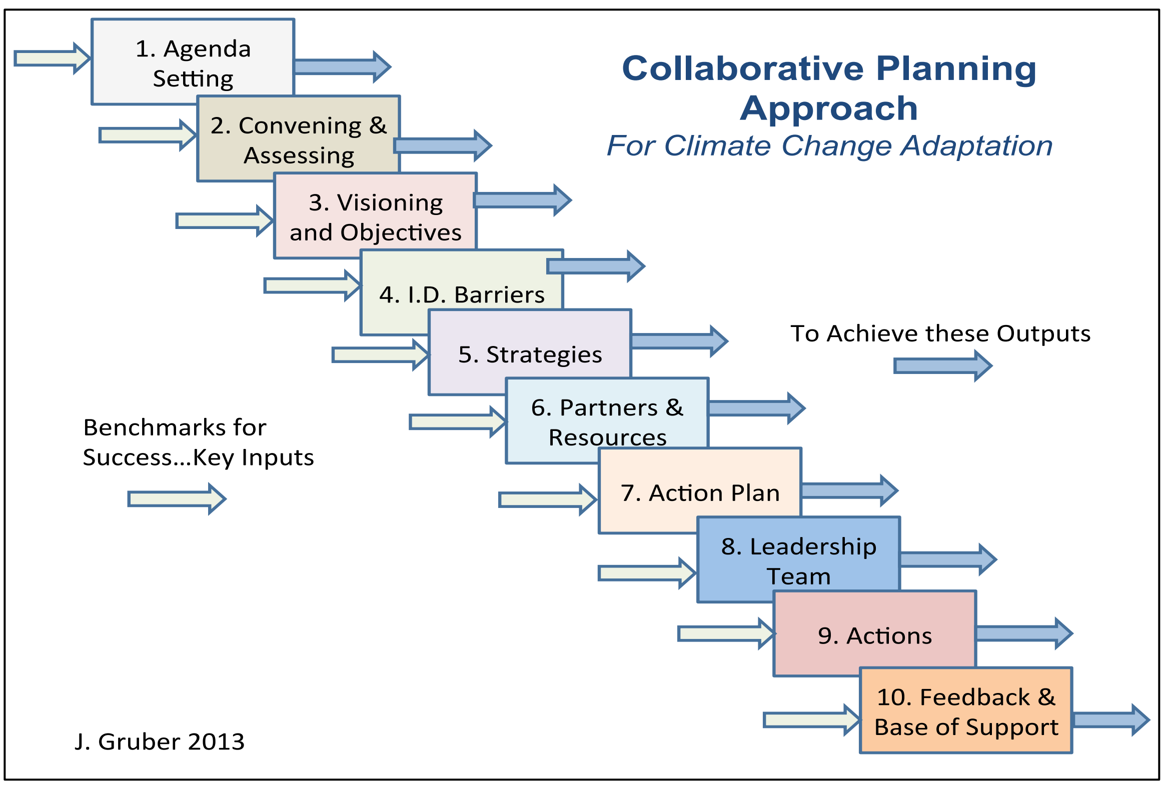


Figure O.1 Collaborative Planning Approach for Climate Change Adaptation

The ten-step process presented in Figure O.1 depicts a model of a comprehensive collaborative climate adaptation process. Specifically for this project, steps 1 through 6 represent the scope of the participatory process that was undertaken during this project. Steps 7 and forward are still in process with the MCWD, the City of Minneapolis, City of Victoria, and other local/regional entities.

Our overarching goal with the Minnehaha Creek Watershed Stormwater Adaptation Study was to increase resilience, adaptive capacity, and social capital by engaging the public with vetted data on severe weather trends and best available climate change science, fostering local municipality/region/watershed understanding, trust, and collaboration to increase resilience to stormwater risks, and developing widely shared understanding of the issues and decision challenges. The stakeholder engagement process we used involved distinct phases, including:

1) Convening a broad cross-section of representatives from various levels of government (local, regional, state, federal), NGOs, academia or education organizations, non-profits, community associations, as well as private citizens.

2) Once gathered, we assessed the situation and affiliated issues based on essential data collected by the technical team. During this assessment phase, we crafted guiding questions for large and small discussions wherein stakeholders could express diverse perspectives, reflect, and gain an understanding of underlying causes of the issues at large. We established several communication channels, including a dedicated webpage and a sequential project newsletter, as well as a series of public forums to introduce the topic, the study, and disseminate results. To create a framework that communities can actually use, we collected stakeholder input to identify four (4) priority topics to address in climate change adaptation planning: education, planning, infrastructure and funding.

3) Next, we identified barriers to progress on climate change adaptation and identified strategies and tools for implementation. Work session participants developed potential strategies that were then vetted using an impact vs. feasibility grid. Ideally, we want to identify the strategy with the highest feasibility and greatest impact. The overall vision was framed, broad objectives developed, and four work groups assembled to distill and define specific objectives within the priority topics

4) Few societal changes can be accomplished without a broad group of partners. We identified, engaged and formalized an inclusive Advisory Committee to aid in engaging a broad range of stakeholders as well as provide guidance on how to direct the engagement process itself. This Advisory Committee also provided an opportunity to build leadership capacity within the various groups the committee represented.

5) The final phase of the engagement process convened stakeholders to develop concrete action plans that form a framework for community adaptation planning around changing precipitation patterns and land use. These actions are based on priorities identified by the stakeholders themselves, thereby increasing the legitimacy and relevance of the actions proposed.

6) Lastly, embracing open and dynamic feedback on the process and actions taken is an important component of the process, which will continue to build support for community conversations around adaptation planning and implementation efforts.

The information gathered during the technical modeling and assessment phase was combined with the outputs from the collaborative stakeholder process to create a framework for addressing community stormwater adaptation planning. Information can be provided to local policy makers, developers, landowners and other interested stakeholders about current models and tools, trends, projected conditions, adaptation options and costs, education and communication strategies.

An Advisory Committee was developed to play a central role in helping to facilitate the success of the Minnehaha Creek Watershed Stormwater Adaptation Study as well as build capacity and leadership around adaptation planning at both the local and regional level. The advisory committee included representatives from three municipalities within the Minnehaha Creek Watershed District,, three watershed organizations, three state-level water resources organizations, and two non-profits. The committee was charged with two main tasks:

1. Identify and recruit stakeholders to help insure that the study includes a diverse and thorough representation of community members who would have knowledge to bring to the project or might be affected by the outcomes of the project.
2. Provide input and feedback on the planning and execution of the study as well as evaluation of the process used.

This Advisory Committee was responsible for reaching out to community stakeholders to participate in a series of forums and workshops. These events and key outcomes are detailed in the following sections.

First Forum: "Are We Ready?" (May 15, 2012)

Fifty-nine city officials, regional planners, engineers, and concerned citizens from municipalities throughout the Minnehaha Creek Watershed District gathered to discuss shifting rainfall patterns and the impact on urban runoff and water quality in our area (Figure O.2). The purpose of the forum was to introduce the community to the project, and collectively identify community-wide concerns and priorities related to changing precipitation patterns and overall growth and development in our region. The forum included a number of presentations and activities including an update on the current and historic precipitation patterns in our region, by Mark Seeley, Climatologist at the University of Minnesota, the status of local stormwater infrastructure, extreme weather events, and any actions currently being undertaken in the Cities of Minneapolis and Victoria, our two focus areas, and an introduction to the MCWD Stormwater Adaptation Study and a highlight of the project's purpose, goals, expected outcomes, and limitations. Work groups were developed though a guided activity led by Jim Gruber, Antioch University.

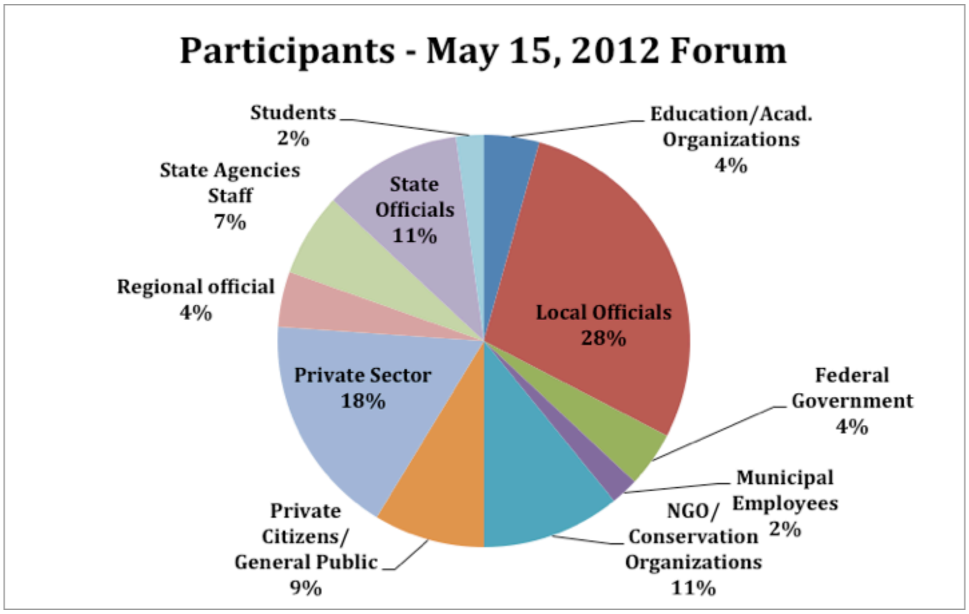


Figure O.2. Participants at May 2012 Forum

Based on output during the collaborative planning portion of the forum, the top challenges were identified and prioritized related to changing precipitation patterns and impacts to our water resources. These challenges were used to develop priority topic as well as specific objectives around climate change and stormwater adaptation planning. The top twelve challenges identified included:

- A conflict between individual rights and what is good for community.
- The lack of education of decision makers and the public on the impacts to stormwater infrastructure by changing weather patterns.
- A lack of funding, which causes cities to be reactive versus proactive.
- A lack of funding to deal with the marginal costs of changing infrastructure.
- The change in intensity of rainfall, which is not accounted for in the engineering of our systems.
- Inadequate minimum requirements set by cities, which do not provide a level of protection needed to prevent damage by the increase in extreme events.
- The treatment of rainfall as a waste product.
- The expectations of property owners and the public must be adjusted to the realities of dealing with more extreme events, and changing weather patterns (for example, people want dry roads and yards).
- The process for decision making is focused on short-term projects with quick or immediate benefits.
- The lack of immediate economic impact, which makes this a long-term problem.
- The focus on cars for transportation which requires significant “car habitat” that is usually high impact.
- A lack of ownership of issue by all stakeholders (local, regional, state, and federal).

Based on the challenges identified, four priority focus areas were developed with topic-specific objectives. These four priority focus areas were later used to identify specific strategies and action plans through a series of stakeholder Work Groups that were held. These four priority areas consist of:

A. Education, Outreach, and Stakeholder Engagement: Identify strategies to increase awareness of management issues, educate and inform policy makers and developers, and strategize on how best to develop a consensus to move forward.

B. Land Use Planning and Policy: Identify how to incorporate study data into design, create guidelines for development and policy, identify opportunities for green infrastructure and low impact development options, and how to communicate planning and policy options.

C. Stormwater Infrastructure (Green/ Grey) and Low Impact Development: Assess current infrastructure and needed upgrades, options for impervious options for water quality and flood control, and determine how to communicate development and redevelopment options.

D. Sustainable Funding for Stormwater Infrastructure: Assess funding needs for updating infrastructure both immediate and long term, including economic impacts of decisions, and finding opportunities for proactive management options.

Second Combined Session of Working Groups and Second Forum: "How to Proceed" - (January 22, 2013)

Stakeholders were convened for a second Work Group session combined with a forum detailing final technical results of the community vulnerability assessments completed for the City of Minneapolis and the City of Victoria using the projected precipitation data. On January 22nd, 2013 at the Eisenhower Community Center, Hopkins small groups worked on developing specific action plans for stormwater adaptation strategies identified during the first Work Group session (Appendix E). These action plans were themed by the four work groups: Education, Outreach, and Stakeholder Engagement; Land Use Planning and Policy; Stormwater Infrastructure (gray/green) and Low Impact Development; and Sustainable Funding for Stormwater Infrastructure. Action plans were then prioritized by the whole group, which resulted in six priority action plans that could be applied by communities or the broader Twin Cities Metro Area to further stormwater adaptation planning:

1. <u>Education, Outreach, and Stakeholder Engagement</u>

Objective: Identifying strategies to educate local policy makers about stormwater vulnerabilities, long term needs, and options

Timeline: Not identified

Responsible Parties: Minnehaha Creek Watershed District, UMN Extension, Water Resources Center (Karlyn Eckman), Freshwater Institute, Local Leaders, NOAA, MN Sea Grant

Project: Convene a summit(s) to educate local policy makers about creating resilient stormwater infrastructure.

Action Items:

a. Identify audience: local decision makers, commissioners, volunteers Assess/Prioritize vulnerabilities

b. Convene a focus group of audience. What draws them? Will draw them? Needs assessment of targeted audience.

c. Frame the summit – Develop learning (summit) objectives with:

a. Planning team

b. Include participants in planning summit

d. Identify compelling speakers and most effective mediums to feature at the summit(s). Include: risks, funding options, solutions

a. Breakouts, smaller groups, with visualizations and activities

b. Cohorts

e. Target local policy makers to fill the seats, target participants

f. After the summit(s), prepare a road-show that we can go to them with that includes visualizations.

2. *Land Use Planning and Policy*

Objective: Identifying and encouraging proactive strategies for managing stormwater, including green infrastructure, low impact development, and stormwater reuse.

Timeline: Not identified

Responsible Parties: Met Council, MN DOT, League of Minnesota Cities

Project: Adapt development and zoning codes to minimize the use of structural conveyances associated with transportation by preserving natural corridors and conveyance systems. Benefits: traffic calming, natural corridors preserved, more stable conveyance systems.

Action Items:

a. MN DOT and Met Council develops policies that require communities to preserve natural conveyance systems through design of transportation systems

b. Develop a model ordinance that cities can adopt requiring that roads avoid or span natural drainage pathways rather than fill them in or using berms, culverts.

c. City develops/amends comprehensive plans and adopt zoning controls consistent with policy. Preserve areas prone to flooding and natural conveyance systems (includes an inventory)

d. City public works projects implement the comprehensive plan

3. *Stormwater Infrastructure (Gray/Green) and Low Impact Development*

Objective: Protecting and enhancing vegetative cover and natural areas to reduce flooding and improve water quality.

Timeline: Begins in December 2015, is reviewed by stakeholders in December 2016, and implemented in 2017

Responsible parties: Watershed management organizations, cities, DNR, MPCA, UMN

Project: Develop an ordinance requiring soil de-compaction and organic matter incorporation in every construction project

Action Items:

a. Educate city officials on the need for soil improvement

b. Create a stakeholder team working group to write a draft ordinance

c. Review draft ordinance by public, city councils, county counsels, and state

d. Pursue cities to adopt ordinance, search out state laws to require it, and encourage county regulators to implement it as well

Objective: Identifying strategies to increase stormwater storage capacity and reuse in urban areas

Timeline: Ongoing

Responsible Parties: watershed management organizations, cities, counties, state

Project: Integrate reuse in development plan and reducing amount of water going into stormwater systems

Action Items:

a. Identify where most potential and biggest impacts are. Examples are reuse for golf course (Pipeshed 76-010) and large industrial sites (commercial)

b. Identify planned redevelopment. Street reconstruction: set minimum width of streets and create storage.

c. Retrofit existing sites with BMPs: cisterns for roof runoff, permeable driveways, rain gardens

Objective: Assessing needed infrastructure upgrades to accommodate current and predicted stormwater runoff

Timeline: Jan-September 2014 complete GIS, January determine expense, May put staff/consultants in play, Jan-Mar select sites to evaluate, April 2014-October 2014

Responsible Parties: Cities and consulting agencies

Project: Identify source of funding – including education of decision making as needed to support funding

Action Items:

a. Is the convergence network mapped? If not, it needs to be. Determine attributes: inverts, m/h rim elv. diameter and material condition, storage ponds, lakes, subwatershed divides, LiDAR contours. Gather available soils information, directionality, what is coming from upstream?

b. Run scenarios: current 10-year, 100-year, projected 10-year a/b/c, etc. on the ground monitoring, surveying, and calibration. Decide on software, Build model(s)

c. Can upgrades be phased? Do the upgrades need to be phased as to not cause flooding elsewhere?

4. <u>Sustainable Funding for Stormwater Infrastructure</u>

Objective: Evaluating immediate versus long term economic impacts of stormwater management issues

Timeline: estimate that it will take 18 months to complete

Responsible parties: City lead process, support from water management organizations, University of Minnesota, and possibly federal or regional agencies (NOAA)

Project: Commission a report to evaluate economic impacts of climate change on stormwater management to better evaluate the immediate versus long term economic impacts.

Action Items:

a. Complete an internal assessment related to economic impacts related to culvert installations, and identify knowledge gaps.

b. Complete scenario planning and choose 2-4 most likely scenarios and other pertinent issues (such as timeframe; lengthy of storm events) and modeling requirements.

c. Define economic impacts in city and downstream (property, infrastructure, loss of life, project costs, health impacts, commercial shutdown, utility impacts, etc.) aquatic invasive species.

d. Identify possible regulatory behaviors.

e. Summarize information and finalize. Issue a request for proposals (RFP) – develop criteria for evaluation.

f. Evaluate RFP and make recommendations to council with funding recommendations for the study

Summary Comments on Major Elements of the Public Process

The stakeholder outreach process provided an opportunity for broad stakeholder input to develop a community adaptation framework that is locally relevant and grounded in scientific data. An effort was made to bring varying perspectives to the table for conversations around adaptation planning, and various channels were developed to disseminate information and allow for stakeholder feedback. The public participation process was developed to allow for co-leadership and co-creation of priories and implementation strategies (as exemplified by the results generated at various points in the process).

Overall, the public input process was well received and generated very useful and locally relevant information to develop a guiding framework that communities can use for local stormwater adaptation planning. The heightened interest in the topic (which also is concurrent with the release of Atlas 14 Volume 8 for the Midwest Region), can be directly contributed to the public process of engagement and outreach that was used during this study.

Broader Public Outreach of Dissemination of Information

Numerous public presentations on community stormwater adaptation have been given to various groups and organizations beyond the two cities involved in this study. Below is a current listing of presentations involving either the technical results developed during the course of this study, the stakeholder engagement process that was used, or on both:

- Minnehaha Creek Watershed District Citizen's Advisory Committee Meeting – Deephaven, MN, February, 2012
- Climate Change Honors Seminar, University of Minnesota – Minneapolis, MN, March 2012
- Metro Waters Partnership – Rosemount, MN, April 2012
- Minnesota Association of Watershed Districts 2012 Annual Conference – Alexandria, MN, December 2012
- Environmental Decision-Making, University of Minnesota – St. Paul, MN, April 2013
- Seminar Series on Sustainable Development, University of Minnesota Humphrey Institute – Minneapolis, MN, April 2013
- Riley Purgatory Bluff Creek Watershed District Evening With the Watershed Event – Chanhassen, MN, May 2013
- Watershed Partners Annual Mississippi Tour – Minneapolis, MN, June 2013
- Minnehaha Creek Watershed District Board of Managers Meeting – Minnetonka, MN, June 2013
- Metro Association of Watershed Districts Monthly Meeting – St. Paul, MN, July 2013
- Clean Water Summit: The Essential Role of People in Clean Water – Chanhassen, MN, September 2013
- Preparing Stormwater Systems for Climate Change – Monroe, MI October 2013
- Minnesota Association of Watershed Districts 2013 Annual Conference – Alexandria, MN, December 2013

Minneapolis Transportation and Public Works Committee of the City Council and City of Victoria Open House/Workshop (June 2013)

In May, 2013 a brief presentation was given to the Transportation and Public Works Committee of the Minneapolis City Council. The purpose was to disseminate the technical results of the study pertaining to Minneapolis, as well as an overview of the stakeholder engagement process that was used. Unfortunately due to time constraints of the meeting, the study presentation was abbreviated to a few key points. There is an intent to identify a future opportunity for outreach with this particular planning body.

A community-wide open house for the City of Victoria was also held in June of 2013 to disseminate results of the study through story boards, as well as generate conversation around local stormwater adaptation strategies (Appendix F). The learning objectives of the open house/workshop with the City of Victoria included:

1. Increase understanding among city leaders, staff and community members of changes in land use and precipitation, and how they impact stormwater runoff, gray/green infrastructure and downstream water resources.
2. Share the outcomes of the Minnehaha Creek Stormwater Adaptation Study, including flood vulnerability assessments, and adaptation options and costs.
3. Review City of Victoria past and present plans and policies that relate to land use, stormwater management, and flooding.
4. Start a city conversation about potential actions and next steps to prepare the city for growth, changes in land use and changing precipitation.

