Managing Turf to Improve Water Infiltration and Retention

A Five-year Field Study at University of Wisconsin-Milwaukee

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Acknowledgements:

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3. Abstract:

Much attention has been given to amending soils with compost to improve water retention and infiltration. However, prior work has usually involved significant disturbance of soil horizons, including soil replacement with a compost/soil blend, or by active incorporation of compost into lower horizons using rototilling etc. Little work has been done to explore how surface applications alone can improve soil quality for water infiltration and retention.

A five-year study of water infiltration was conducted on adjacent parcels of turf on the campus of University of Wisconsin-Milwaukee, where soils have high clay content. The soil was tested for biological, mineral and physical properties, and water infiltration was tested using 24”and 12” double ring infiltrometers. An area approximately 8000 ft^2 in size was divided in half. One half of the parcel served as the experimental control (Control), and it was treated with a simple turf protocol of yearly fertilization and one total aeration over five years. The other half of the parcel served as the experimental treatment (Managed) side, and it received a rigorous protocol of turf treatment including regular mechanical aerations along with applications of compost, liquid compost tea, mineral amendments and granular fertilizer. The purpose of the experiment was to observe whether the intensive management of the turf resulted in improved water infiltration, and to what degree.

After three years of turf treatments, the two sides were tested with the 24” infiltrometer, returning to the same six exact locations where pre-tests occurred, three years later. Post-test data showed better infiltration on the Managed side versus Control, but wide variability in the data prompted a continuation of the study for two more years.

In 2019, after five years of turf treatments, infiltration was again tested using the 24” infiltrometer, along with additional testing with a 12” infiltrometer and the number of sites tested was expanded. The expanded testing of 48 total sites showed strong trends in favor of the Managed plot, which infiltrated water at significantly higher rates than the Control, and also showed improved soil organic matter, higher macro nutrients, reduced compaction and improved biological markers. The findings of this study suggest taking a managed approach to lawncare improve infiltration and water retention, resulting in reduced sheet flow.

4. Methods:

Earthcare Natural Lawn and Landscapes conducted a five-year study of water infiltration with support from Milwaukee Metropolitan Sewerage District and the University of Wisconsin-Milwaukee. The study was run on adjacent parcels of turf on the campus of University of Wisconsin-Milwaukee, near the corner of Edgewood and Downer Avenues. The area below was bisected, with the southern side serving as the experimental control (Control) and the northern side serving as the experimental treatment plot (Managed).

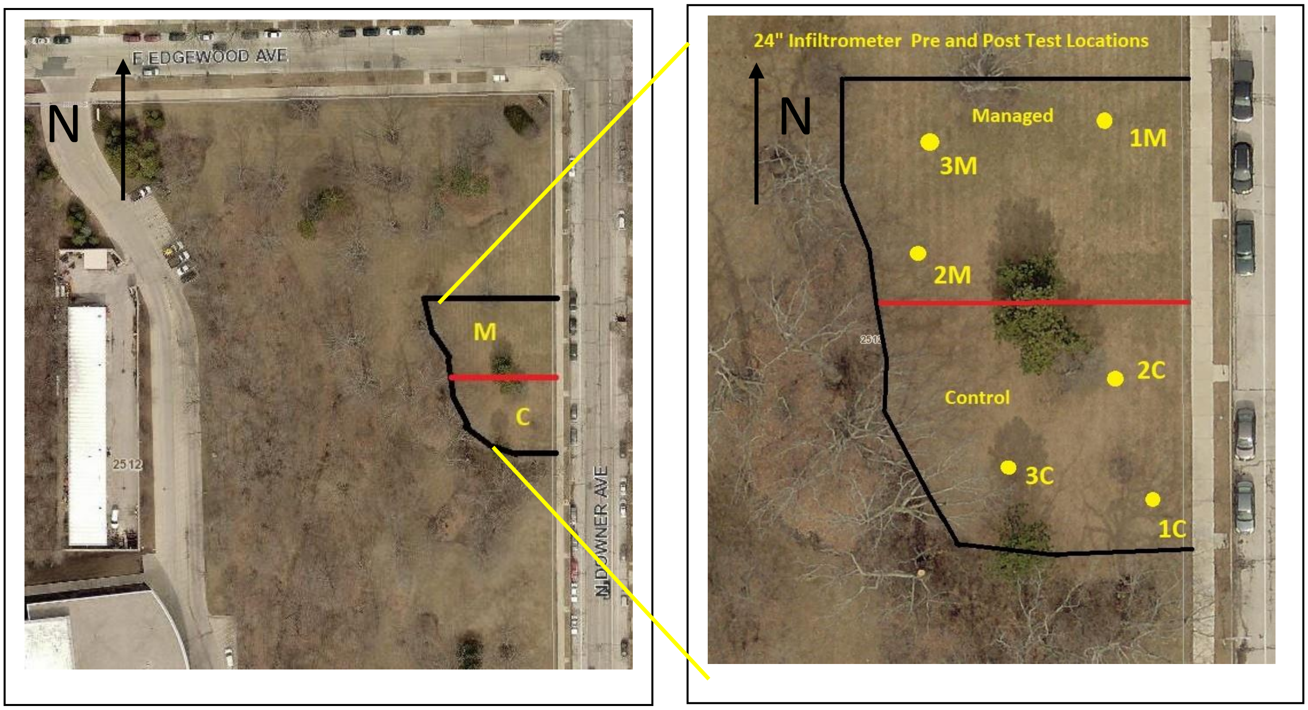


Figure 1: Aerial view of project site south of the corner of Edgewood and Downer Ave, Milwaukee, WI.

The soils were pre-tested for biological, mineral and physical properties as described in Appendix A. Soil health is known to be a function of the interaction between biological, mineral and physical properties, affecting the availability of nutrients to plants, the role of air and water in the soil column, and the complementary role of soil biology in promoting healthy plant growth. These parameters were pre and post tested in order to show the impacts of surface applied amendments and mechanical aeration.

Water infiltration was tested across six sites using a 24" double-ring infiltrometer in general accordance with the guidelines expressed in the WDNR modified procedures for performing a double ring infiltrometer test per ASTM D3385. The sites were selected based on pre-testing using a Turftech 2" mini infiltrometer, with the goal of finding three sites on each side of the trial that, when averaged together, were roughly similar in their infiltration rates. Care was also taken to make sure that sites on each side did not have any particular bias, such as distance from tree canopies, drainage pathways, foot traffic patterns, etc.

The specific locations for the double ring infiltrations were marked using metal spikes that were buried in the ground and were located for subsequent testing using a metal detector. The initial 24" double-ring tests were conducted in September of 2014 by the engineering firm Professional Services Inc. (PSI), using a the WDNR Modified Method for Grass Swales. This process is outlined in Appendix B. One change was made to the WDNR process regarding the start time of recording infiltrations. The timer was started soon after the initial pour to more closely test the initial water infiltration of the top inches of the soil. This exception is described in the field notes at the bottom of Appendix B. The tests were run on three Control and three Managed sites.

Figure 2: 24" Double Ring Infiltrometer

The Control turf area was treated with a basic turf care regimen: occasional fertilization (approximately once a year) with granular slow release fertilizer, Milorganite®, and one (total) core tine aeration during the five-year period. The Managed plot received a rigorous protocol of turf treatment to promote soil biological life and improved water infiltration. The Managed side received three mechanical aerations per year along with applications of compost, liquid compost tea, mineral amendments and Milorganite three times a year. Mechanical aeration is a standard practice designed to reduce the bulk density of soils and improve root establishment in turf, both of which were projected to be helpful in increasing water infiltration. Compost applications have been frequently shown to improve the physical structure of soils by, lowering bulk density, increasing porosity and adding beneficial soil biology that improve turf health. Similarly, compost tea can infuse the soil with beneficial soil biology that promotes plant health and has been theorized to improve soil ecosystem functions. Milorganite was included as a broadly available high quality "natural" source of nitrogen fertilizer that would not diminish soil biology with the salts that are inherent in conventional fertilizers. Mineral amendments such as gypsum have been used by organic and biological farmers for years with the goal of loosening soil structure. While the practice is debated, it has been recently adopted as a practice funded by the Natural Resources Conservation Service of the USDA within the Great Lakes Basin and was incorporated in this study. No single practice listed above was tested in isolation. The thought was to bring together a broad spectrum of soil management practices, aka applying "the kitchen sink," to influence soil structure and water infiltration performance.

After three years of turf treatments, the two sides were tested again by PSI, Inc with the 24" infiltrometer, returning to the exact locations where pre-tests were conducted. The post test data was compared to pre-test data, with a particular focus on the first two inches of water infiltration, in order to focus on the initial "first flush" stages of major rain events. Due to the high variability of results, the study was extended for another two years to add more data points. After five years of treatment, the study concluded with two double ring infiltration tests in 2019—one in June and one in September.

Earthcare conducted a second parallel test in the summer and fall of 2019 to add enough data points to measure statistical significance. The 12" rings were not used in pre-tests because it was a strategy that was adopted mid-study as a way to increase data points dramatically, from six to forty-eight. Earthcare obtained a mid-sized 12" double-ring infiltrometer pictured in Figure 3 and 4 below and conducted 42 double ring tests (21 on each side) between July 2019 and October of 2019. The 12" rings were also tested alongside the 24" rings in September 2019, to calibrate and determine if the two infiltrometer sizes showed strong correlation. The results showed strong correlation for five out of six calibration tests.

Figure 3: 12" Infiltrometer incorporated into double ring testing starting in July 2019.

Figure 4: Insertion of 12" infiltrometer using a serated knife to slit the turf and seat the iniltrometer with minimal soil disturbance.

5. Results

5a. 24" Infiltrometer

With the 24" ring tests, all sites showed lower infiltration rates in 2017 versus 2014, likely due to the very dry conditions. Similarly, all sites in 2019 were slower than in 2014, this time likely due to much wetter conditions. However, Managed sites slowed to a much lesser degree than the Control, suggesting that they retained their infiltration properties better.

Insert clay content of SE WI and how these practices help.

At the start of the trial, the Control sites were comparatively better infiltrating than Managed sites. There was no apparent difference is surface wear/compaction and the only other factor that apparently would have caused this was a higher percentage of sand in the control samples, enough to classify it as a "sandy loam" while the Managed site was classified as "loam". These two tests are included in the Appendix C on Soil Textural Analysis. In 2014, Control sites had an average rate of 40.30 inches per hour for the first two inches, which was more than twice the rate of Managed sites at 17.8 inches per hour (Figure 5). In 2019, after five years of managed turf care, the results were reversed when comparing Managed to Control. Managed sites averaged 5.7 inches per hour, more than twice the rate of Control sites at 2.8 in/hr (Figure 6). Looked at another way, Control sites slowed 93% from 2014 to 2019, while Managed sites slowed only 68%. The 24" test data did not provide statistically significant data because of high variability amongst Control and Managed sites.

