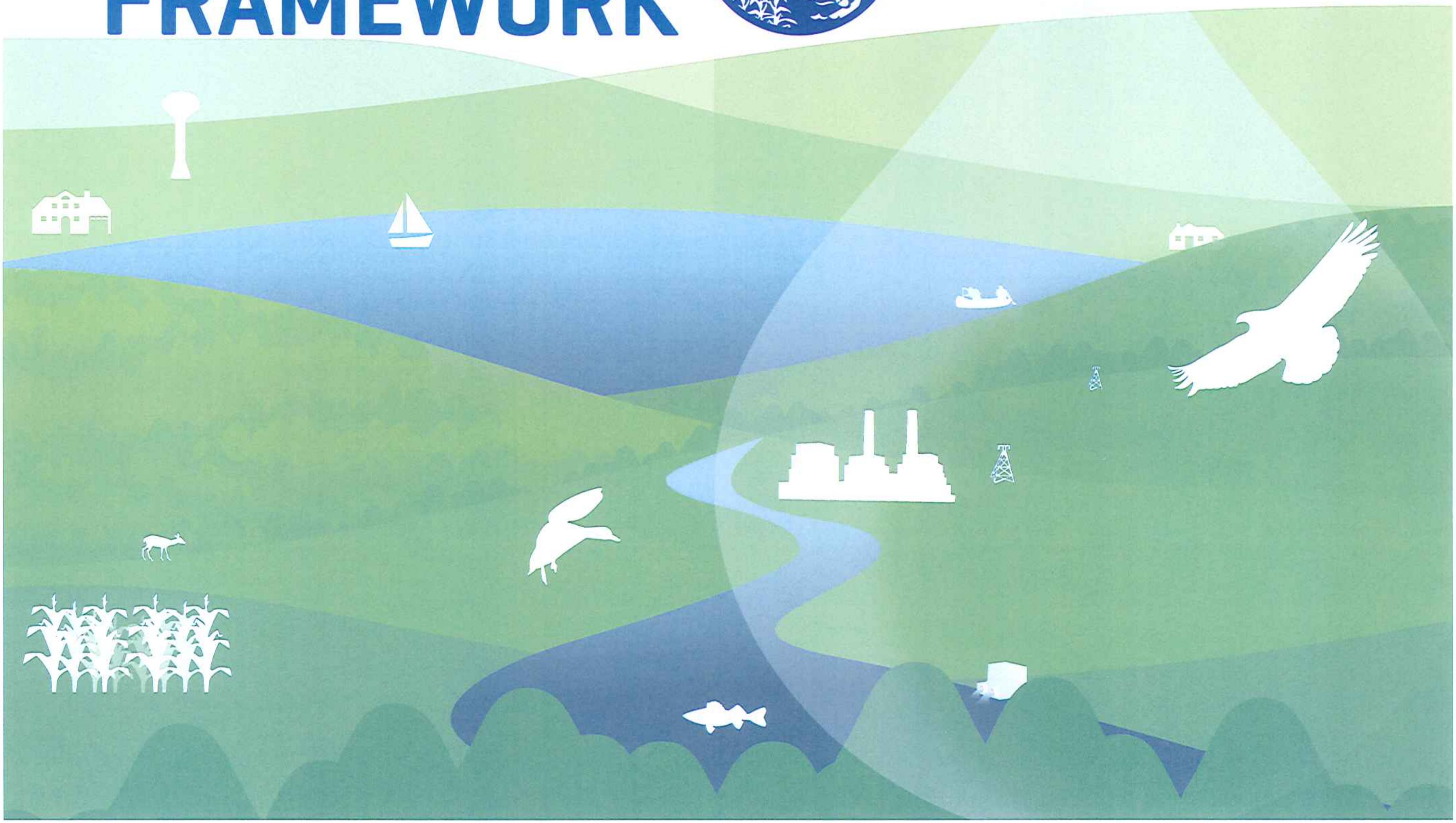
MINNESOTA WATER SUSTAINABILITY FRAMEWORK



RECOMMENDATION	IF FUNDED, WHO SHOULD IMPLEMENT	RESEARCH TASK	IMPLEMENTATION PHASE	LEVEL OF BENEFIT TO WATER RESOURCES	MULTIPLE BENEFITS
H.1.c: adopt Effective Utility Management program	Other		Phase 1	💧💧	✓
H.2.a i: determine long-term funding strategy for public water infrastructure	Executive	R	Phase 1	💧💧💧	
H.2.a ii: implement long-term funding strategy for public water infrastructure	Executive		Phase 3	💧💧💧	
I.1.a: ensure long-term citizen engagement and support	Executive		Phase 2	💧💧💧	✓
I.2.a: ensure youth water literacy	Other		Phase 2	💧💧💧	✓
I.2.b: ensure adult water literacy	Other		Phase 2	💧💧💧	✓
J.1.a: review statutes and laws for water sustainability	Legislative		Phase 1	💧💧💧	✓
J.1.b: enact Water Sustainability Act	Legislative		Phase 1	💧💧	✓
J.1.c: re-establish the Legislative Water Commission	Legislative		Phase 1	💧💧💧	✓
J.1.d: create Water Sustainability Board	Legislative		Phase 2	💧💧	✓
J.1.e: form Watershed and Soil Conservation Authorities	Legislative		Phase 3	💧💧	✓
J.2.a: create interagency data and information portal	Executive		Phase 1	💧💧💧	
J.2.b: maintain Framework as "living" document	Legislative		Phase 3	💧💧💧	✓

