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Memorandum

To: MIDS Work Group
From: Barr Engineering Company
Subject: Stormwater Harvesting and Reuse for Irrigation
Date: 3/4/2013
Project: 23621050

Executive Summary

Recently, stormwater reuse is being looked to as more than a water conservation practice but also as a viable alternative to help meet stormwater management requirements. This Minimal Impact Design Standards (MIDS) workplan was focused specifically on stormwater reuse for irrigation of non-food crops, such as turf and ornamental landscaping, based on a request from the MIDS technical team.

The goal of the work completed as part of this MIDS workplan was to:

- Perform a literature review of select documents related to water reuse and summarizing the available information in the context of stormwater reuse for irrigation including:
  - general discussion about stormwater reuse,
  - concerns related to stormwater reuse systems,
  - existing guidelines, standards, treatment requirements, and (draft) code related to stormwater reuse,
  - typical contaminants and concentrations in stormwater, and
  - components of a typical reuse system for irrigation.
- Conduct preliminary modeling considering growing season/irrigation season use rates to estimate the relationship between stormwater volume reduction credits versus storage capacity including and estimated range of annual volume, phosphorus, and suspended solids removals for these systems.
- Conduct a total of three meetings with state agency staff and the MIDS technical team to begin discussing the guidelines and standards currently available, regulatory jurisdiction and concerns

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related to reuse systems and how these concerns may impact future guidelines, and the potential impact of these reuse system on stormwater management.

Based on the work completed, the following is a summary of the major conclusions related to stormwater harvesting and reuse for irrigation and the suggestions for the next steps:

Summary of Conclusions:

- One of the major concerns related to stormwater reuse for irrigation (and other uses) is the public health risk due to exposure to pathogens, such as *E. coli*, and potential for cross-contamination of the potable water supply.
- The lack of national guidance for stormwater reuse has resulted in differing use and treatment guidelines/standards among state and local governments, and in many areas, rainwater and stormwater harvesting is largely unaddressed by regulations and codes. Additionally, many of the existing standards were originally developed for the reuse of reclaimed water (treated wastewater) rather than stormwater.
- Often, the treatment requirements ultimately come down to the risk of exposure to pathogens determining the most stringent levels of treatment. Many jurisdictions evaluate stormwater reuse projects based on whether the application area has restricted or unrestricted public access. However, the level of treatment required by each municipality can influence the number of harvesting and reuse systems that are actually implemented.
- Currently, the State of Minnesota does not have a state-specific code or guidance applicable to stormwater harvesting and reuse and generally relies on the *State of California Water Recycling Criteria* (2000) as guidance for water reuse projects. At present, there is limited regulatory jurisdiction by the various state agencies over stormwater reuse systems for irrigation.
- From the stormwater management perspective, there is a large range in the expected impact of a stormwater reuse system for irrigation on average annual volume and pollutant load reductions, ranging anywhere from 1 percent to upwards of 90 percent average annual removal. There are several variables that can impact the expected removal efficiency of the reuse system, including the reuse storage volume, the expected area for application, the irrigation rate and season, and any potential pretreatment prior to reuse (e.g., reuse from a wet

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pond meeting National Urban Runoff Program, NURP, criteria). Assuming that the reuse storage volume is optimized to the contributing watershed and there is sufficient application area to utilize the stormwater, typical volume reduction and pollutant removals from reuse alone would be expected to range from approximately 20 to 50 percent on an average annual basis.

Summary of Suggestions for Future Work:

- Development of a workgroup with representatives of each state agency, including the Department of Labor and Industry (DLI), the Minnesota Department of Health (MDH), the Minnesota Pollution Control Agency (MPCA), the Minnesota Department of Natural Resources (MDNR), and Minnesota Department of Agriculture (MDA), focusing on stormwater reuse (for irrigation) to begin clarifying the roles and jurisdiction for each agency and any associated guidance. The intent of the work group would be to facilitate discussions surrounding stormwater reuse systems, jurisdiction of the various agencies, and potential guidance (appropriate water quality and treatment standards) for these systems.
- Completion of health risk assessments of non-potable water sources (including stormwater) and the potential uses for these sources, including investigation into cases of human illness related to stormwater reuse systems. These assessments will help begin quantifying the actual health risks associated with stormwater reuse (for irrigation) and to begin understanding if the current water quality guidelines (from the various programs in other states) are too stringent, appropriate, or not stringent enough and to help better define levels of required treatment. These assessments would eventually lead to the development of statewide water quality guidelines (or standards) and treatment requirements that would help guide the design of stormwater reuse systems (for irrigation and potentially other uses).
- Because one of the major demands for stormwater reuse systems in Minnesota is irrigation of golf courses and athletic fields from existing stormwater ponds, it is important to understand the actual water quality in stormwater ponds (after settling), in the context of the public health concerns, irrigation equipment function, and impact of stormwater pollutants on plant health. A comparison of the levels observed in actual stormwater ponds to current stormwater reuse water quality standards/guidelines would help regulators begin understanding if additional treatment,

such as filtration or disinfection, is needed for reuse systems utilizing water from stormwater ponds.

- The purpose of the preliminary modeling analysis performed as part of this MIDS work was to begin understanding the potential impact of stormwater reuse for irrigation with regards to stormwater management standards. Performance curves were developed based on specific assumptions related to the various parameters. Therefore, these curves only apply to sites that would meet the specific assumptions that were included in the modeling analysis. However, it is expected that there would be significant variability in the model parameters related to the stormwater reuse. Therefore, additional modeling would be necessary to develop a full range of performance curves related to cover the potential site conditions and variability in watershed area, stormwater storage volume, application area for irrigation, irrigation rates, and irrigation periods to be incorporated into the MIDS Calculator.

Overview of Stormwater Harvesting and Reuse for Irrigation

Stormwater harvesting and reuse is a practice of collecting and reusing stormwater for a potable (for consumption) or non-potable applications. Outdoor irrigation is considered a non-potable water use. For this work plan, we have assumed irrigation of non-food crops, such as turf and landscaping. For the purposes of this document, stormwater is defined as runoff collected from roof and ground surfaces, including roadways, driveways, parking lots and other impervious areas. Rainwater is defined as runoff from roof surfaces only. Some of the literature sources reviewed as part of the development of this memorandum place emphasis on rainwater only, while others focus on stormwater for harvesting and reuse. Additionally, some of the documents and standards reviewed were originally developed for the reuse of reclaimed (treated wastewater).

The following documents were reviewed as part of the development of this memorandum:

- *Stormwater Harvesting and Reuse: Literature Review* (EOR, 2011 (draft))
- *Guidelines for Water Reuse* (EPA, 2012)
- *Managing Wet Weather with Green Infrastructure Municipal Handbook Rainwater Harvesting Policies* (EPA, 2008)
- *Metropolitan Council Stormwater Reuse Guide* (Metropolitan Council, 2011)

- *Metropolitan Area Master Water Supply Plan (*Metropolitan Council, 2010)
- *Minnesota Stormwater Manual, Version 2* (MPCA, 2008)
- *Municipal Wastewater Reuse.* (MPCA, 2010)
- *Water Use in Minnesota.* (University of Minnesota Water Resources Center, 2010 (draft)).
- *Chapter 16 Alternative Water Sources for Nonpotable Applications* (Uniform Plumbing Code, 2012 (draft))
- *Chapter 17 Nonpotable Rainwater Catchment Systems* (Uniform Plumbing Code, 2012 (draft))
- *Contech Webinar – Rainwater Harvesting as a Runoff Reduction Tool for Areas with Moderate to High Intensity of Rainfall* (Contech, 2012)
- *Managing Mosquitoes in Stormwater Treatment Devices* (California Department of Health Services, 2004)
- *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Stormwater Harvesting and Reuse* (Natural Resource Management Ministerial Council, the Environment Protection and Heritage Council, and the National Health and Medical Research Council (Australia), 2009)
- *Watering Lawns and Other Turf* (University of Minnesota Extension, 2009)

There are several overarching goals for the implementation of stormwater harvesting and reuse systems. These goals include (EOR, 2011 (draft)):

- reduction of stormwater pollutant loads and flows to surface waters, helping achieve local stormwater management requirements,
- reduction in the size of other stormwater Best Management Practices (BMPs) needed to achieve local stormwater management requirements,
- reduction of the demand on potable water sources, and
- reduction of stress on the existing water supply infrastructure.

Additionally, stormwater harvesting and reuse systems can be used to help achieve Leadership in Energy and Environmental Design (LEED) and other sustainable design credits related to stormwater quantity and quality as well as water efficiency.

The scale of stormwater harvesting and reuse systems can range from small residential systems to very large commercial systems. According to the EPA, when harvested rainwater is re-used, it generally is best for irrigation and non-potable uses of water closets, urinals, and HVAC, as these uses require a lesser amount of on-site treatment than potable uses (EPA, 2008). Because of this, one of the most common reuse applications of stormwater and rainwater is urban irrigation (EOR, 2011 (draft)), which can include irrigation of athletic fields, golf courses, parks, landscaping, community gardens, and creation of water features (Metropolitan Council, 2011).

Nationally, outdoor water uses represent 58% of the domestic daily water uses while for hotels and office buildings, outdoor uses represent 10 to 38% of the daily water uses, respectively (EPA, 2008). In Minnesota during the summer, as much as 50% of potable water supply is used for outdoor, non-potable uses. During hot weather and extended periods of drought, Twin Cities' property owners will use 45 to 120 gallons of treated drinking water per person per day for outdoor uses with peak usage on large lots and new turf reaching as much as 200 gallons per person per day (Metropolitan Council, 2011).

Concerns Related to Stormwater Harvesting and Reuse

Although stormwater harvesting and reuse systems appear to be a viable alternative to help achieve the required stormwater management standards as well as reducing the demand on the potable water supply, it is not without its associated concerns.

One of the main concerns of regulatory agencies related to the harvesting and reuse of stormwater is public health and the risk of potential exposure to pathogenic bacteria (EOR, 2011 (draft)). These concerns includes human exposure to pathogens, cross-contamination of the potable water supply (EPA, 2008), and in the case of stormwater being reused for irrigation exposure during or after application and for crops and gardens, exposure due to ingestion of crops potentially contaminated with pathogens.

In addition to the public health concern, there are other documented environmental concerns related to stormwater reuse is the risk of toxic spills (within the stormwater reuse catchment area and potential for reuse of toxic/contaminated water), along with mosquito breeding and contaminated pond sediments (EOR, 2011 (draft)).

Additionally, there are often not well-defined operation and maintenance procedures for rainwater and stormwater harvesting and reuse programs (EOR, 2011 (draft)). These operation and maintenance programs help ensure that the stormwater reuse systems are functioning as designed and that they are meeting the required water quality to protect the public health.

Stormwater Reuse Treatment Guidance

Background

In many areas, rainwater and stormwater harvesting is largely unaddressed by regulations and codes (EPA, 2008), although some cities and states have established stormwater harvesting and reuse requirements. Many of these standards were originally developed for the reuse of reclaimed water (treated wastewater) rather than stormwater. However, the confusion about the different types of water to be reused (reclaimed, rainwater, stormwater, etc.) and the lack of national guidance for this topic has resulted in differing use and treatment guidelines/standards among state and local governments. And because of the lack of guidance for rainwater and stormwater reuse, these sources of reuse water are often regulated the same level as reclaimed water, which typically has more clearly defined guidance and standards. Although the general guidance for the reuse of rainwater and stormwater would be similar to reclaimed and graywater, it may also differ because of lower levels of initial contamination and the potential end uses (EPA, 2008). Often, the treatment requirements ultimately come down to the risk of exposure to pathogens determining the most stringent levels of treatment (EPA, 2008).

The level of treatment required by each municipality can influence the number of harvesting and reuse systems that are actually implemented. Simplifying the treatment requirements when public health is not at risk can lower the project cost for those entities intending to install stormwater harvesting and reuse systems and encourages broader adoption of the practices (EPA, 2008).

Because the main concern of stormwater reuse to human health is exposure to pathogenic bacteria, many jurisdictions evaluate stormwater reuse projects based on whether the application area has restricted or unrestricted public access. Restricted reuse applications are defined by areas where public access can be controlled such as irrigation of gated/private golf courses, cemeteries, and highway medians. Unrestricted use applications include areas where public access is not controlled which often includes irrigation in parks, playgrounds, school yards, and residences, and use in ornamental fountains and aesthetic impoundments. In order to limit the public health risk and exposure to pollutants in stormwater during reuse, reuse projects in unrestricted areas have more stringent water quality regulations than restricted areas (EOR, 2011 (draft)).

Australia has implemented numerous water reuse projects throughout the country and the guidelines for managing the human health risk associated with stormwater reuse includes recommendations about signage and fencing around the irrigated areas to limit public exposure. However, if access cannot be controlled, then the guidelines recommended secondary treatment (which includes disinfection) (EOR, 2011 (draft)).

In addition, the scale of the stormwater reuse system may impact whether the system is regulated. For example, in Portland, Oregon, residential rainwater that is only used for outdoor irrigation is not covered by code and needs no treatment prior to use (EPA, 2008). Often, larger scale applications of reuse require treatment, but the extent of treatment is determined by the end use and is up to the jurisdiction to determine what treatment is required. However, most systems are required to include some level of screening/filtration and most jurisdictions will require disinfection (UV or chlorination) (EPA, 2008). Some stormwater reuse systems primarily rely on the pollutant removal abilities of stormwater best management practices to treat stormwater (EOR, 2011 (draft)).

Cross-contamination of the potable water supply is another concern of water reuse systems and is often addressed in building codes. Cross-contamination concerns are usually most applicable when reuse water is brought inside for use within a building or if a potable water supply line is needed to make-up water in the reuse system if the harvested stormwater cannot meet the water demand, which is often the case for irrigation systems utilizing harvested stormwater. Codes will often require a backflow prevention device on the potable water supply lines, an air gap, or both along with a dual pipe system (purple pipes that indicate water reuse lines) and appropriate stenciling and signage (EPA, 2008).

Operation and maintenance of stormwater reuse systems are the responsibility of the property owner. However, there are often not well-defined operation and maintenance procedures for rainwater and stormwater harvesting and reuse programs (EOR, 2011 (draft)). Operation and maintenance should require regular maintenance to ensure the system is functioning as designed because of greater corrosion and clogging of pipes resulting from higher sediment and microbial loads in stormwater (EOR, 2011 (draft)). Maintenance of these systems can include backwashing or replacement of filters (depending on the system design), periodic flushing of pipes to remove sediment build-up and chlorination of pump heads or emitters to clear microbial scum.

Water testing to verify water quality is recommended as well as regular interval maintenance of the treatment system (replacement of filters, UV lights, etc.) (EPA, 2008). In Australia, officials have a major concern with lack of ongoing monitoring after construction which could lead to the potential risk of exceeding water quality guidelines. As a result, they recommends the biannual/quarterly monitoring of nutrients, sediments, pathogens to assess stormwater quality for irrigation (EOR, 2011 (draft)).

Many water reuse programs recommend municipal inspections occur during installation and annual inspections of backflow prevention systems. For example, the State of Florida requires filing of annual inspection reports and maintenance logs every two years. In North Carolina, the state requires inspection of the system (by owner/operator) within 24 hours of each rain event and on a monthly basis, keeping record of the operations and maintenance (EOR, 2011(draft)).

