Stormwater Runoff Benefits of Urban Agriculture

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Executive Summary

We worked with the Mississippi Watershed Management Organization (MWMO) to determine if converting vacant lots to urban gardens will decrease stormwater runoff. Soils in urban gardens are likely to be more permeable and therefore absorb more stormwater compared to vacant lots, although data to support this hypothesis are lacking. To answer this question, we used runoff coefficients found in literature review and from data previously collected at the University of St. Thomas to quantify the absorbance capacity of urban garden soils. We found that converting vacant lots to urban gardens could reduce stormwater runoff by around 85%. However, nutrient concentrations in any runoff that does come from urban gardens are likely to be 2-3 times higher in dissolved nitrogen, and up to 100 times higher in dissolved phosphorus concentrations, compared to typical urban stormwater, potentially undermining any stormwater benefits. Therefore, it is important to implement best management practices that minimize the possibility of runoff from urban gardens in order for these to function as green infrastructure.

Introduction

The growth of cities and the emergence of suburbs and new cities presents a problem for managing stormwater. This is because urbanization removes natural, pervious surfaces and replaces them with impervious surfaces like roads, buildings, and vacant lots. Vacant lots are areas where buildings have been demolished and the lot has been filled and compacted tightly with fill dirt.[1] This tightly packed soil creates an impervious surface. It is difficult for stormwater to infiltrate impervious surfaces, which causes the runoff to move horizontally across the lot directly to roads and storm drains. This runoff takes with it different chemicals and nutrients, which in turn lead to nutrient loading within nearby aquatic environments. Stormwater that lands on vacant lots is not handled at the source as it would be if these lots were converted to a type of green infrastructure.

The need for green infrastructure in cities is crucial and expanding. Green infrastructure is any strategy that handles stormwater at its source rather than after it has entered the stormwater system. Examples of green infrastructure include rainwater harvesting, rain gardens, permeable pavements, and green roofs[2].The reason green infrastructure is so crucial is because it helps reduce the negative affects urbanization has on the hydrology of the landscape.

Urban agriculture has not been considered green infrastructure as its primary purpose is for local food production rather than for stormwater management; however, it is possible that converting vacant lots into garden plots may have stormwater benefits. Urban agriculture is increasing steadily in Minneapolis: Between 2012 and 2014 the number of food-producing urban farms and community gardens has increased by 20% in the Twin Cities[3]. This increase leads to the question of urban agriculture as a type of green infrastructure. The increase of urban agriculture raises the question of whether urban agriculture has stormwater benefits and could be considered a type of green infrastructure.

Runoff Coefficients for Vacant Lots

In order to understand how urban agriculture might affect stormwater runoff in cities, we first examined runoff coefficients reported in the literature. Runoff coefficients are a measurement of the fraction of precipitation that ends up as surface runoff, rather than being absorbed in soils and either ending up as groundwater or being removed through evapotranspiration. We first looked at typical runoff coefficients found in urban watersheds.

Studies have been done on vacant lots to determine a way to reduce runoff. Before 1996 demolition companies would tear down buildings and then fill the lots with soils that consisted of clay loams, sandy loams, and construction debris, all of which have very low hydraulic conductivity (the ability for water to permeate through a porous media). Lots filled after 1996 would be done in a similar manner and with the same soil types, but the lots wouldn't have construction debris buried under them. These lots had the same hydraulic conductivity as those with debris, showing that compacting the fill dirt is what leads to the reduction in hydraulic conductivity. These types of lots produce the runoff coefficients that are seen in downtown areas today[1.]

Land Use	Runoff Coefficient
Downtown	0.7-0.95
Neighborhood	0.50-0.7
Asphalt	0.70-0.90
Concrete	0.8-0.95
Sandy Soil Average	0.02-0.07
Heavy Soil Average	0.02-0.07
Heavy Soil with Crop Average	0.20-.0.40
Sandy Soil with Crop	0.10-0.25

Fig. 1 Selected soils that most closely represent soils found in vacant lots and urban gardens and the corresponding runoff coefficients.

Of all the types of soil analyzed in the three studies, these soil types are the expected soils for vacant lots and urban gardens. Vacant lots would have runoff coefficients similar to downtown, neighborhood, asphalt, and concrete. Urban gardens have runoff coefficients similar to the four types of soils. The full results from each of the three studies can be found in the appendix.