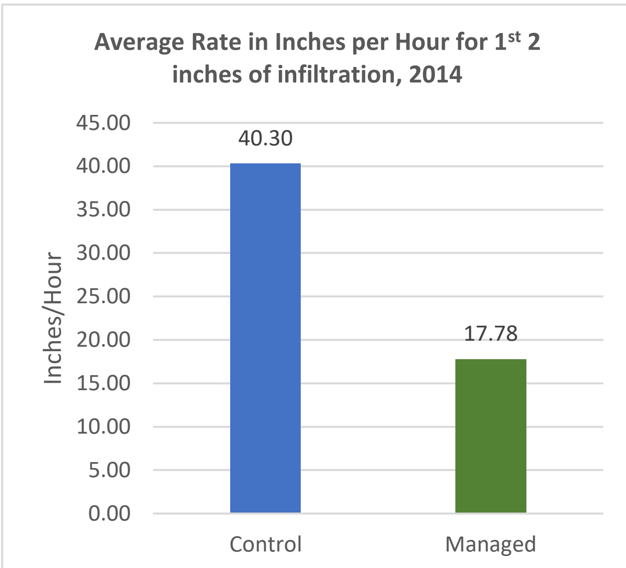


Figure 5: Pre-test, September 2014

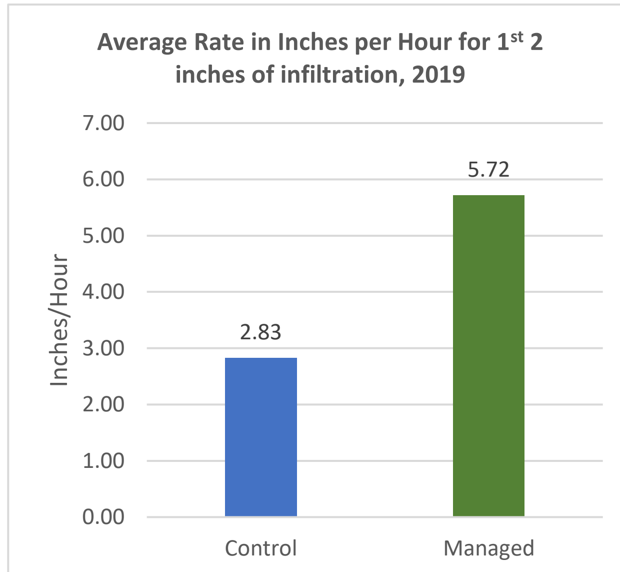


Figure 6: Post-test, September 2019

5b. 12" Infiltrometer

Results using the 12" double ring infiltrometer showed more dramatic differences between Control and Managed Sites. Although they could not show changes per site over time, they provided an aggregate "post-test" lens to look at results, and the data that supported the narrative that emerged from the 24" tests. The 21 Managed sites showed on average 84% higher infiltration rates than the 21 Control sites. The data result was statistically significant with $p < .05$ (t-value = 2.09404, p-value = .02149) using the T-Test Calculator, Social Science Statistics, Jeremy Stangroom, https://www.socscistatistics.com/tests/studentttest/default2.aspx. See Appendix D for data analysis.

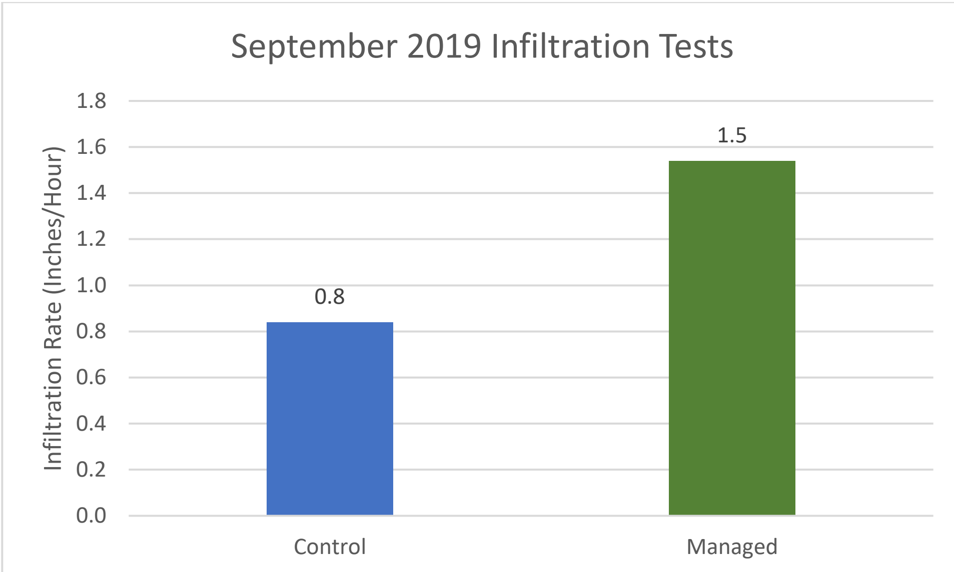


Figure 7: Comparison of infiltration tests between control and managed plots using medium double rings (12” diameter) with removal of one high and one low test result.

5c. Soil compaction testing

Both sites were tested with a soil penetrometer in 2014 and 2019. Pre-test data in 2014 showed equal compaction readings for both Control and Managed sites (generalized tests at 3” and 6” levels showed 250 psi and 300 psi respectively). In the Post-tests in the fall of 2019, both Control and Managed sites showed less compaction, likely due to the higher soil moisture. However, in post-tests control sites showed 27% higher compaction across 3”, 6”, and 9” depths vs Managed sites. This data was consistent with the subjective feeling under foot that the Managed site was noticeably softer.

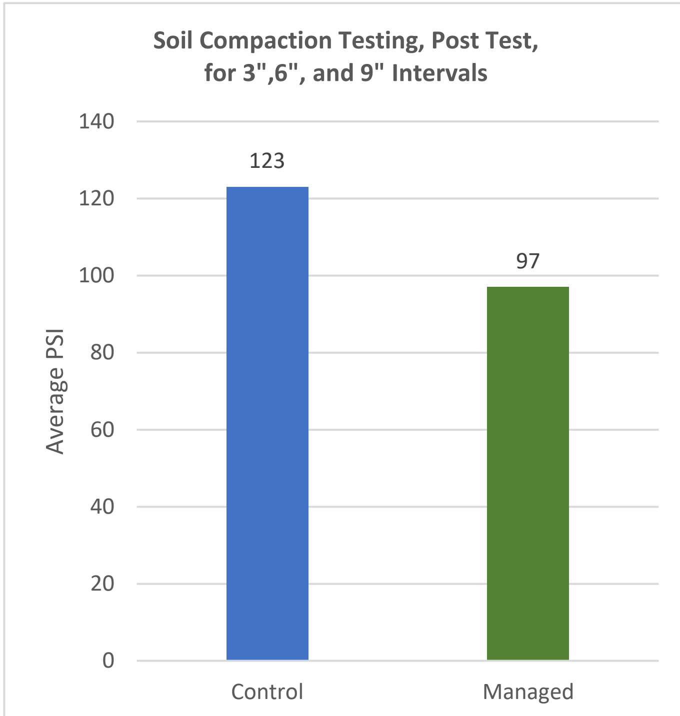


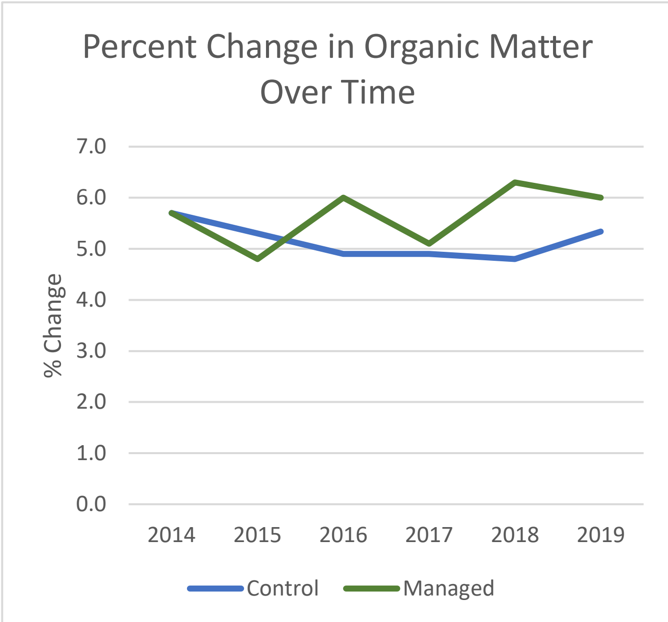
Figure 8: Soil compaction testing, post test, average PSI for 3”, 6”, and 9” intervals

5d. Lab tests:

Lab tests showed Managed soils with greater nutrient levels and higher biological metrics. Macro nutrients and organic matter were higher across the board on the Managed plot, after beginning the study on par with the Control plot. Bacterial and fungal populations grew at more than twice the rate compared to the Control, including a dramatic increase in endomycorrhizal fungi, a key indicator of soil health. Mycorrhizal fungi require more air content in soils, which is associated with less compaction and plenty of pore space. As they grow, they also release glomalin, a substance that helps to bind soil particles together, promoting the growth of macro pores that will improve infiltration further.

5d(1). Soil Chemistry

Soil Organic matter started out equal in both Control and Managed sites. By the end of the five-year period, Managed sites were .7% higher in organic matter than Control sites. The value of this from a water retention standpoint is described in Section 8 below. In between the pre and post-tests, both sites showed decreases in organic matter, and then the Managed sites rebounded to pre-test levels, but Control sites did not. The interim lowering of organic matter may have been due to differences in how deep the samples were taken (sampling error). In general, lower levels of the soil column exhibit lower levels of soil organic matter, and thus, inconsistencies in soil sample depth can affect soil organic matter readings. Since soil organic matter readings are measured in very minute terms, they can be susceptible to sampling error.



