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A DYNAMIC LIFE CYCLE ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF GREEN INFRASTRUCTURES

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A DYNAMIC LIFE CYCLE ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF GREEN INFRASTRUCTURES

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TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ABSTRACT

A DYNAMIC LIFE CYCLE ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF GREEN INFRASTRUCTURES

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As stormwater and its embedded nutrients continue to impede our nation's waterways, green infrastructures (GIs) have been increasingly applied in urban and suburban communities as a sustainable alternative to the combined sewer systems. Although GIs have been widely studied for their life cycle impacts and benefits, most of these studies adopt a static approach which is not transferrable to other environments on a spatial or temporal scale. This research utilizes a dynamic life cycle assessment (LCA) to evaluate seven different GIs through both an economic and environmental perspective by integrating the conventional LCA with a system dynamics model simulating the daily loading and removal of nutrients by the GIs. The model was calibrated by the measured annual nutrient removal efficiencies through field studies. Evaluated impacts include cumulative energy demand, global warming potential, marine and freshwater eutrophication potentials, and life cycle cost in terms of net present value across a life span of 30 years. The influence of geographical locations, land use types, system design sizes, and climate change scenarios on the GIs' performance was examined. It was found through this research that the system which, on average, performed best at reducing dissolved inorganic nitrogen (DIN) across its lifespan is the subsurface gravel wetland. This high capacity for reducing dissolved inorganic nitrogen is upheld across all other scenarios with it experiencing at least the second highest to highest life cycle DIN reductions. The subsurface gravel wetland also shows high resiliency (37% average deviation) as compared to other systems (107% average deviation for bio-retention systems). The gravel wetland showed similar performance capabilities within the phosphorous model with this system out ranking all others regardless of scenario. Similarly, within the total phosphorous scenarios the system which on average performed the best is the gravel wetland. It has the highest capacity and maximum removal percentage which allows this system to handle a large range of influent masses. It is also shown to be the most resilient against environmental changes with an average deviation of 12% as compared to other systems (20% average deviation for sand filters).

1. Introduction

Green infrastructures (GIs), such as subsurface gravel wetlands, bio-retention systems, permeable pavement, are nature-mimicking urban stormwater management systems designed to treat, transport, filter, and infiltrate runoff[1-2]. In the past few decades, GIs have been increasingly implemented for managing combined sewer overflow (CSO)[1, 3-13] and sequestering of nutrients and carbon[1, 3-4, 6-21]. They have also been widely recognized for their functions in terms of flood/drought mitigation, heat island effect reduction, or coastline erosion protection[1, 3, 5-11, 13, 15, 18, 20, 22-24]. These benefits have been acknowledged by the US Environmental Protection Agency (EPA) by the addition of their use as a "maximum extent possible" option under the municipal separate storm sewer systems (MS4) final ruling in 2016[25].

In the past, these systems have been implemented into areas based on their peak flow reduction capabilities[26]. However, under new rulings through the US EPA National Pollution Discharge Elimination System (NPDES), stormwater is now to be managed for pollution reduction and water quality improvement[26]. Reduction of pollutants such as organics, metals (zinc, lead, chrome), and nutrients (nitrogen, phosphorous) have been targeted and mandated[26]. Nevertheless, the NPDES recommending systems are on a sole basis of GIs' performance during their use phase, while their life cycle impacts are neglected.

Several life cycle assessments (LCAs) have been conducted to assess the environmental and economic impacts and benefits of GIs. These studies utilized static rainfall values, pollution inflows, and system treatment efficiencies to assess GIs' performances. Little consensus has been reached. This is best exemplified through research on bio-retention systems which has been studied in areas such as the northeast[12,21] and southeast[10] US as well as in China[20]. These studies have reported large ranges between impacts and benefits which vary in many categories such as greenhouse gas emissions (0.3 to 21,000 kg of CO_2), economic cost ($20,000-630,000), and nutrients (-23.2 to 0.0014 kg N and -23.9 to 0.02 kg P eq.)[7,10,12,14,20]. This inconsistency is likely contributed by the heterogeneous geospatial characteristics, such as the varied rainfall quantities, pollutant fluxes, and local land/construction costs, as well as system characteristics, such as size, lifespan, and treatment efficiencies. For example, spatial changes in land use or impervious coverage can cause drastic changes in pollutant loads and runoff volumes, each affecting the overall removal efficiency of GIs[26]. Temporal variations such as seasonal or climate change[27] can affect the GIs' performance through changes in biological activities [2] as well as in rainfall depths and volumes. A similar trend of variability is also observed in the LCAs of green roofs (13,300 to 60,000 kg CO_2 eq., 0 Kg N, and 0.3 to 2.15 kg P eq.)[6-7], permeable pavement (132,000 to 350,000 kg CO_2 eq., 0 kg N, and -51.3 to 5 kg P eq.)[7,9,14], and rain gardens (-7701 to 2100 kg CO_2 eq., 0.15 to 560 kg N, and 0 kg P eq.)[4,8,28]. The heterogeneous geospatial characters (Eastern US[4-5,9-10,12,14,21], Central US[7,15,19,28], Europe[6,16,22], Asian Pasific[8], and China[20]), system sizes, and lifespans (30 years[4,8,10,12,15,20], 35 years[28], 40+ years[5-6,10,21]).

Although these studies do provide valuable insight, they lack the ability to capture changes in environment and to predict GI performances based upon dynamic environmental and system characteristics. Meanwhile, enhanced understandings of how GIs respond to such spatial and temporal changes could help guide and support future design and implementation of GIs. Dynamic LCAs have been conducted for rainwater harvesting previously[21,29]. However, no dynamic studies have been conducted for wet ponds, sand filters, subsurface gravel wetlands, bio-retention systems, permeable pavement, or tree filters especially for understanding the nutrients related impacts.

In light of the limitation of the previous studies, this study aims to develop and apply a dynamic LCA framework to analyze seven different stormwater management systems under different geographical locations, land uses, system sizes, and climate change scenarios.

2. Methodology

2.1. System Overview

Seven different GIs were studied in this work, a swale, a wet pond, a sand filter, a subsurface gravel wetland, a bio-retention system, permeable asphalt pavement, and a tree filter. A baseline model was developed for each GI based upon the systems that are currently installed on the campus of the University of New Hampshire (UNH; Durham, NH). Durham, NH has a humid continental climate with cold and snowy winters and warm summers[2]. Average monthly temperatures vary from -5ºC in January to 21 ºC in July[30]. Monthly precipitation varies from a monthly average of 6.5 cm in March to 3.8 cm in August[30].

The catchment area of each GI was scaled to 4047 m^2 (one acre) of land for comparison purposes. From this catchment area, the GIs of interest were designed to treat 2.54 cm (1 inch) of precipitation and a water quality volume of 91.4 m^3. These systems were built in 2004 and stormwater runoff and treatment data were recorded up through 2010. During this time span a notable difference between summer and winter treatment capabilities arose which is due primarily to changes in biological activities and soil permeability. Table 1 summarizes the footprint, median annual, summer, and winter removal efficiencies for each GI of interest.

Table 1: The seven investigated GIs design footprint and median seasonal/annual removal efficiencies

Green Infrastructure Systems	System Footprint (m^2)[2]	Median Annual Removal (%)[2]		Median Summer* Removals (%)[2]		Median Winter** Removals (%)[2]	
		DIN	TP	DIN	TP	DIN	TP
Vegetated Swale	130	0.0	0.0	0.0	0.0	0.0	0.0
Wet Pond	300	32.7	0.0	63.6	0.0	9.8	0.0
Sand Filter	221	0.0	33.4	0.0	30.9	0.0	34.9
Subsurface gravel wetlands	507	75.0	57.6	84.5	57.6	33.3	57.6
Bio-Retention System	25	32.3	12.0	44.0	12.1	19.6	0.0
Permeable Pavement	3872	0.0	57.5	0.0	0.0	0.0	70.3
Tree Filter	26	1.4	0.0	7.6	0.0	0.0	0.0

* Summer spans the months of May through October.
** Winter spans the months of November through April.

2.2. Life Cycle Environmental and Economic Assessment

A life cycle environmental and economic assessment was carried out to investigate the economic and environmental tradeoffs of each GI over their assumed lifespan of 30 years[14]. Inventories for the GIs were created over three different life cycle phases: construction, use, and maintenance. End-of-life inventories were ignored as it is assumed that the systems will be left in place after their life span and hence do not require any disposal activities. Material and energy requirements during the construction and maintenance stages were modeled after constructional blueprints of the GIs[31] and supplemented by literature data[2, 12, 14, 32]. Maintenance was assumed to occur every year and the primary activities include inspection of systems, removal of accumulated debris, and trimming of overgrown vegetation. Removal and retention of nutrients during the use phase were simulated via a system dynamics model (SDM) on a daily step, the details of which can be found under Section 2.3. The environmental impacts of these requirements were modeled through SimaPro 8.3. Four types of environmental impacts were investigated: embodied energy (Cumulative Energy Demand V 1.09 method), carbon footprint (IPCC 2013 100a V 1.02 method), and freshwater and marine eutrophication potentials (ReCiPe Midpoint Hierarchist V 1.12 method). The reduction of greenhouse gas across each GIs life cycle was ignored for all systems but tree filters as it was assumed that these systems would be replacing areas previously covered by foliage.

A life-cycle cost assessment was conducted alongside the environmental assessment to capture the economic impacts of the GIs. Cost data for the construction and maintenance phases of the GIs were sourced from literature[2, 14, 32]. This cost data was converted to net present values in 2017 US dollar through the use of Equation 1 with an assumed discount rate of 5%. Detailed calculations of the life cycle environmental and economic impacts of the GIs are provided in Table S-1 of the supporting information (SI).

$$N_{PV} = \sum_{i=0}^{30} \frac{F}{(1+r)^i} \qquad \text{(Equation 1)}$$

Where:

N_{pv}= Net present value, \$2017;

F= Future value, \$;

r = discount rate, 5%[7];

i= years from the beginning of construction in 2017, years; and

2.3. Integrating Dynamic Modeling of Nutrient Removal with the LCA

An SDM was developed to capture the dynamic changes of nutrient retention and removal efficiencies within the GIs in response to changes in climate, land use, and pollutant loading variations. Vensim DSS® was used to develop this SDM. Vensim DSS is a computer-based model which uses stocks (e.g., time-dependent cumulative levels of nutrients) and its associated inflows (e.g., nutrient deposition) and outflows (e.g., nutrient removal) to characterize dynamic changes of system states. The SDM developed in this study consists of two major segments. The first simulates the nutrient accumulation in the catchment area, whereas the second simulates the nutrient retention and removal within the GIs (Figure 1). The nutrients modeled in this section are dissolved inorganic nitrogen (DIN) and total phosphorus (TP). These were chosen as they are the nutrient forms most effectively removed by the GIs[2] and identified to be greatly affecting water quality across the nation[33]. DIN is removed primarily through the nitrification and denitrification processes facilitated by microbes, while TP is removed primarily through adsorption to sediments.

The SDM was developed to run on a daily time step across the GIs' lifespan of 30 years[2]. The model was then linked with the LCA results to produce a dynamic assessment of the GIs' performance.

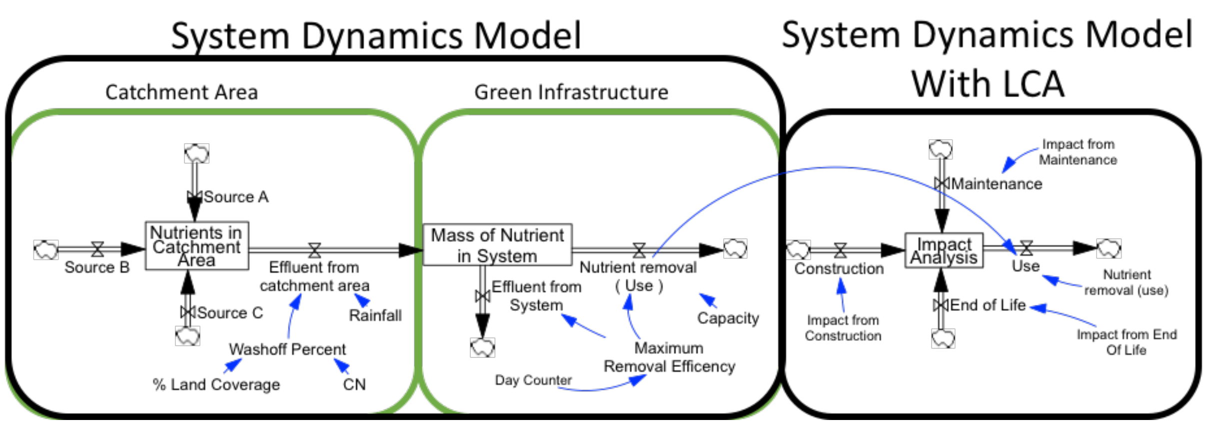

Figure 1: Base Green Infrastructure System Dynamic Model Base System Dynamics Model showing nutrient flows into and out of the catchment area, GIs, and impact analysis stocks

2.3.1. Modeling Nutrient of the Catchment Area

Nutrient accumulation in the catchment area, left green box in Figure 1, was calculated via the integral of the daily nitrogen and phosphorus fluxes in and out of the catchment area (Equation 2).

$$\boldsymbol{N_T} = \int_{t_0}^{t} \left(\sum \boldsymbol{K_t} - \sum \boldsymbol{E_t}\right) \boldsymbol{dt} + \boldsymbol{N_{t_0}} \qquad \text{(Equation 2)}$$

Where:

$\boldsymbol{N_t}$ **=** Total accumulation of nutrients in catchment area, kg;

$\boldsymbol{K_t}$ **=** Deposition of nutrients to catchment area from inflows, kg/day;

$\boldsymbol{E_t}$ **=** Removal of nutrients from catchment area, kg/day;

$\boldsymbol{N_{t_0}}$ **=** Nutrient mass in the catchment area at time zero, kg; and

t = time, days.

The four largest inflows of nitrogen[34] into the catchment area are atmospheric deposition[35], farmland fertilization, lawn maintenance, and automobile exhaust. Atmospheric deposition rates of nitrogen were assumed to be 1.26 kg/ km^2-day as reported by the NH Department of Environmental Protection's estimation of the New England region[35]. Nitrogen application on farmlands was assumed to be 9,405 kg/km^2 applied during each fertilization activity[36]. A weekly fertilization application frequency during the summer months was assumed. Summer months are defined as months in which the average temperature is equal to or larger than 12 ºC[2, 32]. Lawn maintenance activities include the fertilization and clipping of grass which is assumed to occur at the same time and frequency as assumed in farm fertilization[37]. Fertilization of the lawn was assumed to have the same application rate as fertilization on farms. The nitrogen deposition rate from grass clippings was assumed to be 4,455 kg/km^2 [36]. Mowing practices were also assumed to occur once per week during the summer months. Nitrogen deposition from automobile exhaust was calculated using Equation 3.

$$K_c = L_u \times C_E \times L_M \times C_D \times P_t \times A \qquad \text{(Equation 3)}$$

Where:

K_c= Nutrient deposition to catchment area from cars, kg/day;

$\boldsymbol{L_u}$ = Percent of a year that the lot is in use, %;

$\boldsymbol{C_E}$ = Nitrogen emission from car exhaust, 0.00032 kg/min[38];

$\boldsymbol{L_M}$ = Maximum number of cars that can park within the lot, 52632 cars/km^2 [39];

$\boldsymbol{C_D}$ = Average parking lot utilization, %[39];

$\boldsymbol{P_T}$ = Time to park per car, 2.5 min/car-day[39]; and

A= Surface area of parking lot, 0.0038 km^2.

The three major sources of phosphorus into the catchment area modeled were farmland fertilization, lawn maintenance, and foliage deposition. Phosphorous applied during farming activities was assumed to be 304.4 kg/km^2, applications occurred at the same rate as in the nitrogen model[36]. Lawn maintenance within the phosphorous model only includes fluxes from grass clippings. Phosphorous from lawn fertilization is neglected because the New Hampshire law mandates that public fertilizers be free of phosphorous[40]. The amount of phosphorous released during each mowing event is assumed to be 34.9 kg/km^2[41]with the same mowing frequency as in the nitrogen model. Phosphorous to the catchment area from arboreal deposition was assumed to be 1.06 kg/km^2-day[42] as reported for the Durham, NH area.