5. Present input from multiple community stakeholder meetings on strategies and priorities for future action.

Some key findings that were shared at the open house include:

- Modeled prediction for precipitation is ~6-10" of rain for a 10-yr event by mid-21st Century.
- In Victoria, no significant infrastructure damage is expected, even under pessimistic conditions.
- Some increase of surface flooding in low lying/recreational areas would be expected.
- Past policies and plans have led to the ability of the community to absorb increases in precipitation.
- Adaptation options can manage flood volumes at varying costs. Low Impact Development can reduce some flood volume and infrastructure upgrade costs. However, LID provides water quality protection as well as some flood reduction.

A separate report of the workshop was provided to the Victoria City Council on Monday, October 28, 2013.

Presentations and Workshop at Low Impact Development Symposium, Saint Paul, MN (August 18-21, 2013)

The project team identified an opportunity to host a four-hour pre-conference workshop as well as two 40-minute technical sessions to disseminate study results at the 2013 International LID Symposium, which attracted over 700 local, regional, national and international professionals in the area of stormwater management and low impact development (http://www.cce.umn.edu/2013-International-Low-Impact-Development-Symposium/). The workshop was attended by local and national professionals, who came to learn about the stormwater adaptation process (Appendix G). The interactive workshop included practical information on how to:

- Assess stormwater infrastructure vulnerability and required capacity under both existing and future precipitation conditions.
- Identify stormwater adaptation options and costs - including the role of Low Impact Development (LID) - to mitigate impacts from changing precipitation patterns.
- Manage uncertainty associated with modeling future conditions.
- Effectively communicate technical information to local stakeholders and decision-makers to promote stormwater adaptation planning.

Two 40-minute technical sessions were also held; one focusing on the technical aspects of the study including precipitation modeling, hydraulic and hydrologic modeling, local vulnerability assessments, and adaptation strategies for the two study communities, and the other on the stakeholder engagement process that was used to disseminate results and collaboratively generate an adaptation framework for local community adaptation. Attendees, including those involved in stormwater management, community development and redevelopment, municipal operations, design professionals, developers, contractors, local policy makers, and others concerned about local stormwater adaptation planning were expected to leave with an understanding of the need for action, the knowledge and resources required to act, and the skills for empowering decision-makers in their community to respond to a changing climate.

Upcoming Presentations:

- City of Minneapolis Council Workshop – Minneapolis, MN, Spring 2014
- Minnesota Pollution Control Agency Webinar Series On Water – St. Paul, MN, May 2014

Public Outreach and Dissemination of Information

Various channels for public outreach and communication have been established to raise awareness about the outputs of the Minnehaha Creek Watershed Stormwater Adaptation Study as well as community adaptation to changing precipitation and land use. Public outreach during the public stakeholder process has included:

- Development and distribution of periodic newsletters detailing progress on the study (Spring 2012, Summer 2012, Fall 2012, Fall 2013)
- Development of a Study Factsheet with Frequently Asked Questions and Extreme Event Factsheets for various storm events to aid in outreach
- A dedicated project website at www.minnehahacreek.org/WET
- Press releases and news coverage, including electronic newsletter Splash and WaterPro

Local News Coverage

Table O.1 lists earned local news coverage of the project.

Table O.1. Local news coverage

Date of publication	Headline	Local media title
4/1/12	Study to Focus on Minneapolis and Victoria	Victoria Gazette
5/10/12	Minnesota Watershed Studies How to Adapt its Stormwater System for Climate Change	Water World
5/9/12	Are We Ready? Watershed District Will Participate in NOAA Stormwater Study	Lake Minnetonka Patch
5/4/12	MCWD to Study Climate Change's Effects on Storm Water	The Laker
5/5/12	Climate Change and Storm Water Park Study	The Laker
5/21/12	Warmup has Cities Rethinking Waterways	Star Tribune
5/27/12	Planning for Extreme Weather	Southwest Journal
5/24/12	Researchers Say Metro is Awash in Climate Change	St. Louis Park Sun Sailor, Excelsior/Shorewood Sun Sailor
5/25/12	Awash in climate change: St. Louis Park forum considers future impacts of heavier than normal rains on infrastructure	Sun Sailor
6/25/12	Duluth eyes rebuilding for a wetter climate	Star Tribune
3/6/13	Planning for Changing Weather Patterns	Tonka Times

Summary Comments on Presentations, Outreach and Dissemination of Information

Efforts have been made to disseminate information in a timely manner throughout the duration of this study, and there has been a heightened interest in the topic of changing precipitation patterns and impacts on stormwater management systems and downstream water resources. In general, the information is clearly well received by communities and organizations, with the hope of encouraging deeper discussion on stormwater adaptation, both locally and regionally. The most effective means of disseminating information seem to be through the project website, newsletters, and individual presentations. However press releases have also generated media coverage, especially following large precipitation events in the Twin Cities Metropolitan Area. The Minnehaha Creek Watershed District will continue to make the data public, as well as host community meetings and workshops on stormwater adaptation to climate change.

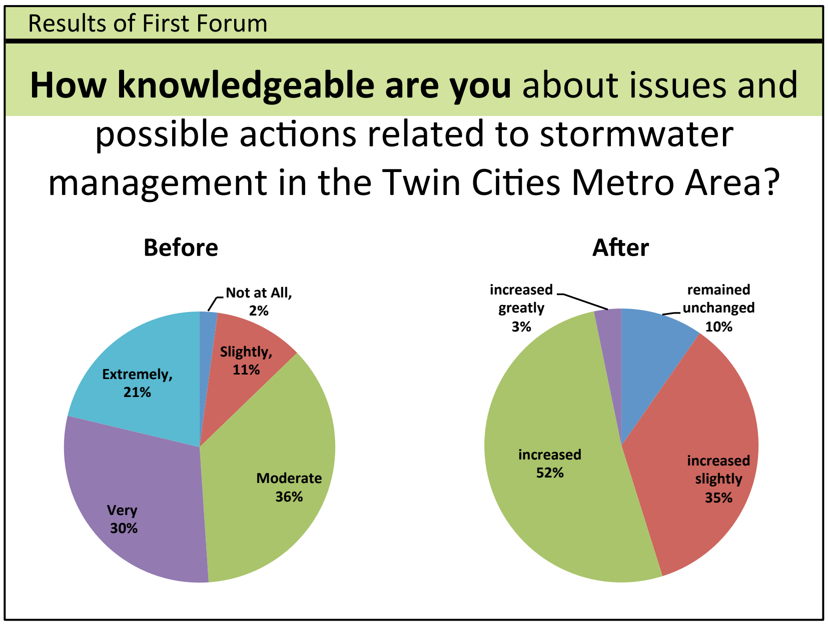


Figure O.3 Change in perceived knowledge due to the first public forum

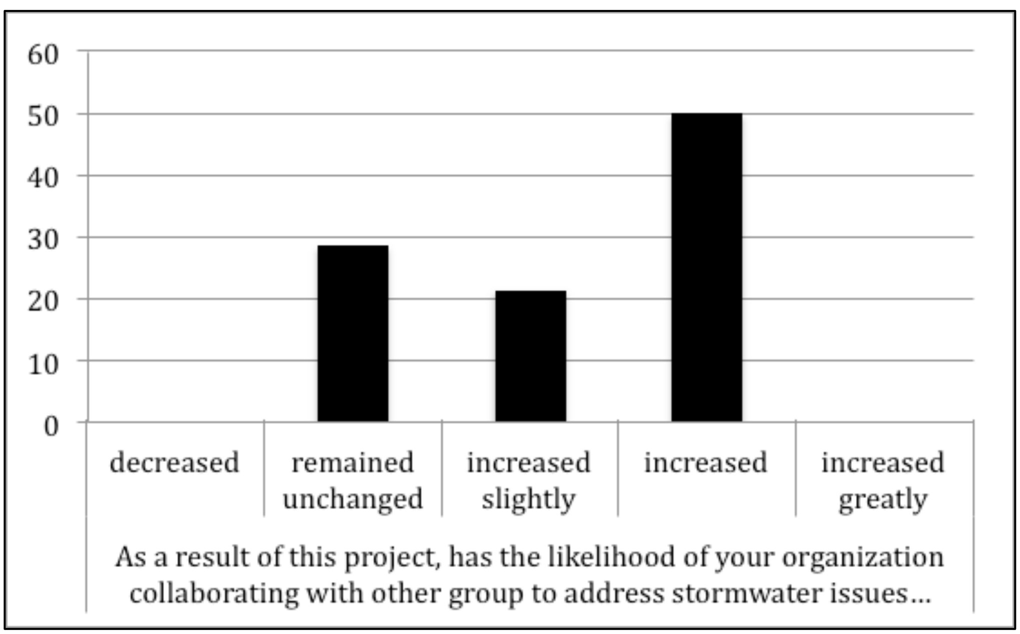


Figure O.4. Change in expected collaboration resulting from the project.

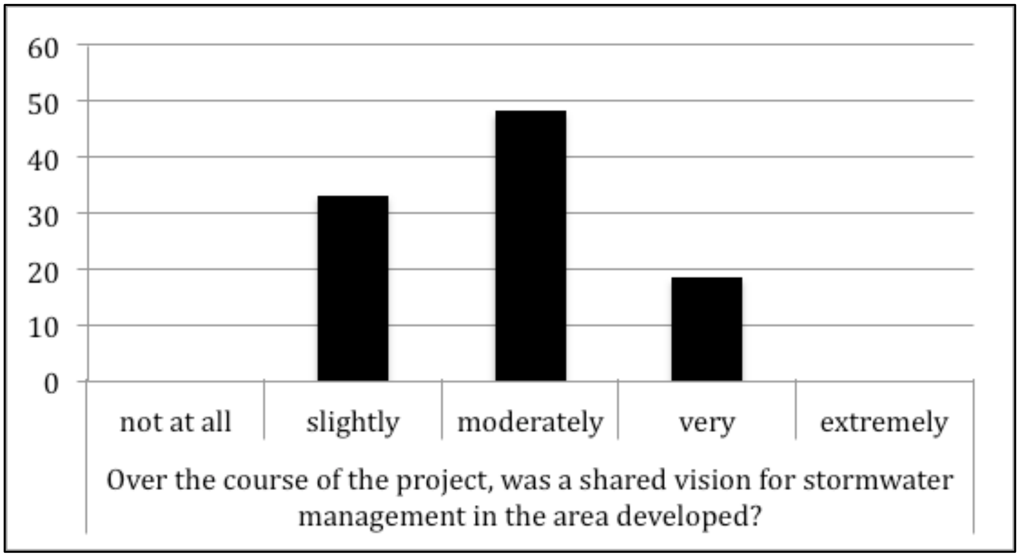


Figure O.5. Development of a shared vision for stormwater management, resulting from the project.

Q-5 Are any tangible next steps being pursued?

The Director of the Stormwater Department of the City of Minneapolis, the City Engineer and Administrator for the City of Victoria, and the Director of the Minnehaha Creek Watershed District (MCWD) all have indicated that the results of this project are valuable and useful for their areas of work. For example, the MCWD is about to begin its next long range planning process and the result of this project will help inform this process. The City of Minneapolis has provided information from this project to its consulting stormwater engineers to use as a resource as they plan the next phases of stormwater infrastructure upgrades.

Assessment of Collaborative Public Process through "Collaborative Planning for Climate Change Adaptation" model

The collaborative public process used in this project will be reviewed using the "Collaborative Planning for Climate Change Adaptation" model in Figure O.1. As noted earlier, the intent of the project was to achieve steps 1 through 6. Each of the steps is described and followed, briefly, by the way in which the project addressed this step. More specifics of how each step was achieved are described under section 2 of this report.

1. Agenda setting: Researching and raising awareness about the relevant climate change related issues

The agenda setting phase was achieved through a number of efforts that included fact sheets, an initial newsletter, a robust web site and earned-media coverage in the local newspapers. At the same time, research by the project science team (that included the University of Minnesota and Antioch University) documented and presented changes in sever weather conditions for this region. There was also an Advisory Committee established to help with this and other stages of the project.

2. Convening and Assessing: Convening a broad cross-section of the community to assess the evolving situation and affiliated problems and confirm the need for adaptation planning.

The Project Team and the Advisory Committee identified and organized a number of convening events, the first of which was the Forum. There was a broad diversity of stakeholders representing the Minnehaha Creek watershed region attending these events. Changes in weather patterns and climate conditions were presented that included frequency and intensity of recent storms. The first Forum session also encouraged participants to review and discuss current impacts from weather patterns and land-use patterns. There was a focus on helping all participants better understand the underlying causes of the current conditions and to recognize the urgency to undertake planning.

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3. Visioning and Objectives: An overall vision and primary objectives are developed and agreed upon.

During the first Forum and following Working Groups sessions, an overall understanding of the “big-picture” and prioritized objectives were established. The collaboratively developed objectives received general support by all participants involved in the project. These results were then synthesized and disseminated to the broader community.

4. Identify Barriers: The social, financial, political, logistical, philosophical, and cultural difficulties that need to be addressed are identified in order to inform the approach for achieving the agreed-upon objectives.

During the first cycle of Working Groups, participants identified actual and perceived barriers to achieving agreed-upon objectives.

5. Strategies: The potential strategies are assessed and prioritized based upon technical and financial considerations as well as social and cultural values and public priorities.

At the Working Groups sessions a collaborative process was convened that included the development of specific strategies and policy tools to address the identified barriers. Potential impact of each strategy and the feasibility of implementing that strategy were then developed by the stakeholder groups.

6. Partners and Resources: Potential partners are identified and engaged and types of resources required are identified.

Throughout the project, potential partners were identified that included state level agencies, NGOs, regional and other groups. This was done in parallel with the framing of an overall strategic approach.

Assessment of Collaborative Public Process through NRC Criteria

Referring back to the National Research Council criteria for assessing an effective collaborative public process, their three principles will be used to assess the overall process.

Principle 1 - *Draw on local knowledge to improve decision making through a public process.*

Throughout the project local knowledge ranging from local officials, citizens, businesses, NGOs, to researches at the University of Minnesota were core to every phase of the project. Local knowledge drawn upon include technical information, local values and interests and concerns of those that might be affected by the climate adaptation process. New scientific information was incorporated in the project as it became available including down-scaling of weather data.

Principle 2 - *Foster legitimate and equitable decision making by a process*.

The project was not a formal public policy decision making process but a collaborative public process that could inform a future formal process. This process was perceived a legitimate in respect to its purpose and we have indication that the outputs from this process will be used in the near future by for public policy making bodies.

Principle 3 - *Increase resilience, adaptive capacity, and social capital*

The project appears to have increased watershed wide cooperation and understanding. Dialogue and cooperation between local governments in the watershed and the MCWD appeared to have been enhanced. The public engaged in the issue and need for climate change adaptation through outreach of public collaborative planning sessions. They were provided down-scaled climate data in a clear and understandable form. Social capital was enhance through building a shared view of priorities in responding to changing climate conditions and the challenges that need to be faced.

In summary, as reflected by our assessment based on these three principles, this was an effective collaborate project.

Discussion: Synthesis of findings

In both study sites, pipe upsizing was by far the most effective means of adapting the stormwater system to manage flooding associated with projected changes in climate. This observation comes with a caveat in the case of Minneapolis Pipeshed 76-010=, in which the effectiveness of pipe upsizing was limited to a design storm depth of about 6 inches (which is 50% greater than the current 10-year design storm and within the range of increase expected under a moderate climate change scenario). The inability to mitigate flooding through pipe upsizing beyond this depth was somewhat surprising, but upon examination, reflects a system in which backwater effects are dominant and surface storage and other detention opportunities are limited. Such a condition is not uncommon in urban areas, particularly where surface storage and infiltration capacity have been lost to accommodate dense development, and thus, the limitations of pipe upsizing as a stand-alone adaptation strategy may be applicable to other urban communities in the region. Additionally, the performance of a given adaptation measure on the basis of flood volume alone is not necessarily a good indicator of the capacity of the measure (or combination of measures) to build resiliency into the overall system. For example, in both Victoria and Pipeshed 76-010, pipe upsizing led to an increase in predicted peak flows at the watershed outlet relative to the do-nothing (i.e., maintain the existing system) or LID adaptation approaches. The increase was somewhat substantial in the Pipeshed 76-010 case (10% as averaged across all precipitation scenarios). Downstream impacts such as channel stability, water quality, and flooding of downstream communities should also be considered in assessing the effectiveness of adaptation approaches toward creating more climate-resilient communities.

Projected increases in flooding were not mitigated through LID at either study site for even the most optimistic mid-century precipitation scenario. This is not surprising, however, as LID practices – as modeled here and in their typical application – are designed to capture runoff associated with relatively frequent, small storms (e.g., 25 mm) rather than the 10-year storm modeled in this study. Of the two study sites, LID was least effective in Victoria. The saturated hydraulic conductivity of underlying soils, which was 35% lower in the Victoria SWMM model, exerts an important control on the effectiveness of infiltration-based stormwater management practices. LID approaches are not wide-spread in Victoria currently, due to the high clay content of soils (personal communication, Cara Geheren, April 19, 2013). Still the relative resiliency of Victoria's existing network of stormwater ponds, wetlands, and lakes suggests that climate change resilience in Victoria (or in other communities with infiltration-limited native soils) can still be achieved through preserving (and/or creating systems that mimic) the hydrologic functions of naturally-occurring ecosystems, in this case wetlands and lakes, even apart from enhance infiltration.

In an already built-out community such as Minneapolis, infiltration-based adaptation practices come with a different set of challenges, including retrofitting around existing foundations, utilities, and, in brownfield applications, the potential to mobilize contaminant plumes. Despite these challenges, LID practices have been applied more widely in the City of Minneapolis and neighboring urban communities. That the greatest incremental decrease in flood volume was achieved through the lowest LID intensity examined (here, applied to only 10% of model subcatchments) in the Pipeshed 76-010 model was encouraging. This intensity of LID is well within the realm of possibility. For example, in the neighboring urban center of St. Paul, a combination of bioretention/bio-infiltration facilities and underground storage/infiltration trench retrofits store up to 1.1 MG of runoff from a relatively impervious (44%), 25-ha (62-ac) watershed (CRWD, 2012). Coincidentally, this is nearly the same volume of storage provided by the 10% LID scenario in Pipeshed 76-010, and thus provides an example of local application of LID at a scale to impact flooding projected under climate change. Coupling a similar intensity of LID with pipe upsizing seems to be a promising means by which to adapt stormwater systems for future climate, even in a built-out community such as Minneapolis.

It is worth reiterating the relative degree of resiliency in the City of Victoria's existing stormwater network. The volume and locations of flooding predicted in SWMM for even the most pessimistic climate scenario were not expected to impact structures or safety based on local topography. Therefore, a viable adaptation option for Victoria would be to allow flooding in streets and open spaces (e.g., a ball field and golf course) rather than upsizing pipes or adding additional capacity for infiltration. Victoria's relative climate resiliency is not by accident, nor should similar results be automatically assumed for other lower-density/rural communities. One factor in Victoria's resilience is the extensive network of stormwater ponds. The ponds, which drain areas ranging from 4 to 80 acres, were designed to capture and store up to the 100-year, 24-hour design storm. In this locale, the 100-year storm is 6 inches, or just under the 6.56 inch climate scenario in which ponds modeled in SWMM first began over-topping. Because the ponds are generally situated in low-lying areas adjacent to preserved stream channel and wetland networks, overflow from ponds, while potentially damaging to the integrity of the pond itself, posed no flooding threat to buildings or other structures. The role of these wetland complexes, as well as the lakes, in regulating flood pulses is an essential part of Victoria's resilience. Through its development policies of buffer setbacks and restricting floodplain development, Victoria has retained much of the landscape's capacity to provide hydrologic ecosystem services.

