Nine Springs Recharge Project

Exploration and Evaluation of Water Reuse in Fitchburg, Wisconsin

2011

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The Water Resource Management Workshop is a regular part of the curriculum of the Water Resources Management Graduate Program at the University of Wisconsin-Madison. The workshop involves an interdisciplinary team of faculty members and graduate students in the analysis of a contemporary water resources problem.

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Acronyms

BOD	Biological Oxygen Demand		TSS	Total Suspended Solids
BOD_5	5-day Biological Oxygen Demand		USEPA	U.S. Environmental Protection Agency
CFS	Cubic feet per second		USGS	United States Geological Survey
COD	Chemical Oxygen Demand		VSSF	Vertical Sub-surface Flow
EC	Electrical Conductivity		WDRN	Wisconsin Department of Natural Resources
EC_w	Electrical Conductivity of Water			
ESP	Exchangeable Sodium Percentage		WPDES	Wisconsin Pollutant Discharge Elimination System
GIS	Geographical Information Systems			
GWV	Groundwater Vistas		WRM	Water Resources Management
HSSF	Horizontal Sub-surface Flow			
LOTT	Cities of Lacey, Olympia, Turnwater and northern Thurston County		**Elements and Compounds**	
MG&E	Madison Gas & Electric		Al	Aluminum
ML	Low-plasticity Silt Layer		B	Boron
MGD	Million Gallons per Day		Ca	Calcium
MMSD	Madison Metropolitan Sewerage District		Cd	Cadmium
MPN	Most Probable Number		Cl	Cloride
NPDES	National Pollutant Discharge Elimination System		CO_3	Carbonate
			Cr	Chromium
NHI	Natural Heritage Index		Cu	Copper
NR	Natural Resources		Fe	Iron
NSWWTP	Nine Springs Wastewater Treatment Plant		HCO_3	Bicarbonate
PPCPs	Pharmaceutical and Personal Care Products		K	Potassium
			Mg	Magnesium
SAR	Sodium Adsorption Ratio		Mn	Manganese
SAT	Soil Aquifer Treatment		Ni	Nickel
SC	Sand/clay Layer		N	Nitrogen
SDWA	Safe Drinking Water Act		Na	Sodium
SF	Surface Flow		NH_3	Ammonia
SFF	Sub-surface Flow		NO_3	Nitrate
TDS	Total Dissolved Solids		NO_2	Nitrite
TKN	Total Kjeldahl Nitrogen		P	Phosphorus
TKN-D	Total Kjeldahl Nitrogen - Dissolved		Pb	Lead
TN	Total Nitrogen		PO_4	Phosphate
TOD	Transit Oriented Development		S	Sulfur
TP	Total Phosphorus		SO_4	Sulfate
TP-D	Total Phosphorus - Dissolved		Zn	Zinc

Regulations

Chapter § NR 1.95: Wetlands Reservation, Protection, Restoration and Management
Chapter § NR 44: Master Planning for Department Properties
Chapter § NR 102: Water Quality Standards for Wisconsin Surface Water
Chapter § NR 103: Water Quality Standards for Wetlands
Chapter § NR 140: Groundwater Quality
Chapter § NR 206: Land Disposal of Municipal and Domestic Wastewaters
Chapter § NR 217: Effluent Standards and Regulations for Phosphorus

Preface

The Water Resources Management (WRM) Master's degree program in the Gaylord Nelson Institute of Environmental Studies at the University of Wisconsin – Madison is an interdisciplinary program designed to prepare students for employment as water resources management professionals. Since the 1970s the cornerstone of the WRM program has been a seminar focusing on current issues in Wisconsin water resources management. This seminar has developed into a year-long applied learning opportunity known as the WRM Practicum and is the central requirement of the program's Master of Science Degree.

The purpose of the 2011 WRM Practicum is to evaluate the use of treated wastewater to recharge shallow groundwater in the City of Fitchburg. This study identifies potential sites and practices for groundwater recharge and conditions as well as the environmental impacts of effluent recharge. The 2011 Practicum is funded in part by the Madison Metropolitan Sewerage District and the City of Fitchburg. This project was completed and printed in February, 2012.

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Executive Summary

Population growth increases the demand for water as well as the supply of wastewater. In the expanding Madison metropolitan area, the public draws its water supply from groundwater. This increased water use has decreased groundwater levels in the regional aquifers. Continued declines have the potential to decrease flows in the local springs and streams that receive significant groundwater inflows. One way to offset the increased water use is to offset groundwater diversion with groundwater recharge.

In recent years, some municipalities have used treated wastewater to support groundwater recharge. The Madison Metropolitan Sewerage District (MMSD) produces about 45 million gallons of treated wastewater every day but, in order to avoid excess nutrient loading in the lakes, this effluent is transported outside of the watershed to surface waters south of the Yahara Lakes. The effluent could instead contribute to groundwater recharge projects within the watershed.

Because of this opportunity to improve watershed management, MMSD and the City of Fitchburg have chosen to work together on an enhanced groundwater recharge initiative. They requested that the students in the Water Resources Management (WRM) graduate program at the University of Wisconsin–Madison study the issue and develop recommendations to guide the initiative. For the 2011 WRM Practicum, the students assessed the feasibility of using treated wastewater from MMSD for enhanced groundwater recharge within the City of Fitchburg. The Practicum also explored relevant alternatives, including the development and expansion of local water reuse and water conservation programs.

The investigation began with a search for sites within Fitchburg that would accommodate an enhanced groundwater recharge project. Several practical, physical and legal restrictions limited the results of the search to a Wisconsin Department of Natural Resources (WDNR) hunting ground. In order to use greater amounts of effluent, we expanded the scope of the study to include water reuse.

Water reuse benefits an area by preventing additional groundwater withdrawals and limiting the extent of watershed diversions. The Practicum identified the Nine Springs Wetlands as a study site because it is suitable for effluent discharge and because the additional water would support the health of the wetland ecosystem. The group also included the Nine Springs Golf Course in its investigation because the course managers had already initiated a pilot study using treated wastewater to irrigate part of the course and there was the potential that they could use treated wastewater more extensively.

The Practicum used a combination of research, fieldwork, and computer modeling to develop a better understanding of the suitability of the sites for enhanced groundwater recharge and water reuse. The group also investigated a means of delivering and distributing the treated wastewater at the sites, reviewed applicable laws and regulations, and solicited input from residents at outreach events. Based on this analysis, the Practicum recommends that MMSD and the City of Fitchburg take some or all of the following actions.

1. Construct an enhanced groundwater recharge facility at the WDNR hunting grounds and deliver treated wastewater to the site to replenish the local aquifer.
2. Launch a wetland restoration project in the Nine Springs Wetlands and add treated wastewater to the site to raise the water table and improve conditions for native wetland plants.
3. Expand the effluent irrigation project at the Nine Springs Golf Course to both limit groundwater use and promote water reuse.
4. Work with the WDNR to develop and improve the legal framework for enhanced groundwater recharge and water reuse in Wisconsin.
5. Educate and engage the public on watershed management, water conservation, and water reuse.
6. Promote water conservation on the industrial level.
7. Upgrade the Nine Springs Wastewater Treatment Plant to improve the quality of the effluent and, consequently, make water reuse projects more feasible and acceptable.
8. Provide environmental leadership in Wisconsin by including water reuse in future development strategies.

Chapter 1 • Introduction

The Madison area relies upon groundwater for its public water supply. As the metropolitan area has developed and expanded, rates of groundwater pumping have increased. Once removed from the ground, distributed to the public and used in homes, businesses and industries, most of the water is treated and released to streams outside of the Yahara watershed. This out-of watershed diversion adversely affects local ecosystems.

In 2010 the Madison Metropolitan Sewerage District (MMSD) and the City of Fitchburg requested that the University of Wisconsin–Madison Water Resources Management (WRM) program investigate opportunities for using treated wastewater to recharge shallow groundwater in Fitchburg. With funding from MMSD and the City of Fitchburg, the 2011 WRM Practicum conducted a study with the following objectives:

- Identify potential sites and practices for enhanced groundwater recharge and/or effluent reuse based on existing and field data

- Evaluate potential applications, recharge rates, and environmental impacts

- Select promising sites for enhanced groundwater recharge and/or effluent reuse

- Suggest regulations for groundwater recharge water quality standards in Wisconsin

- Involve the community in the development process through public meetings

- Educate the community on the significance of reclaimed water

- Offer alternative options for effluent reuse

- Review the current conservation efforts

The group selected three sites for investigating the effects of effluent application and establishing the feasibility of a larger scale effluent project. Two of the sites, the Upland Site and the Wetland Site, were selected for their potential to accept effluent inflows for a recharge project. These two sites also have the potential to restore degraded environments and promote naturally vegetated, aesthetically pleasing areas. The third site, the Nine Springs Golf Course, was selected because there is potential to expand the current effluent use. The group studied the water quality and soil content of the three sites to ascertain whether effluent would cause any negative environmental or human health impacts. Additionally, the group performed a preliminary analysis to assure that the water flow avoided well locations. Finally, throughout the report, the treated wastewater in discussion will be referred to as recycled water, reclaimed water, or effluent.

Through the implementation of this study's recommendations, the City of Fitchburg can serve as a model to other cities and businesses in the region for its sustainable development and innovative uses of effluent.

1.1 Motivating Factors for the Project

Groundwater pumping, urbanization and the out-of-watershed diversion of effluent have affected both the shallow and deep aquifers. However, this report focuses on identifying solutions to recharge the shallow aquifer. The deep aquifer contains adequate groundwater supplies and experts foresee no risk of the deep municipal wells running dry. In Dane County, the problems associated with increasing groundwater extraction are seen in negative impacts to ecosystems, such as springs, streams and wetlands. These systems are dependent on the shallow aquifer for their steady water inflows.

The group examined lowland areas in the Nine Springs watershed, an 8,144 acre sub-basin of the 208,000 acre Yahara watershed (Figure 1.1). Previous land use practices resulted in drained wetlands, reed canary grass invasions, and degraded water quality. Current groundwater use further exacerbates these problems. As the Nine Springs watershed contains a number of natural springs, the effects of groundwater depletion are especially visible in this area.
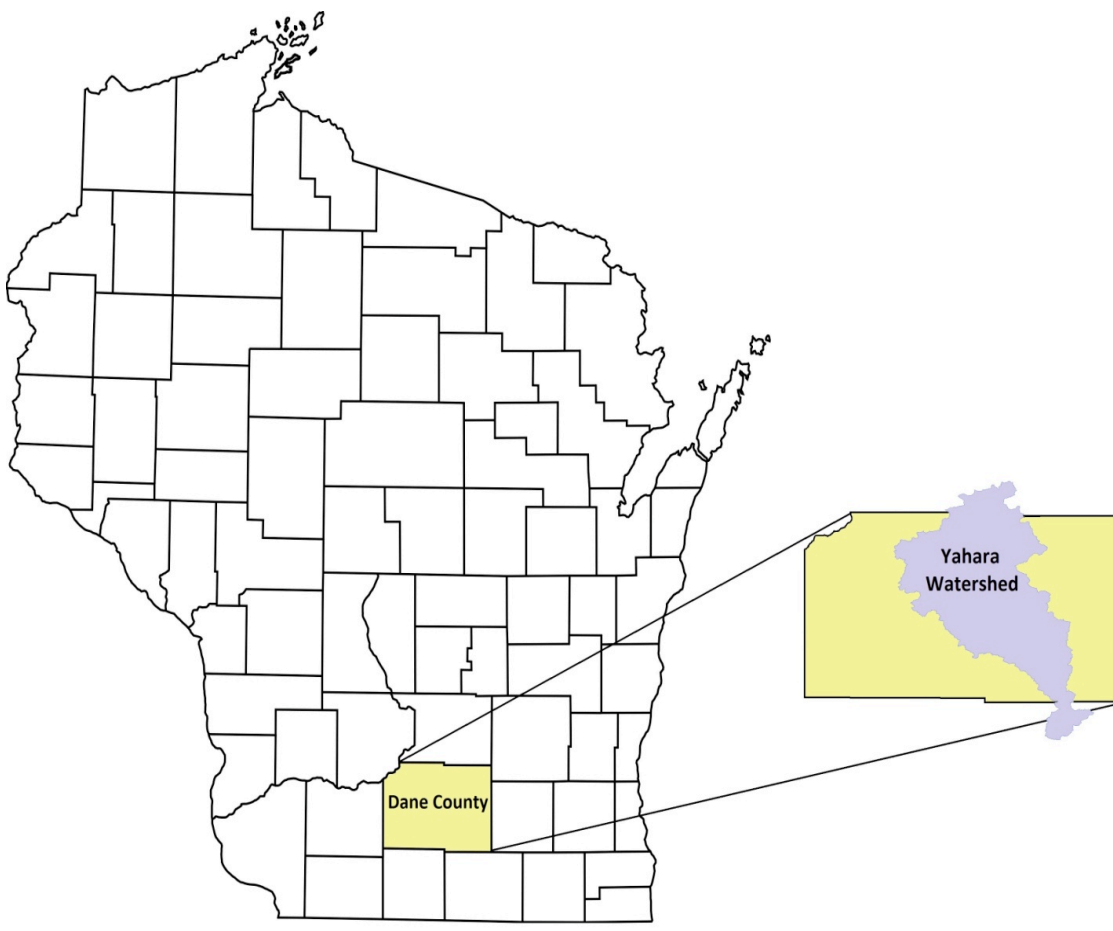
Figure 1.1. Nine Springs Watershed. The Nine Springs Watershed lies within the Yahara Watershed in Dane County, Wisconsin.

1.1.1 The Cause of the Problem

Dane County demands 69.1 million gallons per day (MGD) of groundwater for all needs other than thermoelectric power generation, which uses water drawn from surface waters. Dane County withdraws more groundwater for public supply than any other county in Wisconsin; in fact, Dane County withdraws double the amount of the county with the next highest groundwater withdrawal. Dane County's residential population of 488,073 (U.S. Census Bureau, 2011) also has one of the highest domestic water-use-per-capita in the state at 66.5 gallons per person per day (as compared to 49.6 gallons per person per day for the Wisconsin state average) (Table 1.1 and 1.2).

	Dane County Water Use, MGD		
Category	**Ground Water**	**Surface Water**	**Total**
Domestic	30.46	0.0	30.46
Irrigation	6	.16	6.16
Livestock	2.51	.28	2.79
Aquaculture	2.10	.04	2.14
Industrial	4.74	.57	5.31
Commercial	13.94	0.0	13.94
Thermoelectric	0.0	226.69	226.69
Mining	0.0	1.6	1.6
Public use and loss	9.36	0.0	9.36
Total	69.11	229.34229.34	298.45

Table 1.1. Dane County Water Use, MGD. Buchwald, C.A., 2009. Water use in Wisconsin, 2005: U.S. Geological Survey Open-File Report 2009-1076, 74p.

	Wisconsin Water Use, MGD		
Category	**Ground Water**	**Surface Water**	**Total**
Public Supply	305.42	246.97	552.39
Domestic	87.32	0	87.32
Irrigation	386.57	15.22	401.79
Livestock	65.57	7.27	72.84
Aquaculture	38.48	43.24	81.72
Industrial	70.93	399.96	470.89
Commercial	10.66	0	10.66
Thermoelectric	3.37	6,894.56	6,897.93
Mining	17.59	14.93	32.52
Total (excluding thermoelectric)	982.54	727.59	1,710.13
Total	985.91	7,622.15	8,608.06

Table 1.2. Wisconsin Water Use, MGD. Buchwald, C.A., 2009. Water use in Wisconsin, 2005: U.S. Geological Survey Open-File Report 2009-1076, 74p.

Nine Springs Wastewater Treatment Plant (NSWWTP)

The NSWWTP treats 15 billion gallons of wastewater and stormwater per year with advanced secondary treatment. The standards set by NSWWTP comply with the Wisconsin Pollutant Discharge Elimination System. NSWWTP serves 21 municipalities in the metropolitan area including the cities of Fitchburg, Madison and the more distant areas of Verona, Pleasant Springs, and Windsor (MMSD, 2011).

The wastewater that enters NSWWTP, called influent, first receives a preliminary treatment process using fine screens and a vortex grit removal system to filter out large objects, grease, and grit. Then the water moves into the 19 settling tanks (also called clarifiers) for primary treatment. Suspended solids and organic matter sink and settle to the bottom for removal. Slightly less than half of the suspended solids generally settle out during this phase of treatment and are collected and removed (Asano, 2007). Secondary treatment incorporates biological processes by introducing bacteria and microorganisms to the wastewater. Aerators provide oxygen for the organisms, allowing the organisms to consume P, ammonia, and organic material in the wastewater. Final clarifiers provide an opportunity for the bacteria, microorganisms, solids and organic material to settle out. Lastly, the wastewater receives disinfection by ultraviolet irradiation, an advanced treatment process to kill bacteria and viruses.

Despite the advanced secondary treatment, the wastewater discharged from NSWWTP, the effluent, contains components of concern such as P, nitrates (NO_3), chlorides (Cl), bacteria, and emerging contaminants. In excess, P and NO_3 cause algae blooms in surface waters, bacteria pose a drinking water health hazard, Cl hinders plant growth and emerging contaminants may act as endocrine disruptors.

2010 Water Quality of Effluent Discharged from Nine Springs Wastewater Treatment Plant.

Parameter	Average	Median	Min	Max	Unit
BOD5	3.62	3.6	0	7.8	PPM
Ca	76	76	72	82	PPM
Cd	0.1	0.09	0.07	0.17	PPB
Cl	385	384	281	499	PPM
Cr	0.9	0.8	0.6	1.6	PPB
Cu	7.4	7	3.7	15.6	PPB
FCOLI*	140	117	14	482	#/100 ml
FSS	0.7	0.7	0.6	2	PPM
Hg	1.3	1.28	0.954	1.85	PPT
K	13	13	12	14	PPM
Mg	42	42	39	44	PPM
Na	233	232	206	267	PPM
NH3-N	0.11	0.07	0	1.37	PPM
Ni	1.1	1	0.8	1.8	PPB
NO3+NO2-N	16.5	16.2	12.6	19.3	PPM
NO3-N	17.1	17.1	13.1	25.1	PPM
Pb	0.8	0.7	0.7	1.1	PPB
pH	7.4	7.4	7	7.8	SU
SO4	36	36	32	45	PPM
TDS	1091	1085	988	1200	PPM
TKN	1.37	1.36	0.34	2.71	PPM
TP	0.28	0.26	0.13	0.95	PPM
TSS	4	4	1.8	7.2	PPM
VSS	3.6	3.6	2	6.4	PPM
Zn	46	48	35	58	PPB

*Between April 15th and October 15th when MMSD provides ultraviolet irradiation, the average fecal coliform falls to 122 organisms per 100 mL.

Population growth in the Madison metropolitan area is predicted to cause groundwater withdrawals to increase. In the next 15 years, the population is expected to grow by 12 percent across these municipalities (Demographic Services Center, 2004). Per capita water use has been declining in recent years (City of Madison Water Utility, 2008), but significant conservation efforts will be necessary to counteract the additional demands of an increased population. As a result, groundwater depletion due to groundwater pumping is likely to continue in the future.

The concentrated groundwater extractions that are required to meet the Madison metropolitan area's water needs lowers the groundwater levels in the deep aquifer. This causes what is

referred to as a cone of depression around the pumping wells.. The cone of depression expands nearly 20 miles in diameter within the deep aquifer. As the shallow aquifer recharges the deep aquifer, the cone of depression also causes a drawdown effect in the shallow aquifer. Another factor in lowering groundwater levels is urbanization. As the area introduces more impervious surfaces, such as buildings and pavement, and soils are compacted by construction and heavy traffic, there is less infiltration of precipitation or irrigation water into the soil. Instead, increased volumes of rainwater and irrigation water flow over land to surface waters or sewers. This hinders the natural recharge of the shallow aquifer.

After distribution and use, the sanitary sewer system directs the wastewater to MMSD's Nine Springs Waste Water Treatment Plant (NSWWTP) for treatment. NSWWTP receives approximately 43 MGD from household toilets, sinks, and showers, and from industrial cleaning and manufacturing. After treatment, the water travels through pipelines that extend outside of the Yahara watershed basin to Badfish Creek and Badger Mill Creek. On average in 2010, MMSD discharged 40.63 MGD of effluent to Badfish Creek and 3.57 MGD to Badger Mill Creek.

Badfish Creek flows to the south of the Yahara Lakes. It was selected to receive the treated effluent since it has a relatively steep gradient that allows for a high rate of natural reaeration. It also has the right head conditions for constructing a cascade structure for additional reaeration if necessary (D. Taylor, personal communication, November 21, 2011). Wisconsin state law prohibits MMSD from discharging the effluent into the Yahara lakes. The effluent often has high concentrations of nitrogen (N) and phosphorus (P), which facilitate algae growth in Madison's already algae-ridden lakes. In 1949, Wisconsin mandated the diversion of effluent in order to improve Madison area surface water quality. Since the diversion also prevents effluent from naturally recharging the aquifers, and therefore offset a portion of the pumping and urbanization effects, surface water quantity is now a growing issue. The concentrated groundwater pumping and the removal of 43 MGD of water from the basin impacts the groundwater levels, alters the water table and surface water daily inflows, and threatens the viability of local springs, streams and wetlands.

1.1.2 Environmental Impacts

The decline in groundwater levels in the Madison metropolitan area is significant and extensive. Between 1900 and 2000, water levels in the shallow aquifer are estimated to have fallen at least five feet throughout the Madison metropolitan area and by as much as 50 feet in limited areas on the city's west side (Figure 1.2 and 1.3). Between 2000 and 2030, experts predict additional drawdowns of five to 20 feet around the current cone of depression in both aquifers (Dane County Regional Planning Commission, 2004) (Figure 1.4 and 1.5).

When groundwater emerges at the land surface, it forms springs, supports wetlands, and contributes water as baseflow to streams. Streamflow is derived from both groundwater that discharges into streams, and from rainwater that flows through the shallow subsurface soil layer during storm events. The stormwater runoff contributions vary from day to day as storm events occur. The groundwater contributions create a more constant source of flow, commonly called baseflow. Although baseflow provides a more consistent source of stream flow than stormwater, the flow depends on the groundwater levels near the stream. When groundwater levels are higher relative to the water level of the stream, there is more baseflow. Therefore, when groundwater pumping lowers the water table, baseflow in nearby streams can fall below historic rates.

Diminished baseflow can impede recreational activities, such as boating, and degrades the health of the aquatic plants and animals that make their homes along the streams. Additionally, diminished groundwater inflows to streams, springs, and wetlands can degrade water quality by increasing temperature, nutrient levels, and contaminant concentrations. The Madison area boasts a number of cold-water streams and springs, such as those at Token Creek, Pheasant Branch, and Nine Springs. The springs in the Nine Springs watershed are particularly susceptible to the adverse impacts of diminished baseflow because they are close to the cone of depression.

In recent dry years, the Yahara River itself has experienced severe low flows. When pumping creates a cone of depression, the hydraulic gradient shifts. The slope of groundwater levels towards a stream may become shallower or shift completely. This forces the groundwater to flow away from streams to pumping areas. In some areas of the watershed, the direction of groundwater flow is shifting so that the lakes are losing water to the shallow aquifer, thereby lowering lake levels. These impacts have not been very noticeable during recent wet years, but in dry years lake levels have fallen and streamflow on the Yahara has been very low. The Yahara River gage in McFarland recorded a minimum average flow of 10 cubic feet per second (cfs) on one day in 2005 and a minimum average flow of 8 cfs on one day in 2006 (United States Geological Survey, 2011). To put these numbers in context, the average daily streamflow at this gage is about 170 cfs.

This situation is not unprecedented or unexpected. Cline saw evidence of groundwater depletion in Madison as early as 1965; he observed depressions in the water levels of the deep aquifer that is pumped for municipal water supply (Owen, 1995). Many hydrogeological studies and models have demonstrated that drawdown in the aquifers, seepage from the Yahara Lakes to the groundwater, and baseflow reductions in area springs and streams are now persistent problems in the area (Bradbury, Swanson, Krohelski, & Fritz, 1999).
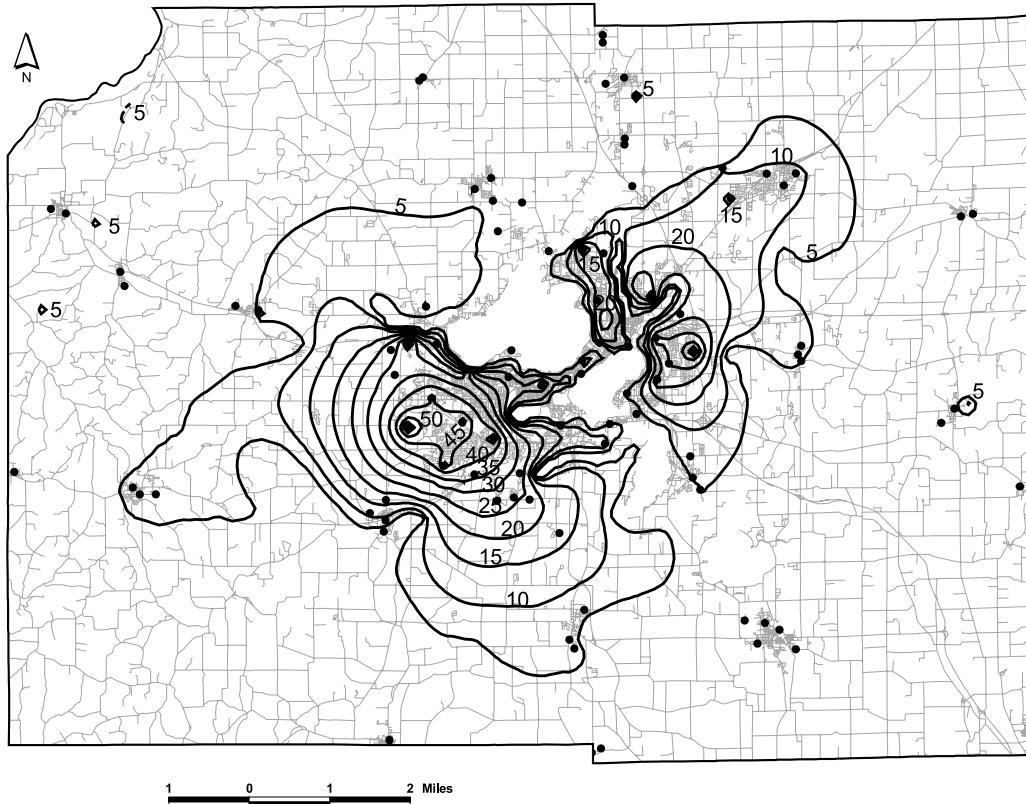
Figure 1.2. Simulated Drawdown at Water Table, 1900-2000. Contours represent water level declines in feet. Source: Dane County Regional Planning Commission, 2004, The 2004 Modeling and Management Program. Retrieved from http://danedocs.countyofdane.com/webdocs/PDF/capd/2004_hydrostudy.pdf
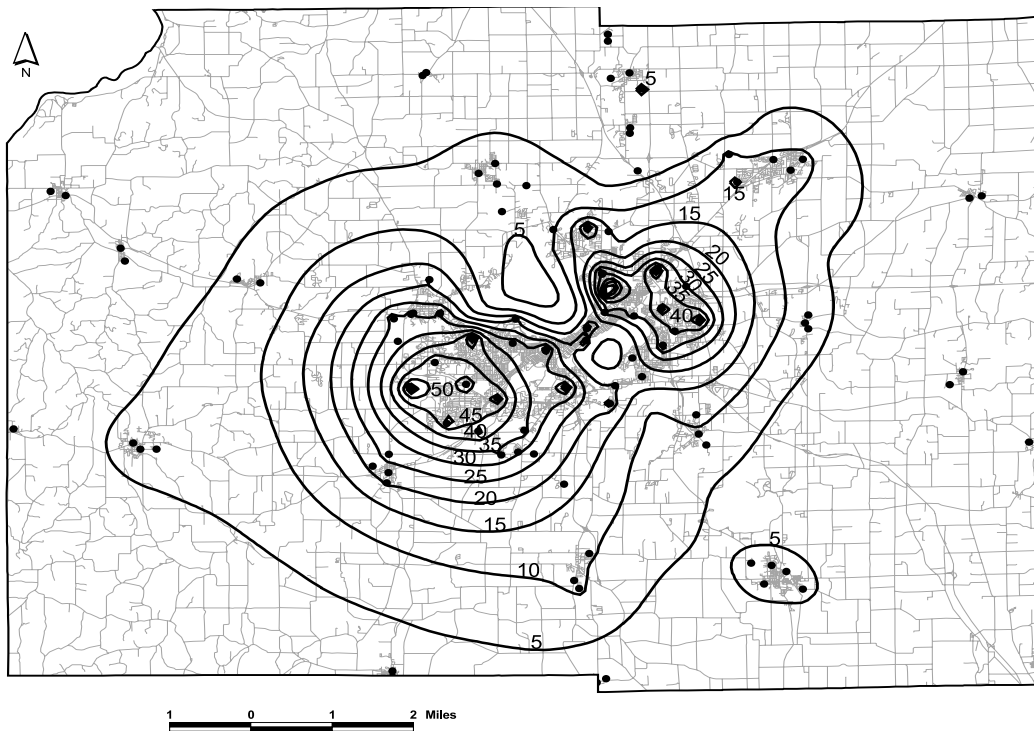
Figure 1.3. Simulated Drawdown in Deep Aquifer, 1900-2000. Contours represent water level declines in feet. Source: Dane County Regional Planning Commission, 2004, The 2004 Modeling and Management Program. Retrieved from http://danedocs.countyofdane.com/webdocs/PDF/capd/2004_hydrostudy.pdf
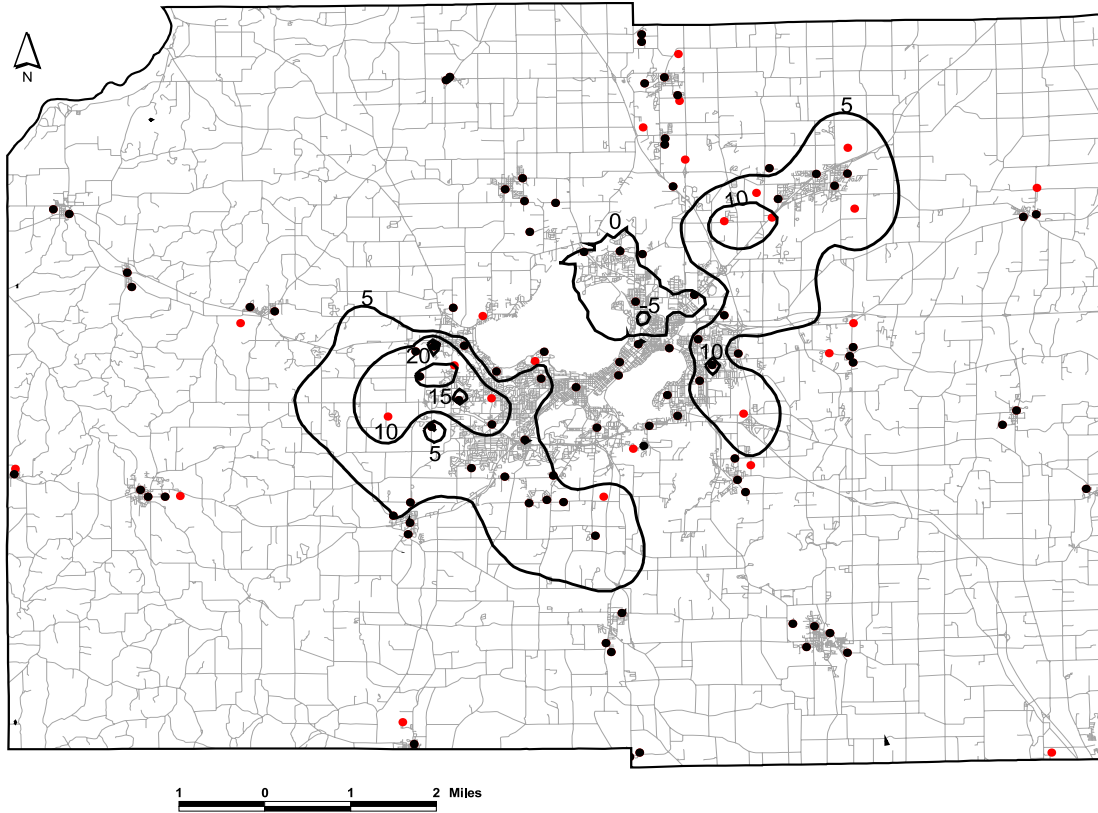
Figure 1.4. Simulated Drawdown at Water Table, 2000-2030. Contours represent water level declines in feet. Source: Dane County Regional Planning Commission, 2004, The 2004 Modeling and Management Program. Retrieved from http://danedocs.countyofdane.com/webdocs/PDF/capd/2004_hydrostudy.pdf
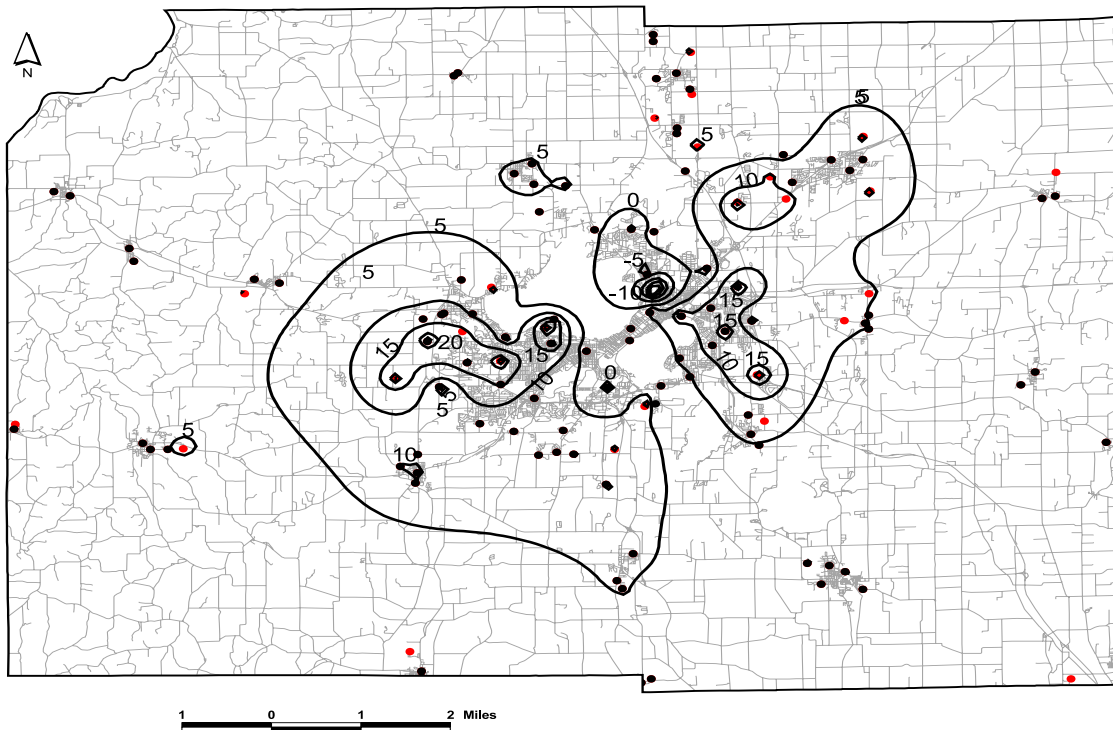
Figure 1.5. Simulated Drawdown in Deep Aquifer, 2000-2030. Contours represent water-level declines in feet. Source: Dane County Regional Planning Commission, 2004, The 2004 Modeling and Management Program. Retrieved from http://danedocs.countyofdane.com/webdocs/PDF/capd/2004_hydrostudy.pdf

Groundwater Recharge and Wastewater Reuse Strategies in Washington

The LOTT Alliance wastewater treatment system in Washington receives water from the cities of Lacey, Olympia, Turnwater and northern Thurston County (LOTT). LOTT began reclaiming water in response to urban needs and the public's request to treat wastewater as a resource. The project aims to lower the pollutant levels in Puget Sound estuary by limiting discharge of treated wastewater into surface waters, educate the public about reclaimed water use, use reclaimed water in downtown Olympia for irrigation and industrial purposes, and infiltrate reclaimed water through a constructed wetland and infiltration basin system to recharge groundwater.

The project included both an upgrade to the original LOTT's Budd Inlet wastewater treatment facility and the construction of three satellite treatment facilities. Each of the LOTT's Hawks Prairie Satellite facilities treats 1.0 MGD, expanding up to 5.0 MGD each (Cupps & Morris, 2005). The discharged effluent meets Class A standards, the strictest treatment levels for applications with high potential for human exposure set by the Washington Departments of Health and Ecology. The LOTT's Budd Inlet Facility treats wastewater to an advanced secondary treatment level, including N removal and ultraviolet disinfection. This highly treated wastewater effluent is discharged into Puget Sound and diverted to the upgraded portion of the wastewater facility designated for reclaimed water. Before distribution, the system adds sodium hypochlorite (bleach) for additional disinfection. Continuous monitoring of the flow, turbidity and chlorine residual ensure the treated wastewater maintains a Class A level of sanitization. The satellite sites allow for reduced environmental impacts, costs, and size and management requirements, while producing high quality water that exceeds Class A standards. In addition to the Inlet Facility treatment, the water flows through a biological membrane reactor, a tertiary treatment method that filters particulate matter and bacteria through microscopic pores.

1.2 Solutions

Many communities around the world that have overexploited their groundwater reserves have begun to implement treated effluent recharge projects to address their groundwater depletion problems. The projects use different methods of treatment and recharge. Projects range in scale, and include backyard rain gardens, rapid infiltration basins, absorption ponds, injection wells or constructed wetlands. Other projects focus on reusing treated effluent for irrigation or industrial purposes to avoid further groundwater extraction. Projects have typically been implemented in regions where drinking water shortages are a major concern, such as in southern California and Florida.

Dane County has reliable drinking water supplies; therefore, the Practicum focused on finding potential solutions to the local environmental concerns. Incorporating enhanced groundwater recharge mechanisms and treated effluent reuse projects within the Yahara watershed can partially mitigate the impact of increased pumping and the out-of-watershed diversion. Replenishing groundwater supplies in Wisconsin using a larger scale treated effluent project will require a comprehensive plan. Recharge strategies like the LOTT Alliance (a partnership between Lacey, Olympia, Turnwater, and northern Thurston County), the City of Yelm project, and the City of Cheney project, all in Washington state, offered models and sources of insight for the design of the Nine Springs Recharge Project. The studies varied in size, cost, infiltration rates, level of disinfection, reclaimed water use and the general public's response. The City of Fitchburg will need to consider a multitude of factors, including residents' concerns, state regulations and local hydrological and geological features. All of these aspects will influence the path of the project and determine if and how treated wastewater could be the solution for Dane County's groundwater depletion problems.

Another effluent reuse project in Washington, in the City of Yelm, also produces Class A reclaimed water for similar uses as the LOTT Alliance. In addition to irrigation and groundwater recharge though, the City of Yelm generates power via treated wastewater. Unlike the LOTT Alliance, public concerns created a larger challenge for the project planning. In order to better address these concerns, the City designed the treatment wetlands for an additional aesthetic purpose and built a fishpond with treated effluent to raise trout for recreational fishing.

The City of Yelm project will only distribute approximately 0.25 MGD, although the wastewater treatment plant has the capacity to produce up to 1.0 MGD as the city continues to grow (Cupps & Morris, 2005). Wastewater treatment includes a sequencing batch reactor for biological oxidation and N removal, and tertiary treatment including chemical coagulation, upflow sand filters and chlorine disinfection.

In contrast to the previous two projects, the City of Cheney in Spokane County, Washington currently produces Class D reclaimed water, a lower quality effluent, suitable for recharging an onsite wetland system with the intention of creating wildlife habitat and allowing for environmental treatment before discharge. The City plans to add a filtration unit, ultraviolet disinfection and an upgraded monitoring system in order to produce Class A reclaimed water. At that point, the water will be discharged into city grounds for irrigation and wetland restoration. The upgrade will cost approximately $6 million. However, the City estimates this amount is no greater than the cost of expanding wastewater treatment to accommodate future growth, and to meet the current National Pollutant Discharge Elimination System permit requirements (Cupps & Morris, 2005).

1.2.1 Existing Enhanced Recharge Projects in the Madison Area

The Nine Springs Recharge Project aims to break new ground in Dane County by using treated wastewater for groundwater recharge. Other projects have been constructed to address the groundwater depletion and effluent diversion in the vicinity. The Odana Hills Golf Course Groundwater Recharge Project and the Badger Mill Creek effluent return line project established the concept of managing stormwater and wastewater, respectively, as a resource within the Madison metropolitan area.

1.2.1.1 Odana Hills Golf Course Groundwater Recharge Project

In 2006, the energy utility Madison Gas and Electric (MG&E) and the University of Wisconsin-Madison launched the Odana Hills Groundwater Recharge Project at the Odana Hills Golf Course in Madison, Wisconsin. Co-owners of the West Campus Cogeneration Facility, MG&E and the University needed water for use in the newly built power plant and wanted to draw water from Lake Mendota. The recharge project served as a compensation for the plant's water withdrawal from the Yahara watershed. Unlike the Practicum, the Odana Hills Groundwater Recharge Project used stormwater rather than effluent. However, at present this is the only major project to recharge groundwater within the Yahara watershed.

The project research, design and construction occurred in 2005 and 2006. The site for the recharge facility, the Odana Hills Golf Course, was selected since the site possessed appropriate hydrogeological characteristics for recharge, a stormwater pond on the property provided an easily accessible source of water, and public wells were sufficiently far from the recharge area. Additionally, the owners of the Odana Hills Golf Course agreed to help support the project. The design included a mechanical infrastructure to pump water from the stormwater pond, a microfiltration system to remove suspended solids, and an underground drain field to distribute the filtered water across an area between fairways. The mechanical system has several advantages over a passive system: it runs continuously, processes water at a faster rate, and requires less area to be effective. The system has exceeded the target, set by the Wisconsin Department of Natural Resources (WDNR) permit, of 50 million gallons per year; thus far, the

project has replenished the local aquifer with 61 million gallons per year. When the cogeneration plant upgrades to produce more power, thereby using more water, the Odana Hills Groundwater Recharge Project will increase the target to 80 million gallons per year. Monitoring of the facility, the groundwater quality and the groundwater mounding, continue at the project site (Gaffield, 2011). Both the development and monitoring of the Odana Hills Groundwater Recharge Project provide guidance towards planning a similar project using treated effluent.

1.2.1.2 Badger Mill Creek Effluent Return Project

The City of Verona abandoned its aging wastewater treatment plant in 1996 in favor of sending its wastewater to MMSD. For two years, the City of Verona pumped groundwater out of the Upper Sugar River watershed for residential, commercial and industrial purposes. The city sent the wastewater to the NSWWTP in the Yahara River watershed, which discharged the water to Badfish Creek in the Badfish Creek watershed. This process put the Sugar River at risk for environmental degradation similar to the effects seen within the Nine Springs watershed. In order to relieve these potential problems, MMSD and the City of Verona constructed a pipeline to carry the treated effluent from NSWWTP back to Badger Mill Creek, a tributary of the Sugar River. The pipeline returns the amount of wastewater generated by the City of Verona in order to maintain a stable quantity of water within the watershed.

The Badger Mill Creek return line alleviates a significant problem, but it exists outside of the Yahara watershed where the Practicum focused their research. Due to the algae concentrations within the Madison lakes, MMSD will not discharge effluent directly into a surface water body within the upper watershed. Nonetheless, the City of Verona's initiative to mitigate the problem of the area's declining water levels can act as a framework for MMSD to work with the City of Fitchburg to produce a larger scale project with similar objectives. Most importantly, the construction of the effluent return line provided MMSD and the City of Fitchburg with the physical infrastructure that would ease the initial implementation of an enhanced recharge project in Fitchburg.