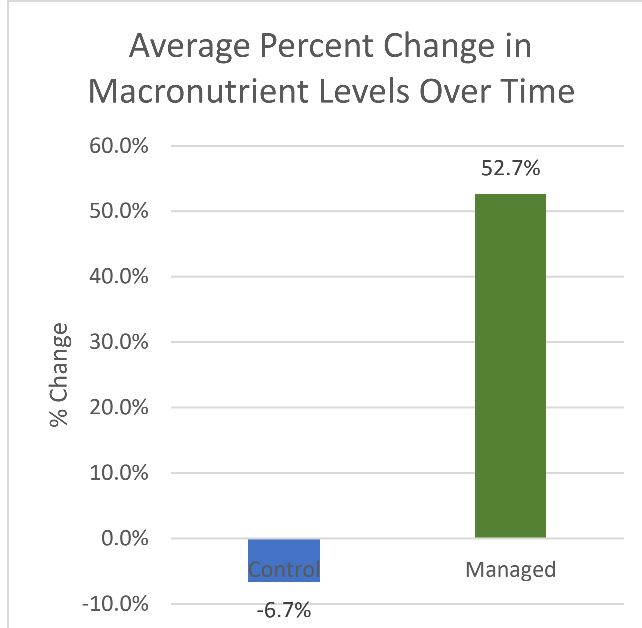


Figure 9: Percent change of organic matter between control and managed sites, 2014-2019

Figure 10: Average percent change in macro-nutrient levels (P2, K, Ca, Mg) between control and managed sites, 2014-2019

Table 1. Macronutrient levels, 2014 to 2019

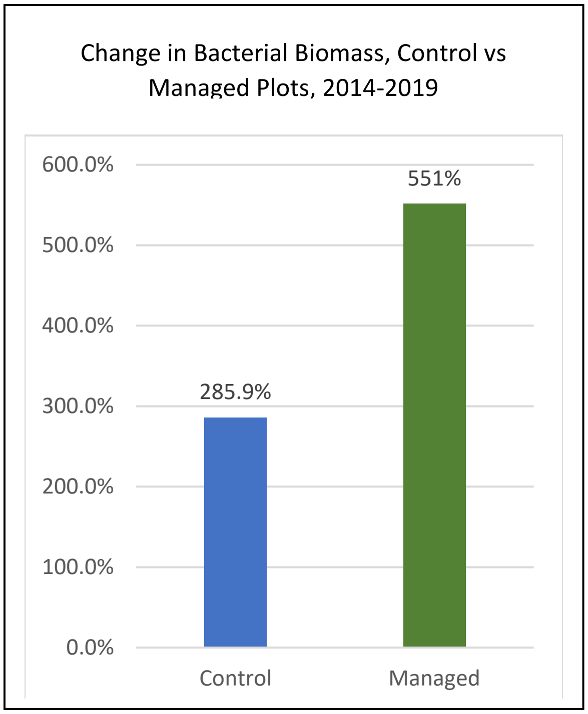
Chemistry/Nutrients:

Control	2014	2015	2016	2017	2018	Avg 2019
OM (%)	5.7	5.3	5.3	4.9	4.9	5.3
P1 (weak bray, ppm)	9	5	5	7	7	13
P2, (strong bray, ppm)	31	19	19	23	21	32
K, (ppm)	120	96	91	105	97	104
Ca, (ppm)	2600	2239	2068	2171	2215	2381
Mg, (ppm)	572	517	464	476	519	533

Managed	2014	2015	2016	2017	2018	Avg 2019
OM (%)	5.7	4.8	6	5.1	6.3	6.0
P1 (weak bray, ppm)	12	16	17	19	25	31
P2, (strong bray, ppm)	32	33	42	45	58	73
K, (ppm)	124	160	209	210	214	217
Ca, (ppm)	2470	2478	2503	2498	2486	2794
Mg, (ppm)	553	493	482	431	439	531

5d(2) Soil biological properties- Percentage Change from 2014 Pre-tests to Post-tests (2018/2019 averaged)

All major indices of soil health for the Managed Plot showed improvement compared to the Control plot, with the exception of beneficial protozoa, which declined for both Control and Managed (possibly due to adverse soil moisture levels).



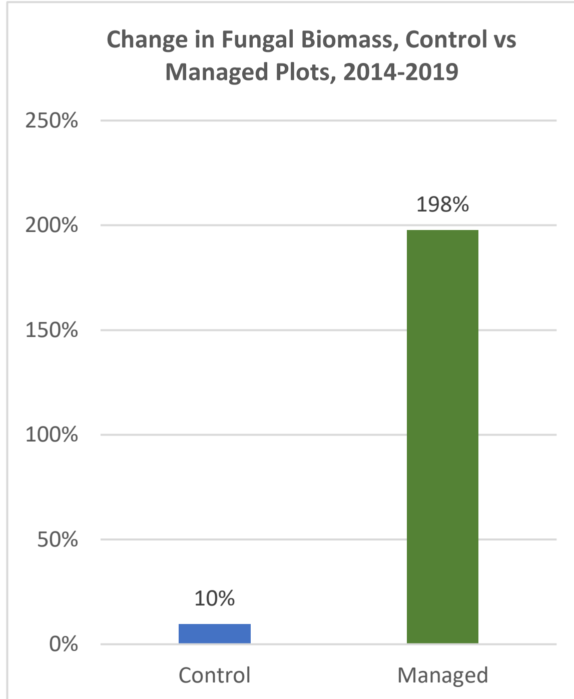
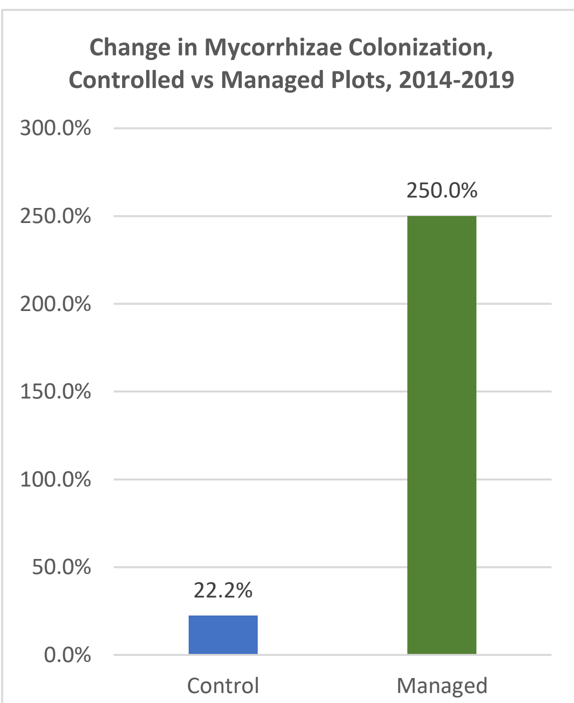


Figure 11: Percent Change in Bacterial Biomass

Figure 12: Change in Fungal Biomass



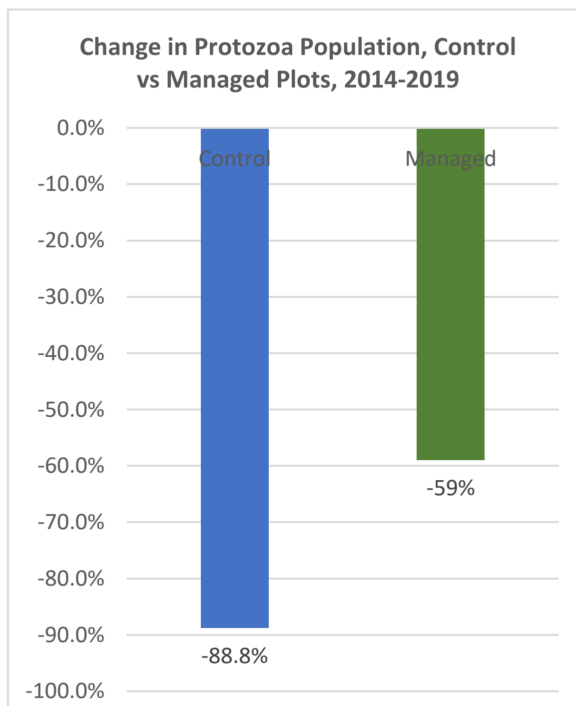


Figure 13: Percent Change in Mycorrhizae

Figure 14: Percent Change in Protozoa

Table 2: Data on Biological Testing, Soil Foodweb NY, 2014 to 2019

Biological Tests

Control	2014	2015	2016	2017	2018	2019	2018/19 Avg
Total Bact, (µg/g)	337	333	482	607	1413	1188	1301
Total Fung, (µg/g)	218	218	419	673	123	356	239
Total Flagellate, (num/g)	38287	17470	5891	5535	6162	5936	6049
Total Amoebae, (num/g)	51584	34940	2738	59799	615	3573	2094
Total Ciliates, (num/g)	70	35	177	8	62	74	68
Nematodes, (num/g)	1.44	0.68	2.87	1.54	3.40		
Total N, (est lbs/acre)	100-150	100-150	50-75	100-150	25-50	25-50	
Endo Mycor. (% colinization)	9%	4%	13%	22%	NT	11%	

Managed	2014	2015	2016	2017	2018	2019	2018/19 Avg
Total Bact, (µg/g)	206	255	490	846	1517	1167	1342
Total Fung, (µg/g)	156	367	515	169	443	486	465
Total Flagellate, (num/g)	32278	57465	59908	2754	6282	36245	21264
Total Amoebae, (num/g)	66983	17295	59908	5485	18908	2799	10853
Total Ciliates, (num/g)	67	0	109	179	38	0	19
Nematodes, (num/g)	0.97	0.59	2.78	1.74	2.14		
Total N, (est lbs/acre)	200+	100-150	200+	25-50	74-100	100-150	
Endo Mycor. (% colinization)	6%	16%	16%	9%	NT	21%	

5e. Calibration of 12” infiltrometer to 24” infiltrometer

To determine if the 12” infiltrometer provided an adequate assessment of infiltration rates similar to engineering firm’s 24” infiltrometer, Earthcare conducted side-by-side experiments. Two 12” infiltrometer tests were run about 36 inches away from each 24” infiltrometer site, immediately following the 24” test by PSI, Inc. The 36” distance was chosen to get as close as possible to the same location and therefore the same soil conditions, without being in the immediate area of soil impacted by the 24” test. The data from the two 12” tests were then averaged and compared to the 24” data. A more comprehensive calibration study could have been done, but time and budget limitations affected this protocol. Results from the calibration tests showed strong correlation for five out of the six 24” sites, as seen in the figures below. One outlier (site 1C) showed divergent values and this is possibly due the unique characteristics of the spots chosen for adjacent 12” tests. As discussed below in Section 5, surface wear patterns caused variability in data and it is likely that the 12” on location 1C were in the path of mower wheels or directly on areas compacted by personnel and equipment used in the 24” test.