Nutrient outflows from the catchment area were modeled using the curve number method. The depth of rainwater runoff was estimated using the weighted curve number method (Equation 4 & 5)[43]. Curve numbers for different land types (lawn, tree coverage, parking/driveway, building coverage, farmland uses, and miscellaneous) were obtained from the United States Department of Agriculture[43]. Percent coverage of these land types within the baseline catchment area were approximated via aerial images of the site from Google Maps©[44] and reported in Table 3. Percent land coverage was utilized to calculate a weighted curve number for the catchment area. Daily precipitation data (both rainfall and snowmelt) were sourced from the National Oceanic and Atmospheric Administration (NOAA) through the climate station closest to the study site with the most complete data[30]. The correlation between depth of surface runoff and percent mass of nutrients washed off was estimated using the curve that was obtained from a previous field study (Figure 2)[45]. Once washed off of the catchment area, the nutrients enter into the GIs.

$$S = \frac{1000}{\sum C_L \times CN} - 10 \qquad \text{(Equation 4)}$$

$$Q = \frac{(R - 0.2 \times S)^2}{(R + 0.8 \times S)} \times 2.54 \qquad \text{(Equation 5)}$$

Where:

$\boldsymbol{Q}$ = Runoff depth, cm.;

$\boldsymbol{R}$ = Rainfall depth, in.;

$\boldsymbol{S}$ = Potential maximum soil retention, in.

$\boldsymbol{C_L}$ = Percent land coverage, %; and

$\boldsymbol{CN}$ = Curve number for that land coverage, dimensionless.

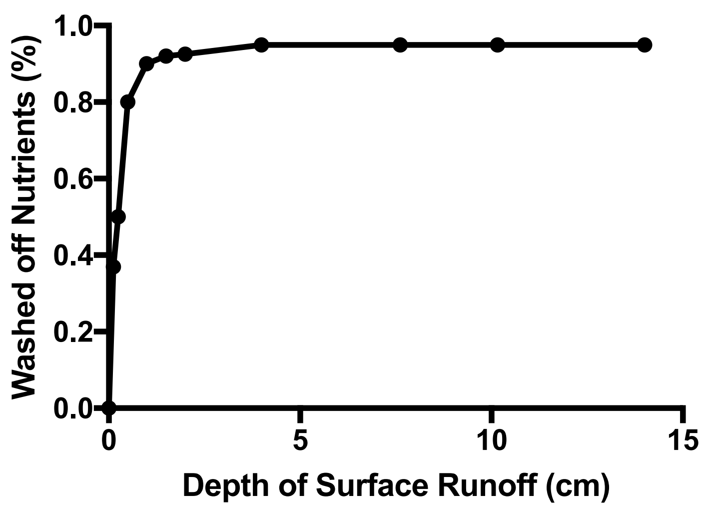

Figure 2: Runoff curve which relates the depth of rainfall to the percent nutrients washed off of the catchment area

Additional equations, assumptions, and constants for all accumulation, runoff, treatment, and lifecycle impacts may be found in **S-2** of the SI**.**

2.3.2. Modeling Nutrient Removal in Green Infrastructures

Nutrient accumulations within the GIs were calculated via Equation 6 as the integral of daily nutrient inflows (e.g., nutrient loading from the catchment area runoff) and outflows (e.g., biological nutrient removal or nutrient leaving GI without treatment).

$$N_R = \int_{t=0}^{t} \left(\sum P_t - \sum O_t\right) dt + N_{R_{t0}} \quad \text{(Equation 6)}$$

Where:

N_R = Nutrients within the system, kg;

P_t = Nutrient inflow from catchment area, kg/day;

O_T = Nutrient treatment or effluent, kg/day;

$N_{R_{t0}}$ = Nutrient mass in GIs at time zero, kg; and

t = time, days.

Nutrient removals by the GIs were assumed to depend on two parameters: nutrient holding capacity and the nutrient removal efficiency. The nutrient holding capacity serves as an upper limit of the mass of nutrients that can remain in the GIs at a time. The mass of nutrients within the GIs is dependent on the nutrient inflow, effluent, and removal which can vary between zero and the holding capacity. This mass was assumed to start at zero at t=0 and increases over time.

Nutrient effluent is determined by the proportion between the nutrient influent and the GIs' available holding capacity at time t (Equation 7).

$$E_{R,t} = \begin{Bmatrix} M_{I,t} > \left(C - M_{N,t}\right), \left(M_{I,t} - C\right) + M_I \times (1 - I_M) \\ M_{I,t} \leq (C - M_{N,t}), M_{I,t} \times (1 - I_M) \end{Bmatrix} \quad \text{(Equation 7)}$$

Where:

$\boldsymbol{E_{R,t}}$= Nutrient effluent at time T, kg;

$\boldsymbol{M_{N,t}}$= Nutrient mass within the GIs, kg;

$\boldsymbol{C}$ = Capacity of GIs, kg;

$\boldsymbol{M_{I,t}}$ = Influent nutrient mass, kg;

$\boldsymbol{I_M}$ = Maximum nutrient removal efficiency, %; and

$\boldsymbol{t}$= Time index, dimensionless.

Nitrogen removal by microbe activities, on the other hand, occurs in the process calculated by Equation 8 where actual nitrogen removal efficiency was assumed to be linearly related to the amount of nitrogen mass in the GIs and the maximum time delay for removing nitrogen at full capacity was assumed to be 2 days. $I_{M,t}$ is a value which is seasonally altered [2,32] and follows the seasonal pattern as outlined in Table 2. Removal of phosphorous was neglected.

$$E_t = M_{N,t} \times I_{M,t} \times (1 - 0.5 \frac{M_{N,t}}{C}) \quad \text{(Equation 8)}$$

Where:

E_t= Nutrient removal at time T, kg;

$\boldsymbol{M_{N,t}}$= Nutrient mass within the GIs, kg;

$\boldsymbol{C}$ = Capacity of GIs, kg;

$\boldsymbol{I_{M,t}}$= Maximum nutrient removal efficiency, %; and

$\boldsymbol{T}$= Time index, dimensionless.

Further equations, assumptions, and constants for all accumulation, runoff, treatment, and lifecycle impacts can be found in **S-2** of the SI**.**

2.3.3. Calibration of the Green Infrastructures System Dynamics Model

The maximum removal efficiency and capacity of the GIs were calibrated to match the observed annual average median removal efficiencies for the base models[37] (Figure 3). Calibration was conducted by first adjusting the model to a time range of 2004-2010 to match the conditions where the field measurements were taken. The nutrient holding capacity of the GIs was initially set as the amount of nutrient masses embedded in the water quality volume of the GIs (0.6 kg for the nitrogen model and 0.1 kg for the phosphorous model)[14]. The maximum nutrient removal efficiency was then varied at a range between the GI's annual median removal efficiency[37] and 1. The model was then run to calculate the simulated annual median removal efficiency. If the returned simulated average median removal percent matches the observed, the calibration stops. If a match was not found, the capacity of the GI was either increased or decreased as per the directions in Figure 3 and run again. This process was repeated until the GIs simulated and observed median annual removal efficiencies matched one another. Results of calibration can be found in S-4 of the SI.

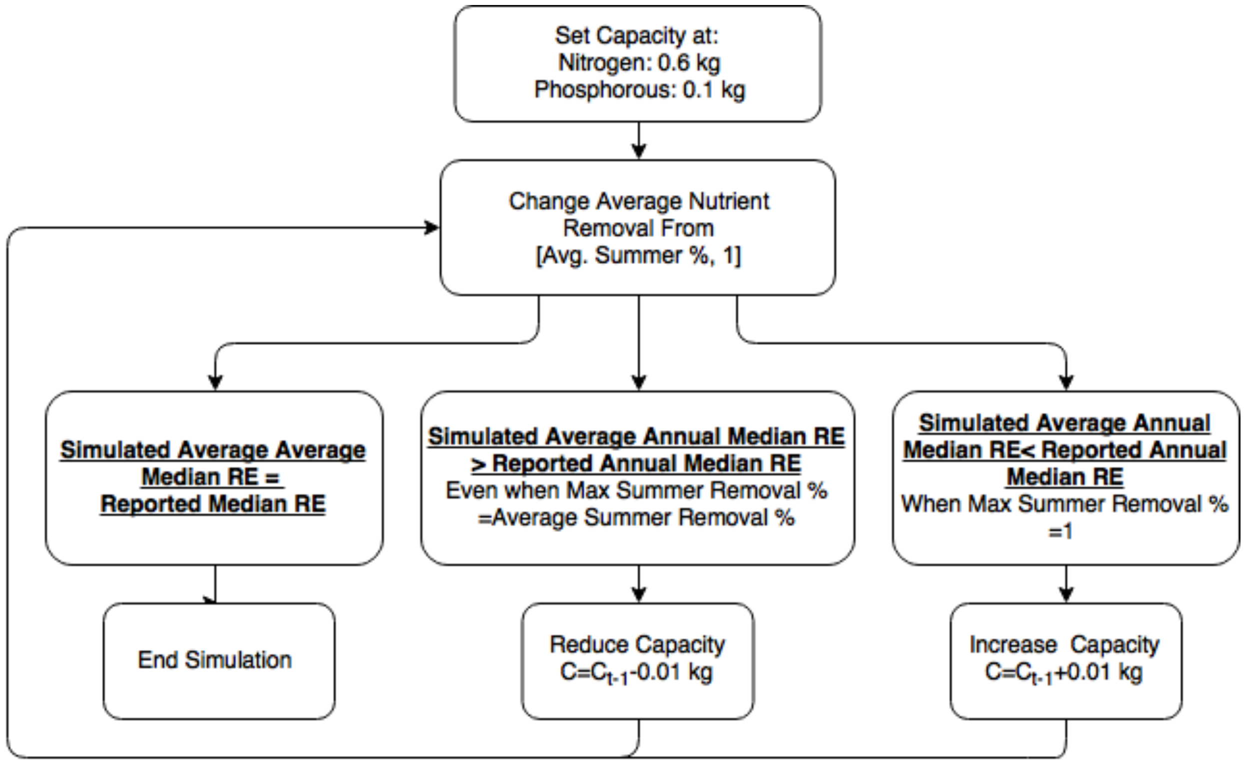

Figure 3: Flowchart used during the calibration of the GIs SDM. This was used as a method by which each of the seven systems maximum summer removal and system capacity was changed with respect to the average median removal observed versus the average median removal calculated. RE stands for Removal Efficiency.

2.4. Sensitivity and Validity of the Green Infrastructures System Dynamics Model

The simulated values were compared with the field measurements reported by the UNH Stormwater Center to validate the model. Additionally, a sensitivity analysis was conducted to test the influence of system changes on the key model outcomes. Nine variables were altered by ±10% to test their sensitivity. These variables include parking lot capacity, time to park, nutrients in car emissions, nutrients in grass clippings, nutrients in fertilizer, and foliage deposition. They were selected as they were constants in the model which were not calibrated or directly observed from the study site.

3. Scenario Analysis of the Life Cycle Environmental and Economic Assessment of the GIs Under Different Scenarios

Four different scenarios were applied to this model to evaluate the GIs performance under varying conditions. Each scenario was chosen to represent a different geospatial or temporal condition.

3.1. The Effect of Location on the Life Cycle Impacts of Green Infrastructures

Seasonal and rainfall pattern fluctuations in varying geospatial locations have direct implications on a GI's performance. To model this effect, environments from seven different cities were assessed (Table 2). These cities were chosen on the basis of varying NOAA regions and were separated into four climates. Ten years of precipitation data (2007 to 2017)[30] from each city were retrieved and replicated to create a 30-year data set. This produced rainfall data were assumed to be independent of any climate change assumptions or occurrences. Summer and winter removal efficiencies and residential/agricultural mowing/fertilization activities were then adjusted in respect to each cities seasonal pattern.

Table 2: Eight cities and their base climate information used to simulate the studied GIs removal efficiency performance under different weather patterns

Cities of Interest

	NOAA Region	Annual Precip. (cm)	Avg. temp. (°C)	Summer Months
Durham, NH (DH)	North Atlantic	228.6	7.2	April-September
Atlanta, GA (AT)	South and Caribbean Region	127	17.2	All year
Chicago, IL (CH)	Great Lakes	99	10.6	March-October
Dallas, TX (DS)	Gulf of Mexico	104.1	17.8	All year
Phoenix, AZ (PO)	Western	20.3	23.9	All Year
San Diego, CA (SD)	Western	25.4	17.8	All Year
Honolulu, HI (HI)	Pacific Islands	43.2	25.6	All Year
Wichita, KS (WI)	Central	86.4	13.9	February-November

3.2. The Effect of Land Use on the Life Cycle Impacts of Green Infrastructures

Changes in land use (i.e. pavement, lawn, etc.) have direct implications on the nutrient inflow into the GIs. Four typical land use types were studied, including urban, rural, industrial, agricultural (Table 3)[46]. Miscellaneous coverage includes but is not limited to, street lights, man holes, curbs, walk ways.

Table 3: Land Type Distribution for 4 different Land Uses and Their Associated Curve Numbers applied to the studied GIs to simulate removal efficiencies under different nutrient loading scenarios

Land Coverage Distribution (%)

Land Type	Curve Number[43]	Durham Location	Rural[46]	Industrial[46]	Agricultural[46]	Urban[46]
Trees	43	5	17	10	40	8
Lawn	49	10	32	25	0	19
Farm	85	0	0	0	50	0
Misc.	98	5	6	25	5	13
Parking/Driveway	98	80	25	25	5	35
Building	98	0	20	15	0	25

3.3. The Effect of Size Change on the Life Cycle Impacts of Green Infrastructures

A GI's design size is directly correlated to the capacity of the GIs. Thus, many cities mandate that GIs be designed to treat the 24-hour rainfall event which in most conditions equates to a capacity of about 0.75 to 1 inch of rainfall[47]. Such a capacity often requires the GIs to be designed with a large footprint. It can be difficult for many communities to adopt this technology, especially in urban areas where land is a valuable commodity[32].

This analysis aims at assessing the treatment performances of each GIs under different size restrictions. Each system is analyzed at 25%, 50%, 75% of the baseline size (1 inch of rainfall)[48]. Annual median removal efficiencies under each design restriction were retrieved from the New Hampshire small MS4 general permit system performance curves, which were then used to calibrate the new nutrient loading capacities and maximum removal efficiencies of the GIs using a similar process as illustrated in Figure 3.

Efficiency curves and equations can be found in Section S-3 of the SI. All curves are based on Hydrologic Soil Group D which is assumed to have similar removal curves to those in the study site as those systems are lined to prevent infiltration.

3.4. The Effect of Global Climate Change on the Life Cycle Impacts of Green Infrastructures

GIs' performances were also investigated under two different global climate change scenarios: high and low emissions. The high emission scenario is defined as the business as usual path which leads to an increase in global surface temperatures by 2.6-4.8 ºC by 2100[27, 49-51]. This was represented by the CIMP5 RCP8.5 climate scenario model. The low emission scenario is defined as "substantial and sustained emissions reductions" and projects an increase in the global surface temperature increase of 0.3-1.7ºC by 2100[27, 49-51]. This was represented by the CIMP5 RCP2.6 climate scenario model.

A 30-year daily rainfall dataset spanning from 2060 to 2090 was selected for simulation of climate change impacts. This range was chosen as it portrays the largest difference in climate conditions between the low and high emission scenarios with the low emission scenario producing an average of 3.00% less rainfall as compared to the high emission scenario.