1.3 Summary

The consequences of the groundwater pumping in the deep aquifer include drops in the water table, which put surface water features (streams, springs and wetlands) that are supported by groundwater discharge at risk of drying out. Urbanization and the out-of-watershed diversion of effluent prevent adequate natural recharge to the aquifers. The 2011 WRM Practicum proposes that MMSD and the City of Fitchburg develop a long term water management plan that puts a priority on the return of effluent to the basin for enhanced groundwater recharge.

Chapter 2 • Regulations

There are currently no federal regulations or requirements for water reuse, although the U.S. Environmental Protection Agency (USEPA) did issue a comprehensive set of guidelines in 1992, which was last updated in 2004. The guidelines are intended to help states establish technically defensible standards (R. Bastian, personal communication, November 20, 2010). Additionally, there is a current study of water reuse by the National Research Council that aims to provide recommendations for national regulations. As will be further discussed in this chapter, Wisconsin has not yet established thorough water reuse regulations. This lack of standards has made it difficult to determine what kinds of water reuse projects are feasible. Therefore, the Practicum relied on the USEPA guidelines and other states' existing reuse regulations to evaluate the proposed projects.

2.1 Water Reuse Categories

Each state's water use generally falls within categories established by the USEPA in its 2004 Guidelines for Water Reuse. These categories include urban, agricultural, industrial, environmental/recreational, groundwater recharge, and potable supply augmentation. The USEPA also establishes guidelines for direct potable reuse, though no state in the United States currently uses reclaimed water for this purpose. The only place in the world using reclaimed water for potable use is Windhoek, Namibia (Crook, 2010). In 2004, an estimated 1.7 billion gallons per day of wastewater were reused in the United States. The USEPA expects that number to grow by 15 percent each year (U.S. Environmental Protection Agency [USEPA], (2004).

2.1.1 Urban

Urban water reuse applications include irrigation for parks, cemeteries, schools, and other green spaces. One common use is for golf course irrigation since access can be controlled during periods of irrigation. Other uses include fire protection, toilet flushing, and ornamental water features like fountains. Water quality standards for urban reuse applications depend on the level of public access to the site.

2.1.2 Industrial

Industrial water reuse applications include using reclaimed water for cooling water and industrial process water for textiles, paper and concrete. Water quality standards are dependent on the potential for human exposure, and one common avenue for exposure is mist.

2.1.3 Agricultural

Agricultural water reuse applications are common in many states. In Florida and California agriculture accounts for 19 percent and 48 percent of reclaimed water usage, respectively. Crops that have been successfully irrigated using reclaimed water include hay used for fodder,

citrus, strawberries, grapes, alfalfa, and corn. Whether or not the crop is intended for human consumption dictates the level of treatment required and the resultant water quality standards.

2.1.4 Environmental/Recreational

Environmental water reuse applications include wetland and wildlife habitat creation and restoration, and stream augmentation. Reclaimed water has been used for recreational applications such as constructed water bodies for fishing, boating, swimming, golf course water hazards, and other aesthetic impoundments. Like urban water reuse, water quality requirements are dependent on the potential for human contact and restrictions on use.

2.1.5 Groundwater Recharge

Groundwater recharge reuse applications include infiltration to potable and non-potable aquifers, injection to create saltwater intrusion barriers, and seasonal storage for future use. These systems often take advantage of additional soil treatment prior to reaching the aquifer.

2.2 Water Reuse in Wisconsin

Wisconsin is generally perceived to be a water-rich state. Over 15 percent of land surface in the state is covered by freshwater (Buchwald, 2009). Though water reuse is not widely practiced in Wisconsin, there are some current examples, including the wildlife observation area at the Madison Metropolitan Sewerage District (MMSD). Other states, especially those in the water-stressed South and Southwest, have more fully embraced water reuse. Both Florida and California have been practicing water reuse for over 30 years (USEPA, 2004). California even goes so far as to require the use of effluent for irrigation, where it is available (California Water Code, § 32601, 2011). Even though Wisconsin does not currently face extreme water shortages, it is worth asking the whether potable groundwater should be used for irrigating turf while high quality effluent is discharged downstream.

Since passage of the Clean Water Act in 1972, water quality has become a major index of surface water health, especially with respect to effluent contributions. The primary means by which the USEPA regulates point source discharges is through the National Pollutant Discharge Elimination System (NPDES). Most water reuse projects receive a permit through this system. Additionally, the Safe Drinking Water Act (SDWA), passed in 1974, provides regulations for groundwater quality. Any reuse project that involves direct injection into an aquifer, rather than surface application, needs to abide by the stricter of SDWA standards or state groundwater standards. Water reuse regulations most often delineate water quality criteria that include limits for 5-day Biological Oxygen Demand (BOD_5), Total Suspended Solids (TSS) or turbidity, total or fecal coliform counts, and nitrogen (N) concentrations. These vary by state and the intended use. Furthermore, some states define additional measures including required treatment levels, disinfection procedures, setback distances from existing wells and/or private land, monitoring requirements, and treatment facility reliability.

In some states where water reuse is being practiced, states agencies have established their own guidelines or regulations; others choose to deal with water reuse projects on a case-by-case basis (Asano, 2006). Existing regulations and guidelines vary considerably from state to state. Many states, especially those in more water-stressed regions, have regulations that treat reclaimed water as a resource and encourage its use. Other states have guidelines that address water reuse, but from a perspective of effluent disposal, rather than as a beneficial use (USEPA, 2004). Table 2.1 summarizes the current status of water reuse regulations by state.

Wisconsin does not treat reclaimed water as a resource. Most effluent in the state is discharged into a receiving body of water, usually a stream or river, as is done at MMSD. Wisconsin does have regulations in place for land application of effluent. However, these regulations are intended as methods of wastewater disposal where surface waters are not available for this purpose, rather than as a beneficial means to recharge groundwater or irrigate land. According to Ken Johnson with the Wisconsin Department of Natural Resources (WDNR), the state should consider regulations for water reuse, but due to budgetary constraints and the current focus on phosphorus (P) limits, he does not see it being likely in the near future (personal communication, December 2, 2010). In Wisconsin, all effluent discharges are currently regulated by the WDNR through the Wisconsin Pollutant Discharge Elimination System (WPDES). Any reuse project would ultimately need to have a WPDES permit that would specify water quality, setback, monitoring, and any other requirements.

2.3 Existing Regulations in Wisconsin

Existing Wisconsin regulations that are applicable to water reuse include Wisconsin administrative Administrative Codes for Natural Resources (NR), § NR 206 Land Disposal of Domestic and Municipal Wastewaters, § NR 110 Sewerage Systems, and § NR 140 Groundwater Quality. These regulations provide the water quality and quantity parameters for a reuse project. However, because the above regulations are not meant to encourage water recycling, some restrictions, such as the rate of application, may need to be changed and delineated in a WPDES permit in order for benefits to be realized. Additionally, many reuse projects incorporate further treatment prior to the effluent reaching aquifers, so water quality limitations should be considered on a case-by-case basis.

Since spray irrigation is one method of land disposal of wastewater, the USEPA's *Guidelines for Water Reuse* interprets § NR 206 as covering the category of agricultural water reuse applications. § NR 110 further stipulates that any crop irrigated using effluent shall not be used for direct human consumption. § NR 140 prohibits any discharge to an aquifer that does not meet groundwater standards. In addition, § NR 206.07 specifies that, "the underground injection of municipal and domestic wastewaters through a well is prohibited" (even though this water source could potentially be treated to safe drinking water standards). These regulations suggest that any sort of injection well method of water reuse in Wisconsin would not be allowed. § NR 110.255 states, "When possible, absorption ponds shall be constructed in areas which are not groundwater recharge areas." These regulations are all intended to preserve the high-quality drinking water present in Wisconsin's aquifers. One of the practicum's main concerns was ensuring that any possible reuse project would not adversely affect existing drinking water sources.

State	Regulations	Guidelines	No Regulations nor Guidelines	Unrestricted Non-potable Urban Use	Restricted Non-potable Urban Use	Agricultural Irrigation of Food Crops	Agricultural Irrigation of Non-Food Crops	Unrestricted Recreational Impoundments	Restricted Recreational Impoundments	Environmental Uses	Industrial Uses
Alabama		●			●		●				
Alaska	●						●				
Arizona	●			●	●	●	●		●		
Arkansas		●		●	●	●	●				
California	●			●	●	●	●	●	●		●
Colorado	●			●	●						●
Connecticut			●								
Delaware	●			●	●		●				
Florida	●			●	●	●	●			●	●
Georgia		●		●	●		●				
Hawaii		●		●	●	●	●		●		●
Idaho	●			●	●	●	●				
Illinois	●			●	●		●				
Indiana	●			●	●	●	●				
Iowa	●				●		●				
Kansas		●		●	●	●	●				
Kentucky			●								
Louisiana			●								
Maine			●								
Maryland		●			●		●				
Massachusetts		●		●	●		●				
Michigan	●					●	●				
Minnesota			●								
Mississippi			●								
Missouri	●				●		●				
Montana		●		●	●	●	●				
Nebraska	●				●		●				
Nevada	●			●	●	●	●	●	●		
New Hampshire			●								
New Jersey		●		●	●	●	●				●
New Mexico		●		●	●	●	●				
New York		●					●				
North Carolina	●			●	●						●
North Dakota		●		●	●		●				
Ohio		●		●	●		●				
Oklahoma	●				●	●	●				
Oregon	●			●	●	●	●	●	●		●
Pennsylvania		●					●				
Rhode Island			●								
South Carolina	●			●	●		●				
South Dakota		●		●	●		●			●	
Tennessee	●			●	●		●				
Texas	●			●	●	●	●	●	●		●
Utah	●			●	●	●	●	●	●		●
Vermont	●						●				
Virginia	●			●	●	●	●	●	●		●
Washington	●			●	●	●	●	●	●	●	●
West Virginia	●					●	●				
Wisconsin	●						●				
Wyoming	●			●	●	●	●				

Table 2.1. Current Status of Water Reuse Regulations. Adapted and updated from USEPA 2004 Guidelines for Water Reuse.

MMSD currently has a WPDES permit for their discharges to Badger Mill and Badfish Creeks. The permit also covers the use of effluent to irrigate the 7th hole at Nine Springs Golf course. Due to the small quantity of effluent used in the Practicum, the Practicum fieldwork also fell under the existing permit. Any long-term projects would most likely require their own individual permits to be coordinated through the WDNR and MMSD.

Table 2.2 shows the limits proscribed in § NR 206 for land application of effluent. For an absorption pond, the BOD_5 needs to be less than 50 milligrams per liter (mg/L), total nitrogen (TN) less than 10 mg/L, Total Dissolved Solids (TDS) less than 500 mg/L, and chloride (Cl^-) less than 250 mg/L. Comparing those numbers to the MMSD effluent, the only requirement that it meets is BOD_5. However, all other land applications methods consider the above quality standards on a case-by-case basis, so future projects should incorporate additional treatment to meet these limits. In addition, § NR 206 specifies a maximum application rate of 12,000 gallons per acre per day (gal/acre/day) for absorption ponds and 10,000 gal/acre/day for spray irrigation. § NR 110 specifies setback distances of 1,000 feet from municipal wells, 250 feet from private wells, and 100 feet from buildings. However, these distances are for sludge lagoons, so the distance for effluent application could possibly be decreased through a WPDES permit. There are also maximum loading rates for spray irrigation, dependent on the soil, as shown in Table 2.3.

	Limitations
Absorption Pond	BOD_5: 50 mg/L Load/Rest: as per permit Total Nitrogen: 10 mg/L TDS: 500 mg/L CL: 250 mg/L Hydraulic Application Rate: case by case not to exceed 12,000 gal/acre/day
Spray Irrigation	BOD_5: 50 mg/L Load/Rest: as per permit Total Nitrogen: case by case Hydraulic Application Rate: case by case Fecal Coliform: case by case, not to exceed 10,000 gal/acre/day
Ridge and Furrow	BOD_5: 50 mg/L Load/Rest: as per permit Total Nitrogen: case by case Hydraulic Application Rate: case by case not to exceed 10,000 gal/acre/day
Overland Flow	All parameters case by case
Other	All parameters case by case

Table 2.2. § NR 206 Effluent Limitations. Adopted from § NR 206, Land Disposal of Municipal and Domestic Wastewaters.

Soil Texture (USDA-SCS)	Maximum Volume Applied per Load Cycle	Maximum intensity of Application
Sands	0.65 inches	1.00 inches/hour
Sandy Loams	0.90 inches	0.90 inches/hour
Loams	1.30 inches	0.45 inches/hour
Silt Loams	1.40 inches	0.45 inches/hour
Clay Loams	1.10 inches	0.40 inches/hour
Clays	0.70 inches	0.40 inches/hour

Table 2.3. Application Rates by Soil Type. Adopted from NR 110 Sewerage Systems.

2.4 Comparison to Other States' Regulations

Table 2.4 shows MMSD effluent data compared to regulation limits from states that encourage water reuse and that most closely meet the intent of the WRM project. Based on these data, an environmental enhancement, or small wetland compound with limited public access, would be feasible for a full-scale recharge project. Fecal coliform is generally measured as the Most Probable Number (MPN) per 100 mL of substance. The current levels in MMSD's effluent are higher than most states allow for public exposure. With additional disinfection treatment to lower fecal coliform counts, public exposure would not be an issue. Further filtration and/or additional on-site treatment could reduce the amounts of some nutrients to create a high-quality effluent capable of more widespread applications.

Parameter (all mg/L unless noted)	MMSD Effluent Data	WI NR 206		EPA Guidelines Environmental Enhancement	WA Wetland Enchancement		VA Landscape Impoundment		FL Wetland Enhancement	CA Landscape Impoundment
	Ave	Absorption Pond	Spray Irrigation		Non-Contact	Contact	Non-Contact	Contact		
Treatment Level	Secondary, disinfected[1]	NS	NS		Secondary, disinfected	Tertiary, disinfected	Secondary, disinfected	Tertiary, disinfected	Secondary, Disinfected	Secondary, Disinfected
BOD$_5$	3.8	50	50	30	20	20	30	10	5	
Turbidity	NS							2		2
Cl	384	250								
Fecal Coliform (#/100mL)	76		CBC	200	240	2.2	200	14	25	2.2
Total Nitrate and Nitrite	16.4	10	CBC						3	
Total Dissolved Solids (TDS)	1129	500								
Total Kjedahl Nitrogen (TKN)	1.37				3	3				
Total Phosphorous (TP)	0.27				1	1			1	

Table 2.4. MMSD Effluent Content Compared to Environmental Enhancement Requirements.

To investigate the possibility of expanding the irrigation at Nine Springs Golf Course, current effluent data were again compared to the USEPA guidelines and other states' regulations (Table 2.5). Due to the levels of fecal coliform currently present in the MMSD effluent, irrigation only occurs when there is no potential for exposure to golfers or public. However, it should be noted that water quality analyses showed that the fecal coliform levels in the currently used pond irrigation water are quite similar to, if not higher than, the levels present in the effluent.

Parameter (all mg/L unless noted)	MMSD Effluent Data	WI NR 206	EPA Guidelines		WA Irrigation	VA Irrigation	FL Irrigation	CA Irrigation
	Ave	Spray Irrigation	Restricted Irrigation	Urban Reuse	Restricted	Restricted	Restricted	Restricted Access
Treatment Level	Secondary, disinfected[1]	NS	Secondary, disinfection	Secondary, filtration, disinfection	Secondary, disinfected	Secondary, disinfected	Secondary, Disinfected	Secondary, Disinfected
BOD$_5$	3.8	50	30	10	20	10	20	
Turbidity	NS			2		2		2
Cl	384							
Fecal Coliform (#/100mL)	76	CBC	200	0	23	14	200	23
Total Nitrate and Nitrite	16.4	CBC						
Total Suspended Solids (TSS)	3.9		30		20	30	20	
1. Disinfected Apr-Oct								

Table 2.5. MMSD Effluent Content Compared to Irrigation Requirements.

2.5 Phosphorus (P) Issues and Regulations

One additional consideration for water reuse projects in the Yahara watershed is the P content of the effluent. P has long been an issue in the Yahara watershed and is the primary reason that MMSD currently discharges effluent into tributaries outside of the watershed. P is often the limiting nutrient responsible for algal blooms, so preventing the introduction of P into waterways can prevent blooms and subsequent eutrophication. P from point source discharges are regulated by the authority of the Clean Water Act, which was passed in 1972.

In 1992, Wisconsin established statewide limits of 1 mg/L of P for new municipal and industrial discharges. However, this measure alone has not proven adequate to reduce P loads in impaired waters. Non-point sources are also contributing P to waterways, with little to no regulation.

In 1998, the USEPA published the *National Strategy for Development of Regional Nutrient Criteria*, which required states to develop numerical, rather than narrative, nutrient criteria for specific waterways by 2003. This was intended to regulate all inputs into waterways, as opposed to just point sources. The USEPA can take over authority for this if states do not comply. After several environmental advocacy groups filed a notice of intent to sue the USEPA and the WDNR in 2009, the WDNR revised § NR 102, 151, and 217 to set numerical nutrient standards for receiving waters. These new policies went into effect on December 1, 2010. § NR 151 applies to non-point source discharges, like agriculture, and therefore is not applicable to this project.

§ NR 102 sets water quality standards for surface waters. According to § NR 102, 46 different waterways, including the Rock and Yahara rivers, must contain 100 micrograms per liter (µg/L) or less of P. All other rivers and streams not listed must have a total P level of 75 µg/L or less. Proposed limits for reservoirs and lakes (excluding the Great Lakes) range from 15 to 40 µg/L. Wetlands are excluded from § NR 102. While § NR 102 does not necessarily place a limit on any given point discharger, it most likely means that point dischargers will either need to meet this limitation or engage in "phosphorus trading" to offset their discharges to surface waters. An example of this would be creating or restoring wetlands in another area of the watershed to offset the P discharged into the Rock River from the effluent. MMSD is currently in negotiations with the WDNR to determine how they will comply with the new regulation. If P trading is deemed unacceptable, they will have to upgrade their treatment process to lower their P levels further (in 2009, the effluent averaged 290 µg/L).

§ NR 217 was revised to decrease the maximum P levels that can be discharged. § NR 217.04 states that "an effluent limitation equal to 1 mg/L TP as a monthly average shall apply to publicly owned treatment works and privately owned domestic sewage works subject to NR 210, which discharge wastewater containing more than 150 pounds of TP per month…" However, even though MMSD's WPDES permit currently has a limit of 1.5 mg/L for P, the average amount contained in the effluent has remained well below even the revised limit of 1 mg/L. In 2010, the effluent had an average P content of 0.29 mg/L and a maximum discharge of 0.81 mg/L, so § NR 217 revisions should not have as large of an impact on the project as NR 102 revisions might.

Since there are currently no limitations to P in drinking water, the limiting factor for a larger-scale recharge project may be any effluent that is discharged into the wetland as overflow from the infiltration site. § NR 103 sets water quality standards for wetlands, but there are no numerical standards. § NR 103.03 requires only that wetlands maintain their hydrologic and habitat functions. The group recommends discharging effluent into wetlands that are already degraded from human impacts, and therefore, the effluent should not further degrade the wetland and may even aid in restoring some of its previous functions.

As Nine Springs Creek runs through the wetland proposed for recharge overflow, any effluent that would discharge to the creek should meet the limit of 0.075 mg/L as set in NR 102. Soil treatment, via peat adsorption of P prior to it reaching Nine Springs Creek, should allow the water to meet this limitation. This could be verified by a pilot-project in the wetland using effluent.

2.6 Recommendations

The lack of Wisconsin state regulations may allow more flexibility in dealing with water reuse projects because the WDNR permits each situation on a case-by-case basis. However, the absence of state guidelines for final treatment levels made the planning and design of an enhanced recharge project more difficult. Therefore, the Practicum encourages the WDNR to develop regulations based on the USEPA guidelines and modified for Wisconsin's climate and geography. The main considerations for these regulations should include:

- Treatment process, reliability, and storage requirements

- Biochemical Oxygen Demand (BOD)

- TSS and turbidity requirements

- Coliform bacteria limits and disinfection requirements

- Limits and monitoring for pathogenic organisms

- Nutrient limits

- Separation of potable and non-potable water

- Setback distances

Chapter 3 • Pilot Site Selection Process

3.1 Criteria and Processes

The process of finding a suitable site for groundwater recharge began as a search for pilot study sites within the Yahara watershed. In collaboration with the project partners, the group developed criteria for an acceptable enhanced recharge site and proceeded to identify suitable sites for water reuse in Fitchburg. The process included a search for large-scale project sites and for sites where the Practicum could conduct research and begin a pilot study. The group's concerns, about the logistics of construction and the time constraints of the pilot project, contributed to the selection process. More importantly, state and federal regulations, community concerns, and expert opinions generated the following requirements for an enhanced recharge project:

- Treated wastewater must be applied in an area or in a way that allows it to undergo advanced treatment before it reaches the groundwater.

- Treated wastewater must not be applied across an area from which groundwater flows to nearby public or private wells.

- The use of treated wastewater in the system must provide some benefit to ecosystems and/or surface water features in the area.

Based on these criteria the group began to search in areas affected by declining groundwater levels. This included regions that extend throughout the Madison metropolitan region, from Sun Prairie to Middleton, and south through the City of Fitchburg. Since evaluating all suitable sites throughout this region was beyond the scope of this project, the group narrowed the search to publicly owned tracts within the Fitchburg city limits, as suggested by Rick Eilertson, City Engineer for Fitchburg. This suggestion became the first control in the Practicum's site selection. The second major control was also logistical. To reduce the expense of installing pipes and pumping the effluent, the group investigated sites within a mile of the effluent return line that runs through the City of Fitchburg. MMSD maintains the return line, which transports 3.57 million gallons of treated wastewater daily (MGD) through the City of Fitchburg and finally discharges it into Badger Mill Creek on the southwest side of the city. Fitchburg's Geographical Information Systems (GIS) specialist, Felipe Avila, provided the group with a list of six publically-owned parcels located within the City of Fitchburg and within one mile of the effluent return line (Figure 3.1). For details about Felipe's methods, see Appendix A.

From these six sites, the group contributed criteria to further narrow the selection. The site needed the following characteristics:

- Owned by a government entity to avoid costs associated with purchasing private land

- More than four acres in size in order to infiltrate one MGD of effluent

- The same or lower elevation than the effluent return line to avoid pumping water uphill

- A minimum depth to water table of 20 feet in order to reduce the possibility of mounding

- Close to the effluent line to reduce the cost of transporting the effluent to the recharge location

- Contains low clay content and high sand content in order to efficiently infiltrate a large volume of water over a small surface area

- Groundwater flow in the area avoids nearby private wells, public wells or ecologically sensitive areas such as the Nevin Fish Hatchery.

The group conducted a qualitative analysis of the sites based on the information collected with GIS, groundwater modeling (for groundwater modeling methods see Section 4.1.4), and field observations in order to determine the best sites (see Appendix B).
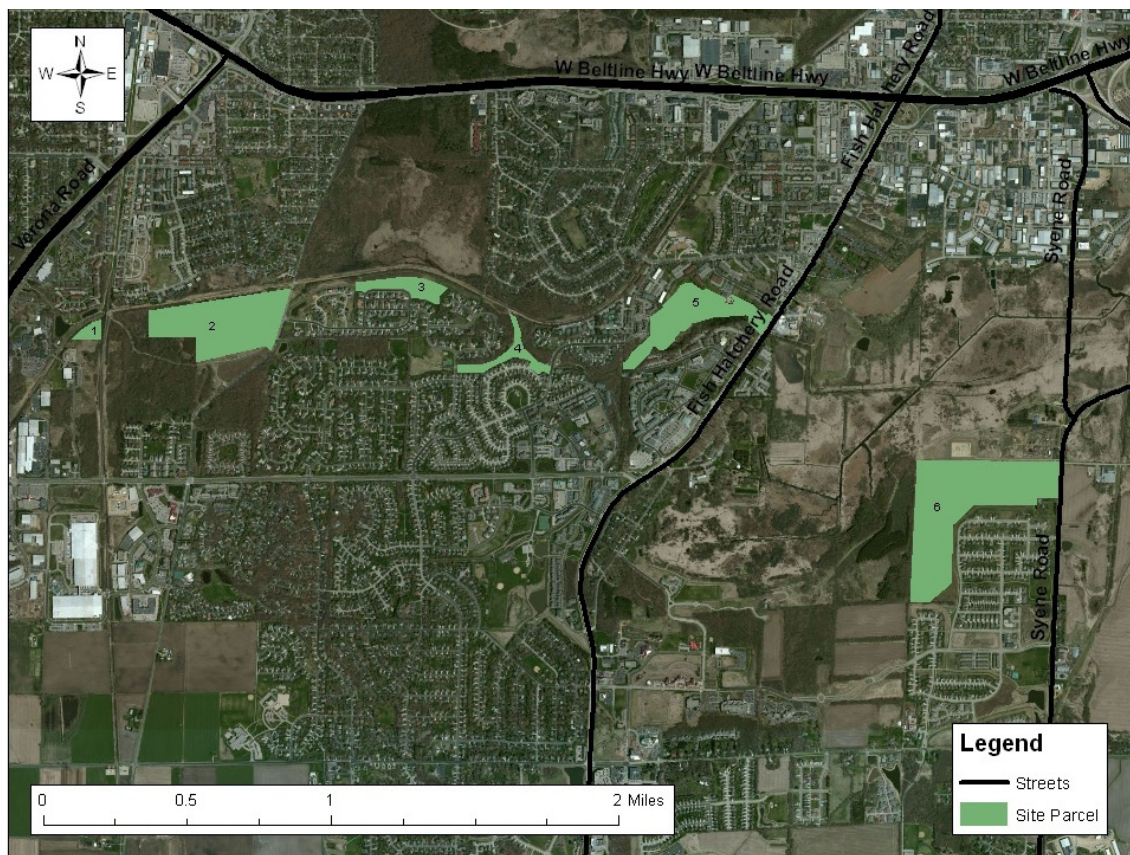
Figure 3.1. Initial Six Sites Investigated for a Recharge Project.

3.2 Enhanced Recharge Pilot Site

After analysis, the group deemed sites 1-5 unacceptable for potential enhanced recharge projects (Table 3.1).

Site	Factors that Prevent a Groundwater Recharge Project
1	Size: too small for an effective recharge site
2	Soils: saturated soils in Dunn's Marsh would complicate construction and obstruct recharge
3	Effluent Flow: groundwater modeling determined effluent would flow towards Nevin Fish Hatchery
4	Size: space constraints due to Capital City E-way bike path
5	Size: the greenway in the Nine Springs Golf Course could not accommodate recharge beds

Table 3.1. Recharge Site Elimination.

As a result, Site 6 is the most highly qualified site for an enhanced recharge project in Fitchburg. The site is owned by the WDNR, which is willing to let the group use the site for a field study. Logistically, the site is located approximately 300 feet from the effluent pipeline and is accessible by vehicle. The nearly 78 acre parcel is a gently sloping upland meadow that is covered with grasses, forbs, and shrubs and has moderately permeable soils. Also, groundwater flow from Site 6 avoids the Nevin Fish Hatchery. Instead, it flows northwest to the Nine Springs wetlands and southeast to Lake Waubesa. Unfortunately, Site 6 is located uphill from the effluent return line. This criterion does not preclude a recharge facility on the site; however, it does increase potential costs as it requires pumping. Consequently, Site 6, also referred to as the Upland Site, was chosen for the Practicum's on-site groundwater recharge project.

3.2.1 Additional Pilot Site Selections

Due to the fact that only one of the six sites proved feasible for groundwater recharge, the group expanded the scope of the Practicum to include other possibilities for using the treated effluent. Two opportunities within the local community readily presented themselves: the Nine Springs Wetlands and Site 5, the Nine Springs Golf Course. The Golf Course was previously rejected as a groundwater recharge site since recharge from the Nine Springs Golf Course flows towards the Nevin Fish Hatchery. Using effluent for turf irrigation would ensure that the majority of the effluent is used for plant growth. The golf course was already using treated effluent in one of its sprinklers, to irrigate Hole 7, and the golf course manager, Sam Schultz, had expressed interest in expanding the use of the effluent. For these reasons, the group decided to look into expanded effluent use at this site.

3.2.2 Wetland Site Selection

The effluent line directed to Badger Mill Creek runs near and through sections of the Nine Springs Wetlands in Fitchburg. Given the proximity of the line to these wetlands and the known ability of wetlands to treat contaminated inflows, the group identified the wetlands as another potential receiving area for the treated wastewater from MMSD. The particular wetland site chosen was convenient based on its proximity to the effluent return pipe. Furthermore, the soils and ecosystems were well-understood: several researchers from UW-Madison have completed research projects in the wetlands in the past. The 1996 WRM Practicum characterized the Nine Springs watershed, its land and water quality, and its ecosystems. For her dissertation (2001), Susan Swanson created a detailed groundwater model of the Nine Springs watershed, based on fieldwork completed in and near the wetland. Michael Schwar (2002) studied wetland restoration and outlined design possibilities for a wetland restoration in the Nine Springs Wetland. Most recently, landscape architecture professor David Bart has been conducting experiments involving application of effluent to plots within the Nine Springs Wetland, which meant that permitting and an effluent delivery mode were already in place. The background information available from these projects, as well as the attractive features of the wetland itself, led the Practicum to select a portion of the Nine Springs Wetland as a potential site for a water reuse project.

Chapter 4 • Upland Site

4.1 Site Characteristics

The Upland Site is a 77 acre parcel of Wisconsin Department of Natural Resources (WDNR) owned land in the northeastern corner of Fitchburg, WI. The site is bordered by the Capital City State Trail to the north and west, Swan Creek of the Nine Springs Neighborhood to the south, and Syene Road to the east (Figure 4.1).
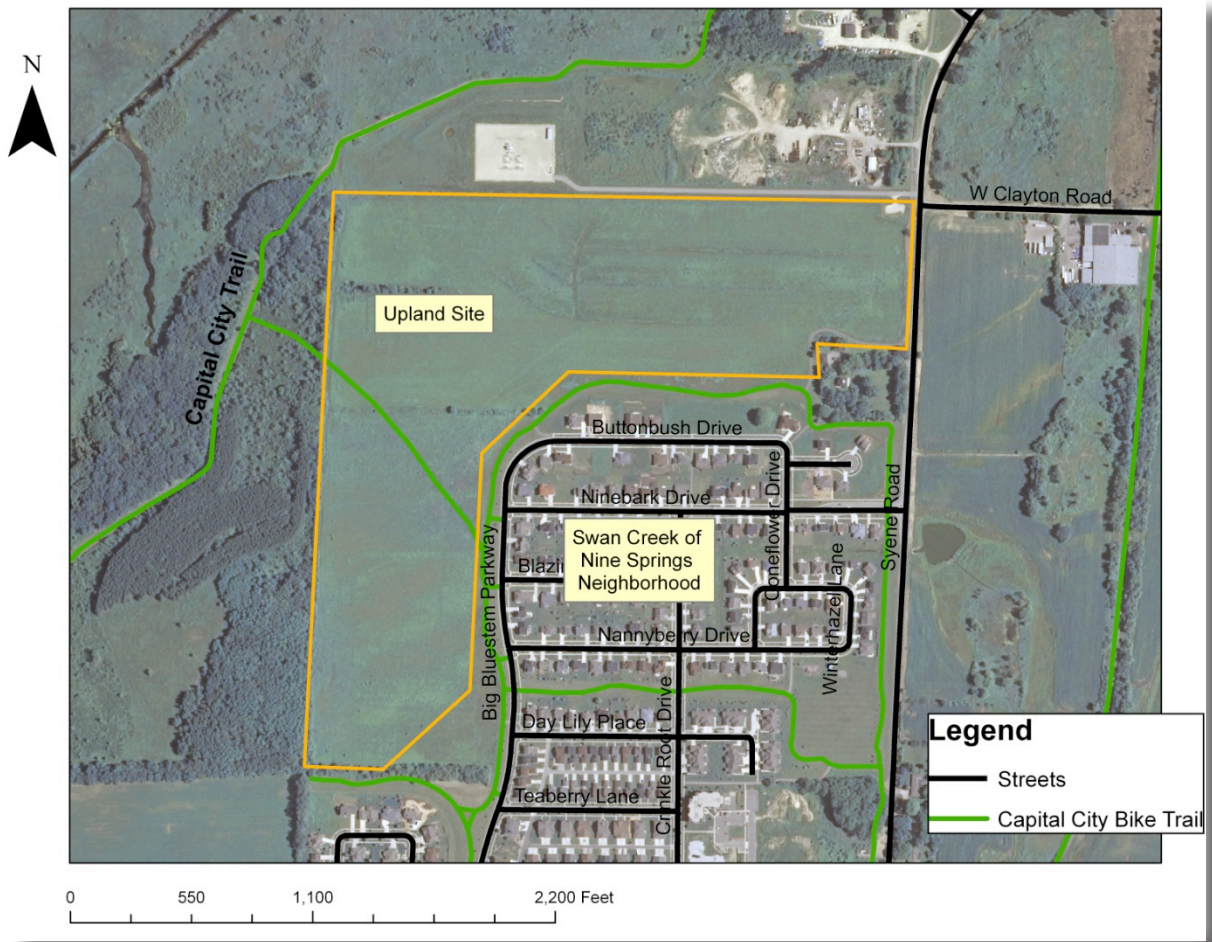
Figure 4.1. Upland Site. The Upland Site is bordered by the Capital City Bike Trail to the north and west, Swan Creek of the Nine Springs Neighborhood to the south, and Syene Road to the east.

The group chose to focus on a 6.11 acre project site at the northwest corner of the overall parcel. The closest access to Madison Metropolitan Sewerage District's (MMSD) effluent return line is 302 feet to the northwest of the site (Figure 4.2).
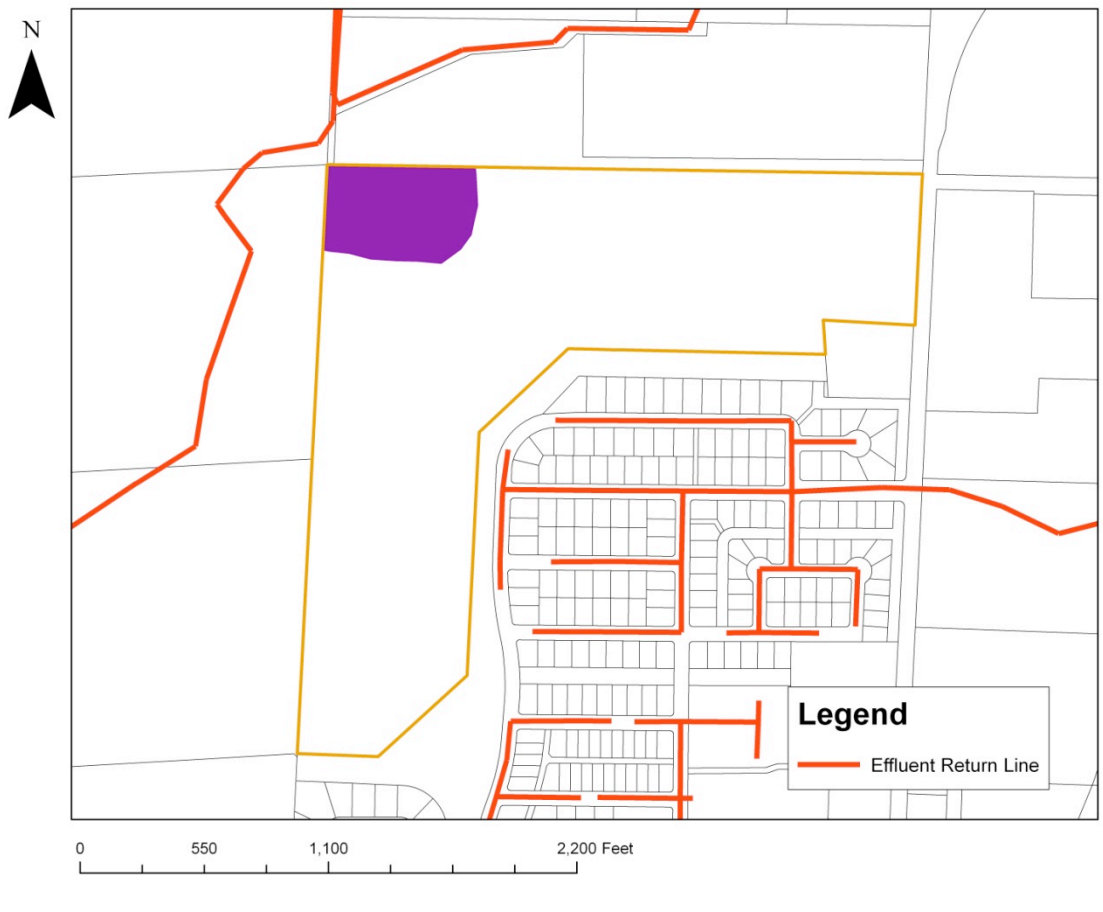
Figure 4.2. Upland Project Area. The Upland Site is the 6.11 acres in purple on the map. It is part of a larger 77 acre parcel owned by the WI DNR. The distance from the effluent line to the south west corner of the project site is 302 feet.

The parcel is part of the 285 acre Nevin Springs Unit of the larger 2,500 acre Capital Springs Recreation Area of Dane County. Purchased by the WDNR in 2006, the former agricultural field is now used as a public hunting ground. According to the WDNR, one of the land use goals of the Nevin Springs Unit is to restore the parcel to natural prairie. Presently, the site is a prairie/grassland ecosystem with profuse invasive vegetation (WDNR, 2010).

The Upland Site soils range from loams to sands. The bedrock is primarily sandstone from the Tunnel City Formation (Geological and Natural History Survey, 2005); the depth to bedrock varies from 16 to 30 feet across the site.

According to the Land Management Classification of the *Capital Springs State Recreation Area: Master Plan and Environmental Assessment* (WDNR, 2010), the area is categorized as an NR 44 Habitat Management Area. Wisconsin Administrative Code § NR 44 states, "Habitats and communities in areas with this designation may be managed for a wide variety of purposes, including focused species production and protection" (2010). A survey conducted by the group found that the site had a slope of approximately four percent over the six-acre area, with the highest elevation occurring at the southeast corner and the lowest elevation at the northwest corner (Figure 4.3 and 4.4).

The primary goal of the Upland Site was to create a facility that allows for further treatment and infiltration of the effluent in order to recharge the area aquifer. In order to accomplish this goal, the group completed a site characterization, a groundwater flow model, and a recharge design.
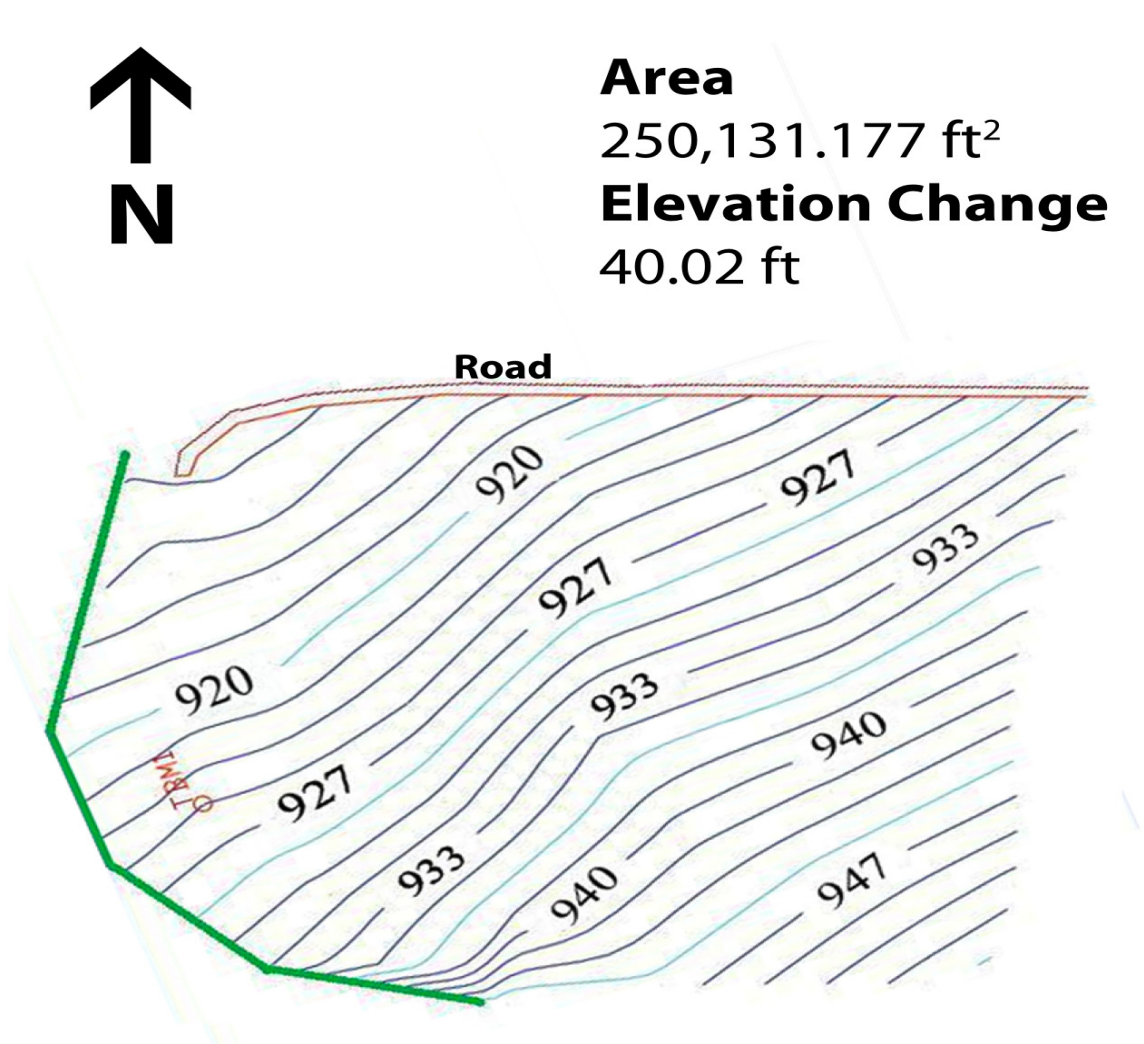
Figure 4.3. Upland Site Survey. The contours in feet of the Upland Site as established by a survey conducted by the WRM group.

NE→

clay

silt/sand

sandstone

500'

5'

10'

20'

vertical exaggeration 2:1
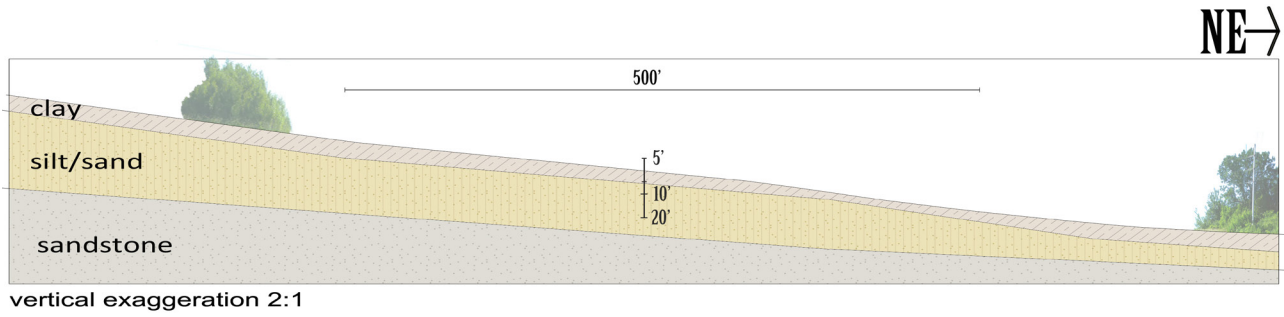
Figure 4.4. Upland Site Elevation. A cross-sectional view of the bedrock and soil layers of the Upland Site. 2:1 vertical exaggeration.

4.1.2 Soils and Geoprobing

To establish the feasibility of a groundwater recharge project at the Upland Site, the group verified the characteristics of the subsoil on the site, such as soil textures and nutrient levels, in all subsurface layers. The group took soil cores using a United States Geological Survey (USGS) geoprobe, provided and operated by USGS technicians Jim Rauman and Jason Smith (Figure 4.5). The purpose of geoprobing is to extract soil sample cores from a site in order to examine the nature of the subsurface. The geoprobe is able to retrieve samples at deeper depths than a hand auger's capability.

