Chapter 3 - Campus Stormwater Evaluation and Best Management Practices

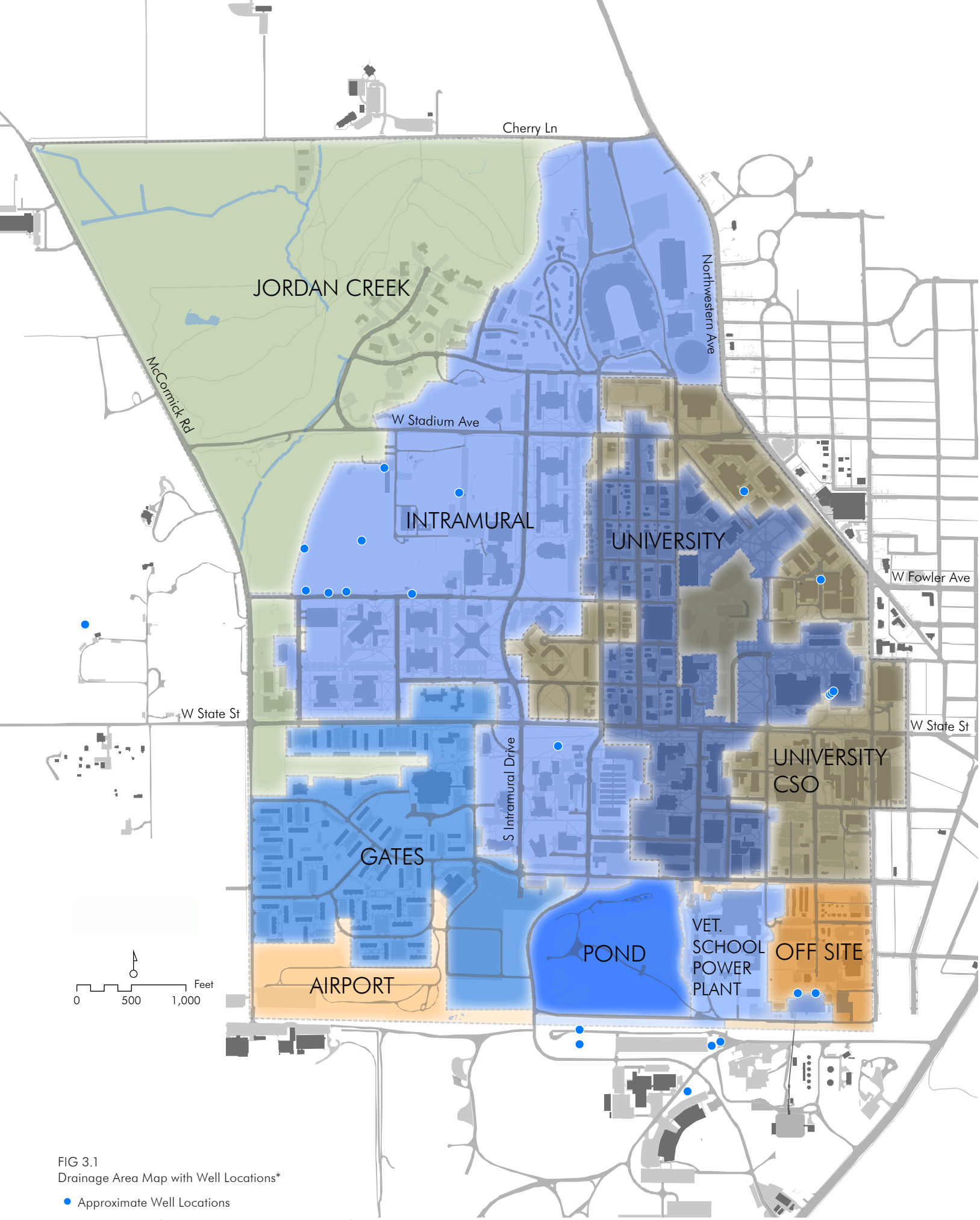


FIG 3.1
Drainage Area Map with Well Locations*

● Approximate Well Locations

*Well Locations derived from GIS data ©1988, Indiana Department of Natural Resources