Because one of the environmental concerns related to stormwater reuse is the risk of toxic spills within the catchment area, guidelines in Australia require the incorporation of a 72-hour residence time into a stormwater pond prior to reuse. This provides a time buffer to stop the reuse of potentially contaminated stormwater (EOR, 2011 (draft)). However, this requirement of a 72-hour holding time is in conflict with suggestions for the control of mosquito breeding in stormwater management devices, which suggest that unless a storage system is completely sealed to prevent the entry of adult mosquitos, the water residence time should be less than 72 hours (CDHS, 2004).

Draft Uniform Plumbing Code and International Plumbing Code for Reuse Systems

In 2012, the Uniform Plumbing Code (UPC) and International Plumbing Code (IPC) released draft code related to rainwater harvesting for review and comments. However, the draft code only includes code for rainwater reuse (i.e., runoff from roof surfaces) and does not include any code regarding the collection and reuse of stormwater from surfaces other than roofs. The focus of the draft code is on treatment requirements, measures necessary to prevent cross-contamination with potable water, and appropriate signage and system labeling.

However, various stakeholders reviewed the UPC draft code and raised concerns related to its current form. Several comments were submitted to the Minnesota Pollution Control Agency (MPCA) MIDS Harvest and Reuse Technical Team, including:

- The draft code would require a permit for all systems greater than 360 gallons.
    - Because of the threshold volume (360 gallons), nearly all systems (with the exception of some residential systems) will required a permit, and depending on the permitting process established there is concern that the permitting will discourage harvesting and reuse.
    - What is the significance of the 360 gallon threshold?
- The draft code requires water treatment for all above ground irrigation systems.
    - The draft code does not provide any specific water quality treatment standards and leaves it up to each jurisdiction to decide what the guidance should be.
    - What are the appropriate water quality standards?
    - Concern that requirements that are "too stringent" could severely limit stormwater harvesting and reuse.
    - We account for potential reuse from stormwater ponds which can significantly improve water quality due to sedimentation of particles and degradation of pollutants by microorganisms in the pond.
- Restricting water sources for non-potable uses to roof surfaces only
    - Excludes the majority of stormwater sources that would greatly benefit from the volume and nutrient reduction benefits of stormwater harvesting and reuse.

As of December 2012, the recommended revisions to Chapters 16 & 17 of the (draft) plumbing code is to removal all mention of reuse for irrigation and that code only addresses water being used within a building.

Requirements for Stormwater Reuse Systems in Minnesota

Currently, the State of Minnesota does not have a state-specific code applicable to stormwater harvesting and reuse. The MPCA has developed guidelines for the use of reclaimed wastewater. In 2011, the

Metropolitan Council developed the *Stormwater Reuse Guide*, which was developed based on review of water reuse programs and guidance from other states.

Current Jurisdiction of Existing State Agencies on Stormwater Reuse Systems for Irrigation

Based on a meeting with staff from the MPCA, the Minnesota Department of Health (MDH), and the Minnesota Department of Labor and Industry (DLI) along with later follow-up with Minnesota Department of Natural Resource (MDNR) staff, Table 1 summarizes the current jurisdiction of the Minnesota state agencies in the context of stormwater reuse systems solely for irrigation.

Table 1 – Summary of Minnesota State Agency Jurisdiction as it relates to Stormwater Harvesting and Reuse Systems for Irrigation

Agency	Description of Jurisdiction
DLI	The focus of the DLI is on protecting the public health and welfare. The DLI is responsible for administering the plumbing code. The state Plumbing Board has the rule making authority. The DLI primarily deals with the requirements related to stormwater conveyance systems (materials, fittings, etc.), which can include both interior as well as exterior storm piping. Typically, the DLI jurisdiction is over any conveyance to an approved "point of disposal," which is either at grade or into a subsurface infiltration system. Beyond the point of disposal, the MPCA often is the regulating authority. The definition of "point of disposal" can vary depending on the site. For example, the conveyance system that outlets to a stormwater BMP (such as a pond, infiltration system, or subsurface infiltration system) or a water of the state, if within the property boundary, would be the point of disposal. If there is not a stormwater BMP or a water of the state within the property boundary, then the property boundary would serve as the point of disposal. In the case of reusing water for irrigation from a stormwater pond, the DLI would have jurisdiction over the conveyance system to the point where it discharges into the stormwater pond; however, the DLI would not have jurisdiction over the stormwater pond or the irrigation system taking water from the pond and would typically not review those components. In the DLI's experience with stormwater reuse projects, it cannot dictate water quality standards (no rule), but highly recommends water treatment and the DLI has provided water quality guidance (fecal coliform limits and Total Suspended Solids—TSS limits). In terms of stormwater collection systems on/within buildings, the plumbing code does not regulate scuppers, gutters, or downspouts on the outside of buildings. (This is

Agency	Description of Jurisdiction
	covered by building code.) However, the plumbing code does outline the requirements of interior roof drain systems. Additionally, plumbers can perform both interior and exterior pipe/conveyance work. Certified pipe layers can only install exterior piping.
MDH	The MDH currently has limited jurisdiction over systems related to stormwater collection and reuse for irrigation. The MDH has no regulatory authority over most routine handling of stormwater, but does administer the Wellhead Protection Program and other drinking water protection programs. Staff in the Source Water Protection Unit assists public water suppliers with preparing and implementing wellhead protection plans, and offer some guidance on implementing stormwater management within wellhead protection areas (especially related to infiltration strategies). In addition, the MDH is concerned with the potential exposure to pathogens in the environment and the effects on public health. Currently there are no federal regulations regarding nonpotable reuse applications. State regulations or guidance for nonpotable reuse are not uniform across the country, and no state water reuse regulations or guidelines are based on rigorous risk assessment methodology. The MDH Health Risk Assessment unit is currently reviewing the EPA/USDA Microbial Risk Assessment (MRA) Guideline in order to assist with a strategy for nonpotable reuse applications. Non-consumptive exposures such as inhalation through mists and aerosols are of particular concern and have not been the focus of current guidelines.
MPCA	MPCA's jurisdiction is typically over the water quality reaching the waters of the state and to ultimately protect the water quality in the lakes, streams, and groundwater. In terms of stormwater management, this typically applies to construction sites disturbing more than one acre of soil, industrial sites that currently have an industrial stormwater permit, or MS4s (Municipal Separate Storm Sewer System operators) trying to meet the requirements of their permits (which can include TMDL—Total Maximum Daily Load—wasteload allocations). Unless the stormwater harvesting and reuse systems for irrigation system is intended to demonstrate compliance with any of the above permits and stormwater management requirements, the MPCA would not be involved in the review of these systems.
MDNR[1]	Appropriations permits are required for withdrawals from any waters of the state. Appropriate is defined as the withdrawal, removal, or transfer of water from its source, regardless of how the water is used. "Waters of the state" means all surface and underground waters, except surface waters that are spread and diffused over the land. By this definition, stormwater ponds (even if not a DNR public water lake or wetland or stream – but a pond constructed in an upland area) are waters of the state.

Agency	Description of Jurisdiction
	A water appropriations permit is required from the MDNR for all users withdrawing more than 10,000 gallons per day or 1 million gallons per year from waters of the state. Exemptions to the appropriations permit include: domestic uses serving less than 25 person for general residential purposes, test pumping of a groundwater source, reuse of water already authorized by a permit (e.g., water purchased from a municipal water system), or certain agricultural drainage systems. In general, if water is pumped out of a stormwater basin, an appropriation permit is required. If the water is temporarily drained out of the basin via an operable outlet structure, an appropriation permit is not required. Additionally, in the Twin Cities seven-county metro area, there is a general permit (2000-6117) that has been issued that allows for temporary appropriations from public waters basins and ponded areas to facilitate flood protection, aquatic plant control, water quality improvement, and stormwater basin maintenance with minimal paperwork. However, this general permit does not apply to stormwater irrigation projects intended to operate consecutive years as all appropriations must be completed within one year of the start of pumping.

1 – Per 12/3/2012 email conversation with Molly Shodeen, Area Hydrologist for the MDNR, 1/10/2013 personal communication with Jeff Berg, Area Hydrologist for the MDNR, and 2/28/2013 email conversation with Dale Homuth, MDNR.

Table 2 summarizes the draft water quality guidelines for irrigation in areas with public access as were determined based on discussion during a meeting with staff from state agencies and a review of standards/guidelines available from other states. These draft guidelines are still considered preliminary to be used for discussion of these standards internally within each agency for additional comment and feedback. Additionally, the MDH would prefer to include treatment requirements along with the water quality outlined in these guidelines (similar to what is outlined in Tables R.3c.1 and R.3c.2 from the Metropolitan Council Stormwater Reuse Guide).

Table 2 – DRAFT Summary of State of Minnesota Water Quality Guidelines for Stormwater Harvesting and Reuse Systems for Irrigation

Water Quality Parameter	Impact of Parameter[10]	Water Quality Guideline – Public Access Areas	Water Quality Guideline – Restricted Access Areas	Water Quality Guideline – Irrigation of Food Crops	Comments
E. coli	Public Health	126 *E. coli*/100mL	TBD[1]	TBD[1]	2,3
Turbidity	Irrigation System Function	2-3 NTU	TBD[1]	TBD[1]	4,5
TSS	Irrigation System Function	5 mg/L	TBD[1]	TBD[1]	4,5,6
pH	Plant Health	6-9	TBD[1]	TBD[1]	4
Chloride	Plant Health; Corrosion of Metals	500 mg/L	TBD[1]	TBD[1]	7
Zinc	Plant Health	2 mg/L (long-term use); 10 mg/L (short-term use)	TBD[1]	TBD[1]	8
Copper	Plant Health	0.2 mg/L (long-term use); 5 mg/L (short-term use)	TBD[1]	TBD[1]	8
Temperature	Public Health	TBD[1]	TBD[1]	TBD[1]	9

1 – TBD: Guidance to be determined at a future date
2 – MPCA Bacterial Impairment Standard: 126 *E. coli*/100mL (geometric mean of 5 samples in 30 day period); no individual samples greater than 1260 *E. coli*/100mL
3 – EPA 2012 Recreational Water Quality Criteria – Recommendation 1 (Estimated illness rate = 36/1000)
4 – Based on typical range/value for water reuse programs in other states
5 –Useful for distribution system design, but often used a general indicator parameter, too.
6 – TSS guidance provided by Cathy Tran, DLI
7 – Per Table R.3b.6 in Metropolitan Council Stormwater Reuse Guide
8 – Suggested by Bruce Wilson. Per Table R.3b.5 in Metropolitan Council Stormwater Reuse Guide
9 - Recommendation from Anita Anderson on 12/6/2012 email as temperature impacts bacterial growth
10 –Per Tables R.1a.1 and R.3b.5 in Metropolitan Council Stormwater Reuse Guide

MPCA Municipal Wastewater Reuse Guidelines

In general, the State of Minnesota relies on the *State of California Water Recycling Criteria* (2000) as guidance for permitting of wastewater reuse and the MPCA has developed the Municipal Wastewater Reuse guidelines based on those requirements. In addition to the water quality limits established (see Table 3), this guidance requires the following to ensure protection of the public health and the environment:

- All use areas must be posted with signs stating that the water being used is recycled, nonpotable, and not fit for consumption.
- Setback distances from wells must be in accordance with the State Well Code.
- No spray irrigation can occur, other than disinfected tertiary water, within 100 feet of a residence, park, playground, school, or other area with similar public exposure.
- Irrigation must be done in such a manner as to prohibit runoff of recycled wastewater from the site.
- No physical connection shall be allowed between any recycled wastewater source and a potable water sources.
- No hose bibs can be installed in areas subject to access by the general public and only quick connect couplers that differ from those used on the potable water system can be used on recycled wastewater.

Table 3 – MPCA Municipal Wastewater Reuse Water Quality Treatment Limits (modified to only include Irrigation-Related Uses)

Types of Reuse	*Reuse permit limits*	*Minimum Level of Treatment*
• Food crops where recycled water contacts the edible portion of the crop, including root crops • Irrigation of residential landscapes, parks, playgrounds, school yards, golf courses	2.2 total coliform/100mL 2 NTU daily average; 10 NTU daily maximum turbidity	Disinfected Tertiary – secondary, filtration, disinfection
• Cemeteries • Roadway Landscaping • Ornamental Nursery Stock and Sod Farms with Restricted Access • Pasture for animals producing milk for human consumption	23 total coliform/100mL	Disinfected Secondary 23 – secondary, disinfection
• Fodder, Fiber, and Seed Crops • Food Crops not for direct human consumption • Orchards and vineyards with no contact between edible portion • Non-food bearing trees, nursery stock and sod farms not irrigated less than 14 days before harvest	200 total coliform/100mL	Disinfected Secondary 200 – secondary, disinfection (stabilized pond systems with 210 days of storage do not need a separate disinfection process)

Metropolitan Council *Stormwater Reuse Guide*

The Metropolitan Council *Stormwater Reuse Guide* summarizes water reuse and water quality standards from a variety of states, with the focus on the California water reuse regulations as these are currently the regulations that the State of Minnesota refers to for guidance (for reclaimed water). The following tables summarize some of the key tables included in the *Stormwater Reuse Guide*. These tables have been modified from the tables in the *Stormwater Reuse Guide* to focus primarily on stormwater reuse for irrigation purposes only. The tables in this memo include:

- Table 4 – Summary of California Water Recycling Criteria (focusing on irrigation uses)
- Table 5 – Summary of Water Reuse Criteria for Irrigation of Parks, Playgrounds, Schoolyards, and Similar Areas from Reuse Programs from Several States
- Table 6 – Summary of Water Reuse Criteria for Select Nonpotable Applications from Reuse Programs from Several States (focusing on irrigation uses)

Additionally, there are select tables from the *Stormwater Reuse Guide* attached to the end of this memorandum for reference and include the following tables:

- Table R.1a.1 Stormwater Constituents of Concern
- Table R.3b.5 Recommended Limits for Constituents in Irrigation Water Supplies
- Table R.3b.6 Typical Parameters and Limits of Concern Related to System Equipment Performance
- Table R.3c.1 Use Criteria Matrix
- Table R.3c.2 Use Criteria Matrix Definitions

Table 4 – Summary of California Water Recycling Criteria (summarized from Table R.3b.1 of the Metropolitan Council Stormwater Reuse Manual)

Type of Use	*Total Coliform Limits (daily sampling is required)*	*Treatment Required*	*Comment (in relation to MIDS)*
Irrigation of fodder, fiber, and seed crops; orchards/vineyards[a]; processed food crops[b], non-food bearing trees; ornamental nursery stock/sod farms[c]	No Limits Established	Oxidation	Most likely applies to non-food bearing trees; ornamental nursery stock/sod farms with restricted access
Irrigation of pasture for miling animals, landscape areas (controlled access); ornamental nursery stock and sod farms where public access not restricted); landscape impoundments	≤23/100mL (running 7-day median) ≤240/100mL (in no more than one sample in any 30-day period)	Oxidation Disinfection	This includes Cemeteries, freeway landscaping, restricted access golf courses, and other controlled access areas
Irrigation of food crops[a]	≤2.2/100mL (running 7-day median) ≤23/100mL (in no more than one sample in any 30-day period)	Oxidation Disinfection	
Irrigation of food crops[d]; Open access landscape areas; Decorative fountains	≤2.2/100mL (running 7-day median) ≤23/100mL (in no more than one sample in any 30-day period) 240/100mL (maximum)	Oxidation Coagulation[e] Filtration[e] Disinfection	This includes parks, playgrounds, schoolyards, residential landscaping, unrestricted access golf courses, and other uncontrolled access areas; This may also apply to scenarios such as community gardens, etc.