RECOMMENDATION	IF FUNDED, WHO SHOULD IMPLEMENT	RESEARCH TASK	IMPLEMENTATION PHASE	LEVEL OF BENEFIT TO WATER RESOURCES	MULTIPLE BENEFITS
E.3.b: model drainage from field scale to watershed scale	Other	R	Phase 3	💧💧💧	●
E.3.c: require multi-benefit drainage management practices with new or replaced tile drainage	Legislative		Phase 1	💧💧💧	●
E.3.d: expand cost-share program for retrofitting existing tile drainage	Executive		Phase 1	💧💧💧	●
E.4.a: preserve and encourage conservation land set-asides	Executive		Phase 1	💧💧💧	●
E.4.b: work to ensure next Farm Bill has strong conservation elements	Executive		Phase 1	💧💧	●
F.1.a: understand and quantify the water-energy nexus	Other	R	Phase 3	💧💧	
F.1.b: review energy policy for water sustainability	Legislative		Phase 3	💧💧	
F.1.c: encourage renewable energy that minimizes water impacts	Executive		Phase 3	💧	●
G.1.a: include ecological benefits in water pricing	Legislative		Phase 2	💧💧💧	
G.1.b: include other economic incentives in water pricing	Legislative		Phase 2	💧💧💧	
G.1.c: transition business to more equitable pricing	Executive		Phase 2	💧💧💧	
G.1.d: research and model value of water ecological benefits	Other	R	Phase 1	💧💧💧	●
G.2.a: provide for shared resources between small and large community water supplies	Executive		Phase 3	💧💧	●
H.1a: create standing advisory committee on new technologies .	Executive		Phase 2	💧💧💧	●
H.1.b: address water reuse	Legislative		Phase 4	💧	

ISSUE H: PUBLIC WATER INFRASTRUCTURE NEEDS

As infrastructure for water delivery and treatment ages, we must replace it. As new pollutants become a concern and new technologies develop, we must implement them. As the population grows and moves, and as we shift to water re-use, we must build new infrastructure to meet new needs.

Desired Minnesota Future

A society that maintains and protects its infrastructure for drinking water, wastewater, stormwater, and flood protection in a manner that sustains our communities and our water resources maintains and enhances ecosystems, and reuses water where appropriate to conserve our sustainable supply.

We must build resiliency into our public-built environment to protect it from unanticipated threats.

PROBLEM STATEMENT

Three broad categories of physical water management systems are associated with use of water in Minnesota: systems to provide drinking water; systems to handle and cleanse wastewater; and systems to manage drainage, which includes agricultural stormwater and urban stormwater. Agricultural drainage is addressed in Issue E: Ecological and Hydrological Integrity, and urban stormwater infrastructure is discussed here. Although not technically public facilities, private wells and individual subsurface sewage treatment systems (septic systems, or SSTS) are often considered part of this basic water infrastructure. Their impacts are interconnected, so they need to be considered and managed together (see Issue B: Excess Nutrients and Other Conventional Pollutants for specific issues regarding private wells and SSTSs.) In Minnesota, all three categories of infrastructure systems are in need of upgrading to replace aging and deteriorating systems, to put effective systems in place to meet needs and regulatory requirements, and to meet the growing needs of a growing population. Specific issues to be addressed include drinking water and wastewater treatment plant building, expansion, new technologies, and maintenance; stormwater infrastructure; infrastructure related to water re-use, and water security (being addressed by the state in partnership with the federal government and not further addressed here).

In Minnesota, drinking water comes from surface water (approximately 25%) and groundwater (approximately 75%). Drinking water infrastructure includes (1) community water systems—publicly owned municipal systems, regional water systems, and privately owned condominium and trailer park systems; (2) nonprofit non-community systems, such as schools, day care centers, churches, and retreat centers; and (3) private wells. In addition, six rural water systems have been installed in northwestern and southwestern Minnesota due to insufficient shallow groundwater for private wells.

Drinking water systems consist of four main parts: the water source, transmission and distribution infrastructure, treatment infrastructure, storage facilities, and other components, such as security and data acquisition facilities.

The need for new water delivery and treatment infrastructure is driven by two converging forces: the aging of existing infrastructure, and demographic changes that are shifting the location, time, and intensity of need for water. Some changes may also be called for by changes in understanding of threats to water safety—for instance, the need to protect drinking water supplies from terrorism, or the growing awareness of the presence and possible health impacts of CECs. In addition, new approaches and technologies for addressing water issues have emerged in recent years. Some utilities are turning to advanced treatment options, including activated carbon, ozonation, ultraviolet (UV) light, and reverse osmosis, in order to remove nitrates and remove CECs, such as EDCs, pharmaceuticals, and pathogens that are not removed by conventional disinfection. The issue of CECs is addressed in Issue C and for a full discussion of the technologies listed here, the Wastewater Treatment Best Practices report (See Appendix G).