3.1 Land Use by Drainage Basin

The focus area of detailed study for the Stormwater Plan includes 1,032 acres of University campus as shown in Figure 3.1. Previous work efforts at Purdue have defined drainage areas within this study area, and for consistency the same eight drainage areas are used here. Within the study area, there are three primary discharge areas; Jordan Creek, Harrison Pond and the City of West Lafayette combined sanitary-sewer system. A little over half of the campus (approximately 584 acres) drains to Harrison Pond, including the Intramural, University, and Gates drainage areas, as well as the pond area itself and the area around the Vet School and Power Plant. Within the drainage areas that discharge to Harrison Pond, there are no longer any naturally occurring surface streams or water features remaining. Surface tributaries have been enclosed within the storm sewer system over the course of campus development. Owned by the University, Harrison Pond is a man-made a remnant of historic gravel mining operations and has no direct surface outflow connections to the Wabash River or any of its tributaries. After rainfall events, the water level in Harrison Pond rises initially and then returns to its normal level. It is thought that the water in the pond is directly connected to a shallow aquifer. The volume of runoff and non-point source pollution generated from these combined areas and discharged to Harrison Pond is of specific concern because the direct link to groundwater. It should be noted, a significant portion of this drainage area is not in ownership of the University, primarily along First through Sixth Streets between Stadium Avenue and State Street.

Purdue University and West Lafayette both depend on groundwater as a major source of potable water. The major water supply wells for campus are upstream of the Harrison Pond (Figure 3.1), regardless, any potential connection between the discharge, stormwater pollutants, and drinking water is a concern.

A second major drainage area (University CSO) discharges to the City of West Lafayette combined sanitary-sewer system, and does not discharge to Harrison Pond. This area is approximately 124 acres in total size but is distributed throughout the center and east side of campus, including areas along Northwestern Avenue and University Street.

The third major watershed area within the study area is Jordan Creek, comprised of 267 acres including the Ackerman Hills Golf Course and Tower Acres housing development. Jordan Creek and its tributaries are the only remaining surface streams within the study area. Although this area does not discharge to Harrison Pond, the tributary has areas of streambank erosion and water quality concerns.

Within the southern portion of the 1,032-acre study area, there are two smaller drainage areas, the Airport drainage area and an area in the southeast corner of the study area named "off Site". These areas do not drain to Harrison Pond. It is assumed they drain to the municpal storm sewer system.

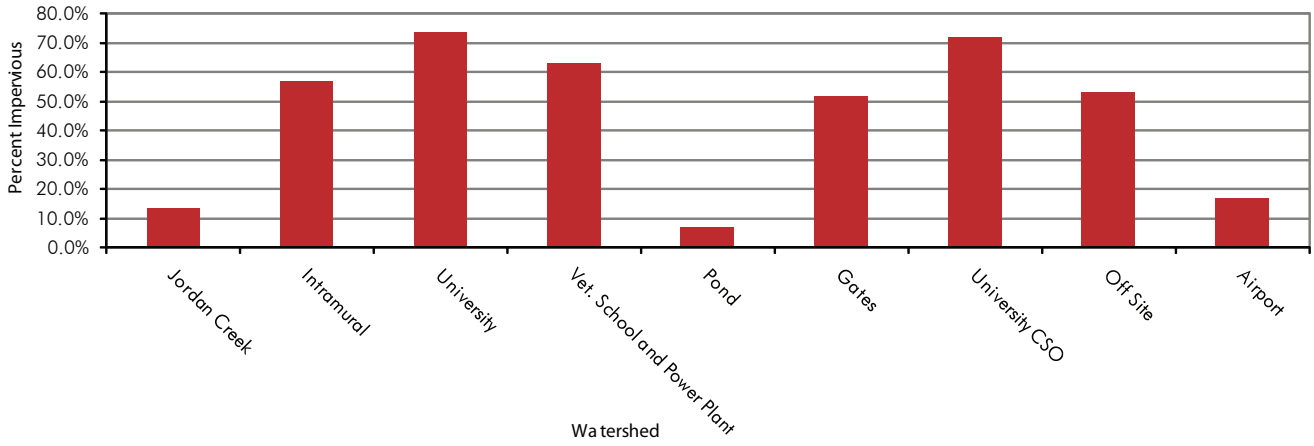


FIG 3.2
Campus Imperviousness by Watershed

FIG 3.3
Watershed Areas and Imperviousness

	Total Area (Acres)	Impervious Area (Acres)	Percent Impervious
Jordan Creek	267	36	13.6%
Intramural	290	165	56.8%
University	117	86	73.6%
School and Power Plant	28	17	62.9%
Pond	36	3	7.0%
Gates	113	58	51.8%
University CSO	124	89	72.1%
Off Site	27	14	53.1%
Airport	30	5	16.9%
TOTAL:	1032	474	46%