4. Results

4.1. Results of the Green Infrastructures Dynamic Life Cycle Economic and Environmental Model

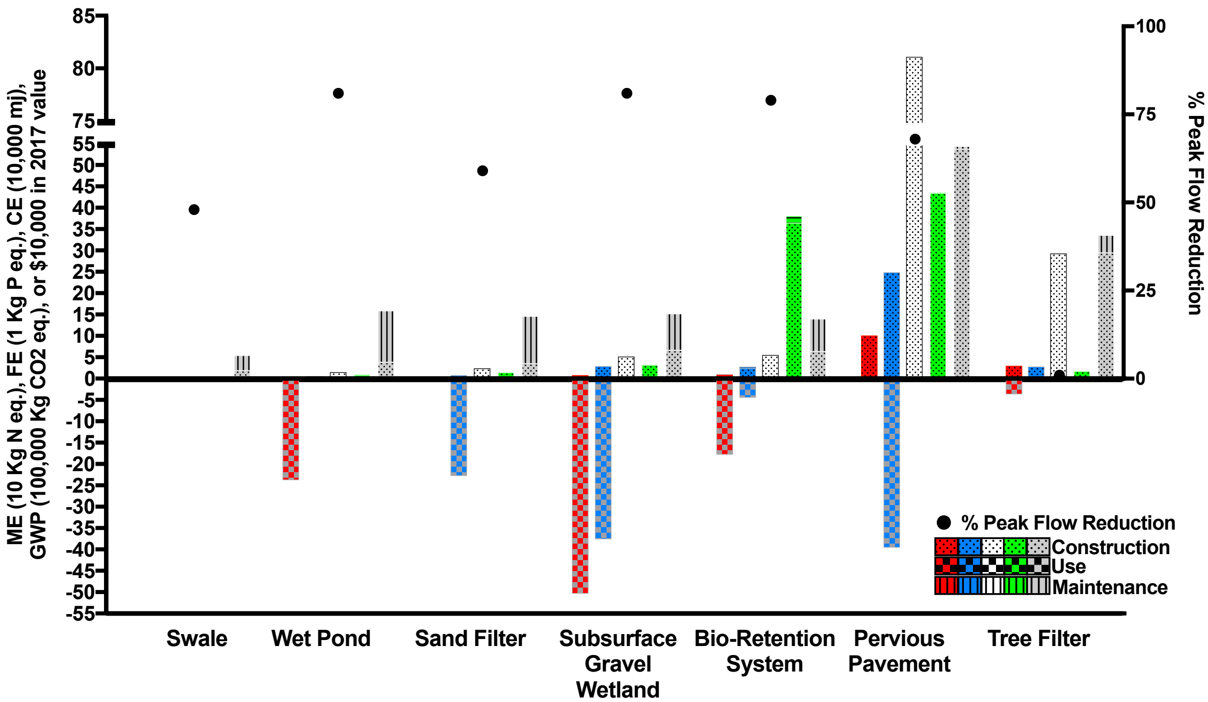

Figure 4: Green Infrastructure's Environmental and Economic Life Cycle Assessment Results Separated by Life Cycle Phase and Impacts of Interest: marine eutrophication (red), freshwater eutrophication (blue), cumulative energy demand (white) global warming potential (green) and economic cost reported in $2017 (grey)

Figure 4 presents the life cycle impacts and benefits of marine eutrophication, freshwater eutrophication, cumulative energy demand, global warming potential, and economic costs of the seven baseline GIs. In terms of marine eutrophication, the systems with the highest biological removal of nitrogen are subsurface gravel wetlands, wet ponds, bio-retention systems, and tree filters. This is due to their incorporation of either vegetation or anoxic zones in design, which provides the ideal environment for denitrification. Systems that emit the highest amount of nitrogen during the construction and maintenance phases are permeable pavements[7], and tree filters. This is because of the large amount of pavement cutting and removal that occur during system constructions. When taking the entire life cycle into consideration, gravel wetlands have the best performance with a net reduction of 423 kg N, followed by wet ponds with a net reduction of 235.8 kg N, bio-retention systems with a net reduction of 169.3 kg N, and tree filters with a net reduction of 7 kg N All other GIs contribute to nitrogen emission over their life cycles. Among them, swales have the lowest net emission at 0.7 kg N, followed by sand filters (contributing 3.9 kg N), bio-retention systems (contributing 9.4 kg N), tree filters (contributing 17.5 kg N), and permeable pavement (contributing 100.8 kg N)

In terms of freshwater eutrophication, the systems that experience the highest removals of phosphorous are permeable pavements, subsurface gravel wetlands, sand filters, and bio-retention systems. This high capacity for phosphorus removal is due to their design incorporation of a media filled filtration area. This filtration area provides the phosphorus with surface to which it can sorb. The systems which emit the highest amount of phosphorous during their construction and maintenance phases are permeable pavement, subsurface gravel wetlands, bio-retention system, and tree filters. This high contribution of phosphorous is due to the use of excavation equipment required during their construction phases. When taking the impacts and benefits occurring across the GIs entire life cycle, subsurface gravel wetlands have the highest performance with a net reduction of 34.5 kg of P eq. followed by sand filters (net removal of 21.8 kg P eq.), permeable pavement (net removal of 14.5 kg P eq.) and bio-retention systems (net removal of 1.5 kg P eq.). All other GIs contribute phosphorous across their life cycles. Among them swales have the lowest net impact at 0.22 kg P eq. followed by wet ponds (net impact of 0.71 kg P eq.), and tree filters (net impact of 2.9 kg P eq.).

In regard to cumulative energy demand, the system which has the lowest life cycle requirement of energy is the swale. This is due to its simplistic design which requires relatively little use of heavy machinery for excavation. The system which requires the highest amount of energy for construction and maintenance is the permeable pavement (810 GJ). This high expenditure of energy from permeable pavements is due to the requirement of the material bitumen oil for sediment adhesion and the paving machinery. After permeable pavement, the GIs which require the most amount of energy are tree filters (290 GJ), bio-retention systems (57 GJ), subsurface gravel wetlands (54 GJ), sand filters (26 GJ) and wet ponds (18 GJ). Regardless of system the highest energy requirements occur during the construction phase.

In respect to global warming potential the system which emits the lowest amount of CO_2 eq. across its construction and maintenance phases is the swale which produces 500 metric tons of CO_2 equivalence. Similar to other impacts, this low emission of CO_2 equivalence is due to the swales rudimentary design which requires little materials and machinery for construction and maintenance. The system which emits the highest amount of CO_2 eq. is the permeable pavement at 44,000 CO_2 eq. This high emittance from permeable pavement is due to the factors which have been previously mentioned. After permeable pavement, the system which produces the highest net global warming potential is bio-retention system which produces 38,500 kg of CO_2 eq. followed by subsurface gravel wetlands (3,500 metric tons of CO_2), tree filters (2,030 metric tons of CO_2), sand filters (1,700 metric tons of CO_2), and wet ponds (1,100 metric tons of CO_2).

Lastly, in relation to economic cost, the system which has the lowest economic impact is the swale which costs $58,000 during its maintenance and construction phases. Unlike other impacts the majority of this cost accumulates during the maintenance phase associated with the maintenance of the vegetation within the system. The system which has the highest economic impact is the permeable pavement which costs $549,500 across its construction and maintenance phases. This high cost is due to the factors which have been previously mentioned. The system which costs the highest after permeable pavement is the tree filter (costing $341,000) followed by wet ponds ($163,000), subsurface gravel wetlands ($156,260), sand filters ($150,200), and bio-retention systems ($143,900). Similar to the swale, the majority of the GIs' impacts occur during the maintenance phase, which indicates alternative maintenance practices or frequencies may be needed to reduce overall cost.

These results identify areas in which improvements may be made, especially during the construction phases of permeable pavement, tree filters, and bio-retention systems. Improvements that may be made during this phase are the utilization of alternative, eco-friendly, materials such as concrete and oil or by reducing the need for machinery such as excavators. This data also reveals that GIs should not be evaluated solely the removal efficiency during the use phase because a high use phase removal does not necessary correspond to a net removal over the GI's life cycle. For instance, swales experience no reduction potentials, thus, beyond peak flow reduction it is primarily an impactful system. Wet ponds have a high peak flow reduction capacity but at a large cost which mainly incurs during the maintenance phases. Sand filters have the third highest phosphorous reduction capacity but this comes at a loss of peak flow reduction capabilities and similar to wet ponds incurs most of the cost during the maintenance phase. Subsurface gravel wetlands while having both nitrogen and phosphorous reductions has the third highest cumulative energy demand. Bio-retention systems has the third highest life cycle nitrogen reduction and like subsurface gravel wetlands and wet ponds have a high peak flow reduction, however, this comes the cost of high greenhouse gas emissions. Pervious pavements have a high capacity for phosphorous reductions and peak flow reduction but they require a large economic input and produce large amounts of greenhouse gasses and phosphorous. Lastly the tree filter reduces a significant mass of nitrogen during the use phase, but when viewed through a life cycle perspective, it has a net positive release of nitrogen, a large amount of carbon emissions, and significant costs nearly as much. These results also signify the need for policy makers to fully conceptualize the tradeoffs between environmental and economic performances of each GI. A system like permeable pavement may reduce a large amount of total phosphorous, but it also requires a significant amount of energy and emits a large amount of carbon. Whereas, subsurface gravel wetlands reduce a slightly higher mass of total phosphorous, but requires a significantly lower amount of energy input and emits less carbon comparatively.

4.2. Scenario Analysis

4.2.1. Results of the Effect of Spatial Change on the Life Cycle Impacts of Green Infrastructures

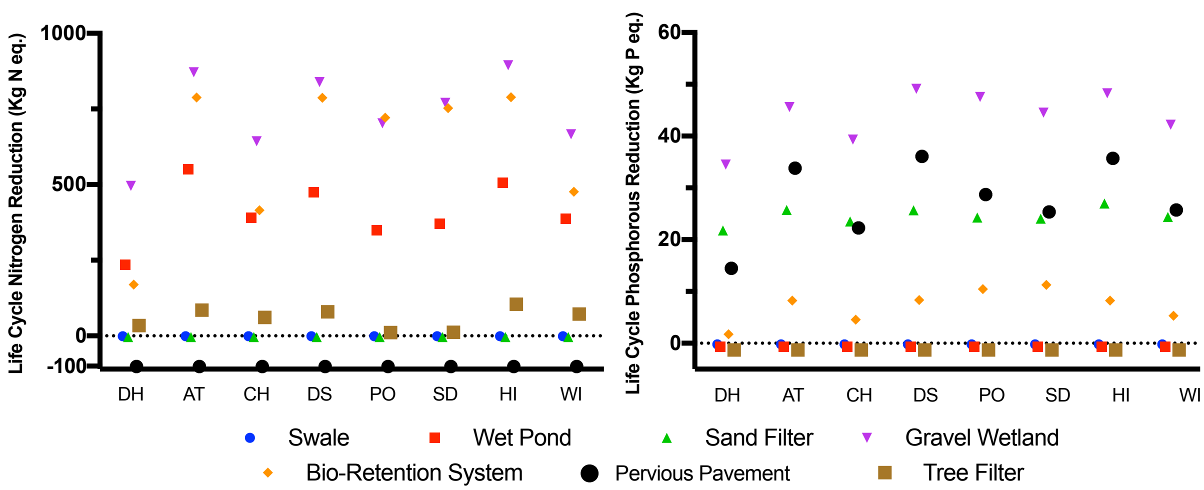

Figure 5: Dynamic Life Cycle Assessment of the Green Infrastructures in Eight Different US Cities (Durham NH, Atlanta GA, Chicago IL, Dallas TX, Phoenix AZ, San Diego CA, Honolulu HI, and Wichita KS)

Within the nitrogen graph in Figure 5, there is a clear ranking among cities with gravel wetlands having the highest average life cycle reduction followed by bio-retention systems, wet ponds, and tree filters. This reveals that the GIs nitrogen reduction capabilities are not sensitive to environmental changes. It is important to note that all of the GIs experience the highest life cycle reduction capabilities in wetter conditions such as in Atlanta, GA or Honolulu, HI as compared to drier climates of Phoenix, AZ or San Diego, CA. This pattern is due to the denitrification processes that occurs in these systems which require a sustained amount of moisture to remain within the system which is better maintained in wetter climates.

Much like the nitrogen results, the system which reduces the highest amount of phosphorus across all cities is the subsurface gravel wetland. The highest life cycle phosphorous reductions are experienced in hotter areas with little to no seasonal change such as Phoenix, AZ or San Diego, CA as compared to colder areas such as Durham, NH or Wichita, KS. This is due to the clogging of the filtration basin via either freezing of the ground or snow pack. Without access to the media the influent runoff is not able to be treated properly.

When looking at the nutrients of nitrogen and phosphorous together, the subsurface gravel wetland has the highest nutrient removal efficiency across all climates. This indicates the effectiveness of incorporating anoxic zones and non-inert sediments in designing future GIs..

4.2.2. Results of the Effect of Land Type on the Life Cycle Impacts of Green Infrastructures

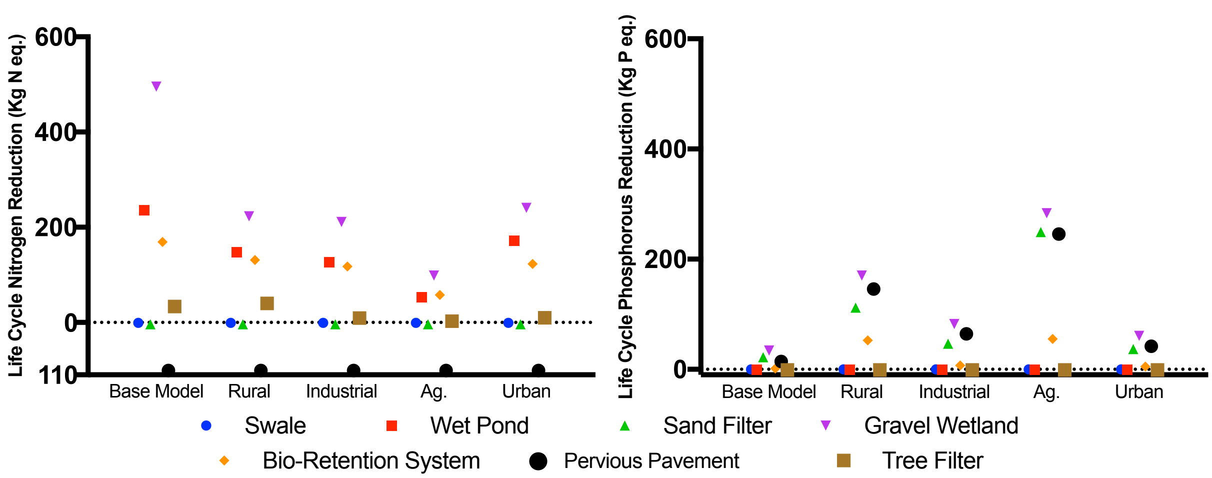

Figure 6: Dynamic Nutrient Life Cycle Assessment of the Green Infrastructures in Four Different Land Types (Rural, Industrial, Agricultural, and Urban)

Rural, industrial, and urban areas are often sources of the highest deposition of nitrogen. This is due to the larger percentage of land being devoted to transportation purposes such as roads or parking lots. Subsurface gravel wetlands perform the best in all the land use scenarios, followed by wet ponds and bio-retention systems. This analysis identifies a significant difference in trends between the nitrogen and phosphorous models. Within the nitrogen model the GIs experiences near identical reductions in rural and industrial land uses with a slight increase in life cycle reductions experienced in urban areas. This is due to each use land use having similar driving/parking coverage which is the primary source of nitrogen deposition to the catchment area. It is also why systems within agricultural areas experience lower life cycle nitrogen reductions despite the increased use of fertilizers. Regardless of surrounding land use the system which experiences the highest life cycle reduction is the gravel wetland followed by wet ponds, bio-retention systems and tree filters. Gravel wetlands have the highest life cycle reductions on account of their incorporation of a large anoxic zone which provides the denitrifying microbes with an ideal environment. Tree filters have the lowest life cycle reduction of nitrogen due to their use of a single plant for nitrogen uptake.

Within the phosphorous model the land uses with the highest life cycle reductions are the agricultural and rural areas. This is because of the larger amount of lawn or farmland which require mowing and fertilizer application. Regardless of land use the system which experiences the highest life cycle phosphorous reduction is the gravel wetland followed by pervious pavement, sand filter, and bio-retention systems. These reductions are due to the incorporation of a media filled filtration basin which provides the phosphorous an ideal surface to adsorb.

When looking at the nutrients together the system which experiences the highest life cycle reductions is the gravel wetland. This is followed by the bio-retention system which depending on the surrounding area may or may not experience any reduction.

Furthermore, land cost could vary significantly among different types of land uses, which is also a significant decision factor in selection of GIs for different land uses. The nitrogen model shows that subsurface gravel wetlands has one of the biggest footprints for unit nutrient reduction at 2.5 $m^2/kg\ N_{eq}$ and 4.3 $m^2/kg\ N_{eq}$. Whereas bio-retention systems require a much smaller footprint at 0.2 $m^2/kg\ N_{eq}$ and 0.5 $m^2/kg\ N_{eq}$. In high land cost urban areas, the bio-retention system could be more appealing than the subsurface gravel wetlands.

This shows that similarly to the nutrient comparison, decision makers need to take into consideration the specific size restrictions that may be present on site.