A major challenge for (and opportunity for improvement in) drinking water supplies in Minnesota is that drinking water is commonly and extensively used for purposes besides drinking: watering lawns, cleaning, and so on. In the Twin Cities metro area, lawn watering and other outdoor water uses account for some 20 percent to 30 percent of annual public water supply use. As infrastructure is replaced and upgraded, an important consideration should be whether modifications to current approaches could help reserve drinking water for drinking water purposes, and use water not treated to drinking water standards, including water that has already served another purpose, for tasks such as watering lawns as a way to reduce demands on water supply infrastructure and on the waterways that serve as sources.

Municipal separate storm sewer systems, known as MS4s, gather water from the community and route it away from streets and walkways to prevent flooding. In the past, municipal stormwater often fed into wastewater treatment infrastructure, adding a huge intermittent burden to wastewater treatment systems and occasionally causing an overflow that resulted in the release of untreated sewage into receiving waters. All but a small percentage of Minnesota's stormwater infrastructure has now been separated from wastewater systems (i.e., the elimination of combined sewer overflows, or CSOs). This reduces the load on wastewater treatment facilities, but it also results in water from streets, which often carries sediment and contaminants, running directly into waterways. To reduce the adverse effects of such flow, communities are starting to route stormwater to land, to containers for use, or to temporary small ponds via rain gardens, rain barrels, pervious pavements, and vegetated swales. Known as low-impact design (LID), such systems are becoming more common across the state. Other innovative management approaches such as pollutant trading, reuse of stormwater, and polluter-pays pricing systems could also impact stormwater management. The federal MS4 program is designed to reduce surface water pollution from storm sewers. MS4s that discharge into designated "special waters" and "impaired waters" require additional runoff controls and BMPs.

Wastewater treatment facilities in Minnesota fall into two main types: municipal treatment facilities and individual sewage treatment systems (ISTSs), or SSTSs, often known as septic systems. Wastewater treatment facilities remove pollutants from used water and then discharge the water to surface waters or to land.

Most municipal wastewater systems in Minnesota operate under federal NPDES permits or state disposal system (SDS) permits for land discharge. Septic systems do not operate under these permits. Costs for wastewater treatment systems include construction, maintenance, and operation (chemicals, etc.).

Many of Minnesota's WWTPs were built in the 1970s and 80s. Some wastewater treatment systems in Minnesota date to the 1800s. Most are approaching the end of their useful lives, estimated at 40 years. New challenges and opportunities may call for new technologies that will need to be considered in future wastewater treatment infrastructure. These new technologies are being developed to remove CECs, such as EDCs and pharmaceuticals, and may be needed in new construction or as upgrades in existing plants. Other opportunities include using wastewater as a feedstock for algae-based renewable energy systems, potential for capturing and recycling nutrients (nitrogen and phosphorus), and potential for reusing some wastewater before sending it to wastewater treatment facilities.

SPECIFIC CONCERNS related to this Issue that have been identified:

- **Drinking water and wastewater treatment infrastructure building, expansion, and maintenance**
- **Stormwater infrastructure**
- **New treatment technologies**
- **Infrastructure related to water reuse**

WHAT IS KNOWN AND NOT KNOWN ABOUT THIS ISSUE:

About 23% of Minnesotans get their drinking water from private wells. The EPA estimates that Minnesota's drinking water infrastructure will need approximately $6 billion for infrastructure upgrades over the next 20 years—not including accommodations for a growing population (*Figure 3-30*). Drinking water systems will also need increasing flexibility and resiliency to deal with the unexpected events of climate change (drought, flood, etc.).

The MPCA estimates that Minnesota's public wastewater infrastructure will need more than $4.5 billion in improvements over the next 20 years. In addition, individual wastewater systems will need more than $1.2 billion in improvements to protect the environment and public health (*Figure 3-31*).

A 2009 needs survey identified 1,200 wastewater projects around Minnesota with a total estimated cost of $4.3 billion. This is a substantial increase over the $2.5 billion reported by a similar survey in 2003.

Sewer systems over 50 years old are generally considered beyond their reasonable life. Minneapolis and St. Paul have the largest percentage of collection pipes above 50 years of age (72%), in contrast with greater Minnesota, where approximately one-third of the collection system is over 50 years old, and the Twin Cities metropolitan area suburbs, with only 10% of sewers over 50. Major structural components of wastewater treatment facilities have an estimated useful life of 40 years. Most treatment facilities were built in the early to late 1970s and are rapidly approaching the end of their useful lives (*Figure 3-32*).

The current model that is used to pay for infrastructure needs for wastewater and drinking water includes the Clean Water State Revolving Fund and the Drinking Water State Revolving Fund, both of which are programs within the EPA. These programs pass funds to the states to finance infrastructure improvements. The Drinking Water State Revolving Fund also emphasizes providing funds to small and disadvantaged communities and to programs that encourage pollution prevention as a tool for ensuring safe drinking water. The Clean Water State Revolving Fund supports water quality protection projects for wastewater treatment, stormwater control, nonpoint source pollution control, and watershed management. In Minnesota, the revolving funds are provided to the MPCA, and the MPCA and MDH determine the priority in which projects are funded for wastewater/stormwater and drinking water, respectively. The Public Facilities Authority, a multi-agency authority, administers and oversees the financial management of the revolving loan funds. The revolving funds provide low-interest loans and grants to finance infrastructure that might otherwise be unaffordable to communities, and require a 20% state match. The communities must provide a general obligation bond to secure the loan.