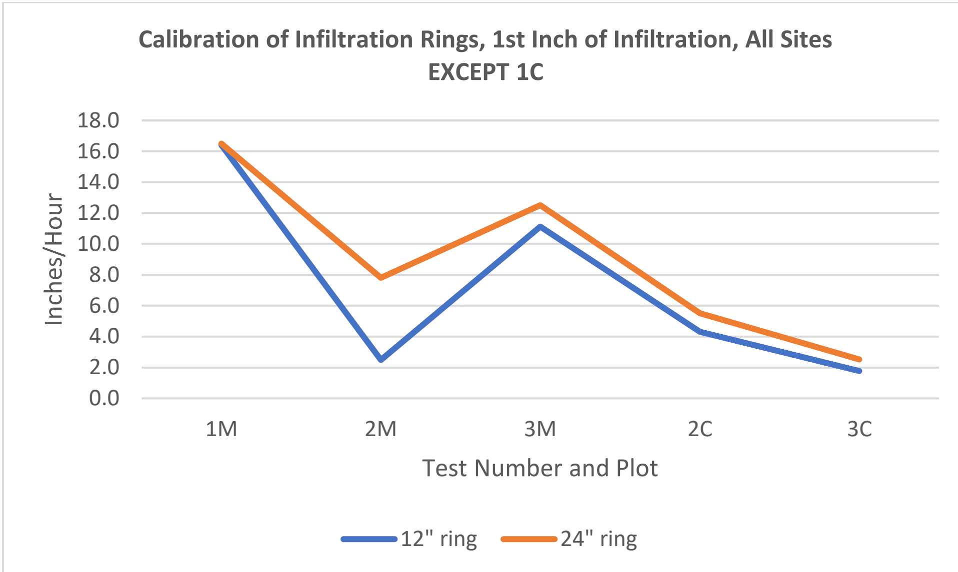


Figure 15: Calibration Rate for Managed and Control Plots, 1st Inch

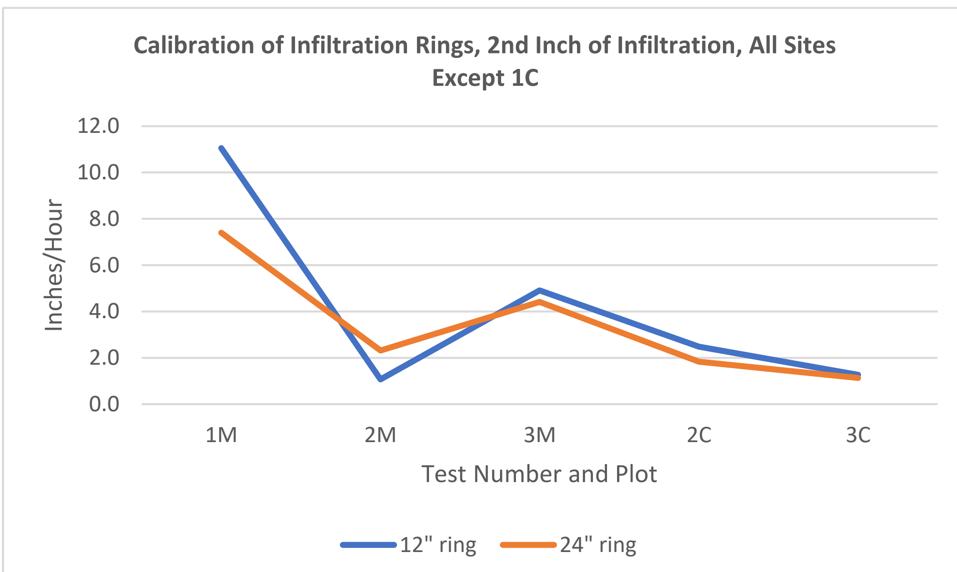


Figure 16: Calibration Rate for Managed and Control Plots, 2nd Inch

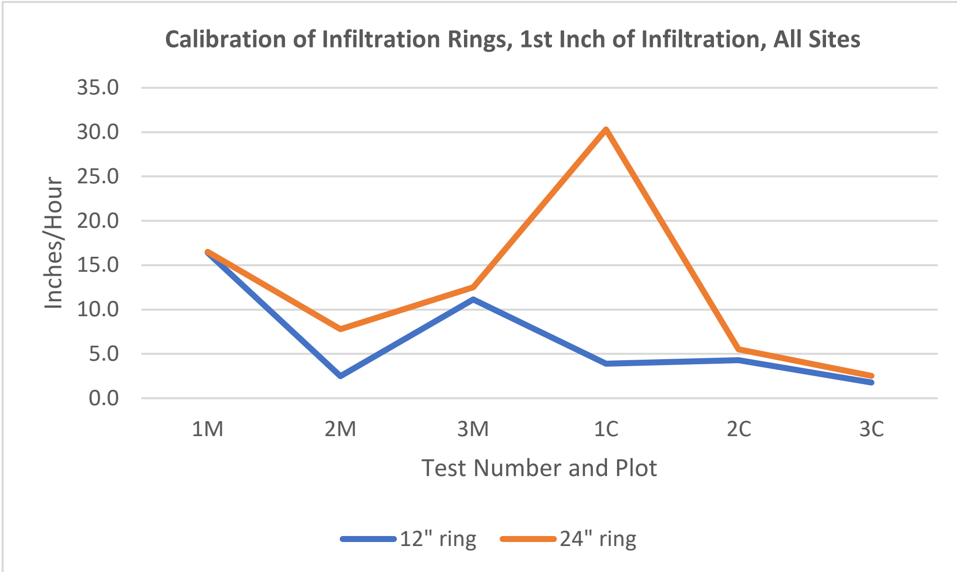


Figure 17: Calibration Rate for Managed and Control Plots, 1st Inch, with 1C

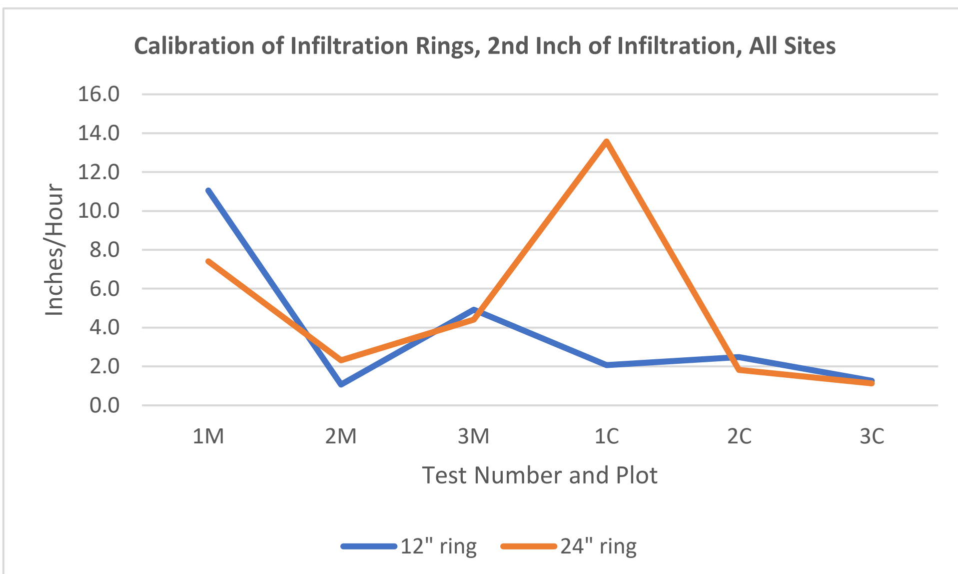


Figure 18: Calibration Rate for Managed and Control Plots, 2nd Inch, with 1C

6. Factors associated with weather:

The 2014 growing season exhibited standard weather patterns and the amount of rainfall in the weeks preceding the double-ring tests were very close to the seasonal average. 2017 was comparatively a dry year, particularly in the weeks preceding the double-ring tests. Conversely, 2019 was a much wetter year and there was significant rainfall in the weeks prior to both scheduled double-ring tests. See Appendix E for graphs of precipitation in Milwaukee by month and year.

The dry 2017 and wet 2019 years likely impacted data in terms of infiltration rates. It was not possible to normalize the sites to compensate for weather conditions. A small amount of water was applied to all sites in 2017 to provide some moisture before the tests, as there was concern that the double ring insertion would not be possible in the high clay content soils unless some degree of moisture was delivered. Ten gallons of water were applied with a gradual circular pour by 2 five-gallon buckets, three days before testing occurred. However, the 2019 wet season provided a different challenge, as there was no way to remove in situ moisture from the soil profile.

Because of the soil moisture factors, the most meaningful analysis of the data was not whether aggregate infiltration rates went up or down, but how each individual site changed in relation to itself and comparing those changes between the Control and Managed plots. For example, in dry weather, all sites showed slower infiltration, however the Managed sites showed less reduction in their infiltration rates, than the Control plots. In other words, in a dry year, the Managed sites did comparatively better; the same was true in very wet conditions.

7. Factors associated with surface compaction

Experimentation with the 12” infiltrometer rings demonstrated that mowing patterns impacted the infiltration results for surface infiltration. In one instance, two tests were run only 6 feet apart. One test was clearly located in the tracks of the ride-on mower wheel where the mower was habitually driven around a tree island. This infiltration rate was seven times slower than a second test only six feet away. This variability showed that surface traffic patterns could play a significant role in soil performance and thus the testing protocol was expanded so that outliers could be removed, and generalized trends could be observed.

8. Estimating the Ecological and Financial Value of Sustainably-Managed Turf

The intensive management of the turf plot at UWM suggests that improved infiltration is possible using management methods that were employed there. How does this improved infiltration rate equate to gallons of water infiltrated? And how does this relate to economic values?

<u>Supposition</u>: If we were to assume that a clay loam soil infiltrated 1 inch of rain per hour (see Appendix F) and a sustainably-managed soil delivered 80% improved infiltration along the lines of our 12” infiltrometer tests, the managed plot would infiltrate 1.8 inches per hour, and the following projection apply:

1 inch infiltrated = 6.27 million cubic inches of water = 27,154 gallons of water per acre.

1.8 inches infiltrated = 48,877 gallons of water per acre. This is an increase of 21,723 gallons.

If this increase occurs in 3 storm events per year (conservative estimate), then this equates to 65,170 gallons of improved infiltration per acre. Additional research is needed to determine if this improvement continues over time, either with continued sustainable turf management or without. Potentially, some management practices would need to be continued to prevent re-compaction from foot/mower traffic etc.