4.2.3. Results of the Effect of Size Change on the Life Cycle Impacts of Green Infrastructures

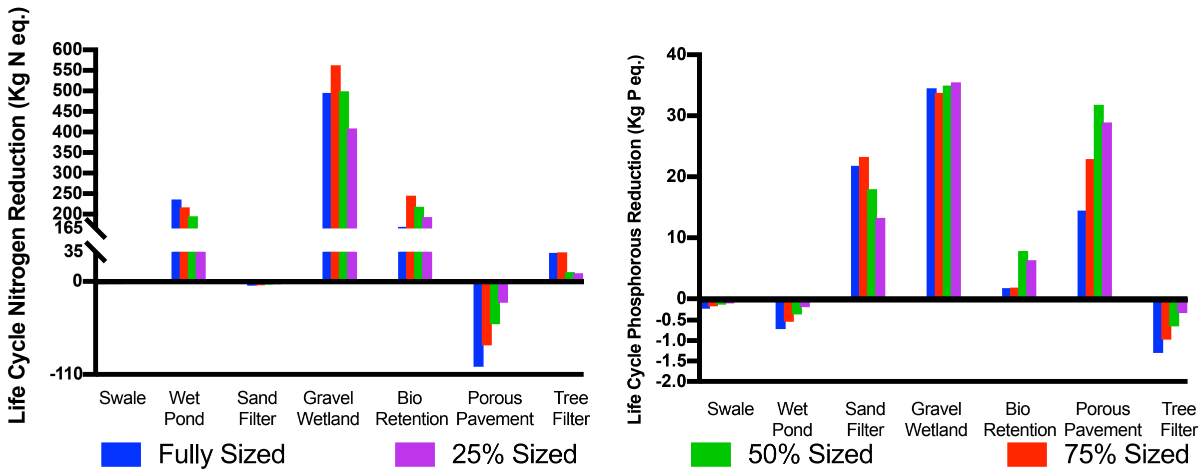

Figure 7: Dynamic Life Cycle Assessment of the Green Infrastructures Under Different Design Sizes (25%, 50%, 75%, and 100% fully sized)

Figure 7 shows a nonlinear relationship between the GIs life cycle nutrient removals and their sizes. The highest removals do not always occur under the fully sized scenario.

Within the nitrogen model it was found that subsurface gravel wetlands, bio-retention systems, and tree filters experience increased removals when the size of the system is decreased by some amount. Bio-retention system, subsurface gravel wetland, and tree filter perform best when designed to 75%, where doing so increase the life cycle reductions by 45%, 14%, 3%, respectively. Alternatively, the wet pond does not experience any increase in nutrient removals when decreased in size. This can be attributed to the low nutrient emissions during the construction size which experiences an insignificant change when reduced. It can also be attributed to the systems utilization of a naturally produced anoxic zone which becomes less resilient to larger fluxes of nutrients due to its decreased capacity.

The phosphorus data show all systems experience higher life cycle phosphorous reductions when reduced in size. Under the 75% undersized condition the sand filter experiences the highest life cycle phosphorous reductions at an increase of 7%. Bio-retention systems and pervious pavements experience the highest life cycle phosphorous reductions under the 50% scenario which causes for increases of 359% and 121% respectively. This high increase in reductions can be attributed to reduction of materials and machinery during the construction phase.

Subsurface gravel wetlands are shown to have the highest reductions of nitrogen under the 75% scenario, however, the phosphorous reduction is the lowest under this scenario. Wet ponds and tree filters reduce as much if not less nitrogen under size restrictions which is due to non-linear reduction in these systems capacities. Pervious pavements, on the other hand, reduce the most amount of phosphorous under the 75% undersized condition, however, this size emits more nitrogen as compared to other undersized scenarios. Thus, tradeoffs between nutrient reductions needs to be considered when under-sizing systems to ensure the best size is chosen for each area’s needs. This also identifies that regulations on the GIs sizes may lead to suboptimal reductions of nutrients for the sake of peak flow reduction.

4.2.4. Results of the Effect of Global Climate Change on the Life Cycle Impacts of Green Infrastructures

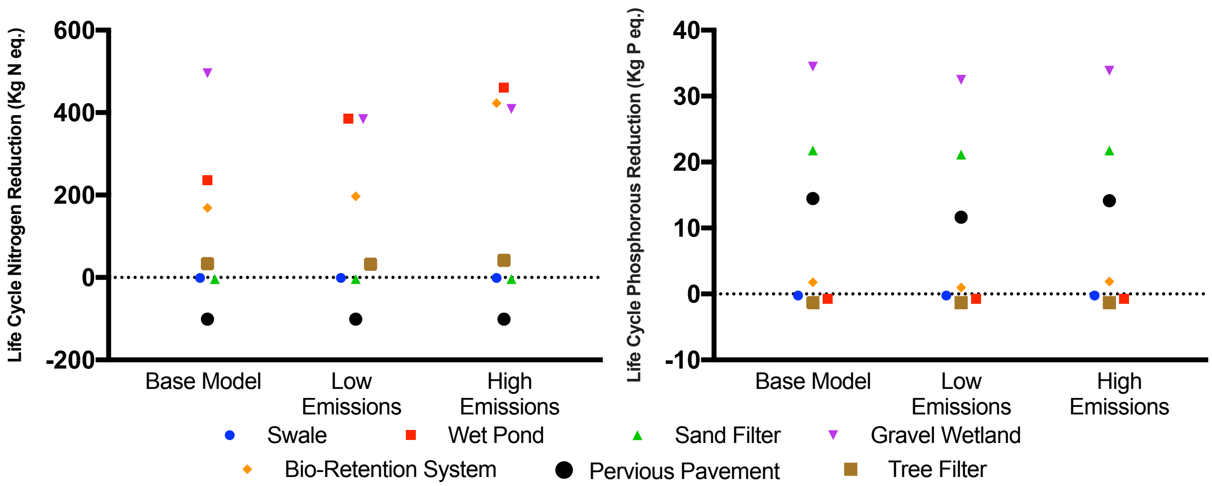

Figure 8: Dynamic Life Cycle Assessment of the Green Infrastructures in Two Different Global Warming Emission Scenarios

In terms of nitrogen reductions there is no clear ranking, however despite the emission scenario the wet ponds can be expected to experience one of the highest life cycle reduction. This is followed by gravel wetlands in the low emission scenario and bio-retention systems in the high emission scenario. This ranking identifies slight sensitivities of the systems under different climate change models. This is best seen in the reduction of treatment potential of gravel wetlands under the emission scenarios as compared to the baseline model. This is due to the tradeoff between construction and maintenance cost and the nutrient reduction capacity of this system. Alternately, wet ponds and bio-retention systems both experience increased treatment capacities under the climate change models and is due to the increase in biologic treatment especially under warmer conditions.

This reduction in removals under the climate models is important to note especially in areas which, as previously identified, produce conditions which make the systems more susceptible to changes in mass fluxes such as in Phoenix or San Diego. Under the climate scenarios these areas are expected to become drier and experiences more intense and less frequent rainstorms which can further overwhelm the GIs capacity.

In terms of phosphorous removals, there is little deviation between the performances of the GIs in the base model as compared to the emission scenarios. Under all models the gravel wetland experiences the highest life cycle reduction of phosphorous followed by sand filters, pervious pavement, and bio-retention systems. This resiliency of treatment is due to the adsorption process by which phosphorous is removed from the runoff which is not as sensitive to temperature or rainfall changes as compared to the biologic treatment seen in nitrogen reduction.

4.3. Sensitivity and Validity of the Green Infrastructure Model

The calibrated model calculates an average effluent of nitrogen and phosphorous of 0.58 kg N and 0.092 kg P eq. from the catchment area, which is respectively around a 3% and 8% smaller than the measured nitrogen loading of the GIs, respectively.

A variation of model constants ±10% produced variances in masses washed off catchment area and GIs life cycle reductions reported Table 4 and 5.

Table 4: Sensitivity Analysis of the Nitrogen Model by Varying the Inputs by + or - 10%

Nitrogen Model Sensitivity Analysis										
Variable	**Deviation in Effluent from Catchment Area (%)**		**Deviation in WP Life Cycle Nitrogen Reduction (%)**		**Deviation in GW Life Cycle Nitrogen Reductions (%)**		**Deviation in BR Life Cycle Nitrogen Reductions (%)**		**Deviation in TF Life Cycle Nitrogen Reductions (%)**	
	+10%	**-10%**	**+10%**	**-10%**	**+10%**	**-10%**	**+10%**	**10%**	**+10%**	**-10%**
Lot Capacity (Cars)	9	9	4	4	7	7	4	5	8	5
Time to Park (Min)	6	9	2	6	4	8	2	8	4	7
Emissions from Cars (kg)	9	7	3	5	7	8	4	6	8	7
Atmospheric Deposition (kg)	2	<1	1	1	1	1	1	1	3	3
Nitrogen in Cut Grass (kg)	1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen in Lawn Fertilizer (kg)	1	1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrogen in Agricultural Fertilizer (kg)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Table 5: Sensitivity Analysis of the Phosphorous Model by Varying the Inputs by + or - 10%

Phosphorous Model Sensitivity Analysis										
Variable	**Change in Effluent from Catchment Area (%)**		**Change in SD Life Cycle Phosphorous Reductions (%)**		**Change in GW Life Cycle Phosphorous Reductions (%)**		**Change in BR Life Cycle Phosphorous Reductions (%)**		**Change in PP Life Cycle Phosphorous Reductions (%)**	
	+10%	**-10%**	**+10%**	**-10%**	**+10%**	**-10%**	**+10%**	**-10%**	**+10%**	**-10%**
Daily Litter Deposition (kg)	8	8	8	8	9	8	9	8	9	9
Phosphorous in Grass clippings (kg)	1	1	1	1	1	2	1	2	5	4
Phosphorous in Agricultural Fertilizer (kg)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Overall, the model is not substantially sensitive to changes in input variables, as all outputs experience less than 10% variation when inputs experience changes of ±10%. In terms of nitrogen removal, the model is most sensitive to changes in car emissions which as automobile emission become more stringent the life cycle reductions of nitrogen will reduce for all systems. In terms of phosphorous removal, the model is most sensitive to changes in daily litter deposition which shows that the highest reduction or increase of life cycle nitrogen reductions as experienced by the GIs can be attributed to changes in surrounding foliage.

5. Implications

Across all models, it was shown that careful consideration must be made when considering the construction of GIs. Things such as local environment, surrounding land use, land availability, and predicted climate changes all have effects on GIs' life cycle performances. Changes in the local environment such as rainfall quantity and masses can cause systems with little smaller capacities to experience lower reductions. This is especially important in drier areas which experience larger less frequent rainstorms such as in Phoenix, AX or San Diego, CA. Surrounding land use can cause drastic changes in both nitrogen and phosphorus fluxes. Agricultural areas need to make careful decisions when constructing GIs as there is up to a 46% variability between the system reductions. Areas in which land costs are high, systems with small footprints are preferred and thus a consideration into the tradeoff between peak flow reduction and stormwater treatment should be weighed. This trade off may lead less rainfall being treated at the benefit of more nutrients reduced over the GIs life span such as in subsurface gravel wetlands reduction of its size by 50% returns similar life cycle reductions of both nitrogen and phosphorous. Lastly, regardless of location, land use or restrictions, it is vital that municipalities or organizations incorporate global warming models into their decision making especially when considering GIs especially if nitrogen is a nutrient of concern. In these areas, wet ponds may be suggested as compared to subsurface gravel wetlands as they exhibit a higher resiliency against these environmental changes.

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S-1 Supporting Information

Life Cycle Economic and Environmental Assessment Inventory

Within this section are multiple screenshots of the LCA inventory. On top of each image is text delineating system and the life cycle phase followed by its corresponding LCA inventory.

Swale: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	Quantity	Units	Adjusted Quantity	Simapro Unit Quantity	Simapro Inventory ID	Marine Eutrophication (Kg N Eq/1 in of rain per acre)	Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost ($ of Metal and Fossil Depletion)	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Vegetated Swale															
Trees and Brush Felled	0.027	acres													
Trees and Brush Skidded	3	hours	3	1h	skidding, skidder {RoW} I skidding, skidder I Alloc Def, U	0.0121	0.00484	962.19	53.8	3.311	0.0363	0.01452	2886.57	161.4	
Trees and Brush Loaded	2	hours	2	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.0842	0	1758	121	
Trees and Shrub Chipped	2	hours	7.7	1h	Wood chipping, chipper, mobile, diesel, at forest road {RER} I wood chipping, mobile chipper, at forest road I Alloc Def, U	0.0413	0.0166	4295.4	276	16.444	0.31801	0.12782	33074.58	2125.2	
Tree Chip Transported	20	miles	13.94	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000469778	0	23.4192	1.56128	
Stump Removal	0.027	acres													
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.518419736	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Stump Excavation via excavator	2	hours	2	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0282	0.01128	2134	136.6	
Excavation of Soil	2800	ft^2	50	1h	Delimbing/sorting, excavator-based processor {RoW} delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.705	0.282	53350	3415	
Generator (25 HP) for Hydroseeding	20	hours	20	1h	Machine operation, diesel, < 18.64 kW, generators {GLO}I market for I Alloc Def, U	0.0012	0.000194	67.69	4.38	0.2616	0.024	0.00388	1353.8	87.6	
Wetland Mix Loam	0.7	lb	0.7	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.006251	0.0002121	9.555	1.176	
Native Mix Loam and Seed	0.8	lb	0.8	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.007144	0.0002424	10.92	1.344	
Meadow Mix Loam and Seed	1	lb	1	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.00893	0.000303	13.65	1.68	
Transport of crew and hydroseeder	30	miles	1.359	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	4.57983E-05	0	2.28312	0.152208	
Total						0.15198708	0.03382302	8406.0064	538.1496	32.032531	1.458249286	0.440257531	120256.003	7786.564788	46201.39256
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	1.459	0.093	0.006	0.001	0.000	41.756	2.704	16.042

Wet Pond: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	Quantity	Units	Adjusted Quantity	Simapro Unit Quantity	Simapro Inventory ID	Marine Eutrophication (Kg N Eq/1 in of rain per acre)	Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost ($ of Metal and Fossil Depletion)	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Wet Pond (NY Stormwater) 3500 ft^2															
Trees and Brush Felled	0.08	acres													
Trees and Brush Skidded	4	hours	4	1h	skidding, skidder {RoW} I skidding, skidder I Alloc Def, U	0.0121	0.00484	962.19	53.8	3.311	0.0484	0.01936	3848.76	215.2	
Trees and Brush Loaded	3	hours	3	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.1263	0	2637	181.5	
Trees and Shrub Chipped	3	hours	7.7	1h	Wood chipping, chipper, mobile, diesel, at forest road {RER} I wood chipping, mobile chipper, at forest road I Alloc Def, U	0.0413	0.0166	4295.4	276	16.444	0.31801	0.12782	33074.58	2125.2	
Tree Chip Transported	20	miles	13.94	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RN	0.0000337	0	1.68	0.112	0.00629	0.000469778	0	23.4192	1.56128	
Stump Removal	0.08	acres													
Stump Excavation via excavator	10	hours	10	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.141	0.0564	10670	683	
Combi Truck Transport	360	miles	250.92	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.008456004	0	421.5456	28.10304	
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.5184197	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Erosion Control via 3' silt fence	596.7	LF													
3' Silt fence transport via combi truck	0.48	miles	0.0818491	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	2.75831E-06	0	0.137506489	0.009167099	
3' silt fence backhoe trenching	1	hours	1	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.0421	0	879	60.5	
Excavation	19320	feet^3	90	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	1.269	0.5076	96030	6147	
Weir Trenching via excavator	0.12	hours	0.12	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001692	0.0006768	128.04	8.196	
Weir Bedding and backfilling via excavator	0.09	hours	0.09	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001269	0.0005076	96.03	6.147	
Weir Instilation va excavator	1.11	hours	1.11	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.015651	0.0062604	1184.37	75.813	
Total						0.208	0.050	12379.046	794.242	47.832	2.212	0.719	174632.108	11266.081	42627.804
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	8.597	0.552	0.033	0.002	0.000	121.272	7.824	29.603

Sand Filter: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Sand Filter (NY															
Trees and Brush Felled	0.029	acres													
Trees and Brush Skidded	3	hours	3	1h	skidding, skidder {RoW} I skidding, skidder I Alloc Def, U	0.0121	0.00484	962.19	53.8	3.311	0.0363	0.01452	2886.57	161.4	
Trees and Brush Loaded	2	hours	2	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.0842	0	1758	121	
Trees and Shrub Chipped	2	hours	7.7	1h	Wood chipping, chipper, mobile, diesel, at forest road {RER} I wood chipping, mobile chipper, at forest road I Alloc Def, U	0.0413	0.0166	4295.4	276	16.444	0.31801	0.12782	33074.58	2125.2	
Tree Chip Transported	20	miles	13.94	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000469778	0	23.4192	1.56128	
Wheel Loader Operation	0	hr	0	0		0	0	0	0	0	0	0	0	0	
Chainsaw Operation	0	hr	0	0		0	0	0	0	0	0	0	0	0	
Stump Removal	0.029	acres				0	0	0	0	0					
Stump Excavation via excavator	4	hours	16	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.2256	0.09024	17072	1092.8	
Stump Transport	0	miles				0	0	0	0	0					
Combi Truck Transport	360	miles	250.92	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.008456004	0	421.5456	28.10304	
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.5184197	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Erosion Control via 3' silt fence	596.7	LF													
3' Silt fence transport via combi truck	0.48	miles	0.0818491	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	2.75831E-06	0	0.137506489	0.009167099	
3' silt fence backhoe trenching	0.99	hours	0.99	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.041679	0	870.21	59.895	
Excavation	7786	feet^3	100	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	1.41	0.564	106700	6830	
Weir Trenching via excavator	0.12	hours	0.12	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001692	0.0006768	128.04	8.196	
Weir Bedding and backfilling via excavator	0.09	hours	0.09	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001269	0.0005076	96.03	6.147	

Sand Filter: Construction Cont.