This data is important in helping answer our research question because it gives an estimate of runoff coefficients for vacant lots and urban gardens. We predict that a typical vacant lot would have a runoff coefficient of 0.70. However, data is only available on runoff coefficients for large-scale agriculture, not small-scale urban farms. To get a better estimate on runoff coefficients of urban farms, we needed to look elsewhere.

Runoff Coefficients for Urban Gardens

Data from UST: Soil Absorbency in Urban Gardens

We used the data above to come up with estimates of runoff coefficients from vacant lots and urban gardens. However, empirical data on the soil hydrology of urban farms are generally lacking. Here, we analyze unpublished data from a study in the University of St. Thomas research gardens during the summer of 2014[7].

In each raised-bed garden plot, a lysimeter collected leachate from a 4 square-foot area, into a 1-L bottle. The volume of collected water was measured 2-3 times per week, and a subsample of leachate was collected for nutrient analysis. Water inputs to each plot were measured based on rainfall and a water gage on the hose when supplemental watering was necessary. We analyzed a subset of these data to measure soil absorbance capacity, i.e. what fraction of water added to a 4 square-foot area in each sampling interval was not accounted for in the leachate collection bottle. Although there was no runoff per se in these raised bed gardens, these data allow us to estimate soil absorbance, which can then be used to infer maximum runoff coefficients for urban agriculture soils. Five different soil amendments (different varieties of commercially available compost) of were used as experimental treatments, so that these soil conditions represented the range of typical soils on urban farms in the Twin Cities.

All soil types generally absorbed >90% of water input, which indicates that runoff coefficients for urban agriculture soils must be <0.10. As one example, after a 0.9" (2.29cm) rainfall, the lysimeter of an unamended soil plot had 0.233 gallons (885 mL) of water and the lysimeter in a plot amended with a mixture of cow manure andbarley had collected 0.160 gallons (605 mL). The unamended soil treatment absorbed 89.4% of the water, and the cow barley plot absorbed 92.7% of the water. We calculated the absorbencies for five different soil types for multiple rainfall events, and calculated an average absorbency for each of the five soils. The results are shown below.

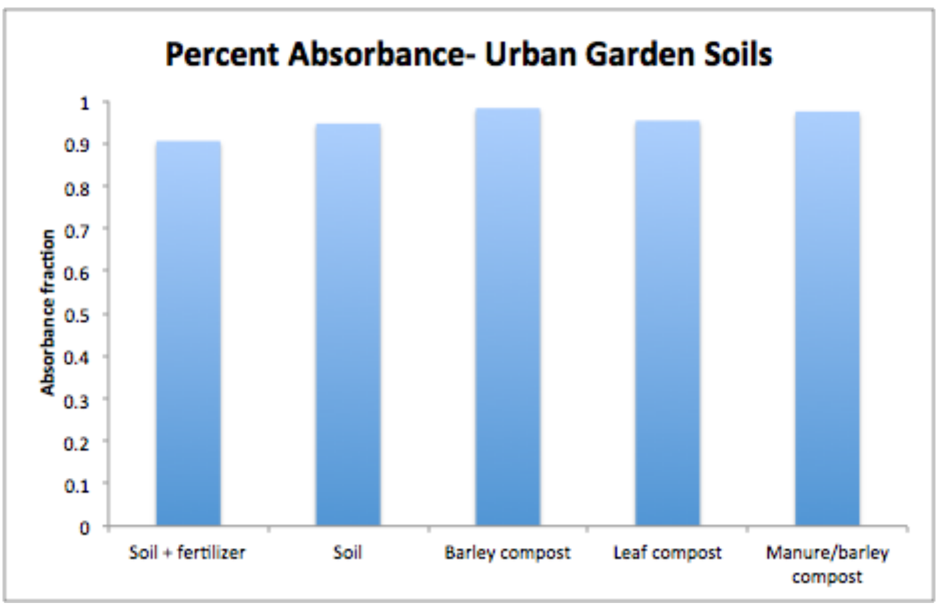


Fig. 2 Percent absorbance of five different soils. These soils represent a range of soil amendments commonly used in urban gardens[9].

Quantifying the Stormwater Benefits of Urban Agriculture

At this point in our research, we concluded that there are stormwater benefits to urban agriculture because urban gardens absorb more stormwater than vacant lots and thus reduce runoff. With simple calculations, we can quantify the volume of water that will be reduced from runoff. Here is an example of a calculation.