The growing expenses of these systems are encountering reduced federal support. For example, the federal government cut funding for the Clean Water State Revolving Fund from $1.35 billion in 1998 to $689 million in 2008.

MINNESOTA WATER INFRASTRUCTURE NEEDS by PROJECT TYPE

20-year drinking water needs

PROJECT TYPE	NEEDS (millions)	PROPORTION
Source	$372.0	6.2
Transmission/ Distribution	$2,819.3	47.1
Treatment	$1,982.9	33.1
Storage	$770.3	12.9
Other	$43.9	0.7
Total	$5,988.4	100.0

SOURCE: DRINKING WATER INFRASTRUCTURE NEEDS SURVEY AND ASSESSMENT, EPA, 2007

Figure 3-30: Drinking Water Infrastructure Needs

20-year wastewater needs

INFRASTRUCTURE NEED	2009 WINS (millions)	2003 WINS (millions)	DIFFERENCE (millions)
Sewer System Rehabilitation	$1,890	$315	$1,575
New Collection	$187	$486	($299)
New Interceptors	$475	$206	$269
Combined Sewer Overflow	$17	$5	$12
Inflow and Infiltration	$216	$206	$10
Unsewered Area Projects	$188	$277	($89)
Advanced Treatment	$192	$272	($80)
Secondary Treatment	$1,167	$773	$394
Total	$4,332	$2,540	$1,791

SOURCE: FUTURE WASTEWATER INFRASTRUCTURE NEEDS AND CAPITAL COSTS, MPCA, 2010

Figure 3-31: 20-Year Wastewater Needs

future wastewater needs

PROJECT TYPES	QUANTITY (million $)		% TYPE	% TOTAL
Sewer System	**2,773.05**			**64**
Rehabilitation		1,897.15	68	
New Interceptors		450.55	16	
Infiltration/Inflow		215.36	8	
New Collection		193.36	7	
Combined Sewer Overflow (CSO) Correction		16.63	1	
Wastewater Treatment Facilities	**1,379.69**			**32**
Secondary Treatment		1,188.21	86	
Advanced Treatment		191.46	14	
Unsewered Area*	**187.63**			**4**
Total	**4,340.37**			**100**

SOURCE: FUTURE WASTEWATER INFRASTRUCTURE NEEDS AND CAPITAL COSTS, MPCA, 2010

*Does not include areas with failed or inadequate SSTS.

Figure 3-32: Future Wastewater Needs

Approximately 450,000 Minnesota homes, 75,000 cabins, and 10,000 businesses (resorts, commercial and industrial buildings) are outside areas served by public wastewater treatment systems. In total, approximately 535,000 locations should have a functioning septic system. Of these, 208,000 —39 percent—are failing or an imminent threat to public health and safety, with a total cost to upgrade of $1.2 billion.

A 2006 MPCA survey found 1,025 small communities in Minnesota with inadequate wastewater management. The combined population of the communities was 108,970, and total discharge was 2.3 billion gallons per year. Problems included straight pipes without treatment, aging equipment and structures, and untreated sewage discharged at the surface. The number of failing or inadequate systems reported each year is most likely lower than the actual number.

With the exception of the Twin Cities metro area, most of Minnesota struggles with the affordability of wastewater infrastructure. Minnesota has new limits for phosphorus and nitrogen discharges from wastewater treatment systems as a part of EPA regulations. In many cases, new limits will require costly upgrades to WWTPs.

Studies done by a variety of cities have concluded that "greening" the "gray" infrastructure is more cost effective. For example, New York City spent $1.5 billion protecting and restoring the ecosystem that surrounds (and filters) its Catskill water supply reservoir rather than invest $9 billion in the equivalent treatment structures that would have been needed. Seattle concluded that green stormwater infrastructure investments in one neighborhood cost only one-quarter of the estimated costs of traditional stormwater pipes and collection systems.

All three types of water infrastructure systems face new challenges today due to global climate change. Increased intensity of summer rainfalls due to climate change could render past stormwater designs inadequate. Climate change will increase the likelihood of pathogen occurrences that will require treatment in drinking water systems.

The following gaps in knowledge and policy have been identified:

SCIENCE & TECHNOLOGY GAPS

1. **The life-cycle costs of all water-related infrastructure are not well known.**
2. **The current status of most infrastructure in the state is unclear.**
3. **There is no system for assessing the status of public and private infrastructure.**

POLICY GAPS

1. **There is no plan by the state and local governments to pay for infrastructure needs not covered by the state revolving funds.**
2. **There is little resiliency or redundancy in current drinking water and wastewater systems.**
3. **State and local governments lack criteria and policy for the management of infrastructure in a manner that encourages sustainable land and water use.**
4. **Minnesota lacks adequate and appropriate water reuse policies.**

H.1. OBJECTIVE: Get ahead of the curve on planning water infrastructure for future needs.