<u>Annual Cost per acre of highly managed turf</u>: \$200 per 1000 ft^2 x 43,560 ft^2= \$8,712. This cost goes down to approximately \$115 per acre when larger acreage (5+ acres) are managed. However, for the purposes of this cost estimate, we will estimate high at \$200 per acre.

Result: The increase in infiltration using the above figures results in a cost of $.13 per additional gallon of water infiltrated. When comparing this to the cost per gallon of water for other types of green infrastructure, evaluated in terms of lifetime cost (installation + 20 years maintenance as calculated in "*Determining the Potential of Green Infrastructure to Reduce Overflows in Milwaukee*, Prepared for MMSD, 2011"), the intensively managed turf is well below other green infrastructure costs, which range from $.50 to $2.50 per gallon. See Appendix G for more information. Even if the above numbers over-estimate the improved infiltration, the practice can still be cost-justified with more conservative values inserted.

The value of improved infiltration may be augmented by the value of improved water retention via improved organic matter in the soil content. An often-quoted statistic is that each 1% organic matter in a soil improves water retention by 20,000 gallons[2]. However, a soil can only retain water that is first allowed to infiltrate. Thus, porosity through the first several inches of soil is critical to water retention. If we allow the 20,000-gallon rule of thumb (See Appendix H for the calculations behind the 20,000-gallon figure), the .7% higher organic content in the Managed plot resulted in the potential retention of 14,000 more gallons of water in rain events in which at least that much water fell and infiltrated properly. We can multiply the volume of water retained in one event by a factor to estimate the effect from multiple high rainfall events in a year. This would add to the cost effectiveness of the high-intensity management of turf.

9. Estimating the Volume of Water Potentially Infiltrated in Milwaukee's Combined Sewer Area

Milwaukee Metropolitan Sewerage District's Combined Sewer Area constitutes an area of approximately 16,700 acres, of which approximately 60% is pervious surface per the Southeast Regional Wisconsin Planning Commission (SEWRPC), whose data can be found in Appendix I. To calculate the potential impact of improved infiltration using intensively-managed turf across the Combined Sewer area, SEWRPC data was utilized and assumptions were made in order to arrive at an amount of turf that would be suitable for higher intensity management.

First, it is assumed that a certain percentage of the pervious area is turf (vs trees, shrubs or perennials) and estimated this specifically for different land use types. For example, dense residential areas have different levels of turf as a subset of their pervious surfaces than parks or educational institutions. While GIS data parsing out these differences was not available, the researcher made an educated guess and estimated on the low end to be conservative about the amount of turf that is present. In addition, the researcher needed to factor in what percentage of the turf area is *managed* turf (fertilized, mowed etc.) and then needed to choose a percentage of the total *managed* turf that warrants higher level investment. This included areas with high runoff potential, high public usage, proximity to combined sewer inflows etc. The identified areas are described as "High Value Turf" for the purpose of this analysis.

The results are as follows:

Estimated Acres of Managed Turf in Milwaukee Combined Sewer Area: 3,243

High Value Turf: 20%

High Value Acreage: 648.7

If high-intensity management improves infiltration by 65,170 gallons per year (per this study), this results in 42,375,473 more gallons of water infiltrated across 648.7 acres.

How can this increase in water infiltration be achieved? Private managers including homeowners, businesses and other private institutions could be encouraged or incentivized to use intensive turf management on High Value Turf. Municipalities could also justify investing in High Value Turf to increase infiltration, and simultaneously reap the aesthetic benefits of improved turf quality through less compacted, more fertile soils. The results of this study suggest that intensively managed turf could have a significant impact on water infiltration.

10. Conclusion

The purpose of the experiment was to observe whether the intensive management of the turf resulted in improved water infiltration, and to what degree. Post-test 12" double-ring infiltration tests showed on average 84% higher rates of infiltration on Managed sites vs Control. This data supported the data from six sites that were pre-and-post tested using 24" rings.

Environmental conditions made it impossible to create identical moisture levels between pre-test and post-test conditions. However, the abundance of data from post-test readings, as well as physical, chemical, and biological properties indicate that intensively managed turf showed greater capacity for water infiltration. When viewed from a cost-benefit perspective, Managed turf practices used in this study show promise as a viable and cost-effective stormwater infiltration strategy.

11. References

T-Test Calculator[1]. Social Science Statistics, Jeremy Stangroom, https://www.socscistatistics.com/tests/studentttest/default2.aspx.
https://www.nrdc.org/experts/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity, https://www.theurbanfarmers.org/store-5000-gallon-of-water-in-14-acre/, https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082147.pdf, https://www.canr.msu.edu/news/compost_increases_the_water_holding_capacity_of_droughty

12. Appendix A. Methods for Soil Biology, Chemistry and Physical Properties Testing

Soils were sampled by soil probe, pulling approximately 15 cores each from the Control and Managed plots. The top ½ inch of soil was discarded from each core as this contained predominantly root mass. Beyond this initial discarding of root material, no macro organic particles (such as roots) were removed in order to standardize the sampling process. The cores for each trial area were hand-blended in a plastic bag to homogenize them. They were labelled and shipped to the following labs.

1. Soil Chemistry testing was done by Midwest Labs Inc, 13611 B St, Omaha, NE 68144

13611 B Street, Omaha, Nebraska 68144 (402) 334-7770 FAX (402) 334-9121 www.midwestlabs.com

SOIL ANALYSIS METHODS

used by Midwest Laboratories, Inc.

Analysis	Method	Reference
Organic Matter	Loss of Weight on Ignition	NCR, p. 32
Phosphorus		
a. P_1	Extraction with dilute acid and ammonium fluoride (Weak Bray)/colorimetric	NCR, p. 14-15
b. P_2	Extraction with strong Bray solution (4 times the acid concentration of weak Bray)/colorimetric	
c. Bicarbonate P	Extraction with sodium bicarbonate/colorimetric	ASA, p. 421-422
Potassium, Magnesium, Calcium, Sodium, Sulfur	Neutral ammonium acetate (1 N) extraction/ Inductively Coupled Argon Plasma (ICAP) detection	RMST, p. 60-65 NCR, p.17-18
pH	1:1 Soil:Water mixture/combination electrode.	NCR, p. 5-8
Soil pH, Buffer index		
Cation Exchange Capacity (CEC)	a. Summation of cations, Ca^{++}, Mg^{++}, K^{+}, Na^{+}, and H^{+} (see 3 & 4) b. Ammonium acetate saturation/displacement with NaCl/distillation and titration	 ASA, p. 149-151
Nitrate-N	Saturated CaO Extraction/Cadmium Reduction/Segmental Flow Analysis (SFA)	NCR, p. 11
Ammonia-N, Exchangeable	Neutral salt (KCl) extraction/SFA	ASA, p. 648
Zinc, Manganese, Iron, Copper	a. DPTA extraction/ICAP detection b. 0.1 N HCl extraction ICAP detection	NCR, p.18-19 NCR, p. 19-20
Boron	DTPA/Sorbitol ICAP	NAPT
Excess Lime	1 N HCl spot test	-
Soluble Salts	Conductivity meter 1:1 Soil:Water	USDA, P. 89-90
Soil Texture	Hydrometer method	ASA, p. 549-566
Chloride	.01 M $Ca(NO_3)_2$ FIA	NCR 13, p. 26-27
Molybdenum, extractable	Acid ammonium oxalate extraction/ICAP	ASA, p. 491-493
Water Soluble Cations	1:5 Water extraction ICAP det.	RMST, p. 87
Field Capacity	Porous plate pressure apparatus	ASTM, D 2325

(1/3 Bar moisture holding capacity)		(1981)
Wilting Point (15 Bar moisture holding capacity)	Porous plate pressure apparatus	ASTM, D 2325 (1981)
Bulk Density	Disturbed sample	Volume weight

References

NCR - Recommended Chemical Soil Test Procedures for the North Central Region. No. 499 (revised). North Dakota State University.

ASA - Methods of Soil Analysis - Part 2: Chemical and Microbiological Properties, Second Edition, 1982. American Society of Agronomy.

RMST - Handbook on Reference Methods for Soil Testing, 1974, Council on Soil Testing and Plant Analysis.

USDA - USDA Agriculture Handbook 60.

ASTM - American Society for Testing and Materials 04.08 Soil and Rock, Building Stones: Geo Textiles

2. Soil biology testing was conducted by Soil Foodweb NY, 17 Clinton St, Center Moriches, NY 11934

Their description of their testing methods is as follows:

Total bacterial biomass is read utilizing epi-fluorescent microscopy. Samples are stained with fluorescein isothiocyanate and organic matter is de-stained with two salts. The samples are transferred onto polycarbonate filter membranes and then enumerated with direct counts with immersion oil. Samples are assayed at 1000x magnification. (100x lens and 10x eyepieces)

The total fungal biomass is determined by direct count microscopy measurements (using differential interface contrast) of hyphae present. Total length of different hyphae present is measured along with corresponding hyphal diameter and tallied. Fungal biomass is assayed under 200 x magnification. (20 x lens and 10x eyepieces).

Protozoa are assayed by first going through a serial dilution of the sample. We start at 10-1 and go down to 10-6. 4 replicates are prepped at each dilution. The diluted samples are incubated on sterile agar for approximately 5 days. Each replicate is assayed for the presence of protozoa and the most probable number was generated.

13. Appendix B. WI DNR Modifications to Double Ring Infiltrometer for Grass Swales

As found at: https://dnr.wi.gov/topic/stormwater/documents/grassswaleserrata.pdf

Errata for Process to Assess and Model Existing Grass Swales (TSS Reduction) Modifications to Double-Ring Infiltrometer Test Procedures in Technical Standard 1002

Existing language in Technical Standard 1002 V. Step C. 4.b.: Measured Infiltration Rate - The tests shall be conducted at the proposed bottom elevation of the infiltration device. If the infiltration rate is measured with a Double-Ring Infiltrometer the requirements of ASTM D3385 shall be used for the field test. Modifications to procedures in ASTM D3385: If the infiltration rate is measured with a Double-Ring Infiltrometer, the dimension and materials used for the double-ring should be based on the requirements of ASTM D3385. The following procedure should be used when using the double-ring infiltrometer for a field test in an existing grass swale. The procedure differs from the field procedures in ASTM D3385 by accepting the infiltration rate measured in a time frame of a minimum of 2 hrs. instead of 24 hours and the water level in both rings does not have to stay constant during the test. The procedure is a more cost-effective approach to obtaining a reasonable estimate of the infiltration rate of existing grass swales. For most soil types the infiltration rate measured by the procedure should represent the soils under more saturated conditions. More sandy soil types might not be represented by saturated conditions, but the higher infiltration rate will probably represent reality for the duration of most storm events. The lowest infiltration rate observed is the one to be used for estimating the TSS reduction for the swales and is considered a static infiltration rate. The static rate should be cut in half to represent the dynamic infiltration rate required by WinSLAMM.