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
						Sand Filter (NY Storm Water) 1271 ft^2 CONT.									
Weir Instilation va excavator	1.11	hours	1.11	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.015651	0.0062604	1184.37	75.813	
stand pipe construction	2	each									0	0	0	0	
Rip Rap	2.99	CY													
Rip rap placement via excavator	0.129	hr	0.129	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0018189	0.00072756	137.643	8.8107	
Rip Rap transportation	0.32	Miles	3.0789824	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000103762	0	5.172690432	0.344846029	
Sand Fill	144	CY													
Sand fill transport via 12 CY dump truck	100	Miles	33595.92	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.132182504	0	56441.1456	3762.74304	
Bank Run Gravel	107	CY													
Gravel transport via dump truck	15	Miles	3089.28	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.104108736	0	5189.9904	345.99936	
Gravel transport via wheel loader	0.08	hours	116117.33	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.152113707	0.099628672	6041.584853	412.2165333	
Stone Outfall Liner	31	CY													
Gravel transport via dump truck	15	Miles	897.822	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.030256601	0	1508.34096	100.556064	
Gravel transport via wheel loader	0.08	hours	33746.6	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.044208046	0.028954583	1755.835598	119.80043	
PVC Transport via utility truck	3	miles'	2.091	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	7.04667E-05	0	3.51288	0.234192	
Generator (25 HP) for Hydroseeding	16	hours	16	1h	Machine operation, diesel, < 18.64 kW, generators {GLO}I market for I Alloc Def, U	0.0012	0.000194	67.69	4.38	0.2616	0.0192	0.003104	1083.04	70.08	
Native Mix Loam and Seed	5	lb	5	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.04465	0.001515	68.25	8.4	
Transport of crew and hydroseeder	30	miles	1.359	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	4.57983E-05	0	2.28312	0.152208	
Total						0.1096337	0.02708	7205.27	458.712	27.32929	3.91178677	0.937954645	262090.9271	17073.31316	39437.10028
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	5.004	0.319	0.019	0.003	0.001	182.008	11.856	27.387

Gravel Wetland: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	Quantity	Units	Adjusted Quantity	Simapro Unit Quantity	Simapro Inventory ID	Marine Eutrophication (Kg N Eq/1 in of rain per acre)	Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost ($ of Metal and Fossil Depletion)	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Subsurface Gravel Wetland (UNH Stormwater Center) 5450 ft^2															
Trees and Brush Felled	0.13	acres													
Trees and Brush Skidded	4	hours	4	1h	skidding, skidder {RoW} l skidding, skidder l Alloc Def, U	0.0121	0.00484	962.19	53.8	3.311	0.0484	0.01936	3848.76	215.2	
Trees and Brush Loaded	3	hours	3	1h	Excavation, Skid-steer loader {RoW} l processing l Alloc Def, U	0.0421	0	879	60.5	3.29	0.1263	0	2637	181.5	
Trees and Shrub Chipped	3	hours	7.7	1h	Wood chipping, chipper, mobile, diesel, at forest road {RER} l wood chipping, mobile chipper, at forest road l Alloc Def, U	0.0413	0.0166	4295.4	276	16.444	0.31801	0.12782	33074.58	2125.2	
Tree Chip Transported	20	miles	13.94	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000469778	0	23.4192	1.56128	
Stump Removal	0.13	acres				0	0	0	0	0					
Stump Excavation via excavator	12	hours	12	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.1692	0.06768	12804	819.6	
Stump Transport	0	miles				0	0	0	0	0					
Combi Truck Transport	360	miles	250.92	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.008456004	0	421.5456	28.10304	
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.5184197	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Erosion Control via 3' silt fence	596.7	LF													
3' Silt fence transport via combi truck	0.48	miles	0.0818491	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	2.75831E-06	0	0.137506489	0.009167099	
3' silt fence backhoe trenching	0.99	hours	0.99	1h	Excavation, Skid-steer loader {RoW} l processing l Alloc Def, U	0.0421	0	879	60.5	3.29	0.041679	0	870.21	59.895	
Excavation	21800	feet^3	100	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	1.41	0.564	106700	6830	
Weir Trenching via excavator	0.24	hours	0.24	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.003384	0.0013536	256.08	16.392	
Weir Bedding and backfilling via excavator	0.18	hours	0.18	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.002538	0.0010152	192.06	12.294	
Weir Instilation va excavator	2	hours	2	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0282	0.01128	2134	136.6	

Gravel Wetland: Construction cont.

Rainfall Events	Average Age							Simapro Values					Inventory Impact		
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Subsurface Gravel Wetland (UNH Stormwater Center) 5450 ft^2 CONT.															
Topsoil	213.12	CY													
Bucket Loader of Topsoil (3 CY Bucket)	0.27	Hour	193342.464	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.253278628	0.165887834	10059.6084	686.3657472	
Topsoil Dump Truck (12 CY)	15.9	miles	5452.270272	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.183741508	0	9159.814057	610.6542705	
Bucket Loader for Stockpiled Topsoil (3 CY Bucket)	0.8	Hours	193342.464	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.253278628	0.165887834	10059.6084	686.3657472	
Stockpiled Topsoil Excavator	234	Hours	234	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	3.2994	1.31976	249678	15982.2	
Bank Run Gravel	640	CY													
Gravel transport via dump truck	15	Miles	18535.68	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.624652416	0	31139.9424	2075.99616	
Gravel transport via wheel loader	0.08	hours	696704	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.91268224	0.597772032	36249.50912	2473.2992	
Stone Outfall Liner	31	CY													
Gravel transport via dump truck	15	Miles	897.822	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.030256601	0	1508.34096	100.556064	
Gravel transport via wheel loader	0.08	hours	33746.6	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.044208046	0.028954583	1755.835598	119.80043	
PVC Pipes	50	LF													
PVC Transport via utility truck	3	miles'	2.091	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	7.04667E-05	0	3.51288	0.234192	
Generator (25 HP) for Hydroseeding	16	hours	16	1h	Machine operation, diesel, < 18.64 kW, generators {GLO}I market for I Alloc Def, U	0.0012	0.000194	67.69	4.38	0.2616	0.0192	0.003104	1083.04	70.08	
Wetland Mix Loam	5	lb	5	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.04465	0.001515	68.25	8.4	
Transport of crew and hydroseeder	30	miles	1.359	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	4.57983E-05	0	2.28312	0.152208	
Total						0.23283452	0.055780452	13535.99452	869.1758	52.426787	8.061802582	3.075390114	539368.7629	34974.30981	70961.25488
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	9.400	0.604	0.036	0.006	0.002	374.562	24.288	49.279

Bio-retention system: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
								Bioretention System (NY Stormwater) 269 ft^2							
Trees and Brush Felled	0.21	acres													
Trees and Brush Skidded	11.2	hours	11.2	1h	skidding, skidder {RoW} I skidding, skidder I Alloc Def, U	0.0121	0.00484	962.19	53.8	3.311	0.13552	0.054208	10776.528	602.56	
Trees and Brush Loaded	7.7	hours	7.7	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.32417	0	6768.3	465.85	
Trees and Shrub Chipped	7.7	hours	7.7	1h	Wood chipping, chipper, mobile, diesel, at forest road {RER} I wood chipping, mobile chipper, at forest road I Alloc Def, U	0.0413	0.0166	4295.4	276	16.444	0.31801	0.12782	33074.58	2125.2	
Tree Chip Transported	20	miles	13.94	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000469778	0	23.4192	1.56128	
Wheel Loader Operation	0	hr	0	0		0	0	0	0	0	0	0	0	0	
Chainsaw Operation	0	hr	0	0		0	0	0	0	0	0	0	0	0	
Stump Removal	0.21	acres				0	0	0	0	0					
Stump Excavation via excavator	16	hours	16	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.2256	0.09024	17072	1092.8	
Stump Transport	0	miles				0	0	0	0	0					
Combi Truck Transport	360	miles	250.92	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.008456004	0	421.5456	28.10304	
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.518419736	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Erosion Control via 3' silt fence	596.7	LF													
3' Silt fence transport via combi truck	0.48	miles	0.0818491	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	2.75831E-06	0	0.137506489	0.009167099	
3' silt fence backhoe trenching	0.99	hours	0.99	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.041679	0	870.21	59.895	
Haybales	198.9	Linear Feet													
Haybales transport	13.3	miles	12.3009705	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000414543	0	20.66563044	1.377708696	
Haybale Onsite Transport via backhoe	0.64	hours	0.64	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.026944	0	562.56	38.72	

Bio-retention System: Construction cont.

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Bioretention System (NY Stormwater) 269 ft^2 CONT.															
Strip and Stock Topsoil via 200 hp Dozer (331.97 CY)	1.66	hours	300792	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} processing Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.39403752	0.258079536	15650.20776	1067.8116	
Hydroseeding	0.1	Lsf													
Generator (25 HP) for Hydroseeding	18.9	hours	18.9	1h	Machine operation, diesel, < 18.64 kW, generators {GLO} market for I Alloc Def, U	0.0012	0.000194	67.69	4.38	0.2616	0.02268	0.0036666	1279.341	82.782	
Wetland Mix Loam	0.62	lb	0.62	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.0055366	0.00018786	8.463	1.0416	
Native Mix Loam and Seed	0.72	lb	0.72	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.0064296	0.00021816	9.828	1.2096	
Meadow Mix Loam and Seed	0.98	lb	0.98	1 lb	Grass seed, organic, for sowing {GLO} I market for I Alloc Def, U	0.00893	0.000303	13.65	1.68	0.0232	0.0087514	0.00029694	13.377	1.6464	
Transport of crew and hydroseeder	30	miles	1.359	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	4.57983E-05	0	2.28312	0.152208	
Topsoil	52.33	CY													
Bucket Loader of Topsoil (3 CY Bucket)	0.27	Hour	47473.776	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} processing Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.062190647	0.0407325	2470.060565	168.5319048	
Topsoil Dump Truck (12 CY)	15.9	miles	1338.763623	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.045116334	0	2249.122887	149.9415258	
Bucket Loader for Stockpiled Topsoil (3 CY Bucket)	0.8	Hours	47473.776	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} processing Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.062190647	0.0407325	2470.060565	168.5319048	
Stockpiled Topsoil Excavator	234	Hours	234	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	3.2994	1.31976	249678	15982.2	
5'-6' acer rubric	1	each	1	1 plant	tree seedling {GLO} I market for I Alloc Def, U	0.000022	0.0000481	1.476	0.12	0.00461	0.000022	0.0000481	1.476	0.12	
5'-6' sail nigra	2	each	2	1 plant	tree seedling {GLO} I market for I Alloc Def, U	0.000022	0.0000481	1.476	0.12	0.00461	0.000044	0.0000962	2.952	0.24	
Tree Planting vis small backhoe	1.26	hours	1.26	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.053046	0	1107.54	76.23	
Hand watering crew transport via pick up truck	10	miles	6.97	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.000554812	0	69.1424	4.68384	
plant delivery via flat bed truck	10	miles	6.97	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000234889	0	11.7096	0.78064	
landscaping crew transport via pickup truck	10	miles	6.97	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.000554812	0	69.1424	4.68384	
Site cleanup via garbage truck	20	miles	13.94	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	0.000448868	0	25.2314	1.68674	
Site cleanup via backhoe	2	hours	2	1h	Excavation, Skid-steer loader {RoW} I processing I Alloc Def, U	0.0421	0	879	60.5	3.29	0.0842	0	1758	121	
Structural excavation via excavator	59.7	hours	59.7	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.84177	0.336708	63699.9	4077.51	
Concrete Median Barriers	10	LF	2156.28	1 Kg	Concrete block {RoW} production I Alloc Def, U	0.0000133	0.0000175	0.719	0.0819	0.00293	0.028678524	0.0377349	1550.36532	176.599332	

Bio-retention System: Construction cont.

Rainfall Events	Average Age							Simapro Values			Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Bioretention System (NY Stormwater) 269 ft^2 CONT.															
Concrete Median Barriers Transport via flat bed truck	37.5	miles	143.60325	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.00483943	0	241.25346	16.083564	
Weir Trenching via excavator	0.12	hours	0.12	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001692	0.0006768	128.04	8.196	
Weir Bedding and backfilling via excavator	0.09	hours	0.09	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.001269	0.0005076	96.03	6.147	
Weir Instilation va excavator	1.11	hours	1.11	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.015651	0.0062604	1184.37	75.813	
Rip Rap	2.99	CY													
Rip rap placement via excavator	0.129	hr	0.129	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0018189	0.00072756	137.643	8.8107	
Rip Rap Liner	0.53	Rolls													
Rip Rap transportation	0.32	Miles	3.0789824	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000103762	0	5.172690432	0.344846029	
Sand Fill	228.39	CY													
Sand fill transport via 12 CY dump truck	100	Miles	53284.52895	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.795688626	0	89518.00864	5967.867242	
Compost	114.9	CY													
Compost hauling via 12 CY dump truck	50	Miles	7394.964	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.249210287	0	12423.53952	828.235968	
Compost Hauling via wheel loader	0.35	hours	82728	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} |processing| Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.10837368	0.070980624	4304.33784	293.6844	
Bioretention soil portioning via exactator	1028.571429	cy/hr	0.35	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.004935	0.001974	373.45	23.905	
Bioretention soil mixing via wheel loader	5	hr	165.6	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} |processing| Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.000216936	0.000142085	8.616168	0.58788	
Excavating 380 cy of bioretention soil	7.61	hr	7.61	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.107301	0.0429204	8119.87	519.763	
Bank Run Gravel	23.82	CY													
Gravel transport via dump truck	15	Miles	689.87484	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.023248782	0	1158.989731	77.26598208	
Gravel transport via wheel loader	0.08	hours	25930.452	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} |processing| Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.033968892	0.022248328	1349.161418	92.0531046	
Rip Rap	2.99	CY													
Rip Rap Transport via 12 CY Dump Truck	5	Miles	48.1091	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.001621277	0	80.823288	5.3882192	
Rip Rap transportation via Wheel loader	0.003	hours	5424.9663	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} |processing| Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.007106706	0.004654621	282.2609966	19.25863037	

Bio-retention System: Construction cont.