With respect to these study aims, important gaps in the research literature have been addressed by assessing the impact of uncertainty, which is inherent in long-term climate projections, on required stormwater system capacity and resulting construction cost. This is necessary because, as recognition widens that no significant decreases in uncertainty is expected in the foreseeable future, and as impacts from climate change increasingly manifest, communities need to understand the significance of uncertainty and the size and affordability of safety factors that accommodate uncertainty. By studying the relationship between climate change, current and required stormwater system capacity, and costs, this study provides important knowledge resources and directly contributes to goals four and five of the U.S. Climate Change Science Program (Beller-Simms et al., 2008):

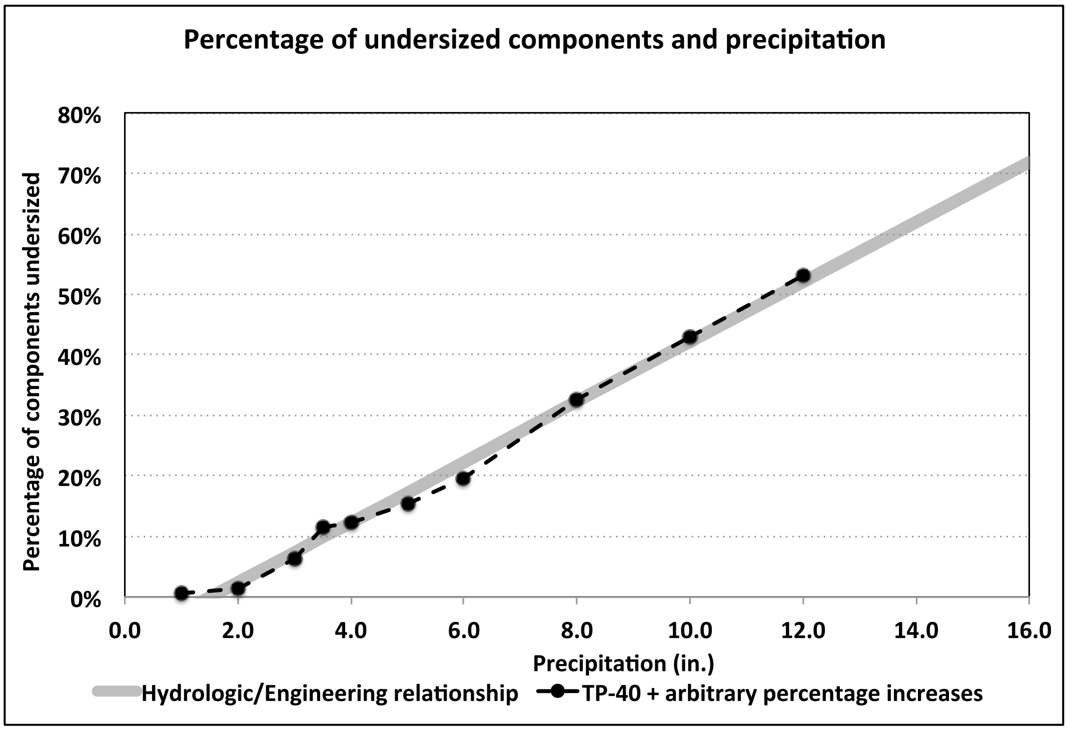
4. Understand the sensitivity and adaptability of…human systems to climate and related global changes;

5. Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change.

Findings show that: (1) Both required capacity and construction cost can be determined for a given combination of climate model, emissions trajectory, and landuse; (2) Both required capacity and construction cost are insensitive to changes in precipitation intensity, and thus insensitive to uncertainty: an approximately 150% increase in the design precipitation results in an approximately 30% increase in the number of undersized components (Figure ST.4); (3) A significant percentage of pipes remain adequately sized even for extremely pessimistic climate change impacts (Figures ST.2, ST.4); (4) Application of LID methods provides a significant reduction in adaptation costs, lowers the impact of uncertainty, and is more beneficial for more pessimistic climate change scenarios; and (6) A program of education and outreach can significantly increase a community's motivation to protect itself from more extreme climate impacts. This motivation has persisted past the completion of the project, and over the near- and mid-term can be expected to significantly reduce the community's exposure to losses from flooding.

Arbitrary percent increases in the current 10-year, 24-hour design storm prescribed by Technical Paper 40 (Hershfield, 1961) were input to the SWMM representation of the Pipeshed 76-010 stormwater network for the purpose of characterizing the hydraulic response of the system to precipitation. The system exhibited a nearly linear response in terms of percentage undersized components with increasing rainfall depth (Figure ST-1). Such a linear response was also observed in previous studies by the investigators (Stack et al., 2010). Overlaying projected, mid-century 10-year events indicates that without adaptation of the stormwater system, 10%-40% of the stormwater network would not be able to accommodate the design level of risk (Figure ST.2).

A series of recent extreme events suggest that a substantial portion of the existing stormwater network is already vulnerable (Figure ST.3). The existing system is also vulnerable under current conditions as modeled by the new design-storm numbers



released in the fall of 2013 by NOAA (Atlas 14).

Figure ST.1. Pipeshed 76-010 relationship between hydrology and engineering

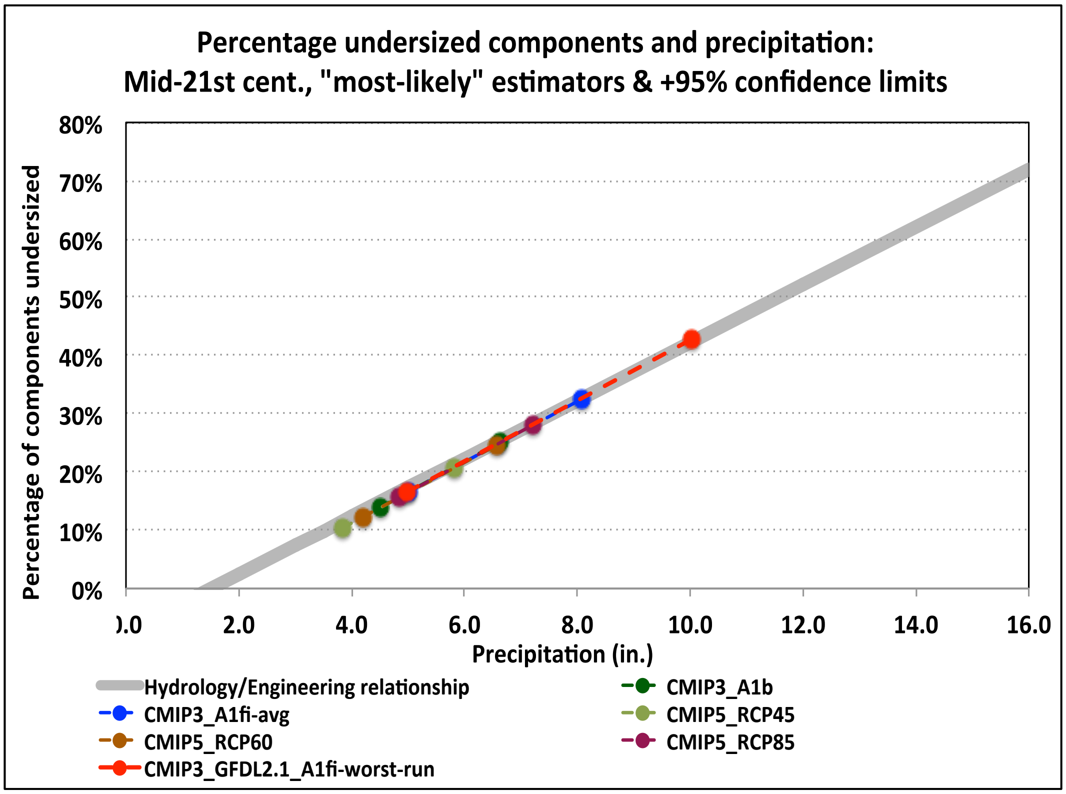


Figure ST.2. Pipeshed 76-010, selected long-term precipitation projections and impact on the rate of undersized components.

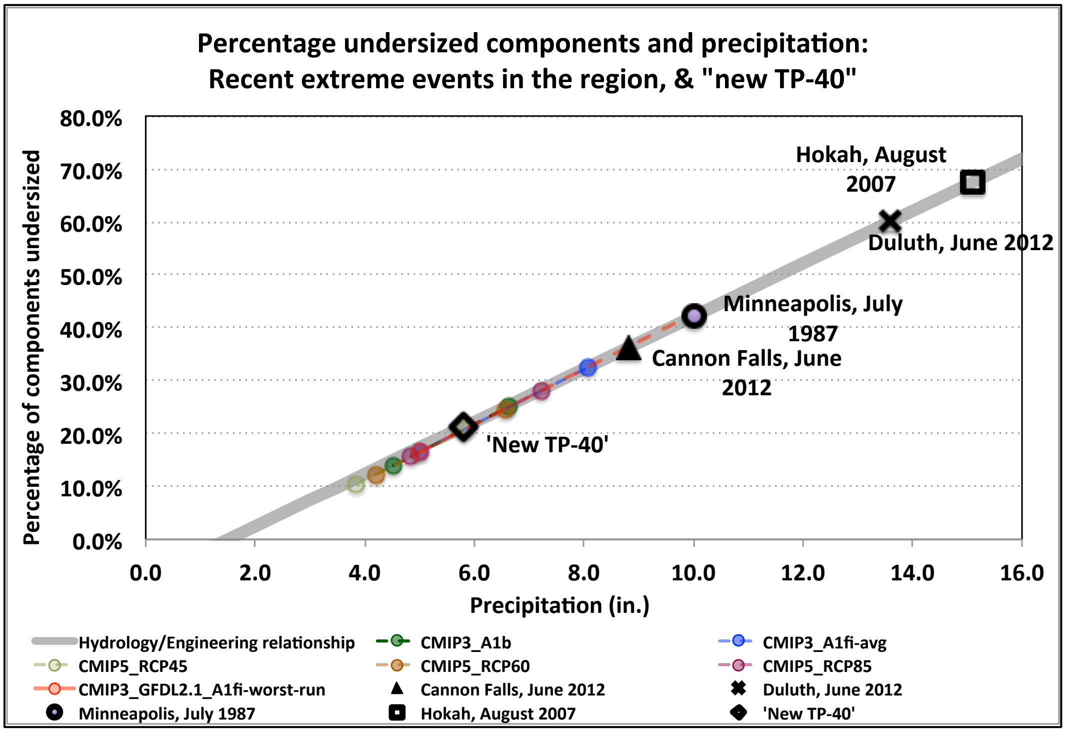


Figure ST.3. Pipeshed 76-010, comparison of climate change scenarios with recent extreme events in the region.

The vulnerability of stormwater systems to more extreme precipitation varies according to region, topography, engineering design standards, and the type of drainage system. Figure ST.4 shows vulnerability in Pipeshed 76-010 compared with previous studies by the project team, in rural and coastal New Hampshire. As indicated by the differing slopes of the engineering/hydrology lines, the Minnesota and coastal New Hampshire sites are less sensitive than the rural New Hampshire sites to increases in precipitation intensity. The reasons for these differences in response are unknown, but will be explored in a paper that is currently in development for publication. The New Hampshire sites utilize a 25-year 24-hour design precipitation, whereas the Minnesota sites utilize a 10-year, 24-hour design precipitation. However, this does not explain all of the variance in response because the coastal New Hampshire site responds similarly to the Minnesota sites. The Minneapolis and coastal New Hampshire sites are flat and therefore less-flashy, than the rural New Hampshire sites.

The series of studies undertaken by the project team have consistently found two results with important implications for stormwater adaptation. A percentage of existing stormwater systems are already undersized even for the recent historical climate (Table ST.1, Figure ST.4). Therefore, communities are already assuming a higher level of risk than intended under historical design standards. This betrays the notion that a “wait and see” strategy is a valid response to changing climate conditions.

Table ST.1. Current undersized rates for existing drainage systems under recent climate conditions.

Site	Undersized % for present conditions	Reference
Minneapolis pipeshed 76-010	10%	(present study)
Victoria	8%	(present study)
Towns in the Lake Sunapee, NH watershed:		
Newbury, NH	14%	Stack et al., 2010
New London, NH	23%	Stack et al., 2010
Springfield, NH	14%	Stack et al., 2010
Sunapee (town of), NH	0%	Stack et al., 2010
Durham, NH	9%	Simpson et al., 201
Keene, NH	26%	Stack et al., 2006
Ottawa, Canada	21%	Waters et al., 2003

In addition, even at pessimistic intensities a portion of systems remains adequately-sized. For the Minnesota sites, the percentage of vulnerable components is estimated to be in the low-40%, for Lake Sunapee vulnerability is estimated at around 70% of components. That only a portion of existing systems are vulnerable is encouraging as communities contemplate responding to the marked increase in extreme storms that are already manifesting and projected to worsen in coming decades.

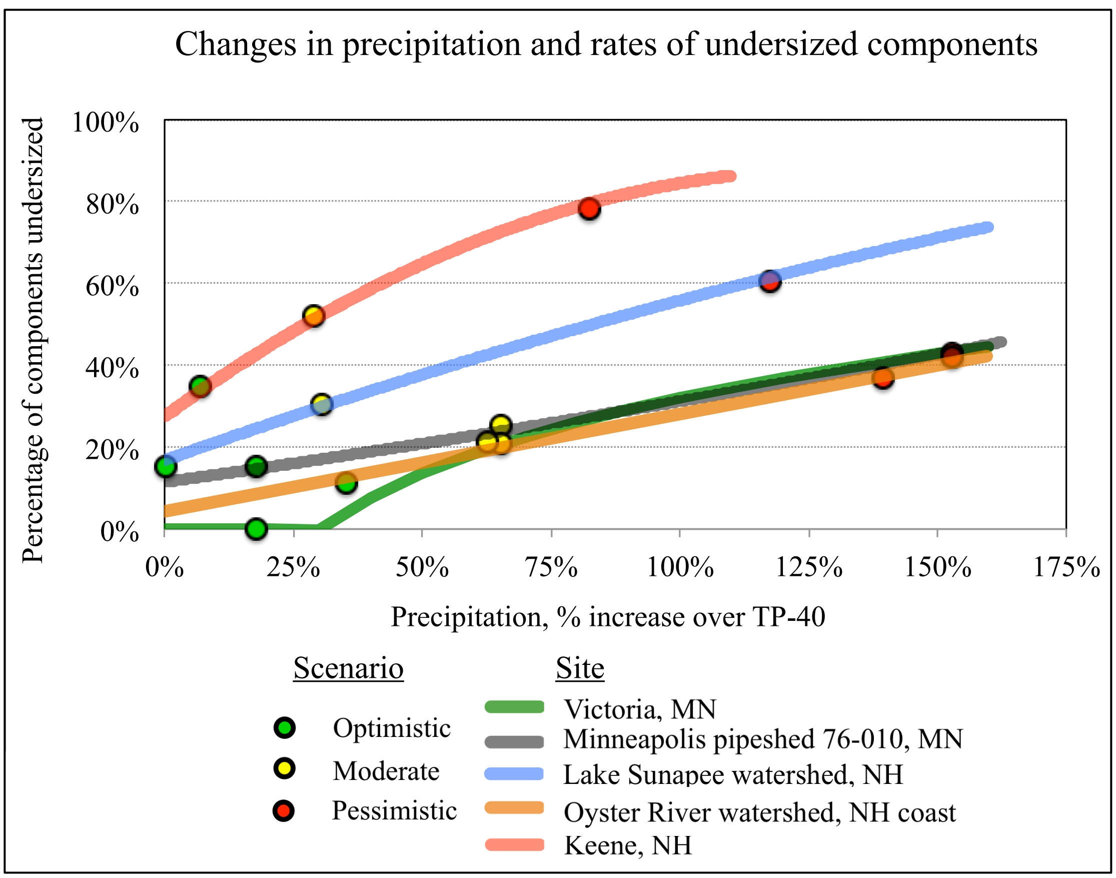


Figure ST.4. Comparison of system vulnerability to climate change, Minneapolis and Victoria sites, versus previous study sites in rural and coastal New Hampshire.

In both the Pipeshed 76-010 and Victoria study sites, pipe upsizing was by far the most effective means of adapting the stormwater system to manage flooding associated with projected changes in climate. This observation comes with a caveat in the case of the Pipeshed 76-010 watershed, in which the effectiveness of pipe upsizing was limited to a design storm depth of about 6 inches (which is 50% greater than the current 10-year design storm and within the range of increase expected under a moderate climate change scenario).

The inability to mitigate flooding through pipe upsizing beyond this depth was somewhat surprising, but upon examination, reflects a system in which backwater effects are dominant and surface storage and other detention opportunities are limited. Such a condition is not uncommon in urban areas, particularly where surface storage and infiltration capacity have been lost to accommodate dense development, and thus, the limitations of pipe upsizing as a stand-alone adaptation strategy may be applicable to other urban communities in the region. Additionally, the performance of a given adaptation measure on the basis of flood volume alone is not necessarily a good indicator of the capacity of the measure (or combination of measures) to build resiliency into the overall system. For example, in both Victoria and Pipeshed 76-010, pipe upsizing led to an increase in predicted peak flows at the watershed outlet relative to the do-nothing (i.e., maintain the existing system) or LID adaptation approaches. The increase was somewhat substantial in the Pipeshed 76-010 case (10% as averaged across all precipitation scenarios). Downstream impacts such as channel stability, water quality, and flooding of downstream communities should also be considered in assessing the effectiveness of adaptation approaches toward creating more climate-resilient communities.

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In an already built-out community such as Minneapolis, infiltration-based adaptation practices come with a different set of challenges, including retrofitting around existing foundations, utilities, and, in brownfield applications, the potential to mobilize contaminant plumes. Despite these challenges, LID practices have been applied more widely in the City of Minneapolis and neighboring urban communities. That the greatest incremental decrease in flood volume was achieved through the lowest LID intensity examined (here, applied to only 10% of model subcatchments) in the Pipeshed 76-010 model was encouraging. This intensity of LID is well within the realm of possibility. For example, in the neighboring urban center of St. Paul, a combination of bioretention/bio-infiltration facilities and underground storage/infiltration trench retrofits store up to 1.1 MG of runoff from a relatively impervious (44%), 25-ha (62-ac) watershed (CRWD, 2012). Coincidentally, this is nearly the same volume of storage provided by the 10% LID scenario in the Pipeshed 76-010 pipeshed, and thus provides an example of local application of LID at a scale to impact flooding projected under climate change. Coupling a similar intensity of LID with pipe upsizing seems to be a promising means by which to adapt stormwater systems for future climate, even in a built-out community such as Minneapolis.

Cost curves were developed to reflect the upper and lower bounds of costs expected to install larger pipes or underground storage reservoirs using data from the City of Minneapolis. Costs associated with the construction and maintenance of bio-infiltration facilities were obtained from Weiss et al. (2007). In Minneapolis, adaptation costs for the moderate climate scenario ranged from $40 to $70 million across the 1100 ac pipeshed; under the most pessimistic scenario, costs could be as high as $140 million to eliminate surface flooding. Expected costs to construct and maintain bio-infiltration facilities were lower than pipe-upsizing and underground storage costs. Accordingly, inclusion of LID – peak flow and flood reductions by which offset some of the need for pipe-upsizing and underground storage – resulted in a 50% - 55% reduction in adaptation costs for the moderate mid-century climate scenario. In Victoria, pipe-upsizing costs to maintain current levels of service ranged from $16 to $30 million for the most pessimistic scenario. However, such measures would not be necessary if street and park flooding were deemed acceptable as other property damage was not predicted for any climate scenario.

The ability to quantify required capacity and related construction costs for specific climate change scenarios, the insensitivity of capacity and costs to uncertainty, and the percentage of pipes and culverts that never require upsizing, all serve to limit the impact of uncertainty inherent in climate change projections. By constructing systems to more extreme scenarios and to the upper limit of confidence intervals, a safety factor is incorporated to adaptation programs to buffer uncertainty. Moreover, the insensitivity of construction cost to increased precipitation intensity provides incentive to incorporate even a very large safety factor. Thus, the ability to manage uncertainty, combined with the affordable impact of adaptation on town budgets and property tax rates, support a conclusion that adaptation is viable under current levels of uncertainty regarding the severity of future climate impacts.

Significance of uncertainty in the context of adaptation

The ability to develop specific capacities and costs for a given scenario derive from the use of standard civil engineering design methods, and standard construction cost compilations, applied on a pipe-by-pipe, and scenario-by-scenario basis. The combination of the number of drainage system components, and the number of landuse and climate-change scenarios modeled, resulted in a large dataset from which to establish the relationship between system capacity and cost, and precipitation and landuse. The use of widely-established methods, and the size of this dataset, provide capacity and cost estimates that have a high degree of reliability, and limit uncertainty to that which is inherent in hydrologic modeling and long-term climate forecasts.

This study examined the effect of a high degree of uncertainty in long-term climate projections, by selecting precipitation scenarios that span a wide range of design storm intensities. For the design storm, projected increases from the recent climate for the A1b and A1fi scenarios for the GFDL 2.1 CCM, are 18% and 153%, respectively (Figure ST.4). This is a span of 135%, and can be compared with the range of uncertainty in hydrological modeling to assess the validity of assumptions that the degree of uncertainty in long-term climate projections is unprecedented and a major impediment to adaptation.

The National Weather Service recently updated the intensity-frequency isofluvial maps for the Midwestern United States, including the study sites (Atlas 14, Volume 8). This work provides the 95% confidence limits for estimates. For the NCDC site used for the present study, the Minneapolis-St. Paul International Airport, for the 10-year 24-hour precipitation, Atlas 14 notes a 95% confidence range of 28% (Table ST.2).

Table ST.2 Uncertainty in the recent National Weather Service estimates of precipitation intensity-frequency relationship for the Minneapolis standard design storm.