Figure 4.5. Geoprobing. With the help of the USGS, the group was able to take soil samples by using a geoprobe.

The group took cores, down to bedrock and the samples were taken at four-foot intervals. These cores were sealed into tubes 48 inches in length and 1.5 inches in diameter. After removing the cores from the geoprobe, hydrogeology students opened and examined the cores in the field under the supervision of Jean Bahr. The students made notes on the color, particle size, sorting, and any other interesting characteristics of each section of the core. Cores were taken with the geoprobe at six locations, labeled A-F (Figure 4.6), to obtain a representative sample of the subsurface at the site.

In total this resulted in the collection of 35 tubes. A diagram of all the core logs was completed by Jean Bahr's students (Figure 4.7). In addition, electrical conductivity profiles were taken of locations B and C. These profiles can be found in Appendix C.
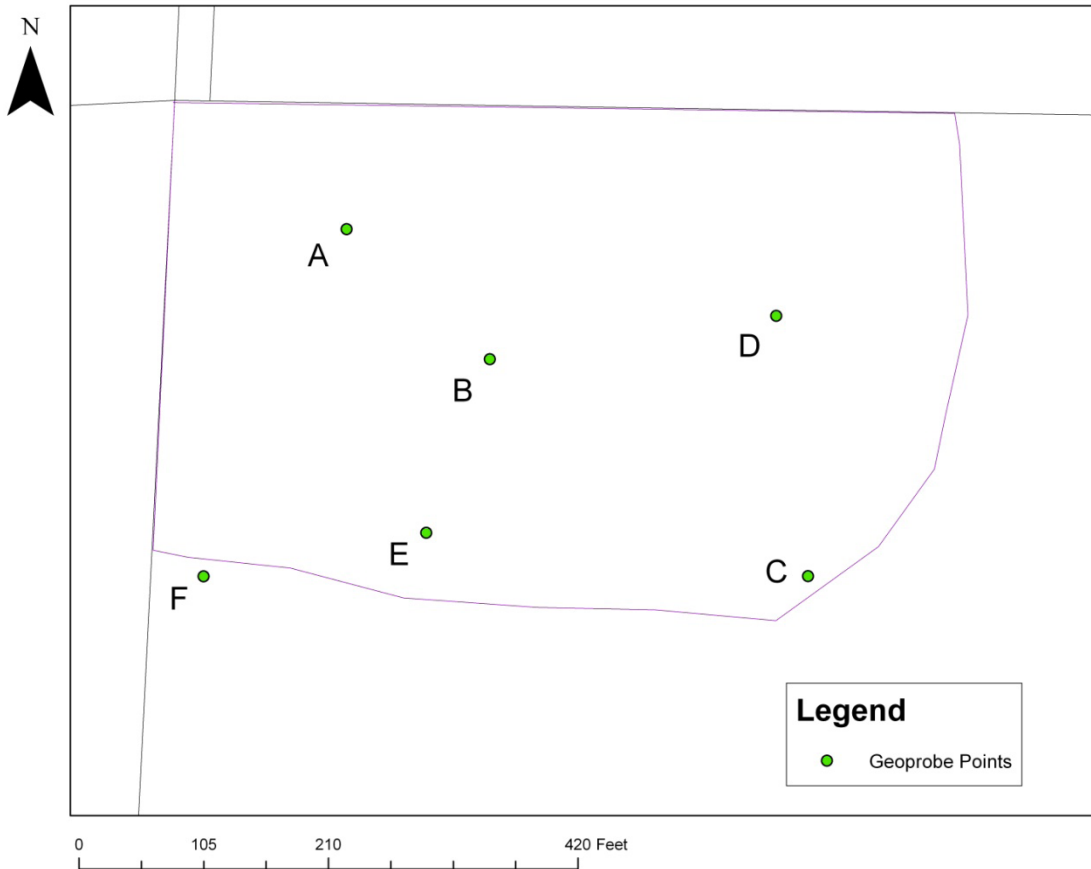
Figure 4.6. Upland Site Geoprobe Locations. Geoprobing was done at six sites within and near the Upland Site project area. These are labeled A-F.

CH	Inorganic clays of high plasticity, fat clays
GM	Silty gravels, gravel-sand-silt mixtures
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
OH	Organic clays of medium to high plasticity, organic silts
OL	Organic silts and organic silty clays of low plasticity
SC	Clayey sands, sand-clay mixtures
SM	Silty sands, sand-silt mixtures
SP	Poorly graded sands, gravelly sands, little or no fines
SW	Well-graded sands, gravelly sands, little or no fines

Table 4.1. Soil Key. The Unified Soil Classification System (ASTM, 2011) was used to identify the different soil types within the geoprobe cores. Source: ASTM. (2011). ASTM D2487-11. Retrieved August, 17, 2011 from http://www.astm.org/Standards/D2487.htm.
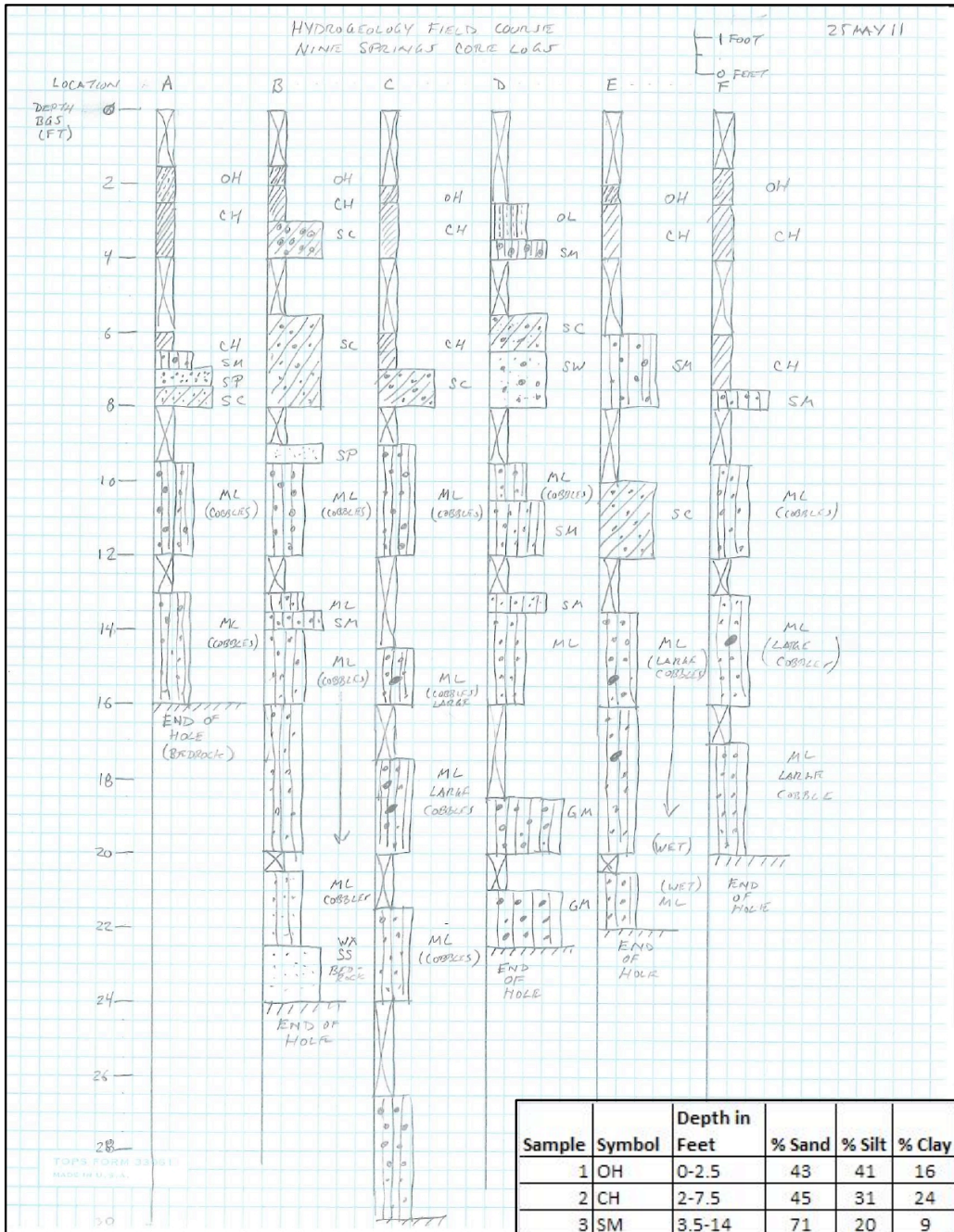
Figure 4.7. Upland Soil Cores and Soil Key. The soil cores taken via geoprobe at the Upland site were documented and diagramed.

Sample	Symbol	Depth in Feet	% Sand	% Silt	% Clay	Texture
1	OH	0-2.5	43	41	16	Loam
2	CH	2-7.5	45	31	24	Loam
3	SM	3.5-14	71	20	9	Sandy Loam
4	ML	9-32	73	19	8	Sandy Loam
5	SC	3-12	72	21	7	Sandy Loam
6	SW	6.5-8	85	12	3	Loamy Sand
7	OL	2.5-3.5	57	25	18	Sandy Loam
8	SP	7-9.5	77	18	5	Loamy Sand
9	GM	18.5-22.5	66	26	8	Sandy Loam
10	Bedrock	16-32	93	4	3	Sand

The hydrogeology students noted 10 different soil types. The group brought representative samples of the soil types to the University of Wisconsin (UW) Soil and Plant Analysis Lab in Madison, Wisconsin. The lab physically analyzed the samples to determine the percent clay, silt and sand, soil texture, Total Nitrogen (TN), and the following minerals: Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), Zinc (Zn), Manganese (Mn), Boron (B), Copper (Cu), Iron (Fe), Sodium (Na), and Aluminum (Al) (see Appendix D). The soil nutrient values were neither high nor low enough to cause concern for the project.

The physical analysis determined that the top seven feet of soil is of a loam texture with 16-24 percent clay (Figure 4.7). Ideally, soils suitable for groundwater recharge have 10 percent clay or less. The soil layers below the approximate seven-foot mark all have nine percent or lower clay content. The lower soil layers have either a sandy loam or loamy sand texture, depending upon the specific layer. The bedrock, which is sandstone, has a sandy texture and is composed of 93 percent sand.

In addition, the group used soil samples from the low-plasticity silt (ML) layer (Sample 4) and from the sand/clay (SC) layer (Sample 5) (Table 4.1) in column test experiments to determine the hydraulic conductivity of the soils.

Cylindrical columns were packed with the soils and completely saturated with water (Figure 4.8). Then water was fed into the columns and the rate of water discharge was observed. Four replicate trials were conducted for each soil. These numbers were then used to calculate the hydraulic conductivity for each soil. For the ML layer the hydraulic conductivity was found to be 9×10^{-3} feet/day (ft/day). The SC layer had an average value of 6×10^{-3} ft/day. These column tests provide a low estimate of the hydraulic conductivity of these soils and may not accurately represent field conditions. If a 5-acre site were used as a recharge basin, the hydraulic conductivities associated with the permeameter tests for the ML and SC layers would only generate recharge rates of 0.018 and 0.012 million gallons per day (MGD) respectively, levels much lower than the goals of the Practicum.

Figure 4.8. Column Test. Two of the sampled soils were used in the shown set-up for column tests.

Although the nutrient levels and clay content were found to be acceptable in some of the soil layers, the column tests showed that the hydraulic conductivity of these layers is too low to recharge significant volumes of water. Any recharge project constructed on the Upland Site would need to use media other than the existing soils.

4.1.3 Current Vegetation and Wildlife

In characterizing the Upland Site, it is important to consider the current vegetation and wildlife that would be affected by a groundwater recharge project. The WDNR has a Natural Heritage Index (NHI) database that contains recent and historic observations of endangered, threatened and special concern species for the townships and ranges in Wisconsin. The database contains both federal and Wisconsin species of concern. The database in use at the time of this writing was updated October 6, 2009. Within the township and range of the project area (Township: 06N, Range: 09E), the NHI indicates that there are no mammal, bird or insect species listed for the area. However, 12 plant species that are either threatened or of special concern were listed.

4.1.3.1 Vegetation

The group compiled a complete list of plants species on the Upland Site by walking the project area and identifying all species on-site. Any species unclassified in the field were collected and taken to the Wisconsin State Herbarium on the UW-Madison campus where Ted Cochrane assisted in the identification. Cochrane also assisted in the identification of native versus introduced species (T. Cochrane, personal communication, July 2011). The species list can be found in the Appendix E.

In addition, the group completed a map of plant communities based upon the dominant species of the area. A species was considered dominant if it represented more than 50 percent of the vegetation coverage of an area. If there were no dominant species, the area was categorized as a plant community based upon the species composition. A map of the predominant vegetation in the wooded area next to the project site was completed prior to the acquisition of the project area by the WDNR (Figure 4.9). By sampling the vegetation, the group was able to determine the dominant species and build upon the work previously completed by the WDNR.

In order to map the vegetation communities, the group first visually noted the change in dominant species on the site and then took GPS points along the edge of the different sections of vegetation. The group entered the points into ArcGIS and created polygons to represent sections of different vegetation. Only two major vegetation communities were noted on the site: a reed canary grass-dominated community (*Phalaris arundinacea*), which occurred on the northwest corner of the site, and a mix of prairie species, which covered the rest of the site (Figure 4.10). To ensure the accuracy of this map, it should be compared with aerial photos of the site. Unfortunately, no recent aerial photos that show the current vegetation of the site exist.
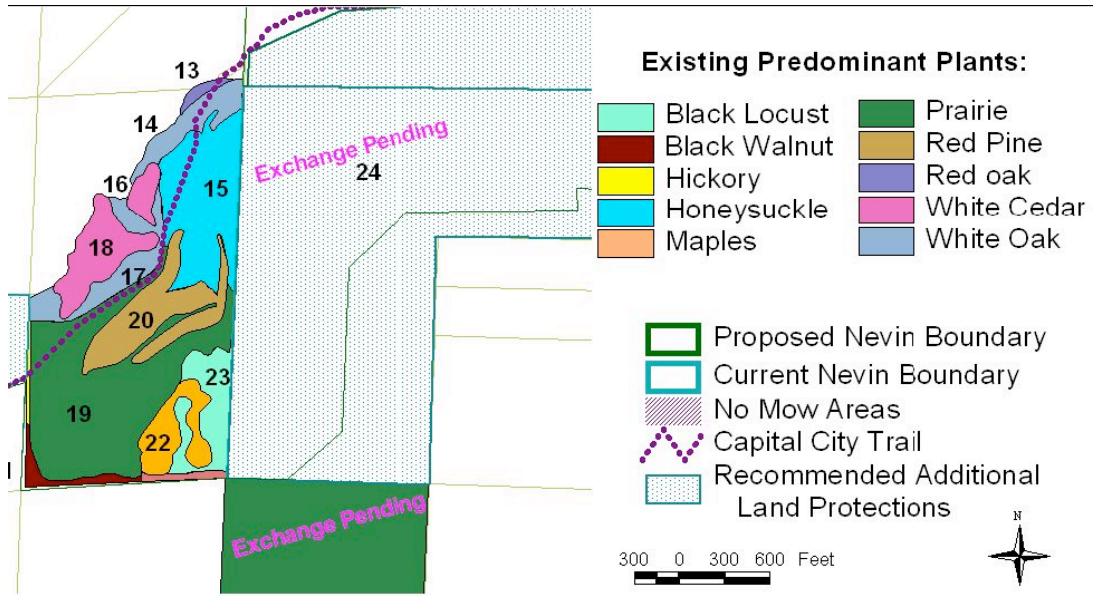
Figure 4.9. Plant Communities Near the WRM Project Area as Determined by the WDNR. Source: Wisconsin Department of Natural Resources, 2000, Nevin Springs Fish & Wildlife Area: Property Master Plan & Environmental Assessment. Retrieved May 26, 2011 from http://dnr.wi.gov/master_planning/completed_archive/fa_wa_nra/nevin.pdf
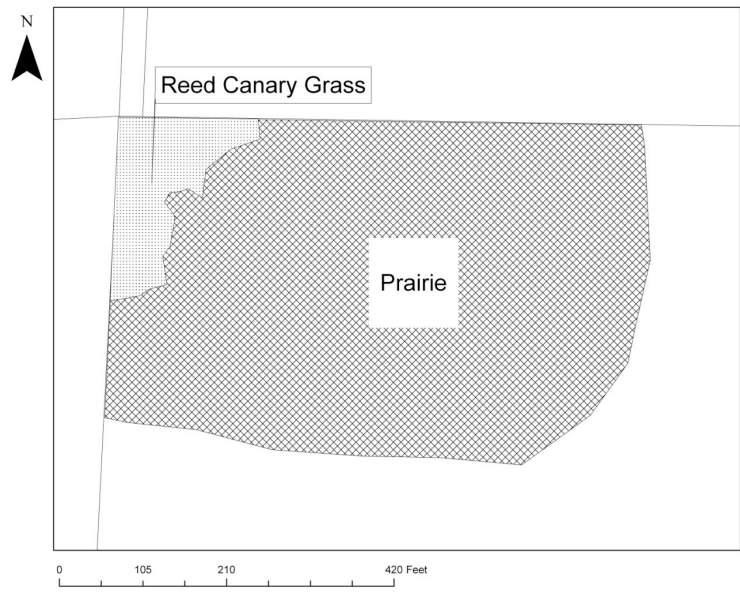
Figure 4.10. Upland Plants. There are two distinct areas of vegetation within the Upland Site. The northwest corner is dominated by reed canary grass while the rest of the site is predominately prairie species.

4.1.3.2 Wildlife

Few mammal species were located in the Upland Site. Only four species were observed during the site investigations. Hunting is allowed on the site for all of the species except for coyotes. Trapping of raccoon and beaver is also allowed on the Upland Site (WDNR, 2010). However, the group has not seen either of these species on the site.

During the group's time on the Upland Site, 17 species of bird were observed. The most commonly observed species were the Red-winged Blackbird (*Agelaius phoeniceus*) and the Common Yellowthroat (*Geothlypis trichas*). No rare or uncommon bird species were observed on the Upland Site. The complete list of bird and mammal species for the Upland Site can be found in Appendix E.

4.1.4 Groundwater Flow and Transport Modeling

The hydrostratigraphy of the region surrounding the Upland Site is an indication of its capability of recharging groundwater. Although many geologic features exist in the subsurface, the deep aquifer, the shallow aquifer, and the confining layer between the two aquifers are most significant for the Practicum. The deep aquifer, also known as the Mount Simon aquifer, is made of Cambrian age sandstone between 500 and 800 feet thick (Bradbury et al., 1999; Swanson, 2001). Due to its size and highly porous flow, the Mount Simon aquifer supplies municipal and industrial high capacity wells in Dane County (Bradbury et al., 1999). The shallow aquifer, known as the Upper Bedrock aquifer, is composed of sandstone and dolomite and provides water for the domestic wells in the rural parts of Dane County. The Eau Claire shale aquitard separates the deep and shallow aquifers. This regional aquitard only reaches a maximum thickness of 18 feet and is completely absent in some areas, including beneath the Yahara Lakes (Bradbury et al., 1999) (Figure 4.11).
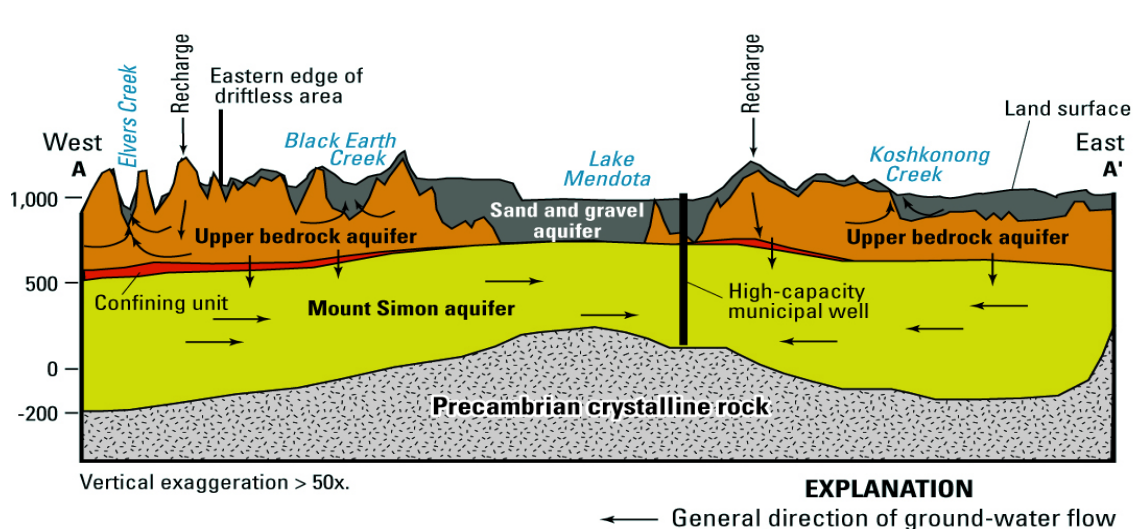
Figure 4.11. Hydrostratigraphy. The upper aquifer is separated from the deep aquifer, the Mount Simon aquifer, by the Eau Claire aquitard (in red). Source: United States Geological Survey, 2001, The effects of large-scale pumping and diversion on the water resources of Dane County, Wisconsin (USGS Fact Sheet FS-127-01). Retrieved from http://wi.water.usgs.gov/pubs/fs-127-01/fs-127-01.pdf

Groundwater modeling indicates the movements within the shallow and deep aquifers and across the Eau Claire aquitard. Specifically, the group aimed to determine the rate at which water could be applied as enhanced recharge without creating substantial groundwater mounding and to determine the flowpath of the recharged water once it reached the aquifer. All the groundwater modeling was done with Groundwater Vistas (GWV) Version 5.51, a graphical user interface that can be used with the USGS codes MODFLOW and MODPATH. The MODFLOW version used was the Original (88/96) while particle tracking was done with MODPATH. The model used was Sue Swanson's Nine Springs Model that was received from Steve Gaffield, a hydrologist with Montgomery Associates, and was developed as a telescoped local model from the Dane County regional model (Swanson, 2001). This model consists of 152 rows, 208 columns and 6 layers of varying thickness. Each cell has an area of 328 ft by 328 ft. Susan Swanson reports that the final calibration of her model has a root mean square error of 26.08 ft for hydraulic head (2001). The model also has a mean error of -3.19 ft and a mean absolute error of 18.50 ft (Swanson, 2001).

The first step in the process was to determine the location of the Upland Site within the model. Felipe Avila from the City of Fitchburg sent ArcGIS shape files to estimate the location of the Upland Site using roads and bodies of water. Once a reference point was determined, for example the intersection of US Highway 151 and Fish Hatchery Road, the distance of the site from that reference point was estimated using known distances from the GIS data and GWV cell size. Next the site shape was estimated in GWV from the known site size in the ArcGIS shape file.

The next step in the process was to add the estimated enhanced recharge and map flow paths from the recharge site to discharge points down gradient, by a method known as "particle tracking." It should be noted that the particles are imaginary and used simply as a mechanism to delineate groundwater flow paths. For modeling of recharge at the Upland Site, the two cells represented five acres of the project area. The recharged volumes that were simulated ranged from 0.25 to 1.5 MGD. The group tracked the groundwater flow using particle tracking from the MODPATH package. Prior to simulation, a circle of 10 particles, with a Z offset of one, was added around the site. The particle tracking showed that all groundwater from the recharge area would flow to the south and east toward private wells, except at the lowest recharge rate of 0.25 MGD. At this rate, the path went north to the Nine Springs Creek. However, further investigation showed that a maximum rate of 0.40 MGD only initially flowed to the south. It then turned to the north and avoided any private wells (Figure 4.12).

Travel times for the simulated particles were also calculated. For calculating the travel times, the porosity of the top unlithified layer was specified to be 0.25 while the rest of the layers had a value of 0.10. These porosities were established by Swanson (2001) and are built into the Nine Springs Model.
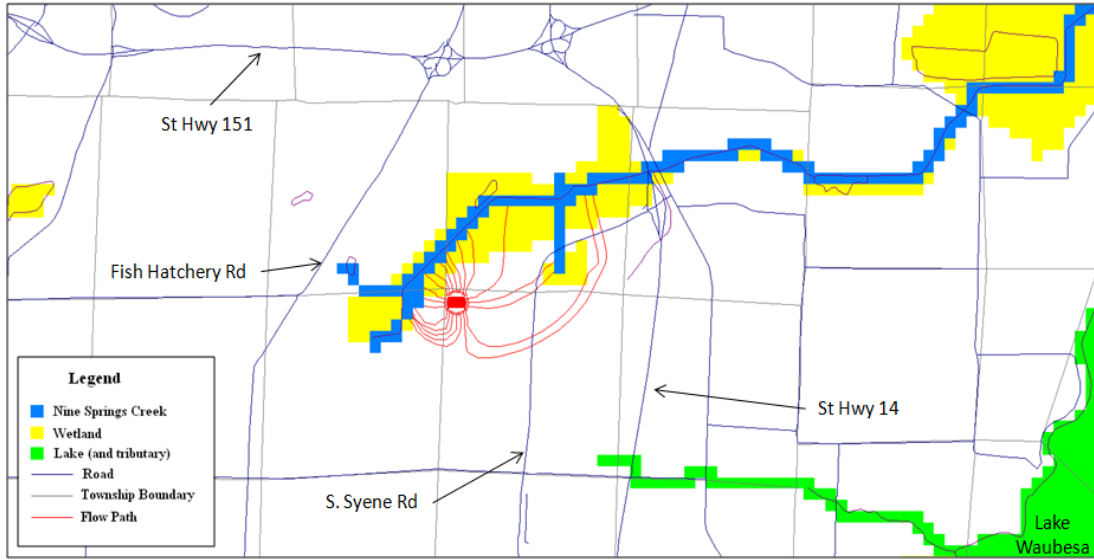
Figure 4.12. Particle Tracking. At a level of 0.4 MGD, all particles tracked from the Upland Site flow toward the wetland.

Another concern addressed by GWV was groundwater mounding. Groundwater mounding in the context of this report is defined as the rise of the local water table above the average level due to enhanced groundwater recharge in a concentrated area. If the recharge rate is too high, the infiltration rate will exceed the rate at which water percolates through the soil to the water table and flows laterally away from the site of recharge. This causes the groundwater to build up. Groundwater mounding causes complications since it lowers recharge rates (Zomorodi, 2005), altering the timing and quantity of groundwater reaching the water table. This has significant consequences for water resources and for the potential movement of pollutants into the groundwater (Lee, 2006).

The following factors need to be considered in order to prevent significant mounding from occurring (Tsay, 1997):

- Local and regional recharge rates

- Hydraulic conductivity of the soil and bedrock

- Flow/head control locations

- Saturated thickness of the aquifer

- Regional flow in the aquifer within the vicinity of the mound

The MODFLOW results suggest recharging at a rate of 0.40 MGD. At this rate, only small amounts of mounding would likely occur. The mounding analysis results (Table 4.2) show that at 0.75 MGD, vertical mounding increases, which may send water intended for recharge to Lake Waubesa in addition to the Nine Springs Creek. When recharge increases to 1.25 and 1.50 MGD, mounding reaches unacceptable levels and creates problems, such as potential surface discharges around the facility and breakout surface discharges down slope from the facility. The results of the mounding analysis agree with the recommendation to recharge 0.40 MGD based on flow path results

Recharge (MGD)	Highest Groundwater Elevation (ft)	Amount of Mounding (ft)
1.50	1070	200
1.25	1040	175
1.00	1020	150
0.75	980	120
0.50	950	90
0.25	890	20

Table 4.2. Modeling Values. This table illustrates the height of groundwater elevation and the amount of mounding caused by various amounts of water used in the GWV model.

Lastly, the group ran a few test scenarios to see how a change in hydraulic conductivity of the up-permost bedrock layer might affect mounding and the simulated particle paths. The area altered was 139 cells in layer 2, right under the flow lines delineated by the particle tracking. Layer 2 represents the Tunnel City formation, a glauconitic sandstone directly beneath the Upland Site (Swanson, 2011). In total, three trials were conducted, none of which significantly altered the particle paths. In the first trial, the hydraulic conductivity of the cells was decreased from five feet/day to one foot/day. The results show that there was an increase in mounding of up to 25 ft, which may raise the water table to the land surface, depending on the height of the water table. For the second trial, the hydraulic conductivity was raised to 25 ft/day. This change in conductivity increased the amount of mounding by 20 ft. In the third trial, the hydraulic conductivity was lowered to 0.5 ft/day. This amount increased the mounding by 50 ft. These results show that further fieldwork aimed at acquiring a more accurate hydraulic conductivity of the local Tunnel City formation, could make a significant difference to mounding but not to the flow paths within the Upland Site.

4.2 Types of Constructed Wetlands

Treating wastewater through the use of constructed wetlands is becoming a more frequent practice due to its relatively low cost, energy, and maintenance requirements in comparison with a more conventional wastewater treatment facility (Kayranli, 2010). Wetlands are an environmentally-friendly means to passively treat wastewater (Halverson, 2004). Constructed wetlands use natural biological and abiotic processes to improve water quality. The three types of constructed wetlands, surface flow (SF), horizontal subsurface flow (HSSF), and vertical subsurface flow (VSSF) (USEPA, 2004) all have the ability to further treat effluent at the Upland Site.

Constructed wetlands can remove components of concern from the effluent through physical and biological processes such as nitrification and DE nitrification, sedimentation, adsorption, and precipitation (Garcia-Aledo, Ruiz-Rueda, Vilar-Sanz, Sala & Baneras, 2011; Kadlec & Wallace, 2009). P removal is limited to substrate sorption, plant uptake, and the creation of new substrate (Kadlec, 2005). Table 4.3 shows some of the relative benefits and limitations of the different types of constructed wetlands. Elements of this table were used in the site design process, along with the site's individual characteristics and the Practicum's goals.

4.2.1 Surface Flow Wetlands (SF)

SF wetlands typically consist of shallow basins that contain a saturated substrate composed of soil or sand and enough ponding to create habitat for emergent, submergent, and floating vegetation. Microbes remove pollutants from the water through biological processes while the water passes above the surface through the vegetated wetland (Kadlec & Wallace, 2009). Basins are usually confined within a plastic, concrete, or very low-permeable substrate liner to prevent contamination of groundwater beneath the wetland (Scholz, Harrington, Carroll, & Mustafa, 2007). Studies have determined that treatment efficiency is positively correlated with hydraulic residence time, wetland area, and number of cells. Square and circular shaped cells, with a length to width ratio approaching one, provide the highest treatment. High residence time can be achieved by low gradients to produce a minimal flow velocity (Scholz et al., 2007). Appendix F contains additional information on SF wetlands.

4.2.2 Subsurface Flow Wetlands (SSF)

SSF flow wetlands are broken down into two major types: HSSF and VSSF. In HSSF wetlands, water usually enters the system through an inlet pipe, flows just beneath the surface through the filtering substrate of the emergent wetland plant roots, and exits through an outlet pipe to a free water surface or to an additional treatment facility. The substrate is normally saturated, excluding the uppermost layer, with no existing ponding (Brovelli, 2011; Kadlec & Wallace, 2009). Like SF systems, HSSF systems are lined with a plastic, concrete or other low permeability confining unit to prevent contamination of nearby groundwater and to force horizontal flow. HSSF wetlands are bordered at the outflow end of the system with a barrier or berm to

Type of treatment system	Logistical pros and cons		Pollutant removal rates			Additional benefits and concerns	
	Land Requirement	Costs	pathogens*	N - nitrates	P - phosphates	Recreation	Ecology
horizontal subsurface flow wetlands (HSSF)	HSSF wetlands require a large area of land comparable to SF wetlands.	HSSF wetlands are typically more expensive than SF wetlands due to the maintenance expenses of replacing media.[4]	HSSF wetlands have a HIGH removal rate of pathogens.[4]	HSSF wetlands facilitate denitrification through their anoxic conditions, which can sustainably remove nitrate-N but is less effective at converting ammonium to nitrate.[3]	Subsurface flow wetlands remove phosphates through sorption to minerals and plant matter, but since they have a limited capacity, removal rates are negligible over the long term.[3]	Subsurface flow wetlands have a low threat of disease vectors from exposure to water or pest species.	Subsurface flow wetlands have the potential for naturalistic habitat of high ecological value.
vertical subsurface flow wetlands (VSSF)	VSSF wetlands require less land than either HSSF or SF wetlands.	VSSF wetlands are more expensive per unit area than HSSF and SF wetlands due to excavation and media replacement costs.[4]	VSSF wetlands have a LOW removal rate of pathogens.[4]	VSSF wetlands facilitate high rates of ammonium nitrification due to frequent oxygenation of pulsed systems. Thus they are often a sources of nitrates and provide no sustainable N removal.			
surface flow wetlands (SF)	SF wetlands have the largest land area requirements.	SF wetlands are generally less expensive than SSF wetlands due to low maintenance costs and economies of scale.[1]	SF wetlands have a MEDIUM removal rate of pathogens due to additional pathogen loads from animal wastes.[4]	SF wetlands facilitate multiple nitrogen pathways: ammonification, nitrification and denitrification. Sustainable removal of nitrogen through the coupling of the latter two processes.	Phosphate is sustainably removed from the water column through accretion of sediments and organic matter.[2] This process requires a large land area.	SF wetlands harbor nuisance species and disease vectors such as mosquitos and other pests.	SF wetlands provide the best wildlife habitat of the technology evaluated.
Constructed wetland							

Table 4.3. Pros, Cons and Relative Performance Benefits of Three Types of Constructed Wetlands. Citations: 1(Halverson, 2004) 2(Kadlec, 1997) 3(Vyamazal, 2005) 4(Kadlec &Wallace, 2009)

prevent further flow through the substrate and to ensure all treated water exits via the outlet pipe (Kadlec & Wallace, 2009).

VSSF systems cycle through periods of ponding, saturation and unsaturation (Brovelli, 2011; Knowles, 2011). In contrast to HSSF systems, VSSF systems require occasional ponding to increase the hydraulic head, to encourage flow, and, in some systems, to create anoxic conditions for immobilization of metals and DE nitrification. VSSF systems, however, have high levels of oxygen flow relative to HSSF systems and this increases their ability to provide nitrification (Halverson, 2004; Kadlec & Wallace, 2009). Like both previously mentioned constructed wetlands, VSSF systems in North America normally contain emergent vegetation and gravel substrates (Kadlec & Wallace, 2009).

In addition to using each design independently, it is also becoming popular to maximize treatment ability by combining designs into hybrids. This includes a combination of either both SSF systems together, or a SSF system with a SF system. Studies show that hybrid systems are more efficient than either HSSF or VSSF systems on their own, require less labor, lower operational expenditures, and improve surface water quality (Yeh & Wu, 2009). Appendix G contains additional information on SSF wetlands.

4.3 Soil Aquifer Treatment (SAT)

Although not a wetland, another way to recharge groundwater and treat effluent is via a SAT system. In a SAT system, effluent is applied to the ground surface where it then travels through the soil layers and into the aquifer. Treatment occurs during the effluent movement through these layers. Usually, a well is located down gradient from the SAT where the effluent can be extracted and used for other purposes. The well, however, is not necessary and effluent could be allowed to flow uninterrupted through the aquifer. SATs can effectively remove all suspended solids, bacteria, and viruses (Pescod, 1992). One study found a four to five order of magnitude reduction in bacteria and removal of all detectable viruses after flow through a SAT (Nema, Ojha, Kuma, & Khanna, 2011). SATs can also reduce levels of N, P and heavy metals (Pescod, 1992).

4.4 Wildlife Habitat and Aesthetic Appeal

Any treatment system or groundwater recharge project will contain aquatic plants that perform the following structural and mechanical benefits (Kadlec & Wallace, 2009):

- Increasing sedimentation by reducing mixing and inducing flocculation

- Increasing surface area for biofilm formation and sediment capture

- Reducing algal growth and water temperature

- Increasing oxygenation of the soil and water column through the rhizosphere

Studies show that the physical structure, rather than the species composition of the aquatic plant community, has a greater effect on the function of treatment systems. In a review of 35 studies by Brisson and Chazarenc (2009), no single species improved the performance of treatment systems above any others. However, a few traits make some species more successful in colonizing treatment systems. Plants with a quick rate of maturation, combined with complex underwater root structures, cold-climate adaptations, and a tolerance to high levels of pollutants and unnatural water regimes, all quickly colonize treatment systems. Three of the most common adaptable aquatic plants in North America include Cattail *Typha* spp., *Bulrush Scirpus* spp., and Common Reed, *Pragmites australis* spp. (Kadlec & Wallace, 2009). Many studies show these species survive in subsurface and surface wetlands and quickly establish dominance but often trend towards monocultures.

However, since few performance differences exist among wetland plants, the group made plant selections based on the auxiliary benefits of a vegetation community. Thus, recreation, aesthetics, wildlife habitat, and ecological value all become important considerations. Most of these benefits can be maximized by planting polycultures that mimic the composition of native plant communities. The depth of surface water and the frequency of flooding then become guiding factors in deciding what plant communities can be established.

SF treatment wetlands can be colonized with a mix of the plants found in emergent marsh communities. The dominant macrophyte species of emergent marshes in Wisconsin, "include cattails (Typha spp.), bulrushes (particularly *Scirpus acutus*, *S. fluviatilis*, and *S. validus*), bur-reeds, giant reed, pickerel-weed, water-plantains, arrowheads, the larger species of spikerush (such as *Eleocharis smallii*), and wild rice." (Pohlman, Bartelt, Hanson III, Scott & Thompson, 2006). Emergent marshes provide habitat for a wealth of amphibians, reptiles, mammals, and birds, including 53 threatened or endangered species (Pohlman et al., 2006). Most emergent marsh plants will also thrive in SSF wetlands where the soil remains constantly saturated but water stays below the ground surface. In addition, SSF wetlands can be planted with species that are typically found in sedge meadows and wet prairie ecosystems.

Wet prairies can be established in essentially any system with a pulsed water flow and without standing water present for the entire year. This includes SSF wetlands, rain gardens, or soil aquifer treatment systems. The dominant species of these communities are a variety of grasses, sedges, and flowering herbs including: Canada bluejoint grass (*Calamagrostis canadensis*), cordgrass (*Spartina pectinata*), prairie muhly (*Muhlenbergia glomerata*), lake sedge (*Carex lacustris*), New England aster (*Aster novae-angliae*), northern bedstraw (*Galium boreale*), golden alexander (*Zizea aurea*), and prairie blazing-star (*Liatris pycnostachya*). Wet prairies also support a diversity of open field song birds, mammals, reptiles, and a variety of threatened species including the bobolink and the eastern prairie fringed orchid (Pohlman et al., 2006; J. Harrington, personal communication, July 2011).

For soil aquifer treatment systems that require a high infiltration rate, John Harrington, a professor of Landscape Architecture at UW-Madison, recommends planting a wet prairie dominated by warm season grasses that are tolerant to a range of hydrological regimes such as: *Andropogon gerardii*, *S. pectinata*, *C. canadensis*, *Carex* spp., *Scirpus* spp., and *Eleocharis* spp (J. Harrington, personal communication, July 2011). These plants could be expected to aid in infiltration due to their deep spreading root systems, but they would likely require some annual maintenance (burning or harvesting) in order to prevent the accumulation of organic matter that results from decreasing the hydraulic conductivity of the infiltration basin.

4.5 Sample Recharge Design

The Practicum's design for the Upland Site allows for advanced treatment of MMSD's effluent and directs the treated wastewater to the aquifer at a reasonable rate. Infiltration basins (basins 1-3, Figure 4.13) are paired with HSSF wetlands (basins A-C, Figure 4.13) to allow for water quality treatment, groundwater recharge, and environmental enhancement without interfering with the Upland Site's current use as a public hunting ground. The design was based on the specification that only 0.4 MGD of effluent should contribute to groundwater recharge at the site, as suggested by the groundwater flow modeling results.

An infiltration basin is simply an impoundment meant to hold water while it percolates into the ground. The basins for this project were designed using the known limits of the soils, based

upon work completed by the group, and the bedrock at the site. It would have required more area than was available within the project site to infiltrate water through the sands and loams of the upper layers of the subsurface. An excavation to the bedrock, however, would allow for sufficiently fast percolation. The hydraulic conductivity of the bedrock is assumed to be 5 ft/day in the area around the Upland Site based on values used in the ground water model of Swanson (2001).

Consequently, the design requires a minimum of 0.25 acres to be excavated to the bedrock for each infiltration basin. The excavated area should be filled with a medium that has a hydraulic conductivity greater than or equal to five ft/day, the same as the bedrock. This design would allow an infiltration basin to generate 0.4 MGD of recharge. In order to allow for maintenance and to ensure the longevity of the system, two to three infiltration basins should be constructed. To achieve the 0.4 MGD goal, one basin would be used at a time while the others rested.

The group chose to include HSSF systems because they offer the best means to remove nitrates (NO_3^-) through DE nitrification. The effluent currently exceeds the Wisconsin groundwater regulation of 10 mg NO_3^-/L. Studies suggest that a retention time of two to eight days is adequate for N removal (USEPA, 2000; Alberta Environment, 2000; Garcia et al., 2005; Halverson, 2004). For this project, a three-day residence time was deemed sufficient.

To allow flows of 0.4 MGD while retaining the water for an average of three days, the HSSF wetland cells are designed to cover approximately five acres (A-C, Figure 4.12). The design sets the flow depth at two feet and assumes the fill material has a porosity of 37 percent (Kadlec & Wallace, 2009). The HSSF wetland design includes three parallel cells, which flow simultaneously. The cell dimensions are 200 feet wide by 360 feet long, in keeping with USEPA guidelines (USEPA, 2000). Each treatment wetland has a 0.1 percent slope, creating a 0.5-foot head drop over the length of a cell.

The group analyzed variations to the above design (Table 4.4).

Retention Time (days)	Required Area (acres)
1	1.66
2	3.32
3	4.98
4	6.64
5	8.29
6	9.95
7	11.61

Table 4.4. Wetland Area Required for Various Retention Times. Several calculations were run to determine the wetland surface area required to meet a specific retention time

The alternative designs address the following two scenarios:

- Recharge goal increases or decreases, retention time remains at three days

- Recharge goal remains at 0.4 MGD, retention time increases or decreases

The group estimated the required hydraulic conductivity of the soil medium using Darcy's Law and the above flow rates and dimensions. The design requires a fill with a hydraulic conductivity of about 100,000 ft/day, meaning that 5- to 10-mm gravel would suffice (USEPA, 2000). It should be noted that the medium would become less permeable over the course of the wetland's lifetime, leading to lower possible flows. In order to maintain the 0.4 MGD flow, the wetland could be further divided into parallel sections. Then the number of sections receiving flow and the total area of the wetland could be increased over time.

Effluent would flow from the pipeline to the HSSF wetlands to one of the infiltration basins. If the rate of recharge in the basins failed to reach the rate of inflow, flow would be diverted by a spillway to the wetland to the north (Figure 4.13).

The collection system is designed to receive flow from all three subsurface flow wetlands (A, B, C) and channel it to one of the three infiltration beds (1, 2, 3). Each bed is designed to receive and infiltrate the maximum hydraulic load from all three wetlands. The collection manifold will alternate flow between each infiltration bed. A pulsed flow will allow accumulated biofilms to decompose and maintain the maximum hydraulic conductivity of each bed.

The distribution system will receive influent from the return line and divide the flow equally among the 3 treatment wetlands (A, B, C).

Figure 4.13. Upland Site Bed Plan. Zones A, B, and C are horizontal subsurface flow wetlands that each receive 1/2 of the total flow. Zones 1, 2, 3 are infiltration beds. Each infiltration bed is sized to receive and infiltrate the total hydraulic load from all three wetlands. Arrows indicate the direction of the water flow.

4.6 Advantages and Disadvantages

This design has several advantages. The HSSF wetlands can be planted with native vegetation and can be filled with a substrate more easily replaceable than the natural soil, making contaminant removal more effective. The redundant infiltration basins allow for wetting and drying cycles in case clogging becomes a problem. They also ease maintenance operations. The spillway allows flow rates into the area to be maximized without leading to overland flow beyond the basins. Furthermore, the division of the design into numerous cells and basins eases expansion or contraction of the project; if longer retention times are deemed necessary, more treatment wetlands can be added. If the quality of the effluent improves and shorter retention times are permissible, more infiltration basins can be added to accept the larger flows.