a- No contact between reclaimed water and edible portion of crop
b- Food crops that undergo commercial pathogen destruction
c- No irrigation 14 days prior to harvesting, sale, or allowing public access
d- Contact between water and edible portion of crop including edible roots
e- Related to turbidity – See Metropolitan Council Reuse Manual for specific details

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Table 5 – Summary of Water Reuse Criteria for Irrigation of Parks, Playgrounds, Schoolyards, and Similar Areas from Reuse Programs from Several States[a] (summarized from Table R.3b.2 of the Metropolitan Council Stormwater Reuse Manual)

Water Quality Parameter	*Water Quality Limits (Range based on information for all states included in table)*	*State of California Requirements*	*State of Minnesota – Limits Used by DLI[b]*
Total Coliform	2.2 total coliform/100mL	2.2 total coliform/100mL	N/A
Fecal Coliform	No Detect/100mL – 100 fecal coliform/100mL (2.2 fecal coliform/100mL most common)	N/A	100 fecal coliform/100mL
E. coli	126 *E. coli*/100mL (only CO uses *E. coli* as a standard)	N/A	N/A
Turbidity	2 NTU – 3 NTU	2 NTU	N/A
TSS	5 mg/L – 30 mg/L (5 mg/L most common)	N/A	5 mg/L
BOD	5 mg/L – 30 mg/L (10 mg/L most common)	N/A	N/A
pH	6-9	N/A	N/A
NH_3	4 mg/L (only NC has NH3 as a standard)	N/A	N/A
Cl_2 residual	0.5-1.0 mg/L	N/A	N/A

a – Includes review of water reuse programs in AZ, CA, CO, FL, GA, HI, NV, NM, NC, OR, TX, UT, WA, and US EPA guidelines
b – Per 11/28/2012 conversation with Cathy Tran, DLI; General guidance

Table 6 – Summary of Water Reuse Criteria for Select Nonpotable Applications from Reuse Programs from Several States[a] (summarized from Table R.3b.3 of the Metropolitan Council Stormwater Reuse Manual)

Water Quality Parameter	*Water Quality Limit – Food Crop Irrigation*	*Water Quality Limit – Restricted Access Irrigation*	*Water Quality Limit – Unrestricted Access Irrigation*
Total Coliform	2.2 total coliform	23 total coliform/100mL	2.2 total coliform/100mL
Fecal Coliform	No Detect/100mL (some states prohibit use[a])	200 fecal coliform/100mL	No Detect/100mL – 20 fecal coliform/100mL
E. coli	N/A	126 *E. coli*/100mL (only CO uses *E. coli* as a standard)	126 *E. coli*/100mL (only CO uses *E. coli* as a standard)
Turbidity	2 NTU	N/A	2 NTU – 3 NTU
TSS	N/A	20-30 mg/L	5 mg/L
BOD	10 mg/L BOD	20-30 mg/L	5-10 mg/L
CBOD	N/A	15-20 mg/L	5-20 mg/L
pH	N/A	N/A	N/A

Note: Many of these standards are based on water quality limits established for reclaimed water (treated wastewater), not stormwater specifically

a – Includes review of water reuse programs in AZ, CA, CO, FL, GA, HI, NV, NM, NC, OR, TX, UT, WA, and US EPA guidelines

Other State of Minnesota Standards for Bacteria

Because exposure to pathogens, including bacteria, is one of the main concerns related to stormwater harvesting and reuse for irrigation, we have also summarized the fecal coliform standards used by the Minnesota Department of Health (MDH) for swimming beach closures as well as the Minnesota Pollution Control Agency (MPCA) *E. coli* standards for listing water bodies for bacterial impairments for reference (See Table 7).

The MDH tests public beaches for elevated levels of fecal coliform and/or *E. coli* and when high levels are found, beaches are closed to reduce the likelihood of disease. The MDH has established recommendations related to coliform levels to maintain healthy swimming beaches. The MDH will be changing the beach closing standard to reflect the new EPA guidelines (126 *E. coli*/100mL) and additional changes to that standard are likely based on improved testing methodologies and may included additional indicators.

Additionally, the MPCA has established numeric water quality standards for water bodies throughout the state to determine if the water quality in a water body would attain its intended use. Water bodies not attaining those standards are placed on the MPCA 303(d) list of impaired water bodies. The MPCA has established standards for *E. coli* within a water body, with those exceeding the standards being classified as having a bacterial impairment.

Table 7 – Summary of MDH "Swimmable" Standards for Public Beaches & MPCA Standards for Bacterial Impairments

Water Quality Parameter	***Water Quality Limit***	***Source***
Fecal Coliform	200 fecal coliform/100mL (average of 5 samples in a 30-day period should not exceed)	MDH (http://www.health.state.mn.us/divs/eh/beaches/howsafe.html)
	1000 fecal coliform/100mL (no one sample should exceed)	
E. coli	126 *E. coli*/100mL (Geometric mean based on 5 samples in a month)	MPCA Impaired Waters Criteria
	1260 *E. coli*/100mL (maximum standard for one sample)	

Typical Rainwater/Stormwater Water Quality

Common pollutants in stormwater runoff include nutrients, sediments, heavy metals, salinity, pathogens, and hydrocarbons (EOR, 2011 (draft)). The Metropolitan Council *Stormwater Reuse Guide* includes several tables that summarize typical stormwater runoff quality information that are attached to the end of this memo and include the following:

- Table R.1b.1 Roof Runoff Water Quality
- Table R.1b.2 Typical Urban Stormwater Quality
- Table R.1b.3 Typical Urban Stormwater Quality by Landuse Type
- Table R.1b.4 Flow-Weighted Mean Snowmelt Water Quality

However, the fact that the water quality in stormwater runoff is highly variable due to differences in land use and from event to event is extremely important to emphasize and this variability should be considered when evaluating a stormwater harvesting and reuse system and determining what treatment might be necessary.

Additionally, many irrigation systems propose using stormwater directly out of wet retention ponds on the landscape. Although appropriately designed ponds can provide significant particle settling and removal, there is some uncertainty as to the expected level of pathogens within a stormwater pond. There was not specific data within the sources reviewed as part of the development of this memo outlining typical bacteria concentrations within stormwater ponds and information related to this would be useful. However, the Minnesota Stormwater Manual does summarize the expected removal efficiencies of wet ponds and stormwater wetlands for some of the more common contaminants in stormwater. These removal efficiencies are summarized in Table 8.

Table 8 - Summary of Pollutant Removal Efficiencies in Wet Stormwater Ponds/Stormwater Wetlands[a]

Parameter	*Wet Pond Removal Efficiency (%)*	*Stormwater Wetland Removal Efficiency (%)*
TSS	60-90	39-81
TP	34-73	20-54
TN	30	30
NO_3	N/A	N/A
Metals	60	60
Bacteria	70	70
Hydrocarbons	80	80

a – Source: Minnesota Stormwater Manual

General Components of a Stormwater Harvesting and Reuse System

In general, stormwater harvesting and reuse systems are typically comprised of several different components. These components include the collection and pretreatment system, the water storage units, the treatment devices, and the pumping and distribution system (Metropolitan Council, 2011).

The size of stormwater harvesting and reuse systems for irrigation can vary in scale ranging from small residential systems to large scale systems for irrigation. Additionally, reuse systems should be sized to handle peak usage conditions, not average conditions. Residential systems are typically simple systems that may only include primary screens to filter out debris and can have one to several rain barrels (often ranging from 50-100 gallons per barrel). Water collected in residential systems are often used to irrigate the landscaping or gardens on the residential parcel, either manually or via perforated hoses that slowly drain the barrels after each rain event, typically draining to pervious surfaces near the rain barrel system.

Larger scale irrigation systems are often designed to irrigate athletic fields, golf courses, parks, landscaping, community gardens, and supply water to various water features. These large scale irrigation systems are often much more complicated than residential systems used for irrigation.

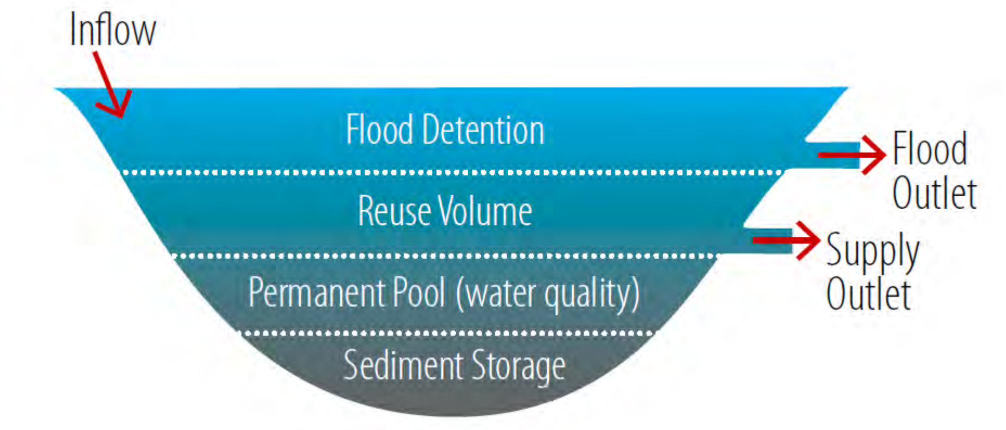
The following sections discuss the typical components of a stormwater reuse system in more details.

Collection and Pretreatment Systems

Stormwater can be collected off of a variety of surfaces including roofs, driveways, sidewalks and trails, parking lots, and streets as well as any runoff generated on pervious surfaces in the catchment area. The collection system can include many of the components typically used in stormwater collection systems, such as gutters, catch basins, storm sewers, underground drains, and other stormwater BMPs. While rainwater (from rooftops) typically has less pollutants and particulates than stormwater, stormwater can be pretreated to improve water quality prior to entering the storage unit (EOR, 2011 (draft)). Therefore, the collection system may also include first flush diversions or other pretreatment systems such as screening or filtration to remove some of the larger particulate load from the runoff to reduce maintenance on the system, to reduce build-up of material in the storage unit, to protect downstream equipment, and to reduce the potential for odors and/or algal blooms.

Stormwater Storage Systems

The second component of a stormwater harvesting and reuse system is the storage units used to collect and store the stormwater runoff prior to reuse. Stormwater storage can be above ground or below ground and can be constructed out of a variety of materials that typically include metal, polypropylene, polyethylene (and steel reinforced polyethylene), plastic, metal, fiberglass, and concrete. In addition to these engineered structures, stormwater may also be reused from stormwater retention ponds or stormwater wetlands that also provide some pretreatment (via settling and biological activity) of the stormwater runoff prior to reuse. When considering utilizing a pond for stormwater reuse, the pond should typically provide sufficient storage for sediment, the water quality treatment volume, the reuse volume, and the flood pool volume (Metropolitan Council, 2011). Figure 1 shows a schematic of an example of a stormwater pond designed specifically for stormwater reuse, including the water quality treatment volume to promote settling. Alternatively, in some situations existing stormwater ponds are being utilized as sources of irrigation water, using a portion of the water quality volume as a source for irrigation water. Regardless of the type of storage selected, the ability to fully access the storage for maintenance is important (Contech, 2012).



Source: Metropolitan Council Stormwater Reuse Guide

Figure 1 – Example of a stormwater pond designed specifically for stormwater reuse

Treatment Devices

The third component of a stormwater harvesting and reuse system is the treatment devices. The type of treatment required is typically dependent on the source of the runoff (and the expected water quality), the end use of the harvested stormwater, and public/human access to the end use and application. In general, the goals of treatment include:

- removal of sediments and particulate to prevent clogging of the distribution and end use equipment,
- prevention of soluble constituents from causing problems (e.g., precipitants that clog system, biofilms from clogging system, toxicity to soils, plants, aquatic plants and animals, corrosion of reuse system equipment or end use facilities),
- removal of organic matter and nutrients from storage systems to avoid odors and pollutant release from sediments in anaerobic conditions and avoid algal blooms that can clog equipment, and
- destruction of pathogens that can affect human health.

This treatment can include varying levels of filtration (for removal of debris, suspended and colloidal solids, residual suspended solids, residual colloidal solids, dissolved solids, residual and specific trace constituents) and disinfection (ultraviolet radiation, chlorination, and ozone). Many of the typical filtration methods can filter out particle sizes greater than 5 microns to 500 microns, depending on the type of filter selected and the level of treatment required (Contech, 2012). Common filtration methods include mechanical sand or disc filtration, in-pipe treatment filtration, cartridge and bag filters, filter screens, and sediment tanks. Ultraviolet (UV) disinfection is the most practical and commonly used disinfection techniques for small- to medium-sized systems, while chlorination can be more common in larger systems (Australia, 2009).

Pumping and Distribution System

The final component of the stormwater harvesting and reuse system includes the pumping and distribution system. Typically, the pumping system is set-up in conjunction with the treatment system. Additionally, the type and requirements for the distribution system are dependent on the end use of the stormwater. Often when designing stormwater harvesting and reuse systems as a means of runoff reduction, there is need for a back-up supply of water for essential applications (Contech, 2012).

There are a variety of irrigation distribution systems. Each type of irrigation system has different potential for public exposure to the water used for irrigation and may impact the required water quality standards for the reused water to be utilized. Systems often used for urban irrigation include:

- Drip, or trickle, irrigation is a method if localized irrigation that allows for water to drip slowly to the roots of plans. This irrigation occurs either at the surface or subsurface, where it is directly to the root zone. This system is comprised of emitters to distribute water either along the length of the line or at point emitters along the distribution line. These systems allows for efficient use of water as well as safe use of non-potable water. However, these systems typically require sufficient filtering of the water as they can easily become clogged with soil and sediment particles, algae, or mineral precipitates (NDSU, 2003).
- Bubble irrigation is a method of localized irrigation that discharges water out of the emitter in an umbrella pattern on a plant by plant basis. These systems allows for efficient use of water as well as safe use of non-potable water. However, these systems typically require sufficient

filtering of the water as they can easily become clogged with soil and sediment particles, algae, or mineral precipitates (NDSU, 2003).

- Spray, or micro-sprinkle, irrigation is a method of localized irrigation that have emitters that are often referred to as spray heads that spray water into the air in predetermined patterns (NDSU, 2003). These sprinkler systems can cover larger areas with fewer emitter heads that would be required by drip or bubble irrigation systems. Because these systems spray water into the air, there is more potential impact on the public health. Additionally, these systems typically require sufficient filtering of the water as the emitter heads can easily become clogged with soil and sediment particles, algae, or mineral precipitates (NDSU, 2003).
- Sub-Irrigation, also known as seepage irrigation, is a system of irrigation where by water is delivered to the plant from below the surface. This type of irrigation is common in some agriculture as well as commercial green houses.

Stormwater Reuse For Irrigation - Preliminary Modeling Analysis

The following section summarizes the preliminary modeling analysis that was performed as part of this work task to begin understanding the potential impact of stormwater reuse for irrigation on annual volume and pollutant load reductions. First, general considerations impacting irrigation in the state of Minnesota, with the focus being on irrigation of turf and landscaping areas (non-agricultural applications), are discussed. Then the modeling methodology used to evaluate the impact of stormwater reuse on annual volume and pollutant load reductions as well as the preliminary results of this analysis is discussed.

Landscape and Turf Irrigation Use Rates in Minnesota

Although the state of Minnesota has abundant water, there are times when the demand for water exceeds the supply(UMN Extension, 2009). As previously noted, , as much as 50% of potable water supply is used for outdoor, non-potable uses in Minnesota during the summer. During hot weather and extended periods of drought, Twin Cities' property owners will use 45 to 120 gallons of treated drinking water per person per day for outdoor uses with peak usage on large lots and new turf reaching as much as 200 gallons per person per day (Metropolitan Council, 2011).