Atlas 14, v.8, 10-yr 24-hr precipitation:		
Estimator	Minn.-St.Paul Int'l Airport	%Δ from TP-40
+95% conf. limit	4.85	21%
Most Likely	4.24	6%
-95% conf. limit	3.73	-7%
range:	1.12	28%

Uncertainty in hydrology/rainfall-runoff modeling

Uncertainty in climate modeling can be put into context through comparison with uncertainty in hydrologic modeling. As indicated in Figures ST.5 and ST.6, the range and distribution of uncertainty in mid-21st century design storm projections falls within that observed in modeled versus measured flows in hydrologic models. In our own study, the calibrated Victoria and Pipeshed 76-010 models were found to vary up to 40% from measured flows at the watershed outlet. This range of uncertainty falls within the median variability between the current 10-year design storm and 10-year, mid-21st century precipitation projections. This overlap begs the question: if planner and engineers deal with this uncertainty in hydrologic analyses on a regular basis through accepted stormwater design practices, why should a similar degree of uncertainty in precipitation projections warrant paralysis? This is among the key questions this study, through its strong outreach component, has raised to stakeholders in the stormwater community.

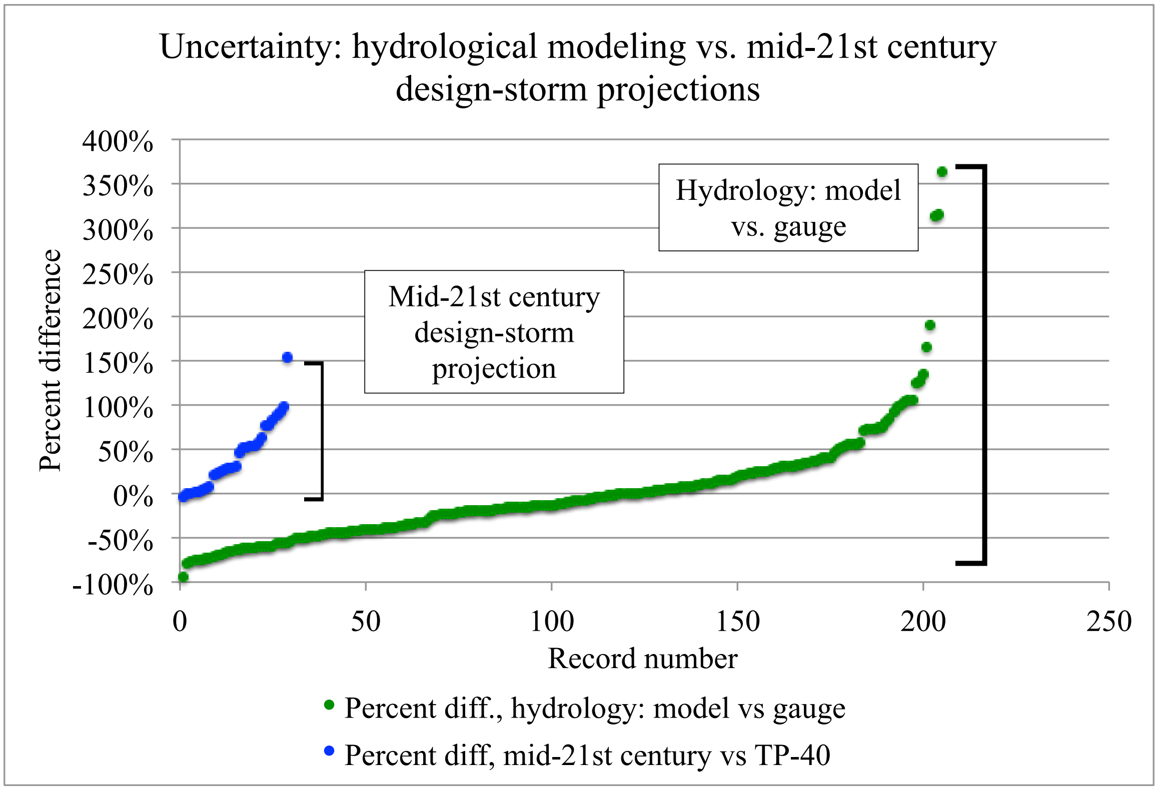

Figure ST.5. Comparison of uncertainty, expressed as a percent difference, between rainfall/runoff modeling and precipitation projections.

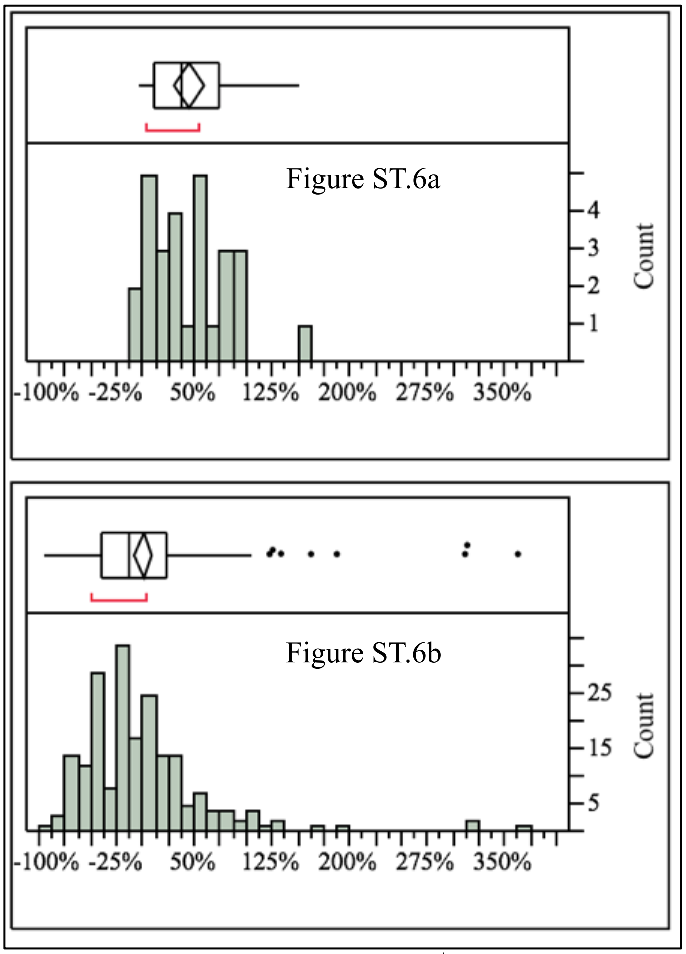

Figure ST.6. a) Distribution of mid-21st century 10-year design storm projections, expressed as a percent difference from the currently accepted TP-40 10-year design storm (4.1 inches), which is similar to b) The distribution of uncertainty in rainfall/runoff modeling, expressed as a percentage difference between modeled and measured flow.

Table ST.3 Comparison of range of uncertainty for results of calibrating 205 hydrological, versus range of precipitation projections from the current study.

	Hydrological: calibrated model vs gauge	Range		mid-21st cent. 10-yr precip: range, GCM + scen.	Range	
Quantiles						
100% maximum	364%			151%		
90%	73%			92%		
50% median	-12%	134%	459%	39%	94%	155%
10%	-61%			2%		
0% minimum	-95%			-4%		
Moments						
N	205			28		
Mean	0.5%			44.6%		
Std Dev	0.630			0.373		

That not all components require upgrading, even under an extreme climate change scenario, increases the manageability of uncertainty by making the incorporation of a safety factor more affordable. From Figure ST.4 it can be seen that about 80% of pipes remain adequately-sized under the *"most likely"* A1fi scenario. Even at the upper 95% confidence limit for this scenario, a precipitation amount 146% greater than the recent historical event, 55% of culverts remain adequately sized.

In published literature, "soft" adaptations such as general resilience and capacity building remain the standard prescription for potential civil infrastructure vulnerability due to uncertainty in GCM output (e.g. Rosenberg, 2010). Yet "soft" adaptations are likely insufficient by themselves, requiring eventual supplement from "hard" adaptation methods (White House Climate Change Adaptation Task Force, 2010; Miller et al., 2010), presumably when anticipated reductions in uncertainty occur.

Implicit in the standard conclusion to delay hard adaptation are the following assumptions, portrayed in Figure ST.7:

- The cost of uncertainty will significantly decline within the planning horizon;
- The cost of damages are not yet significant enough to require "hard" adaptation, but will increase as climate change impacts increasingly manifest;
- The costs of uncertainty and damages will reach equilibrium, after which it will make economic sense to perform "hard" adaptations;
- We have not yet reached this equilibrium.

The belief that the cost of uncertainty currently exceeds the cost of damages is problematic, however:

- No significant reduction in climate change-related uncertainty is expected in the foreseeable future (Smith, 2008);
- Significant damages and loss of life from overwhelmed stormwater systems are already occurring, resulting in a penalty from inaction.
- Present systems may not be as adequate as we assume, even for current conditions. Both Waters et al (2003), and our studies, have found that existing systems are already undersized (Table ST.1), and not large enough to convey stormwater associated with their intended level of service.

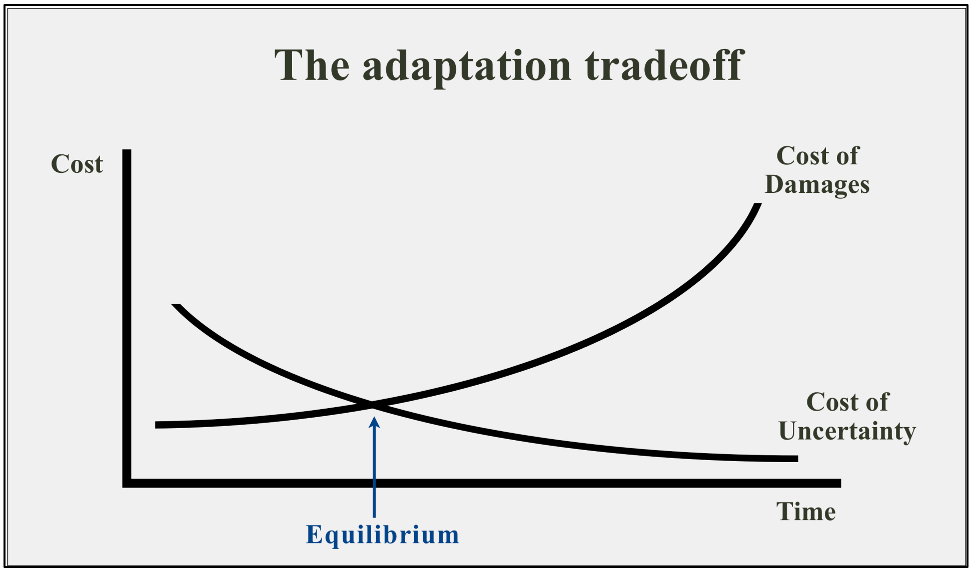

Figure ST.7. Cost curves of adaptation uncertainty and damage from failure to adapt.

Non-stationarity in long-term forecasts as a change from past and current conditions, and as an obstacle to adaptation

Previous and current climate conditions are assumed to be stationary, and the precision of historical design standards such as *TP-40*, are seen in sharp contract to the non-stationarity resulting from increasingly manifesting climate change. This contrast is considered a major obstacle to adaptation. However, the assumption that past and current climates have been stationary, and design standards precise, is inaccurate. For example, as shown in Figure 4ST.8, isoplubial contours for the 24-hour, 25-year event, as published in 1961 for *TP-40* (Hershfield, 1961) generally are 25% greater than similar contours published twenty-five years earlier by Yarnell (Yarnell, 1935).

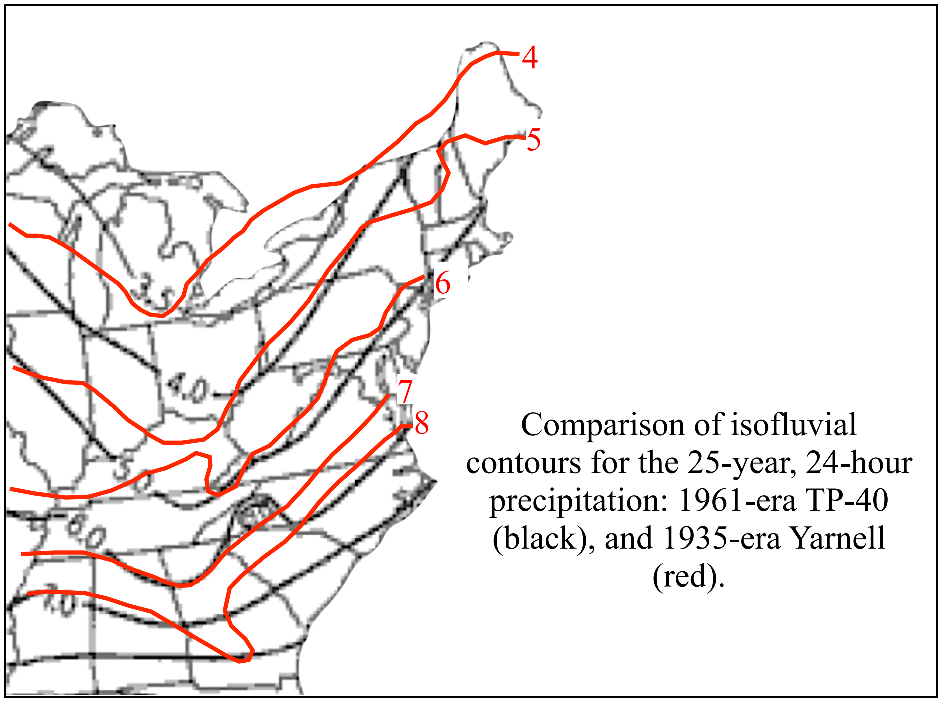

Figure ST.8*. For the 24-hr 25-yr event, isoplubial lines from Yarnell (1935), overlaid with red isoplubial lines from TP-40 (Hirshfield, 1961).*

The assumption that *TP-40* itself was accurate and precise is fallacious (Wilson, 2008). Standard intensity-duration-frequency modeling of rainfall asserts that a minimum thirty year record is required to accurately estimate lower frequency events such as the twenty-five year storm. However, *TP-40* utilized historical datasets that, on average, were only fifteen years. In addition, *TP-40* provided only point estimates for precipitation levels, omitting confidence intervals and thus portraying a false degree of precision. As a result of concerns about *TP-40*, there was controversy about whether to release it for publication.

Finally, the development of climate change-cognizant design specifications is possible under conditions of non-stationarity. European practice has applied *change factors* to increase design standards according to the useful life of the infrastructure being designed. For example, see Figure 9 in Hennegriff et al., 2006.

<u>*Outreach program*</u>

Climate and associated stormwater modeling results were presented to stakeholders through a participatory process designed and implemented during 2012 and 2013 in the Minnehaha Creek Watershed District. The goals of this process were to engage a wide range of stakeholders in assessing the current conditions, develop an overall set of objectives to address identified concerns and challenges, and develop strategies to move forward on implementing prioritized actions. This process was informed by results shared from the science team including downscaled climate data and related stormwater impacts. Public, multi-stakeholder, collaborative planning events included Forums and Working Group sessions. Substantive and broadly supported outputs resulted from this process. Each of these events and their outputs are described in the Outreach section of this report.

All outputs are included in this section of the report or in the Appendices.

Public outreach included a wide range of communication and media tools. These included newsletters, e-mail dissemination, meeting with Governor's Office, earned media coverage, fact-sheets, and comprehensive project web site.

An evaluation of this collaborative public process included reviewing the process and the deliverables. Three different frames were used to evaluation the public process. The first included quantitative and qualitative feedback from participants attended each of the events. The second compared this process to a 10-step "Collaborative Planning Approach for Climate Change Adaptation" model. The third approach used the criteria from the 2008 report of the National Research Council on effective public participation processes. The overall findings are that this public process was well received, provided significant and useful outputs, and was collaborative in approach. This project comes to a close alongside increased public awareness and interest, as indicated by well-attended workshops and conference presentations and numerous inquiries into the status of this project itself.

Conclusion

Foundational premises of this project were that: information and methods are available today to support adequately-reliable infrastructure adaptation; the resolution of certain key issues in infrastructure adaptation will be attained most efficiently through learning-by-doing; and these issues can be studied concurrently with providing actionable adaptation guidance to communities.

Findings of this study have broad application nationally and internationally, as communities transition civil infrastructures to accommodate already-occurring and projected change, in order to maintain historically accepted risk-levels. Together, these findings posit a solution to arguably today's most significant challenge in civil infrastructure adaptation: translating the extensive corpus of adaptation policy theory and regional-scale impacts analyses into local-scale action. Though focusing on stormwater management systems, the principles and methods developed provide a template for other local, regional, and national infrastructure systems. The conviction that knowledge and methods available today are sufficiently reliable to support local-scale action, places this project at the fore of adaptation work world-wide. These findings significantly improve national and international capacities to respond to climate variability and change.

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Appendix "A"

Precipitation downscaling methodology

Model output was statistically downscaled using a variation of the Change Factor method (Diaz-Nieto and Wilby, 2005), also known as the Delta, or Perturbation Factor, method. This was applied using a direct, multi-site approach (Haylock et al., 2006). Change factors were derived using extreme value statistics to model the low frequency (high return period), more hazardous events residing at the tail of the precipitation distribution. Civil infrastructure is generally designed to accommodate a specific low-frequency/extreme-value event. As noted above, Minneapolis practice is to design systems to accommodate peak flow resulting from the once-in-ten year event (i.e. the event having a 10% probability of occurring in any given year), specified by the TP-40 standard established in 1961 (Hirshfield, 1961). Although NOAA has just published Atlas-14 to supersede TP-40, existing systems have been designed based on the older standard. Recent studies have applied *point process* theory to extreme value statistics in the modeling of precipitation (Coles and Pericchi, 2003), and the present study fit data to a *point process* model of *peaks-over-threshold*, following the methods of Zwiers and Kharin (1998), and Katz et al. (2002). Semenov and Bengtsson (2002), and Watterson and Dix (2003) proposed that extreme value methods were potentially reliable means for downscaling coupled-climate model output, and this method may be considered state-of-the-art in statistical downscaling.

Thirty-year records of continuous daily precipitation for CCM output and observed NCDC station data, for CCM gridpoints and NCDC stations proximate to the study site, were extracted from the full datasets. The thirty-years of records were conditioned for comparability between CCM and NCDC data, and between that data and design storm requirements:

- Units of measure were converted to inches of rainfall;
- In order to convert daily rainfall totals, from CCM output and NCDC historical records, to the 24-hour totals required per Minnesota stormwater design guidelines, daily records were multiplied by 1.13, following the results of Young and McEnroe (Young and McEnroe, 2003). This multiplier must be applied to compensate for the difference found between daily precipitation totals obtained from measurements taken at a specific time of day (or daily totals in the case of CCM output), and totals obtained by taking 24-hour totals regardless of when the 24-hour period occurs. For example, a 24-hour event might occur from 8:00 p.m. to 8:00 p.m. the following day. If cumulative precipitation measurements are taken at 9:00 a.m. every morning, for this rainfall event precipitation would be divided between that accumulated between 8:00 p.m. and 9:00 a.m., and that accumulated between 9:00 a.m. and 8:00 p.m. Studies have shown that multiplying daily records by a factor 1.13 accurately converts daily totals to 24-hour totals (ibid.).
- Rain gauges used for NCDC records have a detection limit of 0.05 inches, with precipitation amounts of less than 0.05 inches recorded as "Trace". Generally accepted hydrological practice converts "trace" records to 50% of the minimum detectable value, in this case 0.025 inches (Mitsch and Gosselink, 2000). For NCDC

records, 0.025 inches was substituted for all notations of "Trace". For CCM output, 0.025 inches was substituted for all values less than 0.05 inches.

Coupled Climate Model (CCM) output:

Data used to estimate the impact of climate change on precipitation were taken from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 and 5 (CMIP3, CMIP5) multi-model datasets. Downscaling was achieved via the modified delta method described below and used in previous studies by the project team.

The selection of CCMs used for the modified delta method downscaling was based on the common international practice of national adaptation programs utilizing the CCM supported by that country, e.g. United Kingdom uses the HadCMx series of CCMs, and Canada uses the CCCma CCCMx series of CCM. Therefore, two of the three potential candidates for a hypothetical future United States adaptation program were selected for this study. The Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 and CM3 models (Delworth et al., 2006) were selected based on skill at modeling the North American climate-changed and 20th century climates (Tebaldi et al., 2005; Knutson et al., 2006). In addition, the National Center for Atmospheric Research (NCAR) PCM and CCSM4 models (Washington et al., 2000) were selected due to their frequent use in climate impacts studies, and their representation of a "drier" climate than predicted by the GFDL. To determine the impact of the number of gridpoints on results, we used sets of four (2 x 2), six (2 x 3), and nine (3 x 3) gridpoints encircling and closest to the study site. Selecting a group of gridpoints surrounding the study site avoids the erroneous assumption that regional climate can be inferred from a single gridpoint (Wilby, et al. 2004, cited in de Loe and Berg, 2006), and at any rate is necessary because CCM gridpoints are not located precisely at the study site. Due to the expected reduced precision of the 4-gridpoint schema, this was used for only two scenarios.