H.1 STRATEGY: Incorporate adaptive management strategies, new technological advances, and water reuse technologies into drinking water and wastewater treatment plant and stormwater infrastructure decision-making.

H.1 OUTCOMES, MEASURES OF SUCCESS, AND BENCHMARKS: *Outcomes* refers to improvements in water quality and movement toward water sustainability, *measures* refers to the indicators that are used to assess progress, and *benchmarks* refers to the time frame over which progress is achieved. Generally, progress requires considerable time and data, and thus achieving or measuring progress has a longer time frame than the time frame for implementing the related recommendation.

If the Recommendations are implemented, the following outcome should result:

- **Achievement of on going process to identify and recommend new technologies to the MPCA and the Public Facilities Authority ➲ BENCHMARK: Report to the MPCA every 2 years with updated review and efficacy of treatment and reuse technologies, and recommendations for their adoption**

The following actions are recommended to implement this strategy:

Action Plan

RECOMMENDATION H.1.a: Create a standing Emerging Technologies and Green Infrastructure advisory committee of water treatment experts; utility managers; scientists from the water treatment industry, consulting, and academic sectors; League of Minnesota Cities, the American Council of Engineering Companies (ACEC); and MPCA staff to provide biennial updates and advice to the Legislature, MPCA, MDH, and LGUs on new treatment technologies (including green infrastructure), their efficacy, their costs and benefits, and their appropriateness for adoption. They would serve as an expert clearinghouse for this important and rapidly changing information.

TIME FRAME: 1–2 YRS COST*: L

RECOMMENDATION H.1.b: Implement appropriate water reuse strategies—See Recommendation A.2.a.

TIME FRAME: 1–2 YRS COST*: L

RECOMMENDATION H.1.c: Adopt Effective Utility Management promoted by EPA to help utilities respond to current and future challenges (See also new EPA Clean Water and Drinking Water Infrastructure Sustainability Policy)

TIME FRAME: 1–2 YRS COST*: L

**Cost: L is estimated to be $1 million or less; M is estimated to be greater than $1 million and less than $10 million; H is estimated to be greater than $10 million.*

NOTES

H.1.a: Treatment technologies and their applications are changing very rapidly, as are the costs. The regulation of wastewater may also change rapidly in response to CEC regulation (see Issue C: Contaminants of Emerging Concern). Current best practice reports are listed in Appendix G of this report; however, the knowledge base is currently in its infancy and will expand greatly over the next decade. Experts in green infrastructure and treatment technologies can position the state and cities to be ready to incorporate state-of-the-art approaches rather than plan for infrastructure replacement that is out of date, and identify green infrastructure options for use across the state. This reduces redundancy in effort, and gets the information up front to improve decision making. This advisory group should consider innovative technologies, such as water-free waste treatment.

H.1.b: see Recommendation A.2.a

H.1.c: In this national program, EPA is developing technical assistance for utility managers.

H.2 OBJECTIVE: To develop a strategy for paying for future infrastructure needs as they are needed, rather than deferring the problem.

H.2 STRATEGY: Adopt improved methods for economic valuation of water infrastructure investments to pay for future investments, and for life cycle of water-related infrastructure.

H.2 OUTCOMES, MEASURES OF SUCCESS, AND BENCHMARKS: *Outcomes* refers to improvements in water quality and movement toward water sustainability, *measures* refers to the indicators that are used to assess progress, and *benchmarks* refers to the time frame over which progress is achieved. Generally, progress requires considerable time and data, and thus achieving or measuring progress has a longer time frame than the time frame for implementing the related recommendation.

If the Recommendations are implemented, the following outcome should result:

- **An ongoing plan to pay for infrastructure needs will be designed and implemented**
  BENCHMARK: **Implementation within 5 years, with review of strategy and its ability to fund future projections completed every 5 years thereafter**

The following actions are recommended to implement this strategy:

RECOMMENDATION H.2.a: Develop a long-term strategy for funding new and expanded infrastructure and its maintenance.

Research Plan

i. Fund research to identify different funding options and approaches that are sustainable, and incorporate the cost of future technologies and infrastructure replacement into utility pricing to make infrastructure sustainable, including life-cycle costs. This research should also consider the costs and benefits of centralized vs. decentralized treatment, and relative economic impacts of reuse feasibility for both approaches.

Action Plan

ii. Adopt a funding structure after consideration of the recommendations from the panel in J.2.a.i; costs required above those covered by the state revolving funds should be shared by the state and communities (since benefits are accrued both locally and statewide).