However, there are a few disadvantages to this design as well. Generally, HSSF wetlands are more expensive to construct than SF wetlands. SSF wetlands also have issues with clogging and substrate saturation for certain nutrients. More information about this can be found in Appendix G. Information on the factors affecting the life-span of the constructed wetlands can be found in Appendix H.

4.7 Recommendations

MMSD and the City of Fitchburg should use the Upland Site for an enhanced groundwater recharge project. In order to both treat effluent and allow groundwater recharge, a two-part system will be necessary. The first part would consist of a single or multiple treatment wetland(s) to further refine the effluent and remove components of concern such as P, N, and bacteria. The second part would be an infiltration basin excavated down to the bedrock to allow water to penetrate into the unconfined aquifer. The permeability of the soils above the bedrock is too low to allow for large amounts of recharge. Although it would be possible to construct a single flow path system, a system involving multiple wetlands and infiltration basins would allow for continuous flow even during maintenance and prolong the life-span of the entire system. The wetlands and infiltration basins should be planted with a polyculture of native vegetation. This vegetation would treat the effluent, create a diverse ecosystem, and create an aesthetically appealing site for users of the hunting ground and Capital City State Trail. Finally, it is possible to expand designs beyond the 6.11-acre scope of the Practicum's project site. The example recharge project presented above was partially limited by the size of the area that the group chose to investigate. A larger area would likely allow more effluent to be treated and recharged. In addition, since the group only had time to initially investigate a single site, there may be other, more suitable, sites in the Fitchburg area for a recharge project. Further site scoping and characterization should be carried out in the surrounding area to find other potential sites for additional groundwater recharge projects.

The group also recommends using the Upland Site to educate the public about water reuse. Signs describing the project and its goals could be placed along the bike trail for community members to see. A similar sign is currently in use at the Nine Springs Golf Course to discuss its use of effluent for irrigation. In addition, walking trails could be added through or near the treatment wetlands to allow the public a closer look at the system. These ideas would not only inform the public about the project but also possibly improve public perceptions of effluent use.

Chapter 5 • Wetland Site

5.1 Introduction

The Practicum explored the possibility of applying treated wastewater to the Nine Springs Wetland in a manner that would simultaneously improve the wetland and the quality of the effluent. The water table within the wetland has fallen in recent decades, compromising the health of a wetland area that was already disturbed by agricultural use and degraded by the spread of invasive species. The groundwater levels would eventually rise if an enhanced groundwater recharge project were launched in a local recharge area, such as at the Upland Site. Rather than implementing an enhanced recharge project and waiting for improvements to become noticeable, the Madison Metropolitan Sewerage District (MMSD) and the City of Fitchburg could directly augment the groundwater inflows to the wetland by adding treated wastewater to the Nine Springs wetland area.

The Practicum evaluated the wetland as an additional area for water reuse. A successful project should accomplish these three goals:

- Reuse a significant quantity of effluent in the watershed

- Improve the quality of the effluent

- Support the health and biodiversity of the wetland ecosystem as well as downstream aquatic ecosystems

The group completed research, conducted fieldwork and ran computer models to determine the practicality, usefulness and implications of such a project. The group concluded that the wetland has a very limited capacity to transmit high flows, but a pilot project can begin to address concerns about the quality of the wetland ecosystem through the addition of treated wastewater.

5.2 Site Description

A series of wetlands spread across the landscape from Dunn's Marsh by Seminole Highway to Lake Farm Park by Lake Waubesa. The Practicum's investigations and designs focused on a single site (Figure 5.1).
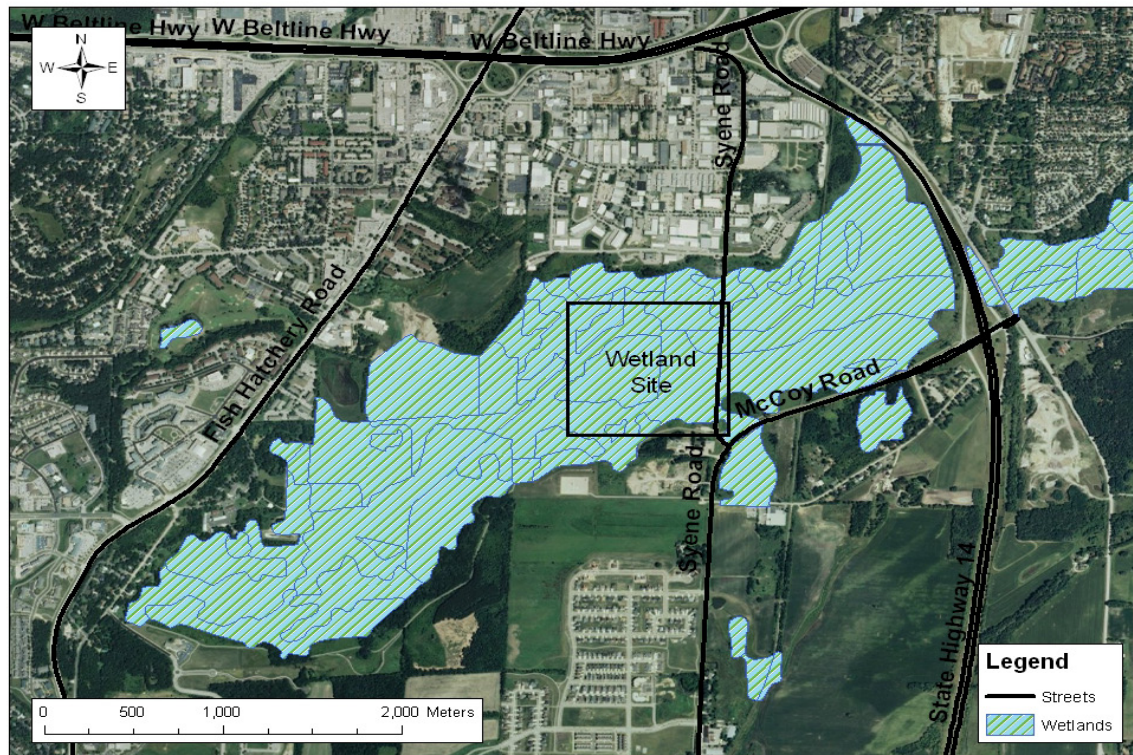
Figure 5.1. Nine Springs Wetlands and the Wetland Site Project Area.

The Wetland Site is contained within the Jenni and Kyle Preserve, which stretches across 170 acres in and around the wetlands to the west of Syene Road in Fitchburg, and is a part of the greater Capital Springs State Recreation Area. The Wetland Site covers about 50 acres in the eastern half of the Jenni and Kyle Preserve. It is enclosed by the Nine Springs Creek to the north, Syene Rd to the east, the Capital City State Trail to the south, and the remaining portion of the Jenni and Kyle Preserve to the west. MMSD's effluent return line runs adjacent to the bike trail in this area, and the closest hydrant is less than 100 yards from the edge of the site (Figure 5.2).

The wetland was once identified as a sedge meadow and, in sections where springs emerged at the surface, a fen. The creek was channelized and the wetland was drained for agricultural purposes in the first decade of the 20th century. The area was used for cattle pasture, and exotic vegetation was introduced. After the years of agricultural use ended, invasive vegetation continued to replace the native species. Currently there is a mixed vegetation community that includes sedges (*Carex aquatilis*, *C. lacustris*, *C. lasiocarpa*), reed canary grass (*Phalaris arundinacea*),

bluejoint grass (*Calamagrostis canadensis*), cattail (*Typha latifolia*, *T. angustifolia*), and giant reed grass (*Phragmites australis*) (Owen, 1995). Since the invasive reed canary grass now dominates the wetland, it is considered degraded (Schwar, 2002). In 1998, Dane County purchased the land to be a part of the Jenni and Kyle Preserve.

There is a complex soil structure at the site. Peat extends eight to ten feet below the wetland surface. The peat includes a highly decomposed layer at the surface, a dense and less-decomposed second layer, a third layer with discontinuous pockets of un-decomposed wood, and a deep layer of silt, sand and small shells (Schwar, 2002). Fine silt and clay, likely deposited in a former lake covering the area, defines a layer between the peat and the underlying glacial till and outwash (WRM, 1996). The bedrock in the area is sandstone.

Due to its land classifications, the Wetland Site must be managed in accordance with several state regulations. As a parcel within the Capital Springs State Recreation Area, the Wetland Site is regulated according to § NR 44, Master Planning for Department Properties. Activities in the wetland are also restricted by § NR 1.95, Wetlands Preservation, Protection, Restoration and Management, and by § NR 103, Water Quality Standards for Wetlands. The State of Wisconsin regulates construction activities in all wetlands, and a permit or certification from the WDNR is mandatory for excavation of soil or placement of fill.
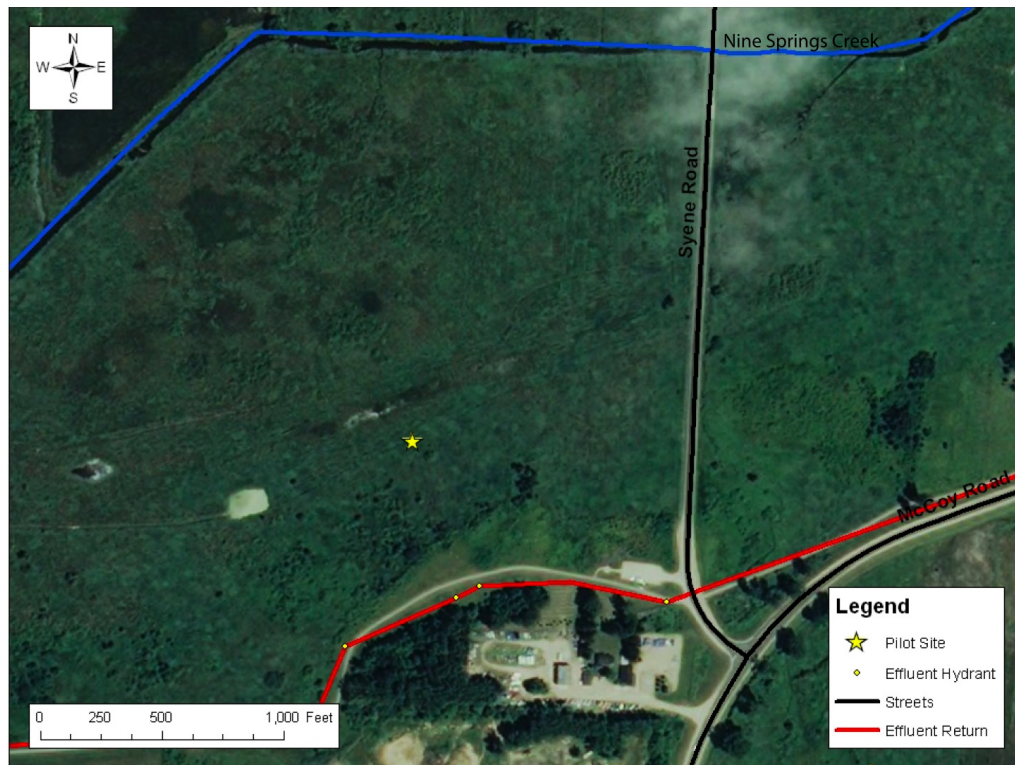
Figure 5.2. Wetland Site Project Area.

5.3 Basic Appeal: Uses for Treated Wastewater at the Wetland Site

Originally, the Practicum chose to investigate the Nine Springs wetland because the group anticipated that the site was large enough to transmit significant flows of treated wastewater, and because, in general, wetlands effectively provide advanced treatment for wastewater. Furthermore, it seemed possible that a new flow regime would support improvements and enhancements to the ecosystems in the wetlands and to downstream surface waters.

5.3.1 Introduce More Water to the Wetland and the Watershed

The practicum looked at different ways in which water could be used to enhance the wetland. The two most efficient ways to do this are to increase water storage within, or flow rates through, the wetland.

5.3.1.1 Increase Water Storage in the Wetland

The wetlands within the Nine Springs watershed are so extensive that they could receive a significant volume of treated wastewater from MMSD. Wetlands stretch with few interruptions from Dunn's Marsh to Lake Waubesa. The wetland soils are frequently saturated, but a layer of unsaturated soil lies at the surface in many areas. Treated wastewater from MMSD could be added in order to increase the soil moisture in unsaturated soils and raise the level of standing water in depressions and flat areas. In other words, the treated wastewater could be reused in the watershed by increasing the volume of water stored in the wetland.

The extent of the increase in water storage depends on initial water levels, final water levels, and the porosity of the wetland soils. For instance, if the water table had fallen to one foot below the surface of the wetland and the available pore space in the soil measured 20 percent of its volume, about 65,000 gallons of water could be added per acre to bring the water table to the surface. If water continued to be added until the water was one inch above the land surface as ponding, an additional 25,000 gallons could be added per acre. If treated wastewater were applied across a sufficient area, the total inflows to the wetlands could reach high enough rates to make the project effective.

5.3.1.2 Increase Flow Rates through the Wetland

Increasing the use of treated wastewater within the watershed could also be accomplished by increasing the water flow rate through the wetland. An addition of water would raise the water table around the point of inflow and thereby increase the hydraulic gradient and increase the flow of water through the soil and across the surface. The rate of surface flow would depend on the rate of water supply, the ability of the soil to infiltrate water, and the microtopography of the area. The rate of groundwater flow would depend on the hydraulic conductivity, a soil property that determines the ease of water transmission, and the hydraulic gradient, the change in groundwater level with distance that controls the direction of groundwater flow. The combination of steep hydraulic gradients and high hydraulic conductivities maximizes the groundwater flow.

The increases in water flow through the wetland are difficult to predict given the characteristics of the wetland soils. The soils in the Nine Springs wetland are classified as Houghton muck, a dark, finely-divided, well-decomposed soil derived from organic deposits (Soil Survey Staff, 2011). This soil is generally referred to as peat. In wetlands, where the soils are frequently saturated, peat builds up with a characteristic structure. Peats commonly feature two distinct layers: the upper layer experiences fluctuations in its water content as the water table rises and falls and has a relatively high hydraulic conductivity; the lower layer is always saturated and has a low hydraulic conductivity (Holden & Burt, 2003). These two distinct layers often cause water to flow horizontally through the upper layer rather than penetrate the low-permeability lower layer.

Across and within the layers of peat, the hydraulic conductivity is quite variable. Since the peats formed as grasses and tree branches have decomposed, the irregular arrangement of those pieces results in irregular flow characteristics. The water flows in pores, macropores, and pipes, and, consequently, measurements of hydraulic conductivity have been seen to vary across several orders of magnitude within only a few lateral yards (Holden, 2003). Chason and Siegel (1986) determined hydraulic conductivities in the saturated depths of a spring fen to range from 1.9 to 45 ft/day. In her study in a wetland downstream of the Wetland Site, Owen (1995) also observed high variability in the hydraulic conductivities; additionally, her mean hydraulic conductivity was much lower than the maximum value at 5.1×10^{-3} ft/day. Several studies have listed higher values of hydraulic conductivity in peats. Baird, Surridge, and Money (2004) made measurements of hydraulic conductivity in the root mat of a fen and found a median value of 13.7 ft/day. Their specific methodology prompted them to suggest that their tests even provided underestimates of the true values; they noted that Koerselman (1989) used a water balance approach in a similar setting and found the peat muck to have a hydraulic conductivity of 210 ft/day.

In order to confirm and refine Owen's information about the ability of the local wetland soils to transmit water, the Practicum's fieldwork included measurements of the hydraulic conductivity at the Wetland Site. Given the variable nature of hydraulic conductivities in peat and the limits of the data the group could generate during the field season, the group calculated possible rates of flow through the wetland for a variety of possible hydraulic conductivities and based on available information. Therefore, considerable uncertainty about the potential rates of flow still exists.

5.3.1.3 Wetland Flow Model

In order to estimate a range of inflows achievable at the wetland site, the group made a series of calculations based on groundwater flow properties and a simple potential design. In the design, effluent was to be applied across a 1000-foot-wide section of the wetland and allowed to flow down gradient for 1400 feet to the Nine Springs Creek. The goal was to determine the rate of flow that could be sustained from the effluent line to the wetland.

Since the results relied heavily on the value of the hydraulic conductivity, the group calculated the achievable inflow for a variety of hydraulic conductivities. The achievable inflows ranged from 28 gallons per day (gal/day) to 5610 gal/day for hydraulic conductivities of 0.5 ft/day to 100 ft/day, respectively (Table 5.1). The group concluded that, if field tests reveal that the hydraulic conductivities of the peat in the wetland are on the high end of the range, the wetland would be an effective receiving area for a significant inflow of effluent from MMSD.

Hydraulic Conductivity (ft/day)	Inflow (gal/day)
0.5	28
1	56
2	112
10	561
100	5610

Table 5.1. Modeled Potential Inflows at the Wetland Site. Inflows are given for several possible hydraulic conductivity values.

5.3.2 Provide Advanced Treatment to the Treated Wastewater

A successful water reuse project site would not only need to contain a significant volume of water, but it would need to transmit a significant volume of water in a reasonable amount of time. The rate of flow through the wetland would need to be high enough to guarantee that the project would use enough water to significantly diminish the diversion from the watershed. However, the rate of flow also would need to be low enough to give the wetland plants and soils enough time to treat and filter the water to an appropriate standard.

Finding ways to improve the quality of the treated wastewater from MMSD was a central goal of the Practicum. Due to the characteristics of their soils and vegetation, both natural and constructed wetlands have the capacity to take up excess nutrients and contaminants from the waters that pass through them. It was conjectured that the wetland area within the Nine Springs watershed had soils that might provide advanced treatment to MMSD's effluent and that current plants could be used, or new plants could be introduced, to supplement the soil treatment.

5.3.2.1 Treatment in Peat

Some constituents of the treated wastewater could be removed in the wetland soils by sorption and accretion. Sorption is the process by which a constituent such as ammonium (NH_3) or phosphorus (P) moves from the water to the surfaces of soil particles and transforms into the solid phase. Accretion is the process by which organic matter accumulates in anaerobic sediments and forms stable new residuals (Kadlec & Wallace, 2009). Removal of organic matter, nutrients, and bacteria can be achieved in the soil, but contaminants such as chlorides (Cl^-) and NO_3^- are not effectively removed by soil alone. Rather, Cl^- and NO_3^- contaminants can be removed by alternate means or concentrations can be reduced through dispersion and dilution.

The Wetland Site was particularly appealing due to its potential for P removal in the peat. Richardson and Marshall (1986) conducted studies on P removal in peat and concluded that microorganisms from the upper soil layer, including fungi and yeast, are primarily responsible for the immediate uptake of added P and that plant uptake begins only when P amounts have exceeded the microorganism sorption capacity. In their study, the combined sorption capacity for the wetland was found to be 40-83 kilogram per hectare (kg/ha) P, with sorption by microbes, 5-10 kg/ha; algae, 10 kg/ha; sedge, 10-25 kg/ha; and soil adsorption, 15-38 kg/ha. It should be noted that, like microorganism uptake, soil adsorption may become ineffective over time. Sorption sometimes only removes P effectively for one year, after which the soils can become essentially saturated (Kadlec & Wallace, 2009). At that point, P removal depends upon accretion and plant uptake, but plants, too, have a limited capacity to absorb the nutrient. Nevertheless, P removal by accretion can be a sustainable removal process. For example, a treatment wetland at Houghton Lake in Michigan has been in operation for 30 years and maintains an 88 percent mass reduction of P. A treatment wetland at Brillion Marsh in Wisconsin has maintained at least a 22 percent reduction in P concentration in 51 years of operation (Kadlec &Wallace, 2009). A water reuse project at the Wetland Site could provide advanced treatment of the effluent in the soil for years to come.

5.3.2.2 Treatment by Plants

The wetland holds potential as a receiving area for treated wastewater because the dense and diverse vegetation within it could provide advanced treatment through phytoremediation. The utilization of phytoremediation for wastewater treatment takes advantage of the natural abilities of plants to extract contaminants from water and soil by collecting them within the plants' stems, shoots, and leaves. Phytoremediation effectively removes total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, pesticides, chlorinated solvents, surfactants, cadmium (Cd), copper (Cu), nickel (Ni), Zn, lead (Pb), chromium (Cr), and organic and nutrient contaminants. This practice has been implemented to treat both contaminated water and soils and has resulted in environmental and economic benefits.

Phytoremediation relies on an intricate relationship between the plants, microbes, soils, and contaminants. The biological processes are enhanced at a pH between five and ten; a lower pH hinders vegetative growth. The microbial aspects are maximized when 60 percent of the soil pore space is filled with water (Hinman, 2005). Greater saturated states limit the available oxygen and lower microbial activity. Small pores, as found in soils with high clay content, lower the hydraulic conductivity and diffusion coefficients. This limits the availability of the contaminants to the microorganisms. There are six types of phytoremediation: phytoextraction, rhizofiltration, phytostabilisation, phytodegradation, rhizodegradation, and phytovolatilisation. The types differ in their ability to remove organic matter and/or heavy metals. Depending on the process, the chemicals will either go inside the plant through the roots or remain around the roots. If absorbed by the roots, the chemicals are stored in the roots, stems or leaves.   By harvesting the plants, the chemicals are transformed into less harmful chemicals or released into the air via transpiration. For chemicals that sorb to the roots' outer surfaces, the entire plant, including roots, must be harvested. Microbes in the near vicinity of the roots (the rhizosphere) change the remaining contaminants into less harmful chemicals. Out of the six processes, rhizofiltration involves sorption, precipitation, or uptake of toxins from water. Organic chemicals, NO_3^-, NH_3, phosphate (PO_4^{3-}), and pathogens are all present in the MMSD effluent. Plants that

exhibit the rhizofiltration process would be particularly useful additions to the wetland if it were selected to receive treated wastewater from MMSD.

In order to permanently remove pollutants from a treatment system, harvesting is often necessary. Once harvested, the plants can be discarded normally as long as any organic chemical contaminants have decayed into less harmful substances, such as water or carbon dioxide. Furthermore, according to the U.S. Environmental Protection Agency (USEPA), most plants will not accumulate a significant amount of toxins during a single growing season; therefore, the plants do not require any specific treatments or disposal methods regardless of the chemical uptake (2000b). For toxic metals that present a risk to human health, the plants undergo a controlled incineration at designated waste sites, or phytomining, before disposal. Phytomining smelts the extracted metals and recovers them for reuse. Current research is investigating the potential of sun-drying, composting, or leaching (BioBasics, 2008).

Phytoremediation holds many benefits for potential water reuse projects. In addition to treating several contaminants simultaneously, the process limits the opportunity for toxic metals to enter the food chain. It also provides a cost-effective alternative to soil excavation, which requires transport to a specified disposal site. Several factors limit the site's effectiveness for using phytoremediation. Contaminants need to interact with plant roots at about three to six feet below ground for herbaceous plants. The success of the system relies on a large surface area and local growing conditions such as climate, geology, altitude, and temperature. In areas of high contamination, or strongly sorbed contaminants like polychlorinated biphenyls, most plants will perish. Lastly, an effective phytoremediation project takes time because the plants must fully establish themselves in the ecosystem.

Several factors would influence the plant selection for a water reuse project in Fitchburg. To avoid issues with invasive species, it would be advisable to utilize only species native to south-central Wisconsin. While most plants will absorb a limited amount of wastewater nutrients, such as Zn, Fe or P, hyperaccumulators are optimal as they absorb anything, including toxic metals. The plants listed in Table 5.2 accommodate these restrictions. Unfortunately, due to a lack of re-search in the south-central Wisconsin environment, many plants are still unidentified as hyper-accumulators. For instance, water hyacinth (*Eichhornia crassipes*) thrives in high concentrations of nutrients, with a growth rate of 0.33 to 0.38 shoots per day (Kutty, Ngatenah, Isa, & Malakah-mad, 2009). With observed removal rates of 92 percent NO3-, 67 percent P, 81 percent NH3, and 49 percent of COD (Kutty et al., 2009), this aquatic plant appears ideal for the project except for the fact that it is a nonnative, aggressively invasive plant in Wisconsin. Ultimately, plant selection will depend on the central goals of a project; non-native plants can be selected to maximize the treatment ability of the wetland, but native plants can be selected to restore the wetland and provide treatment.

Common Name	Latin Name
Ragweed	*Ambrosia*
Indian mustard	*Brassica juncea*
Rapeseed	*Brassica napus*
Cabbage	*Brassica oleracea*
Fescue	*Festuce*
Geranium	*Geranium*
Sunflower	*Helianthus annuus*
Juniper	*Juniperus*
Duckweed	*Lemnaoideae*
Alfalfa	*Medicago sativa*
Rabbitfoot grass	*Polypogon monspeliensis*
Cottonwood	*Populus deltoids*
Pondweed	*Potamogetonaceae* (family)
Poplar	*Saliceceae* (family)
Willow	*Saliceceae* (family)
Common osier	*Salix viminalis*
Bulrush	*Scirpus lacustris*
Bladder campion	*Silene vulgaris*
Common duckmeat	*Spirodela polyrrhiza*
Arrowhead	*Syngonium podophyllum*
Cattail	*Typha*
Eelgrass	*Vallisneria*

Table 5.2. Wisconsin Native Plants Recommended for Phytoremediation Projects. These plants are native to Wisconsin and useful for phytoremediation, making them well-suited for inclusion in a water reuse project in Fitchburg. The plants are listed by their common and Latin names. The genus and species are listed, except in cases where a larger set of plants is acceptable, in which case only family or genus is included.

5.3.3 Wetland Restoration

There are multiple explanations for the degradation of the Nine Springs wetlands, but it can certainly be said that water levels have fallen and invasive vegetation has thrived. A water reuse project at the Wetland Site would introduce a new flow regime. It is possible that the subsequent increases in water levels would pave the way for the return of a variety of native species and the restoration of the wetland ecosystem. A wetland restoration would require deliberate and continual plant management, but the changes in the plant composition would naturally help to improve habitat and make the wetlands more aesthetically pleasing.

5.4 Initial Concerns

Although the practicum identified several advantages to launching a water reuse project in the wetland, there were drawbacks to the potential projects.

5.4.1 Persistence of Invasive Species

In the absence of a strict vegetation management program, the application of nutrient-rich effluent would likely encourage a continued monoculture of reed canary grass. Galatowitsch (1999) studied invasive wetland species in North America and found that increased nutrient loads and eutrophication can lead to a shift towards invasive species. The study found that five invasive wetland species, including reed canary grass, showed increased growth, productivity, and distribution as a result of increased nutrient loads. Similarly, Zedler and Kercher (2004) found that nutrient enrichment, particularly of nitrogen (N), caused a larger relative increase in reed canary grass than in other native Wisconsin prairie species. Additionally, a recent study by Prasser and Zedler (2010) found reed canary grass to be significantly more salt-tolerant than native competitive species such as *Carex stricta*, tussock sedge. In conditions of high salinity, reed canary grass produced more biomass, experienced later necrosis (cell death), and had a greater survival rate than tussock sedge (Prasser & Zedler, 2010, p. 239). These characteristics suggest that reed canary grass is particularly well-suited to survive in areas where treated wastewater is applied. Since this site is nearly a monoculture of reed canary grass, a water reuse system on this site could have little positive impact on the current vegetative cover and, in fact, could interfere with a wetland restoration project.

5.4.2 Impacts on the Aquatic Ecosystems

It is possible that aquatic species in nearby water bodies would be negatively affected by the addition of treated wastewater to the environment. The treated wastewater contains some of the same pollutants as stormwater. In their study of streams in Southwest Wisconsin, Wang, Lyons, Kanehl, Bannerman, and Emmons (2000) found that non-point pollution from surface water runoff had a degrading effect on aquatic species and fish communities. There is limited research from Wisconsin specifically on the effect of effluent on native fish and aquatic species, but Kadlec and Knight (1996) conducted a study of treatment wetlands and found that, "To date, no conditions in wetlands designed for treatment of municipal wastewater and stormwater have been found to be problematic to propagation of fish or other wildlife populations." Indeed, MMSD's effluent is being discharged directly into surface waters that remain popular recreation and fishing areas. If, in a future project, the effluent received treatment in a wetland before proceeding to surface waters, any threat to aquatic species would be even less severe.

5.5 Investigations

The Practicum conducted several investigations at the Wetland Site in order to better understand the ecosystem and the water flow regime, and to collect baseline information for a future water reuse project. The field study included measurements of contaminant attenuation in a small-scale pilot project that used effluent in the wetland, water level measurements, tests of hydraulic conductivity in the wetland, and water quality testing at nearby springs and streams.

5.5.1 Small-scale pilot

The group conducted an experiment at the Wetland Site to assess the ability of the wetland soils and plants to transmit and treat the effluent. The experiment served as a model of what might occur in the wetland if it received inflows of treated wastewater from MMSD. Through the study, the group aimed to better understand how the addition of effluent to the wetland would affect the water quality and the groundwater flow.

The experiment site was selected because infiltration tests showed the soils to be relatively permeable (See Section 5.5.2, Infiltration Tests and Slug Tests). Furthermore, the site was located west of an existing field study site. Effluent had been applied to an area at the existing field study site, potentially already causing changes in the nearby groundwater chemistry. The group wanted to avoid the possible contaminant plume located down-gradient of that site. Groundwater flow paths at the Wetland Site move north and northeast, toward the Nine Springs Creek and old drainage tiles within the wetland (Schwar, 2002). The fieldwork therefore took place to the west, slightly up-gradient and away from the existing field study site (Figure 5.3).
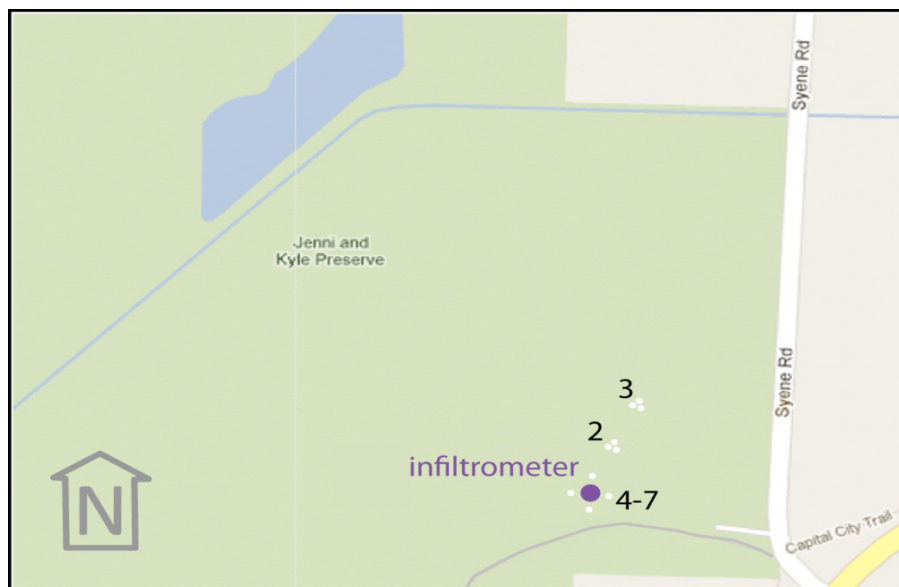
Figure 5.3. Experiment Setting for Small-scale Pilot Project. This map shows the relative locations of the well nests (2-7) and the infiltrometer. The map is not to scale.

5.5.1.1 Methods

A two-ft-diameter, four-ft-long PVC pipe was pushed about nine inches into the ground, which had been cleared of the root mat and peat in the upper four inches of soil. Monitoring wells were installed around and down-gradient of the standpipe, also referred to as the infiltrometer (Figure 5.3). Two nests were installed in a line to the northeast; one nest was five feet from the center of the pipe (Wells 2A, 2B, and 2C), the other was 10 feet from the center of the pipe

(Wells 3A, 3B, and 3C). A group of nests is a set of piezometers placed at different depths within a close vicinity to each other. They are used to measure differences in vertical concentrations. Each nest consisted of wells with two-foot screens, installed to depths of three, five, and eight feet. Four additional wells encircled the pipe at a distance of three feet from the center of the pipe and at a depth of five feet (Wells 4B, 5B, 6B, and 7B) (Figure 5.4).
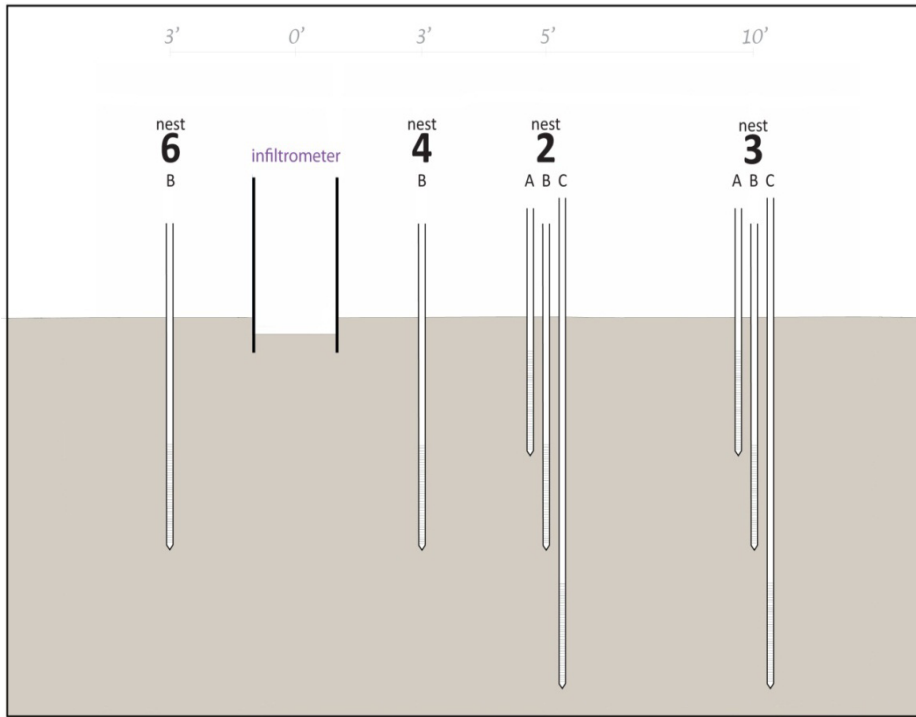
Figure 5.4. Experiment Setup for Small-scale Pilot Project. Wells with labels A, B and C were installed at depths of three, five and eight feet, respectively. Two wells are not included in the figure; these wells formed a square around the infiltrometer with the wells at nests six and four and were also installed to a depth of five feet.

Water samples and measurements of electrical conductivity, temperature, and depth to water were taken at the two well nests on July 21. These measurements provided the group with some baseline information. Then, until August 30, effluent was routinely added to the pipe to create a zone of high hydraulic head. As the water infiltrated and spread through the area, it was anticipated that the electrical conductivity of water in the wells would change due to the high conductivity of the effluent relative to the groundwater. In particular, it was conjectured that the high concentrations of Cl⁻ in the effluent would lead to increased conductivities in the wells as soon as the effluent reached them. In contrast, it was anticipated that the high concentrations of N and P might be reduced as the water flowed through the wetland.

Measurements of the conductivity, temperature, and depth to water were taken in each well every day for several weeks and every other day in the ensuing weeks. The conductivity and temperature were measured with an YSI 30 handheld conductivity meter. These measurements allowed the group to track the movement of the effluent as the effluent conductivity is much greater than ambient groundwater conductivity.

On July 18, August 9, August 16, and August 30, water samples were collected in order to more thoroughly assess the water quality and the treatment ability of the peat and the plants. The baseline water samples were taken from 2B, 2C, 3B, and 3C. Subsequent samples were taken at wells 2B, 2C, 3B, 3C, and 4B. For the well water sampling, the group followed the protocol of the WDNR's *Groundwater Sampling Field Manual* and employed a peristaltic environmental pump, the Masterflex E/S Portable Sampler from Cole-Parmer Instrument Company. Samples were delivered to MMSD, where they were tested for fecal coliform, Cl-, NH3, NO3-, Total Kjeldahl Nitrogen (TKN), and TP.

5.5.1.2 Results

Effluent was added to the standpipe over the time period from July 21 to August 30. In total, about 550 gallons of effluent infiltrated (Figure 5.5).
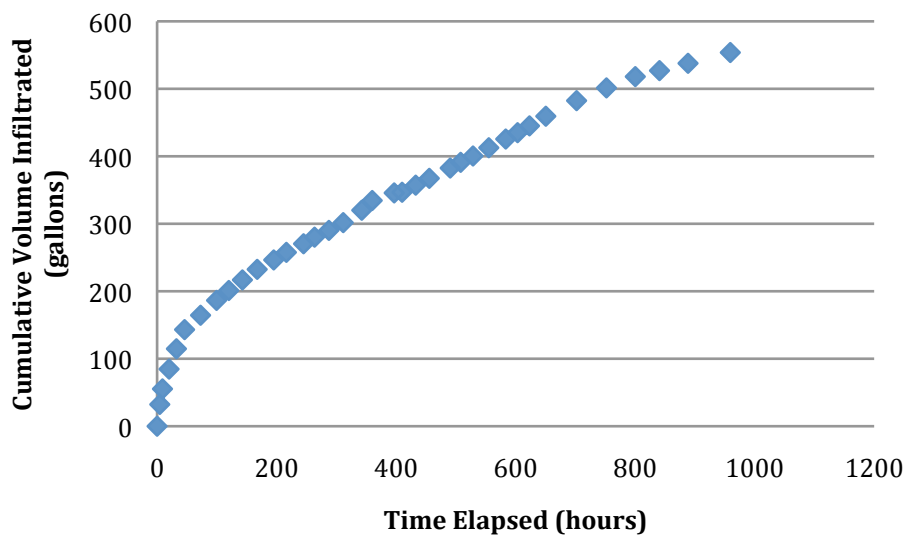
Figure 5.5. Cumulative Infiltration of Effluent at the Wetland Site.

The infiltration rate of the effluent from the standing pipe into the peat ranged from 3.67 inches per hour (in/hr) to 0.001 in/hr. The infiltration rate was faster at the beginning of the experiment; during this time the soil was unsaturated and readily accepting water. Once the soil below the standpipe became more saturated, the infiltration rate leveled off at an average infiltration rate of 0.025 in/hr (Figure 5.6).
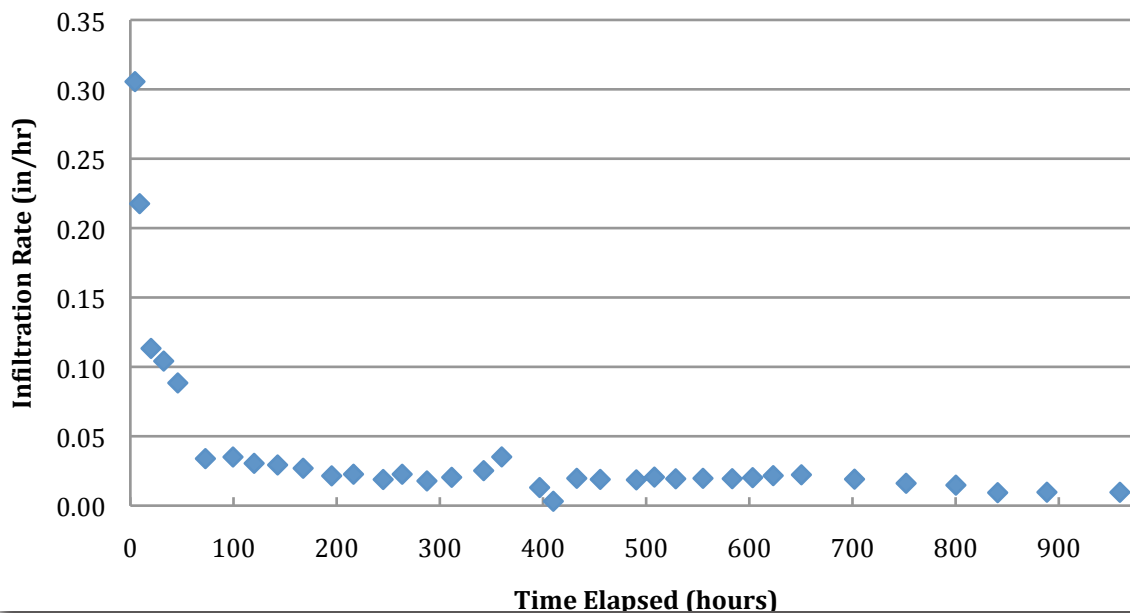
Figure 5.6. Infiltration Rates of Effluent in the Standpipe at the Wetland Site. Infiltration rates at the standpipe were measured from July 21 to August 30. The rates fell over time with few exceptions; in one case, following a heavy rainfall on August 6, extremely low rates of infiltration were recorded, as seen in the figure around the 400-hour mark, but infiltration rates returned to expected levels soon afterwards.

The group used specific electrical conductivity as an indicator of effluent arrival in the wells surrounding the standpipe. After two and a half weeks of sampling at nests 2 and 3, there were no obvious increases in the specific electrical conductivity (Figure 5.7). It was at this time that the wells located two feet from the standpipe (4B, 5B, 6B, 7B) were installed and measured for specific electrical conductivity.