The study's schema for the CCM, emissions, and gridpoint combinations is presented in Table AP.1. The A1fi and A1b SRES pathways were used for the GFDL 2.1. The A1b SRES pathways were used for the PCM, however PCM data for the A1fi pathway was not available from the ESG data portal. For the CMIP5 Representative Concentration Pathways (RCPs), RCPs 4.5, 6.0, and 8.5 were used. However, only a single scenario was used for the RCP 4.5, due to the minimal likelihood that this trajectory will transpire. For all CCMs from each downscaling method, data for the 1971-2000 period from the Climate of the Twentieth Century scenario was utilized as the baseline from which to estimate the percentage change in the design storm.

Table AP.1. *PCMDIA model generation, CCM, emissions trajectory, and gridpoint combinations used in the present study.*

Generation:	Model:	Grid_size:	Scenario:
Historical	NCDC	Station	Recent
CMIP3	CM2.1	9-grid	A1b
CMIP3	CM2.1	9-grid	A1fi
CMIP3	CM2.1	6-grid	A1b
CMIP3	CM2.1	6-grid	A1fi
CMIP3	CM2.1	4-grid	A1b
CMIP3	CM2.1	4-grid	A1fi
CMIP3	PCM	9-grid	A1b
CMIP5	CCSM4	9-grid	rcp45
CMIP5	CCSM4	9-grid	rcp60
CMIP5	CCSM4	9-grid	rcp85
CMIP5	CM3	9-grid	rcp60
CMIP5	CM3	9-grid	rcp85
CMIP5	CM3	6-grid	rcp60
CMIP5	CM3	6-grid	rcp85
Average, all GCMs/Scenarios/Grids:			A1b
			A1fi
			rcp45
			rcp60
			rcp85

Downscaling model

Thirty year-long records of data for each model generation, CCM, SRES pathway, model run, time period, and gridpoint (comprising 978 sets of data), were fit to a *point process* model of *peaks-over-threshold*. *Maximum negative log-likelihood* (*NLLH*) was used to select *best-fit* values for the three parameters location *m*, scale *s*, and shape *x*, which established the curve of the probability distribution. Probability and quantile diagnostic plots of estimated/modeled versus actual/empirical precipitation, were used to assess the goodness of fit of the *point process* curve generated from parameters at the *NLLH* (Figure AP.1). Note, on the Quantile plot in Figure AP.1 that the most extreme observed (empirical) value, a bit more than 3.5 inches, is above the line of perfect fit. This means that the best-fit model according to *NLLH* under-estimated this value. Although this underestimating occurred fairly often, occasionally the divergence was large. For these cases a better fit was sought across a range of *NLLH* values. For several datasets a local maximum *NLLH* yielded a better fit of extreme values than the global maximum, in this case the local maximum was selected.

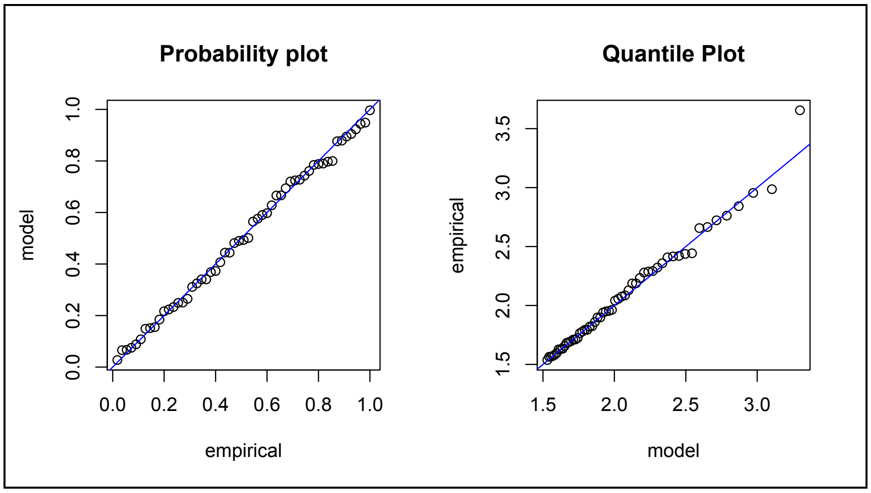

Figure AP.1*. Example of diagnostic plots used to assess goodness-of-fit of the point process model computed for each 30-year data record.*

The parameters μ, σ, and ξ, were used to estimate the ten-year return period (10% annual probability of occurrence) event for each gridpoint. The percentage change in this value, from recent to climate-changed periods, was computed and transferred to the study site. For this purpose we modified a method proposed by Shamseldin et al (2006), whereby relationships between CCM gridpoints and observed NCDC stations are established via least-squares regression. At each gridpoint, Δ% in the 10-year event, from the baseline to the mid-21st century periods, was calculated. Stepwise regression identified sets of significant factors (p = 0.05) able to predict, at a high r^2, Δ% in the 10-yr event across the six CCM gridpoints. The resulting regression equation was used to transfer the Δ% from CCM gridpoints to NCDC stations. In order that regression equations derived from CCM gridpoints could be applied to NCDC sites, candidate factors included in the stepwise regression analysis needed to be available for both CCM gridpoints and NCDC sites. Physical factors tested were elevation, latitude, longitude, and probability of precipitation P_p. Statistical factors tested were, from the *point process* fit, *NLLH*, number of records exceeding the *threshold* value, baseline μ, σ, and ξ, and baseline 10-year event estimates. Residual values were assumed to be independent and normally distributed. Regression transfer functions derived from the CCM gridpoints were used to estimate Δ% in the 10-year event, from baseline to mid-21st century, for NCDC stations.

In accordance with common hydrological practice, the shape parameter ξ was regionally averaged to increase the reliability of results, using the standard method developed in Hoskings and Wallis (1997), and Hosking (1990). For the 28 NCDC stations, L-Moments were computed for the Generalized Pareto Distribution, using the *lmrgpa* command in the *lmom* package of "*R*", version 11.1.1 (Table AP.2). L-moments are computed from the *scale*, *location*, and *shape* parameters:

e.g. Amery, MN, Coop ID 470175

lmrgpa(para = c(*scale*, *location*, *shape*), nmom = 3)

lmrgpa(para = c(1.78694651, 6.12911407, -0.04391885), nmom = 3)

L-moments were used to cluster the stations for regionalization, using the Cluster function in JMP version 7.02. Both Centroid and Ward clustering methods were used, both gave the same results (Figure AP.2).

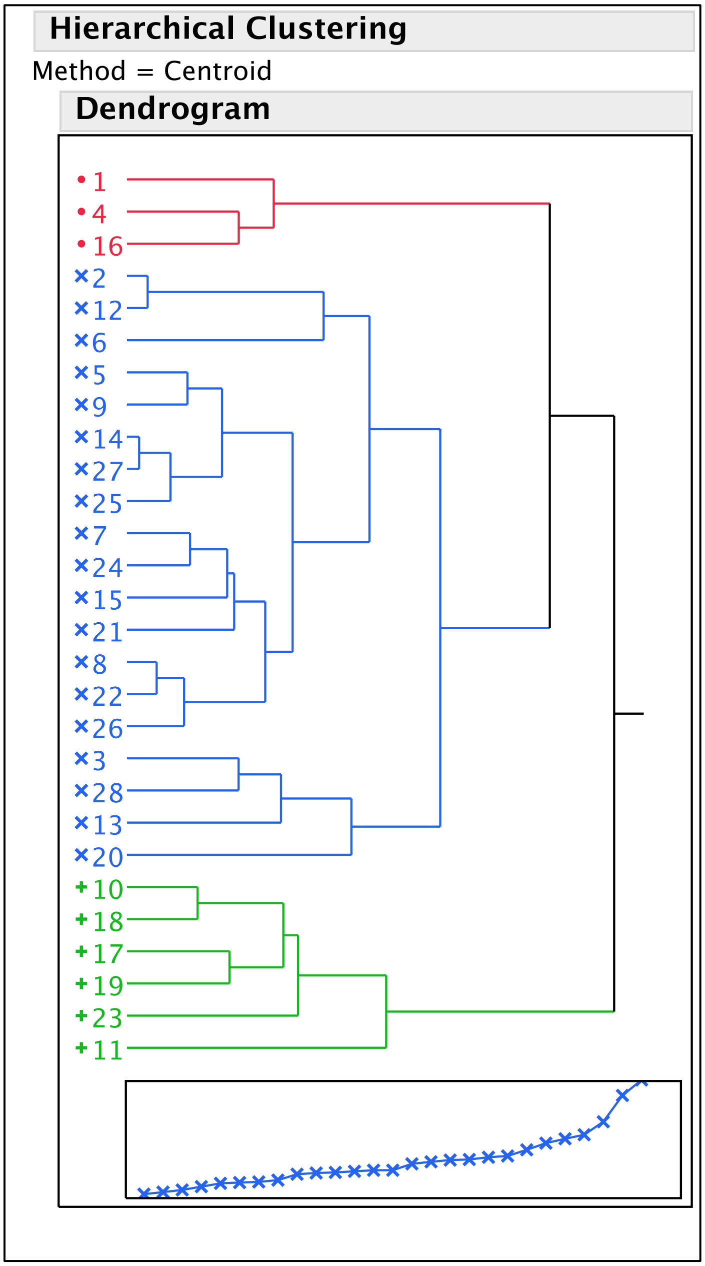

Figure AP.2. Results of cluster analysis to identify NCDC stations that are regional homologues to the Minneapolis-St. Paul International Airport NCDC station.

Table AP.2. Statistical output from regionalization clustering using the method of L-Moments (Hoskings and Wallis,1997).

Coop ID	sca	loc	sha	lambda_1	lambda_2	tau_3	Centroid	Ward
470175	1.78695	6.12911	-0.04392	8.1976095	3.2772991	0.3531428	1	1
210287	1.48310	5.28248	-0.04043	6.9881362	2.8093029	0.3515465	3	3
211107	2.60716	6.70314	0.17186	8.3272419	2.6337208	0.261089	3	3
211198	1.82024	6.71183	-0.01905	8.6624343	3.4540009	0.3418554	1	1
211227	2.00927	6.31531	0.04425	8.0569644	2.9583885	0.3139519	3	3
211263	1.65873	5.66474	-0.05140	7.6304308	3.0646124	0.3565768	3	3
211465	1.84237	6.12663	0.07799	7.5257323	2.7350212	0.2995476	3	3
211691	1.62525	5.81689	0.04082	7.2140125	2.7384899	0.3154352	3	3
471923	1.87684	6.22091	0.01913	7.9809927	3.0231596	0.3248856	3	3
471978	1.99475	5.66403	0.21345	6.6624616	2.1087964	0.2447685	2	2
212038	1.52424	5.04155	0.05547	6.3008187	2.323831	0.3091259	2	2
212248	1.55179	5.22888	-0.04780	7.043142	2.812901	0.3549205	3	3
212486	2.23301	6.52447	0.17235	7.7983024	2.5618734	0.2608944	3	3
212500	2.01329	6.29517	0.06024	7.950753	2.881924	0.3070852	3	3
472556	1.96980	6.42817	0.11458	7.7371627	2.7274268	0.2842829	3	3
212721	1.85513	6.27301	-0.07207	8.6153184	3.5064446	0.3661511	1	1
473244	1.92492	5.51952	0.16636	6.6571998	2.1844417	0.2632821	2	2
473242	2.07464	5.93208	0.24478	6.8402123	2.1229571	0.2327494	2	2
213793	1.69107	5.73205	0.13526	6.7401565	2.3646192	0.2758094	2	2
213808	2.36519	6.96751	0.26433	7.8760346	2.4337676	0.2253674	3	3
213962	2.03560	5.95759	0.10264	7.4386488	2.5696528	0.2892262	3	3
215615	1.65457	5.66787	0.03249	7.1440977	2.7008935	0.3190491	3	3
215435	1.74220	5.11956	0.16153	6.1498122	2.0391192	0.2652112	2	2
215887	1.86652	6.09403	0.05513	7.6421335	2.8103423	0.3092734	3	3
217004	2.02787	6.42668	0.08442	7.9542345	2.8431681	0.2968393	3	3
217907	1.68675	5.80065	0.02580	7.3414974	2.7913656	0.3219639	3	3
217405	1.98990	6.34727	0.06651	7.9413548	2.879957	0.3044153	3	3
218692	2.31680	6.73404	0.12833	8.2849336	2.8041344	0.2786364	3	3

The NCDC station used to feed the hydrologic and hydraulic modeling was the Minneapolis-St. Paul International Airport, Coop ID 215435. The method of L-Moments identified five NCDC stations as regionally similar to the Minneapolis-St. Paul International Airport (Table AP.3), for a total of six stations. For these stations, the mean historical x was computed, and increased by the mean Δx.

Table AP.3. Stations identified as regional homologues to the Minneapolis-St. Paul International Airport NCDC station that was used to provide precipitation estimates to the hydrology/hydraulic model.

Name	Coop ID	Cluster	No. of yrs	Longitude (deci	Latitude (decim
DAWSON	212038	2	38.6	263.92	45.55
HINCKLEY	213793	2	38.6	266.35	46.65
MSPIntAir	215435	2	41.3	266.77	44.88
DANBURY	471978	2	39.8	267.38	46.01
GRANTSBURG	473242	2	39.9	266.87	46.31
GLENWOOD 2 \	473244	2	38.0	266.85	46.29

The above downscaling analysis estimated mid-21st century *point process* parameters for the study site. These were input to the equation for the *generalized pareto distribution* (Shamseldin et al., 2006), to estimate a set of mid-21st century, 24-hour, 10-year design storms for a range of scenarios. These values were used for the hydrologic/hydraulic models to estimate *peak flow*, Q_p, and drainage capacity, under mid-21st century climate-changed conditions. See the precipitation results section of the report for these values (Table P.1).

Extreme value statistical analyses were performed using the ISMEV and EVIR packages in “R” (R Development Core Team, 2005), regression analyses were performed in JMP 7.0 (SAS Institute, 1989-2005). Note that statistical analyses described elsewhere in the project were also performed in JMP.

Model validation

The validity of the downscaling model, described in detail in the *Results/Discussion* section of this report, was established in previous studies, most recently Stack et al. (2010). That study tested the methods skill at deriving the 25-yr event for a known historical period, 1971-200, from data for the baseline period 1926-1955. Across twelve NCDC stations, including the study site, that were homologous based on Hoskins’ and Wallis’ (1997) L-moment regionalization method, the average error in predicting the 25-yr event was −0.3%, with a range of −20.0% to +19.3%, all of which were within the 95% confidence bounds of the *most likely* estimator.

Appendix "B"

Outreach

The abstract of the proposal for this project entitled "Long-term climate forecasts and information supporting adaptation decisions" that was submitted to the Climate Program Office for Urban Water Resources of NOAA stated that:

"The overarching purpose of this program is to promote stakeholder-driven adaptation of vulnerable stormwater management systems and related water resources, by demonstrating, implementing, and disseminating a quantified, local- scale, and actionable protocol for maintaining historical risk levels in communities facing significant impacts from climate change. The proposed project will utilize an interdisciplinary team of investigators and stakeholders, to transfer coupled-climate model projections to the sub- watershed scale, in a form understandable to planners, resource managers and decision-makers."

The public process team under this project, working closely with the science team, planned and implemented a collaborative stakeholder-driven planning process that engaged a wide range of constituency groups. These stakeholders, through this public process, completed strategic planning efforts that resulted in specific and prioritized adaptation strategies for addressing growing stormwater intensive events. The disseminated results of this collaborative process are in a form that is understandable to planners, resource managers and decision-makers. This following sections describe this process, the outcomes, and provides an evaluation of its effectiveness.

Outreach process overview

In a 2008 report, the National Research Council identified three main goals for stakeholders in assessment and decision-making: (1) improve quality; (2) improve legitimacy; and (3) improve capacity of environmental assessment and decisions. First, quality of the outcomes is enhanced by incorporating social values, interests, concerns of all those that are affected, including best available knowledge/science, into the decision-making process. Recommended actions or solutions, no matter how brilliant, are of little value if the process is not legitimate. The process must inherently be, and be perceived as, fair, competent and follow due process of law. Finally, building the overall capacity of the system to make needed changes includes raising awareness of the situations, building networks and partners, and developing a shared understanding of both the challenges that need to be addressed and how to move forward.

Our overarching goal with the Minnehaha Creek Watershed Stormwater Adaptation Study was to increase resilience, adaptive capacity, and social capital by engaging the public with vetted data on severe weather trends and best available climate change science, fostering local municipality/region/watershed understanding, trust, and collaboration to increase resilience to stormwater risks, and developing widely shared understanding of the issues and decision challenges. The stakeholder engagement process we used involved distinct phases, including:

1) Convening a broad cross-section of representatives from various levels of government (local, regional, state, federal), NGOs, academia or education organizations, non-profits, community associations, as well as private citizens.

2) Once gathered, we assessed the situation and affiliated issues based on essential data collected by the technical team. During this assessment phase, we crafted guiding questions for large and small discussions wherein stakeholders could express diverse perspectives, reflect, and gain an understanding of underlying causes of the issues at large. We established several communication channels, including a dedicated webpage and a sequential project newsletter, as well as a series of public forums to introduce the topic, the study, and disseminate results. To create a framework that communities can actually use, we collected stakeholder input to identify four (4) priority topics to address in climate change adaptation planning: education, planning, infrastructure and funding.

3) Next, we identified barriers to progress on climate change adaptation and identified strategies and tools for implementation. Work session participants developed potential strategies that were then vetted using an impact vs. feasibility grid. Ideally, we want to identify the strategy with the highest feasibility and greatest impact. The overall vision was framed, broad objectives developed, and four work groups assembled to distill and define specific objectives within the priority topics

4) Few societal changes can be accomplished without a broad group of partners. We identified, engaged and formalized an inclusive Advisory Committee to aid in engaging a broad range of stakeholders as well as provide guidance on how to direct the engagement process itself. This Advisory Committee also provided an opportunity to build leadership capacity within the various groups the committee represented.

5) The final phase of the engagement process convened stakeholders to develop concrete action plans that form a framework for community adaptation planning around changing precipitation patterns and land use. These actions are based on priorities identified by the stakeholders themselves, thereby increasing the legitimacy and relevance of the actions proposed.

6) Lastly, embracing open and dynamic feedback on the process and actions taken is an important component of the process, which will continue to build support for community conversations around adaptation planning and implementation efforts.

The information gathered during the technical modeling and assessment phase was combined with the outputs from the collaborative stakeholder process to create a framework for addressing community stormwater adaptation planning. Information can be provided to local policy makers, developers, landowners and other interested stakeholders about current models and tools, trends, projected conditions, adaptation options and costs, education and communication strategies.

An Advisory Committee was developed to play a central role in helping to facilitate the success of the Minnehaha Creek Watershed Stormwater Adaptation Study as well as build capacity and leadership around adaptation planning at both the local and regional level. The advisory committee included representatives from three municipalities within the Minnehaha Creek Watershed District,, three watershed organizations, three state-level water resources organizations, and two non-profits. The committee was charged with two main tasks:

3. Identify and recruit stakeholders to help insure that the study includes a diverse and thorough representation of community members who would have knowledge to bring to the project or might be affected by the outcomes of the project.

4. Provide input and feedback on the planning and execution of the study as well as evaluation of the process used.

This Advisory Committee was responsible for reaching out to community stakeholders to participate in a series of forums and workshops. These events and key outcomes are detailed in the following sections.

First Forum: "Are We Ready?" (May 15, 2012)

Fifty-nine city officials, regional planners, engineers, and concerned citizens from municipalities throughout the Minnehaha Creek Watershed District gathered on Tuesday, May 15 to discuss shifting rainfall patterns and the impact on urban runoff and water quality in our area. The purpose of the forum was to introduce the community to the project, and collectively identify communitywide concerns and priorities related to changing precipitation patterns and overall growth and development in our region. The forum included a number of presentations and activities including an update on the current and historic precipitation patterns in our region, by Mark Seeley, Climatologist at the University of Minnesota, the status of local stormwater infrastructure, extreme weather events, and any actions currently being undertaken in the Cities of Minneapolis and Victoria, our two focus areas, and an introduction to the MCWD Stormwater Adaptation Study and a highlight of the project's purpose, goals, expected outcomes, and limitations. Work groups were developed though a guided activity led by Jim Gruber, Antioch University (Appendix B, C).