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	Quantity	Units	Adjusted Quantity	Simapro Unit Quantity	Simapro Inventory ID	Marine Eutrophication (Kg N Eq/1 in of rain per acre)	Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost ($ of Metal and Fossil Depletion)	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Bioretention System (NY Stormwater) 269 ft^2 CONT.															
Pipe installation	181	LF	181	1 ft	Polyethylene pipe, DN 200, SDR 41 {RoW} IProduction I Alloc Def, U	0.000397	0.00053	88.002	2.85	0.297	0.071857	0.09593	15928.362	515.85	
Elbow fitting installation	6	each	3	1 ft	Polyethylene pipe, DN 200, SDR 41 {RoW} IProduction I Alloc Def, U	0.000397	0.00053	88.002	2.85	0.297	0.001191	0.00159	264.006	8.55	
Cap instilation	23	each	5.75	1 ft	Polyethylene pipe, DN 200, SDR 41 {RoW} IProduction I Alloc Def, U	0.000397	0.00053	88.002	2.85	0.297	0.00228275	0.0030475	506.0115	16.3875	
T joints	1	each	1	1 ft	Polyethylene pipe, DN 200, SDR 41 {RoW} IProduction I Alloc Def, U	0.000397	0.00053	88.002	2.85	0.297	0.000397	0.00053	88.002	2.85	
Pipe installation via Excavator	1.106	hr	1.106	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0155946	0.00623784	1180.102	75.5398	
Pipe transport via combi truck	5	miles	4.86934888	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000164097	0	8.180506118	0.545367075	
Distribution transportation of pipes	77	Miles	74.98797275	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.002527095	0	125.9797942	8.398652948	
Backfilling (41 CY) via excavator)	0.82	hours	0.82	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.011562	0.0046248	874.94	56.006	
Compacting via excavater (41 cy)	0.59	hours	0.59	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.008319	0.0033276	629.53	40.297	
PVC Pipes	5	LF													
PVC Transport via utility truck	3	miles'	2.091	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	7.04667E-05	0	3.51288	0.234192	
Total						0.46370475	0.092462726	22993.21961	1477.92935	89.343514	8.71	2.58	576375.57	36905.37	68025.80728
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	15.968	1.026	0.062	0.006	0.002	400.261	25.629	47.240

Pervious Pavement: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Pervious Pavement (UNH Stormwater Center) 5200 ft^2															
Gravel for Asphalt	15	Miles	35681.184	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.202455901	0	59944.38912	3996.292608	
Bitumen	174	ft^3	5026.86	1 Kg	itumrn Seal, Polymer EP4 flame retardant {GLO}lMarket forl Alloc Rec,U	0.000198	0.000389	44.8	0.947		0.99531828	1.95544854	225203.328	4760.43642	
Gravel for Choker	10	Miles	33480.072	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.128278426	0	56246.52096	3749.768064	
Gravel for Infiltration resovoir	10	Miles	33480.072	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.128278426	0	56246.52096	3749.768064	
Sand For filter	10	Miles	181977.9	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	6.13265523	0	305722.872	20381.5248	
Excavation	13000	ft^3	40	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.564	0.2256	42680	2732	
Steam Rolling	10	hr	10	1h	Delimbing/sorting, excavator-based processor {RoW} l delimiting, with excavator-based processor l Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.141	0.0564	10670	683	
Mixing	1500	ft^3	1080000	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} lprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	1.4148	0.92664	56192.4	3834	
Total											12.71	3.16	812906.03	43886.79	68791.57622
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.070	0.017	4480.302	241.880	379.142

Tree Filter: Construction

Rainfall Events	Average Age					Simapro Values					Inventory Impact				
48	30					ReCiPe Midpoint H	ReCiPe Midpoint H	Cumulative Energy Demand V 1.09	ICPP 100a	ReCiPe Endpoint H					
Material	**Quantity**	**Units**	**Adjusted Quantity**	**Simapro Unit Quantity**	**Simapro Inventory ID**	**Marine Eutrophication (Kg N Eq/1 in of rain per acre)**	**Freshwater Eutrophication (Kg P Eq)/(1 inch of rain per acre)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost ($ of Metal and Fossil Depletion)**	**Marine Eutrophication (Kg N Eq)**	**Freshwater Eutrophication (Kg P Eq)**	**Cumulative Energy (MJ of summed energy Use)**	**Green House Gas Emission (kg CO2 eq)**	**Economic cost 2017$**
Tree Filter (Unh Stormwater Center) 280 ft^2															
Equipment trucking via Utility Transport	60	Miles	41.82	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.003328872	0	414.8544	28.10304	
Daily Crew Transportaion Via utility pick up transport	3240	Miles	2258.28	1 TKM	Transport, light commercial truck, gasoline powered, east north central / TKM / RNA	0.0000796	0	9.92	0.672	0.0372	0.179759088	0	22402.1376	1517.56416	
Toilet Transport via flat bed truck	10	miles	1678.187	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.056554902	0	2819.35416	187.956944	
Toilet Waste Water Transport	2.57	Miles	1.79129	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam / RNA	0.0000322	0	1.81	0.121	0.00677	4.88931E-05	0	2.748339722	0.183728788	
Waste Water Treatment	0.51	m^3	1.518419736	1 Kg	Waste water treatment, domestic waste water according to the Directive 91/271/EEC concerning urban waste water treatment, at waste water treatment plant EU-27 s	0.00000458	2.01E-08	0.0864	0.0286	0.000291	6.95436E-06	3.05202E-08	0.131191465	0.043426804	
Excavation (453 cf)	1	hr	1	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.0141	0.00564	1067	68.3	
72 inch concrete vault	32424.9	in^3	0.5115	1 m^3	Concrete, normal {CH} I market for I Alloc Def, U	0.0218	0.0203	1300.9	165	3.968	0.0111507	0.01038345	665.41035	84.3975	
72 inch concrete vault delivery	5	miles	19.1471	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.000645257	0	32.167128	2.1444752	
72 inch concrete vault implementation (via excavator)	0.5	hr	0.5	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.00705	0.00282	533.5	34.15	
Gravel transport via dump truck	15	Miles	76.45968	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	0.002576691	0	128.4522624	8.56348416	
Gravel transport via wheel loader	2.64	CY	2873.904	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.003764814	0.00246581	149.5292251	10.2023592	
PVC Pipes	5	LF													
PVC Transport via utility truck	3	miles	2.091	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	7.04667E-05	0	3.51288	0.234192	
Tree Delivery	5	Miles	0.544	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.83328E-05	0	0.91392	0.060928	
Tree (Caliper Ash)	1	tree	1	1 plant	tree seedling {GLO} I market for I Alloc Def, U	0.000022	0.0000481	1.476	0.12	0.00461	0.000022	0.0000481	1.476	0.12	
Tree planting (via excavator)	0.5	hr	0.5	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.00705	0.00282	533.5	34.15	
Bioretention soil portioning via exactator	0.25	cy/hr	0.25	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.003525	0.00141	266.75	17.075	
Bioretention soil mixing via wheel loader	2.2	CY	1584	1 Kg	Solid Manure loading and spreading, by hydraulic loader and spreader {RoW} Iprocessingl Alloc Def, U	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.00207504	0.001359072	82.41552	5.6232	
Excavating 380 cy of bioretention soil	0.25	hr	0.25	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.003525	0.00141	266.75	17.075	
Grate Transport	5	miles	0.544	1 TKM	transport, combination truck, short-haul, diesel powered, Northeast/TKM/RNA	0.0000337	0	1.68	0.112	0.00629	1.83328E-05	0	0.91392	0.060928	
Grate Implementation (via excavator)	0.25	hr	0.25	1h	Delimbing/sorting, excavator-based processor {RoW} I delimiting, with excavator-based processor I Alloc Def, U	0.0141	0.00564	1067	68.3	4.278	0.003525	0.00141	266.75	17.075	
Total											0.298815344	0.029766462	29638.2669	2033.083366	30000.000
Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.002	0.000	205.821	14.119	208.333

Swale: Maintenance

Rainfall Events	Average Age		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Simapro: Marine Eutrophication	Simapro: Freshwater Eutrophication	Simapro: Cumulative Energy	Simapro: Green House Gas Emission	Simapro: Economic cost	Inventory Impact: Marine Eutrophication (Kg N Eq)	Inventory Impact: Freshwater Eutrophication (Kg P Eq)	Inventory Impact: Cumulative Energy (MJ of summed energy Use)	Inventory Impact: Green House Gas Emission (kg CO2 eq)	Inventory Impact: Economic cost 2017$
48	30																		
Vegetated Swale	.808 HA																		
		Mowing / Vegetation removal	60	2800	168000	ft^2	15624	1 m^2	Mowing, by motor mower {RoW} I processing I Alloc Def, U	4.46E-08	4.46E-08	0.003	0.000163	0.00000115	0.00069683	0.00069683	46.872	2.546712	0
		Fertilization	60	2800	168000	ft^2	15624	1 m^2	Fertilizer, switchgrass, 2022/ha/RNA	0.000137	0	0.184	0.0588	0.000688	2.140488	0	2874.816	918.6912	0
		Pesticides	30	3.39	101.7	lb	101.7	1 lb	Pesticide, unspecified {GLO} Imarket for I Alloc Def U	0.00545	0.00283	90.1	4.86	0.3168	0.554265	0.287811	9163.17	494.262	0
		Pesticide Personnel Transport	30	10	300	miles	209.1	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.01664436	0	2074.272	140.5152	0
		Sediment Vacuum Truck Mobilization	30	30	900	miles	627.3	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.04993308	0	6222.816	421.5456	0
		Total													0.001	0.001	46.872	2.547	1125.077
		Total Adjusted (impact per 1 inch of rain per acre of IC)								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.195

Wet Pond: Maintenance

Wet Pond	.404 HA																		
		Mowing / Vegetation removal	60	3500	210000	ft^2	19530	1 m^2	Mowing, by motor mower {RoW} I processing I Alloc Def, U	4.46E-08	4.46E-08	0.003	0.000163	0.00000115	0.000871038	0.000871038	58.59	3.18339	0
		Sediment Vacuum Truck Mobilization	30	30	900	miles	627.3	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.04993308	0	6222.816	421.5456	0
		Total													0.051	0.001	6281.406	424.729	656.476
		Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.362	0.295	0.456

Sand Filter: Maintenance

Rainfall Events	Average Age									Simapro					Inventory Impact				
48	30		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Marine Eutrophication	Freshwater Eutrophication	Cumulative Energy	Green House Gas Emission	Economic cost	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Sand Filter	.404 HA																		
		Mowing / Vegetation removal	60	1271	76260	ft^2	7092.18	1 m^2	Mowing, by motor mower {RoW} | processing | Alloc Def, U	4.46E-08	4.46E-08	0.003	0.000163	0.00000115	0.000316311	0.000316311	21.27654	1.15602534	0
		Sediment Vacuum Truck Mobilization	30	30	900	miles	627.3	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.04993308	0	6222.816	421.5456	0
		Oil and grease removal	60		0			No Impact Hand Removal											0
		Debris cleanup via hand	60					No Impact Hand Removal											0
		Total													0.050	0.000	21.277	1.156	1313.106
		Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.001	0.912

Gravel Wetland: Maintenance

Rainfall Events	Average Age									Simapro					Inventory Impact				
48	30		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Marine Eutrophication	Freshwater Eutrophication	Cumulative Energy	Green House Gas Emission	Economic cost	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Subsurface Gravel Wetland	.404 HA																		
		Removal of sediment Biomass	30	30	900	miles	627.3	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.04993308	0	6222.816	421.5456	0
		Vegetation Maintenance	60	1271	76260	ft^2	7092.18	1 m^2	Mowing, by motor mower {RoW} | processing | Alloc Def, U	4.46E-08	4.46E-08	0.003	0.000163	0.00000115	0.000316311	0.000316311	21.27654	1.15602534	0
		Total													0.050	0.000	6244.093	422.702	656.166
		Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.336	0.294	0.456

Bio-Retention System: Maintenance

Rainfall Events	Average Age									Simapro					Inventory Impact				
48	30		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Marine Eutrophication	Freshwater Eutrophication	Cumulative Energy	Green House Gas Emission	Economic cost	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Bioretention System	.404 HA																		
100		Inspection personnel Transport	30	10	300	miles	209.1	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.01664436	0	2074.272	140.5152	0
		Waste Handling	30	2.26	67.8	CY	67.8	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.00539688	0	672.576	45.5616	0
		Landscaping Mowing	30	8.46	253.8	MSF	23603.4	1 m^2	mowing, by motor mower {RoW} |processing | Alloc Def, U	4.46E-08	4.46E-08	0.003	0.000163	0.00000115	0.001052712	0.001052712	70.8102	3.8473542	0
		Pruning	1	0.73	0.73	MSF	1	1h	Delimbing/sorting, excavator-based processor {RoW} | delimiting, with	0.0141	0.00564	1067	68.3	4.278	0.0141	0.00564	1067	68.3	0
		Pesticides	30	3.39	101.7	lb	101.7	1 lb	Pesticide, unspecified {GLO} |market for | Alloc Def U	0.00545	0.00283	90.1	4.86	0.3168	0.554265	0.287811	9163.17	494.262	0
		Pesticide Personnel Transport	30	10	300	miles	209.1	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.01664436	0	2074.272	140.5152	0
		Sediment Vacuum Truck Mobilization	30	30	900	miles	627.3	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.04993308	0	6222.816	421.5456	0
		Pipe Cleaning crew materials and personnel transport	30	10	300	miles	209.1	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.01664436	0	2074.272	140.5152	0
		Forebay Sediment Removal crew and machinery	6	30	180	miles	123.66	1 TKM	transport, combination truck, short-haul, diesel powered,	0.0000337	0	1.68	0.112	0.00629	0.004167342	0	207.7488	13.84992	0
		Forebay excavation via 1/2 CY bucket	6	0.22	1.32	hr	19932	1 Kg	Solid Manure loading and spreading, by hydraulic loader	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.02611092	0.017101656	1037.06196	70.7586	0
		Forebay sediment hauling (22 LCY)	6	40	240	miles	19932	1 Kg	Solid Manure loading and spreading, by hydraulic loader	0.00000131	0.000000858	0.05203	0.00355	0.000229	0.02611092	0.017101656	1037.06196	70.7586	0
		Underground unit pipe cleaning crew and material	1	30	30	miles	29.01	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.002309196	0	287.7792	19.49472	1.079172
		Total													0.733	0.329	25988.840	1629.924	906.871
		Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	18.048	1.132	0.630

Porous Pavement: Maintenance

Rainfall Events	Average Age									Simapro					Inventory Impact				
48	30		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Marine Eutrophication	Freshwater Eutrophication	Cumulative Energy	Green House Gas Emission	Economic cost	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Porous Pavement	.05 HA																		
		Inspection	30	10	300	miles	209.1	1 TKM	Transport, light commercial truck, gasoline powered, east north central /	0.0000796	0	9.92	0.672	0.0372	0.01664436	0	2074.272	140.5152	
		Street Vacuum	90	5200	468000	ft^2	0.00702	1 TKM	Transport, refuse truck, diesel powered, east north central/ tam	0.0000322	0	1.81	0.121	0.00677	2.26044E-07	0	0.0127062	0.00084942	
		Total													0.017	0.000	2074.285	140.516	38.689
		Total Adjusted (impact per 1 inch of rain per acre of IC)						0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	11.432	0.774	0.213

Tree Filter: Maintenance

Rainfall Events	Average Age									Simapro					Inventory Impact				
48	30		Life Time Frequency	Quantity	Total Quantity	Unit	Adjusted quantity	Simapro Unit Quantity		Marine Eutrophication	Freshwater Eutrophication	Cumulative Energy	Green House Gas Emission	Economic cost	Marine Eutrophication (Kg N Eq)	Freshwater Eutrophication (Kg P Eq)	Cumulative Energy (MJ of summed energy Use)	Green House Gas Emission (kg CO2 eq)	Economic cost 2017$
Tree Filters	0.0404 HA								No Impact: Manual Labor										
		Removal of Surface sediment	60	Biannually				0	No Impact: Manual Labor										
		Removal of debris in outlet	60	Biannually					No Impact: Manual Labor										
		Maintenance of soil structure	60	Biannually					No Impact: Manual Labor										
		Potential need for watering	62	Quarterly (1 year) / Biannually					No Impact: Manual Labor										
		Inspection of systemm	30	Annually \					No Impact: Manual Labor										
		Total													0.000	0.000	0.000	0.000	0.000
		Total Adjusted (impact per 1 inch of rain per acre of IC)								0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

S-2 Supporting Information

Equations, Values, and Assumptions for the System Dynamics Model

Reported are the equations which are embedded into the System Dynamics Model of Green Infrastructures. Equation Numbers are associated with stocks and flows with stocks being delineated as the farthest left number and flows as the second number. All numbers following indicate constants or auxiliary values associated with the numbers before it. Citations with the word "N/A" mark entries that are equations without any imbedded equations. Citations with the word "Assumption" mark equations or variables which have been assumed.