A ¼ acre vacant lot (10,890 square feet) has a runoff coefficient of 0.70. This means in a 0.9" rainfall, 0.9"*0.70=0.63" of rain will be runoff. Multiply this by the area of the lot to get 571.72 cubic feet, or 4,277 gallons, of water will be runoff. If this lot is converted to an urban garden, then the new runoff coefficient will be around 0.1 (conservative estimate). So in a 0.9" rainfall, 0.9*0.1=0.09" of rain will be runoff. Multiply this by area of the lot to get 611 gallons of water that will be runoff. To conclude, converting a ¼ acre vacant lot an urban garden will reduce runoff in a 0.9" rainfall event by 85%.

To put these stormwater benefits into perspective, the Minneapolis City Council has expanded the City-owned lots by adding 43 additional lots[8]. If we assume an average city lot is ¼ acre and average annual rainfall in Minneapolis is 30.64 inches[9], then 125,000 gallons of stormwater runoff will be eliminated annually by these 43 additional lots.

For future reference, the equation for calculating reduction of stormwater runoff from converting a vacant lot to an urban lot is given below:
*Reduction of stormwater runoff (cubic feet) =amount of rainfall (in feet) * (vacant lot runoff coefficient – urban lot runoff coefficient) * area of lot (in square feet)*

In a meeting with an MWMO staff member, we learned that to receive a grant from MWMO to start an urban garden, the applicant must show that the garden will have a community benefit and a water quantity benefit. Water quantity benefit is the volume of water that would have been storm water runoff in a vacant lot, but is absorbed into the soil of the garden.

The following table can be used to easily determine the water quantity benefit. To determine water quantity benefit, the following information is needed: annual rainfall, runoff coefficient of both the vacant lot and the garden, and the area of the lot. These values were calculated using the average annual rainfall in Minneapolis, which is 30.64”, or 2.553 feet[9].

			Agriculture lot		
	type of lot		generic	heavy soil, flat	sandy soil
		runoff coefficient	0.2	0.15	0.3
Vacant Lot	generic	0.7	1.3	1.4	2.8
	gravel area	0.5	0.8	0.9	1.5
	neighborhood	0.7	1.3	1.4	2.8
	downtown area	0.95	1.9	2.0	4.4
	asphalt/concrete	0.95	1.9	2.0	4.4

To determine the annual water quality benefit:

1. Select the type of vacant lot and the type of urban garden. If unsure of the soil types, select generic.
2. Find the number (highlighted in blue) that lines up with the vacant lot and urban garden.
3. Multiply the blue number by the area of the lot. (Note: area of the lot must be in square feet).
4. This number estimates the annual volume of water (in cubic feet) that would have been runoff if the lot was kept a vacant lot, but that is now absorbed by the garden.

Nutrient Loading from Urban Agriculture

Data from UST: Dissolved N and P

Converting vacant lots to urban lots decreases storm water by 85%. This is a huge benefit as far as stormwater *quantity* goes, but there is a negative affect on stormwater *quality.* Urban gardens add nutrients (typically as compost), and this creates the potential for high nutrient concentrations in any runoff that does occur.

We used the same unpublished data from UST[7] to estimate nutrient concentrations of runoff from urban gardens. Chip Small and Adam Kay conducted a study to determine the difference in total dissolved nitrogen and total dissolved phosphorus between different types of soil amendments. Their data shows that runoff has high concentrations of nitrogen and phosphorus. Concentrations of nitrogen runoff range from 3 mg to 18 mg/L. Concentrations of phosphorus range from 3 mg/L to 10mg/L.

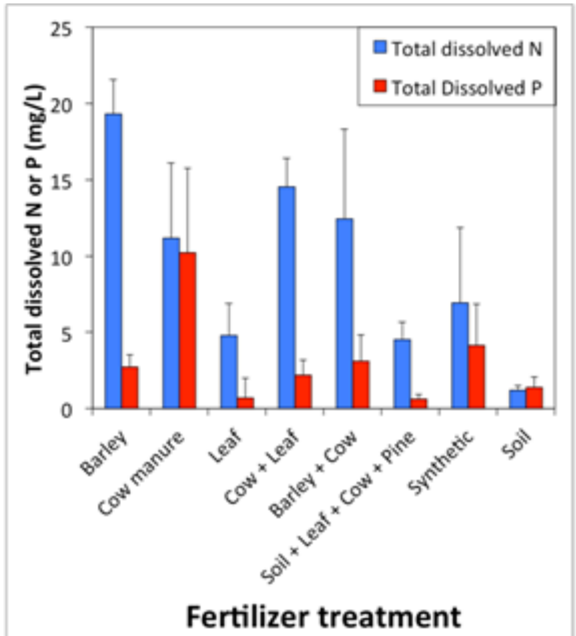


Fig. 3 Total dissolved N and P concentrations from different soil ammendments.