Based on output during the collaborative planning portion of the forum, the top challenges were identified and prioritized related to changing precipitation patterns and impacts to our water resources. These challenges were used to develop priority topic as well as specific objectives around climate change and stormwater adaptation planning. The top twelve challenges identified included:

- A conflict between individual rights and what is good for community.
- The lack of education of decision makers and the public on the impacts to stormwater infrastructure by changing weather patterns.
- A lack of funding, which causes cities to be reactive versus proactive.
- A lack of funding to deal with the marginal costs of changing infrastructure.
- The change in intensity of rainfall, which is not accounted for in the engineering of our systems.
- Inadequate minimum requirements set by cities, which do not provide a level of protection needed to prevent damage by the increase in extreme events.
- The treatment of rainfall as a waste product.
- The expectations of property owners and the public must be adjusted to the realities of dealing with more extreme events, and changing weather patterns (for example, people want dry roads and yards).
- The process for decision making is focused on short-term projects with quick or immediate benefits.
- The lack of immediate economic impact, which makes this a long-term problem.
- The focus on cars for transportation which requires significant "car habitat" that is usually high impact.
- A lack of ownership of issue by all stakeholders (local, regional, state, and federal).

Based on the challenges identified, four priority focus areas were developed with topic-specific objectives. These four priority focus areas were later used to identify specific strategies and action plans through a series of stakeholder Work Groups that were held. These four priority areas consist of (Appendix D):

E. **Education, Outreach, and Stakeholder Engagement:** Identify strategies to increase awareness of management issues, educate and inform policy makers and developers, and strategize on how best to develop a consensus to move forward.

F. **Land Use Planning and Policy:** Identify how to incorporate study data into design, create guidelines for development and policy, identify opportunities for green infrastructure and low impact development options, and how to communicate planning and policy options.

G. Stormwater Infrastructure (Green/ Grey) and Low Impact Development: Assess current infrastructure and needed upgrades, options for impervious options for water quality and flood control, and determine how to communicate development and redevelopment options.

H. Sustainable Funding for Stormwater Infrastructure: Assess funding needs for updating infrastructure both immediate and long term, including economic impacts of decisions, and finding opportunities for proactive management options.

First Sessions of Working Groups: "What Could Be Done?" – (September 19 and September 26, 2012)

Participants used input from the May forum during the Work Group session "What Can Be Done" to develop possible approaches to stormwater infrastructure adaptation. Major objectives identified by Work Groups are listed below, including the most feasible approaches to meet the given objectives (Appendix D):

A. Education, Outreach, and Stakeholder Engagement – the need for cooperation, better dissemination of information, and refocusing energy after crisis events and promoting success stories.

Objective 1: Identify strategies to increase stakeholder awareness, level of interest and ownership of stormwater management issues, including transparency of water use fees and costs.

Top Priority:

- Showcase studies to demonstrate need for adaptation. Capitalize on crisis events to create a sense of urgency among decision makers and public.
- Publicize and disseminate the data and science we already have, and do it in an effective way that makes use of media, case studies and recent crisis events.

High Priority:

- Educate existing and new local leaders, and promote activities that cultivate personal connections within the community.

Other Priorities:

- Find supportive leaders and get them engaged.
- Educate a broad array of groups (businesses, residents, city staff, etc.) on issues related to climate change and adaptation.

Objective 2: Identify strategies to educate local policy makers about stormwater vulnerabilities, long-term needs, and options.

High Priority:

- Educate policy makers and technical staff about climate change and adaptation issues using existing programs, including Nonpoint Source Education for Municipal Officials (NEMO)[17] and the University of Minnesota's Stormwater U[18].
- Make use of successful unified groups and adopt their model (i.e. Aquatic Invasive Species Task Force)[19]
- Use and publicize current and proven data in climate change education to alleviate questions related to uncertainty.
- Recommend new standards or specific actions that local leaders can take. Make it concrete and concise.

Other Priorities:

- Develop coalitions between interest groups that will communicate unified messages.
- Educate with and incorporate 'new' science as it becomes available.

Objective 3: Identify strategies to inform developers of alternative stormwater management methods and techniques.

Top Priority:

- Highlight success stories and publicize good projects to make innovation the norm among developers.

High Priority:

- Use a certification program to reach developers.
- Focus on past experiences and be direct about lessons learned.
- Use enforcement capabilities and encourage rule changes to promote alternative stormwater methods and techniques.

Other Priorities:

- Incentivize early adopters of new and innovative technologies.
- Educate associations (i.e. Minnesota Utility Contractors Association, Minnesota Erosion Control Association) to have information 'trickle down' to constituents.

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[17] "NEMO (Nonpoint Education for Municipal Officials) is a nationally recognized educational program for local elected and appointed decision makers addressing the relationship between land use and natural resource protection." Learn more at http://northlandnemo.org/

[18] Stormwater U is an education program "to promote environmentally sound Water Resources Management & Policy best practices among stormwater professionals: contractors, developers, engineers, and field staff through locally tailored workshops currently known as Stormwater U." Learn more at http://www.extension.umn.edu/stormwater/stormwaterU.html

[19] The Aquatic Invasive Species Plan Task Force is comprised of residents, water-oriented businesses, outdoor recreationists, and policy-maker-level representatives of key local governments. Their primary goal is to develop and recommend a policy-based AIS Management Plan, with an emphasis of what should be in the Plan, rather than how it should be accomplished or implemented.

Objective 4: Identify strategies to develop consensus and cooperation among different stakeholder groups for addressing stormwater management and adaptation planning.

Top Priority:

- Capitalize on recent crisis moments and/or current flooding issues to create sense of urgency.

High Priority:

- Find a champion to convey messages and link different stakeholders together.
- Avoid highlighting mistakes and frame as 'opportunities for success' for innovation.

Other Priorities:

- Bring education to staff to reduce barriers to education opportunities. Educate the educators.

B. Land Use Planning and Policy – using cost and benefit analysis to guide adaptation, evaluate costs of extreme storms, and use applied research to disseminate current knowledge.

Objective 1: Incorporate changes in rainfall patterns into stormwater infrastructure design.

Top Priority:

- Run different design storm[20] scenarios and determine management implications for different types and intensities of storms

High Priority:

- Analyze incremental costs based on various design scenarios and quantify the risks of inaction and adaptation for decision makers (public safety risk, how often will basements flood, and are people at risk injury or death?).
- Show historical data with present (TP-40[21] vs. Atlas 14[22]) and demonstrate that things have changed and are continuing to change.
- Use the best available models and tools currently available. (Note: data is available to run the trends and is not that expensive.)
- Have a public dialogue about expectations for level of service, level of protection, and associated costs.

Other Priorities:

- Create sense of urgency and convince decision makers there is a problem.

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[20]A **design storm** is based on a particular storm frequency, duration, and volume expected for a specific region for engineers to size stormwater infrastructure by.

[21] **TP40 (Technical Paper No. 40)** is the precipitation-frequency atlas used to evaluate how much volume stormwater infrastructure must be designed to handle. TP40 provides the return periods and duration of rainfall events in a given area.

[22] **Atlas 14** is the precipitation-frequency atlas being completed to replace the TP40. It will be used to evaluate how much volume stormwater infrastructure must be designed to handle. It includes more data with a denser network and longer period of record.

Objective 2: Create guidelines for future development, including changes in planning and policies related to stormwater management.

Top Priority:

- Do a market analysis to determine what people are willing to pay for 'sustainable' design for stormwater management and demonstrate that this type of development is an asset.
- Demonstrate the cost of repairing blown-out systems versus installing and upgrading the necessary stormwater infrastructure.
- Incorporate climate adaptation in the THRIVE MSP Met Council 2040 plan[23].

Other Priorities:

- Identify a dedicated funding source (e.g. stormwater utility fees) so communities don't need to compete for funding.
- Use good collaborative processes to level the playing field, create mutual understanding of different views, and get agreement among stakeholders (i.e. Minimal Impact Design Standards).
- Demonstrate the potential consequence of inaction for stakeholders and engage them in a collaborative dialogue.

Objective 3: Identify and encouraging proactive strategies for managing stormwater, including green infrastructure[24], low impact development[25] and stormwater reuse[26].

Top Priority:

- Host alternative design tours of functioning Stormwater Best Management Practices to highlight success and lessons learned.
- Demonstrate the benefits of systems (Low Impact Development, reuse, etc.) through life cycle analyses.
- Continue applied research and distribute up to date information to stakeholders.

High Priority:

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[23] **THRIVE MSP Met Council 2040 plan** is the regional plan for the 7-county metropolitan area to provide a planning framework for the next 30 years. This framework will maximize opportunities of growth and prosperity, create a regional vision, and assist regional areas to maintain a strong quality of life for residents and businesses.

[24] **Green infrastructure** is designed to collect and manage rainwater where it falls, and uses the natural environment like vegetation and soil. These systems can be incorporated into our neighborhoods for stormwater management, but provide additional benefits like flood mitigation, air quality benefits, and habitat for wildlife.

[25] **Low impact development** is an innovative, ecosystem-based approach to land development and stormwater management. The goal is to mimic a site's natural hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source, resulting in a landscape altered in a way that was modeled after natural conditions.

[26] **Stormwater Reuse** is a system designed to collect and store rainwater and recycle it for another need, such as irrigation.

- Educate homeowners/business owners (those who could install these practices) on the benefits of low impact development and green infrastructure practices, creating a demand that will in turn drive policy makers and developers.

Other Priorities:

- Create a credit system based on regional climate runoff quality to encourage adoption of best management practices.
- Reduce or break down barriers to cooperative behavior between jurisdictional units to motivate collaboration.
- Encourage agencies to work together to formulate guidance (e.g. currently lacking regulation of stormwater reuse).

Objective 4: Foster dialogue and cooperation among stakeholders around planning issues and stormwater adaptation to changing precipitation patterns and land use.

High Priority:

- Fix the educational system – use an interdisciplinary approach so that engineers understand planning and vice versa, and incorporate in Continuing Education Units (CEUs).
- Provide graphical, real world examples of flood damage and changes in floodplains. Try to communicate: "Who is at risk now, and who will be at risk in the future?"

Other Priorities:

- Include education of the watershed concept to promote the idea of regional responsibility and provide incentives for cooperation among stakeholders.
- Reduce risk of backlash from public councils when projects sometimes 'fail'.
- Find ways to encourage long-term community investment in stormwater adaptation planning.

C. Stormwater Infrastructure (Gray/Green) and Low Impact Development – assessing our communities for vulnerability, incorporate most current data into planning, use green space for storage and project standard this work group include.

Objective 1: Assess needed infrastructure upgrades to accommodate current and predicted stormwater runoff.

Top Priority:

- Update the TP40[27] with predicted changes.
- Determine the existing risk/tolerance and resiliency of communities.
- Include assessment procedures in planning and communicate to communities.

High Priority:

[27] **TP40 (Technical Paper No. 40)** is the precipitation-frequency atlas used to evaluate how much volume stormwater infrastructure must be designed to handle. TP40 provides the return periods and duration of rainfall events in a given area. Atlas 14 Is the updated version of TP40, to be released soon.

- Educate city staff, public officials and other stakeholders about adaptation options, including costs.

Other Priorities:

- Pursue sources of funding to complete community assessments, including Clean Water Funds and other grants.
- Promote public stewardship without government incentives.
- Keep community comprehensive plans updated.

Objective 2: Reduce and disconnect impervious surfaces.

High Priority:

- Identify cost-share opportunities to promote impervious surface reduction and disconnection.
- Provide education to promote the benefits of impervious surface reduction and disconnection.

Other Priorities:

- Garner support from policy makers to pursue and develop pro-Low Impact Development[28] road, storm sewer, and innovative storage solutions.
- Increase stormwater utility fees to cover costs of promoting LID and green infrastructure practices that reduce and disconnect impervious surfaces.
- Incentivize property owners to incorporate LID practices on private land by allowing a reduction in stormwater utility fees.
- Design different systems for different solutions (e.g. cisterns for irrigation where dense soils make infiltration less effective).

Objective 3: Identify strategies to increase stormwater storage capacity and reuse in urban areas.

Top Priority:

- Manage water levels in Waterbodies to sustain biodiversity and maintain storage capacity, not just for recreational purposes.

High Priority:

- Create an incentive program that encourages green infrastructure as a measuring stick for a given location.
- Redirect pipes and conveyance systems to areas that will maximize storage.

Other Priorities:

- Make use of both public and private real estate to maximize storage capacity for stormwater.
- Promote “stacked green infrastructure” which allows for multiple comparable uses in the same location (e.g.. green roofs and underground cisterns).
- Change people’s mindset about need for habitat and stormwater infiltration.

[28] **Low impact development:** An innovative, ecosystem-based approach to land development and stormwater management. The goal is to mimic a site's natural hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source, resulting in a landscape altered in a way that was modeled after natural conditions.

Objective 4: Protect and enhance vegetative cover and natural areas to reduce flooding and improve water quality.

Top Priority:

- Include alternative vegetation education as part of professional standards during planning and implementation of projects.
- Change MnDOT specifications for vegetative cover.

High Priority:

- Change ordinances that encourage and allow for short lawns and low maintenance landscapes.
- Encourage the use of new technologies for making recreation areas pervious.

Other Priorities:

- Promote education on the benefits of maintaining and enhancing native vegetative cover (large scale green infrastructure).
- Identify and pursue revenue source for encouraging the use of green infrastructure.
- Incentivize the use of green infrastructure by reducing or giving rebates on property taxes that incorporate green infrastructure practices (similar to stormwater utility fee reductions).

Objective 5: Identify key messages to educate stakeholders on the stormwater infrastructure (gray/green) and the role of low impact development techniques in stormwater adaptation planning.

Top Priority:

- Highlight development that incorporates LID and Conservation Design principles[29] to illustrate that this is a more attractive approach and can allow more land to be available for development (e.g. – using storage cisterns versus storage ponds).

Other Priorities:

- Identify and communicate common denominators and benefits of green infrastructure and LID.
- Quantify and make certain there is a cost-benefit analysis incorporated into key messages.

D. Sustainable Funding for Stormwater Infrastructure: setting standards and making rules to reset the status quo, disseminate information on funding sources and economic analysis of adaptation measures.

Objective 1: Assess funding needs for costs of updating stormwater infrastructure (gray/green[30]).

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[29] **Conservation Design Principles** are a set of guidelines to ensure development maintains valuable natural features and functions. The principles include sustainable stormwater management, a reduction of impervious surfaces, incorporation of natural areas, and flexibility in design standards for lots.

[30] **Gray infrastructure** is designed with the purpose of conveying rainwater off impervious surfaces like streets and parking lots. It includes stormwater catch basins, pipes, and outlets. Whereas g**reen**

Top Priority:

- Use planning agencies like Met Council to set standards for policy changes for cities to follow.
- Use students and interns to keep current programs working while staff focuses on managing change.

High Priority:

- Economic analysis should look beyond infrastructure upgrades to other private costs (e.g. flood proofing, lower property value and lower tax revenue).

Other Priorities:

- Education of elected and appointed decision makers.
- Reassess urgency and make sure urgency is real (e.g.. use photos of Duluth's recent storm damage).
- Educate on the domino effect of not acting or changing costs over time.
- Engage people that live at the bottom of the hill.
- Use social change agents: identify people most excited about the "change" and focus efforts on those people.

Objective 2: Evaluate immediate vs. long-term economic impacts of stormwater management issues.

High Priority:

- Change rules and planning to account for an increased risk of flooding.
- Participate in national flood insurance programs.

Other Priorities:

- Prioritize and promote policies that can be adapted to changing risks for communities.
- Promote programs that adapt to changing risks.
- Use adaptive management strategies to increase temporary stormwater storage capacity.
- Build to the 100 year rain event versus current design standards.

Objective 3: Find funding opportunities for proactive stormwater management, including reviewing current water use and stormwater utility fees and costs.

High Priority:

- Set up clearing houses of information for stakeholders to draw from regarding funding sources and opportunities.

Other Priorities:

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infrastructure is designed to collect and manage rainwater where it falls, and uses the natural environment like vegetation and soil. These systems can be incorporated into our neighborhoods for stormwater management, but provide additional benefits like flood mitigation, air quality benefits, and habitat for wildlife.

- Create partnerships among stakeholders to look at all water uses and sources (e.g. sewer changes, drinking water fees, etc.)
- Use credits similar to wetland credits to promote stormwater infrastructure adaptation.
- Eliminate funding overlaps and encourage wise use of limited resources.
- Streamline water agencies to look for efficiencies and implement standardized requirements.
- Target stakeholders who are doing well in this economy.
- Make a clear case for urgency of problem, and educate on funding sources.

This input was used at the next work group: “How to Proceed” on January 22nd, 2013 to develop prioritized action plans for how to meet the given objectives.

Second Combined Session of Working Groups and Second Forum: “How to Proceed” - (January 22, 2013)

Stakeholders were convened for a second Work Group session combined with a forum detailing final technical results of the community vulnerability assessments completed for the City of Minneapolis and the City of Victoria using the projected precipitation data. On January 22nd, 2013 at the Eisenhower Community Center, Hopkins small groups worked on developing specific action plans for stormwater adaptation strategies identified during the first Work Group session (Appendix E). These action plans were themed by the four work groups: Education, Outreach, and Stakeholder Engagement; Land Use Planning and Policy; Stormwater Infrastructure (gray/green) and Low Impact Development; and Sustainable Funding for Stormwater Infrastructure. Action plans were then prioritized by the whole group, which resulted in six priority action plans that could be applied by communities or the broader Twin Cities Metro Area to further stormwater adaptation planning:

2. Education, Outreach, and Stakeholder Engagement

Objective: Identifying strategies to educate local policy makers about stormwater vulnerabilities, long term needs, and options

Timeline: Not identified

Responsible Parties: Minnehaha Creek Watershed District, UMN Extension, Water Resources Center (Karlyn Eckman), Freshwater Institute, Local Leaders, NOAA, MN Sea Grant

Project: Convene a summit(s) to educate local policy makers about creating resilient stormwater infrastructure.

Action Items:

g. Identify audience: local decision makers, commissioners, volunteers Assess/Prioritize vulnerabilities

h. Convene a focus group of audience. What draws them? Will draw them? Needs assessment of targeted audience.

i. Frame the summit – Develop learning (summit) objectives with:

a. Planning team

b. Include participants in planning summit
j. Identify compelling speakers and most effective mediums to feature at the summit(s). Include: risks, funding options, solutions
a. Breakouts, smaller groups, with visualizations and activities
b. Cohorts
k. Target local policy makers to fill the seats, target participants
l. After the summit(s), prepare a road-show that we can go to them with that includes visualizations.

5. Land Use Planning and Policy

Objective: Identifying and encouraging proactive strategies for managing stormwater, including green infrastructure, low impact development, and stormwater reuse.

Timeline: Not identified
Responsible Parties: Met Council, MN DOT, League of Minnesota Cities
Project: Adapt development and zoning codes to minimize the use of structural conveyances associated with transportation by preserving natural corridors and conveyance systems. Benefits: traffic calming, natural corridors preserved, more stable conveyance systems.
Action Items:
e. MN DOT and Met Council develops policies that require communities to preserve natural conveyance systems through design of transportation systems
f. Develop a model ordinance that cities can adopt requiring that roads avoid or span natural drainage pathways rather than fill them in or using berms, culverts.
g. City develops/amends comprehensive plans and adopt zoning controls consistent with policy. Preserve areas prone to flooding and natural conveyance systems (includes an inventory)
h. City public works projects implement the comprehensive plan

6. Stormwater Infrastructure (Gray/Green) and Low Impact Development

Objective: Protecting and enhancing vegetative cover and natural areas to reduce flooding and improve water quality.

Timeline: Begins in December 2015, is reviewed by stakeholders in December 2016, and implemented in 2017
Responsible parties: Watershed management organizations, cities, DNR, MPCA, UMN
Project: Develop an ordinance requiring soil de-compaction and organic matter incorporation in every construction project
Action Items:
e. Educate city officials on the need for soil improvement
f. Create a stakeholder team working group to write a draft ordinance

g. Review draft ordinance by public, city councils, county counsels, and state

h. Pursue cities to adopt ordinance, search out state laws to require it, and encourage county regulators to implement it as well

Objective: Identifying strategies to increase stormwater storage capacity and reuse in urban areas

Timeline: Ongoing

Responsible Parties: watershed management organizations, cities, counties, state

Project: Integrate reuse in development plan and reducing amount of water going into stormwater systems

Action Items:

d. Identify where most potential and biggest impacts are. Examples are reuse for golf course (Pipeshed 76-010) and large industrial sites (commercial)

e. Identify planned redevelopment. Street reconstruction: set minimum width of streets and create storage.

f. Retrofit existing sites with BMPs: cisterns for roof runoff, permeable driveways, rain gardens

Objective: Assessing needed infrastructure upgrades to accommodate current and predicted stormwater runoff

Timeline: Jan-September 2014 complete GIS, January determine expense, May put staff/consultants in play, Jan-Mar select sites to evaluate, April 2014-October 2014

Responsible Parties: Cities and consulting agencies

Project: Identify source of funding – including education of decision making as needed to support funding

Action Items:

d. Is the convergence network mapped? If not, it needs to be. Determine attributes: inverts, m/h rim elv. diameter and material condition, storage ponds, lakes, subwatershed divides, LiDAR contours. Gather available soils information, directionality, what is coming from upstream?

e. Run scenarios: current 10-year, 100-year, projected 10-year a/b/c, etc. on the ground monitoring, surveying, and calibration. Decide on software, Build model(s)

f. Can upgrades be phased? Do the upgrades need to be phased as to not cause flooding elsewhere?