Field Test Procedure for Double-Ring Infiltrometer:

1. Select a relatively flat test area so that the double-ring infiltrometer will not be placed at an angle.

2. Cut the grass to a height of between two to four inches.

3. Gently drive the infiltrometer into the ground.

4. Inspect the soil seal around each ring to make sure that it is even and smooth.

5. Pour clean water into the inner chamber and allow it to overflow and fill up the outer ring. Maintain a level in the outer ring approximately equal to the level in the inner ring.

6. Add more water to both rings when the level in the inner ring has dropped a measurable amount. For most soil types this should be less than an inch.

7. Repeat this step until the rate the water level drops begins to decline.

8. When the rate of decline begins to slow, bring the water level up to the top and start timing the decrease in water level.

9. Record the start time.

10. Stop timing when the water level in the inner ring has gone down a measurable level (the ASTM standard requires keeping the water level constant). Timing the rate of decline should probably be started almost immediately for more clayey soils, since it might be difficult to observe when the rate change has slowed.

11. Record the time, elapsed time, and change in water level.

12. Refill both rings and restart the timing.

13. Record the time, elapsed time, change in water level, and the elapsed time since the beginning of the first measurement.

14. Repeat the timing steps until the infiltration rate has become relatively constant or the test has been conducted for a minimum of two hours. (The ASTM standard requires 24 hours).

15. The measured rate of infiltration is considered a static infiltration rate. The dynamic infiltration rate is ½ the static rate. Be aware some models, such as WinSLAMM, call for the dynamic rate for swales.

Field notes for the UWM Study: One modification was made to the WDNR process regarding the start time of recording infiltrations. The process outlined above states in step 8 (italicized and bolded) that that recording is started when the decline in the rate of water infiltration starts to slow. In other words, the rate of infiltration has started to reach a level rate. The parameters of this study required a change for two reasons:

1) Using the standard method, several inches of water may infiltrate before the rate reaches a steady state. If all data prior to the steady state is ignored, crucial information is lost. Waiting for infiltration to reach a steady state ignores the soil dynamics that reflect the initial stages of a natural rain event, in which “first flush” rainfall may significantly impact runoff and pollutant loads. As a result, we chose to alter the methodology to include the initial data points as soon as possible after the pour was initiated. The timer was started approximately 30 seconds after the start of pouring, a methodology that was kept consistent across control and variable plots. A video of this process can be downloaded upon request to Milwaukee Metropolitan Sewerage District.

2) Waiting for infiltration to level out first before recording would significantly increase the length of time needed to complete readings at each site, thereby increasing the time and budget we had for each site to be tested.

14. Appendix C. Soil Textural Analysis

REPORT NUMBER
14-269-0010
COMPLETED DATE
Sep 30, 2014
ACCOUNT
1234
RECEIVED DATE
Sep 26, 2014

Midwest Laboratories Inc.®
13611 "B" Street • Omaha, Nebraska 68144-3693 • (402) 334-7770 • FAX (402 334-9121
www.midwestlabs.com

PAGE 1/1
TODAY'S DATE
Oct 02, 2014

EARTH CARE
HENRY MOSS
457 BROADVIEW AVE
HIGHLAND PARK IL 60035

SOIL TEXTURE REPORT

Lab Number	Sample Identification	SAND	SILT	CLAY	SOIL TYPE
26895577	UWM CONTRL	52%	28%	20%	SANDY CLAY LOAM

REPORT NUMBER
14-269-0011
COMPLETED DATE
Sep 30, 2014
ACCOUNT
1234
RECEIVED DATE
Sep 26, 2014

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PAGE 1/1
TODAY'S DATE
Oct 02, 2014

EARTH CARE
HENRY MOSS
457 BROADVIEW AVE
HIGHLAND PARK IL 60035

SOIL TEXTURE REPORT

Lab Number	Sample Identification	SAND	SILT	CLAY	SOIL TYPE
26895578	UWM MANAGE	45%	40%	15%	LOAM

15. Appendix D. Statistical analysis of P Value, 12" Infiltrometer tests, Time and Duration for 2 inches:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1+N_2-2}\right)\left(\frac{1}{N_1}+\frac{1}{N_2}\right)}}$$

Social Science Statistics

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{(N_1-1)s_1^2 + (N_2-1)s_2^2}{N_1+N_2-2}\right)\left(\frac{1}{N_1}+\frac{1}{N_2}\right)}}$$

Home | Calculators | Descriptive Statistics | Merchandise | Tutorials | Quizzes | Which Statistics Test? | Contact

T-Test Calculator for 2 Independent Means

Success!

Explanation of results

The output of this calculator is pretty straightforward. The values of *t* and *p* appear at the bottom of the page. If the text is blue, your result is significant; if it's red, it's not. The only thing that might catch you out is the way that we've rounded the data. The data you see in front of you, apart from the *t* and *p* values at the page bottom, has been rounded to 2 significant figures. However, we did not round when actually calculating the values of *t* and *p*. This means if you try to calculate these values on the basis of the summary data provided here, you're likely going to end up with a different, less accurate, result. This is especially the case if you're dealing with numbers that are fractions of 1.

HOW TO CITE THIS WEBSITE

Treatment 1 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* (*X* - *M*)^2
9.1	-69.04	4766.52
14.4	-63.74	4062.79
17.7	-60.44	3652.99
19.7	-58.44	3415.23
21.1	-57.04	3253.56
22.7	-55.44	3073.59
28.0	-50.14	2514.02
36.3	-41.84	1750.59
37.0	-41.14	1692.50
46.9	-31.24	975.94
57.4	-20.74	430.15
70.2	-7.94	63.04
71.1	-7.04	49.56
97.4	19.26	370.95
160.0	81.86	6701.06
213.3	135.16	18268.23
274.3	196.16	38478.75
70.4	-7.74	59.91
21.5	-56.64	3208.09
274.3	196.16	38478.75

Treatment 2 (*X*)	*Diff* (*X* - *M*)	*Sq. Diff* (*X* - *M*)^2
25.1	-118.45	14029.22
35.8	-107.75	11608.99
42.2	-101.35	10270.81
49.2	-94.35	8900.98
62.4	-81.15	6584.51
64	-79.55	6327.41
84	-59.55	3545.61
106	-37.55	1409.63
107.8	-35.75	1277.71
114	-29.55	872.91
128	-15.55	241.65
137.1	-6.45	41.54
180.9	37.35	1395.40
213.3	69.76	4865.76
240	96.45	9303.57
240	96.45	9303.57
320	176.46	31136.37
126.5	-17.05	290.53
114.6	-28.95	837.81
480	336.46	113201.97

Significance Level:

- .01
- .05 (selected)

Difference Scores Calculations

Treatment 1

Significance Level:

- ○ .01
- ◉ .05
- ○ .10

One-tailed or two-tailed hypothesis?:

- ◉ One-tailed
- ○ Two-tailed

Difference Scores Calculations

Treatment 1

N_1: 20
$df_1 = N - 1 = 20 - 1 = 19$
M_1: 78.14
SS_1: 135266.21
$s^2_1 = SS_1/(N - 1) = 135266.21/(20-1) = 7119.27$

Treatment 2

N_2: 20
$df_2 = N - 1 = 20 - 1 = 19$
M_2: 143.55
SS_2: 235445.91
$s^2_2 = SS_2/(N - 1) = 235445.91/(20-1) = 12391.89$

T-value Calculation

$s^2_p = ((df_1/(df_1 + df_2)) * s^2_1) + ((df_2/(df_2 + df_2)) * s^2_2) = ((19/38) * 7119.27) + ((19/38) * 12391.89) = 9755.58$

$s^2_{M_1} = s^2_p/N_1 = 9755.58/20 = 487.78$
$s^2_{M_2} = s^2_p/N_2 = 9755.58/20 = 487.78$

$t = (M_1 - M_2)/\sqrt{(s^2_{M_1} + s^2_{M_2})} = -65.41/\sqrt{975.56} = -2.09$

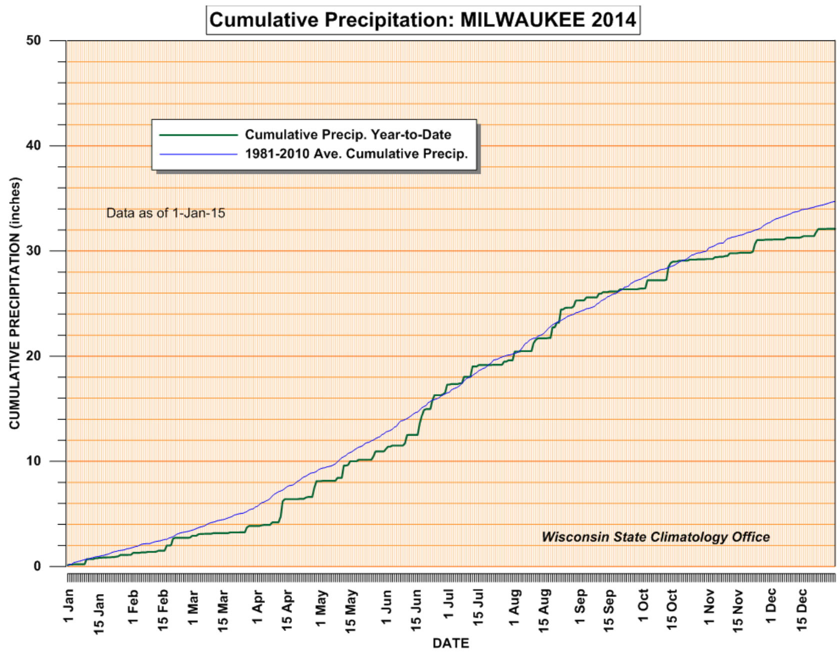
The *t*-value is -2.09404. The *p*-value is .02149. The result is significant at $p < .05$.