FIG 3.4
Harrison Pond Watershed Areas and Imperviousness

	Total Area (Acres)	Impervious Area (Acres)	Percent Impervious
Intramural	290	165	56.8%
University	117	86	73.6%
School and Power Plant	28	17	62.9%
Pond	36	3	7.0%
Gates	113	58	51.8%
TOTAL:	584	329	56%

Within each of these drainage areas, the land use cover and amount of impervious area is directly related to the amount of stormwater runoff generated and the types and amounts of pollutants contained in that runoff. Impervious areas include any area where rainfall is unable to soak into the soil and is translated immediately into runoff, and includes buildings, parking lots (paved and gravel), sidewalks, and roads. The land drainage area and percent impervious for each of the watershed areas is provided in Figure 3.2 and Figure 3.3, while the same information for just those areas draining to Harrison Pond is provided in Figure 3.4.

As can be seen from these tables, within the study area of 1,032 acres there are approximately 474 acres of impervious area, or approximately 46% impervious. This percentage is only an average for the entire study area, a closer look at each drainage area provides a better understanding of impervious cover type and distribution. For example; the Jordan Creek watershed is 13.6% impervious, while the central portions of the campus (University and University CSO) are both more than 70% impervious. As discussed later, this has implications for both the amount of runoff and pollutants generated, as well as the types of stormwater BMPs and interventions that can be implemented.

At the same time, it should not be assumed that pervious areas are all equal – athletic fields, golf courses, and urban lawn areas are much less pervious than forested lands or naturalized planting areas, largely due to soil disturbance and repeated compaction from activities such as game-day parking and mowing. These areas can be nearly as dense (based on measured bulk density of the soil) and as impervious areas such as concrete (Figure 3.5). Additionally, the application of synthetic fertilizers can contribute to pollutant loads in runoff.

A more detailed examination of the land use provides additional information regarding the types of impervious cover within the study area (Figure 3.6). Specifically, roads and sidewalks together comprise the single largest impervious land cover (184 acres) followed by parking lots (151 acres) and buildings (139 acres). Again, this is of interest with regards to both the sources of runoff and pollutants, and the opportunities to intervene with local measures and designs to reduce that runoff at the source. Sidewalks especially represent areas that are within the University's control and provide areas for localized stormwater interventions that address both sidewalk and street runoff. Additionally, "urban pervious" areas, comprised mostly of lawn, represent approximately 34% of the study area and, as discussed later, represent another significant opportunity for stormwater management interventions.

FIG 3.5
Bulk Density by Land Use
Bulk Density is defined as the weight of a unit volume of soil including its pore space (g/cc or grams/cubic centimeter). David B. Friedman, District Director -- Ocean County Soil Conservation District, NJ

Undisturbed Lands: Forest & Woodlands
1.03g/cc

Residential Neighborhoods
1.69 to 1.97g/cc

Golf Courses, Parks, Athletic Fields
1.69 to 1.97g/cc

Concrete/Asphalt
2.2g/cc

FIG 3.6
Detailed Land Use by Drainage Area

	Total Area (Acres)	Impervious Area (Acres)	Paved Parking Lots (Acres)	Unpaved Parking Lots (Acres)	Roads (Acres)	Sidewalk (Acres)	Buildings (Acres)	Wetland (Acres)	Forest Cover (Acres)	Surface Water (Acres)	Athletic Fields (Acres)	Urban Pervious (Acres)
Jordan Creek	267	36.3	11.3	0.4	9.6	9.1	5.8	0.0	60.1	1.4	95.4	74.2
Intramural	290	165.0	54.4	3.0	31.2	30.5	45.9	0.0	0.0	0.0	26.2	99.1
University	117	86.0	15.8	4.2	20.8	18.4	26.8	0.0	0.2	0.0	0.0	30.7
Vet. School and Power Plant	28	17.4	6.5	0.8	1.7	1.0	7.3	0.0	0.7	0.0	0.0	9.5
Pond	36	2.5	0.0	0.0	2.4	0.1	0.0	2.3	8.3	10.3	0.0	12.6
Gates	113	58.5	16.6	10.8	9.7	7.6	13.9	1.5	0.5	0.0	0.0	52.6
University CSO	124	89.3	15.0	2.4	16.8	19.4	35.8	0.0	0.0	0.0	0.0	34.6
Off Site	27	14.4	6.2	0.9	2.7	1.3	3.4	0.0	0.3	0.0	0.0	12.4
Airport	30	5.0	2.5	0.1	2.4	0.0	0.0	0.0	4.0	0.0	0.0	20.6
TOTAL:	1032	474	128	23	97	87	139	4	74	12	122	346
To Harrison Pond Only	584	329	93	19	66	58	94	4	10	10	26	204