7. Sustainable Funding for Stormwater Infrastructure

Objective: Evaluating immediate versus long term economic impacts of stormwater management issues

Timeline: estimate that it will take 18 months to complete

Responsible parties: City lead process, support from water management organizations, University of Minnesota, and possibly federal or regional agencies (NOAA)

Project: Commission a report to evaluate economic impacts of climate change on stormwater management to better evaluate the immediate versus long term economic impacts.

Action Items:

g. Complete an internal assessment related to economic impacts related to culvert installations, and identify knowledge gaps.

h. Complete scenario planning and choose 2-4 most likely scenarios and other pertinent issues (such as timeframe; lengthy of storm events) and modeling requirements.

i. Define economic impacts in city and downstream (property, infrastructure, loss of life, project costs, health impacts, commercial shutdown, utility impacts, etc.) aquatic invasive species.

j. Identify possible regulatory behaviors.

k. Summarize information and finalize. Issue a request for proposals (RFP) – develop criteria for evaluation.

l. Evaluate RFP and make recommendations to council with funding recommendations for the study

Minneapolis Transportation and Public Works Committee of the City Council and City of Victoria Open House/Workshop (June 2013)

In May, 2013 a brief presentation was given to the Transportation and Public Works Committee of the Minneapolis City Council. The purpose was to disseminate the technical results of the study pertaining to Minneapolis, as well as an overview of the stakeholder engagement process that was used. Unfortunately due to time constraints of the meeting, the study presentation was abbreviated to a few key points. There is an intent to identify a future opportunity for outreach with this particular planning body.

A community-wide open house for the City of Victoria was also held in June of 2013 to disseminate results of the study through story boards, as well as generate conversation around local stormwater adaptation strategies (Appendix F). The learning objectives of the open house/workshop with the City of Victoria included:

6. Increase understanding among city leaders, staff and community members of changes in land use and precipitation, and how they impact stormwater runoff, gray/green infrastructure and downstream water resources.
7. Share the outcomes of the Minnehaha Creek Stormwater Adaptation Study, including flood vulnerability assessments, and adaptation options and costs.
8. Review City of Victoria past and present plans and policies that relate to land use, stormwater management, and flooding.
9. Start a city conversation about potential actions and next steps to prepare the city for growth, changes in land use and changing precipitation.
10. Present input from multiple community stakeholder meetings on strategies and priorities for future action.

Some key findings that were shared at the open house include:

- Modeled prediction for precipitation is ~6-10” of rain for a 10-yr event by mid-21st Century.
- In Victoria, no significant infrastructure damage is expected, even under pessimistic conditions.

- Some increase of surface flooding in low lying/recreational areas would be expected.
- Past policies and plans have led to the ability of the community to absorb increases in precipitation.
- Adaptation options can manage flood volumes at varying costs. Low Impact Development can reduce some flood volume and infrastructure upgrade costs. However, LID provides water quality protection as well as some flood reduction.

Unfortunately the open house was not well attended other than a few key city staff, the Mayor and a planning commissioner, therefore a separate report to the City Council was given on Monday, October 28, 2013.

Presentations and Workshop at Low Impact Development Symposium, Saint Paul, MN (August 18-21, 2013)

The project team identified an opportunity to host a four-hour pre-conference workshop as well as two 40-minute technical sessions to disseminate study results at the 2013 International LID Symposium, which attracted over 700 local, regional, national and international professionals in the area of stormwater management and low impact development (http://www.cce.umn.edu/2013-International-Low-Impact-Development-Symposium/). The workshop was attended by local and national professionals, who came to learn about the stormwater adaptation process (Appendix G). The interactive workshop included practical information on how to:

- Assess stormwater infrastructure vulnerability and required capacity under both existing and future precipitation conditions.
- Identify stormwater adaptation options and costs - including the role of Low Impact Development (LID) - to mitigate impacts from changing precipitation patterns.
- Manage uncertainty associated with modeling future conditions.
- Effectively communicate technical information to local stakeholders and decision-makers to promote stormwater adaptation planning.

Two 40-minute technical sessions were also held; one focusing on the technical aspects of the study including precipitation modeling, hydraulic and hydrologic modeling, local vulnerability assessments, and adaptation strategies for the two study communities, and the other on the stakeholder engagement process that was used to disseminate results and collaboratively generate an adaptation framework for local community adaptation. Attendees, including those involved in stormwater management, community development and redevelopment, municipal operations, design professionals, developers, contractors, local policy makers, and others concerned about local stormwater adaptation planning were expected to leave with an understanding of the need for action, the knowledge and resources required to act, and the skills for empowering decision-makers in their community to respond to a changing climate.

Summary Comments on Major Elements of the Public Process

The stakeholder outreach process provided an opportunity for broad stakeholder input to develop a community adaptation framework that is locally relevant and grounded in scientific data. An effort was made to bring varying perspectives to the table for conversations around adaptation planning, and various channels were developed to disseminate information and allow for stakeholder feedback. While the public participation process was developed to allow for co-leadership and co-creation of priories and implementation strategies (as exemplified by the results generated at various points in the process), there are a few lessons learned that will aid in future efforts to move the conversation forward regarding localized adaptation planning relative to stormwater systems and impacts of changing precipitation and land use to our communities. Some of these lessons include:

- Clearly define and articulate why the public should be involved in conversations around community adaptation and changing precipitation patterns that speaks to a variety of stakeholders, not just those most likely to take part. In other words, clearly articulate the need for adaptation planning (the “why”) to develop a network of stakeholders with diverse backgrounds and viewpoints, and avoid simply bringing in ‘the choir’.
- Break down the public participation events into understandable points in the process, making sure the purpose is clearly understood. Often there was not enough clarity in the outreach regarding the purpose of the individual events that were held, producing some confusion regarding the goal of the events.
- When the topic is interesting and there are powerful questions being asked, it is important to leave enough time for input at the individual events. One common theme was that there wasn’t enough time to get the work done, which also implies a deeper discussion of the topic is desired.
- Developing action plans to address priority topics and objectives identified during a broad public process produced both locally as well as regionally relevant strategies. While it is necessary to address stormwater adaptation at multiple levels, it also makes it necessary to continue discussions at the local level for moving forward on adaptation planning because stormwater systems are management at the local level.
- Generating continued interest in a complex topic such as changing precipitation patterns and stormwater systems requires new and novel approaches to outreach. During this study, it was challenging to keep stakeholder’s interest in participating in individual events, especially when they felt they were not up-to-speed on the topic at hand. Perhaps finding different ways for gathering input (such as online surveying or using a scripted phone interview process), or hosting events associated with other existing events might garner more interest and more participation.
- Make more intentional use of the Advisory Committee, or other type of leadership team, to generate continued involvement in the public process as well as help disseminate the results and move community adaptation conversations forward. As with other stakeholders, there was a lagging lack of interest on the part of the Advisory Committee to be involved at the advisory level.

Overall, the public input process was well received and generated very useful and locally relevant information to develop a guiding framework that communities can use for local stormwater adaptation planning. The heightened interest in the topic (which also is concurrent with the release of Atlas 14 in the Midwest Region) can be directly contributed to the public process of engagement and outreach that was used during this study.

Broader Public Outreach of Dissemination of Information: Public Presentations

Numerous public presentations on community stormwater adaptation have been given to various groups and organizations beyond the two cities involved in this study. Below is a current listing of presentations involving either the technical results developed during the course of this study, the stakeholder engagement process that was used, or on both:

- Minnehaha Creek Watershed District Citizen's Advisory Committee Meeting – Deephaven, MN, February, 2012
- Climate Change Honors Seminar, University of Minnesota – Minneapolis, MN, March 2012
- Metro Waters Partnership – Rosemount, MN, April 2012
- Minnesota Association of Watershed Districts 2012 Annual Conference – Alexandria, MN, December 2012
- Environmental Decision-Making, University of Minnesota – St. Paul, MN, April 2013
- Seminar Series on Sustainable Development, University of Minnesota Humphrey Institute – Minneapolis, MN, April 2013
- Riley Purgatory Bluff Creek Watershed District Evening With the Watershed Event – Chanhassen, MN, May 2013
- Watershed Partners Annual Mississippi Tour – Minneapolis, MN, June 2013
- Minnehaha Creek Watershed District Board of Managers Meeting – Minnetonka, MN, June 2013
- Metro Association of Watershed Districts Monthly Meeting – St. Paul, MN, July 2013
- Clean Water Summit: The Essential Role of People in Clean Water – Chanhassen, MN, September 2013
- Preparing Stormwater Systems for Climate Change – Monroe, MI October 2013
- Minnesota Association of Watershed Districts 2013 Annual Conference – Alexandria, MN, December 2013

Upcoming Presentations:

- City of Minneapolis Council Workshop – Minneapolis, MN, Spring 2014
- Minnesota Pollution Control Agency Webinar Series On Water – St. Paul, MN, May 2014

Public Outreach and Dissemination of Information

Various channels for public outreach and communication have been established to raise awareness about the outputs of the Minnehaha Creek Watershed Stormwater Adaptation Study as well as community adaptation to changing precipitation and land use. Public outreach during the public stakeholder process has included:

2.1.1 Development and distribution of periodic newsletters detailing progress on the study (Spring 2012, Summer 2012, Fall 2012, Fall 2013) (Appendix H)

2.1.2 Development of a Study Factsheet with Frequently Asked Questions and Extreme Event Factsheets for various storm events to aid in outreach (Appendix I)

2.1.3 A dedicated project website at www.minnehahacreek.org/WET

2.1.4 Press releases and news coverage, including electronic newsletter Splash and WaterPro (Appendix J)

Local News Coverage:

Date of publication	Headline	Local media title
4/1/12	Study to Focus on Minneapolis and Victoria	Victoria Gazette
5/10/12	Minnesota Watershed Studies How to Adapt its Stormwater System for Climate Change	Water World
5/9/12	Are We Ready? Watershed District Will Participate in NOAA Stormwater Study	Lake Minnetonka Patch
5/4/12	MCWD to Study Climate Change's Effects on Storm Water	The Laker
5/5/12	Climate Change and Storm Water Park Study	The Laker
5/21/12	Warmup has Cities Rethinking Waterways	Star Tribune
5/27/12	Planning for Extreme Weather	Southwest Journal
5/24/12	Researchers Say Metro is Awash in Climate Change	St. Louis Park Sun Sailor, Excelsior/Shorewood Sun Sailor
5/25/12	Awash in climate change: St. Louis Park forum considers future impacts of heavier than normal rains on infrastructure	Sun Sailor
6/25/12	Duluth eyes rebuilding for a wetter climate	Star Tribune
3/6/13	Planning for Changing Weather Patterns	Tonka Times

2.1.5 Outreach to the Office of Governor for the State of Minnesota – Letter of Interest (Appendix J)

Summary Comments on Presentations, Outreach and Dissemination of Information

Efforts have been made to disseminate information in a timely manner throughout the duration of this study, and there has been a heightened interest in the topic of changing precipitation patterns and impacts on stormwater management systems and downstream water resources. In general, the information is clearly well received by communities and organizations, with the hope of encouraging deeper discussion on stormwater adaptation, both locally and regionally. The most effective means of disseminating information seem to be through the project website, newsletters, and individual presentations. However press releases have also generated media coverage, especially following large precipitation events in the Twin Cities Metropolitan Area. The Minnehaha Creek Watershed District will continue to make the data public, as well as host community meetings and workshops on stormwater adaptation to climate change.

Evaluation of Collaborative Public Process

A number of specific evaluation techniques were drawn upon in order to assess the evaluation goals of the public participation component of this project. These included surveys, feedback from participants, and a review of each of the deliverables. These approaches were drawn upon to assess both the *process* and the project stated *deliverables* of the public process.

The assessment of the public process that was utilized in the project was informed by the National Research Council (NRC) 2008 Report: “Public Participation in Environmental Assessment and Decision Making.” In this report, three goals of public participation in an environmental assessment and decision-making process are a) improve the quality, b) improve the legitimacy, and c) improve the capacity of environmental assessment and decisions. These three NRC public participation goals are further clarified with the following specific benchmarks:

a. Draw on local knowledge to improve decision making through a public process that:

- Identifies values, interests, and concerns of all who are interested in or might be affected by the process or decisions
- Uses the best available knowledge
- Incorporates new information, methods, and concerns

b. Foster legitimate and equitable decision making by a process that is seen by the interested and affected parties as fair and competent and follows the governing laws and regulations.

c. Increase resilience, adaptive capacity, and social capital by:

- Engaging the public with vetted data on severe weather trends and best available climate change science
- Fostering inter-town/region/watershed wide understanding, trust, and collaboration to increase resilience to stormwater risks
- Developing widely shared understanding of the issues and decision challenge.

At the end of this section of the report, the overall assessment of the participatory component of this project will reference these three guiding criteria of the NRC 2008 Report. We also have applied a recently developed 10-step model for “Collaborative Planning Approach for Climate Change Adaptation” (J. Gruber 2013) to help evaluate the public process and the outcomes to date. This model is shown if Figure 1.

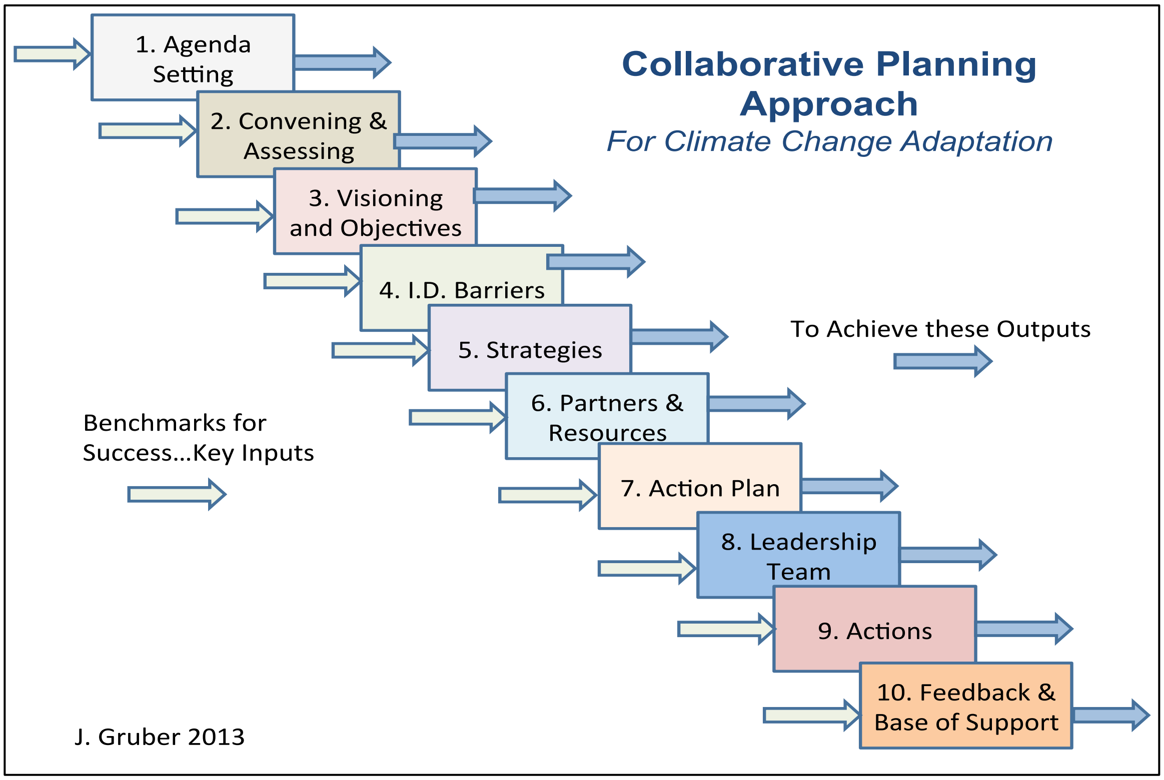

Figure 4.1 Collaborative Planning Approach for Climate Change Adaptation

The ten-step process presented in Figure 1 depicts a model of a comprehensive collaborative climate adaptation process. Specifically for this project, steps 1 through 6 represent the scope of the participatory process that was undertaken during this project. Steps 7 and forward are still in process with the MCWD, the City of Minneapolis, City of Victoria, and other local/regional entities. The evaluation of the participatory process will therefore focus on steps 1 through 6.

Surveys and Feedback from Events

Surveys were issued at the end of almost every meeting (including the Forums, Working Groups, and Workshop), to help the project management team in the assessment process. These surveys are included in the Appendices.

Assessment of May 2012 Forum. Two surveys were completed for the May 15, 2012 Forum, one pre-forum and one post forum. There were 59 participants at this forum that represented a fairly broad cross section of the Minnehaha Watershed region. Figure 4.2 summarizes the diversity of the participants.

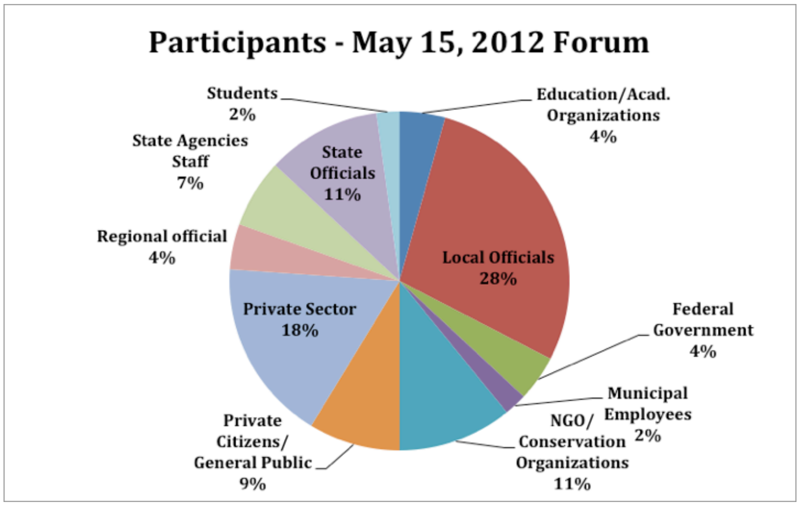

Figure 4.2 Participants at May 2012 Forum

Included in the pre-forum survey was an assessment of participants' current knowledge about stormwater management, the level of urgency for addressing stormwater, their willingness to collaborate with others, and the current level of trust that existed between various groups that were currently active in stormwater related issues. These results were then compared to the post-forum survey. Change in knowledge in shown below in Figure 4.3 for pre-forum and post-forum. Change in trust between stakeholders is shown in Figure 4.4. There was a significant increase in knowledge and a moderate increase in the level of trust between stakeholders.