Exactly how much water is required for irrigation is dependent on many factors. These factors include the amount of precipitation and the potential evapotranspiration. The potential evapotranspiration is the amount of water that could be evaporated from the land, water, and plant sources if soil water were in unlimited supply and is a function of the soil moisture, daily available sunlight, and air temperature (EOR, 2011 (draft)).

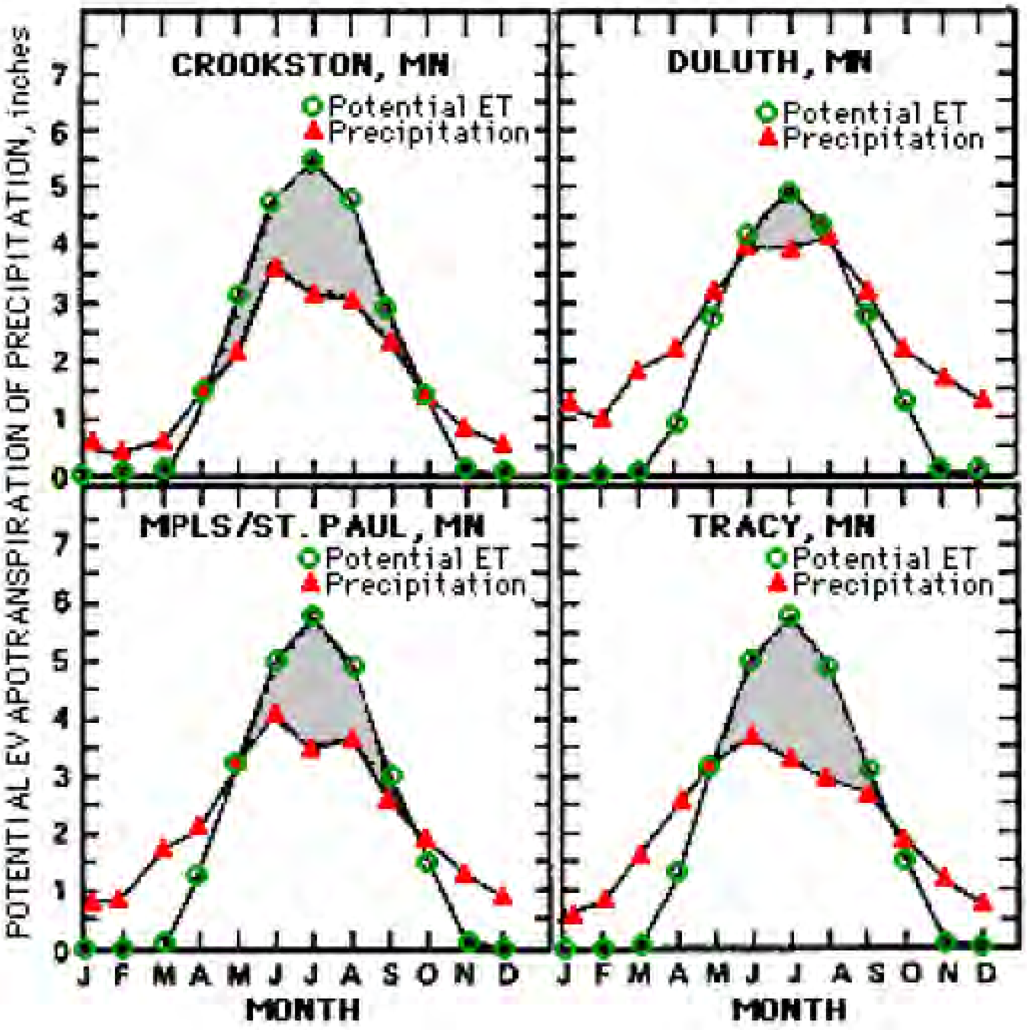
The University of Wisconsin (UW) Agriculture Extension Service has estimated potential evapotranspiration based on satellite derived measurements of solar radiation and air temperatures at regional airports using the UW Soil Science model. Table 9 summarizes the estimated potential evapotranspiration for Minneapolis-St. Paul from 2001-2010 based on the UW model.

Table 9 - Potential evapotranspiration for Minneapolis-St. Paul from 2001-2010[a]

Year	Mean Potential Evapotranspiration (in/d)	Maximum Potential Evapotranspiration (in/d)	Standard Deviation Potential Evapotranspiration (in/d)
2001	0.17	0.31	0.07
2002	0.18	0.33	0.06
2003	0.16	0.29	0.07
2004	0.14	0.28	0.06
2005	0.16	0.29	0.07
2006	0.16	0.30	0.07
2007	0.17	0.29	0.06
2008	0.17	0.28	0.06
2009	0.16	0.32	0.05
2010	0.16	0.29	0.07
Avg (2001-2010)	**0.16**	**0.30**	**0.06**

a – Source: EOR, 2011 (draft) based on Bland and Diak, 2011

Figure 2 compares the monthly average rainfall with the average potential evapotranspiration (i.e., the sum of evaporation and plant transpiration from the surface to the atmosphere) for several locations within Minnesota. Periods when the potential evapotranspiration is greater than the average precipitation indicate periods of the year when irrigation may be necessary. These periods are indicated by the gray areas in Figure 2. The periods where irrigation may be necessary typically fall within the period from May through September; however, because of the geographic variation in climate, the expected irrigation periods vary across the state (UMN Extension, 2009).



Source: University of Minnesota - Extension

Figure 2 – Average monthly evapotranspiration and precipitation values for four sites in Minnesota. Shaded area indicates time when rainfall needs to be supplemented by irrigation. Evapotranspiration values were determined using the method by C.W. Thornthwalte.

The amount of water that needs to be applied during irrigation depends on the soil type and wetness of the soil. However, typical irrigation depths for turf and landscaping in Minnesota range from 1 to 1.5 inches (minus any rainfall received) per week (UMN Extension, 2009). Additionally, the frequency of watering can be highly variable and is affected by the plant species, soil texture, climate, exposure, and intensity of use (UMN Extension, 2009). There is also variability based on the season. In the spring and summer, plants only require 40-60% of evapotranspiration, while in mid-summer, turfgrass can require up to 100% of evapotranspiration (EOR, 2011 (draft)). Because of this variability in the supply and demand of water for irrigation, stormwater reuse systems for irrigation typically require a potable water back-up supply as well.

Transpiration (water use) by urban trees can also vary by type of tree. Peters *et al.* (2010) found that water use by evergreens was greater than deciduous trees because they transpire more water and have a longer growing season. For example, transpiration from an evergreen can be on the order of 0.075 inches/day/meter^2 of canopy, while for deciduous trees, the transpiration is on the order of 0.044 inches/day/meter^2 of canopy (EOR, 2011 (draft)).

When utilizing stormwater for irrigation as a means of managing stormwater for volume reduction and/or water quality improvements, the approach to the application of the irrigation water will likely vary from typical irrigation methods with the goal of the reuse being to maximize the saturation of the soil without limiting plant growth (EOR, 2011 (draft)). Additionally, because there is typically elevated levels of pollutants in stormwater runoff (e.g., nutrients, sediments, heavy metals, hydrocarbons, chlorides, and pathogens), there are not only human health concerns related to the potential exposure to pathogens but also on the impact of these increased pollutant loads on plants. Therefore, if possible, the plants selected for a stormwater irrigation system should have both high water logging and pollutant tolerance.

Stormwater Reuse for Irrigation Modeling Methodology

P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) is a computer model used for predicting the generation and transport of stormwater runoff and pollutants in urban watersheds. Barr used the P8 model, Version 3.4, in this analysis to simulate the stormwater runoff and phosphorus loads generated from hypothetical development sites with varying levels of imperviousness to represent variation in typical development density. The model requires user input for watershed characteristics, local precipitation and temperature, and other parameters relating to water quality and BMP pollutant removal performances.

Barr then utilized a daily water balance spreadsheet model of the runoff water and pollutant loads generated by the P8 model to estimate the potential impact of stormwater reuse for irrigation on runoff volume reduction, and, ultimately, the pollutant load reduction.

P8 Watershed Modeling

The P8 analysis evaluated runoff from several hypothetical 10-acre development scenarios with varying levels of imperviousness. Twenty hypothetical watersheds were included in the P8 modeling analysis, including

1) A soils with 10% imperviousness,
2) A soils with 30% imperviousness,
3) A soils with 50% imperviousness,
4) A soils with 70% imperviousness,
5) A soils with 90% imperviousness,
6) B soils with 10% imperviousness,
7) B soils with 30% imperviousness,
8) B soils with 50% imperviousness,
9) B soils with 70% imperviousness,
10) B soils with 90% imperviousness,
11) C soils with 10% imperviousness,
12) C soils with 30% imperviousness,
13) C soils with 50% imperviousness,
14) C soils with 70% imperviousness,
15) C soils with 90% imperviousness,
16) D soils with 10% imperviousness,
17) D soils with 30% imperviousness,
18) D soils with 50% imperviousness,
19) D soils with 70% imperviousness, and
20) D soils with 90% imperviousness.

Watershed runoff volumes from pervious areas were computed in P8 using the SCS Curve Number method. Pervious curve numbers were selected for each hypothetical watershed based on soil type and an assumption that the pervious areas within the hypothetical development would be open space areas in fair to good condition. References on SCS curve numbers provide a range of curve numbers that would apply to pervious areas in fair to good condition. Pervious curve numbers of 39, 65, 74, and 80 were used for hydrologic soil groups A, B, C, and D, respectively.

Depression storage represents the initial loss caused by such things as surface ponding, surface wetting, and interception. As previously discussed, the P8 model utilizes the SCS Curve Number method to estimate runoff from pervious areas. For impervious areas, runoff begins once the cumulative storm rainfall exceeds the specified impervious depression storage, with the runoff rate equal to the rainfall intensity. An impervious depression storage value of 0.06 inches was used for the P8 simulation.

The P8 model requires hourly precipitation and daily temperature data; long-term data was used so that watersheds and BMPs can be evaluated for varying hydrologic conditions. The hourly precipitation and average daily temperature data were obtained from the National Weather Service site at the Minneapolis-St. Paul International Airport. The simulation period used for the P8 analysis was January 1, 1955 through December 31, 2004 (50 years).

For the P8 analysis, the 50-year hourly dataset was modified to exclude the July 23-24, 1987 "super storm" event, in which 10 inches of rainfall fell in 6 hours. This storm event was excluded because of its extreme nature and the resulting skew on the pollutant loading and removal predictions. Excluding the July 23-24, 1987 "super storm", the average annual precipitation throughout the 50-year period used for the P8 modeling was 27.7 inches.

The NURP50.PAR particle file was used for the P8 model. The NURP 50 particle file represents typical concentrations and the distribution of particle settling velocities for a number of stormwater pollutants. The component concentrations in the NURP 50 file were calibrated to the 50th percentile (median) values compiled in the EPA's Nationwide Urban Runoff Program (NURP).

There are numerous additional input parameters that can be adjusted in the P8 model. Several of the parameters related to simulation of snowmelt and runoff are summarized below:

- Minimum Inter-Event Time (Hours) = 10. P8 summarizes results in a series of discrete events. The minimum inter-event time is equals the minimum number of consecutive dry hours which must occur before a new storm event is initiated. This parameter influences event-based model output, but will not impact overall mass balance or load reductions.

- Snowmelt Factors—Melt Coefficient (Inches/Day-Deg-F) = 0.06. The rate of snowmelt is governed in P8 by the SCS degree-day equation, in which the snowmelt (inches/day) is a product of the melt coefficient and the difference between the observed daily mean temperature and the specified melt temperature (32 degrees F).

- Snowmelt Factors— Scale Factor For Max Abstraction = 1. This factor controls the quantity of snowmelt runoff from pervious areas by adjusting the maximum abstraction used with the SCS Curve Number method (i.e., controls losses due to infiltration). With a scale factor of 1

(P8 default), the maximum abstraction is unmodified during snowmelt or frozen ground conditions.

- Snowmelt Factors— Soil Freeze Temperature (Deg-F) = 32. This temperature setting can be adjusted to control the rate of runoff from pervious areas when the soil is likely to be frozen. At the start of each precipitation or snowmelt event, if the 5-day-average antecedent air temperature is below the soil freeze temperature, the pervious curve number will be modified to reflect Antecedent Moisture Condition (AMC) III and the Maximum Abstraction scale factor will be applied.
- Runoff Factors- 5-day Antecedent Rainfall and Snowmelt (inches): Growing Season AMC-II = 1.4 and AMC-III = 2.1 (P8 defaults), Non-growing Season AMC-II = 0.5 and AMC-III = 1.1 (P8 defaults). These input parameters allow the model to make curve number adjustments based on antecedent moisture conditions.

Daily Mass Balance/Volume Reduction Modeling

A daily spreadsheet mass balance model was developed to estimate the expected annual stormwater runoff volume reduction due to reuse of stormwater for irrigation. We assumed that the annual pollutant reduction would be equivalent to the estimated annual volume reduction as the result of stormwater reuse for irrigation.

There are a variety of parameters that can influence the annual stormwater runoff reduction due to stormwater collection and reuse for irrigation. These parameters include:

- Watershed Characteristics: Area, Imperviousness, Soil type
- Volume for reuse storage
- Available application area for irrigation
- Irrigation rate
- Irrigation period

To begin understanding the range in the potential impact of stormwater reuse for irrigation on stormwater runoff volume and pollutant removal, we ran a variety of reuse scenarios for each of the twenty watershed conditions. The daily mass balance modeling for the stormwater reuse was evaluated for the same period that was run in the P8 analysis, from January 1, 1955 through December 31, 2004 (50 years). The following is a summary of the assumptions used in the preliminary mass balance modeling analysis to develop the range in the potential impact of stormwater reuse for irrigation.

As previously mentioned, to generate the watershed runoff loads, the P8 model was used, evaluating 20 different 10-acre development scenarios, varying the imperviousness and soil types. A variety of potential application areas for irrigation were evaluated, ranging from 1% of the hypothetical watershed area (0.1 acre) to three (3) times the watershed area (30 acres). For the preliminary model runs, we assumed that the irrigation use rate was equivalent to 1 inch per week (or 0.14 inches per day) over the application area during the irrigation season and that the storage volume for stormwater (for irrigation) was equivalent to the one week demand for irrigation water. For the preliminary model runs, we assumed irrigation would begin in May and continue through the end of September and that irrigation would occur at a rate of 0.14 inches per day during that period, regardless of the amount of precipitation.

On a daily time step for the 50-year period that was evaluated in P8, the mass balance model tracked the available storage volume in the stormwater reuse system at the beginning of the day, the volume of watershed runoff (as generated by P8), the amount of watershed runoff that would bypass the system (due to storage not being available), the irrigation volume (if applicable and available), and the storage volume remaining in the stormwater reuse system at the end of the day. The estimated annual volume reduction (and equivalent pollutant reduction) was determined based on comparison of the average annual volume used for irrigation with the average annual watershed runoff volume.

Estimated Impact of Stormwater Reuse for Irrigation

The results of the long-term continuous simulation P8 and daily mass balance modeling analyses are presented in the following section.

Table 10 summarizes the average annual watershed runoff volumes from the hypothetical 10-acre watersheds along with the range of average annual runoff volume reduction based on reuse for irrigation. Figures 3 through 9 show the estimated average annual runoff volume reductions due to irrigation for a range of soil types (HSG A through D) based on the modeling analysis for the Twin Cities region. The curves shown in the figures are based on a relationship between the estimated stormwater reuse storage volume and watershed area.