Equation No.	Model Variable	Units	Equation	Citation
1	Nitrogen Deposition to Catchment Area	Kg N	=integral(Atmospheric Deposition + Car Deposition + Lawn Care Deposition – Effluent from Catchment Area)	N/A
1.1	Atmospheric Deposition	Kg N	0.0114	[35]
1.2	Car Deposition	Kg N	=percent of year that the lot is in use x cars) x (*percent parking/paved))	N/A
1.2.1	Percent of year that the lot is in use	%	=0.55+0.45 x COS(2π x Daily Counter/365)	Assumption
1.2.1.1	Daily Counter	Time	=MODULO(Time, 365)	N/A
1.2.2	Cars	Kg N	=Emissions from cars x Lot Capacity x (Percent of Cars that drive every day) x Time to park	N/A
1.2.2.1	Emissions from cars	Kg N	0.459	[38]
1.2.2.2	Lot Capacity	Cars	200	[44]
1.2.2.3	Percent of Cars that drive every day	%	=70+15 x SIN(2π x Day of the Week Counter/7)	Assumption
1.2.2.3.1	Day of the Week Counter	Time	=MODULO(Time/7)	N/A
1.2.2.4	Time to Park	Days/Car	0.0017	Assumption
1.2.3	Percent Parking / Paved	%	80	[44, 46]

1.3	Lawn Care Deposition	Kg N	= Nitrogen from Grass Clippings + Nitrogen from Agricultural Fertilizer + Nitrogen from Lawn Fertilizer	N/A
1.3.1	Nitrogen from Grass Clippings	Kg N	=If then else (frequency of mowing and fertilization>0, nitrogen in cut grass, 0) x percent lawn	N/A
1.3.1.1	Frequency of Mowing and Fertilization	Dmnl	=If then else (Day of the Week Counter=1, 1, 0)) x Summer Months	N/A
1.3.1.1.1	Day of the Week Counter	Time	Same as 1.2.2.3.1	N/A
1.3.1.1.2	Summer Months	Time	=If then else (90<daily counter: and: daily counter < 304, 1, 0)	[2, 32]
1.3.1.1.2.1	Daily Counter	Time	Same as 1.2.1.1	N/A
1.3.1.2	Nitrogen in Cut Grass	Kg N	1.52	[36]
1.3.1.3	Percent Lawn	%	10	[44, 46]
1.3.2	Nitrogen from Agricultural Fertilizer	Kg N	=If then else (frequency of agricultural fertilization>0, nitrogen in agricultural fertilizer, 0) x percent farm	N/A
1.3.2.1	Frequency of agricultural fertilization	Dmnl	=If then else(Daily Counter = 150, 1, 0)	N/A
1.3.2.1.1	Daily Counter	Time	Same as 1.2.1.1	N/A
1.3.2.2	Nitrogen in Agricultural Fertilizer	Kg N	4.237	[40]
1.3.2.3	Percent Farm	%	0	[44, 46]
1.3.3	Nitrogen from Lawn Fertilizer	Kg N	=If then else (Frequency of Agricultural fertilization>0, 1, 0) x Nitrogen in Lawn Fertilizer x percent lawn	N/A
1.3.3.1	Frequency of Agricultural Fertilization	Dmnl	Same as 1.3.2.1	N/A
1.3.3.2	Nitrogen in Lawn Fertilizer	Kg N	1.29	[40]
1.3.3.3	Percent Lawn	%	10	[44, 46]
1.4	Effluent from Catchment area	Kg N	Nitrogen Deposition to Catchment Area x Rainfall Wash off Capability	N/A

1.4.1	Nitrogen Deposition to Catchment Area	Kg N	Same as 1	N/A
1.4.2	Rainfall Wash off Capability	Dmnl	Rainwater Runoff v % Runoff	[45]
1.4.2.1	Rainwater Runoff	In	=If Then Else (Rainfall>0, ((Rainfall-0.2 x SN)^2)/(Rainfall+0.8 x SN), 0)	N/A
1.4.2.1.1	Rainfall	In	Varies	[30]
1.4.2.1.2	SN	Dmnl	=(1000/Total CN)-10	[43]
1.4.2.1.2.1	Total CN	Dmnl	=((Lawn Curve Number x Percent Lawn) + (Misc. Curve Number x Percent Misc.) + (Parking/Paved Curve Number x Percent Parking/Paved) + (Trees/Forested Curve Number x Percent Trees/Forested) + (Building Curve Number x Percent Building) + (Farmland Curve Number x Percent Farmland)) / 100	[43]
1.4.2.1.2.1.1	Lawn Curve Number	Dmnl	49	[43]
1.4.2.1.2.1.2	Percent Lawn	%	Same as 1.3.3.3	N/A
1.4.2.1.2.1.3	Misc. Curve Number	Dmnl	98	[43]
1.4.2.1.2.1.4	Percent Misc.	%	5	N/A
1.4.2.1.2.1.5	Parking/Paved Curve Number	Dmnl	Same as 1.2.3	[43]
1.4.2.1.2.1.6	Percent Parking/Paved	%	80	[44, 46]
1.4.2.1.2.1.7	Trees/Forested Curve Number	Dmnl	43	[43]
1.4.2.1.2.1.8	Percent Trees/Forested	%	5	[44, 46]
1.4.2.1.2.1.9	Building Curve Number	Dmnl	98	[43]
1.4.2.1.2.1.10	Percent Building	%	0	[44, 46]
1.4.2.1.2.1.11	Farmland Curve Number	Dmnl	85	[43]
1.4.2.1.2.1.12	Percent Farmland	%	Same as 1.3.2.3	N/A
2	Phosphorous Deposition to Catchment Area	Kg P	=Integral(Grass Clippings + Leaf Deposition + Fertilizer Phosphorous Deposition) –	N/A

			Phosphorous Effluent from Catchment Area	
2.1	Grass Clippings	Kg P	Phosphorous from Grass Clippings	N/A
2.1.1	Phosphorous from Gras Clippings	Kg P	=If then Else (Frequency of mowing and fertilization=1, Phosphorous in Grass Clippings, 0) x (Percent Lawn)	N/A
2.1.1.1	Frequency of Mowing and Fertilization	Dmnl	Same as 1.3.1.1	N/A
2.1.1.2	Phosphorous in Grass Clippings	Kg P	.129	[41]
2.1.1.3	Percent Lawn	%	Same as 1.4.2.1.2.1.2	N/A
2.2	Leaf Deposition	Kg P	= Daily Litter x Percent Trees/Forested	N/A
2.2.1	Daily Litter	Kg P	0.0043	[42]
2.2.2	Percent Trees/Forested	%	Same as 1.4.2.1.2.1.8	N/A
2.3	Fertilizer Phosphorous Deposition	Kg P	Phosphorous from Fertilization	N/A
2.3.1	Phosphorous from Fertilization	Kg P	= (If then else (Frequency of Agricultural Fertilization>0, Phosphorous in Agricultural Fertilizer, 0) x Percent Farmland + (If Then Else (Frequency of Mowing and Fertilization=1, Phosphorous in Lawn Fertilizer x Percent Lawn), 0)	N/A
2.3.1.1	Frequency of Agricultural Fertilization	Dmnl	Same as 1.3.2.1	N/A
2.3.1.2	Phosphorous in Agricultural Fertilizer	Kg P	1.23	[52]
2.3.1.3	Percent Farmland	%	Same as 1.4.2.1.2.1.12	N/A
2.3.1.4	Frequency of Mowing and Fertilization	Dmnl	Same as 1.3.1.1	N/A
2.3.1.5	Phosphorous in Lawn Fertilizer	Kg P	0	[40]
2.3.1.6	Percent Lawn	%	Same as 1.4.2.1.2.1.2	N/A

3	Nutrient Mass In GIs	Kg N or P	=Integral(Effluent from Catchment Area-(Effluent from System + Removal of Nutrients from System)	N/A
3.1	Effluent from Catchment Area	Kg N or P	Same as either 1.4 or 2.4 depending on nutrient of interest	N/A
3.2	Effluent from System	Kg N or P	=If then else (Effluent from Catchment area>(System Capacity-Nutrient Mass in GIs) : And : Nutrient Mass in GIs< System Capacity), (Effluent from Catchment Area-System Capacity)+(System Capacity-Nutrient Mass in GIs) x (1-Max System Removal Percent), Effluent from Catchment Area x (1- Max System Removal Percent)	N/A
3.2.1	Effluent from Catchment Area	Kg N or P	Same as either 1.4 or 2.4 depending on nutrient of interest	N/A
3.2.2	System Capacity	Kg N or P	Calibrated Value	Assumption
3.2.3	Nutrient Mass in GIs	Kg N or P	Same as 3	N/A
3.2.4	Max System Removal Percent	%	=If then else (Summer months=0, (Reported System Winter Removal Efficiency/Reported System Summer Removal Efficiency) x Max System Summer Removal Efficiency, Max System Summer Removal Efficiency)	N/A
3.2.4.1	Summer Months	Time	Same as 1.3.1.1.2	N/A
3.2.4.2	Reported System Winter Removal Efficiency	%	Varies	[2, 32]
3.2.4.3	Reported System Summer Removal Efficiency	%	Varies	[2, 32]
3.2.4.4	Max System Summer	%	Calibrated Value	Assumption

	Removal Efficiency			
3.3	Removal of Nutrients from System	Kg N or P	=Nutrient Mass In GIs x System Removal Efficiency	N/A
3.3.1	Nutrient Mass In GIs	Kg N or P	Same as 3	N/A
3.3.2	System Removal Efficiency	%	=Max System Removal Percent x System Nutrient Removal Coefficient	N/A
3.3.2.1	Max System Removal Percent	%	Same as 3.2.4	N/A
3.3.2.2	System Nutrient Removal Coefficient	Dmnl	=If then else (Nutrient Mass in GIs <= System Capacity, -0.5 x Nutrient Mass in GIs / System Capacity + 1, 0.5)	N/A
3.3.2.2.1	Nutrient Mass in GIs	Kg N or P	Same as 3	N/A
3.3.2.2.2	System Capacity	Kg N or P	Same as 3.2.2	N/A

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S-3 Supporting Information:

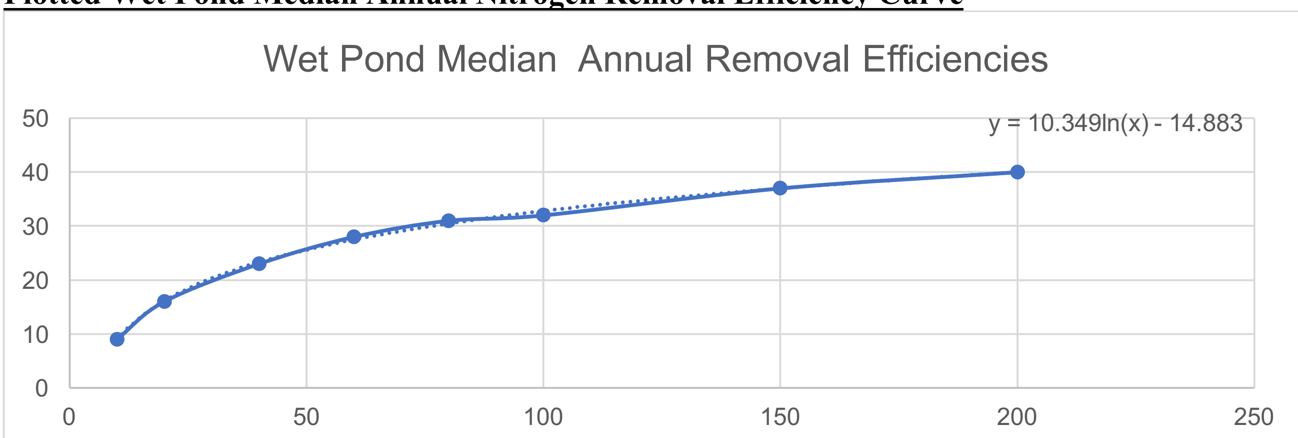
Removal Efficiencies and Curves for Differently Sized Green Infrastructures

Reported changes of removal efficiencies for each infrastructure under seven different design sizes. These values were plotted and the equations of these curves retrieved.

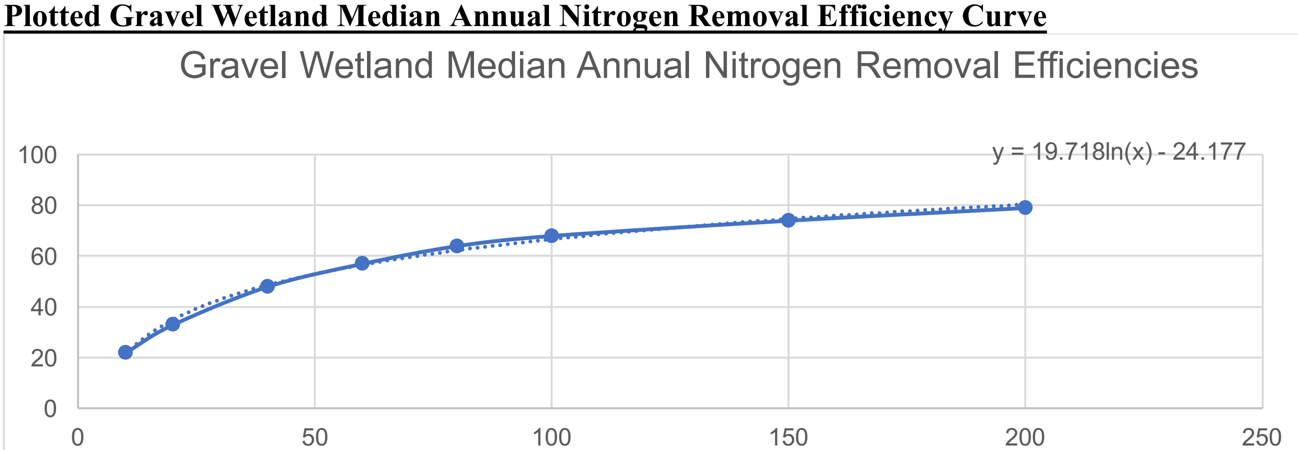
Nitrogen

Percent Design Size	10	20	40	60	80	100	150	200
Swale	0	0	0	0	0	0	0	0
Wet Pond	9	16	23	28	31	32	37	40
Sand Filter	0	0	0	0	0	0	0	0
Gravel Wetland	22	33	48	57	64	68	74	79
Bio Retention system (.27 in / hr. infiltration rate)	52	69	85	92	96	98	99	100
Pervious Pavement	0	0	0	0	0	0	0	0
tree filter	52	69	85	92	96	98	99	100

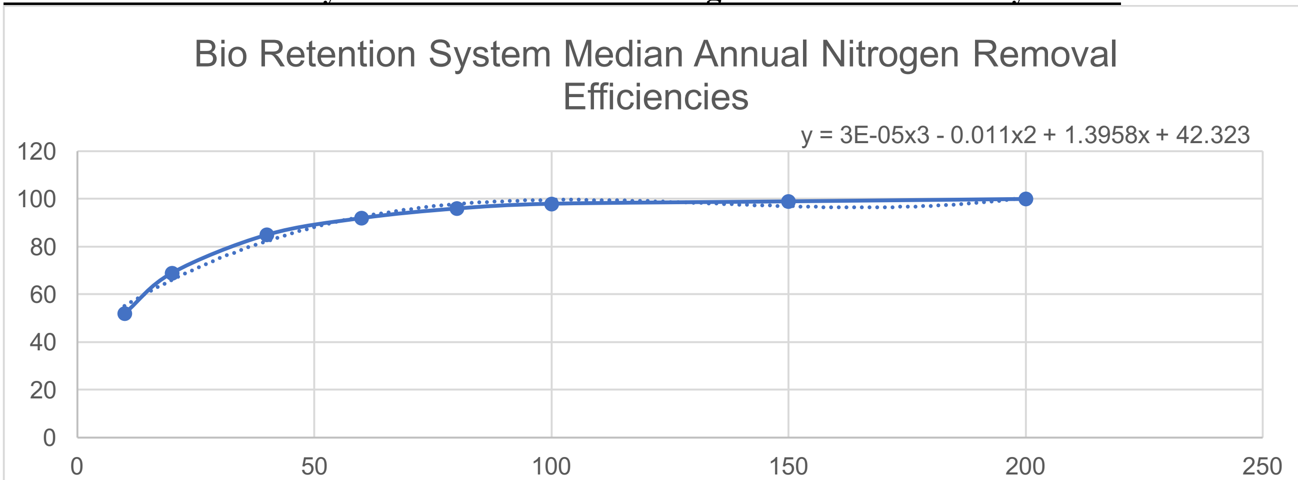
Plotted Wet Pond Median Annual Nitrogen Removal Efficiency Curve