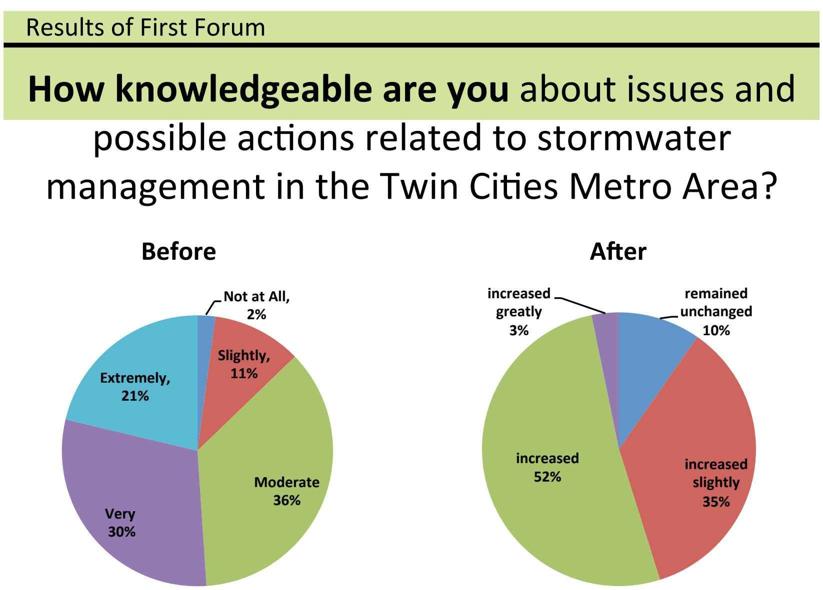

Figure 4.3 Change in level of knowledge before and after forum

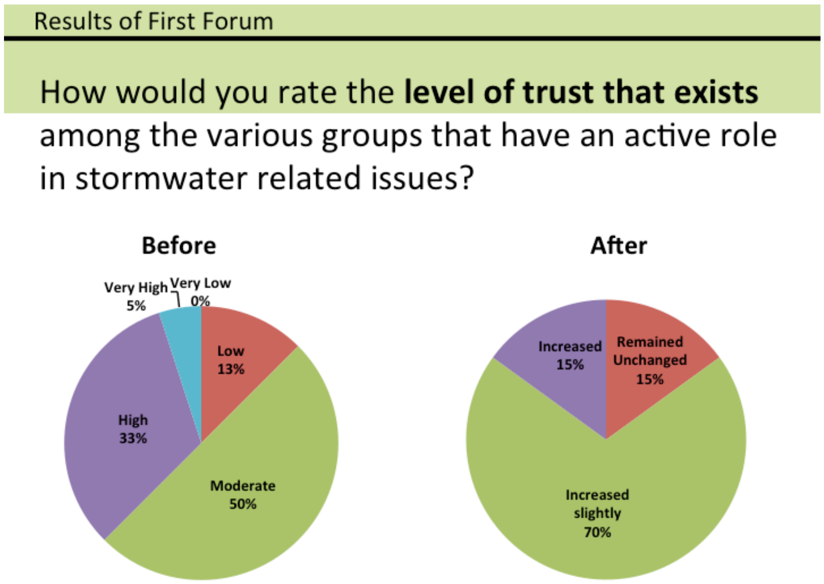

Figure 4.4 Changes in level of trust between stakeholders

The final pre-forum survey question was "What is one question you hope to have answered by the end of this study." Responses to this question helped guide the project team. Examples of representative responses included:

- *How urgent is the need for new infrastructure?*
- *What planning process should be followed to help cities prepare for climate change?*
- *How to* (do we) *arouse citizen and government action?*
- *What types of innovative ways can help deal with stormwater runoff?*
- *How do we get people/communities to take action?*
- (What are the) *impacts of climate change on stormwater infrastructure?*

All of the results of the pre-survey are included in Appendix 5B. In summary, the participants were fairly knowledgeable and concerned about current extreme storms and growing impacts on their communities. Although this enhanced the depth of the outputs from the working groups during this forum, it also limited the perspectives from those who were skeptical about climate change impacts.

A post-forum survey was also conducted with the three following questions:

Q-1 Was the scientific information useful and presented clearly?

Q-2 Do you feel like progress was made during this meeting? In what areas?

Q-3 What could be done to make future meetings more effective?

There was a generally positive response to this forum. A "yes" to Q-1 was given by 92% of those attending. Making progress question (Q-2) received 71% favorable and 4% not favorable responses. Participants provided significant and valuable ideas in response to question Q-3. Full results of this post-forum survey are included in Appendix 5B.

There were also specific and relevant outputs from the break-out small groups that were convened during this forum. The framing questions used were able to solicit from the participants underlying issues that need to be addressed for proceeding on climate change adaptation. These questions were:

- *In what ways have you observed or heard about land-use/development and changing weather patterns impacting this region?*
- *Do you think some of these impacts might reoccur?*
- *What are the underlying causes and/or problems?*

The outputs included agreement upon four to five focus areas for future Working Group sessions. These are:

1. Education for the public, policy makers, and developers
2. Land-use and planning regulations/policy
3. Issues related to impervious surfaces
4. Working with local decision makers
5. Lack of funding and sustainable funding

In summary, written and verbal feedback from the May 2012 Forum seemed to have been successful at drawing on local knowledge, fostered the first stages of successful decision making, and increased social capital by enhancing watershed wide understanding, trust, and collaboration. It also made progress in developing widely shared understanding of the issues and decision challenge. The first forum focused on steps 1, 2, and part of step 3 in the Collaborative Planning Approach that is shown in Figure 4.1.

Assessment of Working Groups Process. Four Working Groups were formed based upon the focus area developed during the first Forum. The goals of the Working Groups were to finalize the climate change adaptation objectives previously framed at the first Forum, identify barriers and/or challenges related to achieving these objectives, and to develop and prioritize potential approaches and strategies to move forward a region-wide climate change adaptation plan. In addition, building collaboration between stakeholders and a higher level of trust was an on-going goal. The four Working Groups were: A) Education, Outreach and Stakeholder Engagement; B) Land Use Planning and Policy; C) Stormwater Infrastructure (Green/Grey) and Low Impact Development; and D) Sustainable Funding for Stormwater Infrastructure. Each Working Group meet twice during the fall 2012 and winter 2013 and developed specific approaches and priorities for taking action relevant to their area of focus. They were provided updated technical information during each of their sessions from the project technical team.

Significant and specific output from the first session of the four Working Groups included identifying and clarifying a total of 16 specific adaptation objectives with specific approaches and strategies under each objective. Each of these strategies was prioritized by the Working Group's participants based upon its anticipated impact on addressing the identified concern and its feasibility of being accomplished. These results were then categorized as "Top", "High", and "Other" priority. The full list of results from the first Working Group sessions is included in Appendix 3D.

Participants feedback from an end-of-working-group survey indicated that the

Working Groups were useful and made progress. Specifically for groups A and B, 100 % responded with as "yes" to the question "Do you feel like progress was made during this meeting." For groups C and D, 72% responded with a "yes", 22% responded with a "some/maybe", and 6% with a "no."

Participants were asked to specify in which areas they thought there was progress. Representative responses provided included: assessing the infrastructure, identification of barriers and initial solutions, building consensus around goals, working with developers and elected leaders, focusing on the approaches, and sharing ideas. Nearly half of responses focused on the importance of talking, dialogue, and building consensus among the participants.

Reviewing the quantity and specificity of the outcomes along with the feedback of participants, these Working Groups sessions seem to have been valuable and productive from a process and outputs perspective. Also note that the results were then disseminated to the general public and were used in the next project public session, the Second Forum.

Assessment of the Combined Second Session of Work Groups and Second Forum. The Second Forum was combined with the second session of the Working Groups. This open public event, held in January 2012, included providing significantly more scientific information that was developed by the project technical team during the previous year. This information provided specific data on anticipated areas of flooding, cost data, and related information. The other goals of this Second Forum was to use the new technical data from the project science team and the outputs from the previous Working Groups to develop and prioritize next steps along with the resources needed to move forward in the development of an adaptation action plans for region. It was also a goal of the project team for this Second Forum to encourage opportunities for regional cooperation and collaboration.

Feedback from participants was positive on the quality and effective communication of the new scientific information that was developed during the previous year. For example, one participated stated: "Seeing the future of the 100 year storm event is critical in developing future stormwater infrastructure … even the change in the 10 year event if major."

The effort to frame action plans for each of the top priority objectives was overly ambitious for the time allowed (2 ½ hours) and the broad mix of knowledge and skills of the participants. Some groups were more successful than others with framing an action plan for a climate adaptation objective (identifying action steps, responsible parties, timeline and resources required). The results were broader or less defined by some groups than others. However, there were significant actions and ideas that were organized each of the top objectives. The Minnehaha Watershed District will utilize these results as they begin the next cycle of their long-term planning process.

Public Outreach Effort

Significant public outreach was provided throughout the project. This outreach resulted in "earned media" coverage. This public outreach effort is summarized in Section 2.0 of this report. Appendix H includes newsletters developed during the project that were disseminated via numerous e-mail lists. Appendix K included news articles that were published on the project. There was also targeted outreach such as a presentation at the Governors Office. MCWD staff provided a number of presentations on the project at other association events, conferences, and public events. The web site was very robust with frequently updated information on the project along with recent and future public events. This included PDFs of Power Point presentations, video clips of some presentations, and key outputs form work sessions.

Summative Evaluation on the Effectiveness of the Project

Feedback on Overall Project. At the final public event, the Second Forum, feedback was solicited from participants on the overall effectiveness of the project. This summative evaluation on the effectiveness of the project is based upon this feedback along with other data and observations. It is organized by five framing questions.

Q-1 Were project events (including pilot projects, workshops, and trainings) useful and relevant?

Overall, the workshop outcomes (Forums and Working Sessions) were well received by most participants. These outcomes are specific and reflect priorities of the participants. Representatives of MCWD, the City of Minneapolis, and City of Victoria indicated that the results are of interest and will be used in the future as each of these local/regional entities continue to plan for climate change adaptation. The project led to increased awareness of stormwater management issues and potential actions (Figure 4.5).

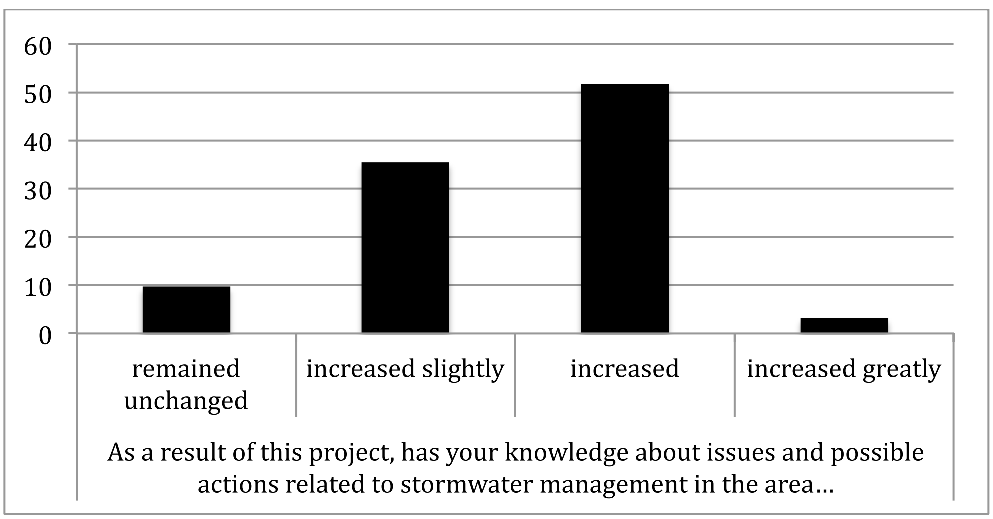

Figure 4.5 Increase in knowledge about stormwater management issues and possible action (percent)

Feedback at the four presentations given by the project team at the International Low Impact Development Conference, Saint Paul, MN, in August, 2013 indicated that this research and collaborative public process is a valuable model for other areas dealing with similar challenges on addressing climate change adaptation.

Q-2 Was trust of scientific information increased?

The initial session (First Forum) started with a talk from a highly respected individual (Mark Seeley) from the University of Minnesota on climate change data and impacts. There seemed to be no disagreement with the scientific information presented. Later in the project, Michael Simpson' presentation of "down-scaled" weather data for the region backed up with historic data trends was also well received and appeared to be accepted. Part of the reason that this information was accepted may have been the severe storms that impacted Duluth, MN during the project that resulted in severe flooding in that region.

Q-3 Was participation equitable, fair, and representative in the process?

Although we did not specifically ask this question of participants, we did ask if the participatory processes were effective (refer to Figure 4.6). This is an indicator of an equitable and fair process. The diversity of stakeholders of each session varied based upon the topic. For example, the Stormwater Infrastructure Working Group had many engineers and the Education, Outreach and Stakeholder Engagement Working Group had more educators. However, the First Forum (Figure 4.2) had a fairly broad cross section of stakeholders. The two noted areas where more representation could have enhanced the diversity include: lower income individuals and land developers/businesses. These groups are frequently under represented at public related events.

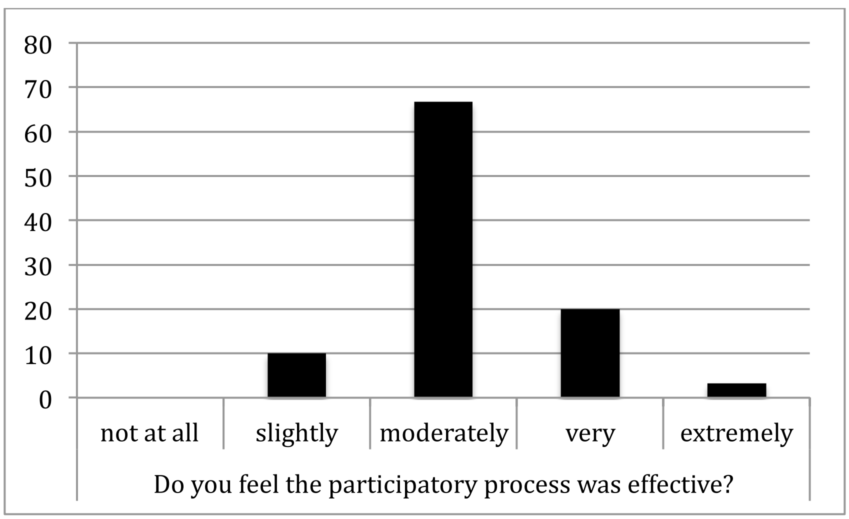

Figure 4.6 Effectiveness of participatory process (percent)

Q-4 Were mechanisms and opportunities developed for increased collaboration?

The public events were designed to encourage and provide opportunities for enhance collaboration. These events included small mixed break-out groups collaborative decision making processes. Figure 4.7 (Increase in likelihood of collaborating) illustrates that over 70% of participants agreed to the statement that, as a result of this project, they are more likely to collaborate with other organizations on stormwater issues. The wide range of stakeholders involved in this project developed a shared vision on the critical objectives to achieve climate change adaptation and on the specific prioritized approaches that should be drawn upon in achieving these objectives. Documentation of this shared vision is shown in Figure 4.8.

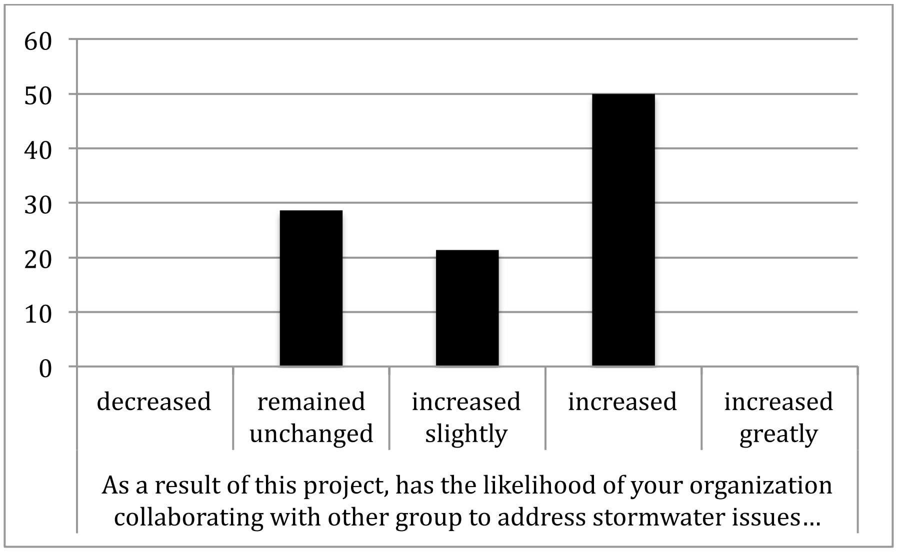

Figure 4.7 Increase in likelihood of collaborating (percent)

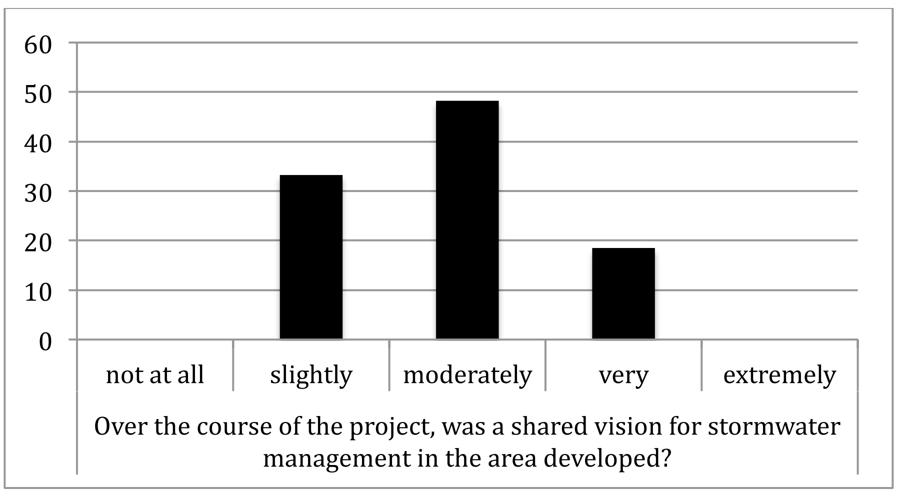

Figure 4.8 Development of a shared vision for stormwater management (percent)

Q-5 Are any tangible next steps being pursued?

The Director of the Stormwater Department of the City of Minneapolis, the City Engineer and Administrator for the City of Victoria, and the Director of the Minnehaha Creek Watershed District (MCWD) all have indicated that the results of this project are valuable and useful for their areas of work. For example, the MCWD is about to begin its next long range planning process and the result of this project will help inform this process. The City of Minneapolis has provided information from this project to its consulting stormwater engineers to use as a resource as they plan the next phases of stormwater infrastructure upgrades.

Assessment of Collaborative Public Process through "Collaborative Planning for Climate Change Adaptation" model. The collaborative public process used in this project will be reviewed using the "Collaborative Planning for Climate Change Adaptation" model in Figure 4.1. As noted earlier, the intent of the project was to achieve steps 1 through 6. Each of the steps is described and followed, briefly, by the way in which the project addressed this step. More specifics of how each step was achieved are described under section 2 of this report.

1. Agenda setting: Researching and raising awareness about the relevant climate change related issues

The agenda setting phase was achieved through a number of efforts that included fact sheets, an initial newsletter, a robust web site and earned-media coverage in the local newspapers. At the same time, research by the project science team (that included the University of Minnesota and Antioch University) documented and presented changes in sever weather conditions for this region. There was also an Advisory Committee established to help with this and other stages of the project.

2. Convening and Assessing: Convening a broad cross-section of the community to assess the evolving situation and affiliated problems and confirm the need for adaptation planning.

The Project Team and the Advisory Committee identified and organized a number of convening events, the first of which was the Forum. There was a broad diversity of stakeholders representing the Minnehaha Creek watershed region attending these events. Changes in weather patterns and climate conditions were presented that included frequency and intensity of recent storms. The first Forum session also encouraged participants to review and discuss current impacts from weather patterns and land-use patterns. There was a focus on helping all participants better understand the underlying causes of the current conditions and to recognize the urgency to undertake planning.

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3. Visioning and Objectives: An overall vision and primary objectives are developed and agreed upon.

During the first Forum and following Working Groups sessions, an overall understanding of the "big-picture" and prioritized objectives were established. The collaboratively developed objectives received general support by all participants involved in the project. These results were then synthesized and disseminated to the broader community.

4. Identify Barriers: The social, financial, political, logistical, philosophical, and cultural difficulties that need to be addressed are identified in order to inform the approach for achieving the agreed-upon objectives.

During the first cycle of Working Groups, participants identified actual and perceived barriers to achieving agreed-upon objectives.

5. Strategies: The potential strategies are assessed and prioritized based upon technical and financial considerations as well as social and cultural values and public priorities.

At the Working Groups sessions a collaborative process was convened that included the development of specific strategies and policy tools to address the identified barriers. Potential impact of each strategy and the feasibility of implementing that strategy were then developed by the stakeholder groups.

6. Partners and Resources: Potential partners are identified and engaged and types of resources required are identified.

Throughout the project, potential partners were identified that included state level agencies, NGOs, regional and other groups. This was done in parallel with the framing of an overall strategic approach.

Assessment of Collaborative Public Process through NRC Criteria. Referring back to the National Research Council criteria for assessing an effective collaborative public process, their three principles will be used to assess the overall process.

Principle 1 - *Draw on local knowledge to improve decision making through a public process.*

Throughout the project local knowledge ranging from local officials, citizens, businesses, NGOs, to researches at the University of Minnesota were core to every phase of the project. Local knowledge drawn upon include technical information, local values and interests and concerns of those that might be affected by the climate adaptation process. New scientific information was incorporated in the project as it became available including down-scaling of weather data.

Principle 2 - *Foster legitimate and equitable decision making by a process*.

The project was not a formal public policy decision making process but a collaborative public process that could inform a future formal process. This process was perceived a legitimate in respect to its purpose and we have indication that the outputs from this process will be used in the near future by for public policy making bodies.

Principle 3 - *Increase resilience, adaptive capacity, and social capital*

The project appears to have increased watershed wide cooperation and understanding. Dialogue and cooperation between local governments in the watershed and the MCWD appeared to have been enhanced. The public engaged in the issue and need for climate change adaptation through outreach of public collaborative planning sessions. They were provided down-scaled climate data in a clear and understandable form. Social capital was enhance through building a shared view of priorities in responding to changing climate conditions and the challenges that need to be faced.

In summary, as reflected by our assessment based on these three principles, this was an effective collaborate project.