Based on the results summarized in the Table 10 and Figures 3 through 9, there is a significant amount of variability in the estimated average annual removal efficiencies related to stormwater reuse for irrigation, based on the sizing of the reuse storage, application area, the irrigation rate and irrigation period. Again, the average annual removals reflected in the set of curves (Figures 3 – 9) is based on the assumptions that the stormwater reuse storage volume is equivalent to the one week demand for irrigation water with an application rate of 1 inch per week over the application area for an irrigation period from May through September. Depending on the combinations of variables, the estimated annual volume reduction (and equivalent pollutant removal) can range from 1 to 98 percent.

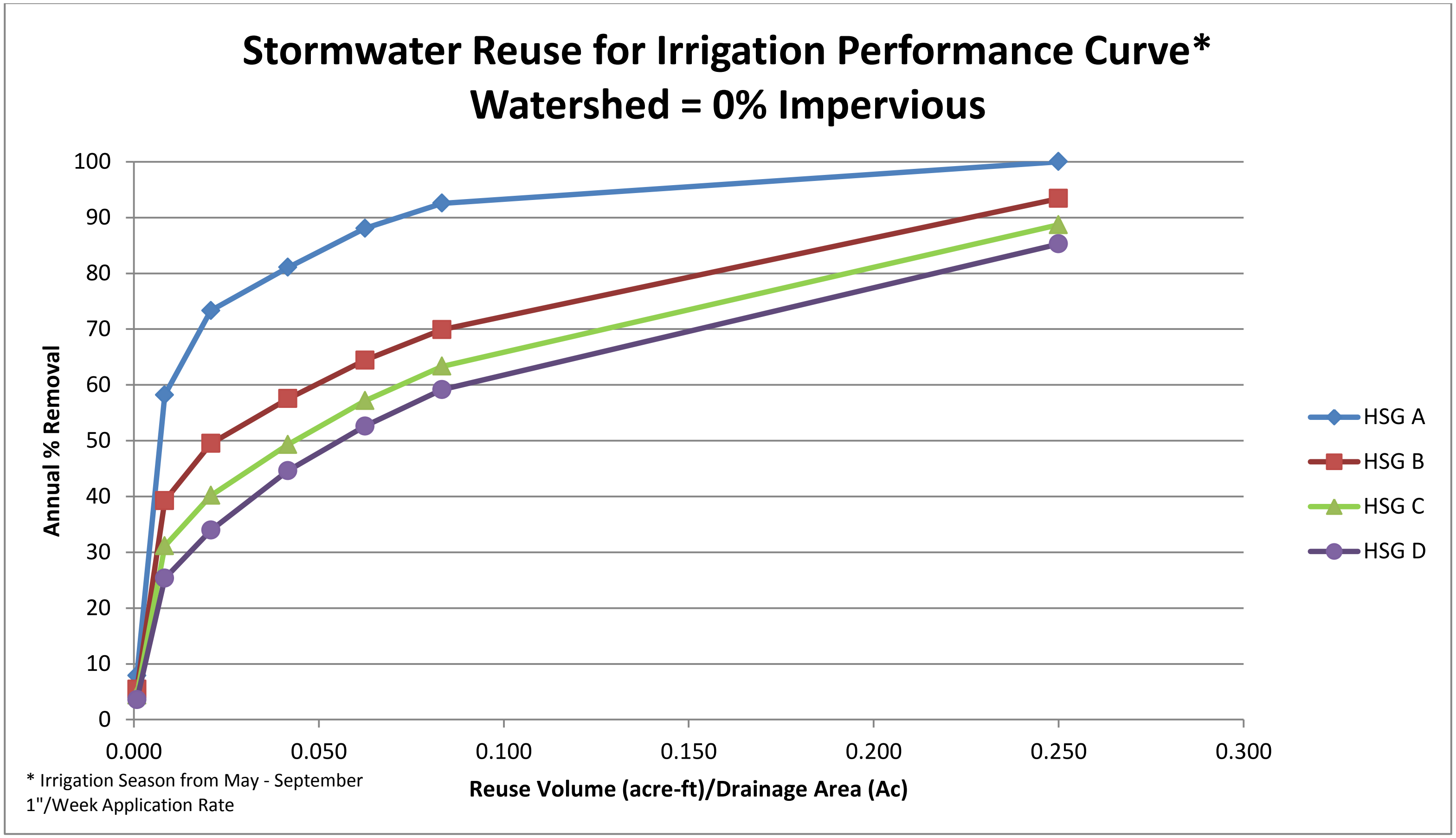
However, exactly how stormwater reuse for irrigation can be incorporated into a site design or retrofitted into an existing system will vary. In some cases, the application area available may control the sizing of the reuse storage. In other situations, there is sufficient application area but a limited watershed area to generate the runoff for reuse resulting in a smaller storage volume for reuse water. Spatial constraints on the site may limit the amount of storage volume that could be included into the site design and layout. Additionally, depending on the geographic location within the state, the current climate, and/or the type of plant species that are being irrigated, the application rate may be vary (0.5 – 2.0 inches per week) along with the irrigation period throughout the year. Currently, the set of curves developed from the preliminary modeling does not capture the potential variability in all these parameters (and resulting removal efficiencies).

Table 10 – Estimated Impact of Stormwater Reuse for Irrigation on Average Annual Runoff Reduction

Hydrologic Soil Group (HSG)	Watershed Area	Watershed Imperviousness	Average Annual Runoff Volume[1]	Range of Average Annual Runoff Volume Reduction[2]	
	(acre)	(%)	(acre-ft)	(%)	
A	10	10	2.3	6.0	98.3
	10	30	6.2	2.2	93.6
	10	50	10.2	1.4	86.2
	10	70	14.1	1.0	80.6
	10	90	18.1	0.8	76.7
B	10	10	3.2	4.3	91.7
	10	30	6.9	2.0	88.2
	10	50	10.7	1.3	83.3
	10	70	14.4	1.0	79.3
	10	90	18.2	0.8	76.4
C	10	10	3.9	3.5	87.6
	10	30	7.5	1.9	85.4
	10	50	11.1	1.3	81.8
	10	70	14.7	1.0	78.6
	10	90	18.3	0.8	76.2
D	10	10	4.7	2.9	84.6
	10	30	8.1	1.7	83.2
	10	50	11.5	1.2	80.5
	10	70	14.9	0.9	78.1
	10	90	18.4	0.8	76.0

1 - Based on 50-year P8 model run from January 1, 1955 through December 31, 2004 utilizing MSP climate data

2 - Assumes stormwater storage volume for reuse equivalent to the one week demand for irrigation water assuming an application rate of 1"/week over the application area & irrigation period from May through September


Stormwater Reuse for Irrigation Performance Curve*
Watershed = 0% Impervious

* Irrigation Season from May - September
1"/Week Application Rate

Figure 3 – Stormwater Reuse for Irrigation Performance Curve – Watershed 0% Impervious

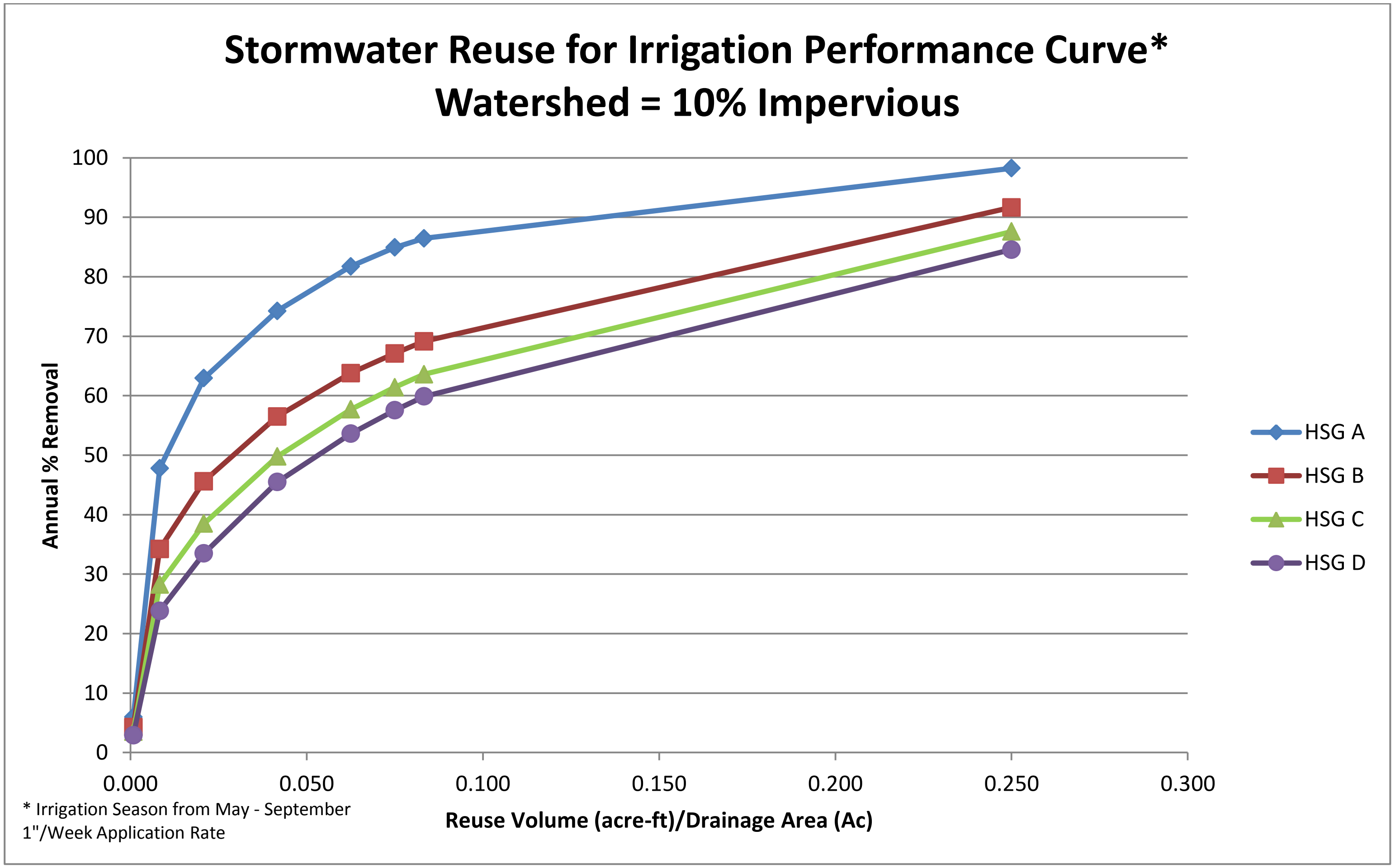
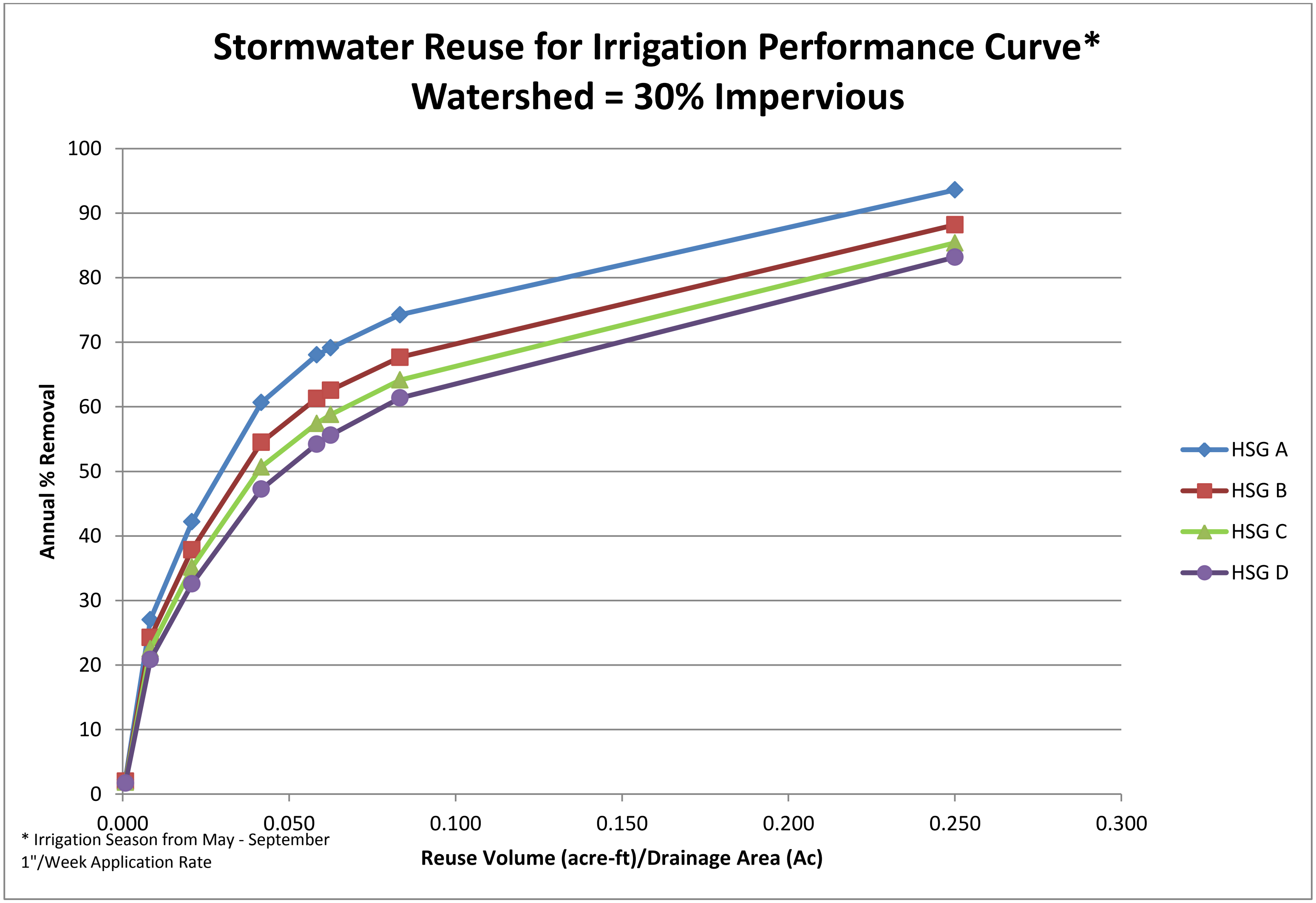


Figure 4 – Stormwater Reuse for Irrigation Performance Curve – Watershed 10% Impervious



* Irrigation Season from May - September
1"/Week Application Rate

Figure 5 – Stormwater Reuse for Irrigation Performance Curve – Watershed 30% Impervious