The treated effluent reached well 4B between August 14 and 15 (Figure 5.8). Well 4B was located north and down-gradient of the stand pipe. The specific electrical conductivity of the water in well 4B stabilized at an average of 1.4×10^3 microsiemens (µS) (August 18 to August 30). The specific electrical conductivity of groundwater taken from wells 5B, 6B, and 7B was 8×10^2 µS on average over the sample period. The change in the reading at well 4B confirmed the group's assertion that groundwater flows to the north, toward the creek, in this section of the wetland. The length of time – 24 days – that it took for the reading to change in the closest well confirmed that groundwater flow rates through the wetland are very low. Slug tests (described below) further validated these results.
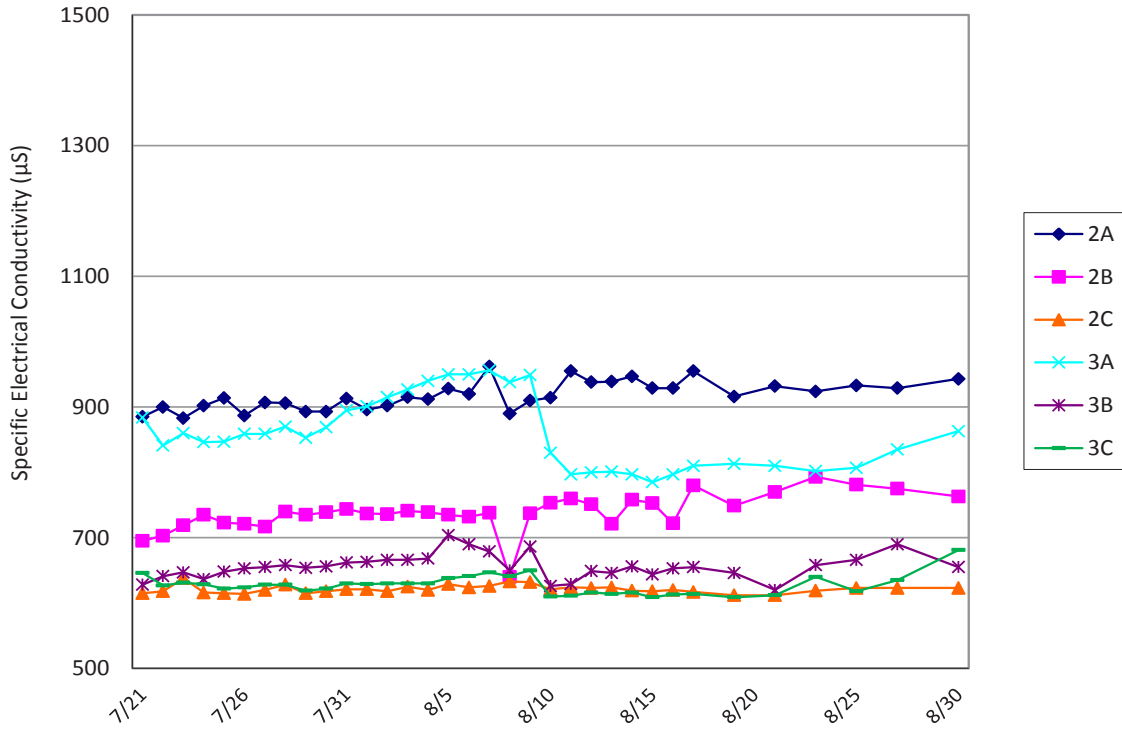
Figure 5.7. Record of the Specific Electrical Conductivity at Well Nests 2 and 3 following addition of Effluent at the Standpipe.
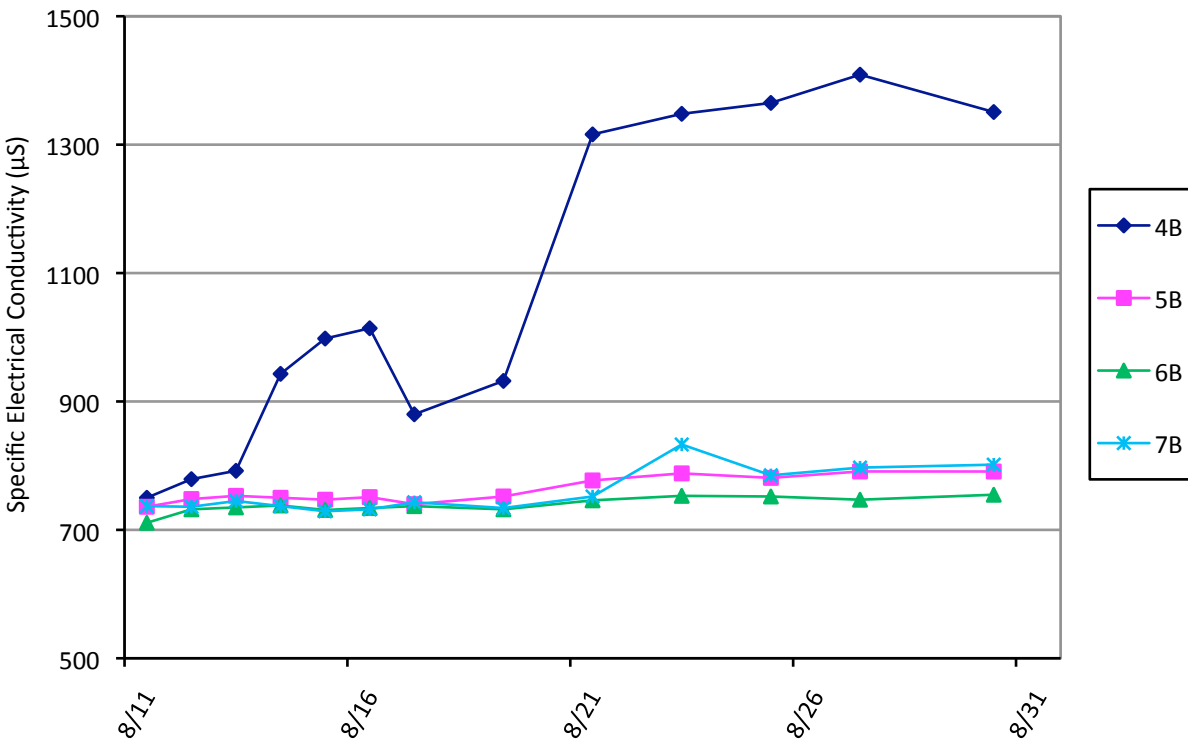
Figure 5.8. Record of the Specific Electrical Conductivity at Well Nests 4, 5, 6 and 7 following addition of Effluent at the Standpipe and Installation of the Wells. Well 4B was situated to the north and down-gradient of the stand-pipe and was the only well in which the water quality changed significantly.

After observing the sharp increase in conductivity in well 4B, the group collected the final set of groundwater samples, which included a sample from well 4B. The average concentrations of the samples from the nearby wells are displayed in Table 5.3, along with the results from the sample at well 4B. There were higher contaminant concentrations at well 4B than at the other wells; the effect of the effluent was noticeable. The data are limited, however, and the sampling size does not provide a strong representation of the nutrient levels at the site. Additionally, the concentrations of nitrogen and phosphorus at the surrounding wells could change over time if effluent were continuously sent into the peat. Therefore, the current results are inconclusive. Further testing over a longer period of time would be necessary to determine the treatment ability of the peat and the plants of the wetland.

5.5.2 Infiltration Tests and Slug Tests

	Cl (PPM)	NH3-N (PPM)	NO3-N (PPM)	TKN (PPM)	TKN-D (PPM)	TP (PPM)	TP-D (PPM)
Well 2B	10.04	0.70	0.02	1.96	1.02	0.15	0.06
Well 2C	6.59	0.63	0.02	1.16	0.85	0.10	0.08
Well 3B	7.59	1.37	0.02	4.15	1.81	0.31	0.11
Well 3C	7.49	1.20	0.02	2.40	1.53	0.15	0.07
Well 4B	182.00	1.07	0.05	7.75	2.53	0.73	0.09

Table 5.3. Wetland Groundwater Quality. Baseline groundwater samples were collected from wells 2B, 2C, 3B, and 3C in nests 2 and 3 on July 18 and August 9. The mean concentrations for each well are listed along with the concentrations from the sample taken at well 4B on August 30, following the arrival of the effluent plume.

To assess the infiltration ability of the wetland soils, infiltration tests using a single-ring, two-foot diameter infiltrometer were completed at two sites in the wetland.

5.5.2.1 Methods

Before installing the infiltrometer, the group removed four inches of material, consisting of a dense root mat and peat, from the surface. The group installed the infiltrometer three inches below the initial excavation. The group added a known volume of water to the infiltrometer and measured the distance from the top of the infiltrometer to the top of the water. After a given amount of time, the distance from the top of the infiltrometer to the water was measured again.

Although this method did not give enough information to calculate the hydraulic conductivity of the soil, the group was able to find a site with relatively permeable soils. The first site allowed for a short term initial infiltration rate of 1.027 gallons/hour while the second site allowed for 1.711 gallons/hour. Since the Practicum was interested in finding a location where additional inflows would be easily accepted, the second site was used for the small-scale pilot project.

At the project site, as previously described, two nests of piezometers (nests 2 and 3) were installed with wells at depths of three, five, and eight feet (wells 2A, 2B, 2C, 3A, 3B, and 3C, respectively). At the wells with five- and eight-foot depths, slug tests were conducted to determine the hydraulic conductivity of the peat. A solid PVC slug with a 150 milliliter (mL) displacement was lowered into a well more than 24 hours prior to testing in order to allow sufficient time for full re-equilibration of groundwater levels within the wells. For each test, a water level measurement was taken using an electrical tape and then the slug was removed. An electrical tape and stopwatch were used to measure the rate at which water rose in the well until the water had returned to the initial level. The Hvorslev approach, as described in Schwartz and Zhang (2003), was used to calculate hydraulic conductivity from the slug test data.

5.5.2.2 Results

The hydraulic conductivities at wells 2B, 3B, and 3C were 0.117 ft/day, 0.011 ft/day, and 0.003 ft/day, respectively. There was not enough information gathered to calculate a hydraulic conductivity at well 2C, but the very slow recovery suggests a very low hydraulic conductivity for those soils. Wells 2B and 3B were installed at the same depth in the peat (screens extended from three to five feet below ground surface) but differed by an order of magnitude in terms of hydraulic conductivity, exhibiting the variable nature of flow in peat. The measurement at well 3C, an eight-foot well, was an order of magnitude smaller than the measurement at well 3B, a five-foot well, showing the relative inability of the lower peat layers to transmit water and, again, the variable nature of flow in peat. Although there was variation in the measurements, all three values were on the low end of the range of expected hydraulic conductivities. Complete values from the slug tests are shown in Appendix I.

5.5.3 Baseline Water Sampling

Water samples were collected from springs and streams near the Wetland Site in order to gauge the quality of the water under current conditions and create a baseline data set in case a water reuse project leads to changes in local water quality.

5.5.3.1 Methods

Sampling sites were located on Nine Springs Creek, its North Fork, its South Fork, and at two springs that flow to the creek (Figure 5.9). Sites along the streams were selected according to the guidelines in the U.S. Geological Survey's *National Field Manual for the Collection of Water-Quality Data* (2010). Water sampling took place six times for the streams and five times for the springs. The stand pipe, which was used to add effluent to the wetland, was sampled once in order to compare effluent quality to the existing water quality in the streams and springs. Samples were collected in sterile bottles provided by MMSD. All samples were collected in the middle of the spring or stream and six inches beneath the water surface, using a grab technique. MMSD filtered, preserved, and analyzed the water samples.

The water samples were analyzed for TKN, TKN-D (TKN-dissolved), TP, TP-D (TP-dissolved), NO_3^-, NH_3, fecal coliform, E. coli, and Cl^-. Cl^- and NO_3^- were analyzed using ion chromatography, E. coli and fecal coliform were analyzed by Membrane Filtration, NO_3^- was analyzed by the Automated Phenate Method, TKN and TKN-D were analyzed using Total Kjeldahl Nitrogen - Block Digestion, and TP and TP-D were analyzed using Total Phosphorus Block Digestion (USEPA, 1983; USEPA, 1993a; USEPA 1993b; USEPA 1993c; Clesceri, Greenburg, & Eaton, 1998).
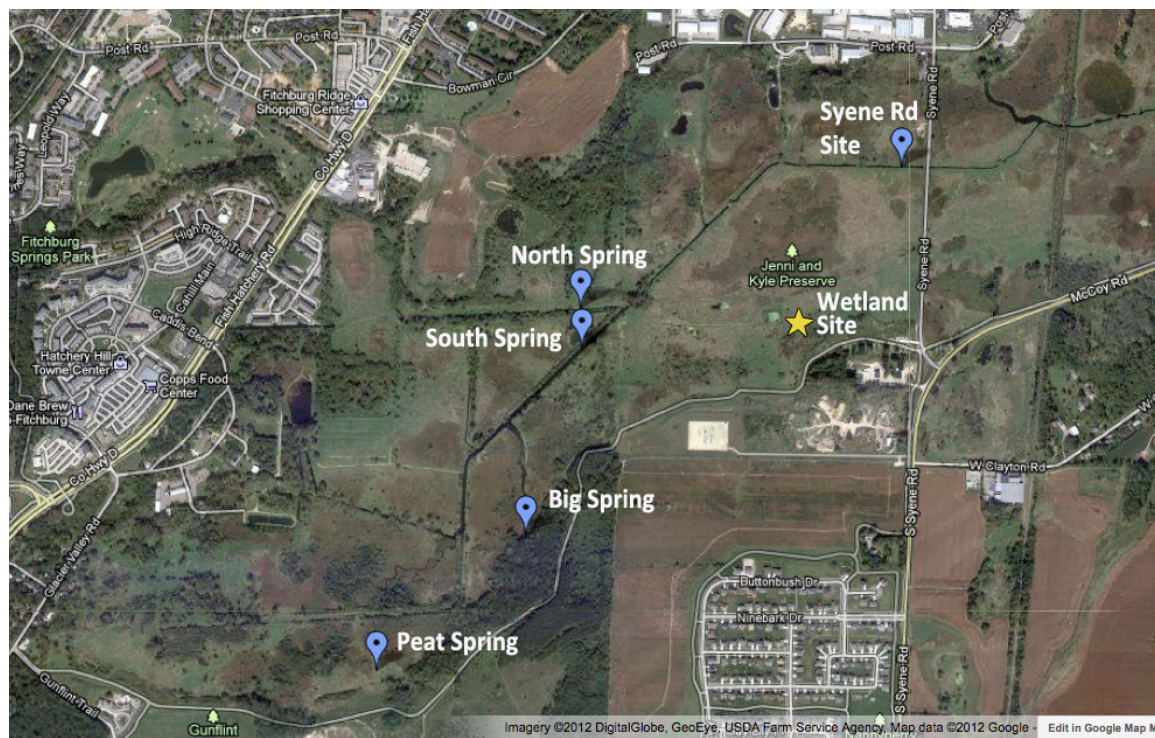
Figure 5.9. Stream Sampling Locations.

5.5.3.2 Results

Selected water quality results are included in Tables 5.4, 5.5, 5.6, and 5.7 while complete water quality results are listed in Appendix J. The group recommends MMSD and the City of Fitchburg consider these results if water quality in nearby surface water changes following the implementation of a water reuse project.

There were several noticeable differences between the effluent and the stream and spring samples. Cl^- levels were significantly higher in the effluent than in the stream and spring samples. The effluent sample contained 393 ppm Cl^- (MMSD's 2010 effluent average was 385 ppm) while the mean value across the spring and stream samples was 57 ppm. NH_3, NO_3^- and TKN levels within the effluent did not differ significantly from those of the spring and stream samples. TKN-D levels were higher in the effluent, but, if the effluent were reused in the wetland, these levels would likely fall as the water received additional treatment from the wetland vegetation. TP levels in the effluent were much higher than those in the springs and streams. This distinction could be eliminated if MMSD further treated the wastewater to

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reduce P levels or if advanced treatment in the wetland ecosystem were ensured. In terms of fecal coliform levels, the surface waters had an average concentration of 342 organisms/100ml (Table 5.4). The effluent had an average concentration of five organisms/100ml, according to the sample results. This measurement was likely inaccurate since the average concentration in MMSD's effluent in 2010 was 140 organisms/100ml (Table 5.5). Nevertheless, the average effluent concentration remains lower than the average surface water concentration in the wetland area, and the fecal coliform counts in the effluent would not present a new challenge for the wetland environment.

Location	n	CL (PPM)	NH3 (PPM)	NO3 (PPM)	TKN (PPM)	TKN-D (PPM)	TP (PPM)	TP-D (PPM)
Syene Rd	6	56.53	0.07	3.90	0.65	0.59	0.09	0.06
North Fork	6	94.20	0.19	0.56	0.79	0.67	0.15	0.08
South Fork	6	51.38	0.06	3.65	1.42	0.79	0.29	0.13
Spring 1	5	48.50	0.01	10.31	0.15	0.10	0.09	0.06
Spring 2	5	31.27	0.01	8.86	0.10	0.10	0.05	0.04
Wetland Area Means		57.13	0.09	5.65	0.56	0.43	0.12	0.08

Table 5.4. Water Quality Results for Surface Waters near Wetland Site. Values reported in mean concentrations.

Location	n	CL (PPM)	NH3 (PPM)	NO3 (PPM)	TKN (PPM)	TKN-D (PPM)	TP (PPM)	TP-D (PPM)
Standpipe	1	393.00	0.10	3.39	4.71	1.97	0.42	0.07

Table 5.5. Water Quality Results for Effluent in Standpipe.

Location	n	Mean Conc. (#/100ml)	SD
Syene Rd	6	539	801.9
North Fork	6	736	721.0
South Fork	6	354	567.3
Spring 1	5	13	23.5
Spring 2	5	69	133.0
Wetland Area Mean		342	

Table 5.6. Fecal Coliform Concentrations for Surface Waters near Wetland Site. Mean and standard deviation values are reported.

Location	n	Mean Conc. (#/100ml)
Standpipe	1	5*
MMSD	57	140**

Table 5.7. Fecal Coliform Concentrations in MMSD Effluent.

*Extremely low value was measured, likely through an error in sampling or testing.

**(Source: MMSD, 2011) Routine measurements of the fecal coliform concentration in the MMSD effluent provice a more accurate estimate of the concentration that could be expected in effluent used for a water reuse project.

5.5.4 Design

The Nine Springs wetland has become relatively dry as a result of reductions in groundwater inflows and the channelization of Nine Springs Creek. An enhanced groundwater recharge project at the Upland Site could reverse this trend. It would supplement the natural flow of groundwater into the Nine Springs wetland, allowing the water table within the wetland to rise. Given that groundwater moves very slowly, however, it would take years for significant changes to the flow regime and improvements to the ecosystem to take place. Immediate improvements would be realized if water were applied directly to the wetland. By sending water from the effluent pipe or overflow from the Upland Site system (See Chapter 4) to the wetland, a water reuse project would rapidly raise the water table in the wetland and increase the baseflow in the Nine Springs Creek.

The source of water for the wetland project would be effluent from the MMSD pipeline or runoff from an enhanced recharge system at the Upland Site. If it passed through the Upland system, the water would receive additional treatment before entering the wetland. Thus the water quality at the inlet to the wetland would be better if runoff from the Upland Site, rather than effluent from the MMSD pipeline, were used. The inflows to the wetland would be either constantly or intermittently delivered.

5.5.4.1 Constant Additional Flow Example

One possible design for a water reuse project would send water into the wetland at a nearly constant rate from below the ground surface. This wetland has historically been categorized as a fen, a wetland that receives significant inflows from springs. These springs have provided little to no flow in recent years and the wetland has transitioned into a sedge meadow in places. Consequently, adding water to the wetland by way of the groundwater would mimic a historic flow pattern.

The treated wastewater would be effectively delivered to the wetland with a simple, relatively non-invasive system. A small hydraulic gradient already exists across the wetland; the groundwater flows toward the Nine Springs Creek. Adding water to the southern edge of the wetland would raise the hydraulic head in that area and increase the hydraulic gradient, speeding up the flow of groundwater to the creek. A trench would be excavated along the southern edge of the wetland within the unsaturated zone. Then a perforated pipe would be installed in the trench, which would be re-filled with gravel or another material. The pipe would run approximately parallel to the stream, allowing water to flow through the pipe, seep into the peat along the southern edge of the wetland and flow down gradient to the stream (Figure 5.10). The desired flow rate would influence the design of the pipe, including the size, shape, number and orientation of the orifices, the length and slope of the pipe, and the backfill of the trench (Duchene and McBean, 1992). Once the effluent is released into the wetland, some advanced treatment would occur by adsorption and plant uptake within the wetland.

It is unlikely that the peat would transmit a very sizeable quantity of water down gradient. The hydraulic gradient would be shallow even after the hydraulic head was increased at the

pipe. Slug tests in the wetland revealed that the hydraulic conductivity of the peat is low, even in the upper layers where peats often readily transmit water. Indeed, when the wetland flow model was run with the hydraulic conductivities found in the field, it was determined that the total possible inflow across the 1000-foot-wide area would be 0.2, 0.6, and 6.6 gal/day for the Practicum's measured hydraulic conductivities of 0.003, 0.011, and 0.117 ft/day, respectively. The group concluded that, although the additional water would saturate the peat and initially increase the water storage of the wetland, the movement of water through the peat at steady state would be very limited.
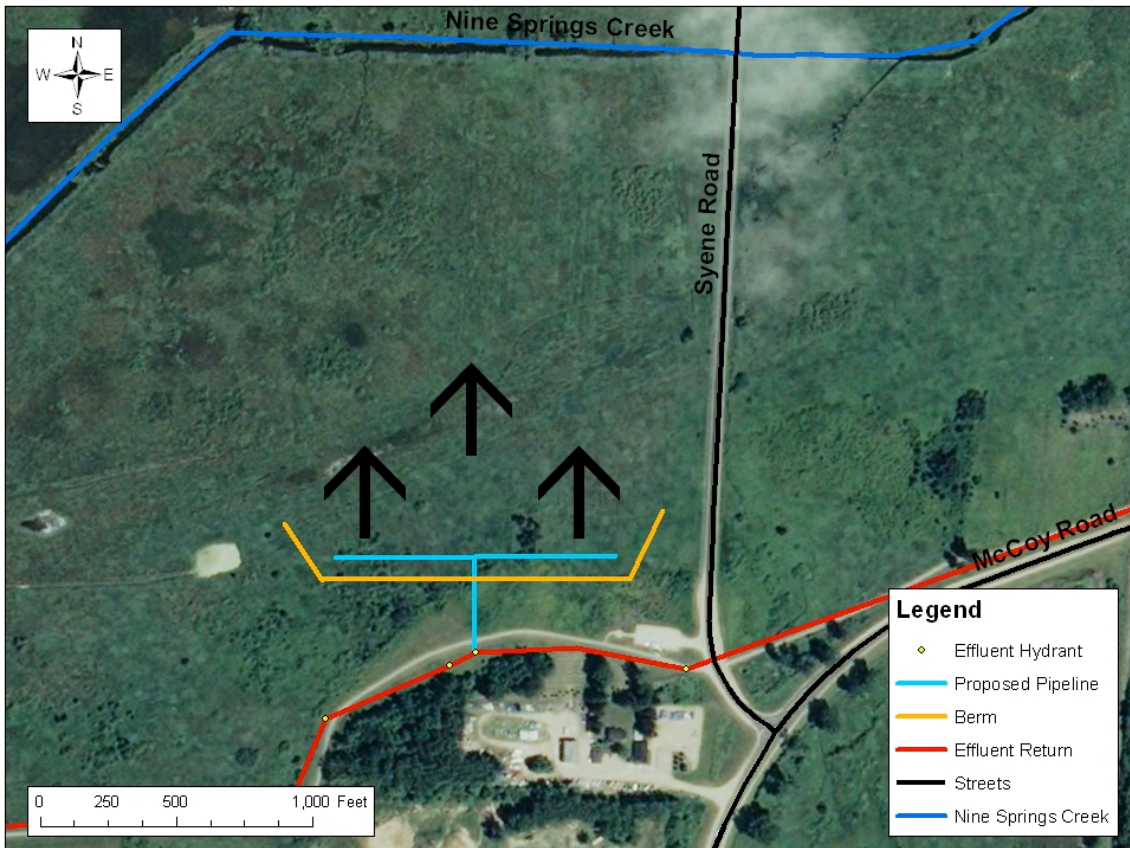
Figure 5.10. Water Reuse Project Sample Design.

5.5.4.2 Pulses of Flow Example

Although the hydraulic conductivities measured in the peat were very low and the groundwater flow rates through the wetland were very small, there was steady infiltration at the standpipe. Water was not moving rapidly through the soil, but the soil was absorbing water because it was very dry. In fact, the wetland was never saturated to the surface during the course of the Practicum's summer fieldwork; the water table was often one to two feet below the ground surface as measured from the well nests. Such unsaturated conditions are not always observed in the wetland and there are certainly areas with standing water, but there are times and places where treated wastewater could be applied to bring the soils to saturation and even to create standing water.

A second possible design would allow the treated wastewater to be added to the wetland area through a perforated pipe, as in the constant flow design, but at higher flow rates and for short intervals of time. The higher rates would force the trench to overflow and encourage overland flow. Water would spread across the surface, flow to unsaturated areas and infiltrate. Consequently, a berm on the southern side of the trench would be necessary to restrict the flow of the water and ensure that flooding occurred across the intended section of the wetland (Figure 5.10). The short pulse of flow would saturate the soils and create ponded conditions without promoting the constant lateral flow that was seen in the constant flow example. Rather, water would evaporate from the soils and transpire from plants. This outflow to the atmosphere would gradually return water levels to the original levels, at which point another pulse of flow could be delivered from the effluent return line.

The impact of such a project would depend upon the rainfall record. During dry periods, the water table falls, increasing the unsaturated zone. Additionally, available pore space within the unsaturated soils increases as evapotranspiration and drainage draw water from the soil. In dry years, significant volumes of effluent would be received in the wetland. If the water table were three feet below the surface and an average of 20 percent of the pore space was available, the 50 acres used for the Practicum would infiltrate nearly 9.8 million gallons before reaching saturation. If the water rose one inch above the surface, the area would hold an additional 1.4 million gallons.

Once the wetland had been saturated, it would take time for the water table to fall again and for another pulse of water to be required. The length of time between pulses would determine the number of pulses in a year; more pulses would make the project more effective.

5.5.4.3 Improve wetland plant management

A water reuse project at the Wetland Site would ideally be paired with a restoration of the wetland ecosystem. This restoration would be accomplished by controlling the reed canary grass (*Phalaris arundinacea*) and increasing the plant diversity, perhaps with phytoremediative plants that would be appropriate for the MMSD effluent. There are over 700 Wisconsin-native wetland plants that could be incorporated into a restoration project, but particular species are recommended in this restoration situation due to their ability to survive in monocultures and tolerate high concentrations of nutrients.

As the wetland currently consists of almost entirely reed canary grass, the initial seedlings would need to adapt quickly to the environment. *Asclepias incarnata*, *Aster puniceus*, *Epilobium coloratum*, *Leersia oryzoides*, *Lobelia siphilitica*, *Lycopus americanus*, *Mentha arvensis*, *Verbena hastata*, *Bidens cernuus*, *Polygonum hydropiper*, *Alisma subcordatum*, and *Bidens cernua* all establish stable populations even in competition with monocultures (Wilcox & Zedler, 2005). Plants that adjust well to cold climates such as *Schoenoplectus* (*Scirpus*) species (ex: *Scirpus atrovirens* and *Scirpus fluviatilis*) would better ensure vegetation survival through the winter season (Kadlec & Wallace, 2009, p. 764). In order to foster diversity, Dr. Zedler, Research Director at the University of Wisconsin – Madison Arboretum, and Michelle Peach of the University of Wisconsin – Madi-

son, suggest planting *Carex stricta* tussock sedge (2005). One tussock sedge will support up to 16 additional native species by creating micro-habitats. The sedge would accommodate a progression of species from early spring to late summer and increase the wetland surface area by up to 45 percent (Peach & Zedler, 2005). This effect is strengthened when planted with co-dominant species like C. lacustris and Calamagrostis canadensis (Peach & Zedler, 2005).

As advised by the University of Wisconsin – Madison's Arboretum Committee "Policy on unintended negative impacts of construction projects," the project at the Wetland Site should incorporate monitoring of the development of the wetland restoration for a minimum of five years (2010). Maintenance especially will be needed to control the invasive reed canary grass. Methods of eradication include burning, mowing, hand pulling, mechanical removal, and herbicides (Kadlec & Wallace, 2009, p. 787). Reed canary grass populations often show resistance to these methods individually. Based on studies completed on wetlands in Dane County, the Practicum recommends first trying an herbicide. Restoration should focus on forbs rather than grasses. Therefore, a grass-specific herbicide would target reed canary grass, not native plants (Wilcox & Zedler, 2005).

Due to the nutrient and contaminant load in the effluent, the site should include species that specialize in improving water quality. Rye grass (*Lolium L.*), western wheatgrass (*Pascopyrum smithii*), blue gamma grass (*Bouteloua gracilis*), and buffalograss (*Bouteloua dactyloides*) all act as general phytoremediative plants using rhizodegradation and accumulation (Hinman, 2005). The N and P levels are of particular concern within the project design. Pickerelweed (*Pontederia L.*), vetch (*Vicia* spp.), and tall fescue (*Festuca arundinacea*) are all recognized for their rhizo-degradation and phytoextraction characteristics and for specifically removing N and P (Hinman, 2005).

Ideally, a project would include plant harvesting in order to remove accumulated chemicals. By cutting the aboveground parts of the plants once every eight weeks to two times a year, harvesting shows potential to reduce nutrient inputs to the wetland (Kadlec & Wallace, 2009, pp. 289, 363). According to Herskowitz and Toet, harvesting only reduces 10 percent or less of the annual P input (Kadlec & Wallace, 2009, p. 363). If the effluent recharge expanded across the entire wetland, harvesting would have little effect and the costs for the equipment and labor would likely outweigh the benefits (Kadlec & Wallace, 2009, p. 786). If the project will incorporate harvesting, proper plant disposal needs to be followed in order to avoid reintroducing the toxins into the environment. Disposal methods include composting and digesting to form a biogas product (Kadlec & Wallace, 2009, p. 290).

5.6 Recommendations

The group recommends implementing a pilot project that delivers pulses of flow to the Wetland Site. A 1000- to 3000-foot-long perforated pipe should be installed along the southern edge of the Wetland Site and connected to the effluent return line. This connection should be restricted by an on/off mechanism. Whenever the water table drops to a specified level, the switch should be turned on and treated wastewater should be allowed to saturate the soils and flood the wetland. After the area has been flooded to the desired maximum level, the switch should be turned off until the water table again drops to the specified minimum level. This drop would be caused by a combination of evapotranspiration, seepage into lower soil layers, and discharge as baseflow into the Nine Springs Creek.

The flow rates into the wetland, the water levels within the wetland, and the flow rates in Nine Springs Creek should be monitored. The water quality within the wetland and in Nine Springs Creek should also be monitored in order to ensure that the water reaching the creek has received sufficient levels of advanced treatment in the wetland.

When subsequent pulses of flow are required, the pilot project should adjust the flow rates. Adjustments should be made until the study identifies a flow regime that best supports the health of the wetland ecosystem and the quality of the local surface waters. Specific goals regarding plant composition and water quality should be established prior to the start of the pilot project in order to set up guidelines for the assessment of trial flow regimes.

A description of the final flow regime would specify the minimum and maximum water levels that would govern the timing and frequency of the pulses of flow. These specifications would determine the impact of the project in terms of water usage. For example, a project could take place within the Practicum's Wetland Site. Then, if a 1000-foot-long pipe delivered flows to a 1400-foot-wide section of the wetland and if the water table was allowed to fall to two feet below the surface while the average available pore space of the unsaturated soils measured 20 percent (number chosen hypothetically), 5.1 million gallons could be added. This water would saturate the soil to the surface and generate one inch of ponding at the surface. A 3000-foot-long pipe delivering flows across an otherwise identical system could deliver 15.2 million gallons. These volumes would be the result of one pulse of flow, but multiple pulses could be achieved each year.

There are extensive wetlands in Fitchburg that can and should be a part of a water reuse project that employs treated wastewater from MMSD. The Practicum recommends that a 1000-foot-long pipe be installed and that a pilot project be launched at or near the Wetland Site. Then further investigations at the site can refine the design and quantify the impact of the pilot project. Eventually a final project can be established as an expansion or revision of the pilot. Finally, a wetland restoration can and should be linked to a permanent water reuse project within the wetland, and decisions about plant selection and management of the wetland should be based on the permanent flow regime.

Chapter 6 • Nine Springs Golf Course

6.1 Introduction

Recent low surface water levels in the Yahara watershed, due to intrabasin water transfers, generated interest from the City of Fitchburg and the Madison Metropolitan Sewerage District (MMSD) to possibly expand the Nine Springs Golf Course effluent irrigation pilot project. The Practicum investigated this possible expansion. By exploring the economics, politics, and science behind golf course effluent irrigation, the group established a plan for this type of effluent use. This plan will aid the City of Fitchburg and MMSD as they develop their future water reuse strategy.

6.2 Site Characteristics

The Nine Springs Golf Course is a public, par three, nine-hole course owned by the City of Fitchburg and managed by certified golf instructor Sam Schultz. The 34-acre course, which includes a 3.2-acre stormwater retention pond for irrigation, is located in northeastern Fitchburg, WI (Kussow, 2008). MMSD's effluent return line runs adjacent to the course property; the return line lies approximately 25 feet from the edge of the stormwater pond and 600 feet from the irrigation pump house. The course is bordered by Post Road and Traceway Drive (and their apartment complexes) to the north, Whispering Pines Way and Leopold Way to the west, Highbridge Trail to the south, and Fish Hatchery Road to the east.

The Nine Springs Golf Course has operated at the site since 1969. The native vegetation of the 34-acre parcel is prairie grass, though various species of turfgrass and ornamental plants, flowers, and trees have been planted on the parcel. The putting greens are composed of creeping bentgrass (*Agrostis stolonifera*), tees are composed of Kentucky bluegrass (*Poa pratensis L.*), and fairways contain a Kentucky bluegrass and annual bluegrass (*Poa annua L.*) mixture. The soil series at the course is a mixture of different types of silt loams. All soils have a hydraulic rating of "B" or "B/D" suggesting moderate to slow water infiltration rates (Kussow, 2008). According to the Natural Resources Conservation Service's Web Soil Survey, the soils at the Nine Spring Golf Course are considered moderately well drained to well drained (Soil Survey Staff, 2011).

6.3 Current Effluent Irrigation Project.

In 2000-2001, the Nine Springs Golf Course added culverts to connect storm sewers from neighboring residential areas to the stormwater pond on the golf course property (S. Schultz, personal communication, May 6, 2011). An outflow pipe on the east side of the stormwater pond leads to Nine Springs Creek and carries flow during and/or after heavy precipitation events. Figure 6.1 provides a Google Earth map of Nine Springs Golf Course.
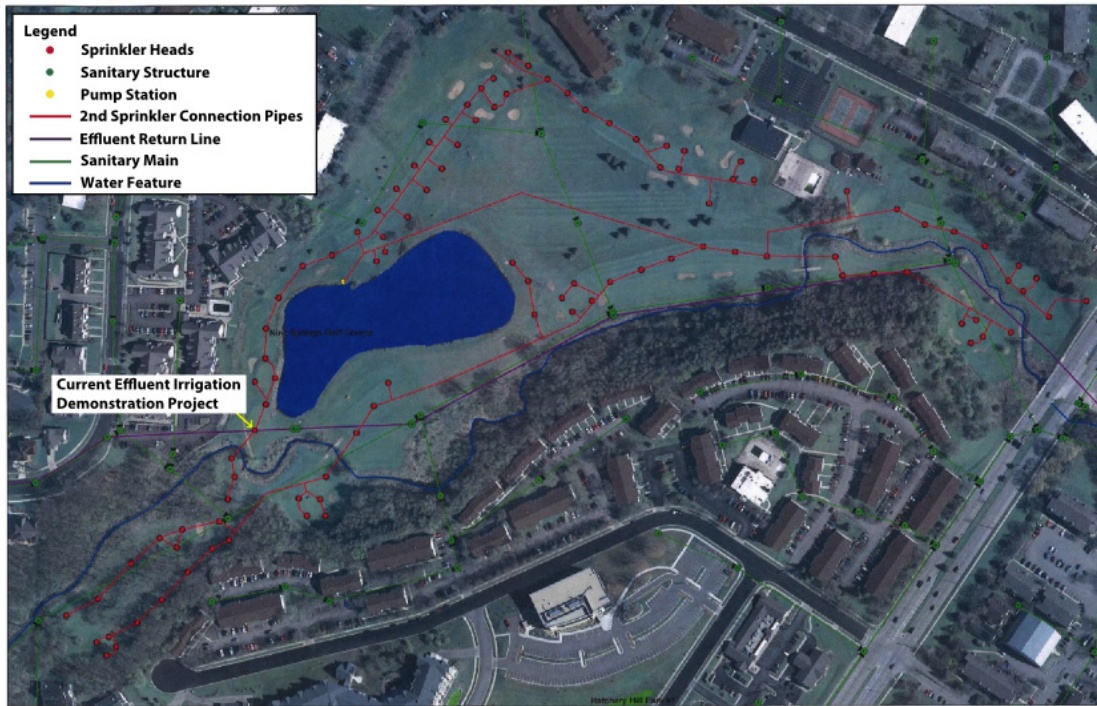
Figure 6.1. Map of Nine Springs Golf Course. This map shows the sprinkler irrigation system, the effluent return line, and the location of Hole 7 sprinkler head, which utilizes direct effluent irrigation, at Nine Springs Golf Course. Google Map image courtesy of the Stormwater and Water Utility Intern of the City of Fitchburg, Lauren Jansen.

The course is currently irrigated with stormwater from the course's pond. Approximately 100 sprinkler heads are used to irrigate the course, with nearly all areas irrigated with water drawn from the stormwater pond. One exception is a section of the fairway on hole number 7, which is irrigated by the direct application of effluent from MMSD's effluent return line. Over the past five years, an average of 51,000 gallons of effluent were used each season to water this section of Hole 7. The pressure generated in the effluent return line provides enough power to operate this sprinkler head with no additional pump. Turfgrass quality at Hole 7 has shown no appreciable decline since effluent irrigation began, according to Schultz. This project, which is a collaboration between MMSD, the City of Fitchburg and Nine Springs Golf Course, has been utilizing effluent for irrigation at Hole 7 for nearly six years.

6.4 History of Effluent Golf Course Irrigation

It is increasingly popular for golf courses across the United States to turn to effluent to irrigate their courses, with approximately 12 percent of United States courses using effluent for irrigation (Throssell, Lyman, Johnson, Stacey, & Brown, 2009). Over 37 percent of golf courses in the Southwest use effluent for irrigation, while only 3 percent of courses in the Midwest irrigate with effluent (Throssell et al., 2009). Studies suggest an economic benefit to using effluent for irrigation as well; effluent water can cost up to 80 percent less than groundwater (Huck, Carrow, & Ducan, 2000). The non-differential cost of effluent and groundwater, abundant rainfall, and

available freshwater supply in the Midwest region are likely responsible for observed utilization trends in the Midwest (DeBels, 2009).

The majority of United States effluent use is voluntary, though some states in the Southwest mandate the use of effluent for irrigation (Huck et al., 2000). This water conservation effort is illustrated in California, where legislation was passed in 1992 requiring effluent use for irrigation, where available (Stier, 2001). Golf courses use considerable amounts of water for irrigation; the average 18-hole golf course uses 250,000 to 1,000,000 gallons of water per day for irrigation (Huck et al., 2000). Golf course effluent reuse prevents groundwater withdrawals and can improve the quality of effluent entering the environment. Turfgrass filters out nutrients as water percolates through the grass root zone and soil profile. Research indicates that turfgrass has the potential to effectively filter excess nutrients in effluent waters (Qian & Mecham, 2005).

6.5 Common Challenges Associated with Effluent Irrigation of Golf Courses

The success of effluent irrigation of turfgrass depends on a myriad of factors including individual site characteristics, soil quality, turfgrass cultivation methods, quality of effluent, climatic conditions, and the management of these components (Huck et al., 2000). Effluent typically contains more dissolved salts, chemicals and other nutrients than groundwater. Much of the concern with effluent use for turfgrass irrigation revolves around total salinity and sodium permeability (D. Soldat, personal communication, June 14, 2011). The use of effluent for irrigation also requires evaluation of the effluent's pH, chloride (Cl^-), boron (B), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and other nutrient content (Huck et al., 2000; D. Soldat, personal communication, June 14, 2011). Many wastewater treatment plants regularly check the water quality of their effluent. However, from a turfgrass management standpoint, it is often beneficial to have soil and water samples analyzed to assess the effect of effluent on turf and soil qualities at the individual site.

6.5.1 Salinity

Total salinity is the measure of the accumulation of salt in soil and is typically measured by electrical conductivity (EC) or electrical conductivity of water (EC_w) (DeBels, 2009; Huck et al., 2000). Numerous ions, including sodium (Na^+), Cl^-, magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), sulfate (SO_4^{2-}), and HCO_3^-, may accumulate in the soil and interfere with proper water uptake by turfgrass species (Kopec, Mancino, & Nelson, 1993). Turfgrass can lose desired coloring and show signs of drought damage in excessive salt conditions (Huck et al., 2000). The hazardous salinity of soil depends on the initial salt concentration in the effluent, annual irrigation rates, annual precipitation, and the physical and chemical characteristics of the soil at each individual site (Harivandi, 2004). Since effluent typically contains greater total salinity than groundwater, the EC_w of effluent should be considered before implementing effluent irrigation of turfgrass.

Highly permeable soils, with suitable drainage and in areas of adequate precipitation, may tolerate effluent with high salt loads (up to 2,000 ppm of soluble salts) (Harivandi, 2004). Golf

course managers or greens superintendents can leach excessive salts from turfgrass root zones with proper precipitation events and/or excessive irrigation (Harivandi, 2004). In areas with light precipitation, heavy irrigation events may be necessary to leach salts below the root zone (Kopec et al., 1993). Adequate and steady precipitation, characteristic of the Midwest, often leaches out excessive salts from soil, thereby decreasing the need for salt accumulation management (DeBels, 2009).

6.5.2 Sodium Permeability Hazard

Na^+ and other ions can also have detrimental effects on soil structure and/or plant species. Na^+ may be directly toxic to turfgrass. It can accumulate in leaves and cause injury to the plant (Harivandi, 2004). Cl^-, which also contributes to total salinity, may be toxic to ornamental plants, trees, and flowers. However, turfgrass is not particularly susceptible to Cl^- toxicity (Harivandi, 2004). Along with salt stress caused by excess Na^+ and direct Na^+ toxicity, sodium permeability hazard—the effect of Na^+ ions on soil structure—is frequently an effluent irrigation concern (Huck et al., 2000). The sodium permeability hazard of irrigation waters, often measured as the Sodium Adsorption Ratio (SAR), is often the focal point of turfgrass managers (Harivandi, 2004). SAR is a measure of the Na^+ in relation to Mg^{2+} and Ca^{2+} in irrigation waters and is calculated by the following equation:

$$SAR = (Na) / ((Ca + Mg) / 2)^{1/2}$$

Close attention should be paid to Na^+ concentrations as they can greatly influence effluent water quality.

Whereas SAR is used in evaluating irrigation waters, the exchangeable sodium percentage (ESP) is used to evaluate the Na^+ status of a soil sample to determine if there is a possible sodium permeability hazard (Carrow, Waddington, & Reike, 2001). The ESP of a soil measures how much Na^+ occupies the soil exchange capacity, also described as the level of absorbed Na^+ within the soil (Malcolm, 2000). The equation for calculating ESP is as follows:

$$ESP= ((Na)/(Na+Mg+Ca+K)) \times 100\%$$

Both SAR and ESP are key parameters for evaluating irrigation water suitability.

Excess Na^+ can cause structural damage to soils by displacing Mg^{2+} and Ca^{2+} on the charge exchange sites of soil particles (Huck et al., 2000). This can cause soil structure to deteriorate by obstructing soil aggregates and causing the breakdown of soil structural units (Harivandi, 2004; Kopec et al., 1993). Sodic soils, which are soils with an ESP ratio greater than 15, typically have reduced soil aeration and water infiltration/percolation (Harivandi, 2004).

Irrigation water quality's effect on soil structure and permeability is best evaluated by the irrigation water's SAR and EC_w combination (Harivandi, 2004). Since clay soil particles are negatively

charged, they attract the cations in irrigating waters. Sodium (Na^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}) are cations that commonly fill the exchange sites of negatively charged clay soil particles. Sodium is generally considered a poor flocculating cation, which causes more soil swelling. Magnesium and calcium are considered better flocculating cations, leading to less swelling and better soil aggregate structure. Therefore, soil aggregate stability (the amount of flocculation and swelling) are dependent on the ratio of Na^+, Ca^{2+} and Mg^{2+}.

Soils with adequate drainage can tolerate higher levels of Na^+ in irrigating waters without becoming sodic, as long as corresponding high levels or Ca^{2+} and Mg^{2+} are present, as measured by high EC_w (D. Soldat, personal communication, September 14, 2011). Soil with high EC_w typically contains Ca^{2+} and Mg^{2+} that can replace Na^+ in the ion exchange sites of soil particles (Walworth, 2006). More information on the relationship between SAR and EC_w in irrigation water can be found in Table 6.1.

Turfgrass managers may balance sodic soils by applying additional Ca^{2+} to the soil, which is often done by applying gypsum (calcium sulfate) (Kopec et al., 1993; Stier, 2002). The SO_4^{2-} in gypsum bonds with excess Na^+ in the soil to form sodium sulfate, which can leach out from the soil (Stier, 2002).

The bulk of research conducted on the effluent irrigation of turfgrass has been conducted in the southern and southwestern parts of the United States where climate and soil types differ significantly from those in the Midwest (Qian & Mecham, 2005). Recent turfgrass research has examined effluent's effect on soil structure and turf grass quality, though primarily in areas with limited rainfall (DeBels, 2009). Traditional negative effects of effluent irrigation on turfgrass may be mitigated by Wisconsin's abundant rainfall of nearly 30 inches per year (DeBels, 2009). Research exploring effluent effect on turfgrass and soil qualities in areas with moderate to heavy precipitation is currently underway at the University of Wisconsin-Madison's O.J. Noer Turfgrass Research and Education Facility (D. Soldat, personal communication, June 14, 2011).

6.6 Challenges Encountered by Golf Courses in the Midwest

In an effort to understand the history and common challenges of golf course effluent irrigation use in the Midwest, the group conducted an extensive search for golf courses utilizing effluent irrigation in Michigan, Illinois, Wisconsin, Iowa, and Minnesota. This research proved challenging; according to one study, only three percent of golf courses in the Midwest region use effluent for irrigation (Throssell et al., 2009). The Executive Director of the Midwest Golf Course Owners Association, Curtis Walker, indicated that effluent is not commonly used for golf course irrigation in the Midwest due to the low cost of well water (C. Walker, personal communication, June 13, 2011).