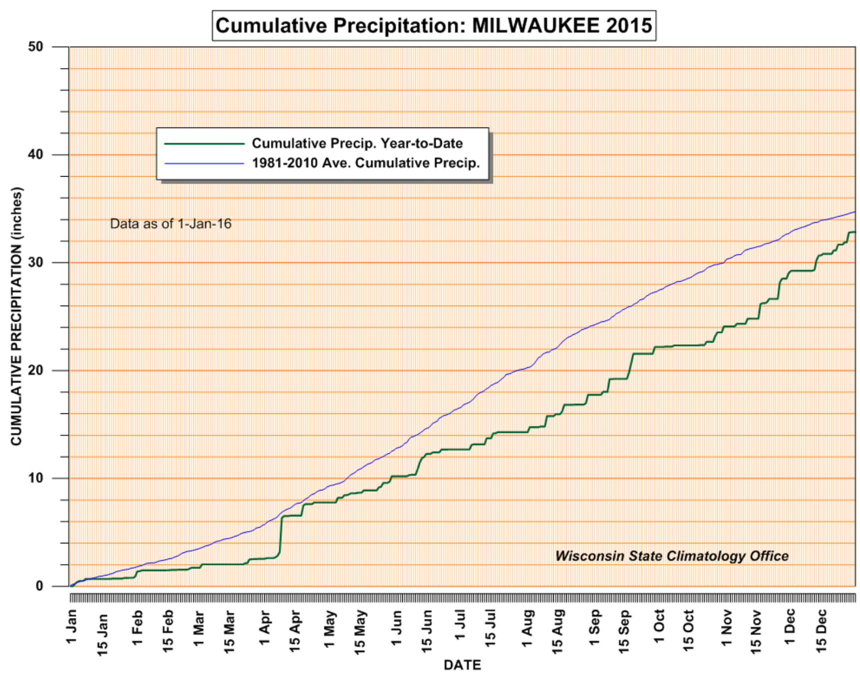
Note: If you wish to calculate the effect size, this calculator will do the job.

Analysis run 1-24-2020. The data resulted was statistically significant with p < .05 (t-value = 2.09404, p-value = .02149) using the T-Test Calculator. Social Science Statistics, Jeremy Stangroom, https://www.socscistatistics.com/tests/studentttest/default2.aspx.

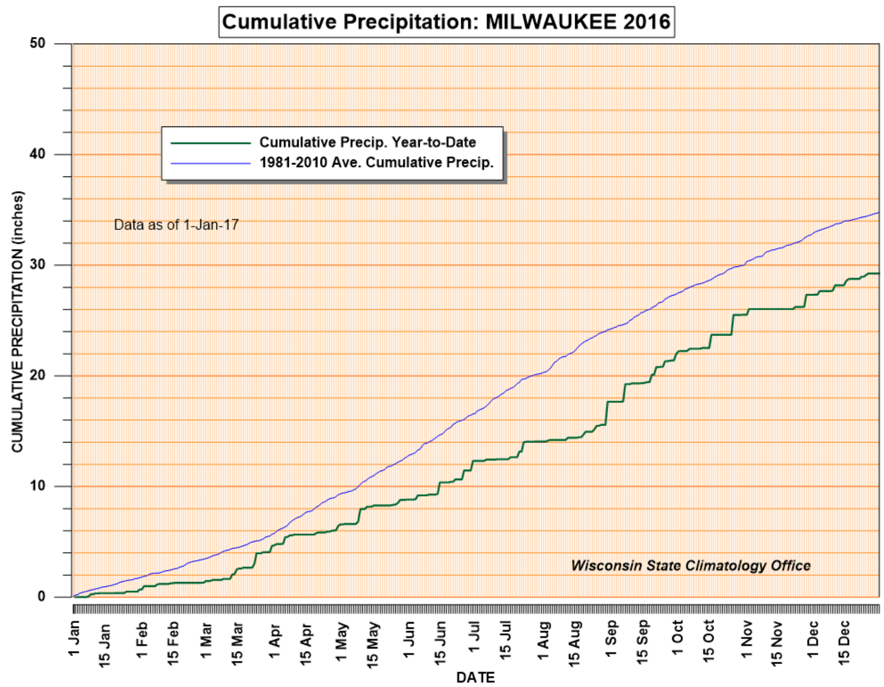
16. Appendix E: Precipitation History:

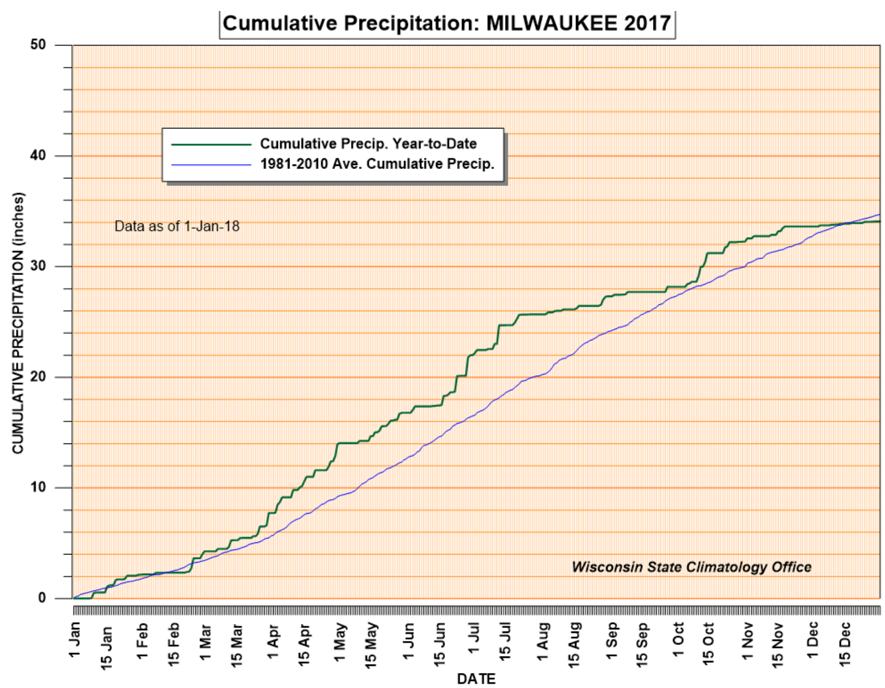
http://www.aos.wisc.edu/~sco/clim-history/7cities/milwaukee.html#Precip



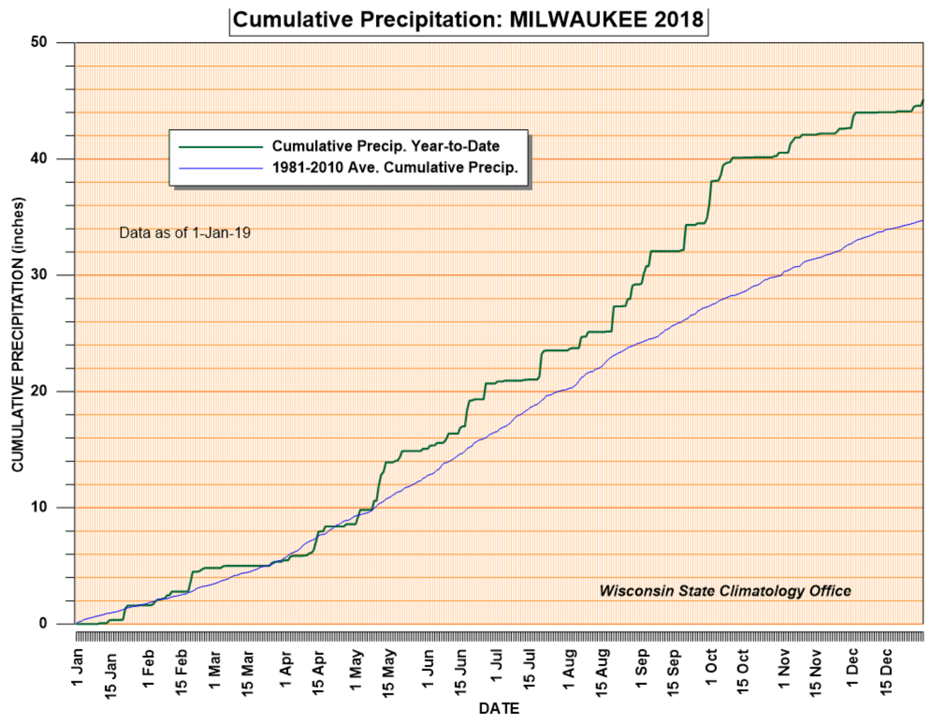


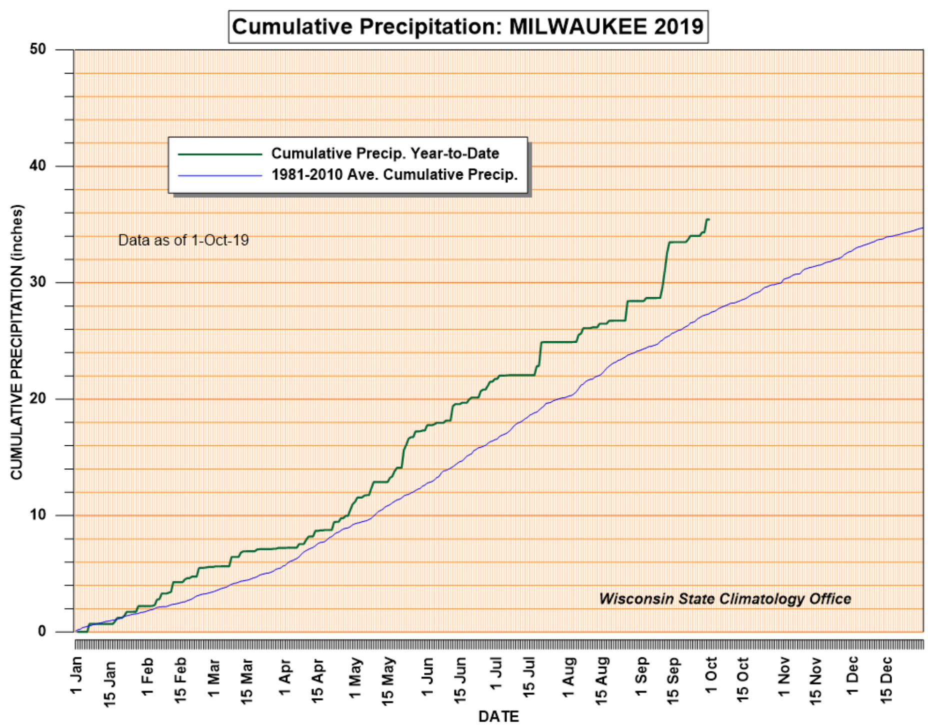
http://www.aos.wisc.edu/~sco/clim-history/7cities/milwaukee.html#Precip





http://www.aos.wisc.edu/~sco/clim-history/stations/mke/mke-rts-2019.gif





17. Appendix F: Infiltration Rate for Clay Loam Soils

The infiltration rates of soils are notoriously variable. In order to model the effect of improved infiltration, we can assume a 1-inch average rate for clay loam soils per measurements discussed in the article below.