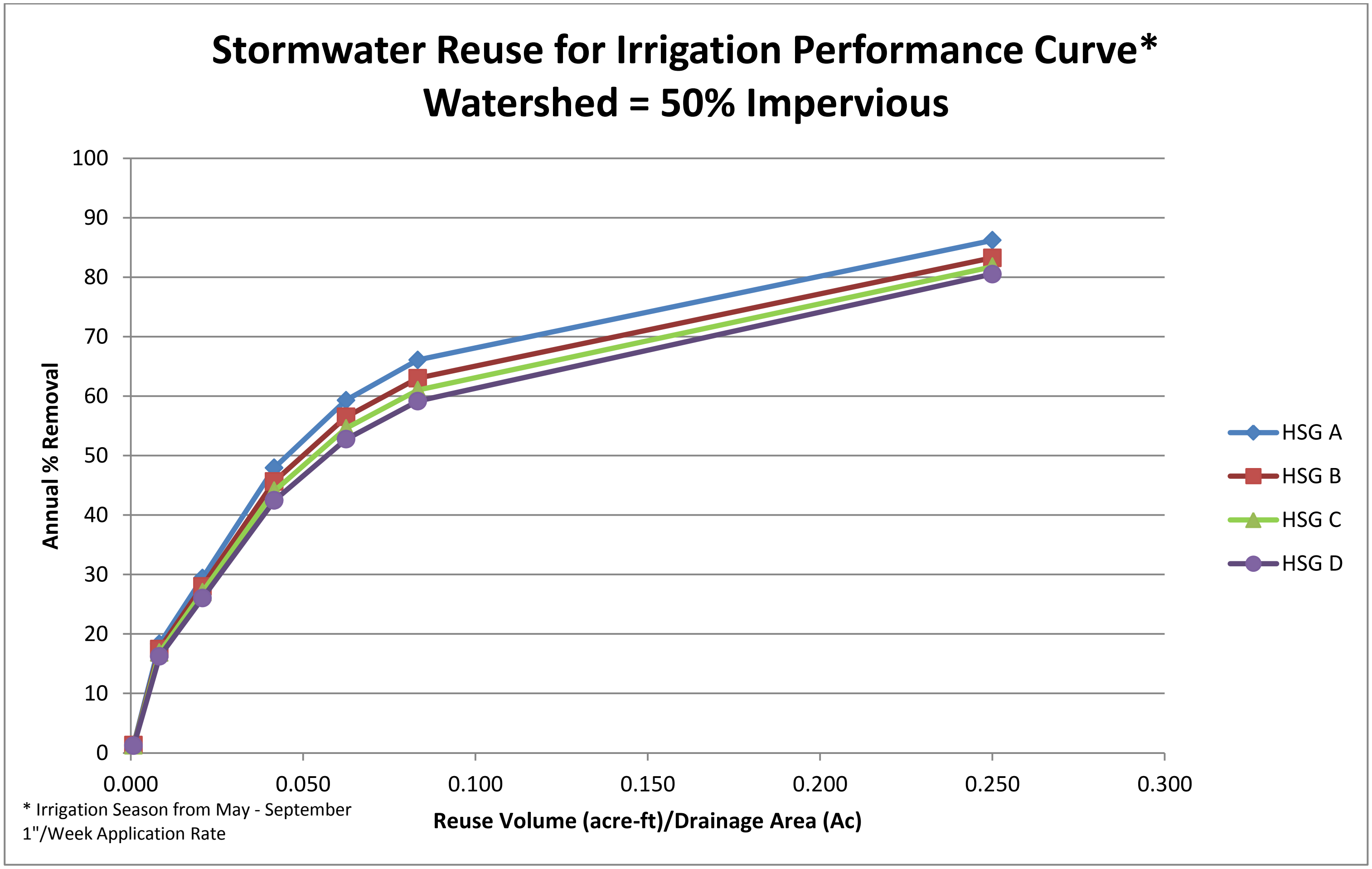
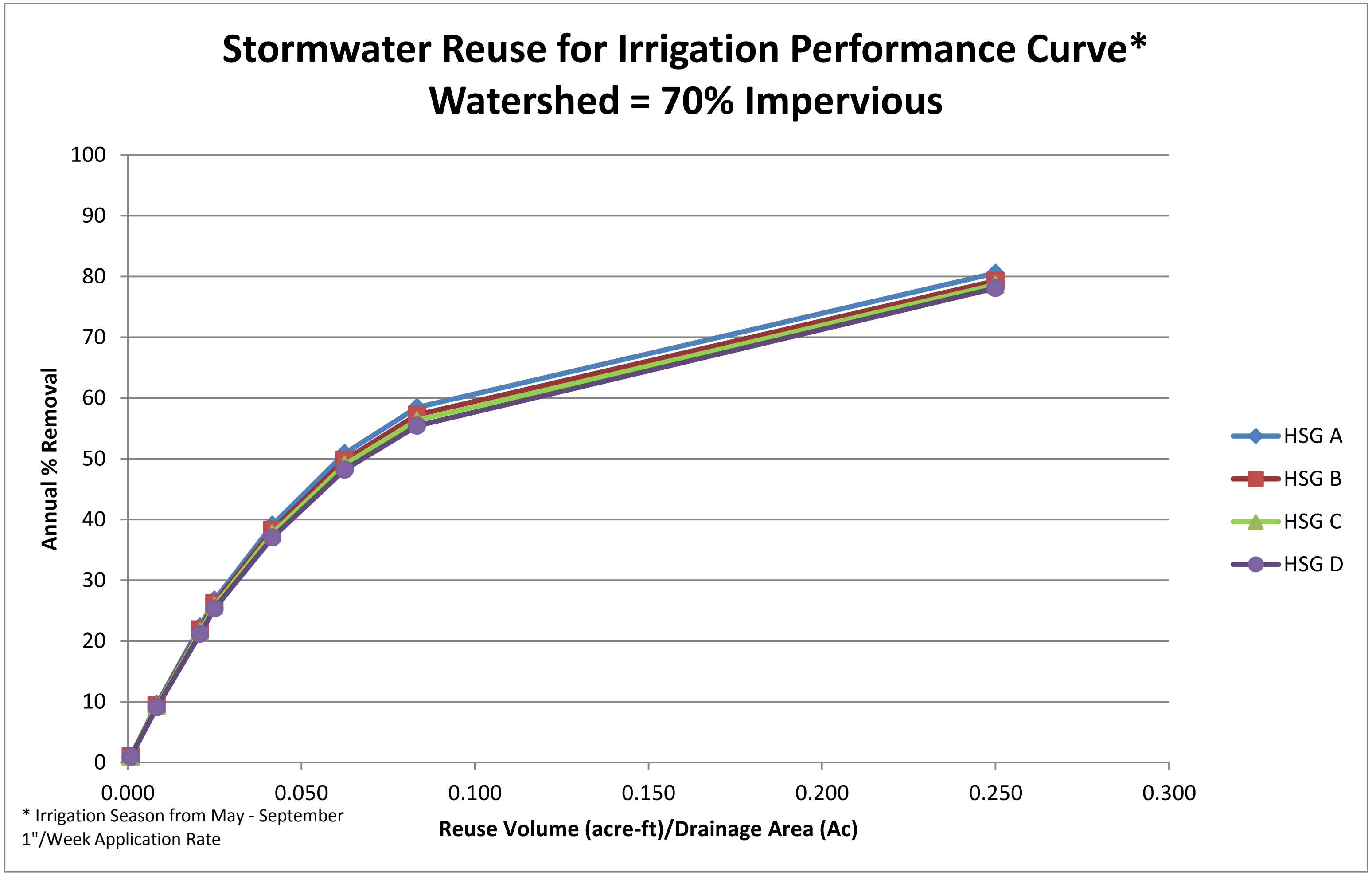


Figure 6 – Stormwater Reuse for Irrigation Performance Curve – Watershed 50% Impervious



* Irrigation Season from May - September
1"/Week Application Rate

Figure 7 – Stormwater Reuse for Irrigation Performance Curve – Watershed 70% Impervious

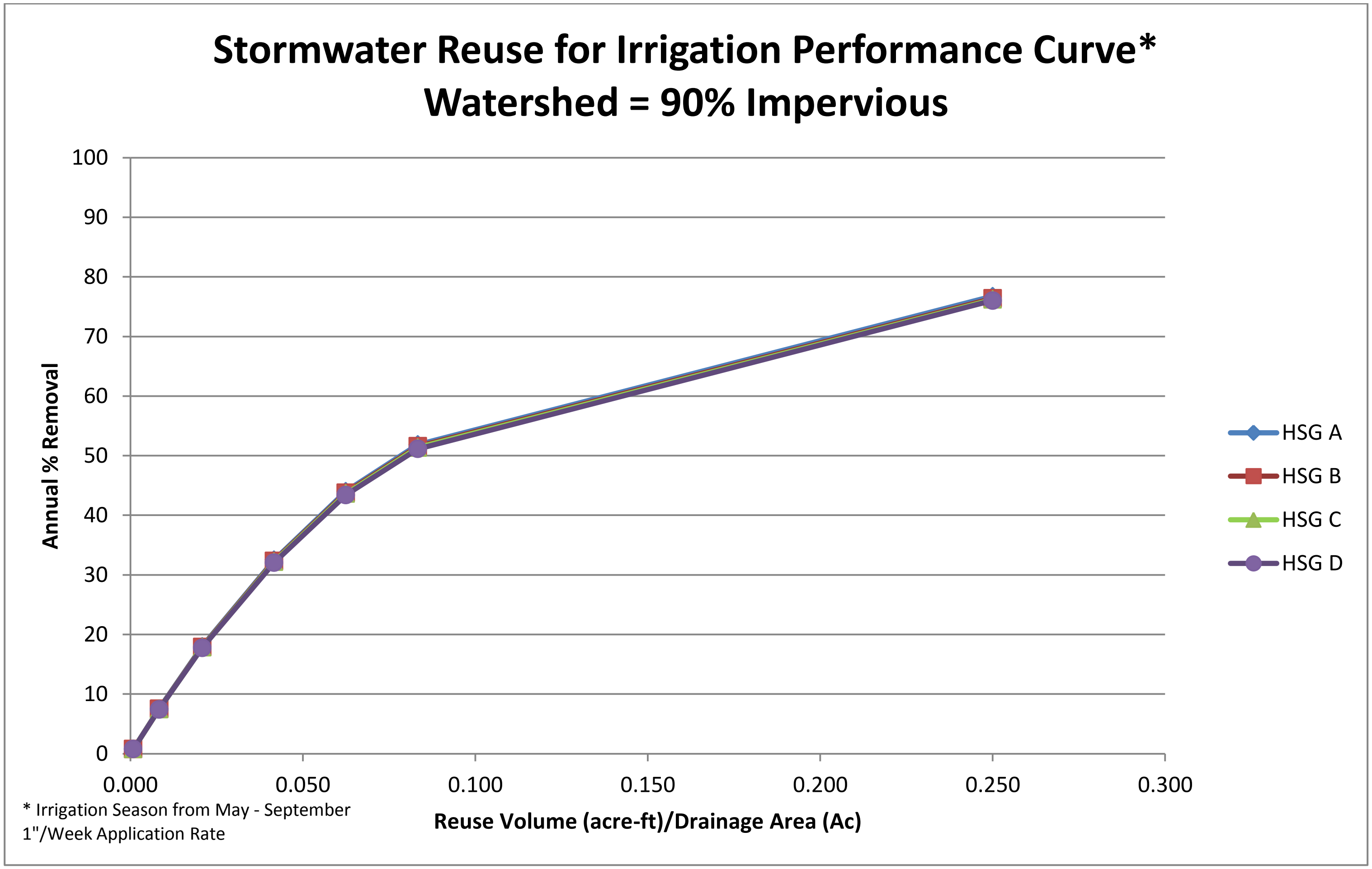


Figure 8 – Stormwater Reuse for Irrigation Performance Curve – Watershed 90% Impervious

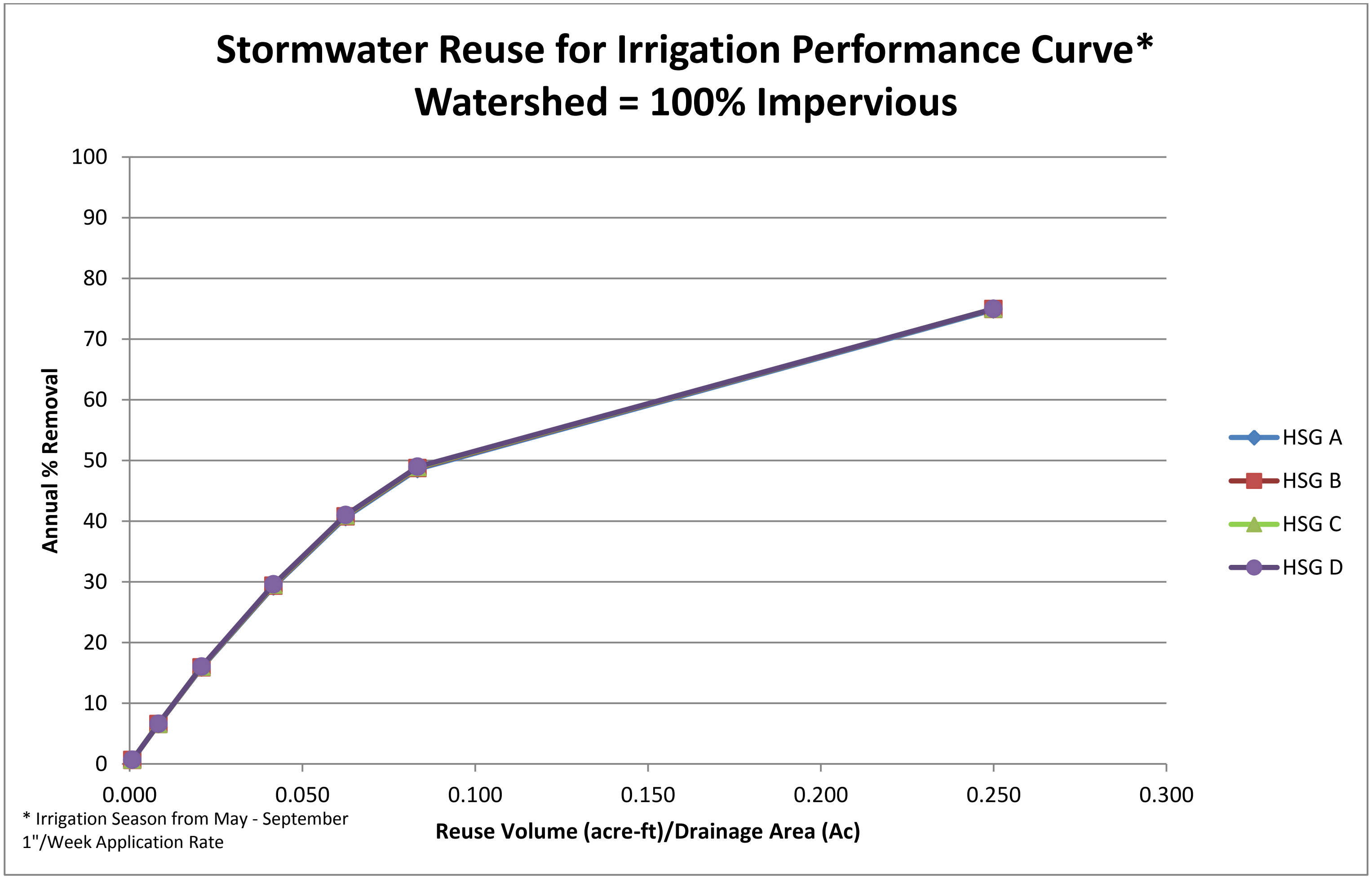


Figure 9 – Stormwater Reuse for Irrigation Performance Curve – Watershed 100% Impervious

Also, it is important to look at the relationship between all of these variables when designing a stormwater reuse system to optimize the sizing of the system for a specific site to maximize the cost-benefit of the system. For example, for a hypothetical 10-acre watershed at 50% impervious and B type soils, the average storm event runoff (based on the 50-year climatic period evaluated in P8) is 0.16 acre-feet. Assuming the stormwater reuse volume is sized to store the average event runoff from the watershed (and that there is sufficient application area to reuse the stormwater), this would result in an average annual reduction in stormwater runoff volumes of approximately 24%. Table 11 summarizes examples of the estimated runoff volume reduction for a stormwater reuse storage system sized for the average storm event runoff volumes for a hypothetical 10-acre watershed with type B soils. Table 12 summarizes the expected water quality treatment for the same examples, first considering stormwater reuse only and the second considering NURP pond treatment followed by reuse.