In contrast, nutrient concentration in runoff from other urban surfaces is *much* lower. Average total nitrogen concentrations range from 1.5mg/L to 3 mg/L, and average total phosphorous concentrations are about 0.10 mg/L[10]. This indicates that any runoff from an urban garden has around 10 times higher disolved nitrogen and 100 times higher dissolved phosphorous compared to typical stormwater, potentially undermining any water quality benefits of converting vacant lots into urban agriculture.

However, there are ways to ensure an urban garden can have both stormwater quantity and quality benefits. Reducing nutrient runoff and improving stormwater quality can be done with best management practices.

Best Management Practices to Reduce Nutrient Loading, Reduce Stormwater Runoff ,and Avoid Erosion

To prevent nutrient loading:

- Don't leave soil exposed: Bare soil has the potential to be as impervious as concrete, depending on the type of soil being used. If there is no plan to plant vegetation on an open patch of soil, the soil should be covered with mulch, wood chips (that don't float), gravel, or cover crops. This will help to hold the soil together as well as prevent stormwater runoff from carrying the soil and fertilizer to nearby aquatic environments[11].

- Fertilization, if needed, needs to be used sparingly and only during correct times. Phosphorus should not be a problem since it is now illegal in fertilizers in the Twin Cities. However, nitrogen can still be an issue. Fertilizers should be used far from the edges of the farm. The farm should either have a berm surrounding it or the vegetation should be planted in raised beds. This will help to minimize fertilizer runoff[12].

- Add organic matter to the soil: Adding compost or mulch to soil makes plants happier, and also reduces runoff. The best results are seen when a 2-4" layer of organic material is spread once a year[13].

- Install berms and vegetated swales: A berm is a slightly raised area and a swale is a ditch with a small slope. Berms are used to slow runoff that comes off of steep slopes. Swales that have grass and/or other plants are able to direct water into a rain garden or storm drains if needed. Since they significantly reduce the amount of runoff, very little water that enters a vegetated swale will actually make it to the street or drain. This will help prevent nitrogen from fertilizers from running off of the farm[11].

To reduce stormwater runoff:

- Preserve existing trees: If trees are already present on lot, it would be best to leave them there. The root systems of trees are good at absorbing water, especially over a large area. The canopy of a tree helps to slow the fall of rainwater. These two services allow the ground more time to absorb larger amounts of water than they would be able to in the absence of trees. If the lot does not have enough trees, it may be a good idea to plant some in order to provide shade for the vegetation. If needed, native trees, trees that absorb a large amount of water, and trees that are able to thrive in the surrounding environment will be the most effective for absorbing water and providing shade[12].

- Create a rain garden: A rain garden is a garden that has been planted in a small depression that collects and absorbs stormwater runoff. Rain gardens can be made in different sizes and are often found at the bottom of a slope or near an outlet where water naturally flows. Water-loving plants are most suitable for a rain garden, as well as those that can survive with a base of permeable soil that is enhanced with fertile loam and a topcoat of mulch. This topcoat allow the garden to absorb large amounts of water within just a few hours. They also do a tremendous job of filtering heavy metals and nutrients[14].

- Replace grass areas with native plants: Lawns aren't good at absorbing and retaining water, specifically during storms. The type of grass found at vacant lots is very compact and bad at absorbing storm water. This type of vegetation also requires more irrigation (which leads to further runoff). Native plants, such as shrubs and wildflowers, are able to grow better root systems which help to absorb and hold significantly more water than grass could. Furthermore, native plants require much less work. It may help to plant native vegetation near berms and swales to reduce further fertilizer and stormwater runoff[13].

To avoid erosion:

- When a plot is not currently in use, cover crops should be used on open/bare soil to reduce erosion and improve soil quality. Mulching will help to hold in water and soil so that the area doesn't need to be watered as frequently. Mulch that doesn't float should be used to that it is not carried away by stormwater runoff. Another helpful technique to reduce erosion is to build a berm along edges where the impervious surface and plot meet[12].