3.2 Water Balance Model Findings: Runoff Volumes and Pollutant Loads

One of the primary concerns of stormwater management at Purdue is to reduce the amount (volume) of stormwater runoff and pollutants discharged to surface waters, especially Harrison Pond and its direct connection to the groundwater table. Additionally, there is a desire to maintain recharge to this groundwater table in a safe and sustainable manner. Flooding is also a concern, although flooding problems tend to be localized.

Discussion in Chapter 2 of this document included an evaluation of the precipitation patterns at Purdue, including recognition that most of the annual precipitation occurred in small frequent rainfall events. It follows that most of the annual runoff and pollutant loads will be generated from these small frequent events, and that management of runoff volume and water quality should focus on these small rainfalls.

To first evaluate the runoff volume within the 1,032-acre study area, the Small Storm Hydrology Method was applied using the land use data and the precipitation records for an average year represented by 1996, with 32.3 inches of precipitation (slightly below average of 36 inches), but well distributed throughout the year. The Small Storm Hydrology Method has been developed by Dr. Robert Pitt (1994) using an extensive runoff database for urban areas. Based on this data, runoff coefficients have been developed for different urban land use types and rainfall amounts, as shown in Figure 3.7.

FIG 3.7
Small Storm Hydrology Coefficients by Land Use and Precipitation Amount

Rain Depth	Paved Parking Lots	Unpaved Parking Lots	Road	Sidewalk	Buildings	Wetland	Forest Cover	Surface Water	Athletic Fields	Urban Pervious
Under .1	0.93	0.13	0.25	0.25	0.25	0	0	0	0	0
0.1 to 0.2	0.96	0.285	0.52	0.52	0.8	0	0	0	0	0.025
0.2 to 0.4	0.97	0.35	0.58	0.58	0.89	0	0	0	0.125	0.065
0.4 to 0.6	0.97	0.395	0.62	0.62	0.94	0	0.015	0	0.17	0.09
0.6 to 0.8	0.97	0.425	0.656	0.656	0.95	0	0.02	0	0.195	0.105
0.8 to 1.2	0.98	0.455	0.7	0.7	0.97	0	0.025	0	0.21	0.12
1.2 to 2.0	0.99	0.513	0.785	0.785	0.99	0	0.05	0	0.24	0.145
2.0 to 3.2	0.99	0.583	0.87	0.87	0.99	0	0.11	0	0.3	0.2
3.2 to 4.9	0.99	0.653	0.915	0.915	0.99	0	0.2	0	0.39	0.295

The Small Storm Hydrology Method was developed specifically in recognition that in urbanized areas, small storms (between 0.5" and 1.5") are responsible for most of the annual runoff volume and pollutant load, and that rains greater than 1.5 inches that are associated with drainage design (i.e. piping conveyance and detention systems) are only responsible for relatively small portions of the annual pollutant discharges. The Small Storm Hydrology Method also recognizes that the relationship between land cover and rainfall can vary significantly depending on the amount of rainfall, and that not all impervious areas respond equally. For example, large impervious parking lots tend to generate more runoff than small impervious areas with shorter lateral distances to pervious areas. Because the Small Storm Hydrology Method has been developed specifically for small rainfalls using an extensive national database, the ability of this method to accurately predict runoff volume in small events has been verified to be far more accurate than other commonly used methods such as the NRCS Cover Complex Method (i.e., TR-55 or TR-20).