TIME FRAME: 2–4 YRS COST*: H

**Cost: L is estimated to be $1 million or less; M is estimated to be greater than $1 million and less than $10 million; H is estimated to be greater than $10 million.*

TIME FRAME for COMPLETION of ISSUE H RECOMMENDATIONS

The Recommendations above will take varying amounts of time to act on and implement. The times shown represent time for the state to act, and are not the times when outcomes would be realized. The dotted lines are the time frame for outcomes, or indicate ongoing repeated outcomes, if they are different from the implementation time frame. Research Recommendations (those that need additional scientific or technological understanding) are shown in blue to distinguish them from Action Recommendations in black (those that have sufficient scientific justification and can be undertaken now). *Note: Each time frame bar represents the progression after start of implementation. For recommended actual start date, see Figure 2-3, Implementation column and the table's preceding explanatory text.*

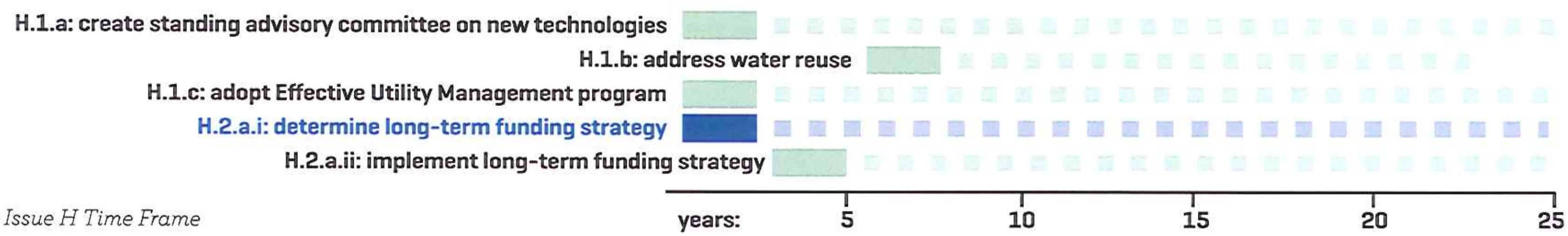


Figure 3-33: Issue H Time Frame

IMPACT MATRIX for ISSUE H RECOMMENDATIONS

Cost \ Impact	L	M	H
H			H.2.a
M			
L	H.1.b	H.1.c	H.1.a

Figure 3-34: Issue H Impact Matrix

This figure indicates the relative impact of implementing a given Recommendation (how much difference it will make to achieving sustainable water use and management), compared to an estimate of the total cost of the Recommendation to the public sector (i.e., state funds) for its full implementation. Cost estimates: L (low) is estimated to be $1 million or less; M (medium) is estimated to be greater than $1 million and less than $10 million; H (high) is estimated to be greater than $10 million.

Wastewater Treatment Best Practices

Minnesota Water Sustainability Framework
January 2011

Wastewater treatment refers to the treatment of sewage and water used by residences, business, and industry to a sufficient level that it can be safely returned to the environment. It is important to treat wastewater to remove bacteria, pathogens, organic matter and chemical pollutants that can harm human health, deplete natural oxygen levels in receiving waters, and pose risks to animals and wildlife. Wastewater discharge quality is regulated by the US EPA and MPCA under the Clean Water Act through the National Pollutant Discharge Elimination System (NPDES). Wastewater treatment plants (WWTP) are issued permits for allowable discharges of solids, oxygen (as biological oxygen demand, or BOD), bacteria, nutrients, and other regulated pollutants on a plant-by-plant basis, depending on their receiving waters.

Conventional Treatment. Wastewater undergoes multistage treatment involving the removal of physical, biological, and chemical contaminants. After debris removal, the first stage is primary treatment, which removes solids by settling. Secondary treatment is a biological treatment stage to remove dissolved organic matter from wastewater. Sewage microorganisms are cultivated and added to the wastewater, and the organic matter serves as their food supply. The microorganisms absorb nutrients and organic matter as they grow. There are three approaches used for secondary treatment, and they include fixed film, suspended film and lagoon systems. Fixed film treatment grows microorganisms as a film on a solid substrate (such as rocks), and technologies include trickling filters, rotating biological contactors, and sand filters. Suspended film systems grow the bacteria in suspension, and they settle out as sludge which is removed, treated, and disposed of. Suspended film systems can be operated in a smaller space than fixed-film systems that treat the same amount of water. However, fixed-film systems are more able to cope with drastic changes in the amount of biological material and can provide higher removal rates for organic material and suspended solids than suspended growth systems. Activated sludge, extended aeration, and sequential batch reactor systems are all examples of suspended film systems. Lagoon systems are shallow basins which hold the wastewater for several months to allow for the natural degradation of nutrients and organic matter by naturally occurring bacteria. This approach is usually used by smaller plants (< 1 million gallons/day).

Constructed wetlands are being used more frequently, and, depending on design, can act as a primary, secondary and sometimes tertiary treatment. However, design is critical to their performance, more so than for other systems, and they are subject to space limitation.

Membrane bioreactors (MBR) are also used for secondary treatment, and combine activated sludge treatment with the use of a membrane to separate solids from liquid. This approach can overcome poor settling of sludge in conventional activated sludge systems. It allows for very effective removal of both soluble and particulate biodegradable materials at higher loading rates. This increases sludge retention times, usually exceeding 15 days, and ensures complete nitrification (the biological conversion of ammonia to nitrate) even in extremely cold weather.

The cost of building and operating an MBR is usually higher than conventional wastewater treatment plants, and the membranes can be fouled over time. This technology is becoming more common, and life-cycle costs have been steadily decreasing. The small footprints of MBR systems, and the high quality effluent produced, make them particularly useful for water reuse applications. They are typically used for small-to-medium systems (<10 million gallons/day)

Tertiary Treatment. The minimal level of wastewater treatment that is universally required is secondary. However, tertiary treatment of wastewater is often required to further remove contaminants to a sufficient degree to protect receiving waters, and may be mandated for certain plant permits. Tertiary treatment can consist of an extension of secondary biological treatment for additional nutrient removal, or advanced treatments to remove other contaminants.