Members of the group consulted with Scott Witte and Tommy Witt, golf course superintendents in Illinois, who use effluent for turfgrass irrigation at their courses: Cantigny Golf of Wheaton and Northmoor Country Club of Highland Park. A common practice at both courses is the addition of acid into the effluent to mitigate the high pH of the effluent used. However, the pH of the

effluent used at these courses is higher than MMSD's effluent. Both courses reported routinely testing soils for various nutrients to determine if excess nutrients collect in the topsoil.

The presence of sodic soils due to effluent irrigation has been a challenge at Cantigny Golf. This course routinely remedies these problems with the application of gypsum or lime. However, this challenge may be partially due to the heavy clay soils covering the course (S. Witte, personal communication, June 13, 2011). Cantigny Golf also reported effluent irrigation issues due to the presence of excess HCO_3^- ions in the effluent. According to the golf course superintendent at Cantigny Golf, this issue is alleviated by the injection of acid to the effluent water before it leaves the pump house (S. Witte, personal communication, July 21, 2011). Northmoor Country Club did not report any challenges regarding the use of effluent for irrigation.

It is important to note that both of the Illinois courses that use effluent for irrigation are adjacent to waste water treatment plants. Northmoor Country Club indicated that the differential cost of effluent water as compared to well water was the principle motive behind their utilization of effluent. Cantigny Golf suggested the proximity of the course to the treatment plant, and water conservation efforts, accounted for their decision to use effluent for irrigation. Cantigny Golf has calculated that over one billion gallons of groundwater have been conserved in the 22 years that the course has used effluent for its irrigation demands.

Although there are golf courses in the Midwest employing effluent irrigation methods, there were only two course superintendents willing to speak with the group about effluent use at the time of publication. Both of these courses use effluent that is of a higher quality than MMSD's effluent in terms of Na^+, Cl^-, SAR, and Total Suspended Solids (TSS). The fact that the courses have faced some challenges in spite of the relatively high quality of their effluent suggests further treatment of MMSD effluent may be necessary if it is to be more widely used for turfgrass irrigation.

6.7 Water Quality Results

Knowing the common issues associated with effluent irrigation of turfgrass, the group compared the water quality of the stormwater pond to that of MMSD effluent. Table 6.2 indicates the *Guidelines for Irrigation Water Quality* (Huck et al., 2000) for Na^+, Cl^- and EC_w. It is important to note that these are general guidelines for water quality irrigation; these guidelines are not specific to turfgrass or golf courses and do not take into account precipitation dilution. The water quality data from MMSD's effluent reveals that the effluent falls into the severe restriction categories for Cl and Na^+. The stormwater Cl^- levels fall into the no restriction category; Na^+ was not tested for in the stormwater pond. EC_w of effluent water was measured using an electrical conductivity meter. EC_w of MMSD's effluent and the stormwater fall into the moderate restriction category. These results indicate that both types of water contain a moderately restrictive amount of total salt.

Table 6.1 shows the degree of restriction for irrigation water based on the *Guidelines for Irrigation Water Quality* by Huck et al. (2000). The combination of the irrigation water's SAR and EC_w determines the effect it will have on soil structure and permeability. High EC_w in water prevents sodium from dispersing in the soil-water matrix (Huck et al., 2000). The group calculated the SAR value of the effluent by the following equation:

$$SAR = (Na) / ((Ca + Mg) / 2)^{1/2}$$

According to Table 6.1, when considering the SAR (5.65) and EC_w (1760 uS/m) values of MMSD's effluent, it falls into the no restrictions category. The addition of moderate to heavy precipitation in the Midwest may further dilute irrigation waters with high total salinity and elevated sodium concentrations.

6.8 Nine Springs Golf Course Soil Quality Results

In addition to exploring the differences in water quality between the effluent and stormwater, the group evaluated the soil quality at Hole 7 of Nine Springs Golf Course. In June of 2011, the group took soil cores from the course to determine if there was a substantial chemical difference between soils located in areas irrigated by effluent and those irrigated by stormwater. It is important to note that soil testing is typically not performed unless the golf course superintendent notices a visible deterioration in turfgrass health and soil quality at the course.

Using a one-inch diameter soil auger, the group took three samples of soils within the radius of the effluent sprinkler. These samples were divided into depths of 0-6 inches and 12-18 inches, and the soil from 6-12 inches was discarded. The samples from 0-6 and 12-18 inches in the effluent treated area were combined to obtain a more representative sample. This process was repeated for the non-effluent treated area, which is irrigated using stormwater. After removing all grass and root mass the samples were sent to the University of Wisconsin Soil and Plant Analysis Laboratory.

As evidenced by Table 6.3, there was no clear trend in cation and anion distribution among effluent irrigated and stormwater irrigated soils. Since the ESP of the soil is a more accurate way to assess the effect of Na^+ and other salts on soil structure and integrity, these values were calculated for each sample. The amount of Mg^{2+} and Ca^{2+} is greater in the stormwater-irrigated soil, which is an important parameter when evaluating the ESP of soil. The ratios of Na^+ to Ca^{2+}, Na^+ to Mg^{2+} and Na^+ to K^+ are the most significant parameters for measuring the sodium permeability hazard.

As shown by Table 6.4, both of the soil cores taken from the effluent irrigated soils yield higher ESP values than that of the stormwater irrigated soils. It is important to note that these ESP values are an approximation of the real ESP value due to the soil extract paste used in the analysis; they may be plus or minus five percent the actual value (D. Soldat, personal communication, September 14, 2011). The Mehlich III extraction method was used in soil core analysis, which is not the standard soil extract paste for calculating ESP.

SAR and ECw Values	Degree of Restriction for Irrigation Water Quality		
	No Restriction	Moderate Restriction	Severe Restriction
If SAR= 3-6 and EC_w (uS/m)=	>1,200	1,200-300	<300

Table 6.1. SAR and ECw Relationship on Water Infiltration into Soil. Guidelines for degree of restriction for irrigation water quality adopted from Huck et al. (2000). MMSD's 2010 effluent has a mean SAR of 5.65 and an ECw of 1,760 uS/m.

Parameter of Interest	Effluent	Storm Water	Degree of Restriction for Irrigation Water Quality		
			No Restriction	Moderate Restriction	Severe Restriction
Cl (ppm)	385	178	<0-70	70-355	>355
Na (ppm)	233	62	<0-70	70-210	>210
EC_w (uS/m)	1,760	750	<700	700-3,000	>3000

Table 6.2. Ion Concention and ECw Value Relationship to Water Infiltration into Soil. These Guidelines for Irrigation Water Quality were adopted from Huck et al. (2000). MMSD's effluent parameters were calculated from 2010 average water quality supplied by MMSD. The storm water parameters were averaged from two sampling events in the summer of 2011. ECw of effluent water was provided by MMSD and the ECw of the storm water was measured using an electrical conductivity meter.

Parameter of Interest	Effluent Irrigated Soil 0-6"	Storm Water Irrigated Soil 0-6"	Effluent Irrigated Soil 12-18"	Storm Water Irrigated Soil 12-18"
P (ppm)	22.35	63.56	64.21	57.88
K (ppm)	107.0	168.9	140.7	112.7
Ca (ppm)	965	2243	1337	1631
Mg (ppm)	167	321	275	308
Na (ppm)	322	315.6	366.5	304.8
Cl (ppm)	20.1	31.36	43.8	10.06
B (ppm)	2.841	2.368	2.640	2.415

Table 6.3. Soil Quality Results from Nine Springs Golf Course. Soil quality results from effluent irrigated and storm water irrigated soil cores extracted in June, 2011 from Hole 7 at Nine Springs Golf Course. UW Soil & Plant Analysis Lab Standard Operation Procedures are available from the following link: http://uwlab.soils.wisc.edu/files/procedures/soil_icp.pdf

Parameter of Interest	Effluent Irrigated Soil 0-6"	Storm Water Irrigated Soil 0-6"	Effluent Irrigated Soil 12-18"	Storm Water Irrigated Soil 12-18"
Ca mg/kg soil	965	2243	1337	1631
Mg mg/kg soil	167	321	275	308
Na mg/kg soil	322	315.6	366.5	304.8
K mg/kg soil	107.0	168.9	140.7	112.7
Approximate ESP*	18%	09%	15%	11%

Table 6.4. Calculated ESP Values of Soil Samples from Nine Springs Golf Course.

*The calculated exchangeable sodium percentage of soil from effluent irrigated and storm water irrigated soil cores extracted in June, 2011 from Hole 7 at Nine Springs Golf Course. The ESP was calculated using the Mehlich III soil analysis and therefore is only an estimate of the true ESP value.

According to sodic soil standards, both effluent soil cores are considered sodic. However, the most effective way to determine if the soils are truly sodic, and subsequently have infiltration issues, is to visually evaluate the turfgrass health and soil quality at the course (D. Soldat, personal communication, September 14, 2011). Schultz has reported no turfgrass and/or soils deterioration issues or infiltration problems at Hole 7. This suggests that either the calculated ESP values do not accurately reflect the nature of the soil or sodium levels are not posing a threat to the viability of soil structure at Nine Springs Golf Corse. No soil treatment regimen is necessary at this time. More soil sampling across the golf course would allow for stronger conclusions with regard to effluent irrigation effects on soil sodicity.

Soils need proper drainage to assure that Na^+ and other salts are adequately leached out and no detrimental buildup of ions occurs. The Natural Resources Conservation Service's Web Soil Survey classifies the soils at Hole 7 as moderately well drained (Soil Survey Staff, 2011). The remainder of the course is considered either moderately well drained or well drained; suggesting that other areas of the course will respond as well or better to an expanded effluent irrigation project (Soil Survey Staff, 2011).

6.9 Possible Expansion of Effluent Use at Nine Springs Golf Course

There are two viable possibilities for expanding effluent irrigation at the Nine Springs Golf Course: a) direct application of the entire course, and b) filling of the stormwater pond with effluent instead of ground water.

Direct application would lead to slightly more effluent usage than if it were mixed with the stormwater pond. However, direct application would require more infrastructure to route the effluent to the current pump house location than irrigating with a mixture of effluent and stormwater. As previously mentioned, there has been no noticeable deterioration of turfgrass or development of odor at Hole 7 during the six years of direct effluent irrigation. According to Schultz, maintenance and fertilizer application is consistent across the entire course, including Hole 7. Schultz's main concern with irrigating the entire course using direct application of effluent is the higher levels of salts in MMSD's effluent. High levels of salts can lead to accumulation on ornamental trees, shrubs, and flowers and soil degradation (D. Soldat, personal communication, June 14, 2011). According to Doug Soldat, turfgrass is moderately tolerant of high levels of salts (Na^+, Cl^-, and many other ions) in irrigating waters since the buildup of salts on leaves is avoided by frequent turfgrass mowing.

The use of effluent instead of groundwater to supply the stormwater pond when pond levels recede is another possible way to expand the use of effluent at the Nine Springs Golf Course. A pipe to route effluent to the stormwater pond would require minimal construction, thereby decreasing infrastructure expenditures, compared to direct effluent irrigation. According to Schultz, the stormwater pond recedes to "unacceptably" low levels eight to ten times per season, principally during hot and dry periods. When this water recession occurs (usually eight to ten inches), groundwater is used to fill the pond back to its original level. According to the group's calculations, approximately 4-6 million gallons of groundwater are used to refill the pond each year. Therefore, using effluent to refill the receded stormwater pond could utilize 4-6

million gallons of effluent each year at the Nine Springs Golf Course. By using effluent to fill the receded stormwater pond, irrigation water quality would fall between that of the stormwater and effluent. Utilizing effluent to refill the course's pond will eliminate the need to use groundwater for irrigation purposes, mitigate groundwater withdrawals, and support MMSD's and the City of Fitchburg's quest to return effluent to the Yahara watershed.

6.10 Additional Concerns: Advisory Signage

To protect public health, the USEPA recommends displaying notice of effluent use when the possibility for human contact exists (USEPA, 2004). Signage should be prominent enough to prevent any confusion between a potable water system used for drinking purposes and any non-potable water source. Signage also prevents the improper use or inadvertent use of reclaimed water as potable water.

Currently, Nine Springs Golf Course has two advisory signs established at the course (displayed in Figure 6.2). One sign is posted at the head of Hole 7, and the other is posted on a fence separating Hole 7 from a neighboring apartment complex. If Nine Springs Golf Course decides to expand their effluent irrigation use, the group suggests posting additional signs within and along the course, at the clubhouse, and at the first tee in order to increase community awareness and ensure public health and safety.

Figure 6.2. Current Effluent Irrigation Advisory Sign at Nine Springs Golf Course. Photo courtesy of City of Fitchburg Environmental Engineer, Rick Eilertson.

6.11 Recommendations

The Practicum recommends that Nine Springs Golf Course expand their use of MMSD's effluent by refilling the stormwater pond at the course using effluent rather than groundwater. The group believes that this option would provide better water quality than direct application of effluent for irrigation, with less financial overhead. The mixture of effluent and stormwater would produce higher quality water than direct irrigation and so may circumvent the development of salt accumulation or soil quality issues at the course.

The group believes that expanding effluent irrigation at Nine Springs Golf Course would be less costly than direct effluent irrigation because a shorter and less complex pipe would be required to extend the effluent return line into the stormwater pond. There are also potential savings from using the direct pressure of the effluent return line to fill the pond, rather than having to pay the electricity costs associated with groundwater pumping. This pipe is also a reversible option if any adverse effects are noticed; the groundwater option would still be viable. If Nine Springs Golf Course does decide to directly irrigate with effluent, a longer pipe that would circumnavigate the stormwater pond and extend into the pump house would need to be installed. Should the stormwater and effluent mixture yield adverse effects on turfgrass, ornamental plants, and soil quality, the golf course manager could immediately end effluent irrigation, and return to using groundwater in refilling the stormwater pond.

Nine Springs Golf Course currently uses stormwater to irrigate, and, therefore, already implements the use of recycled or reused water. However, the course should expand the use of effluent in order to eliminate the use of groundwater for irrigation purposes. As previously mentioned, the group calculated that approximately 4-6 million gallons of effluent, in place of groundwater, can be used to refill the pond each year. By expanding the use of effluent at Nine Springs Golf Course, MMSD and the City of Fitchburg will encourage the use of effluent within the Yahara Watershed. Although the amount of water may be negligible in comparison to daily effluent discharges by MMSD (45 million gallons per day), this expanded water reuse project will provide an example for other golf courses and large turfgrass areas within the Yahara Watershed.

Additionally, MMSD, the City of Fitchburg and the Nine Springs Golf Course should continue to visual monitor the course and expand their signage. If permeability and infiltration issues arise at Nine Springs Golf Course, a permeameter test, as shown in Appendix K, will help determine whether or not to use gypsum to address the problem. Permeameter testing compares the rate of water infiltration from an unadulterated soil sample to a soil sample containing gypsum. The addition of gypsum (calcium sulfate) to soil causes Ca^{2+} to replace Na^+ on the soil ion exchange sites. If there is no observed difference in infiltration rates between the unadulterated soil sample and the soil sample containing gypsum, this suggests that excess Na^+ ions are not responsible for infiltration issues (D. Soldat, personal communication, September 14, 2011). However, the group recommends only conducting a physical soil quality test if noticeable infiltration problems occur at Nine Springs Golf Course.

Furthermore, physical soil quality tests, such as aggregate stability and saturated hydraulic conductivity, may help in determining if any physical soil quality issues exist at the course. Nine Springs Golf Course should visually monitor and evaluate the ornamental trees, shrubs, and flowers for sodium and chloride toxicity and switch back to groundwater if any unacceptable effects are noted. Effluent advisory signage should be located at the clubhouse, the first tee, and all external fencing surrounding Nine Springs Golf Course. Lastly, a sodium chloride reduction program would decrease sodicity and toxicity risks, especially for more sensitive plant species.

Finally MMSD should investigate the feasibility of initiating effluent irrigation projects at other golf courses in the vicinity. The 30 golf courses in Dane County withdraw 0.68 MGD of groundwater for irrigation; while this amount is not large relative to the county's total water use, it is larger than golf course irrigation amounts in all but one other county in Wisconsin. Evaluating the potential of scaling-up the Nine Springs Golf Course effluent reuse project to a regional level would contribute to further reducing the use of potable water for irrigation.

Chapter 7 • Community Outreach

7.1 Introduction

Water reuse is not a new concept, particularly in regard to conservation of groundwater resources. The reuse of treated wastewater through enhanced groundwater recharge is an extension of this conservation (Fetter Jr. & Holzmacher, 1974). However, enhanced recharge using treated wastewater presents many concerns to humans and the environment. For instance, chemicals contained in pharmaceutical and personal care products (PPCPs), as well as pathogens, can impinge upon human health, while heavy metals and nutrient loads can affect plant growth.

Many site-specific, environmental issues associated with reusing treated wastewater can be addressed through an engineering framework. However, human health issues of reusing treated wastewater also need to be addressed through a social framework that includes effective outreach, education, communication, and trust-building programs within communities. There are many factors that influence peoples' receptivity to reusing treated wastewater. For instance, seemingly trivial factors such as the name of the product – "recycled water" versus "treated wastewater" – can hinder any effort of implementing a groundwater recharge project.

This chapter is primarily an overview of the Practicum's community engagement with the residents of Fitchburg as well as a literature review of public perception towards using treated wastewater. In addition, the group provides recommendations for gaining community trust for future groundwater recharge projects. The chapter begins with the potential human and environmental health concerns associated with using treated wastewater for artificial groundwater recharge.

7.2 Human Health Concerns

A water reuse project that uses treated wastewater would bring the constituents of the wastewater to new environments, where they might impinge upon human health. In order to address this concern, the group researched the effects of chemical and biological constituents on human health. Although treatment significantly reduces the concentrations of chemical and biological constituents in wastewater, some of these constituents would still be present in trace amounts in the reused water. Understanding and minimizing the risk that these chemical and biological components pose to Fitchburg area residents is an important part of designing a water reuse project.

7.2.1 Chemical Constituents

Chemical constituents include nutrients, salts, heavy metals and organic and inorganic compounds. Organic compounds, such as PPCPs, pose unique concerns since the federal and

Wisconsin state governments have not set regulations or recommendations for levels safe to humans. PPCPs enter the environment in various ways:

- Human activity such as bathing, shaving, or swimming

- Drug use, especially steroids and antibiotics

- Residues from pharmaceutical manufacturing and from hospitals

- Medications that leach out of the landfills

- Medication residues that pass out of the body and into the sewer line

At present, the Madison Metropolitan Sewerage District (MMSD) lacks the technology to remove all the PPCP residues. The effluent contains a mixture of PPCPs such as antibiotics, stimulants, nicotine, and caffeine metabolites. Endocrine disruptors and antibiotics pose significant risks as the former restricts hormone production while the latter can induce resistance in bacteria. As a result, there is concern that these PPCP residues will bioaccumulate within the human body over the years.

Animal exposure tests, environmental risk assessments, and human health risk models allow ecotoxicologists to understand the effects and risks of PPCPs. For instance, one study exposed zebrafish (*Danio rerio*), a fish species typically used in scientific research, to the chemical 17-ethinylestradiol, a form of estrogen used in contraceptive pills (Nash et al., 2004). While the chemical significantly impaired the zebrafish, its effect varied depending on the concentration and the stage at which the fish was exposed to the chemical. During the partial life-cycle of the fish, at two ng/L (nanograms per liter), the chemical induced sex reversal in the fish. Over the entire course of the fish's life-cycle, the chemical lowered hatching success by 20 percent at 0.2 ng/Land caused a 56 percent reduction in fertility of the succeeding generation at 5 ng/L (Nash et al., 2004). Of the 117 streams surveyed in the United States, 5.7 percent showed concentrations of at least five ng/L of 17-ethinylestradiol (Kolpin et al., 2002).

Interactions between different PPCPs may intensify or reverse the effect of others. For instance, while the cholesterol drug bezabfibrate and the asthma drug salbutamol each stimulate cell growth, the combined effect of the two drugs inhibited cell growth (Donn, 2011).

Fortunately, human health risk models indicate that current concentrations of PPCPs in potable water sources are safe (Smith, 2010). In 2009 MMSD conducted its own environmental risk assessment based on the number of years needed for a person to reach the common minimum dose for various drugs from drinking two liters of water per day containing the effluent's organic and inorganic contents. The results ranged from 2,880 years, to reach the 100 mg minimum dose of the antibiotic Trimethoprim, to 1,175,799 years, to reach the minimum dose of 500 mg for the antibiotic sulfadiazine.

While these results provide support to current health risk assessment models about the innocuous effects of PPCPs to human health, the group has taken extra precaution to ensure that the recharged effluent will be safe to humans. As discussed earlier in the site selection process, the group conducted groundwater flow analysis using modeling to ensure that any recharged effluent will not reach public or private wells. In addition, the group has recommended a two-part wetland/infiltration system at the Upland Site to polish the treated wastewater via the media and the mixed native vegetation. In addition, Nine Springs Wetland offers treatment for any overflow of wastewater from the Upland Site. (See Section 7.6, Recommendations, for further details).

7.2.2 Biological Constituents

Biological constituents include bacteria, protozoa, helminthes, and viruses. There are many pathogenic microorganisms and viruses in wastewater. Although each has different characteristics, sources, and impacts, one strain often serves as the indicator organism. The abundance of other organisms can be inferred from the measured concentrations of the indicator.

As recommended by the U.S. Environmental Protection Agency (USEPA), MMSD currently uses fecal coliform as the indicator organism. Between April 15 and October 15, MMSD treats its wastewater to advanced secondary treatment with additional disinfection via ultraviolet irradiation (see Section 7.1). In 2010, the effluent contained an average of 122 fecal coliform per100 mL (milliliters) during this period (MMSD, 2011). The median infectious dose is 106-1010 organisms per 100 mL, though illness can result from consumption of water with lower concentrations (Asano, 2007).

Fecal coliform counts offer some insight into the severity of the contamination by biological constituents. The actual counts of other forms of bacteria, protozoa, helminthes, and viruses are not directly known. Experts warn that methods such as ultraviolet irradiation, which sufficiently inactivates the indicator bacteria, may not treat all pathogens (Blatchley et al., 2007). Nevertheless, ultraviolet irradiation used at MMSD is considered more effective at inactivating viruses than chlorination (Blatchley et al., 2007). The current treatment process may sufficiently eliminate the biological constituents of the wastewater for certain environmental uses.

If the treated wastewater were reused, it would be diluted in the natural environment. It is possible that the organisms within it would inactivate or die off (Asano, 2007). However, once in the environment the complexity of groundwater conditions make it difficult to accurately predict the rates of inactivation and decay of the organisms. For example, indigenous groundwater microorganisms promote the inactivation of pathogenic bacteria and viruses. In addition, the higher temperatures and oxygen levels of the groundwater advance inactivation, though to a lesser extent (Gordon & Toze, 2003). As a result, a reduction of 90 percent of the viable concentrations could take anywhere from 24 hours, for some bacteria, to several months, for some protozoa (Asano, 2007).

While the treatment process at MMSD significantly reduces the concentrations of pathogens in the wastewater, the continued presence of organisms in the effluent, along with and the complexities of groundwater conditions in deactivating the organisms, necessitates monitoring the use of treated wastewater for groundwater recharge in order to minimize human health impacts.

7.3 Environmental Health Concerns

With any wastewater reuse system there is the potential for environmental problems that result from the introduction of pollutants contained in the wastewater.

The two major types of problems are those associated with the following (Kadlec & Knight, 1996):

- the loading of excess water, organic matter, and nutrients

- the introduction of traditional pollutants such as metals, pesticides, and other chemicals

Excess loads of water, organic matter, and nutrients can potentially impact plant growth and, in some cases, cause toxicity. Additionally, because many invasive plant species thrive in high-nutrient conditions, these undesirable species may out-compete more desirable native ones and thus change the natural composition of the ecosystem (Zedler & Kercher, 2004). For this study, phosphorus (P) and nitrogen (N) are of most concern because of their threat to the quality of the Yahara Lakes. In recent years, eutrophication from surface runoff has been a significant issue, as evidenced by the algae blooms and depleted oxygen levels in the lakes. Public concern over this issue led to new regulations in 2005 that restrict the use and sale of fertilizers containing P in Dane County (Dane County, 2011).

The second source of environmental problems is the introduction of traditional pollutants such as chemicals, heavy metals, and other toxins. During the wetland treatment process, these pollutants are removed from the wastewater and stored in soils and plants via adsorption and absorption. One major concern is the bioaccumulation and biomagnification of toxins and heavy metals in an ecosystem. While many metals are concentrated in soils and plants, only certain metals can transfer and concentrate in a food chain through biomagnification (Kadlec & Knight, 1996). Due to their tendency to bioaccumulate, two metals of concern are mercury, in its most bioaccumulated form methyl-mercury, and lead (Kadlec & Knight, 1996). Because of these concerns the initial water quality of effluent, as well as the quantity flowing through a system, should be carefully considered to prevent the development of toxic conditions for plants and other wildlife.

7.4 Understanding Concerns Through Community Engagement

The previous subsections provided an overview of the human and environmental concerns associated with treated wastewater. The following section explores the social aspects of an effluent recharge project, beginning with a literature review of the public perceptions of treated wastewater and followed by a report of the group's public meetings with Fitchburg residents. Finally, the section will present MMSD and the City of Fitchburg with additional factors to consider when developing a groundwater recharge project.

7.4.1 Public Perception of Treated Wastewater

The concept of reusing, or recycling, treated wastewater is not new, particularly in more arid regions of the world. Increased pressure from a growing population, as well as the uncertainty of the effects of climate change on water supply, has forced water-scarce regions to consider water recycling. For the most part, the success of water recycling projects depends on the public willingness to accept recycled water from treated wastewater as a resource.

How the residents of Fitchburg and the surrounding communities will accept a final groundwater recharge project will be a significant factor, if not the deciding factor, for the success of a recharge project. Even water-scarce regions like California have experienced public rejection of water augmentation projects that use recycled water. Rejection generally stems from the "yuck factor" rather than from concerns about the actual chemical composition of the wastewater (Dingfelder, 2004). This is particularly true when the use of the recycled water will involve close or direct human contact. For activities like washing clothes and drinking, desalinated water is preferred over recycled water. Conversely, for activities where human contact is minimal, such as golf course irrigation or industrial cooling, public acceptance for recycled water has been found to be over 90 percent in the United States (Sims & Bauman, 1974).

Past studies have explored how various factors are involved with public acceptance of water recycling programs. Robinson, Robinson, and Hawkin (2011) assessed attitudes, knowledge, and information sources concerning wastewater reuse with respect to population demographics. The study found that activities like firefighting, golf course irrigation, lawn irrigation, car washing, and agricultural irrigation generated positive attitudes with approval ratings between 50-80 percent. The study further explored how age, gender, income, and education influenced acceptance. From their surveys, both men and women unfavorably viewed the use of wastewater for possible consumption and activities involving close personal contact. People who have lower incomes, less education, and are 65 years of age or older had significantly less knowledge of wastewater issues than higher-income, more educated, younger individuals. The study's results largely agreed with Sims and Baumann (1974) and Bruvold and Ward (1972).

Menegaki, Mellon, Vrentzou, Koumakis, and Tsagarakis (2009) explored how different names used to describe treated wastewater impacted people's willingness to pay for the same product. Following a survey conducted in Greece, the authors conclude that more people

were willing to pay for treated wastewater if it were named "recycled water" as opposed to "treated wastewater." According to Menegaki et al., the term "treated" implies that the effluent described has merely been transformed from its previous (polluted) state, while "recycled" denotes a return towards an even earlier, purer source material. "Disgust" was cited most frequently (30 percent) as the main reason for unwillingness to use the product if it were named "treated wastewater."

For MMSD and the City of Fitchburg, it will be important to engage with the public to ensure maximum acceptance for a groundwater recharge project. Success for other water recycling projects has been attributed to factors such as (Hartley, 2006):

- High awareness of water supply problems in the community

- High confidence in local management of public utilities and technologies

- Clear benefit to the environment from water recycling

The group has engaged with the public twice, through public meetings in Fitchburg as well as on various occasions at local farmer's markets in the Madison metropolitan area, to promote the project and to ensure that the public is aware of the groundwater issue. Since public perception plays a major role in acceptance, continuation of such meetings and promotional events would help to increase public acceptance as well as spread positive messages about the benefits of water reuse (Dolnicar, Hurlimann, & Grünac, 2011).

7.4.2 Public Meeting Overview

The first meeting was held on Thursday, January 27th, 2011 from 6:30-8:30PM in the Fitchburg Room of the City of Fitchburg Community Center. There were approximately 50 attendees including Fitchburg residents, affiliated students, faculty, and presenters. The meeting was divided into two parts. The first part was a presentation by four guest speakers that provided an overview of the project and background information about the groundwater issue.

- Dr. Ken Bradbury, a UW-Extension Professor and Hydrogeologist working with the Wisconsin Geological and Natural History Survey, presented "Where's Dane County's Groundwater Going?" It provided a brief overview of Dane County's physical characteristics (hydrogeology) and water use, as well as the effect that water use and pumping has had on local groundwater levels. His colleague Michael Parsen, also a Hydrogeologist, presented information on the new groundwater model for Dane County.

- Dr. Steve Gaffield, Senior Hydrologist at Montgomery Associates, Resource Solutions, LLC, presented a talk called "Who's been doing Recharge Projects so far in Dane County?" It discussed the details of the local Odana Hills Golf Course groundwater recharge system that was installed in 2005 by Madison Gas & Electric.

- Dave Taylor, an Environmental Scientist working for Madison Metropolitan Sewerage District (MMSD), presented, "What's an Effluent Return Line and How can it be used for Recharge Projects?" It provided background on MMSD's effluent return line, as well as information on the Nine Springs Golf Course Irrigation Project.

The second part of the meeting was devoted to small group discussions with the attendees and each group was facilitated by two WRM students. The discussions were designed to be open-ended to provide the best venue for understanding the public's awareness of the groundwater issue as well as to gain feedback on their ideas and concerns about the project.

In general, the participants seemed very optimistic about the project and open to the idea of groundwater recharge, though many had concerns regarding the quality of the treated wastewater that would be used in the recharge process. Specifically, individuals listed areas of concern such as chloride (Cl^-) and P levels, viruses, and chemicals. People also wanted more information about the specifics of the project, such as location, scale and timing, the roles of involved parties, and the project goals and costs. These details will play a large role in public opinion.

The second meeting was held on Wednesday, May 18th, 2011 at the same venue and followed up on the information presented in the first meeting. Four WRM students updated the attendees about the progress of the project as well as details about the summer fieldwork plans at the Nine Springs Golf Course, Nine Springs Wetland, and the Upland Site. However, in spite of the planning and publicity, only seven people not affiliated with the project were present. The meeting still generated important questions:

- What amount of P and N will be removed from the treated effluent by the peat?

- Will the effluent administration be year-round and how will winter weather affect treatment?

- How is the public accepting the use of effluent at the golf course? Are there any complaints of odor, worries about contact, etc.?

- What is the cost of not doing the projects in the long run?

- What would be the result if Madison were to take its water from the lakes instead of from the groundwater?

7.4.3 Gaining Community Trust

During the small group discussions at the first meeting, most of the attendees focused on the water quality concerns, specifically on the constituents of the treated wastewater (viruses, bacteria, chemicals, etc.) and their human and environmental impacts. These water quality concerns are not surprising given the nature of the project. However, MMSD and the City of

Fitchburg should be aware that the perceptions of risk associated with water reuse are not homogeneous across stakeholders.

Baggett, Jeffrey and Jefferson (2006) examined risk perception in participatory planning for water reuse across four broad stakeholder groups in the United Kingdom: researchers, managers/ water suppliers, regulators, and the public. Each stakeholder was asked to identify two risks that they deemed important. In addition, the respondents were asked to rank the extent to which they thought the other stakeholders would agree with their top two risks. Each group of stakeholders emphasized different risks and trust levels in the other stakeholders. For instance, the public regarded the researchers as the most trustworthy and the water suppliers as the least trustworthy. On the other hand, both the water suppliers and the regulators considered themselves the most trustworthy and the public the least trustworthy.

For MMSD and the City of Fitchburg, the important issue will be to further develop and maintain public trust. Hartley (2006) has developed five principles to employ for projects involving water reuse. These principles are:

- Manage information for all

- Maintain individual motivation and demonstrate organizational commitment

- Promote communication and public dialog

- Ensure fair and sound decision-making and decisions

- Build and maintain trust

Hartley states that any limitation in data sharing with the public can create problems. In an attempt to address this, the group developed a public website to disseminate information about the project (https://sites.google.com/site/9springsrecharge/). The website is one means to engage with the public and develop trust by providing background information and access to select documents. Building this trust is necessary to ensure public acceptance. According to Stenekes, Colebatch, Waite, and Ashbolt (2006), the risks associated with water recycling are intricately linked with public trust and credibility of institutions. For instance, in the survey by Menegaki et al. (2009), "distrust of municipal regulating authorities" followed "disgust" as the second reason for unwillingness to use treated wastewater. While issues of trust were not explicitly mentioned in the small group discussions, MMSD and the City of Fitchburg should develop strong public campaigns, or strengthen existing ones, that take into consideration multiple factors including the language used in a groundwater recharge project as well as the demographics of the stakeholders.

Successful campaigns of water reuse programs, like NEWater in Singapore, can act as a model for an outreach strategy in Fitchburg. Though NEWater recycles water from treated wastewater for potable use, its success could be adapted for a groundwater recharge project. According

to Leong (2011), the success of NEWater was attributed to many factors such as consistent key messages, which included the use of identical words by politicians, as well as the political leaders drinking the reused water openly and frequently. These factors helped to reduce uncertainty in the public about the NEWater project. In addition, neutral language was used to help the public overcome their psychological fear of using NEWater. Leong proposes at least two methods to help develop a "pro-policy" media scenario:

- A coherent communications plan by the water manager, to formulate "agreed ideas"

- An engaged media that is neutral at worst, supportive at best, to create genuine knowledge

Trust can be further bolstered by ensuing public involvement at all levels of the decision making process. This level of involvement proved successful in Queensland, Australia (Gibson & Apostolidis, 2001). One such means of engaging public involvement is through economic valuation. While most of the participants in the small group discussion mentioned concerns about the water quality, a few questioned the "worth" of the project. This deserves consideration given that surface water features like springs, streams, lakes, and wetlands provide many market and non-market goods and services to humans, such as drinking water and biodiversity.

According to Wilson and Carpenter (1999), resource managers should acknowledge the value of non-human use services, or "nonuse" values. In economics, "use" value is the satisfaction derived from direct consumption of a good or service. With respect to water resources, these include recreation (fishing and boating) and use for industry and agriculture (Wilson & Carpenter, 1999). Nonuse values pertain to goods and services from which people gain satisfaction via their "existence values." In other words, the value and satisfaction of a good or service is based upon the fact that people know the good or service exists, like a remote wetland, without the need to directly consume the good or service (Wilson & Carpenter, 1999). Neglecting efforts to quantify the value of "nonuse" benefits will not capture the "total economic value" of the freshwater feature. As a result, Wilson and Carpenter state that policies will overestimate the role of use values and underestimate the role of nonuse values, which can lead to environmentally degrading practices.

Environmental valuation and valuation studies can allow ordinary citizens a means to have their opinions heard, regardless of the costs or benefits of the recharge project. Furthermore, valuation studies can help de-emphasize the role of "special interests" in the decision-making process (Loomis, 2000) and ensure equal participation.

7.5 Conclusion

Enhanced groundwater recharge projects that use treated wastewater present many scientific, engineering, and social dilemmas. These issues need to be addressed before they can be

successfully developed and implemented in a community. Also, effluent, though treated, still contains many chemical and biological constituents that can adversely affect the environment and human health. For some constituents, like heavy metals and pathogens, effects are known; for others, such as PPCPs, further studies are warranted.

While animal exposure tests and health risk modeling of treated wastewater provide some assurances regarding human health safety, for many people the mere fact that wastewater is being used may be the largest obstacle in the success of such a project. The "yuck factor" is a natural aversion to wastewater; surpassing this aversion requires gaining public trust through outreach, education, and participation.

This section has provided ways for MMSD and the City of Fitchburg to gain community trust. Yet artificial groundwater recharge should only be viewed as one means towards the conservation of groundwater resources. The next section presents some alternative uses for the treated wastewater, including industrial cooling and irrigation. Furthermore, the Practicum presents other conservation strategies that can be implemented, or further refined from existing ones, to limit the consumptive use of groundwater in Dane County.

7.6 Recommendations

With respect to the social aspects of a groundwater recharge project, MMSD and the City of Fitchburg should strive towards developing trust and credibility with the residents of Fitchburg as well as the Madison-area community. As mentioned earlier, Hartley (2006) and Leong (2011) offer various principles and methods to help bolster public acceptance of a groundwater recharge project:

- Manage information for all

- Maintain individual motivation and demonstrate organization commitment

- Promote communication and public dialogue

- Ensure fair and sound decision-making

- Build and maintain trust

- Educate the public of water supply problems in the community

- Generate high confidence in local management of public utilities and technologies

- Provide a clear benefit to the environment from water recycling

- Formulate "agreed ideas" through a coherent communications plan by the water manager

- Create genuine knowledge through an engaged media

These methods and principles should be developed around the social context of the proposed groundwater recharge area residents as well as the perspective of stakeholder constituents. A demographic study that includes the level of education and income as well as the stakeholder category, public, regulator or engineer, would be useful in developing public outreach for the project. A successful groundwater recharge project incorporates the opinions of all the relevant stakeholders, in particular the public.. An economic valuation, analyzed by Wilson and Carpenter (1999), is another way to win stakeholder support. With any approach, MMSD and the City of Fitchburg should not assume that the experts have all the knowledge compared to the public. Stenekes et al. (2006) mention this as the "deficit model" of public knowledge and that attitude can create mistrust in public stakeholders

Chapter 8 • Recommendations

This chapter provides a summary of the recommendations for expanded treated effluent use based on studies completed at the three on-site pilot projects. The recommendations include a regulatory framework for state regulations for enhanced groundwater recharge and methods of community outreach. Finally, the group recommends alternatives to reach the Practicum's goal of enhanced groundwater recharge that enhances both water sustainability and greater cost-effectiveness.

8.1 Site-based Recommendations

Currently, none of the publicly-owned tracts of land that are within one mile of the effluent return line are large enough to recharge all Madison Metropolitan Sewerage District (MMSD) effluent, or even Fitchburg's share. Based on projects in California and Florida, recharging one million gallons per day can require anywhere between two and 100 acres of land (McConaughy, Vandenberg, & Hutchinson, 2011; Cross, 2011). Locally, the 2.1-acre infiltration trench network at Odana Hills averaged 0.17 million gallons per day (MGD) of recharge from 2007-2009 (S. Gaffield, personal communication, August 15, 2011). There may be land farther away from the effluent return line (especially to the southwest of Madison in the unglaciated region) with more suitable soils that would require less excavation. However, those sites would also require increased infrastructure to transport the effluent to the site. MMSD and the City of Fitchburg should conduct a cost-benefit analysis to determine if alternate areas, outside of the one-mile buffer used for the sites chosen by the Practicum, would provide greater feasibility for a large-scale project. This chapter contains the practicum recommendations for enhancing groundwater recharge based on the Practicum's selected areas.

8.1.1 Upland Site Recommendations

Since the Upland Site has sufficient area to implement an enhanced groundwater recharge project on a pilot-scale, the Practicum recommends developing an approximately 6-acre area. Although this area is currently Wisconsin Department of Natural Resources (WDNR) hunting grounds, the proposed recharge area represents less than a tenth of the overall hunting grounds. In order for the effluent to meet NR 140 groundwater quality standards, the site should include a two-stage wetland/infiltration system. Alternatively, MMSD could increase treatment levels at the wastewater treatment plant as described in Section 8.3. The first stage, the treatment wetland, polishes the effluent to remove components of concern (phosphorus (P), nitrogen (N), bacteria, and viruses.

This polished effluent would then be routed to the second stage of the system, consisting of infiltration basins. These basins would be excavated to bedrock and backfilled with highly permeable sand or gravel to allow water to recharge the unconfined aquifer. Planting mixed native vegetation will polish the effluent, improve habitat, and provide an aesthetically pleasing area for the community.

In order to educate the public about the possibilities of expanded water reuse, the area should incorporate interpretive signage. Like the signage on display at the MMSD Wildlife Observation Area and Nine Springs Golf Course, signs at the Upland Site should have both an advisory and educational role. In addition, constructing a walkway would allow the public to observe the recharge project and area wildlife, while preventing disruption of the treatment.

8.1.2 Wetland Site Recommendations

The Practicum recommends starting a pilot project at the Wetland Site. Whenever the water table drops to a specified level, treated wastewater should be released to saturate and flood the wetland. This additional inflow would raise the water table to historical levels and support the functions of the wetland ecosystem. An accompanying wetland restoration project should augment the water reuse project within the wetland. The permanent flow regime would motivate the decisions about plant selection and management. As with the Upland Site, posting informational signage would inform and engage the public about both wetland restoration and water reuse.

8.1.3 Golf Course Recommendations

The Practicum recommends that the Nine Springs Golf Course expand its use of effluent in order to replace current groundwater usage and serve as a model for future effluent irrigation projects. Installing a pipe to refill the stormwater retention pond with effluent instead of pumping groundwater will not only curtail the use of groundwater during stormwater shortages, but also result in monetary savings to the golf course in terms of decreased electricity costs from pumping. In addition, filling the stormwater pond with effluent requires less construction than direct effluent irrigation. Finally, by mixing the effluent with the stormwater, the sodium ($Na+$) and chloride ($Cl-$) levels will be lower than using effluent directly, leading to a lower risk of sodic soils and toxicity issues. Increased signage will help to educate the public about the possibility of using effluent for irrigation.

8.2 Regulatory Considerations

The Practicum recommends planning and coordinating all future water reuse projects with the WDNR. MMSD and the City of Fitchburg should encourage the WDNR to consider a regulatory framework for water reuse, as water reuse is likely to become an important issue in the near future. New state regulations for reuse should take the United States Environmental Protection Agency's recommendations into consideration, while modifying for factors such as Wisconsin's climate and geology. New regulations should address, at a minimum, the following:

- Treatment process, reliability, and storage requirements

- Biochemical Oxygen Demand (BOD)

- Total Suspended Solids (TSS) and turbidity requirements

- Coliform bacteria limits and disinfection requirements

- Limits and monitoring for pathogenic organisms

- Nutrient limits

- Potable and non-potable water separation

- Setback distances

8.3 Outreach Considerations

The Practicum recommends that MMSD and the City of Fitchburg continue to develop community relations with respect to groundwater recharge. The specific site recommendations above may provide a means to introduce the public to the idea of enhanced recharge and garner interest in expanding water reuse to more areas and uses. MMSD and the City of Fitchburg should work with individuals, community organizations, and local media, as well as state and local institutions to build trust and disseminate information about water reuse and water supply issues.

8.4 Alternatives

In addition to the project designs discussed in this report, the Practicum identified several other methods of reaching the overall, long-term goals of the project. Conservation successfully reduces further groundwater withdrawals, thereby avoiding the issue of out-of-watershed diversions and the consequent need to recharge groundwater. Treating the wastewater at MMSD to a higher standard would allow greater reuse of the water, including direct return into the lakes within the watershed. Even though Wisconsin state law does not require conservation or tertiary treatment, both should be considered as important, if not more so, than the site-specific recharge based recommendations.

8.4.1 Conservation

Conservation includes both using water more efficiently and reusing water for secondary purposes. Reducing water use achieves the same outcome as groundwater recharge and uses far less energy, making this a cost-effective alternative. Both water use reduction and reuse can be implemented at individual levels or at an industrial scale. As conservation is not mandatory by Wisconsin state law, water management strategies are necessary for motivating water use reduction and reuse (e.g. monetary incentives, public education, or water pricing systems) (Midwest Environmental Advocates, Inc., 2005). The following sections describe the current water management strategies and opportunities in Fitchburg. The section concludes with key recommendations for the City of Fitchburg to further develop their comprehensive water conservation plan for the community based on the Environmental Protection Agency's Water Conservation Plan Guidelines.