Because the Small Storm Hydrology Method is focused on small storms (rather than large events where surfaces are well saturated), all impervious areas are not "equal" as seen in Table 3.7, and the coefficients are based on extensive data collected from representative areas in developing the methodology. For example, "Flat roofs and unpaved parking areas behave strangely similar because of detention storage volumes and no infiltration. Large impervious areas have the largest runoff yields because of very poor pavement under-drainage. The drainage path through the pavement base is relatively thin and very long, making it very difficult for water to drain from the base. Street widths are much narrower than the widths of large impervious areas and the base water can drain much more effectively. Pitched roofs have no infiltration rates, but do experience limited initial losses associated with flash evaporation and absorption of moisture in leaves and other roof or gutter debris. After three inches (no longer a small rain) the runoff yields from all impervious surfaces are similar (within 10%), but the differences can be very large for the small rains of most concern in water quality evaluation". (Pitt, 2003)

The Small Storm Hydrology Method estimates the volume of runoff for a given precipitation event based on the equation:

$$\text{Volume} = Rv \times P \times \text{Area}$$

Where Rv is the runoff coefficient (Figure 3.7), P is precipitation, and Area is the drainage area by land cover.

For each of the eight drainage areas, the GIS and supporting data provided detailed information on land use areas, which were grouped into the land use categories shown in Figure 3.8. The runoff volume from each land use within each drainage area was then evaluated for each storm event during an average year, and summarized by land use type and drainage area. The detailed findings of this analysis are discussed in Section 4.1, however, a campus summary is provided in Figure 3.8.

FIG 3.8
Detailed Annual Runoff Volume by Land Use and Drainage Area

	Total Runoff (Acre-feet)	Paved Parking Lots (Acre-feet)	Unpaved Parking Lots (Acre-feet)	Roads (Acre-feet)	Sidewalk (Acre-feet)	Buildings (Acre-feet)	Wetland (Acre-feet)	Forest Cover (Acre-feet)	Surface Water (Acre-feet)	Athletic Fields (Acre-feet)	Urban Pervious (Acre-feet)
Jordan Creek	141	29.32	0.45	16.62	15.74	14.37	0.00	2.95	0.00	42.92	18.96
Intramural	402	140.89	3.27	53.86	52.69	113.95	0.00	0.00	0.00	11.77	25.32
University	188	40.87	4.64	35.87	31.86	66.47	0.00	0.01	0.00	0.00	7.83
Vet. School and Power Plant	43	16.94	0.89	2.92	1.75	18.17	0.00	0.04	0.00	0.00	2.43
Pond	37	29.32	0.00	4.18	0.18	0.04	0.00	0.41	0.00	0.00	3.22
Gates	132	42.99	11.77	16.70	13.07	34.43	0.00	0.02	0.00	0.00	13.43
University CSO	199	38.75	0.00	29.12	33.48	88.69	0.00	0.00	0.00	0.00	8.84
Off Site	35	15.98	0.96	4.66	2.27	8.34	0.00	0.01	0.00	0.00	3.17
Airport	16	6.36	0.07	4.22	0.06	0.00	0.00	0.20	0.00	0.00	5.25
TOTAL:	1,194	361	22	168	151	344	0	4	0	55	88

Not surprisingly, this analysis indicates that most of the runoff volume (87%) is generated from impervious surfaces (Figure 3.9), although pervious areas (primarily athletic fields and urban lawn areas) also contribute. The largest drainage area (Intramural) generates the most runoff volume followed by University CSO and University drainage areas, which have the highest percentage of impervious cover.

FIG 3.9
Annual Runoff Volume by Impervious and Pervious Surfaces

	Amount of Impervious Surface within Drainage Area	Total Runoff from all Drainage Area Surfaces	Total Runoff from Impervious Surfaces Only	Percent of Total Runoff	Total Runoff from Pervious Surfaces Only	Percent of Total Runoff
Jordan Creek	13.6%	141 ac-ft	77 ac-ft	54%	65 ac-ft	46%
Intramural	56.8%	402 ac-ft	365 ac-ft	91%	37 ac-ft	9%
University	73.6%	188 ac-ft	180 ac-ft	96%	8 ac-ft	4%
Vet. School and Power Plant	62.9%	43 ac-ft	41 ac-ft	94%	2 ac-ft	6%
Pond	7.0%	37 ac-ft	34 ac-ft	90%	4 ac-ft	10%
Gates	51.8%	132 ac-ft	119 ac-ft	90%	13 ac-ft	10%
University CSO	72.1%	199 ac-ft	190 ac-ft	96%	9 ac-ft	4%
Off Site	53.1%	35 ac-ft	32 ac-ft	91%	3 ac-ft	9%
Airport	16.9%	16 ac-ft	11 ac-ft	66%	5 ac-ft	34%
TOTAL:		1,194 ac-ft	1,047 ac-ft	87.71%	147 ac-ft	12.29%