When considering stormwater reuse only, it may be possible to increase the reuse storage volume for the same watershed and application area to maximize the expected annual removal efficiency. For example, to achieve an 80% average annual removal efficiency for the same hypothetical watershed, the stormwater reuse volume would need to be increased to 2.5 acre-feet (more than 15 times the average event runoff volume) and would also need sufficient application area to reuse the stormwater within a week at an application rate of one (1) inch per week. This increase in storage volume means that for most storm events, the reuse storage system will remain nearly empty. Additionally, this increase in storage volume typically comes with an associated cost that may be prohibitive, unless the volume is associated with an existing pond that can be utilized for storage and reuse. All of these factors must be weighed when evaluating and optimizing a stormwater reuse system in the context of a specific site.

Table 11 – Examples of the Estimated Runoff Volume Reduction for a Stormwater Reuse Storage System Sized for the Average Storm Event Runoff Volume

Hydrologic Soil Group (HSG)	Watershed Area	Watershed Imperviousness	Average Storm Event Runoff Volume[1]	Average Annual Runoff Volume Reduction[2]
	(acre)	(%)	(acre-ft)	(%)
B	10	10	0.05	21.4
		30	0.10	26.4
		50	0.16	24.0
		70	0.21	21.9
		90	0.26	21.3

1 - Based on 50-year P8 model run from January 1, 1955 through December 31, 2004 utilizing MSP climate data

2 - Assumes stormwater storage volume for reuse equivalent to the average storm event runoff volume and that the application area is sufficient to handle an irrigation application rate of 1"/week over the application area & irrigation period from May through September

Table 12 – Examples of the Estimated Pollutant Load Reductions for a Stormwater Reuse Storage System Sized for the Average Storm Event Runoff Volume

Hydrologic Soil Group (HSG)	Watershed Area	Watershed Imperviousness	Average Annual Runoff Volume Reduction[1,2]	Average Annual TSS Reduction Reuse Only[3]	Average Annual TP Reduction Reuse Only[3]	Average Annual TSS Reduction NURP & Reuse[3,4]	Average Annual TP Reduction NURP & Reuse[3,4]
	(acre)	(%)	(%)	(%)	(%)	(%)	(%)
B	10	10	21.4	21.4	21.4	87.4	60.7
		30	26.4	26.4	26.4	88.2	63.2
		50	24.0	24.0	24.0	87.8	62.0
		70	21.9	21.9	21.9	87.5	61.0
		90	21.3	21.3	21.3	87.4	60.7

1 - Based on 50-year P8 model run from January 1, 1955 through December 31, 2004 utilizing MSP climate data

2 - Assumes stormwater storage volume for reuse equivalent to the average storm event runoff volume and that the application area is sufficient to handle an irrigation application rate of 1"/week over the application area & irrigation period from May through September

3 – Assumes pollutant removal equivalent to volume reduction for reuse only

4 - Assumes average annual NURP pond removal: TP=50%, TSS=84%

Conclusions and Suggestions for Future Work and Research Related to Stormwater Reuse for Irrigation

Currently in Minnesota, there is strong interest in and implementation of irrigation systems utilizing existing stormwater ponds to irrigate golf courses and athletic fields. Not only do these stormwater reuse systems reduce the demand on the potable water system, but in some situations they provide a viable means to meet local and state stormwater management standards and reduce pollutant loads. However, many of these systems are being implemented without review by state or local agencies as there is not well-defined jurisdiction or guidance related to these systems.

The demand to implement these stormwater reuse projects was the impetus for this specific MIDS work, which focused on stormwater reuse for irrigation to begin understanding the current jurisdiction (or lack of jurisdiction) that governs the stormwater reuse systems, the water quality guidance that applies to these systems, and the potential impact of stormwater reuse for irrigation as a means of managing runoff volumes and pollutant loads.

The following is a summary of suggestions for future work and research as it relates to stormwater reuse for irrigation (and potentially other uses).

Jurisdiction

Based on discussions with State of Minnesota agency staff (including DLI, MDH, MPCA, and MDNR), there are currently not well-defined roles or jurisdiction for each agency as they each relate to stormwater reuse systems for irrigation.

The first suggestion is to develop a workgroup with representatives of each state agency, including the DLI, the MDH, the MPCA, the MDNR and Minnesota Department of Agriculture (MDA), focusing on stormwater reuse to begin clarifying the roles and jurisdiction for each agency and any associated guidance. Table 13 summarizes a potential framework for a regulatory model has been proposed for non-potable water applications and currently lays out the following for each agency. This potential framework will help facilitate discussions surrounding stormwater reuse systems, jurisdiction of the various agencies, and potential guidance (water quality and treatment standards) for these systems. However, legislation would be required before the agencies would have the authority to implement the regulatory model.

Table 13 – Potential Regulatory Model for Alternate Sources of Water Usage[1]

Program Administration (MPCA)	Public Health (MDH)	Construction (DLI)	MDNR	MDA
Develop and maintain design guidelines for alternate source applications	Issue water quality treatment and monitoring requirements	Conduct plumbing plan review and issue plumbing permit	Water Appropriations Permits	
Review and approve alternate source nonpotable treatment systems	Assist in guideline development and maintenance	Inspect and approve plumbing installations		
Inspect systems on a regular basis and review water quality reporting	Review and approve alternate source potable treatment systems	Ensure cross-connection control		
Provide technical support and outreach to interested parties				
Administer project tracking and annual potable offset and energy savings achieved				

1 – Potential regulatory model provided by Anita Anderson, MDH after 12/3/2012 meeting

Water Quality Standards/Guidelines

The lack of national guidance related to the appropriate water quality standards related to stormwater reuse to protect the public health has resulted in differing use and treatment guidelines/standards among state and local governments. Additionally, the majority of the information available was original developed based on the reuse of reclaimed wastewater, rather than rainwater or stormwater. Although the general guidance for the reuse of rainwater and stormwater would be similar to reclaimed and graywater, it may also differ because of lower levels of initial contamination and the potential end uses (EPA, 2008).

In some situations, the current water quality guidance surrounding water reuse may require levels of treatment and/or disinfection that could result in significant increases in system costs that could discourage implementation of stormwater reuse projects for irrigation. The level of treatment required by each municipality can influence the number of harvesting and reuse systems that are actually implemented. Simplifying the treatment requirements when public health is not at risk can lower the project cost for those entities intending to install stormwater harvesting and reuse systems and encourages broader adoption of the practices.

We suggest the completion of health risk assessments of non-potable water sources (including stormwater) and the potential uses for these sources. Additionally, investigation into cases of human illness related to stormwater reuse systems could provide some insight into the public health risk associated with these systems. These assessments will help begin quantifying the actual health risks and to begin understanding if the current water quality guidelines are too stringent, appropriate, or not stringent enough and to help better define levels of required treatment. These assessments would eventually lead to the development of statewide water quality guidelines (or standards) and treatment requirements that would help guide the design of stormwater reuse systems (for irrigation and potentially other uses).

Research

Because one of the major demands for stormwater reuse systems is irrigation of golf courses and athletic fields from existing stormwater ponds, it is important to understand the actual water quality in stormwater ponds. Since the concern surrounding many of the stormwater reuse systems is related to the public exposure to pathogenic bacteria and the impact of suspended sediments and PAHs on the function of irrigation equipment, the initial focus could be on these parameters.

A comparison of the levels observed in actual stormwater ponds to current stormwater reuse water quality standards/guidelines help regulators begin understanding if additional treatment, such as filtration or disinfection, is needed for reuse systems utilizing water from stormwater ponds.

Additional Modeling Analysis

The preliminary modeling analysis performed as part of this MIDS work was to begin understanding the potential impact of stormwater reuse for irrigation as a means for meeting stormwater management requirements. The performance curves were developed based on specific assumptions related to the various parameters related to stormwater reuse systems for irrigation including:

- the irrigation use rate was equivalent to 1 inch per week (or 0.14 inches per day) over the application area,
- the irrigation season was from the beginning of May through the end of September, and
- the storage volume for stormwater (for irrigation) was equivalent to the one week demand for irrigation water (irrigation rate over the application area).

Therefore, these curves only apply to sites that would meet the specific assumptions that were included in the modeling analysis. However, in some cases, certain factors may influence the performance of the stormwater reuse system including the application area or the space available to incorporate storage for reuse, so the relationship between these different parameters will vary, impacting the expected performance. Additionally, the expected irrigation rate and irrigation period will influence the average annual removal efficiencies.

If the intent is to incorporate stormwater reuse for irrigation into the MIDS Calculator, additional modeling will be needed to develop a full range of performance curves related to cover the variety of potential site conditions and variability in watershed area, stormwater storage volume, application area for irrigation, irrigation rates, and irrigation periods.

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A guide for city planners, engineers, homeowners and green thinkers.

Fall 2011

Metropolitan Council

Stormwater Reuse
GUIDE

Table R.1a.1 Stormwater Constituents of Concern

Constituent	Basis of Concern Health	 Environmental	 Equipment
Microbiological			
E. Coli (#/100 mL)	x		
Fecal Coliform (#/100 mL)	x		
Total Coliform (#/100 mL)	x		
Physical/Chemical			
Biochemical Oxygen Demand (mg/L)	x	x	
Chemical Oxygen Demand (mg/L)	x	x	
Total Organic Carbon (mg/L)		x	
Total Suspended Solids (mg/L)	x	x	x
Volatile Suspended Solids (mg/L)	x	x	
Turbidity (NTU)	x	x	x
Total Dissolved Solids (mg/L)		x	x
Chlorides (mg/L)		x	x
Anions/Cations (mg/L)		x	x
Total Hardness (mg/L)			x
Free Chlorine (mg/L)	x		
pH		x	
Nutrients			
Total Kjeldahl Nitrogen (mg/L)	x	x	
Ammonia - N (mg/L)	x	x	
Nitrate - N (mg/L)	x	x	
Total Phosphorus (mg/L)	x	x	
Total Dissolved Phosphorus (mg/L)	x	x	
Soluble Reactive Phosphorus (mg/L)	x	x	

Table R.1a.1 lists the water quality constituents that should be investigated and the primary basis of concern for each.

What Levels of Pollutants Are a Concern?

The tremendous variability in the natural landscape, human and animal activity, weather, and other factors makes it difficult to generalize stormwater quality constituents. To provide some context for the concentration of constituents in stormwater, tables in **Tool R.1b** provide the potential range of concentrations and median values for a variety of constituents developed from different studies in the U.S. and Australia. **Table R.1b.1** presents water quality constituents for roof runoff and **Tables R.1b.2** and **R.1b.3** list ground runoff quality concentrations. **Table R.1b.4** characterizes several collection points for snowmelt. Concentration data presented in this tool refer to these tables and the cited references.

Microbiological

Stormwater can contain disease- or illness-causing microorganisms, commonly called pathogens, which pose a health concern for water uses with the potential for human contact. Microscopic parasites, bacteria, and viruses are found in animal and bird feces in the catchment area from which stormwater is collected, including roofs. Pathogens can also be found in stormwater that has received sanitary sewage resulting from an overflow of the sanitary sewer or a cross-connection. While there are no known reports of disease associated with stormwater reuse[3], understanding the potential occurrence of pathogens in stormwater and the risk of exposure to humans, should be an integral part of planning and designing a reuse system.

There are a number of pathogens that have been identified in stormwater, as listed in Table R.1a.2. Given the different types of pathogens and costs to analyze water for pathogens, detection is typically accomplished by measuring an indicator organism. For treated wastewater, the constituent usually measured is fecal coliform or Escheria coli (E. coli). For drinking water and reclaimed water (termed wastewater reuse in Minnesota), total coliform is the standard constituent for regulatory reporting. These bacterial indicators are important in assessing the performance of disinfection processes. Drinking water standards require no presence of indicator organisms.

Bacterial indicator organisms commonly occur in both roof and ground runoff, yet are typically less in rooftop runoff. A comparable monitoring study of urban areas in Australia showed that the log-normal mean concentration of total coliform for roof runoff (1,875 No./100ml) was only 2% of the ground runoff concentration (97,665 No./100ml)[3]. Studies in the U.S. indicate that geometric mean and median total coliform concentrations range from 10,000 – 175,000 No./100ml in total stormwater runoff[3,4,5,6,7] and were less than 1,000 No./100ml in a Minneapolis roof runoff study[8] (refer to Tool R1B - Tables R1B.1-Table R1B.4).

Physical/Chemical

There are a host of physical and chemical constituents that are indicative of health, and/or environmental concerns, or could be an issue for equipment performance in stormwater reuse systems. They can be grouped as solids, oxygen demanding substances, salts/inorganics and other constituents.

Table R.1a.1 Stormwater Constituents of Concern
(continued)

Constituent	Basis of Concern		
	Health	Environmental	Equipment
Metals			
Aluminum	*	X	
Arsenic	*	X	
Beryllium	*	X	
Boron	*	X	
Cadmium	*	X	
Chromium	*	X	
Cobalt	*	X	
Copper	*	X	
Fluoride	*	X	
Iron	*	X	
Lead	*	X	
Lithium	*	X	
Manganese	*	X	
Mercury	*	X	
Molybdenum	*	X	
Nickel	*	X	
Selenium	*	X	
Strontium	*	X	
Tin, Tungsten, & Titanium	*	X	
Vanadium	*	X	
Zinc	*	X	
Organics			
Oils & Greases	X	X	X
Organics (e.g. hydrocarbons, pesticides)	X	X	

* Health-based concern through uptake into crops irrigated with stormwater

Table R.1a.2 Types and Sources of Pathogens in Stormwater

Type of Pathogen	Organism	Source
Parasite	Giardia lamblia	cats and wild animals
	Cryptosporidium parvum	cats, birds, rodents, and reptiles
	Toxoplasma gondii	cats, birds, and rodents
Bacteria	Campylobacter spp.	birds and rats
	Salmonella spp.	cats, birds, rodents, and reptiles
	Leptospira spp.	mammals
	Escherichia coli	birds and mammals
Virus	Hantavirus spp.	rodents

Particulates in stormwater are measured by various constituents including total suspended solids (TSS) and turbidity. Solids in the stormwater may not be a direct health threat, but can harbor pathogens. Particulates carried through a stormwater reuse system can cause problems with pumps, clogging of pipes and irrigation nozzles, and related issues. High concentrations of suspended solids commonly are found in areas with excessive soil erosion and occur during high intensity storm events when larger volumes of water at higher velocities are able to carry heavier solids loads. Mean and median TSS concentrations were found to range from 100-184 mg/L in stormwater[3,4,5,6,7] and from 10-12 mg/L in roof runoff.[3,8,9]

The **organic content** of water presents a food source for organisms in the water that exert a demand for oxygen, measured by biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC). The higher the BOD, the more potential there is to deplete the water of oxygen or possibly result in removal of all oxygen (anaerobic conditions). For stormwater reuse, this becomes an issue in the storage of the stormwater supply, where anaerobic conditions lead to the release of hydrogen sulfide and other gases which produce odors and a corrosive environment. In addition, organic content in the water supports the growth of microorganisms and the potential for pathogens. The mean and median BOD concentrations in stormwater range from 10-55 mg/L and COD ranges from 60-170 mg/L.[3,4,5,6,7]

The **inorganic constituents** in stormwater have not been studied in much detail. Chlorides and other salts are being evaluated in stormwater and the receiving streams of Minnesota. Chlorides and the use of road salt for winter de-icing has commonly been known to destroy vegetation in the areas of application and runoff. Total dissolved solids, of which chloride is one component, is another measure of the salinity of the water. Many types of vegetation and specific turf grasses on golf courses are sensitive to high salt concentrations. Hardness is also a water quality characteristic important to consider with stormwater reuse. Hard water can lead to precipitates forming in pipes and clogging irrigation nozzles. It can also be a problem for non-irrigation uses such as for cooling water. Stormwater runoff for a variety of impervious surfaces was observed to have hardness range from 35-30 mg/L as CaCO3.[9]

Table R.3b.5 Recommended Limits for Constituents in Irrigation Water Supplies[1]

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Considerations
Aluminum	5	20	Can cause nonproductiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.1	2	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than 0.05 mg/L for rice.
Beryllium	0.1	0.5	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans.
Boron	0.75	2	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/L in nutrient solutions. Boron can be toxic to some plants at low concentrations.
Cadmium	0.01	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L. Conservative limits recommended.
Chromium	0.1	1	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5	Toxic to tomato plants at 0.1 mg/L. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5	Toxic to a number of plants at 0.1 to 1.0 mg/L.
Fluoride	1	15	Inactivated by neutral and alkaline soils.
Iron	5	20	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.
Lead	5	10	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at concentrations up to 5 mg/L; mobile in soil. Toxic to citrus at low concentrations - recommended limit is 0.075 mg/L.
Manganese	0.2	10	Toxic to a number of crops at a few-tenths to a few mg/L in acidic soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium.
Tin, Tungsten, & Titanium	-	-	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1	Toxic to many plants at relatively low concentrations.
Zinc	2	10	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.
pH	6	-	Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
Total Dissolved Solids (TDS)	500 - 2,000 mg/l	-	Below 500 mg/L, no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, can affect sensitive plants. At 1,000 to 2,000 mg/L, can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly only for tolerant plants on permeable soils.
Free Chlorine	<1 mg/l	-	Concentrations greater than 5 mg/l causes severe damage to most plants. Some sensitive plants may be damaged at levels as low as 0.05 mg/l.