Phosphorus can be removed by chemical precipitation with alum, ferric chloride, or lime. Phosphorus also can be reduced by enhanced biological phosphorus removal. Specific microorganisms can be selectively enriched and accumulate the phosphorus during their growth, and can be removed and the resulting sludge used as fertilizer. This approach is considered highly effective and cost-efficient. It has been used successfully on the Metro WWTP.

Nitrogen removal involves oxidizing ammonia (the form of nitrogen found in wastewater) to nitrate (nitrification) in a two-step aerobic process, and then reducing the nitrate to nitrogen gas (denitrification) under anoxic conditions. All steps are facilitated by selectively enriched bacteria. The resulting nitrogen gas is harmless and is released to the atmosphere. Sand filters, lagoons, and constructed wetlands can all be used to reduce nitrogen, but a well-designed activated sludge process can do the job the most easily and effectively. Denitrification is often accomplished with mixed slurry reactors, in fixed bed reactors, or denitrification filters. The process is very sensitive to temperature, available organic carbon, sludge age, retention time, and pH. In summary, modern WWTPs can effectively accomplish nitrogen removal when biological nitrification/denitrification is a part of the activated sludge process.

Advanced Treatments and their Efficacy for CEC Removal. A range of new technologies have been developed to remove additional contaminants, including contaminants of emerging concern (CECs; see Part III, Issue C). For wastewater that is discharged to pristine waterways, or is being re-used for other purposes, a higher level of treatment may be needed. The following sections discuss treatments for the removal of certain classes of CECs, including endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs). It should be noted that most of these contaminants are not regulated because there is insufficient data to conduct a human health risk assessment. However, in many instances around the country and internationally, there is clear evidence of impacts of these contaminants in wastewater discharge on fish in receiving waters.

Activated Sludge. Activated sludge processes have been shown to remove >77% and >90% of the natural estrogen compounds estrone (estrone) and estradiol (estradiol) across all biological field treatment types. Natural estrogens have been noted to make up a majority of wastewater effluent estrogenicity in many studies. Another study reports that activated sludge can consistently remove >85% of estradiol, estriol, and ethynyl estradiol (synthetic estrogen used for birth control pills), while estrone is more variable. Natural estrogens tend to be low on the sorption spectrum, and thus most of their removal is due to biodegradation, not simple sorption, although estrogenic activity is still expected in sludge. Maximum removal of natural estrogens is obtained in aerobic conditions; in anaerobic conditions, some compounds are more persistent (e.g., estrone degradation decreases by a factor of 3-5; ethynyl estradiol is only degraded under aerobic conditions, while estradiol is oxidized at similarly high rates across all redox conditions). Estradiol removal efficiencies in a Canadian study of 16 WWTPs found estradiol removal rates of 40-99%, estrone removal rates from net production of 98%, with nitrification being correlated with successful estrone and estradiol removal. Estradiol is also noted to require similar conditions as those that result in nitrification. In general, removal of estrogenic activity is highly variable during conventional secondary treatment.

Natural steroid estrogens degrade slowly (in order of rapidity: estrone>estradiol>ethynyl estradiol, with complete removal of ethynyl estradiol taking up to a few days). Overall, some estradiol and estrone are expected to persist following conventional activated sludge treatment, with relatively lower estradiol persistence (<10%). Cited studies show estradiol removal rates of 70%, 87%, 88%; estrone rates of 74% and 61%; estriol rates of 80-95%; and ethynyl estradiol rates of 30-85%. Assessment of natural estrogen removal is complicated by the possibility that these compounds are being transformed among their different chemical forms inside the WWTP. A full scale mass balance showed that total estrogenic potential was reduced from 58-70ng/L to 6ng/L in one WWTP using conventional activated sludge treatment. Another study reported 50-66% total estrogenic potential reduction in conventional activated sludge treatment, with 5-10% of the total estrogenic potential partitioning to sludge.

WWTPs using activated sludge with nitrification/denitrification processes have been shown to have increased removal of PPCPs, EDCs, and nitrate compared to WWTPs without nitrification/denitrification. Many studies have confirmed that approximately >90% of estrone, estradiol, and ethynyl estradiol will be removed from activated sludge treatment plants with nitrification/denitrification. Sludge age (same as solids retention time), hydraulic retention time, temperature, nitrification/denitrification, and phosphate elimination are thought to be factors affecting removal rates of contaminants in activated sludge systems.

Regarding synthetic EDCs and PPCPs, alkylphenols (nonionic detergent surfactant additives and their stable breakdown products; they can constitute up to 5-10% of dissolved organic carbon in WWTP influent) are less water soluble and tend to accumulate more in sludge than the natural estrogens. They tend to persist in anaerobic sludge environments, although subsequent land spreading may result in >90% degradation in 1-3 months. Additionally, nonylphenol has been detected in surface water that receives WWTP effluent in the 0.1-14µg/L range, indicating that not all NP is bound to sludge; significant portions leave in effluent.