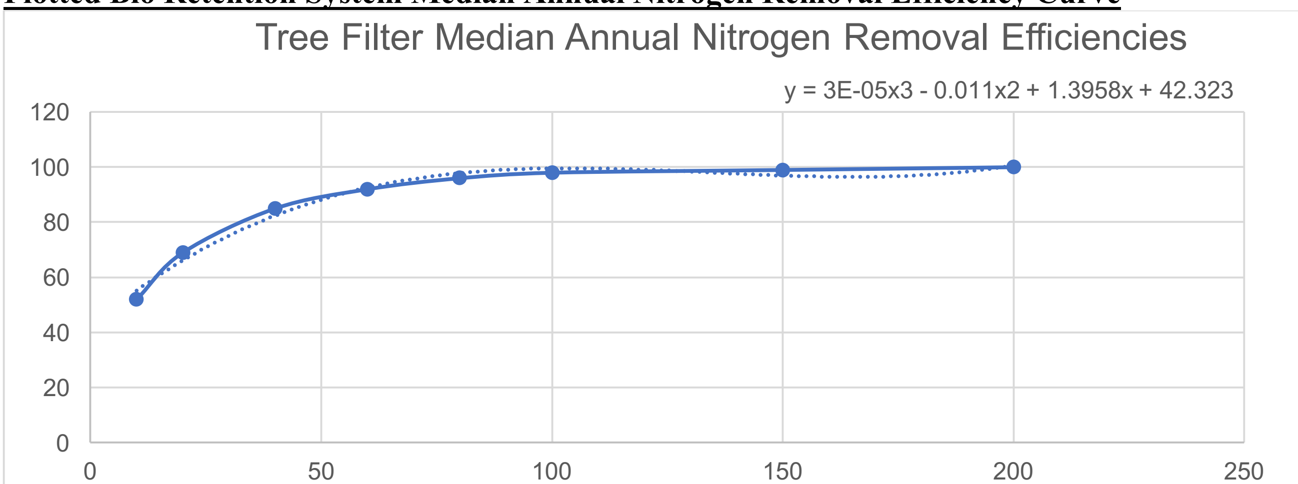
Plotted Gravel Wetland Median Annual Nitrogen Removal Efficiency Curve



Plotted Bio Retention System Median Annual Nitrogen Removal Efficiency Curve



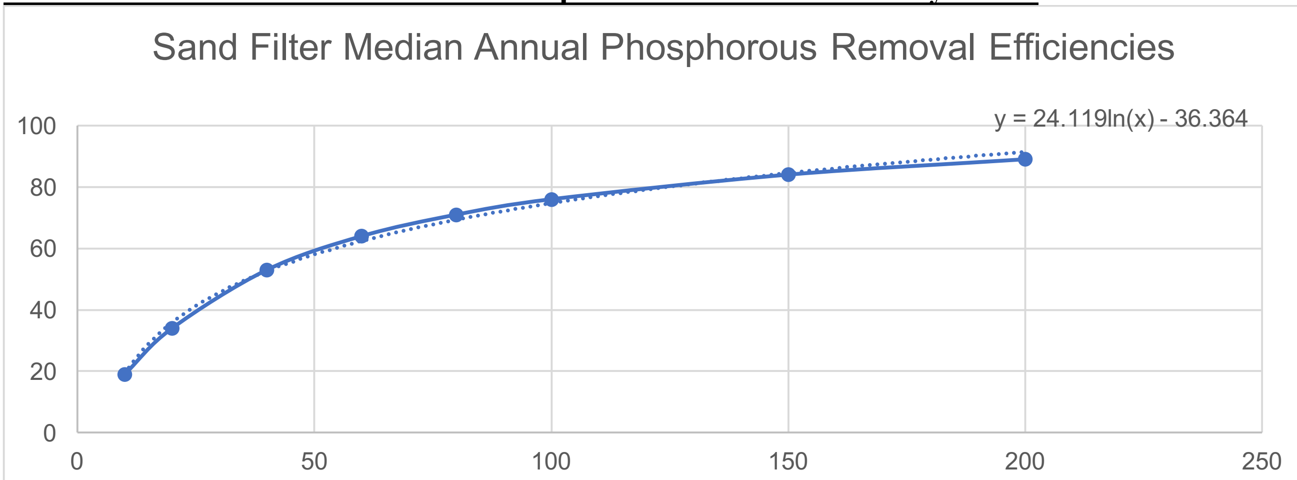
Plotted Bio Retention System Median Annual Nitrogen Removal Efficiency Curve



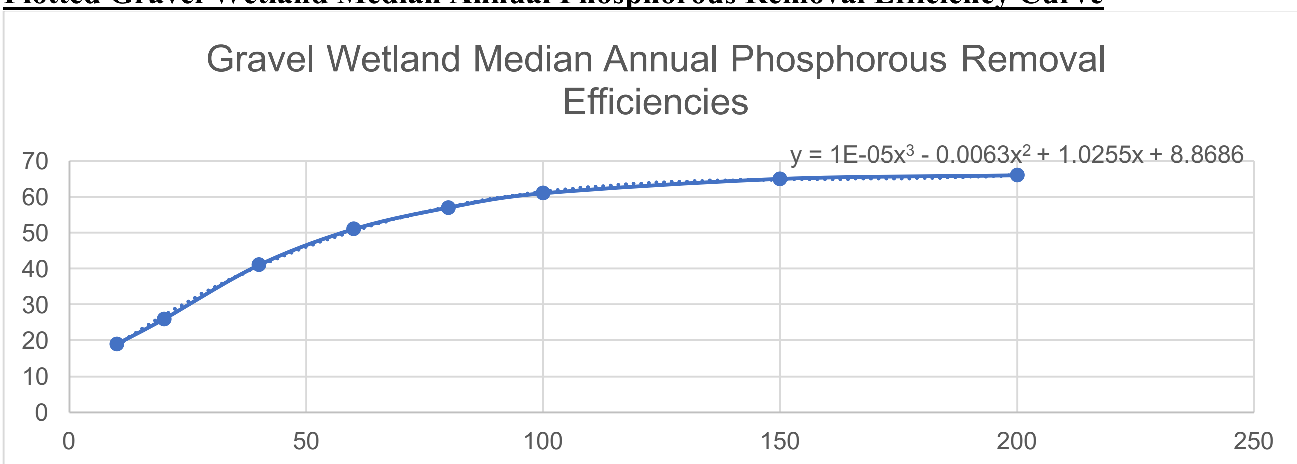
Phosphorous

Percent Design Size	10	20	40	60	80	100	150	200
Swale	0	0	0	0	0	0	0	0
Wet Pond	0	0	0	0	0	0	0	0
Sand Filter	19	34	53	64	71	76	84	89
Gravel Wetland	19	26	41	51	57	61	65	66
Bio Retention system	35	52	72	82	88	92	97	99
Pervious Pavement	35	52	72	82	88	92	97	99
tree filter	0	0	0	0	0	0	0	0

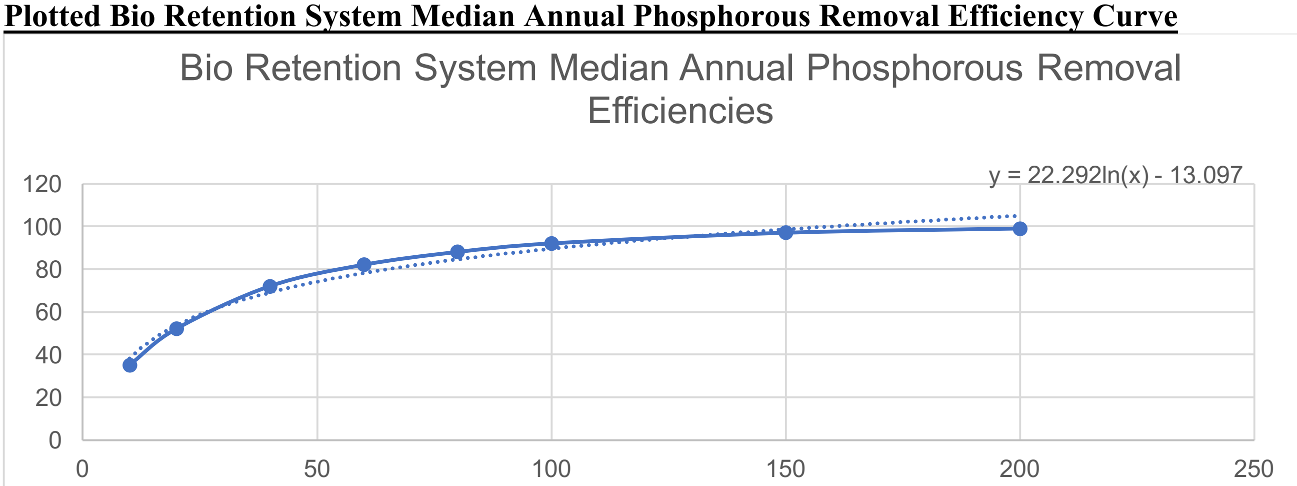
Plotted Sand Filter Median Annual Phosphorous Removal Efficiency Curve



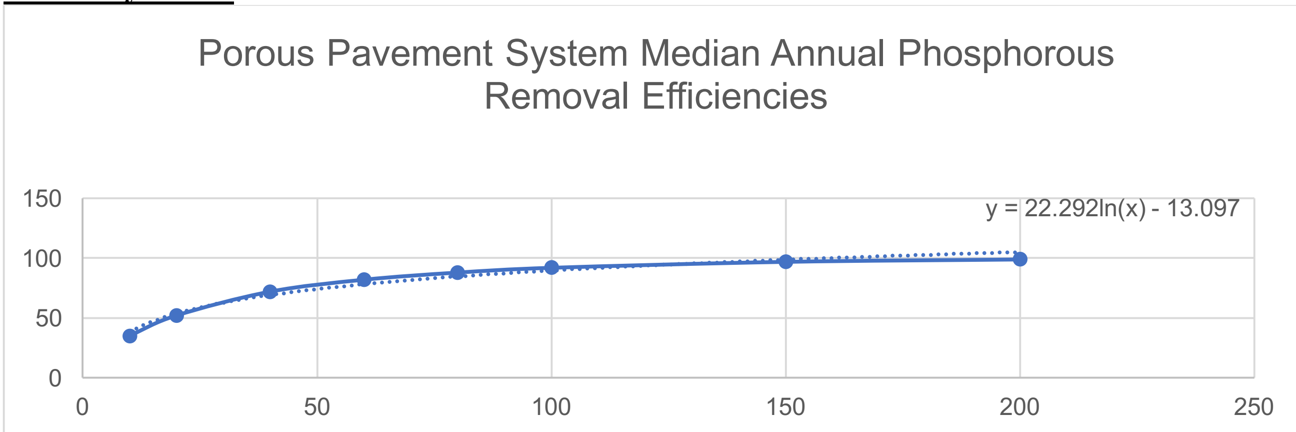
Plotted Gravel Wetland Median Annual Phosphorous Removal Efficiency Curve



Plotted Bio Retention System Median Annual Phosphorous Removal Efficiency Curve



Plotted Porous Pavement (Asphalt) System Median Annual Phosphorous Removal Efficiency Curve



Equations were multiplied by the ratio between the reported removal efficiencies (median annual, summer, and winter) at 100% fully sized and the 100% fully sized median annual removal efficiency as recorded in the graphs. This adjusted equation output removal efficiencies as recorded below for both nitrogen and phosphorous.

Nitrogen

Median							
% Sized			0	25	50	75	100
	Reported Median Annual Removal Efficiency	Ratio					
Wet Pond	32.67	1.02	0.00	18.82	26.14	30.42	33.46
Gravel Wetland	75.00	1.10	0.00	43.34	58.41	67.23	73.49
Bio Retention System	32.30	0.33	0.00	23.34	29.12	32.23	32.35
Tree Filter	1.38	0.01	0.00	1.00	1.24	1.38	1.43
Summer							
% Sized			0.00	25.00	50.00	75.00	100.00
	Reported Summer Removal Efficiency	Ratio					
Wet Pond	63.60	1.99	0.00	36.63	50.89	59.22	65.14
Gravel Wetland	84.52	1.24	0.00	48.84	65.83	75.76	82.81
Bio Retention System	44.0	0.45	0.00	31.79	39.67	43.91	44.1
Tree Filter	7.55	0.08	0.00	5.46	6.81	7.53	7.85
Winter							
% Sized			0.00	25.00	50.00	75.00	100.00
	Reported Winter Removal Efficiency	Ratio					
Wet Pond	9.78	0.31	0.00	5.63	7.82	9.11	10.02
Gravel Wetland	33.33	0.49	0.00	19.26	25.96	29.88	32.66

Bio Retention System	19.60	0.20	0.00	14.16	17.67	19.56	19.64
Tree Filter	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Phosphorous

Median							
% Sized			0.00	25.00	50.00	75.00	100.00
	Reported Median Annual Removal Efficiency	Ratio					
Sand Filter	33.42	0.44	0.00	18.15	25.50	29.80	32.85
Gravel Wetland	57.56	0.94	0.00	28.99	43.07	51.49	55.12
Bio Retention System	12.00	0.13	0.00	7.65	9.67	10.85	12.02
Porous Pavement (Asphalt)	57.47	0.62	0.00	36.64	46.29	51.94	55.95
Summer							
% Sized			0.00	25.00	50.00	75.00	100.00
	Reported Summer Removal Efficiency	Ratio					
SF	30.87	0.41	0.00	16.76	23.55	27.53	30.35
GW	57.60	0.94	0.00	29.01	43.10	51.52	55.16
BR	12.10	0.13	0.00	7.71	9.75	7.81	12.13
PP	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Winter							
% Sized			0.00	25.00	50.00	75.00	100.00
	Reported Winter Removal Efficiency	Ratio					
SF	34.92	0.46	0.00	18.96	26.64	31.14	34.33
GW	57.56	0.94	0.00	28.99	43.07	51.49	55.12
BR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PP	70.29	0.76	0.00	44.82	56.62	63.53	68.43

S-4 Supporting Information

Variables Retrieved through the Calibration Process

Reported are the values which were retrieved as a result of the calibration process. Each table corresponds to a different calibration process starting at the fully sized base model calibration at and ending with the 25% fully sized calibration results. Each table is broken into each GIs, Nutrient Model, and calibrated value. These values were then entered into their corresponding values within the model.

Fully Sized Calibration

	Nitrogen		Phosphorous	
	Capacity	**Maximum Summer**	**Capacity**	**Maximum Summer**
Vegetated Swale	N/A	N/A	N/A	N/A
Wet Pond	0.24	0.67	N/A	N/A
Sand Filter	N/A	N/A	0.13	0.37
Gravel Wetland	0.67	0.98	0.10	0.64
Bio-Retention System	0.50	0.97	0.17	0.15
Porous Pavement	N/A	N/A	0.10	0.78
Tree Filter	0.11	0.09	N/A	N/A

75% Sized Calibration

	Nitrogen		Phosphorous	
	Capacity	**Maximum Summer**	**Capacity**	**Maximum Summer**
Vegetated Swale	N/A	N/A	N/A	N/A
Wet Pond	0.24	0.60	N/A	N/A
Sand Filter	N/A	N/A	0.13	0.36
Gravel Wetland	0.50	0.99	0.075	0.60
Bio-Retention System	0.46	0.49	0.17	0.13
Porous Pavement	N/A	N/A	0.07	0.84
Tree Filter	0.11	0.09	N/A	N/A

50% Sized Calibration

	Nitrogen		Phosphorous	
	Capacity	**Maximum Summer**	**Capacity**	**Maximum Summer**
Vegetated Swale	N/A	N/A	N/A	N/A
Wet Pond	0.23	0.52	N/A	N/A
Sand Filter	N/A	N/A	0.12	0.30
Gravel Wetland	0.30	0.92	0.05	0.54

Bio-Retention System	0.30	0.45	0.04	0.10
Porous Pavement	N/A	N/A	0.05	0.88
Tree Filter	0.11	0.08	N/A	N/A

25% Sized Calibration

	Nitrogen		Phosphorous	
	Capacity	**Maximum Summer**	**Capacity**	**Maximum Summer**
Vegetated Swale	N/A	N/A	N/A	N/A
Wet Pond	0.15	0.45	N/A	N/A
Sand Filter	N/A	N/A	0.10	0.22
Gravel Wetland	0.15	0.91	0.03	0.40
Bio-Retention System	0.15	0.39	0.03	0.10
Porous Pavement	N/A	N/A	0.03	0.93
Tree Filter	0.10	0.07	N/A	N/A