To water plants in a more environmentally-friendly way:

- Install cisterns to help capture rainwater, which can be used for watering plants. This reduces the amount of stormwater that flows into storm drains, saves money, and conserves the city's freshwater preserves. Water collected from a roof/road should be treated before being used on edible plants[14].

Conclusion

Downtown Minneapolis is made up of more than 90% impervious surfaces[10].The entire MWMO watershed is made of between 50 – 60%[15]. impervious surfaces. Impervious surfaces have high runoff coefficients, and, in turn, lots of stormwater runoff. Vacant lots make up a large amount of these impervious surfaces found in the Minneapolis area. These surfaces increase the amount of stormwater runoff and cause the water to carry with it organic matter and pollutants which will decrease the water quality of the watershed and river. If vacant lots in Minneapolis were converted to a form of green infrastructure, the percentage of total impervious surface would decrease, stormwater runoff would be reduced, and water quality would improve.

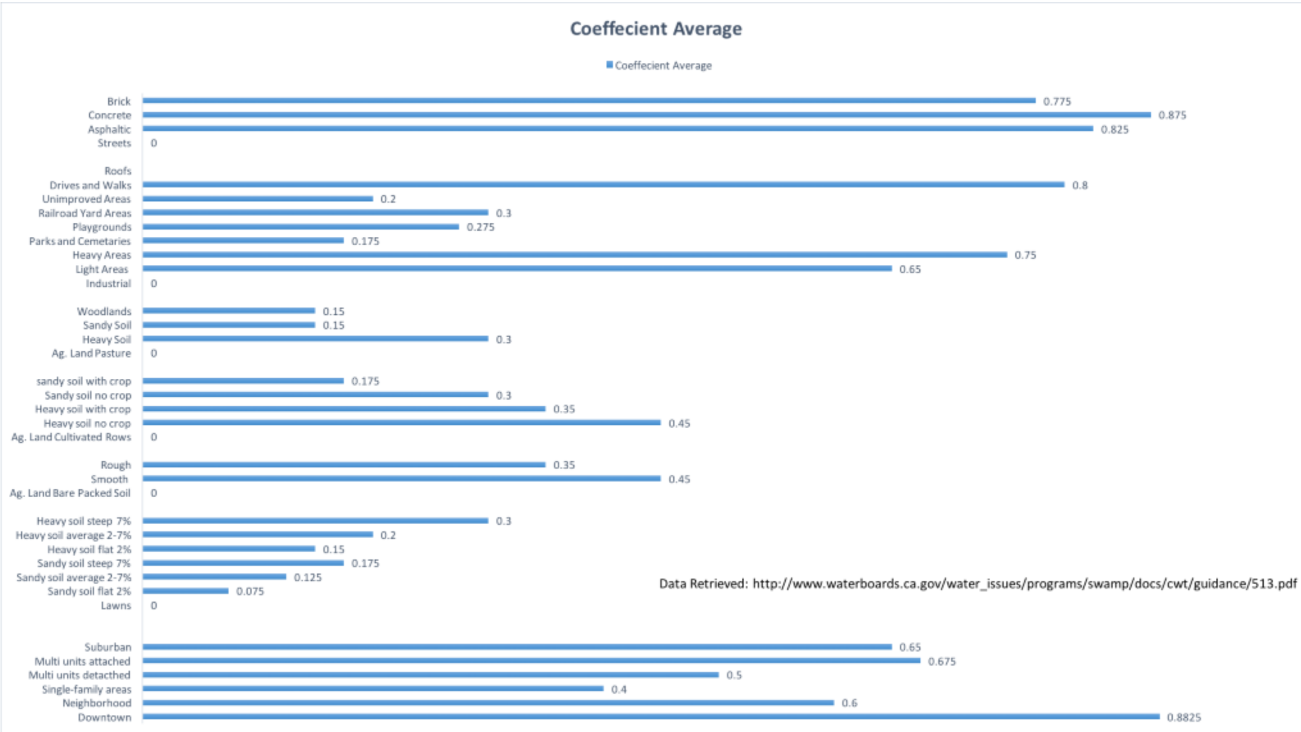
Currently, these vacant lots are being converted to urban gardens. Although urban gardens are not considered green infrastructure, urban gardens do have stormwater benefits. The reason urban gardens have stormwater benefits is because the soil used is loos which allows for better absorption. Our research suggests that of all urban surface types, urban agriculture lots have the lowest runoff coefficients and provide the best benefits to the surrounding aquatic sources.