8.4.1.1 Water Conservation on an Individual Level

Domestic water use in Dane County accounts for approximately 42 percent of total water use, a larger amount than any other sector (Buchwald, 2009). Reducing water use on an individual level includes simple, low cost tasks such as turning off the faucet when not in use while brushing your teeth or showering, fixing leaky pipes, or filling clothes washers completely. In support of individual initiatives, the City of Fitchburg has focused on encouraging the installation of high efficiency plumbing fixtures. This is being done in collaboration with the U.S. Environmental Protection Agency's (USEPA) Water Sense program (City of Fitchburg, 2011). Fitchburg provides incentives to replace older, inefficient toilets with high efficiency models (no more than 1.28 gallons per flush) (USEPA Water Sense, 2007). Installing high efficiency toilets is particularly significant since flushing the toilet is the largest use of household water in the United States (Perlman, 2011).

Although conservation regulations on a state level do not exist, communities can impose lawn-sprinkling limitations. For instance, Waukesha County in Wisconsin restricts watering to only two days per week, and before 9 a.m. or after 5 p.m. (City of Madison Water Utility, 2008). According to Ordinance 13.04, the City of Madison has similar authority and could use the existing structure to mandate irrigation limitations. This opportunity could coincide with a rain garden promotional initiative. Rain gardens provide a natural landscaping method that reduces the need for lawn watering while performing environmental services such as filtering of excess nutrients and contaminants and recharging groundwater supplies. Fitchburg already has the potential to demonstrate the advantages of rain gardens to the public by using the Fitchburg Community Center's rain garden. Additionally, the Fitchburg Creek Supporter Community Education and Action Project, sponsored by the City of Fitchburg's Stormwater Utility, offers a stormwater utility bill credit and rebate program for new rain garden installation (Fitchburg, 2008).

Fitchburg industry represents approximately 12 percent of Fitchburg's total water use (Markham et. al., 2007) and contributes to the watershed's groundwater drawdown. Some companies pull as much as 13 million gallons from the aquifer annually (Foss, 2011). Industrial water use has increased considerably, from 40.8 million gallons in 2008 to 42.3 million gallons in 2010 (The City of Fitchburg Finance Department, 2011). In order to prevent further out-of-watershed diversions, reclaimed water could conveniently be used for industrial purposes either in Fitchburg at industries along the effluent return line, or in Dane County at locations already capable of further treating water to a tertiary level. In general, the Practicum recommends that any of Fitchburg's top ten water customers from 2008 to 2010 consider effluent reuse for industrial purposes (Table 8.1).

2010 Top Water Users

	Customer	Service Address	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Total
1	Promega	5445 E Cheryl Pkwy	1,018,700	1,701,200	1,866,400	3,817,500	8,403,800
2	Promega	2800 Woods Hollow Rd	1,113,840	1,119,890	1,132,900	1,575,980	4,942,610
3	Sub Zero	2866 Buds Dr	351,390	940,000	1,206,680	1,839,270	4,337,340
4	United Vaccines	2919 Commerce Park Dr	876,360	922,860	1,093,080	1,342,080	4,234,380
5	Target	6321 McKee Rd	367,900	512,950	1,356,710	1,875,520	4,113,080
6	St Mary's Medical Ctr	2840 Index Rd	918,130	956,950	972,660	1,011,670	3,859,410
7	Nedrebo's Formal Wear	5237 Verona Rd # 01	469,140	900,140	939,730	1,399,850	3,708,860
8	PDQ	6133 McKee Rd	550,340	587,720	842,680	1,163,850	3,144,590
9	Sub Zero	2866 Buds Dr # A	277,070	656,830	791,590	1,164,230	2,889,720
10	Nu Ventures II	5500 Nobel Dr	587,980	613,290	662,890	763,380	2,627,540
							42,261,330

2009 Top Water Users

	Customer	Service Address	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Total
1	Promega	5445 E Cheryl Pkwy	958,000	1,243,700	1,485,000	2,208,000	5,894,700
2	Promega	2800 Woods Hollow Rd	900,000	1,035,000	1,065,350	1,377,840	4,378,190
3	Sub Zero	2866 Buds Dr	458,000	900,000	991,240	1,576,530	3,925,770
4	United Vaccines	2919 Commerce Park Dr	722,380	923,830	953,000	1,104,000	3,703,210
5	Certco	6150 McKee Rd	200,000	704,130	1,339,000	1,374,330	3,617,460
6	St Mary's Medical Ctr	2840 Index Rd	841,000	859,320	860,590	989,000	3,549,910
7	PDQ	6133 McKee Rd	482,890	588,130	737,000	1,189,000	2,997,020
8	Target	6321 McKee Rd	300,000	356,000	479,820	1,707,520	2,843,340
9	Nu Ventures II	5500 Nobel Dr	509,330	574,000	790,290	813,000	2,686,620
10	Sub Zero	2866 Buds Dr # A	331,000	578,000	655,140	1,002,100	2,566,240
							36,162,460

2008 Top Water Users

	Customer	Service Address	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	Total
1	Promega	2800 Woods Hollow Rd	1,132,000	1,492,000	1,551,000	1,600,000	5,775,000
2	Promega	5445 E Cheryl Pkwy	800,000	1,144,000	1,265,000	2,455,000	5,664,000
3	Sub Zero	2866 Buds Dr	450,000	1,067,000	1,277,000	1,913,000	4,707,000
4	United Vaccines	2919 Commerce Park Dr	520,000	919,000	1,263,000	1,307,000	4,009,000
5	Certco	6150 McKee Rd	300,000	994,000	1,112,000	1,418,000	3,824,000
6	Nu Ventures II	5500 Nobel Dr	823,000	880,000	900,000	1,138,000	3,741,000
7	PDQ	6133 McKee Rd	657,000	749,000	910,000	1,008,000	3,324,000
8	Target	6321 McKee Rd	280,000	336,000	792,000	1,912,000	3,320,000
9	Sub Zero	2866 Buds Dr # A	500,000	729,000	835,000	1,201,000	3,265,000
10	St Mary's Medical Ctr	2840 Index Rd	700,000	810,000	812,000	853,000	3,175,000
							40,804,000

Table 8.1. Fitchburg's Top Water Users for 2008-2010. The City of Fitchburg Finance Department, 2011. 2008 to 2010 Fitchburg Top 10 Water Users [dataset].

Industries situated along the effluent return line avoid the additional construction and costs of pumping water off the return line. An analysis of major water users in the vicinity of the effluent return line shows six industrial users who, in 2010, pumped over 28 million gallons of water collectively. Existing expansion and redevelopment plans project the same six users to pump 38.3 million gallons per year in the near future (Foss, 2011). These six companies have the potential to reduce the amount of fresh groundwater they use without reducing their total water use in general, and therefore not risking lowered production. Certain industrial uses, such as those where human contact is minimized, lend themselves better to effluent reuse.

Placon Corporation, a plastic packaging producer and recycler in Fitchburg, drew 8.3 million gallons of groundwater in 2010. In May 2011 they opened an Eco-Star facility, which they anticipate will increase their groundwater use by an additional 8-10 million gallons per year (Placon, 2011), making Placon Corporation Fitchburg's largest private groundwater user (Foss, 2011). As this is one of the six industries located along the effluent return line, Placon Corporation would make a good candidate for an industrial water reuse project.

Advanced on-site treatment presents greater opportunity for industrial water reuse. For instance, the Capitol Heat and Power Plant, the Blount Generating Station, and Madison's Charter Street Heating Plant will soon treat industrial cooling water to a tertiary treatment level. The Charter Street Heating Plant recently decided to replace their zeolite softener based boilers with a reverse osmosis system. Reverse osmosis, considered a Best Available Control Technology, will remove a high percentage of impurities including excess oxygen (Syska Hennessy Group, Inc, et al., 2008, p. 40). The cost for the new equipment varies from $45,000 to $85,000 depending on the number of boilers replaced (Syska Hennessy Group, Inc, et al., 2008, p. 33). The investment in reverse osmosis systems capable of treating effluent to acceptable standards would present a great opportunity for increased industrial reuse. However, additional infrastructure would be necessary to deliver effluent to areas far from the effluent return line. The WRM practicum recommends that Fitchburg work towards a long-term goal of effluent reuse at one or more of these locations.

8.4.1.3 Water Pricing

Although public education and stewardship influence decisions to increase conservation measures, economic factors typically impact water reduction on a larger scale. For industry in particular, reducing water use can potentially lower production, therefore the cost of water must be significant enough that decreasing production still makes economic sense. However, due to the abundant water resources in Wisconsin, with over 15 percent of the land surface covered by water, Madison chooses to price water at a relatively low amount (Buchwald, 2009). The Madison Water Utility charges $2.58 per 1000 gallons of water (City of Madison Water Utility, 2011) compared to $4.32 for the state overall (Public Service Commission, 2011). Therefore, industries in Madison may feel less inclined to decrease their water use or install costly water efficient equipment.

In order to better advocate water reduction, the City of Fitchburg and Municipal Economics & Planning, with approval from Wisconsin's Public Service Commission, initiated a four-tiered conservation rate structure. Using this rate structure, residents with low water demands qualified for the first tier, and therefore received a small rate decrease. The next tier, for customers with average water demand, received a 2 percent rate increase. The rates for residents with large volume demands were raised considerably by 22 percent. The last tier, specifically for customers with separate irrigation meters, increased in rate by 87 percent (Municipal Economics & Planning, n.d.). The rate structure aims to encourage water use reduction, particularly in less critical areas such as landscaping.

In order to encourage industries to change their perception of the value of water, MMSD could work with the Madison Water Utility to implement a reclaimed water pricing system, such as the ones used in more water scarce states. For instance, on Sanibel Island in Florida, the cost of 1000 gallons of potable water ranges from $3.30 to $6.55, but 1000 gallons of reclaimed water is only $2.42 (City of Sanibel, 2011). Similarly, in San Diego, 1000 gallons of reclaimed water costs $1.06, compared to $2.55 for potable water (City of San Diego, n.d.). Interviews with local industries revealed that while the cost of water is negligible, the electricity costs associated with pumping groundwater was a major factor in water usage (C. Schwoerer, personal communication, August 2, 2011).

8.4.2 Fitchburg's Water Management Strategy

In the long term, ideally, Fitchburg would offset their water use entirely through conservation measures. Presently, the City of Fitchburg uses an average of 2.1 MGD, with a high of 4.4 million gallons for one day in 2005. In 2011, water use remained below 3.1 million gallons for any one day (T. Foss, personal communication, August 8, 2011). In order to conserve amounts of this quantity, Fitchburg needs to advance a water management strategy that balances economic development with environmental preservation and restoration. Through a comprehensive conservation plan that includes education and outreach, incentives and regulations, Fitchburg can effectively increase conservation to offset groundwater withdrawals. Table 8.2 displays the management categories with current efforts and key recommendations for each.

	Current Efforts	Recommendations
EDUCATION AND OUTREACH	• Publish publications to clearly explain the origin of Fitchburg's water supply and the importance of water quality and conservation • Invite the community to Fitchburg's Public Works meetings • Began the Resource Conservation Commission in 2006 to advise the Common Counsel on the "preservation and improvement of the environment" (Resource Conservation Commission (RCC), The City of Fitchburg, WI, 2010)	• Offer audits of home water use and provide information on cost effective methods to reduce in-home water consumption • Promote and report on community events in the Improved Water Quality Program in the Nine Springs Creek Watershed (including class talks, site tours, earth day tours and cleanups, creation and improvement of storm sewers) • Expand the Resource Conservation Commission Community Outreach Subcommittee to plan events that focus on groundwater and water conservation • Design a high school program on local water issues • Include a recycled water newsletter in local newspapers • Create a document to guide architects and engineers on the potential of utilizing treated effluent, and hand out with application for Building and/or Zoning Permit reviews and approvals
INCENTIVES	• Provide rebates for high efficiency toilets	• Expand toilet rebate program to waterless urinals, commercial laundry equipment and commercial dishwashers • Create a program to encourage reclaimed water use similar to the Conserve II project in Orange County, FL that delivered free wastewater for an initial period of time for agricultural purposes (Atwood, 2007, p. 2).
REGULATIONS	None	• Require landscape irrigation plans for new commercial and residential lots in Fitchburg. • Mandate specific times and days for lawn watering.

Table 8.2. Current Water Conservation Efforts and Recommendations for Fitchburg. A review of Fitchburg's current conservation efforts with a set of recommendations for continued sustainable development.

8.4.3 Additional Water Treatment

MMSD's secondary wastewater treatment methods combined with disinfection removes most pathogens and over 85 percent of the BOD and suspended solids. However, other contaminants still exist in the effluent, such as N, P, and heavy metals (Davis & Masten, 2003). With the present contaminant levels, discharge and reuse options are limited. While Wisconsin state law only requires secondary treatment, incorporating specific tertiary treatment methods based on the region's needs is highly recommended. Specifically, increased treatment at MMSD should lower nitrate (NO_3^-), fecal coliform, P, and Total Dissolved Solids (TDS) to a level that allows human

contact. Implementing a Cl- reduction program would not only lower the direct Cl- toxicity risk to certain plants, but also reduce Na+ levels that can be detrimental to soils and plants.

Tertiary treatment refers to any biological, physical, or chemical processes used to remove nutrients and contaminants that remain from primary and secondary treatment. Although MMSD has not yet defined what additional method or combination of methods would be included in any future upgrades, the group supports an investment in tertiary treatment over P trading. While P trading could help MMSD meet P regulations, it does not improve surface water quality, nor does it expand opportunities for reclaimed water use. The following tertiary treatment systems provide a very high quality effluent.

- N Removal – Denitrification reduces the high level of NO_3^- in the wastewater to N gas through anaerobic activity. MMSD already uses nitrification, a necessary preliminary process that converts the ammonia (NH_3) to nitrite (NO_2^-) to NO_3^-. Denitrification will normally lower the NO_3^- levels in wastewater to less than 3 mg/L (milligrams per liter) (The Water Planet Company, 2010), a significant decrease from the 2010 effluent concentration of 16.9 mg/L.

- P Removal - Depending on the priorities of the wastewater treatment plant, P can be reduced by chemical, biological, or physical methods. The chemical process most used, precipitation, adds calcium, aluminum, or iron. The coagulants effectively flocculate and settle the P containing particles, but also produce additional sludge. Biological assimilation, a type of phytoremediation, utilizes plants to take up P as a nutrient. Physical methods include sand filtration, tertiary membrane filtration (an additional, finer filter following secondary treatment), and reverse osmosis. Currently MMSD only filters during the primary stage, removing larger sediments through screenings and grit handling (MMSD, 2011). The group strongly proposes adding ultra- or microfiltration as it not only decreases P, a major concern for Dane County, but also lowers levels of fecal coliform, pharmaceuticals and personal care products, TSS, and residual toxins.

- Cl⁻ Removal – If Fitchburg's golf courses decide to irrigate using reclaimed water, the group recommends increasing MMSD's Cl⁻ reduction campaign to reduce Cl⁻ and Na⁺ to levels that do not stress plants and degrade soil structure. This campaign would be beneficial for expanding irrigation possibilities as well.

Incorporating one or more of the treatment options above expands the alternate uses for the effluent. Besides industrial cooling, reclaimed water can be used to fight fires, to wash cars or to mix concrete at construction sites. Each use has a corresponding recommended level of treatment. For instance, if MMSD increased the ultraviolet treatment or filtration to decrease the detectable fecal coliform in the effluent to less than 2.2 MPN/100ml (current California standard), thereby lowering the potential human health hazards, the effluent could be used for urban and agricultural irrigation. The 97 farms in Dane County currently use 5.15 MGD of groundwater for crop irrigation. Based on the location of the Badger Mill Creek effluent return line, the following locations could use effluent rather than drinking-quality water for irrigation: the farmland between McKee and Lacy Road, McKee Farms, Hawk Ridge, and Pine Ridge Parks. Nearby areas could also benefit from effluent lawn watering. There is additional farmland close to the Badfish Creek effluent return line.

Another option is to discharge the effluent directly into the Yahara watershed lakes, circumventing the issue of watershed diversions and lowering lake levels. The current level of contaminants, however, may make the effluent unsuitable for discharge into lakes because the high residence times and large surface area of the lakes make them more prone to eutrophication than the rivers currently used for discharge. If tertiary treatment is implemented, the effluent quality may surpass the current lake water quality. In this case, discharging the effluent into the lake could improve ecosystem health, addressing one of the public's main interests.

8.5 The City of Fitchburg's Sustainable Development

The City of Fitchburg's innovative water management programs provide the opportunity to set new standards for other cities with abundant, clean potable water sources. Using effluent to restore degraded environments and to create public awareness would extend Fitchburg's conservation reputation.

Efforts that exemplify Fitchburg's work towards sustainable development include its participation in the Capital Region Sustainable Communities Initiative. This public-private partnership considers both the city's investments (e.g. housing, land-use, economic and workforce development, transportation, and infrastructure) and development challenges (e.g. social equity, economic advancement, energy use and climate change, public health, and environmental impact) in sustainable city planning. Similarly, Fitchburg has partnered with the Capital Area Regional Planning Commission in a sub-grantee agreement. The goal of the partnership is to reach 100 percent stormwater infiltration for high-density Transit Oriented Development (TOD). By promoting stormwater infiltration near areas of TOD, Fitchburg integrates environmentally conscious behaviors with economic development. Fitchburg is already titled Wisconsin's Recycling Leader based on physical waste recycling. Expanding to recycling wastewater would further set the City of Fitchburg apart as a model for other Wisconsin cities.

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Glossary

Adsorption – The adherence of a gas, liquid or dissolved chemical to the surface of a solid[2]

Ammonification – Bacterial decomposition of organic nitrogen to ammonia.[2]

Artificial recharge – The process of augmenting natural groundwater recharge by applying stormwater or wastewater to the surface at a location that allows for percolation to an aquifer.

Aquifer – A geological formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses.[1]

Aquifer (confined) –A saturated aquifer with a confining layer, or geologic layer or material that impedes the movement of water. This is typically the shallowest aquifer.

Aquifer (unconfined) – An aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall. [1]

Aquitard – A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for groundwater.[4]

Baseflow – Sustained flow of a stream in the absence of direct runoff. Natural base flow is sustained largely by groundwater discharges. [1]

Bedrock – The solid rock that lies beneath soil and other loose surface materials.[5]

Bioaccumulation – A process by which chemicals accumulate in the tissue of an organism and are not expelled in the lifetime of the organism.

Biofilm – A community of microorganisms that form together to create a continuous layer.

Biological oxygen demand – The amount of oxygen required to decompose the organic material present in the substance. This process assesses the amount of pollution in water, or indicates the effectiveness of wastewater treatment by measuring the amount of oxygen used by microorganisms to consume the organic material in a water sample. During high pollution levels, a large quantity of bacteria works to decompose the impurities, resulting in a high need for oxygen.

Bioremediation – The use of organisms, such as plants, to remove toxic substances from an area.

Bioretention basin – The method of treating first flush runoff from urban areas that maximizes all available physical, chemical and biological pollutant removal.

Cone of depression – A cone-shaped lowering of the water table around a producing well. [7]

Darcy's Law – Mathematical equation which describes one-dimensional flow of water through the saturated zone of a porous material (e.g. soil).

Denitrification – The anaerobic microbial reduction of oxidized nitrate nitrogen to nitrogen gas. [2]

Dolomite – A magnesium-rich carbonate sedimentary rock. [5]

Effluent – Wastewater—treated or untreated—that flows out of a treatment plant, sewer or industrial outfall. Generally refers to wastes discharged into surface waters. [9]

Effluent (treated) – See wastewater (treated).

Effluent polishing – A tertiary treatment process of removing additional BOD and suspended solids typically through a filtering process.

Effluent recharge – Also known as wastewater recharge. Groundwater recharge naturally occurs by the movement (percolation) of rain and snow through the soil to aquifers. In order to counter the increasing groundwater withdrawals, treated effluent can be used to supplement natural sources of groundwater recharge. Methods of effluent recharge include spray irrigation, ridge and furrow, absorption ponds or fields, land spreading, overland flow or infiltration-percolation.

Eutrophication – The process of over-fertilization of water bodies from excessive nutrient inputs, such as phosphorous and nitrogen, that typically results in algal blooms.

Fecal coliform – A bacteria associated with fecal matter of mammals. The presence of fecal coliform bacteria in water is an indicator of pollution and of potentially dangerous bacterial contamination. [8]

Flocculation – The agglomeration (i.e., clumping) of particles suspended in water into larger particles ("flocs") that can be removed by sedimentation or flotation. [6]

Glacial till – Unsorted, unstratified rock rubble or debris carried on and/or deposited by the ice of a glacier. [5]

Groundwater mounding – The rise of the local water table above the average level, decreasing the size of the unsaturated zone, potentially affecting the quantity and quality of groundwater recharge as well as the shape of the ground surface.

Groundwater recharge – This refers to the surface water that percolates downward to groundwater.

Hydraulic conductivity – The measure of soil's ability to transmit water horizontally and vertically through it when subjected to a hydraulic gradient.

Hydraulic gradient – The change in hydraulic head between two points divided by the distance traveled between these points. Conceptually this represents the slope of the water table.

Hydraulic head – The pressure of water above a reference point, usually expressed in units of length.

Hydraulic retention time – The time it takes for water to flow through a system.

Hydrostratigraphy – The description of geologic layers based on water flow characteristics.

Indirect potable reuse – This process uses treated wastewater to augment a drinking water source, either groundwater or surface water. The effluent must meet drinking water standards upon entering the ground, where it flows through an environmental buffer to further treat water, removing impurities or excess nutrients before normal drinking water treatment.

Industrial cooling – A process using water to remove heat from industrial equipment.

Infiltration – The process by which water moves downward from the land surface into the soil.[6]

Infiltration basin – A basin designed to rapidly infiltrate surface water.

Infiltrometer tests– A technique for measuring soil infiltration rates. The infiltrometer retains water to provide constant hydraulic head throughout the test.

Influent – Water, wastewater or other liquid flowing into a water body or treatment unit.[2]

Injection well – A well that is used to place fluid underground.

Macrophyte – Aquatic or emergent plants which are visible to the naked eye. These are often used as indicator species for water quality; a lack of macrophytes may suggest excessive turbidity, the presence of herbicides, or salinization, whereas, excessive growth often indicates eutrophication.

Mineralization – The release of inorganic chemicals from organic matter in the process of aerobic and anaerobic decay.[3]

Nine Springs Environmental Way: An environmental corridor between Dunn's Marsh and Lake Farm Park in Dane County, Wisconsin.

Nitrification – Biological transformation (oxidation) of ammonia nitrogen to nitrate and nitrate forms.[2]

Percolation – The slow movement of water through a porous substance.

Phytomining – A type of phytoremediation specifically aimed at extracting heavy metals.

Phytoremediation – The use of plants to remove toxic substances from an area.

Piezometer – A small non-pumping well typically used for measuring depth to the water table.

Porosity – The percentage of open spaces (pores) in rock or soil. When these spaces are interconnected, water, air or other fluids can migrate from space to space. Interconnected spaces make the soil or bedrock permeable.[5]

Precipitation (mineral) – A chemical reaction that removes an insoluble solid from a soil solution, allowing for the removal of toxic minerals from the environment.

Reclaimed water – See water reuse

Sandstone – Sedimentary rock made mostly of sand-sized grains. [5]

Saturated zone – The zone in which all the voids in the rock or soil are filled with water at greater than atmospheric pressure. The water table is the top of the saturated zone in an unconfined aquifer.[3]

Sandy loams – A soil composed of sand, silt and clay. Sandy loams are typically good for drainage and infiltration.

Sedimentation – A process in which solid particles settle out of a solution forming a bottom layer.

Silt – Intermediate-sized (finer than sand, but coarser than clay) loose particles of rock or mineral (sediment).[5]

Slug and bail tests – Tests used to calculate hydraulic conductivity by creating a rapid change of the water level in a piezometer, by displacing (slug test) or removing (bail test) a known volume of water, and measuring the time it takes for the water level to recover to its original resting level.

Stream stage – Stream stage is the height of the water surface above an established reference height, usually near to or an approximation of the streambed elevation.

Stormwater –This refers to rainwater or snowmelt that does not infiltrate into the soil and runs off the land surface.

Substrate – Surface area of solids or soils used by organisms to attach.[2]

Total suspended solids– Measure of the filterable matter in a water sample. [2]

Turbidity – The visual appearance of cloudy water filled with suspended particles. Turbidity, as an optical property, may be measured and used to rate water quality and clarity.[6]

Unsaturated zone – The zone immediately below the land surface where the pores contain both water and air, but are not totally saturated with water. These zones differ from an aquifer, where the pores are saturated with water.[1]

Peat – Partially decomposed, but relatively stable organic matter formed from dead plants in flooded environments.[2]

Watershed – The entire surface drainage area that contributes runoff to a body of water.[2]

Water table – The top of the water surface in the saturated part of an aquifer.[1] OR – The upper surface of the groundwater or saturated soils.[2]

Wastewater – Spent or used water from an individual home, a community, a farm or an industry that contains dissolved or suspended matter.[9]

Wastewater (treated) – Wastewater that has undergone treatment by one or more processes (physical, biological or chemical) in order to improve its quality and reduce environmental and health risks. Also known as treated effluent.

Wastewater Reuse – Also known as Effluent Reuse, Recycled Water or Reclaimed Water. Wastewater not returned to the environment, is cleaned at a treatment center, and then distributed for approved uses, including irrigating parks, golf courses or agricultural fields, restoring wetlands or running industrial machinery. By reusing wastewater, one can avoid using already stressed supplies of groundwater for non-potable purposes.

Wastewater Treatment (Primary) – The first step in treatment of wastewaters. Primary treatment usually consists of screening and sedimentation of particulate solids.[2]

Wastewater Treatment (Secondary) – Generally refers to wastewater treatment beyond initial sedimentation. Secondary treatment typically includes biological reduction in concentrations of particulates and dissolved concentrations of oxygen-demanding pollutants.[2]

Wastewater Treatment (Tertiary) – This final step in the wastewater treatment process utilizes one or more of the following processes: sand filtration, carbon absorption, lagooning, nitrogen or phosphorous removal and disinfection. Disinfection includes chlorination, ultraviolet light and ozone application.

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Appendix A • Geographical Information Systems Analysis Methods Employed by Felipe Avila

Avila obtained Geographical Information Systems (GIS) data from various sources including Madison Metropolitan Sewerage District (MMSD), Madison Gas and Electric (MG&E), and Fly Dane, a regional partnership among municipalities in Dane County as well as state and federal agencies whereby resources are pooled to update orthophotography, elevation and planimetric data. The Fly Dane program provided Light Detection and Ranging (LIDAR) data in order to create a surface digital elevation model (DEM) of Fitchburg. A modified DEM layer from the United States Geological Survey was used to estimate the water table. By overlaying the two DEM layers, the group established the depth to the water table.

In choosing sites, Avila selected a buffer of one mile from the Nine Springs effluent line as this was considered a reasonable distance from which a potential diversion line would span. Finally, Avila combined other GIS layers ensuring the public wellhead protection area and contamination sources (e.g. gas stations, dry cleaners and auto body shops) were excluded as possible sites. Using these various layers (DEM, effluent line buffer, wellhead protection, and contamination sources), a weighting and ranking system was implemented. For instance, a higher ranking was established for areas closer to the effluent line.

Appendix B • Site Analysis Methods Employed by the Water Resources Management Group

Several methods of analysis were used to compile the information required by the Practicum's criteria. All Geographical Information Systems (GIS) analyses were conducted using ArcGIS version 9.3.1. To start, all six sites were located and marked in GIS using the GPS points provided by the City of Fitchburg. The ownership and parcel size were established by examining the attribute table for the parcels layer. The group found the difference in elevation between the site and the pipeline by subtracting the elevation of the closest points between the site and the pipeline. The difference was then recorded with a positive value if the water would need to be pumped uphill and a negative value if the water would flow downhill. The group also visually identified the maximum and minimum distance to the water table in feet using the Distance to Water Table Layer. The distance between the effluent return pipeline and the sites was measured in feet from the pipeline to the closest edge of the site. In the smaller parcels, the measurement was made from both the closest and furthest edges of the site. If the pipeline went through the site, the distance was recorded as zero. To find the clay content of the soil the group obtained soil maps of the Fitchburg area from the Natural Resources Conservation Service (NRCS). The potential sites were located on these maps and zones with low clay content (15 percent or less) were measured in acres.

For the final criterion, the group evaluated the sites using two different methods to determine whether effluent from a groundwater recharge facility would interfere with public or private wells in the region. First, the group completed a GIS buffer analysis by placing a 100-foot buffer around all the public and private wells in the region, in accordance with NR 110 Sewerage Systems standards. All six sites passed this initial test, so the group performed a particle tracking analysis with the Nine Springs groundwater flow model developed by Susan Swanson (and maintained by Montgomery and Associates)(Swanson, 2001) using the USGS codes MODFLOW and MODPATH through the Groundwater Vistas 5 user interface to determine if the effluent infiltrated at any of the sites would flow to a local well.

Appendix C • Electrical Conductivity Profiles

Upland Site Location B
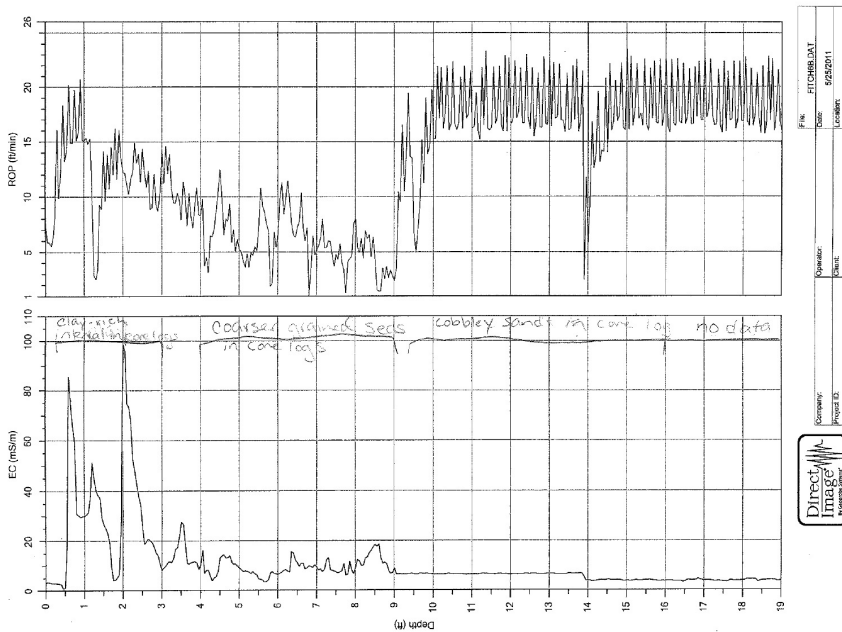
Upland Site Location C
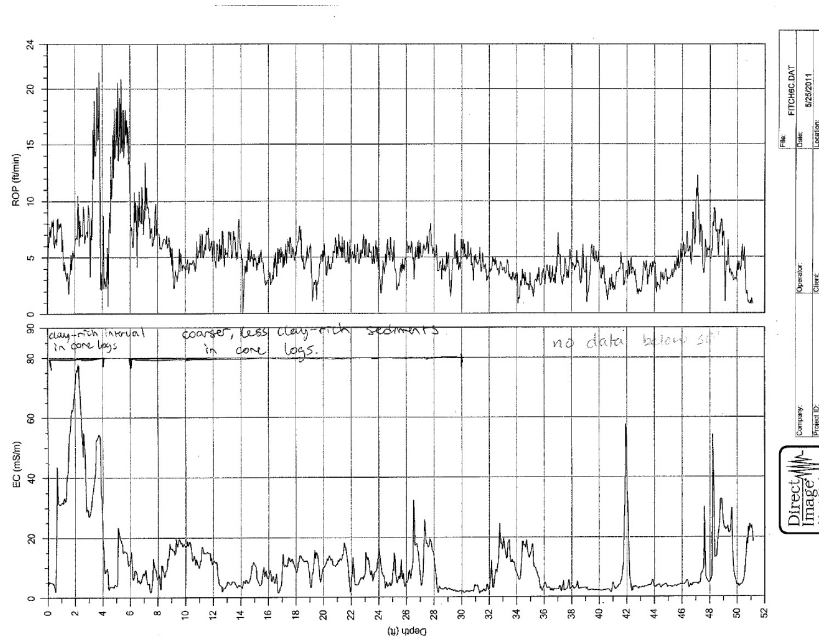
Appendix D • Upland Site Soil Elemental Values

Sample #	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	Total N
	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%
1	0.09	0.09	0.21	0.17	0.01	86.51	5.77	676.97	10159.9	13.53	9706.6	61.71	0.130
2	0.04	0.13	0.23	0.32	0.00	47.36	8.18	434.15	14858.6	14.21	15462.5	76.54	0.032
3	0.03	0.07	3.74	2.64	0.00	17.50	5.65	240.58	6481.8	7.74	5126.9	166.61	0.011
4	0.02	0.05	4.39	2.97	0.00	13.62	4.66	184.96	4387.8	5.70	2465.5	144.41	0.003
5	0.02	0.06	3.62	2.48	0.00	34.37	5.43	226.55	7509.9	8.70	4064.4	122.22	0.006
6	0.02	0.04	5.64	3.94	0.01	21.68	4.72	222.84	4304.4	5.08	1599.3	140.57	0.010
7	0.05	0.11	0.24	0.23	0.01	57.60	6.56	604.99	12396.0	9.51	11784.6	44.44	0.092
8	0.02	0.04	4.39	2.96	0.01	16.72	4.26	216.30	4497.8	5.25	2192.9	106.44	0.004
9	0.05	0.17	10.06	7.02	0.02	159.76	16.46	620.22	4737.8	58.80	2997.9	206.27	0.008
10	< 0.05	0.05	0.06	0.02	< 0.001	1.93	3.72	7.43	202.7	<0.5	577.5	6.85	0.001

Results reported on a 'dry weight' basis. Unit: 1,000 ppb = ppm = mg/kg = mg/liter. 1% = 10,000 ppm.

Upland Soil Elemental Values

These are the results of the elemental and TN analysis of the soil samples taken from the Upland Site.

The methods and standard operating procedures for UW Soil and Plant Analysis Lab can be found on their website:

http://uwlab.soils.wisc.edu/madison/.

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Appendix E • Upland Site Vegetation and Wildlife

Plants

	Scientific Name	Common Name	Native/Introduced
1	*Arctium minus*	Burdock	Introduced
2	*Brassica nigra*	Black Mustard	Introduced
3	*Cichorium intybus*	Chicory	Introduced
4	*Cirsium undulatum*	Wavy-leaved Thistle	Introduced
5	*Desmodium canadense*	Showy Tick Trefoil	Introduced
6	*Festuca pratensis*	Meadow Fescue	Introduced
7	*Hypericum perforatum*	St. John's Wort	Introduced
8	*Lonicera x bella*	Bell's Honeysuckle	Introduced
9	*Lotus corniculatus*	Bird's Foot Trefoil	Introduced
10	*Melilotus alba*	White Sweet Clover	Introduced
11	*Pastinaca sativa*	Wild Parsnip	Introduced
12	*Phalaris arundinacea*	Reed Canary Grass	Introduced
13	*Physalis heterophylla*	Clammy Ground Cherry	Introduced
14	*Pontentilla recta*	Sulphur Cinquefoil	Introduced
15	*Ranunculus acris*	Tall Buttercup	Introduced
16	*Rhamnus cathartica*	Buckthorn	Introduced
17	*Rosa multiflora*	Multiflora Rose	Introduced
18	*Silene cucubalus*	Bladder Campion	Introduced
19	*Silene latifolia*	White Campion	Introduced
20	*Taraxacum officinale*	Common Dandelion	Introduced
21	*Trifolium pratense*	Red Clover	Introduced
22	*Trifolium repens*	White Clover	Introduced

Plants (continued)

23	*Urtica dioica*	Stinging Nettle	Introduced
24	*Verbascum thapsus*	Common Mullein	Introduced
25	*Asclepias syriaca*	Common Milkweed	Native
26	*Asclepias tuberose*	Butterfly Milkweed	Native
27	*Baptisia alba*	White Wild Indigo	Native
28	*Dalea candida*	White Prairie Clover	Native
29	*Elymus canadensis*	Canada Wild Rye	Native
30	*Erigeron strigosus*	Daisy Fleabane	Native
31	*Eryngium yuccifolium*	Rattlesnake Master	Native
32	*Galium aparine*	Stickweed	Native
33	*Geum aleppicum*	Yellow Avens	Native
34	*Helopsis helioanthoides*	False Sunflower	Native
35	*Monarda fistulosa*	Wild Bergamot	Native
36	*Poa palustris*	Fowl Bluegrass	Native
37	*Ratibida pinnata*	Prairie Coneflower	Native
38	*Rubus allegheniensis*	Common Blackberry	Native
39	*Rudbeckia hirta*	Black-eyed Susan	Native
40	*Schizachyrium scoparium*	Little Bluestem	Native

Mammals

	Scientific Name	Common Name
1	*Canis latrans*	Coyote
2	*Odocoileus virginianus*	White-tailed Deer
3	*Sciurus carolinensis*	Eastern Grey Squirrel
4	*Sylvilagus floridanus*	Eastern Cottontail

Birds

	Scientific Name	Common Name
1	*Agelaius phoeniceus*	Red-winged Blackbird
2	*Anas Platyrhynchos*	Mallard
3	*Branta canadensis*	Canada Goose
4	*Buteo jamaicensis*	Red-tailed Hawk
5	*Carduelis tristis*	American Goldfinch
6	*Carpodacus mexicanus*	House Finch
7	*Cyanocitta cristata*	Blue Jay
8	*Dendroica petechia*	Yellow Warbler
9	*Empidonax alnorum*	Alder Flycatcher
10	*Geothlypis trichas*	Common Yellowthroat
11	*Grus canadensis*	Sandhill Crane
12	*Melospiza melodia*	Song Sparrow
13	*Picoides pubescens*	Downy Woodpecker
14	*Poecile atricapillus*	Black-capped Chickadee
15	*Sturnus vulgaris*	European Starling
16	*Tachycineta bicolor*	Tree Swallow
17	*Turdus migratorius*	American Robin

Appendix F • Surface Flow Constructed Wetland Option for Treatment

A surface constructed wetland is one option for further effluent treatment on the Upland Site. The United State Environmental Protection Agency (USEPA) has published many guides for designing constructed wetlands (USEPA, 2000a; 2000b; 1999; 1988). These guides provide a general overview as well as fundamental principles needed for designing SF wetlands.

Layout and Designs

The size of Surface Flow (SF) wetlands varies considerably from small on-site units designed to treat septic tank effluent to large units with more than 40,000 acres (USEPA, 2000b). As such, the quantity of water treated will vary from less than 1,000 gallons per day to more than 20 million gallons per day (MGD) (USEPA, 2000b). Typical hydraulic loading rates vary from 0.7 to 5 cm/day, which corresponds to a wetland of 18.7 to 131 acres per MGD of flow (Halverson, 2004).

SF wetland systems are typically comprised of multiple adjoining cells used to treat wastewater to higher standards (USEPA, 2000a). SF wetlands must accommodate the fact that treatment processes occur in a sequential manner (USEPA, 2000a). A "sequential model" developed by Gearheart and Finney (1999; [cited by USEPA, 2000a]) divides the treatment process into a minimum of three cells, each with a different design to target specific types of pollutants. The first zone is fully vegetated and anoxic for sedimentation of total suspended solids (TSS), denitrification and removal of BOD. The second zone is primarily open water with submerged aquatic plants for nitrification and removal of pathogens. The third and final zone is similar to the first zone in design and function (USEPA, 2000a).

Aquatic plants play a very important role in SF wetlands. In addition to providing a substrate for organisms involved in wastewater treatment, aquatic plants also provide structure for flocculation, sedimentation and filtration of TSS. Furthermore, aquatic plants have been documented to insulate the surface water from cold temperatures during winter periods, thus limiting ice cover (USEPA, 2000a). However, aquatic plants are not the key mechanisms for the removal of nitrogen and phosphorus despite the fact that these are key nutrients for these plants. Nitrogen and phosphorus removal are primarily the result of microbial, chemical and physical processes.

Costs

Below are some of the major costs involved in constructing SF wetlands at the Upland Site:

- Clearing and grubbing of the site

- Excavating the soil and completing earthwork

- Purchasing and installing the liner, fill media, inlet/outlet structures, piping and pumps

- Purchasing and planting selected vegetation

- Removing non-native plants

Prices for these types of work vary greatly. For instance, the 20.2-acre SF wetland in West Jackson County, Mississippi has a unit cost of $3.40/acre while a smaller three-acre SF wetland in Arcata, CA cost $10.1/acre (USEPA, 2000a).

In general, SF wetlands are cheaper than SSF wetlands with some additional benefit of economy of scale. However, the SF liners used to limit groundwater recharge, and gravel used for fill can account for more than half of the total capital cost. Halverson (2004) cites an USEPA estimate of capital cost for a 0.1 MGD SF wetland without a synthetic liner at $58,000/acre using 2004 construction cost estimates. The author also states that gravel in the United States costs around $9.5/ton or $13/yard with delivery cost of at least $20/yard. Liner costs can be eliminated for areas with high soil content, as is the case with the Upland Site, though costs for PVC liners range from $3-10/m^2 (Halverson, 2004). However, since SF wetlands are passive systems, they require minimal operation and maintenance, further reducing costs. Typical operation and maintenance (O&M) costs include:

- influent and effluent testing

- water level adjustment

- maintenance of infrastructure (pipes, distribution devices, etc.)

- weed, odor, and pest control

- potential harvesting of plants

Of these costs, water quality testing generally accounts for the greatest percentage. Using 1999 construction cost estimates, the USEPA quotes O&M costs for a 3.2-acre SF wetland system treating 0.1 MGD at $6,000/yr or $0.16/1000 gallons (Halverson, 2004).

Nutrient removal

The extent of wastewater treatment is clearly dependent upon the hydraulics of the wetland system, which in turn is dependent upon the initial quality of the influent into the system. In the United States, it is routine to provide some preliminary treatment prior to a SF wetland (USEPA, 2000b). Some of the hydraulic variables needed to design a typical SF wetland include flow rates, loading rates and detention time. The effluent from MMSD has been treated up through secondary treatment. However, the wastewater still contains relatively high concentrations of fecal coliform (bacteria), nitrogen and phosphorus. While these pollutants fall within the USEPA standard for water reuse, they do not meet Wisconsin groundwater recharge standards (NR 206). These could be removed in treatment by a SF wetland.

Both nitrogen and phosphorus are removed via physical or biological processes, depending on their form. With respect to nitrogen, the forms of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen (USEPA, 2000a). Phosphorus occurs in natural waters and wastewater primarily as phosphates, which are further classified into orthophosphates, condensed (pyro-, meta-, and poly-) phosphates, and organically bound phosphates (USEPA, 2000a). Physical removal of nitrogen and phosphorus include flocculation and sedimentation as inorganic precipitates that are absorbed into the clay particles. In addition, plant biofilm may also absorb organic nitrogen and soluble phosphate.

Biological removal of nitrogen and phosphorus involves microbial processes to convert the nitrogen and phosphorus into more soluble forms that can be absorbed by the aquatic plants in the SF wetland system. For phosphorus, insoluble inorganic and organic phosphates are transformed into a soluble, inorganic form by microorganisms in the water column and biofilm on aquatic plants that can then be readily absorbed by aquatic plants. Net annual removal of phosphorus by plants range from 1.8 to 18 gP/m^2/yr (USEPA, 2000a).

For nitrogen, multiples processes maybe involved: ammonification, nitrification and denitrification. Ammonification converts organically combined nitrogen, which constitutes almost half of the wastewater nitrogen, to ammonium nitrogen. The rate of this process is limited by pH and temperature, with rates increasing as temperature increases. Once ammonium nitrogen is formed, it can be absorbed by aquatic plants, bound to sediments or aerobically nitrified by aerobic microorganisms, removing the source nitrogen from the water system.