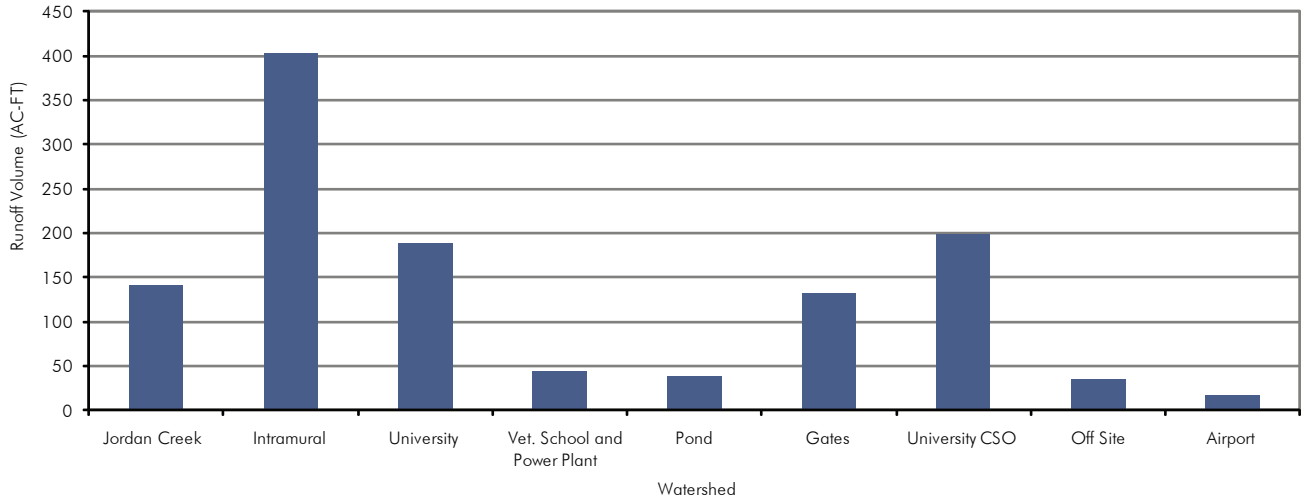
In drainage areas that have less impervious area, such as Jordan Creek and the Airport drainage areas, a greater percentage of the runoff is generated from the pervious surfaces such as athletic fields. This has implications in these areas regarding the amount of pollutants generated, as discussed in the next section and in more detail in Chapter 4.

As can be seen from Figure 3.8, paved parking lots are the single largest source of runoff, followed by buildings, and then by roads and sidewalks. These impervious surfaces generate the most runoff, but may have different amounts of pollutants in that runoff. Additionally, the amount of area covered in parking lots is likely to be reduced in the future, while buildings may increase and streetscapes may be redeveloped. As discussed in Chapter 4, this information can assist in decisions regarding the priority stormwater projects to improve water quality to the Gravel Pit.

For example, the large Intramural drainage area, with 141 acres of parking lots generates more runoff volume than any other drainage area, as seen in Figure 3.10. This area is also located in the upper portions of the campus drainage area. Reducing runoff from the Intramural parking lots can have a significant effect on the volume of water discharged to the Gravel Pit, and as discussed below, on water quality.

The second part of the campus analysis involved evaluating the amount of pollutants generated by the various land use types within the eight drainage areas. The intent of this effort is to identify the types of land use and areas where implementation of stormwater measures would provide the most benefit in terms of reduced pollutant discharges to Harrison Pond, Jordan Creek or the Wabash River. In other words, what are the most significant sources of pollutants

FIG 3.10
Total Annual Runoff Volumes by Drainage Area



and what are the most effective approaches to reduce pollutant load? (recommendations discussed in Chapter 4). Parking lots and roads tend to be the most pollutant-laden areas, whereas roofs tend to be cleaner (and a good source of water for groundwater recharge or for possible re-use) though not pollutant free.