In a study of 5 conventional activated sludge WWTPs, 85-99% of nonylphenol and 38-99% bis-phenol A (BPA) were removed. Alkylphenols and phthalates concentrated in sludges. Nonylphenol has shown indications of being degradable by conventional activated sludge similarly to other major wastewater organic compounds (60-88% removal rate), although widely varying ranges have been reported. Again, where nitrification occurs, removal of nonylphenol tends to be enhanced. Additionally, production of estrogenic byproducts is reduced in aerobic vs. anaerobic sludges.

In one published study, 95% of Ibuprofen was removed, in agreement with other literature stating that ibuprofen, although widely present, can be readily eliminated. "Low" eliminations of Atenolol, Solatol, Trimethoprim, Azithromycin, Erythromycin, macrolide antimicrobials, and "variable" eliminations of sulfamethoxazole and Ketoprofen have been reported in WWTPs using activated sludge. Note that although conventional WWTP can achieve high removal efficiencies, this treatment does not eliminate trace PPCP contamination in surface waters, as removal rates vary greatly due to local conditions and the nature of the contaminant.

Linear alkylbenzene sulfonates (LAS) are used in the production of anionic surfactants; they are readily biodegraded in conventional WWTP settings (~80% biodegradation, with total removal 95-99.5%).

Phthalate plasticizers and brominated flame retardants tend to partition to sludge in the WWTP process.

In summary, overall removal rates of EDCs and PPCPs in conventional WWTPs with activated sludge vary strongly, and elimination is often incomplete. The more polar the molecule, the more likely it is to remain soluble in effluent. Activated sludge processes can result in high EDC removal, but are not likely to achieve concentrations below maximum allowable levels for some estrogens, alkyphenols, or BPA.

<u>Reverse Osmosis.</u> Reverse osmosis removes ionic salts and other molecules by selective filtration. It appears to be a viable treatment for removal of most EDCs/PPCPs in drinking water, except for neutral low molecular weight compounds. Reverse osmosis achieved >90% removal of natural steroid hormones in one study. A combination of reverse osmosis with nanofiltration can result in very efficient PPCP removal, including a wide range of pesticides, alkyl phthalates, and estrogens. Reverse osmosis and nanofiltration foul quickly in the treatment of wastewater, making them prohibitively expensive.

<u>Granulated Activated Carbon (GAC).</u> Water is passed through a bed of activated carbon granules that adsorb contaminants. GAC has been shown to be very effective at removing many pharmaceuticals, except for clofibric acid. Competition with organic matter in WWTP effluent for sorption sites can reduce EDC and PPCP removal rates. EDC and PPCP removal depends on the solubility of the compounds – more soluble, polar compounds are not removed efficiently. Powdered activated carbon has greater efficiencies of removal for some pharmaceuticals, but is typically used in episodically to treat a specific situation.

<u>Ultrafiltration/Nanofiltration.</u> Water is forced through semipermeable membranes that filter out very small particulates (ultrafiltration) and dissolved molecules (nanofiltration). A study of 52 EDC/PPCPs in modeled and natural waters found that nanofiltration exceeded ultrafiltration in EDC/PPCP removal. Nanotfiltration removal efficiencies were between 44-93%, except for naproxen (0% removal), while ultrafiltration removal was typically less than 40%.

Nanofiltration retains these compounds on the membrane both through hydrophobic adsorption and size exclusion, while ultrafiltration retention is typically due to hydrophobic adsorption. However, these systems foul quickly when used on wastewater systems, and are reserved for use in drinking water treatment. These techniques are also highly effective for the removal of pathogens.

Ozonation and other Advanced Oxidation Processes. Water is treated with ozone or other reagents to produce strong oxidizing agents that react and breakdown contaminants. Ozonation has been, in some cases, very effective at removal of pharmaceuticals—diclofenac and carbamazepine (>90%), bezafibrate (50%) – but clofibric acid was stable even at high ozone doses. Ethynyl estradiol and estradiol are expected to be completely transformed; nonylphenols have also been effectively removed. Pairing ozonation with UV or H_2O_2 (peroxide, such as is done in advanced oxidation processes) may be required to achieve the most effective transformation of pollutants. For instance, ozonation alone did not remove clofibric acid, but when pairing O_3 with H_2O_2, improved removal of clofibric acid and other compounds was achieved. This and other advanced oxidation processes are effective for drinking water treatment, but the high levels of organic matter in wastewater use up the oxidizers make them inefficient and yield limited results. Advanced oxidation systems are also effective at removing pathogens. One hypothetical option would be to apply these methods to highly treated wastewater after biological treatments to reduce the dissolved organic matter as much as possible. However, there are no examples of the commercial use of advanced oxidation for wastewater treatment.

Conclusion. Many advanced treatment technologies, especially combinations of them, are efficient at removing EDCs and PPCPs from drinking water. The high organic carbon content of wastewater, however, greater lowers their effectiveness and increases their costs, and thus greatly limits these treatments from being used by WWTPs. Currently there are no well-accepted or established treatment technologies for effectively removing EDCs and PPCPs from wastewater.

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