EPA/600/R-00/016
December 1999

Infiltration Through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity

By

Robert Pit
Birmingham, AL 35226

Janice Lantrip
Department of Civil and Environmental Engineering
University of Alabama at Birmingham
Birmingham, AL 35294

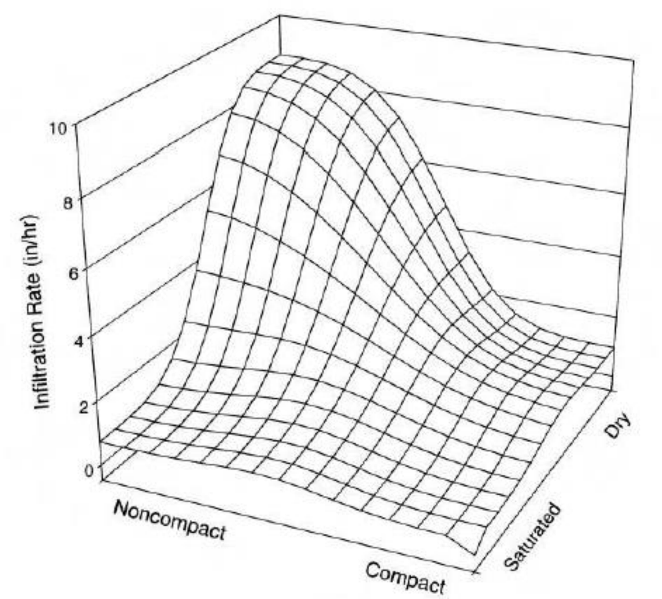


Figure 3-2. Three dimensional plot of infiltration rates for clayey soils.

Soil Type	f_o (in/hr)
Dry sandy soils with little to no vegetation	5
Dry loam soils with little to no vegetation	3
Dry clay soils with little to no vegetation	1
Dry sandy soils with dense vegetation	10
Dry loam soils with dense vegetation	6
Dry clay soils with dense vegetation	2
Moist sandy soils with little to no vegetation	1.7
Moist loam soils with little to no vegetation	1
Moist clay soils with little to no vegetation	0.3
Moist sandy soils with dense vegetation	3.3
Moist loam soils with dense vegetation	2
Moist clay soils with dense vegetation	0.7

Soil Type	f_c mm/hr (in/hr)		k (1/min)
Clay loam, silty clay loams	0–1.3	(0–0.05)	0.069
Sandy clay loam	1.3–3.8	(0.05–0.15)	0.069
Silt loam, loam	3.8–7.6	(0.15–0.30)	0.069
Sand, loamy sand, sandy loams	7.6–11.4	(0.30–0.45)	0.069

Source: Akan 1993.

Table 3-3. Soil infiltration rates for different categories and storm durations

Sand, Noncompacted (in/hr)

	15 minutes	30 minutes	60minutes	120 minutes
mean	22.9	19.5	16.9	15.0
median	25.0	19.7	17.4	15.7
std. dev.	10.6	9.1	8.0	7.2
min	1.3	0.8	0.6	0.5
max	43.0	38.0	32.4	28.6
COV	0.5	0.5	0.5	0.5
number	36	36	36	36

Sand, Compacted

	15 minutes	30 minutes	60minutes	120 minutes
mean	6.7	4.9	3.8	3.0
median	4.3	2.9	1.9	1.3
std. dev.	8.8	6.9	5.4	4.4
min	0.1	0.2	0.2	0.2
max	36.5	29.1	23.8	21.3
COV	1.3	1.4	1.4	1.5
number	39	39	39	39

Clay, Dry, Noncompacted

	15 minutes	30 minutes	60minutes	120 minutes
mean	12.7	10.8	9.6	8.8
median	7.6	6.3	5.8	5.4
std. dev.	10.8	9.5	8.9	8.5
min	1.0	0.5	.5	0.3
max	32.0	29.0	26.5	25.3
COV	0.9	0.9	0.9	1.0
number	18	18	18	18

All other clayey soils (compacted and dry, plus all saturated conditions)

	15 minutes	30 minutes	60minutes	120 minutes
mean	1.8	1.3	1.0	0.7
median	1.3	1.0	0.8	0.6
std. dev.	2.3	1.7	1.3	1.1
min	0.0	0.0	0.0	0.0
max	13.5	11.4	9.4	7.5
COV	1.3	1.3	1.4	1.5
number	60	60	60	60

18. Appendix G. ***Determining the Potential of Green Infrastructure to Reduce Overflows in Milwaukee,*** **Prepared for MMSD, 2011.**

12/20/2011 DETERMINING THE POTENTIAL OF GREEN INFRASTRUCTURE TO REDUCE OVERFLOWS IN MILWAUKEE

The results are different than the SUSTAIN results in Section 3.6.5, which indicate that rain gardens are most cost-effective for volume reduction. The SUSTAIN analysis accounted for size and frequency of storm events within a 10-year period; since rain gardens are best at reducing runoff during small storm events, which are the most frequent events, these practices were most cost-effective across the 10-year period. However, when comparing green infrastructure to deep tunnel costs on a per unit storage basis, porous pavement is most cost-effective among the green infrastructure practices.

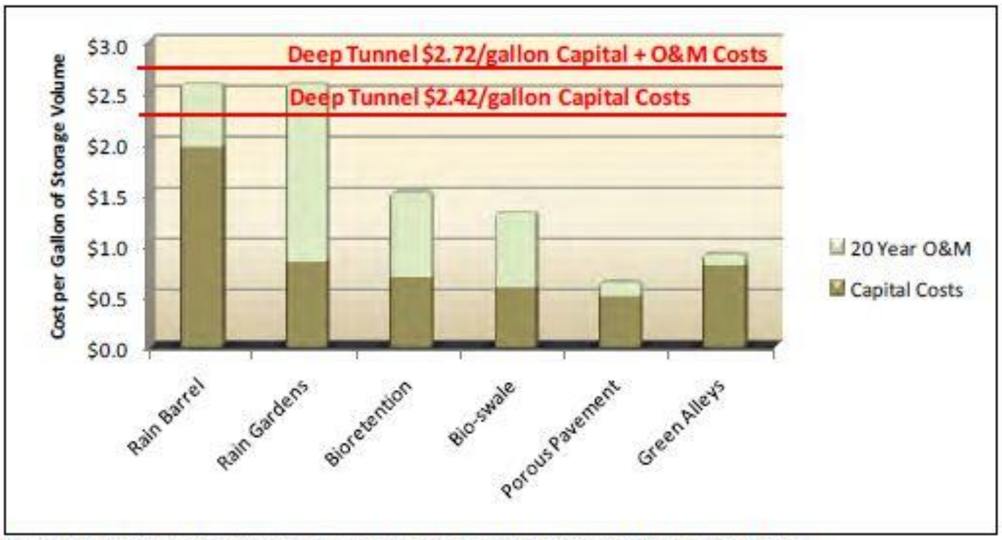


Figure 5-2. Estimated Present Worth Infrastructure Costs per Storage Volume over 20 Years.

19. Appendix H: Calculation of Water Retention Per 1% Organic matter:

https://www.nrdc.org/experts/lara-bryant/organic-matter-can-improve-your-soils-water-holding-capacity

Lara Bryant of the NRDC, May 27, 2015.

An acre of soil contains 820,295 kg of soil based on an assumed bulk density of 1330 kg/cu meter. This results in 1,808,441.49 lbs of soil. If the Organic Matter fraction is assumed to hold 10 times its weight in water, it comes to 21,668 gallons of water retained for each 1% increase in OM.

20. Appendix I: Estimates of High Value Turf Acreage in MMSD Combined Sewer Area:

Acreage by Land Use Type in Combined Sewer Area of Milwaukee Metropolitan Sewerage District, courtesy of Southeastern Wisconsin Regional Planning Commission (SEWRPC), with estimated managed turf and High Value Turf.

LU_CODE	LU_Description	Total Acres	SEWRPC Reported Pervious Acres	Perv Ac as a % of Total Ac (calculated)	% of Perv Ac that is mowed/managed Turf (assumption)	Resulting acres managed turf
	Residential:					
111X	High-Density Single-Family Residential	2913.2	1893.6	65%	50%	946.8
120	Two-Family Residential	2333.8	1517.0	65%	50%	758.5
141	Multi-Family Low Rise	663.9	431.5	65%	50%	215.8
111M	Medium-Density Single-Family Residential	127.0	97.8	77%	50%	48.9
142	Multi-Family High Rise	88.8	57.7	65%	50%	28.9
431	Residential-Related	100.8	65.5	65%	50%	32.7
111L	Low-Density Single-Family Residential	12.6	10.7	85%	50%	5.4
	Government/Institution/Parks/Infrastructure:					
418	Local and Collector Streets	2765.2	1382.6	50%	50%	691.3
414	Standard Arterial Street and Expressway	1519.3	759.6	50%	15%	113.9
731	Public - Land-Related Recreation Areas	598.6	574.6	96%	15%	86.2
436	Government and Institution-Related	264.8	158.9	60%	40%	63.5
641	Educational - Local	270.7	162.4	60%	35%	56.8
611	Administrative, Safety, and Assembly - Local	202.2	121.3	60%	35%	42.5
612	Administrative, Safety, and Assembly - Regional	63.9	38.4	60%	35%	13.4
510	Communication and Utilities	88.7	84.2	95%	15%	12.6
642	Educational - Regional	258.2	154.9	60%	3%	4.6
711	Recreation - Public Cultural/Special Recreation Areas	7.0	6.7	96%	15%	1.0
	Commercial:					
682	G&I Regional - Cemeteries	96.5	92.6	96%	35%	32.4
210	Retail Sales and Service--Intensive	759.4	189.9	25%	15%	28.5
310	Manufacturing	352.1	123.2	35%	15%	18.5
340	Wholesaling and Storage	313.8	109.8	35%	15%	16.5
432	Retail Sales and Service-Related	409.8	102.5	25%	15%	15.4
433	Industrial-Related	177.8	62.2	35%	15%	9.3
		14387.9	**8197.7**	**57%**		**3243**

Estimated Ac Managed Turf	3,243
High Value (estimated):	20%
High Value Acres:	648.7