Various types of impervious surfaces generate greater or lesser concentrations of pollutants. Non-point source (NPS) pollutants contained in stormwater runoff are a highly variable mixture. While the mix of pollutants will vary with land cover type, many pollutants move in association with or attached to particles—as suspended solids or as dissolved solutes.

Storm runoff scours and suspends many pollutants as particulates, which are flushed from the surface of rooftops, pavements and roads. Pollutants transported as particulates include total phosphorus, organic matter, organic nitrogen, metals and some herbicides and pesticides. Several types of NPS pollutants are soluble, or quickly become soluble in runoff. These include nitrates, ammonia, salts, many pesticides as well as hydrocarbons. While the load increases in heavy storms because the heavier volume and velocity of water can scour more pollutants from the land surface, the concentration of pollutants will actually decrease as they are diluted over a given storm. The total amount of pollutants carried by runoff is significantly greater in wet weather than in dry weather, and represents the major portion of the total annual discharge, whereas dry weather sampling reflects the steady discharge of soluble pollutants into the stream flow. Concentrations of oil, solids and other pollutants accumulate on surfaces between rain events. Runoff during the early period of a storm has been found to have a higher concentration of pollutants. This concentrated dirty water, carried off in the early part of a storm is known as "first flush". It is often the most polluted water, as documented by numerous studies and is concentrated within the first one inch of rainfall.

The parameter of Total Suspended Solids (TSS) has been used to evaluate the pollutant loads generated by the various land uses and drainage areas. By applying an average concentration of TSS (in mg/L) based on different land uses, combined with estimates of stormwater runoff, an estimate of the total pollutant loads generated from the various surfaces can be developed.

Stormwater monitoring can be challenging and pollutant loads can vary significantly. There are a number of studies and sources of estimated pollutant loads in stormwater runoff based on data collected from various land uses and climates in the U.S. The most comprehensive evaluation of this data is contained in the National Stormwater Quality Data Base (NSQD), which includes data from over 200 sites collected over a ten-year period, including a significant representation of mid-west climate areas. This data was collected and evaluated under EPA-sponsorship*, and for the purposes of the stormwater evaluation at Purdue, this data and supplemental data provided in the EPA evaluation was used to develop estimates of TSS "event mean concentration" for the different land uses at Purdue. These values are summarized in Figure 3.11, event mean concentration represents an average pollutant concentration over the small storm period, including the first flush effect. As can be seen from Figure 3.11, roads and parking lots tend to have higher concentrations of TSS in runoff than other areas.

FIG 3.11
Mean Event Concentrations of Total Suspended Solids by Land Use Type

Land Cover	TSS (Mg/L)
Paved Parking Lots	99
Unpaved Parking Lots	99
Roads	99
Sidewalk	60
Buildings	17
Wetland	
Forest Cover	48
Surface Water	
Athletic Fields	78
Urban Pervious	78

*Stormwater quality as described in the National Stormwater Quality Database (NSQD) R.E. Pitt and A. Maestre

The next step was to apply this data to the various land uses by watershed, based on the amount of annual runoff estimated from the various storms. This data is presented in Figure 3.12. Although some areas within a drainage area produce a significant amount of runoff, the total pollutant load may be less than that produced from another land use type. For example, in the University drainage area, buildings generate the most runoff of any single land use (66 Acre Feet from Figure 3.8), but generate much less pollutant load than parking lots (3,073 lbs. TSS vs. 12,250 lbs. TSS from parking lots).

These findings inform decisions regarding the priorities for the types and locations of stormwater measures in Chapter 4. First, however, information on types of stormwater BMPs and unit costs are provided in the following sections.

FIG 3.12
Annual Pollutant Load of Total Suspended Solids by Drainage Area and Land Use

	Parking Lots (lbs)	Unpaved Lots (lbs)	Roads (lbs)	Sidewalk (lbs)	Buildings (lbs)	Wetland (lbs)	Forest Cover (lbs)	Surface Water (lbs)	Athletic Fields (lbs)	Urban Pervious (lbs)
Jordan Creek	7,893	122	4,475	2,569	664	0	384	0	9,103	4,021
Intramural	37,929	881	14,499	8,596	5,268	0	0	0	2,496	5,370
University	11,002	1,248	9,656	5,198	3,073	0	1	0	0	1,662
University CSO	10,433	0	7,840	5,462	4,100	0	0	0	0	1,876
Off Site	4,303	259	1,256	370	386	0	2	0	0	673
Vet. School and Power Plant	4,560	239	787	286	840	0	5	0	0	515
Pond	7,893	0	1,124	30	2	0	53	0	0	682
Gates	11,574	3,170	4,495	2,133	1,591	0	3	0	0	2,849
Airport	1,713	19	1,136	10	0	0	26	0	0	1,114
Total (In pounds):	97,301	5,937	45,268	24,654	15,924	0	474	0	11,599	18,762