[1] U.S. EPA, Guidelines for Water Reuse, 2004

Table R.3b.6

Typical Parameters and Limits of Concern Related to System Equipment Performance

Parameter	Limit of Concern	Issue
Debris and organic/soil particulates	*Not applicable*	Blocks or clogs equipment
Organic matter (measured as BOD, COD, TOC)	BOD>30 mg/L	Reduced dissolved oxygen levels through decomposition; results in odors and release of pollutants from sediments
Nitrogen and phosphorus	TP > 0.2 mg/L TKN varies with use	Supports algal growth in open storage facilities, which can lead to higher turbidity and/or create algal blooms with biofilm characteristics that can clog irrigation equipment
Iron	> 1.0 mg/L	Clogging of system, particularly irrigation equipment
Hardness	> 600 mg/L as $CaCO3$	Clogging of system, particularly irrigation equipment
Salts	Chlorides > 500 mg/L TDS > 500 mg/L	Causes corrosion of most metals
Hydrogen sulfide	> 10 mg/L	Gas released in anaerobic conditions that can corrode metal and concrete surfaces

Sources: USEPA, Guidelines for Water Reuse, 2004

Metcalf & Eddy, Water Reuse, Issues, Technologies, and Applications , 2007

Use Criteria Matrix

Identify the health and environmental/system criteria based on the type of water use.

Table R.3c.1 Use Criteria Matrix

Use/Application	Health Criteria*	Environmental / System Criteria
Residential/Commercial/Public Property Areas		
Landscape irrigation (cemeteries, freeway buffers, restricted golf courses and other controlled access areas) Utility washing (paths, fences, outdoor equipment/ areas)	Level 2	Salts, metals, nutrients, hardness *Refer to* **Table R.3b.5** *&* **Table R.3b.6**
Open access landscape irrigation (parks, athletic fields, unrestricted golf courses) Food garden watering Water features and systems (ponds, fountains, waterfalls) Within buildings (toilet flushing) Vehicle washing	Level 3	Salts, metals, nutrients, organic toxics, hardness *Refer to* **Table R.3b.5** *&* **Table R.3b.6**
Municipal Uses		
Street cleaning Roadmaking and dust control Equipment and structure washing Fire protection	Level 2	Salts, metals *Refer to* **Table R.3b.6**
Sanitary sewer flushing	Level 1	---
Commercial Uses		
Nurseries, sod farms, tree farms Pasture	Level 1 & 2	Crop dependent *Refer to* **Table R.3b.5**
Orchards, vegetables/fruit	Level 2 & 3	Crop dependent *Refer to* **Table R.3b.5**
Industrial Uses		
Cooling water Process water Washdown water	Level 2 & 3	Industry specific requirements *Refer to* **Table R.3b.6**, **Table R.3b.7** & **R.3b.8**

*Definitions on following table, Table R.3c.2

Table R.3c.2 Use Criteria Matrix Health Criteria Definitions

Health Criteria Definitions (Based on California Title 22, State of California, 2000)	**Total Coliform Limit (No./100ml)**	**Sampling Basis[1]**	**Treatment Process Requirements [2]**
Level 1			
■ Provides a supply for use with limited human exposure ■ The supply is from a protected source and storage system where there is limited exposure to pathogens or conditions for biological growth	*None required*	*None required*	■ Screening[3]
Level 2			
■ Provides a supply that meets the California Recycling Criteria (State of California, 2000) for a secondary-23[5] recycled water	<23	Running 7-day median	■ Screening[3] ■ Disinfection
■ Provides a supply for use with controlled access and limited human contact	<240	Maximum in 30 days	
Level 3			
■ Provides a supply that meets the California Recycling Criteria (State of California, 2000) for a tertiary recycled water	<2.2	Running 7-day median	■ Screening[3] ■ Chemical Addition[4] ■ Filtration ■ Disinfection
■ Provides a supply for use with uncontrolled access and potential for human contact	<23	Maximum in 30 days	

[1] Daily sampling during period of use (State of California, Water Recycling Criteria, 2000).

[2] Assumes water does not contain oxygen demanding constituent; otherwise may need to remove constituent through oxidation or other process.

[3] Assumes use of a first-flush diverter and other pretreatment processes to minimize pollutants from initial part of storm events.

[4] Chemical addition, coagulation, and clarification may be required for some applications and water quality characteristics.

[5] Defined in California Rule 60301.225 as recycled water that meets 23/100 ml coliform limit.

Reference: State of California. Water Recycling Criteria, 2000

Stormwater Quality Data Tables

Table R.1b.1 Typical Roof Runoff Quality

	Constituent Concentration		
Constituent	**Minneapolis [1]**	**Australia [2]**	**Wisconsin [3]**
E-Coli (#/100 mL)	764	671	--
Fecal Coliform (#/100 mL)	--	93	--
Total Coliform (#/100 mL)	--	1875	--
Biochemical Oxygen Demand (mg/L)	--	--	--
Chemical Oxygen Demand (mg/L)	--	--	--
Total Solids (mg/L)	--	--	126
Suspended Solids (mg/L)	10	17.7	19
Turbidity (NTU)	--	2.48	--
Total Hardness (mg/L)	--	--	44
pH	--	6.42	--
Total Nitrogen (mg/L)	0.421	1.53	--
Ammonia - N (mg/L)	0.268	--	--
Nitrate - N (mg/L)	0.586	--	--
Total Phosphorus (mg/L)	0.104	0.122	0.24
Total Dissolved Phosphorus (mg/L)	0.076	--	0.11
Soluble Reactive Phosphorus (mg/L)	0.065	--	--
Arsenic (mg/L)	--	0.005	--
Cadmium (mg/L)	--	0.0005	0.0004
Chromium (mg/L)	--	0.012	--
Copper (mg/L)	0.0075	0.185	0.01
Iron (mg/L)	--	0.115	--
Lead (mg/L)	0.0032	0.079	0.01
Nickel (mg/L)	--	0.016	--
Strontium (mg/L)	--	0.017	--
Zinc (mg/L)	0.101	2.45	0.363

[1] Arithmetic mean concentrations; Reference: Minneapolis Public Works, City of Minneapolis Neighborhood Rain Barrel Partnership Project, 2008

[2] Log-normal mean concentrations; Reference: Natural Resource Management Ministerial Council et al, Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2), 2009

[3] Highest geometric mean concentration reported; Reference: Roger T. Bannerman and Richard Dodds, Sources of Pollutants in Wisconsin Stormwater, 1992

Table R.1b.2 Typical Urban Stormwater Quality Characteristcs

Constituents	Twin Cities[2]	Marquette, MI[3]	Madison, WI[4]	U.S. Cities[5]	Australia[1]
Total Coliform (#/100 mL)	--	10,200	175,100	21,000	69,500[a]
Biochemical Oxygen Demand (mg/L)	--	15	--	9	54
Chemical Oxygen Demand (mg/L)	169	66	--	65	58
Total Suspended Solids (mg/L)	184	159	262	100	100
Total Phosphorus (mg/L)	0.58	0.29	0.66	0.33	0.48
Dissolved Phosphorus (mg/L)	0.20	0.04	0.27	0.12	0.67[b]
Total Kjeldahl Nitrogen (mg/L)	2.62	1.50	--	1.50	3.09
Nitrate (mg/L)	0.53	0.37	--	0.68	--
Ammonia (mg/L)	--	0.2	--	--	1.14
Lead (mg/L)	0.060	0.049	0.032	0.144	0.073
Zinc (mg/L)	--	0.111	0.203	0.160	0.293
Copper (mg/L)	--	0.022	0.016	0.034	0.055
Cadmium (mg/L)	--	0.0006	0.0004	--	0.0198

[1] Log-normal mean concentrations; Reference: Natural Resource Management Ministerial Council et al, Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2), 2009

[2] Event mean concentrations; Reference: Brezonik and Staldman, 2002

[3] Geometric mean concentrations; Reference: Steuer et al., 1997

[4] Geometric mean concentrations; Reference: Waschbusch et al.. 1999

[5] Median concentrations; U.S EPA, 1983

[a] Fecal coliform, No./100 mL

[b] Soluble reactive phosphorus, mg/L

Table R.1b.3 Urban Stormwater Quality Characteristcs for Diffferent Drainage Areas

	Constituent Concentration									
		Wisconsin Data[2]								
Constituent	**Australia[1]**	**Arterial Street**	**Feeder Street**	**Collector Street**	**Parking Lot**	**Residential Driveway**	**Residential Lawn**	**Outfall**	**Twin Cities Highways[3]**	**Nationwide Highways[3]**
E-Coli (#/100 mL)	59,339	--	--	--	--	--	--	--	--	--
Fecal Coliform (#/100 mL)	69,429	--	--	--	--	--	--	--	--	--
Total Coliform (#/100 mL)	97,665	--	--	--	--	--	--	--	--	--
Aluminum (mg/L)	1.19	--	--	--	--	--	--	--	--	--
Arsenic (mg/L)	0.009	--	--	--	--	--	--	--	--	--
Barium (mg/L)	0.028	--	--	--	--	--	--	--	--	--
Cadmium (mg/L)	0.0198	0.0028	0.0008	0.0017	0.0012	0.0005	--	0.0006	0.0025	0.0063
Chromium (mg/L)	0.009	0.026	0.007	0.013	0.016	0.002	--	0.005	--	--
Copper (mg/L)	0.055	0.085	0.025	0.061	0.047	0.02	0.013	0.02	0.023	0.0527
Iron (mg/L)	2.842	--	--	--	--	--	--	--	--	--
Lead (mg/L)	0.073	0.085	0.038	0.062	0.062	0.02	--	0.04	0.242	0.254
Manganese (mg/L)	0.111	--	--	--	--	--	--	--	--	--
Mercury (µg/L)	0.218	--	--	--	--	--	--	--	--	--
Nickel (mg/L)	0.009	--	--	--	--	--	--	--	--	--
Strontium (mg/L)	--	--	--	--	--	--	--	--	--	--
Zinc (mg/L)	0.293	0.629	0.245	0.357	0.361	0.113	0.06	0.254	0.123	0.923
Total Kjeldahl Nitrogen (mg/L)	3.09	--	--	--	--	--	--	--	--	--
Ammonia - Nitrogen (mg/L)	1.135	--	--	--	--	--	--	--	--	--
Nitrate - Nitrite (mg/L)	--	--	--	--	--	--	--	--	0.77	0.79
Total Phosphorus (mg/L)	0.48	1.01	1.77	1.22	0.48	1.5	3.47	0.86	0.43	0.48
Total Dissolved Phosphorus (mg/L)	--	0.62	0.55	0.36	0.07	0.87	2.4	0.34	--	--
Soluble Reactive Phosphorus (mg/L)	0.664	--	--	--	--	--	--	--	--	--
Bicarbonate (as CaC03 mg/L)	35.21	--	--	--	--	--	--	--	--	--
Biological Oxygen Demand (mg/L)	54.28	--	--	--	--	--	--	--	--	--
Chemical Oxygen Demand (mg/L)	57.67	--	--	--	--	--	--	--	--	--
Chloride (mg/L)[4]	11.4	--	--	--	--	--	--	--	11.5	33
Oil and Grease (mg/L)	13.13	--	--	--	--	--	--	--	--	--
pH	6.35	--	--	--	--	--	--	--	--	--
Sodium (mg/L)	10.63	--	--	--	--	--	--	--	--	--
Total Suspended Solids (mg/L)	--	993	1152	544	603	328	656	462	--	--
Suspended Solids (mg/L)	99.73	875	1085	386	474	193	457	374	--	--
Total Dissolved Solids (mg/L)	139.6	--	--	--	--	--	--	--	116.3	157.3
Total Organic Carbon (mg/L)	16.9	--	--	--	--	--	--	--	--	--
Turbidity (NTU)	50.93	--	--	--	--	--	--	--	--	--
Total Hardness (mg/L)	--	41	30	32	48	34	51	27	--	--

[1] Log-normal mean concentrations; Reference: Natural Resource Management Ministerial Council et al, Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2), 2009

[2] Arithmetic mean concentration; Reference: Roger T. Bannerman and Richard Dodds, Sources of Pollutants in Wisconsin Stormwater, 1992

[3] Reference: University of Minnesota Water Resources Center, Assessment of Stormwater Best Management Practices Manual, 2008.

[4] Data represents chloride concentrations during monitoring season, typically April through October. Chloride concentrations in winter snow melt grab samples have been found to be as great as 3600 mg/l.

Table R.1b.4 Flow-Weighted Mean Snowmelt Concentrations in the St. Paul Area[1]

Constituents	Storm Sewers	Open Channels	Creeks	NURP [2]
Total Suspended Solids (mg/L)	148	88	64	--
Volatile Suspended Solids (mg/L)	46	15	--	--
Chemical Oxygen Demand (mg/L)	169	82	84	91
Total Phosphorous (mg/L)	0.7	0.56	0.54	0.46
Dissolved Phosphorous (mg/L)	0.25	0.18	--	0.16
Total Kjeldahl Nitrogen (mg/L)	3.52	2.36	3.99	2.35
Nitrate (mg/L)	1.04	0.89	0.65	0.96
Chloride (mg/L)	230	49	116	--
Lead (mg/L)	0.16	0.2	0.08	0.18

[1] Reference: Water Environment Research Foundation, Urban and Highway Snowmelt: Minimizing the Impact of Receiving Water, 1999

[2] Median concentrations from more than 2,300 rainfall events monitored across the nation; EPA, 1983