A potential downfall of urban agriculture is nutrient loading. Phosphorus and nitrogen are common nutrients used in fertilizers. Although phosphorus is no longer legal in the Minneapolis area, nitrogen from fertilizers can still be carried into surrounding aquatic environments via stormwater runoff. To minimize nutrient loading, farmers have come up with a number of different methods to use in urban agriculture. Some common methods used for small-scale urban agriculture include the installation of berms and swales and adding organic matter to exposed soil.

The conclusion of our research is that urban agriculture should be considered green infrastructure because there are stormwater benefits of converting impervious vacant lots to absorbent urban gardens, and MWMO should support funding for urban agriculture.

Appendix

Runoff Coefficient Data 1-California Water Board



Data from the California Water Board. The graph shows average runoff coefficients for several different land types. There are seven general categories of land types: streets, industrial, agriculture land pasture, agriculture land cultivated rows, agriculture land bare packed soil, lawns, and downtown. This data shows agricultural lands and lawns have the lowest runoff coefficients.

Runoff Coefficient Data 2 - North Carolina State University

Land Use	Runoff Coefficient, C	Land Use	Runoff Coefficient, C
Business:		Lawns:	
Downtown areas	0.70-0.95	Sandy soil, flat, 2%	0.05-0.10
Neighborhood areas	0.50-0.70	Sandy soil, ave., 2-7%	0.10-0.15
Residential:		Sandy soil, steep, 7%	0.15-0.20
Single-family areas	0.30-0.50	Heavy soil, flat, 2%	0.13-0.17
Multi units, detached	0.40-0.60	Heavy soil, ave., 2-7%	0.18-0.22
Multi units, attached	0.60-0.75	Heavy soil, steep, 7%	0.25-0.35
Suburban	0.20-0.40	Agricultural land:	
Industrial:		Bare packed soil	
Light areas	0.50-0.80	Smooth	0.30-0.60
Heavy areas	0.60-0.90	Rough	0.20-0.50
Parks, cemeteries	0.10-0.25	Cultivated rows	
Playgrounds	0.20-0.35	Heavy soil no crop	0.30-0.60
Railroad yard areas	0.20-0.40	Heavy soil with crop	0.20-0.50
Unimproved areas	0.10-0.30	Sandy soil no crop	0.20-0.40
Streets:		Sandy soil with crop	0.10-0.25
Asphalt	0.70-0.95	Pasture	
Concrete	0.80-0.95	Heavy soil	0.15-0.45
Brick	0.70-0.85	Sandy soil	0.05-0.25
Drives and walks	0.75-0.85	Woodlands	0.05-0.25
Roofs	0.75-0.85		

Another table of runoff coefficients that shows very similar numbers to the California's waterboard data. This table includes unimproved areas. These areas would not be similar to an urban lot because urban lots have been "improved", meaning that there had been a building or structure that had been torn down. This results in vacant lots being filled in and compacted.

Runoff Coefficient Data 3- Gwinnett County Government

Recommended Runoff Coefficient Values Table		
Description of Area		Runoff Coefficient (C)
Lawns	Sandy soil, flat, 2%	0.10
	Sandy soil, average, 2-7%	0.15
	Sandy soil, steep, >7%	0.20
	Clay soil, flat, 2%	0.17
	Clay soil, average, 2-7%	0.22
	Clay soil, steep, >7%	0.35
Unimproved Areas (forest)		0.15
Business	Downtown areas	0.95
	Neighborhood areas	0.70
Residential	Single-family areas	0.50
	Multifamily units, detached	0.60
	Multifamily units, attached	0.70
	Suburban	0.40
	Apartment dwelling areas	0.70
Industrial	Light areas	0.70
	Heavy areas	0.80
Parks, cemeteries		0.25
Playgrounds		0.35
Railroad yard areas		0.40
Streets	Asphaltic and concrete	0.95
	Brick	0.85
Drives, walks, and roofs		0.95
Gravel areas		0.50
Graded or no plant cover	Sandy soil, flat, 0-5%	0.30
	Sandy soil, flat, 5-10%	0.40
	Clayey soil, flat, 0-5%	0.50
	Clayey soil, average, 5-10%	0.60

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