Nitrification requires the presence of oxygen for microorganisms to convert ammonium nitrogen to nitrite and nitrate. In a typical SF wetland system, nitrification occurs in areas of open-water. Unlike ammonium nitrogen, nitrate is unable to bind to sediment for removal. However, nitrate is capable of absorption by aquatic plants. In addition, nitrate may undergo further transformation via denitrification under anoxic conditions, resulting in nitrogen gas that can easily exit the wetland system. Net annual nitrogen removal by aquatic plants has been estimated to range from 0.5 to 3.3 gN/m^2/yr (USEPA, 2000a). However, nitrogen removal rates can vary significantly over the seasons, with minimal removal occurring during the low temperatures of colder climates (Garcia-Lledo, 2011).

Pros and Cons

There are advantages to using SF wetlands. In general, SF wetlands are cheaper to construct and maintain than Subsurface Flow (SSF) wetlands. The difference in cost though, may be minimized due to the larger area needed for treatment in SF wetlands, especially for phosphorus and nitrogen. Much of the treatment is passive requiring little to no mechanical equipment, energy or skilled personnel (expect for periodic testing of water quality). In fact, treatment predominately occurs on the surfaces of submerged aquatic plants and litter by the periphytic-attached growth organisms that are responsible for much of the biological treatment in the system (USEPA, 2000b). They can also help with upgrading and developing wetlands and ecological habitats. There are also disadvantages. As noted before, SF wetlands contain open-water, a beneficial habitat to a variety of species, many of which are insects and categorized as pests by society (Kadlec, 2009). In addition, free-water flow wetlands may put wildlife and humans in direct contact with effluent.

Appendix G • Subsurface Flow Constructed Wetland Option for Treatment

Another option for effluent treatment at the Upland Site is use of a Subsurface Flow (SSF) constructed wetland. Although these are a more recent development than Surface Flow (SF) wetlands, there is almost as much research about these systems.

Layout and Designs

Determining the required minimum size for SSF wetlands is most often based on previous projects' sizes. This method contains inaccuracies unless there are numerous constructed wetlands with similar physical characteristics using influent of approximate equivalent volumes and concentrations as the proposed site. Another method for sizing involves loading charts; however, minimal data exists for statistical analysis of accurate sizing based on treatment performance. Instead, when designing full scale SSF wetlands, it may be beneficial to conduct pilot studies and perform intensive site investigations to gather data which can be used for size determination through first-order kinetic modeling (Kadlec and Wallace, 2009).

Media diameters affect the SSF wetland's ability to integrate optimal macrophyte root growth, surface area for microbial colonization, sorption capacity and effective porosity required for maintaining the necessary hydraulic conductivity (USEPA, 2000). Similar to USEPA recommendations, European, Austrian and Czech Republic guidelines and standards for SSF constructed wetland's gravel diameters, fall within a range of 3 to 16 mm. Research completed by Yousefi and Mohsen-Bandpei on nitrogen and phosphorus removal efficiency through the use of an *Iris sp.* of macrophyte concluded that fine gravel with an effective size of 5 mm in diameter is important for improving treatment in a SSF wetlands (Yousefi, 2010).

The most important consideration in vegetated SSF wetlands may be sediment texture and grain size, however, mineral components of the chosen media can also play an important role in nutrient removal. The USEPA does not recommend the use of artificial mediums due to lack of statistical evidence documenting its effectiveness; however, studies have been performed showing possible alternatives to rock, gravel, sand and soil options (USEPA, 2000). Increasing surface area or depth may result in higher treatment performance, lower loading and more contact time, due to the increase in hydraulic retention (Headley, 2005; Ghosh, 2010).

Vegetation does not play as significant role in treatment for SSF wetlands as it does in SF systems, and is not always necessary. The USEPA and various studies still recommend it because it can be aesthetically pleasing and can help with treatment by supplying oxygen through its roots and rhizomes for decomposition and nitrification (USEPA, 2000). The USEPA manual provided in 2000 advises that although the vegetation startup period for SSF systems is not as pertinent, the system should still involve flooding of the wetland cell to the surface of the media with clean water prior to planting and until the observance of significant plant growth.

Costs

Costs for Horizontal Subsurface Flow (HSSF) and Vertical Subsurface Flow (VSSF) wetlands are nearly impossible to quantify, but individual parts that contribute to costs for construction and maintenance can be identified. The main costs in the construction of an Upland Site subsurface wetland will include:

- Clearing of the site

- Excavating the soil to desired wetland depth

- Potentially excavating the soil, purchasing and installing an internal berm formation to direct flow path of the effluent

- Purchasing and installing new substrate media, inlet/outlet structures, pipes and liners

- Purchasing and planting selected vegetation

- Removing non-native plants

The prices for each individual project can vary significantly based on the characteristics of the site, desired treatment performance goals and federal, state and local regulation requirements (USEPA, 2000; Reed, 1995).

In general, SSF wetlands are significantly higher in construction costs than SF systems, largely due to the volume of excavation, earthwork and media supply necessary to meet effective design parameters. Media costs vary in relation to the original location and transfer of the media and type of media considered (US EPA, 2000; Reed, 1995; Kadlec and Wallace, 2009). Operation and maintenance are relatively simple with monitoring requiring minimal time, thus contributing little to overall costs. The estimated cost ranges from $ 0.04 to $ 0.08 per 1,000 gallons of treatment water (USEPA, 2000). A comparison of five constructed SSF systems from 1986 to 1997 shows the range of construction costs. System sizes ranged from 0.3 to 2.3 hectares with costs ranging from $ 32.18 million to 125.18 million. In this case, the largest constructed wetland was also the least expensive to construct per area, while the most expensive constructed wetland per area was the second smallest in size and had a treatment flow volume thirty times smaller in volume (USEPA, 2000).

Nutrient Removal

Nutrients and pollutant removal in SSF wetlands result from naturally occurring physical, chemical and biological processes including nitrification, denitrification, anammox, adsorption, sorption, sedimentation, filtering, mineralization, precipitation, dissolution, accretion and plant and microbial uptake (Vyamazal, 2007). Both HSSF and VSSF systems are commonly designed for and have demonstrated efficient ability to remove BOD , COD and TSS matter, with VSSF systems

typically showing slightly higher capabilities. BOD removal largely occurs from bacteria in biofilm covering the sand, gravel or other media particles (Kadlec and Wallace, 2009). In regards to other nutrients, HSSF and VSSF systems vary in their capabilities and in some situations are used simultaneously in hybrid systems to meet performance goals and requirements.

HSSF wetlands typically offer high removal of organics and suspended solids, but low removal of nitrogen and phosphorus. Nitrogen removal is limited by the fact that both aerobic and anaerobic conditions are required, whereas HSSF systems usually reside in anoxic states, inhibiting the ability for nitrification (Vyamazal, 2005). When provided with pretreated, nitrified water, HSSF systems can result in substantial nitrogen removal through denitrification. One study found that total nitrogen removal in HSSF wetlands was between 40 to 50 percent with influent concentrations loading 250 to 630 $gm^{-2}yr^{-1}$ (Vyamazal, 2007). A study examining nutrient removal from wastewater in HSSF systems also found low nutrient removal. Removal rates for TN were only 29 percent for secondary treatment, with 35 percent of ammonia passing through the system without any biogeochemical process or treatment, and 41% during tertiary treatment (O'Luanaigh, 2010). An additional study specifies that ammonia removal can be increased through the use of intermittent feeding of shallow HSSF systems. An intermittently fed system resulted in removal of ammonia at 10 percent higher rates on average and up to 50 percent more during the winter when compared to continuous loading systems (Pedescoll, 2011b).

Phosphorus, meanwhile, is constrained in HSSF systems by the medium in use and its sorption capacity. Even with a high sorption capacity, phosphorus removal will eventually decline to negligible amounts, unless the medium is replaced. HSSF systems with low hydraulic loading rates can lower levels of suspended solids and biological oxygen demand (BOD); however, when N and P are insufficient due to limits of oxygen and sorption capacity, HSSF systems remove less than 50 percent of these nutrients at 5 m^2/PE (Vyamazal, 2005). In a study by Ghosh and Gopal on the effects of hydraulic residence times ranging from one to four days, P removal was low, approximately 40 percent, at all four residence time lengths (2010). Similarly, the results for the study on HSSF systems indicate poor TP removal, with removal efficiencies of 45 percent in secondary wastewater treatment and 22 percent in tertiary (O'Luanaigh, 2010).

Data shows fecal coliform removal in HSSF wetlands to improve with longer hydraulic retention times, lower hydraulic loading, finer materials which do not hinder hydraulic performance, warmer water temperatures and shallower media beds. Furthermore, for currently unknown reasons, the addition of plants is beneficial to pathogen removal. A study on fecal coliform removal in HSSF systems with emergent macrophytes gave an overall fecal coliform removal by 2 to 3 log units (Headley, 2005).

In contrast, VSSF systems often are designed for and have high nitrification rates. In general, there is a relatively small amount of studies, especially long term, on VSSF compared to HSSF systems, as HSSF systems were the most commonly constructed wetland type in the United States up until recent years (Kadlec and Wallace, 2009). VSSF systems involve the same pollutant and nutrient removal processes as HSSF systems. Nitrification can be much higher than that of HSSF systems. VSSF systems, when loaded intermittently, have a greater ability to transfer oxygen and are more effective at mineralization of biodegradable organic matter. (Yalcuk, 2010). Pulse loading causes porous space within the media to fill with air during resting phases,

trapping oxygen within the media upon sequential loading, and leading to media oxygenation, the basis for high rates of ammonia and organic nitrogen oxidizing mainly into nitrates. Dosing frequency is timed so the previous dose of wastewater has fully infiltrated through the bed, and void spaces have had sufficient time to refill with air. Typical loading occurs four to six times per day. Use of multiple beds, typically ranging from two to six, is necessary to provide adequate resting periods for each cell while allowing the system to continuously treat wastewater. Due to nitrification requiring aerobic conditions and denitrification requiring anaerobic conditions, little denitrification occurs in pulse loaded VSSF systems and TN removal is insignificant (Kadlec and Wallace, 2009).

Overall, P will not be reduced sustainably in VSSF systems and, as in HSSF systems, the P removal efficiency is assumed to be zero percent long term. Significant removal only occurs at treatment start-up, prior to sorption sites reaching capacity. The length of time TP can be removed is dependent on the treatment area, hydraulic loading and influent concentration, with equilibrium often reached within one year (Kadlec and Wallace, 2009; US EPA, 2000).

Limited data on VSSF systems' coliform removal exists and removal is assumed dependent on hydraulic loading, resting frequency and bed media size. (Kadlec and Wallace, 2009).

Analysis of performance data has indicated that HSSF systems are not significantly more efficient than SF systems, with an equivalent area-to-treatment ratio. VSSF systems do, however, create lower effluent concentrations with the equivalent influent concentrations, and have higher ammonium reduction (Kadlec and Wallace, 2009).

Alternative designs that would aid in N, COD, BOD, TSS and fecal coliform reduction involve hybrid systems. A VSSF system followed by HSSF system or vice versa, as well as hybrids including SF treatment, have shown significant contaminant reductions. Hybrids combining HSSF systems, which have good BOD and TSS removal but no nitrification, with VSSF systems, which have good nitrification, BOD and TSS properties, effectively removed BOD, TN and TSS in effluent concentrations (Vyamazal, 2005).

Pros and Cons

Advantages both SSF wetlands have over SF systems are that the wastewater is being treated underneath the surface within the substrate and minimizing the possibilities of health issues arising from contact with humans. Furthermore, SSF wetlands usually remain operational under cold conditions, with limited decreases in treatment efficiency due to insulation from soil and vegetation (Halverson, 2004; Kadlec, 2009). SSF systems also have a higher contaminant removal per load rate in comparison to SF wetlands, thus requiring less area for the same level of productivity (Halverson, 2004).

There are also disadvantages for using a SSF design. When either a HSSF or VSSF system is fully saturated, nitrification ceases as oxygen becomes limited (Dan, 2011). Typically SSF wetlands

only use small volumes of effluent at low flow rates, and therefore, they cannot improve habitat, restore wetlands or provide for general recreational uses as effectively as SF wetlands (Kadlec, 2009). Also, substrate clogging always needs to be checked. Clogging increases heterogeneities which increases preferential flows and causes declines in both hydraulic residence time and the level of wastewater treatment (Brovelli, 2011).

Appendix H • Long-term Effects and Life-span of Constructed Wetland Treatment Methods

It is important to consider the potential lifespan and long-term impacts of the constructed wetlands in the recharge design. The most common estimate for the lifespan of any subsurface wetland is eight to 10 years (Knowles et al 2011). There are two major aspects of constructed wetlands that can determine their potential life spans: clogging and nutrient removal. Clogging occurs when suspended and dissolved solids build up in the wetland and impede the flow of water. Any substrate used in the construction of the wetland has a finite capacity to absorb nutrients, particularly phosphorus, from the effluent.

Clogging reduces the pore space of the treatment medium and can inhibit the flow of effluent, causing ponding on the surface of SSFs. Ponding exposes wildlife and humans to the effluent and may attract insect pests. In addition, clogging also prevents water from being treated by the wetland and infiltrating into the ground. There are some ways to prevent or reverse clogging. To prevent clogging, allowing the system to dry returns the system to aerobic conditions and allows any clogging material to mineralize. The use of a spherical media that is 6-11 mm in diameter can also reduce the potential of clogging. C

Currently, the normal procedure to take upon constructed wetland media clogging consist of washing of clogged media and returning it to the wetland or partially and/or completely replacing the clogged media (Knowles et al 2011). More recently, hydrogen peroxide has been used to combat clogging in SSF wetlands. The wetland beds are pumped with hydrogen peroxide, which oxidizes any organic material clogging the wetland. This can reduce the amount of clogging material by 60-75 percent. In addition, this method can be done *in-situ* without the excavation and removal of the substrate (Nivala & Rousseau, 2009). Recently, a study on the restoration of clogged VSSF wetlands using various earthworm species was completed. Overall, results demonstrated a 50 percent removal of solids in substrates with earthworms compared to those without. This method proved to be high beneficial for possible future use due to the quickness of restoration, approximately 10 days, the low costs and the lack of any specific training for the staff in charge (Li, 2011).

The type of substrate used can determine how long a constructed wetland will be able to remove certain nutrients. The average life-span of a constructed wetland (SF and SSF) is 2-5 years in regards to phosphorus removal. After that time, the substrate of the system is saturated with phosphorus and will no longer remove it from the effluent. However, using a substrate such as shale or furnace slag, which readily absorbs phosphorus, can increase the life-span to approximately 20 years (Drizo et al, 1999). The processes that dissolve organic matter and nitrogen can continue indefinitely as long as the balance of aerobic and anaerobic conditions remains within the wetland (Idelovitch et al 2003). Heavy metals can also be removed by constructed wetlands. Removal can occur for tens to hundreds of years depending upon the concentration of the metals in the effluent. However, heavy metals do accumulate in the soil which may become an environmental concern for the site in the future (Benham-Blair, 1979).

Appendix I • Slug Test Results

Slug Test Analysis

The purpose of performing a slug test on a well is to determine the hydraulic conductivity of the soil around the well. In order to collect data for the analysis, a slug was inserted into the well and was left to equilibrate for a day or two. At a later point the slug was removed and data was collected on the response of the well recovery. The analysis of the data was done using a derivation of the Hvorslev slug test solution with one of the following equations.

Method A: $$K = \frac{r^2}{t_2 - t_1} \frac{\ln(L/r)}{2L} \ln\frac{H_1}{H_2} K = \frac{r^2}{t_2 - t_1} \frac{\ln(L/r)}{2L} \ln\frac{H_1}{H_2}$$

$$K = \frac{r^2 \ln(L/r)}{2 L T_0} K = \frac{r^2 \ln(L/r)}{2 L T_0} \quad \text{(Simplified Method A)}$$

Method B: $$K = \frac{2.303 \, r^2 \ln(L/r)}{2 L (t_2 - t_1)} \log\frac{H_1}{H_2} K = \frac{2.303 \, r^2 \ln(L/r)}{2 L (t_2 - t_1)} \log\frac{H_1}{H_2}$$

Where K = hydraulic conductivity (feet/min)

r = well radius (feet)

L = length of well (feet)

t_2 = end time of slug test (minute)

t_1 = start time of slug test (minute)

H_1 = hydraulic head at start of test (feet)
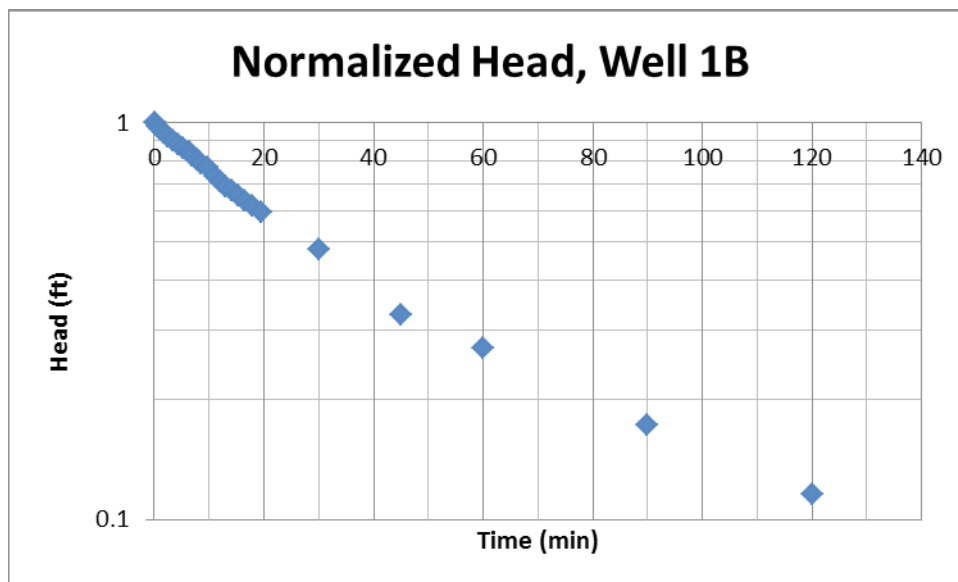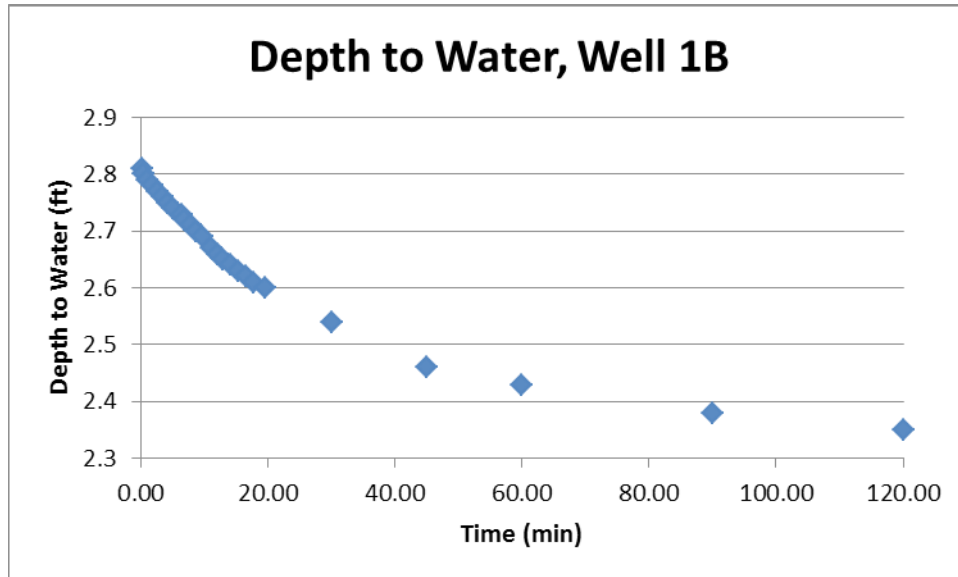
H_2 = hydraulic head at the end of test (feet)

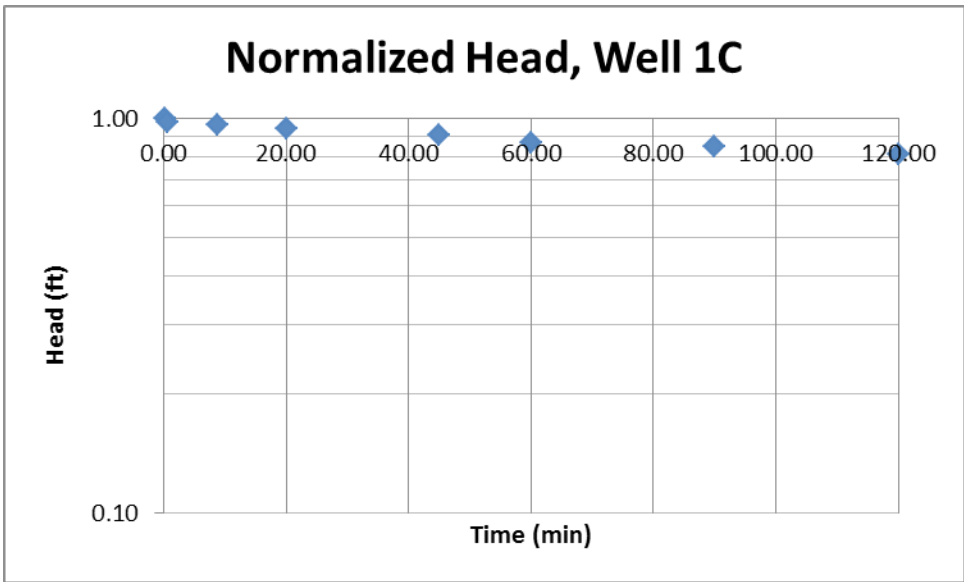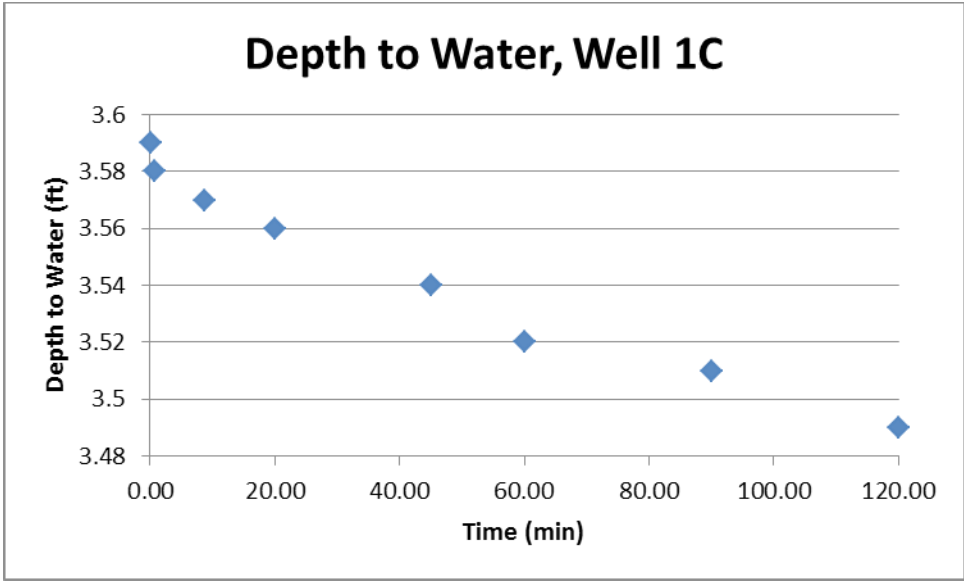T_0 = initial time of slug test (minutes)

Before any analysis could be performed a few preliminary calculations had to be done. The depth to water had to be converted into the normalized drawdown. This is done by determining $s(t)$ which is the hydraulic head of the aquifer (h_{aq}) minus the changing head of the slug test (h_w). Since the slug was taken out of the well the absolute value of the difference was used. Next $s(t)$ was divided by s_0 to determine the normalized head, H.
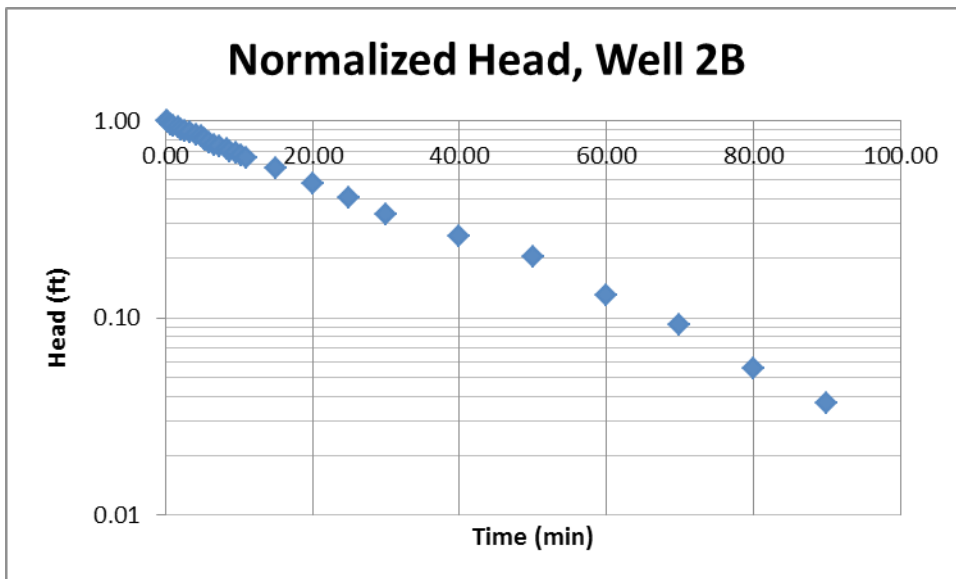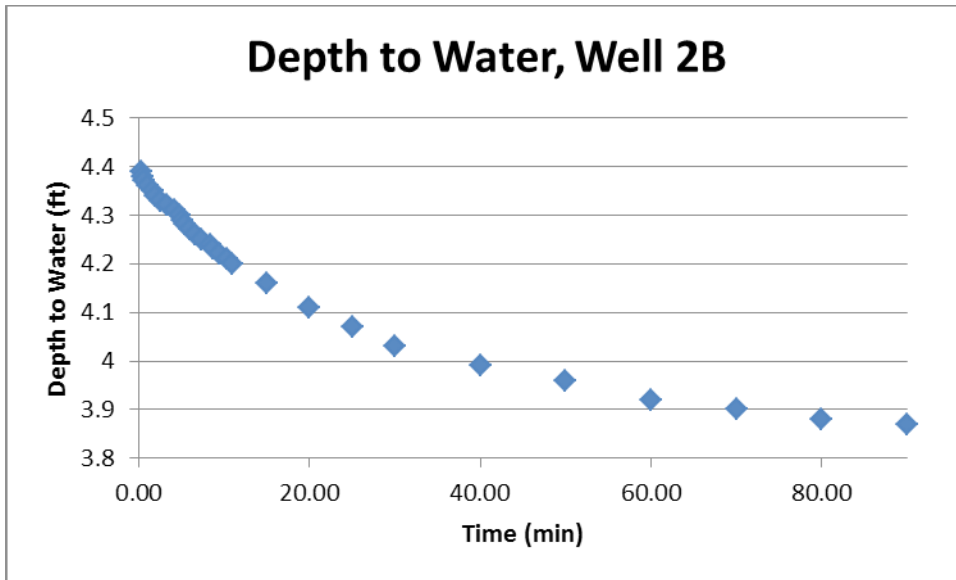
When using Method B, times were chosen so that the $\log(H_1/H_2)$ equals 1, or that H_1 and H_2 vary by a factor of 10, thus the term can be ignored. This method was used on the two wells for which plenty of data had been collected. Method A was used when there wasn't enough variance in the data to perform Method B. Simplifying Method A, t_1 can be chosen as 0 thus making H_1 equal to H_0. In order for the $\ln(H_0/H_2)$ to equal 1, and therefore ignored, H_2 has to equal .37. When this equation was used t_2 was interpolated from a graph of time versus log H. Data for the wells are shown in Table 1 where N/A means not enough data was collected to perform an analysis.

Table 1: Well Information

Well ID	L (ft)	r (ft)	Method	K (ft/day)
Well 1B	7.10	0.104	A	0.074
Well 1C	11.03	0.105	N/A	-
Well 2B	7.13	0.100	B	0.117
Well 2C	11.04	0.100	N/A	-
Well 3B	8.08	0.080	B	0.011
Well 3C	10.00	0.080	A	0.003

Depth to Water, Well 1C

Normalized Head, Well 1C

Depth to Water, Well 2B

Normalized Head, Well 2B

Depth to Water, Well 2C

Normalized Head, Well 2C

Depth to Water, Wll 3B

Normalized Head, Well 3B
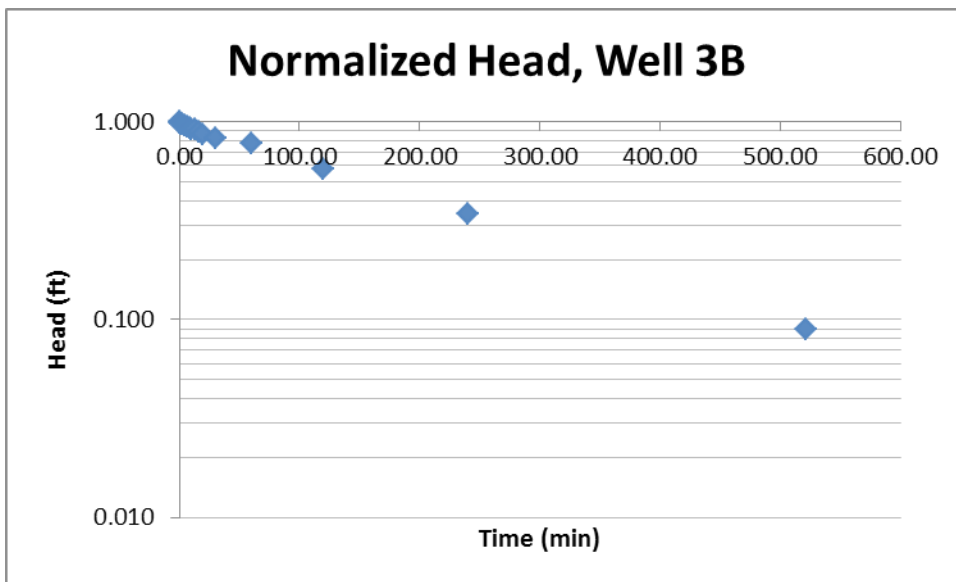
Depth to Water, Well 3C
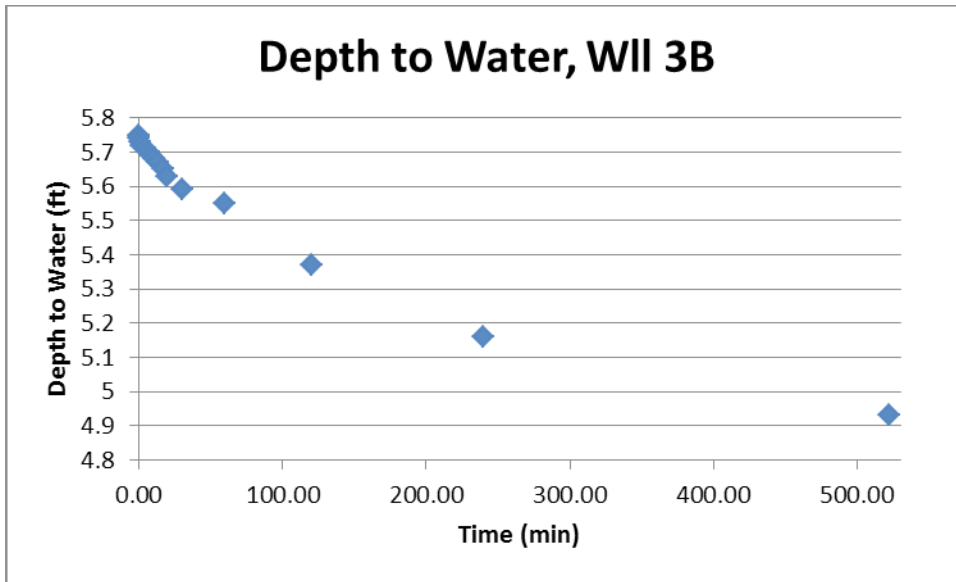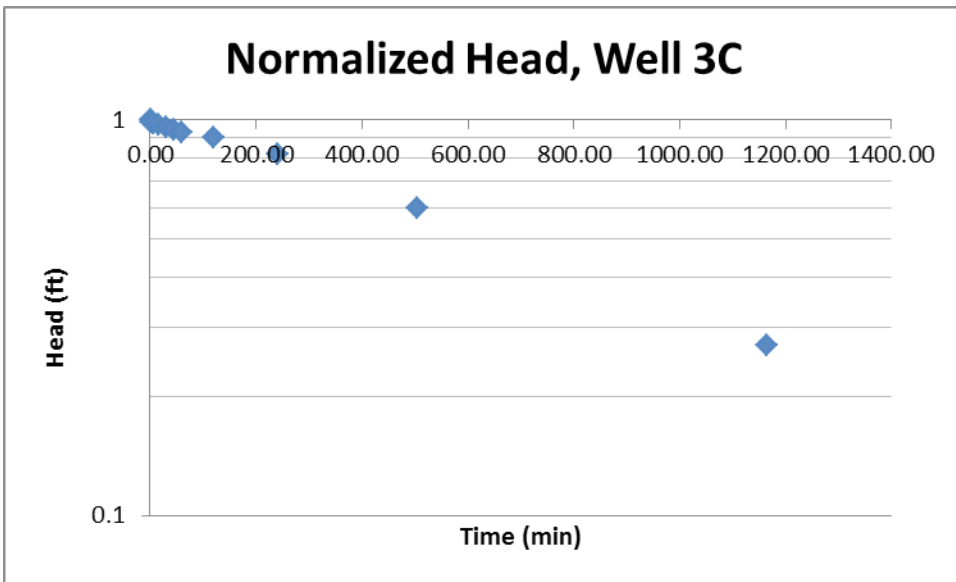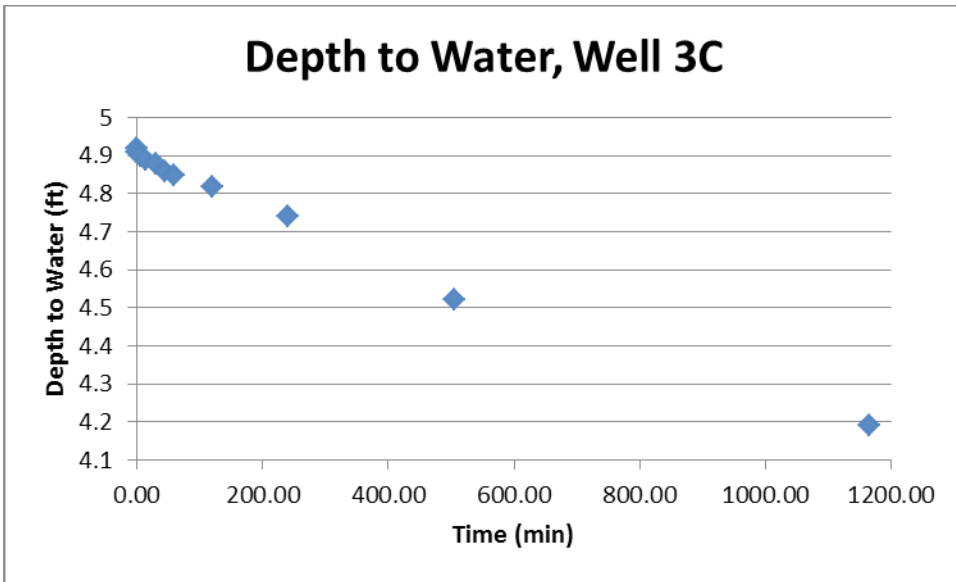

Normalized Head, Well 3C
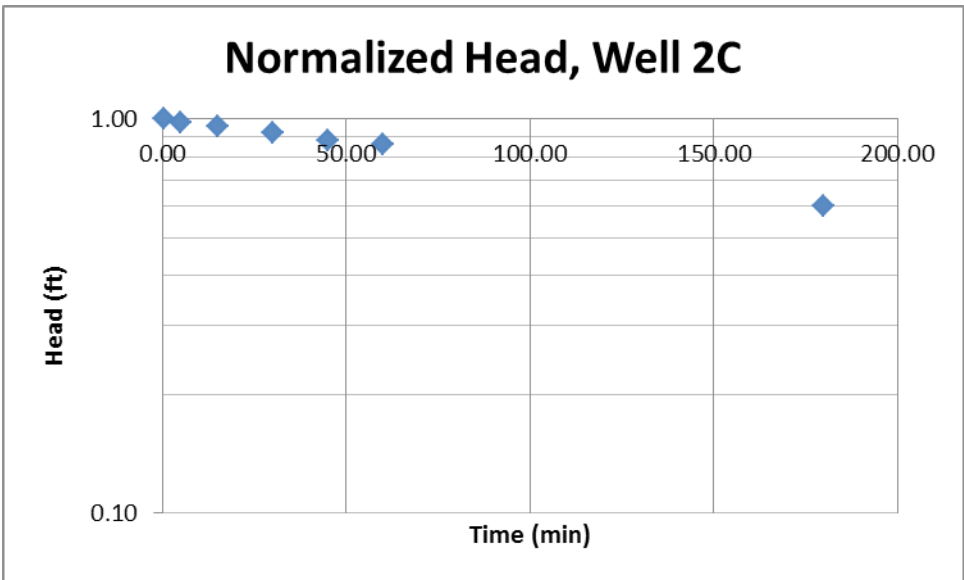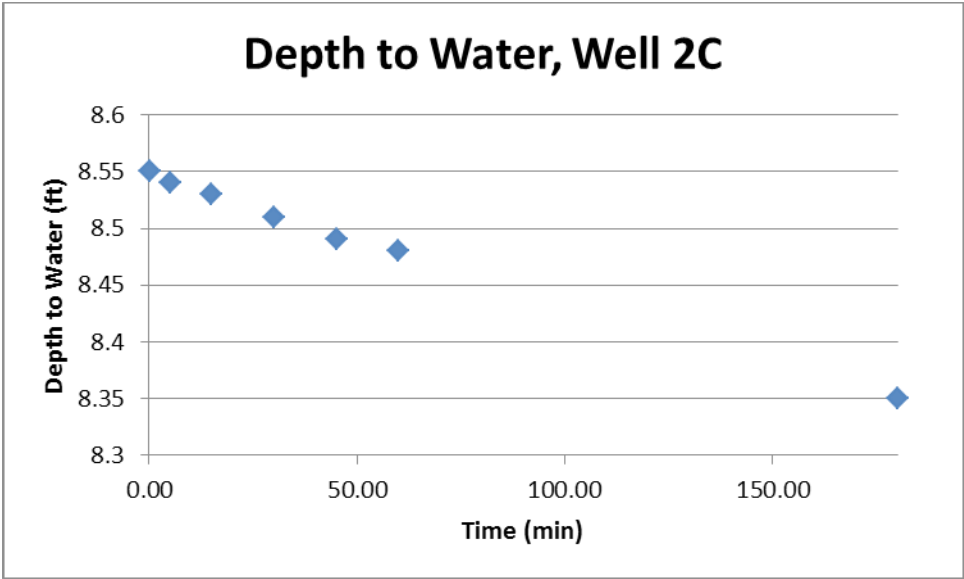
Appendix J • Wetland Sampling Results

Location	Longitude	Latitude	Sample Date	Rain Event (Y/N)	CL (PPM)	NH3 (PPM)	NO3 (PPM)	TKN (PPM)	TKN-D	TP (PPM)	TP-D (PPM)	Fcoli (#/100ml)
Syene Road	-89.3956	43.0236	4/25/11	Y	52.8	0.1	2.13	0.72	0.55	0.1	0.04	240
			5/26/2011	Y	61	0.03	3.5	0.88	0.96	0.1	0.07	2160
			6/14/2011	Y	57.3	0.08	5.67	0.51	0.41	0.09	0.05	89
			6/28/11	N	55	0.05	4.28	0.47	0.44	0.07	0.06	81
			7/18/11	N	57.3	0.13	5.19	0.48	0.42	0.07	0.06	320
			8/9/11	N	56.9	0.06	6.14	0.37	0.35	0.07	0.07	345
North Spring	-89.4063	43.0202	4/25/11	Y	72	0.08	0.22	0.69	0.48	0.15	0.06	1240
			5/26/11	Y	85	0.03	0.3	0.86	0.72	0.16	0.1	1930
			6/14/2011	Y	98.8	0.28	0.84	0.85	0.84	0.16	0.1	694
			6/28/11	N	121	0.35	0.87	0.75	0.63	0.11	0.06	220
			7/18/11	N	107	0.41	0.54	1.11	0.72	0.19	0.13	140
			8/9/11	N	78	0.14	0.65	0.81	0.65	0.21	0.14	192
South Spring	-89.4064	43.0195	4/25/11	Y	49.8	0.08	3.57	0.8	0.78	0.08	0.08	1240
			5/26/11	Y	54.6	0.05	4.62	0.92	0.72	0.11	0.04	410
			6/14/2011	Y	50.4	0.04	6.36	0.23	0.12	0.05	0.03	74
			6/28/11	N	50.7	0.07	0.032	3.74	1.52	0.91	0.37	3
			7/18/11	N	60.8	0.22	4.09	0.73	0.6	0.07	0.06	144
			8/9/11	N	58.2	0.06	5.66	0.45	0.59	0.11	0.08	250
Spring 1	-89.41373	43.011127	5/26/11	Y	47.3	0.01	10.6	0.1	0.1	0.04	0.05	<1
			6/14/2011	Y	50.4	0.02	10.4	0.25	0.1	0.16	0.06	48
			6/28/11	N	47.8	0.01	9.92	0.1	0.1	0.06	0.06	1
			7/18/11	N	49.3	0.06	10	0.13	0.13	0.06	0.06	1
			8/9/11	N	34	0.06	9.2	0.13	0.13	0.07	0.07	1
Spring 2	-89.40875	43.014511	5/26/11	Y	33.6	0.01	8.94	0.1	0.1	0.04	0.03	<1
			6/14/2011	Y	30.1	0.01	8.99	0.1	0.1	0.05	0.04	268
			6/28/11	N	30.1	0.01	8.65	0.1	0.1	0.05	0.06	2
			7/18/11	N	32.9	0.06	8.71	0.13	0.13	0.06	0.06	1
			8/9/11	N	50.7	0.06	10.4	0.13	0.13	0.06	0.07	3

Appendix K • Permeameter Testing

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A PRACTICAL AND QUICK TEST FOR INVESTIGATING SOILS WHICH MAY HAVE EXCESS EXCHANGEABLE SODIUM

David M. Kopec – University of Arizona

Directions

1. Take a soil sample (about 1 quart) from the surface 6 inches of the impermeable area.

2 .Thoroughly dry and pulverize the soil until the largest particles are about the size of coffee grounds.

3. Add 1 heaping teaspoon of powdered gypsum to 1 pint of the pulverized soil and mix thoroughly. Leave an equal amount of soil untreated.

4. Prepare two cans as shown in the drawing. Any can that is 3 to 4 inches in diameter and 4 to 6 inches tall is satisfactory.

5. Put the treated soil in one can and the untreated soil in a separate can. Fill each can about three-quarters full. Pack the soil by dropping the can from a height of about 1 inch onto a hard surface a total of ten times..

6. Fill the can with irrigation water, Disturb the soil as little as possible.

7. Collect the water that drains through the soil. When you have collected 1/2 pint or more of water

from the gypsum-treated sample, compare this volume with that obtained from the untreated sample.

If less than half as much was has passed through the untreated soil cans   *as through the gypsum-treated soil in the same length of time, this………*

•indicates that your soil contains excess exchangeable sodium. If so, it is likely that the addition of a chemical amendment can improve permeability and help reclaim the soil. Look at the "can" on the next page.

Remember:

Chemical amendments, such as gypsum are needed if your soil is impermeable because of excess exchangeable sodium.

Amendments will NOT correct water penetration problems due to fine soil texture, compaction, or hardpan. Amendments are DEFINITELY NOT needed if your soil is permeable and water penetrates it readily.

The University of Arizona, College of Agriculture, U.S. Department of Agriculture and Arizona Counties Cooperating