3.3 Best Management Practices

Stormwater Best Management Practices (BMPs) tend to fall into two general categories: "Structural" BMPs which tend to be built systems, preferably integrated into the landscape as part of a larger system, and "non-structural" BMPs, which tend to be practices or policies that can reduce both runoff volume and pollutant load. Both are equally important, however, non-structural BMPs should always be considered first. By first reducing impervious cover and improving the soil of pervious areas, the size of structural BMPs may be reduced.

Non-Structural Best Management Practice

- Soil Amendment

In urban stormwater management, one of the simplest tools for reducing stormwater runoff and pollutants is to maintain or restore the ability of soils to absorb rainfall. This is important in both landscaped areas and in vegetative stormwater features.

Soil particles have void spaces between them and the more densely compacted the soil particles are (the higher the bulk density) the less pore space will be available for the movement of water and air. (see FIG 3.5) Compaction and disturbance of soils in the upper horizon will eliminate macropores and significantly reduce air and water movement through soils. Correspondingly, runoff volumes and pollutant loads will increase. The health of both vegetation and fauna will decrease with reduced water and air flow. Activities such as regular mowing and vehicle traffic can significantly compact the surface horizon of an otherwise permeable landscape.

Existing soils can be amended to improve porosity, organic matter, and nutrients. This can be accomplished in a variety of ways. Existing soils can be decompacted and organic matter and other materials can be rototilled into existing soils to improve their absorptive properties and health. The addition of compost to lawns will improve porosity, reduce runoff, and correspondingly reduce pollutant loads.

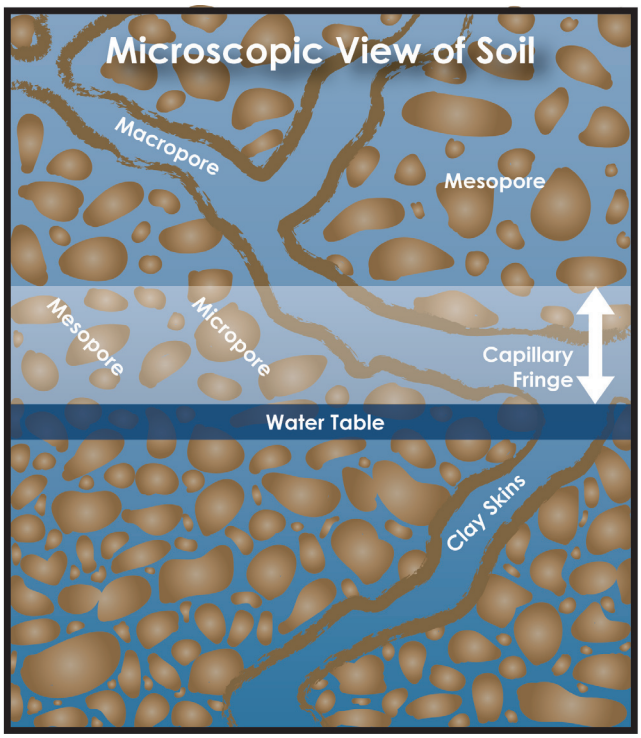


FIG 3.13

Non-Structural Best Management Practice Continued

- Land Cover Conversion

Changing landscaping cover can have a significant affect on stormwater runoff. Increasing the variation and roughness of the land surface with complex vegetation types such as tall grasses, shrubs, and trees slows down the velocity of stormwater runoff. By slowing the flow of runoff, a greater volume is able to soak into the soil, making it available for plant uptake. Lawn areas can be nearly as impervious as impervious surfaces, making them ideal for land cover conversion. Replacing lawn and turf grass with tall grasses and other meadow vegetation greatly reduces the volume and velocity of stormwater runoff, especially on slopes. Reforesting as much area as possible and especially steep slopes, with larger plant species, such as native shrubs and trees, is extremely valuable in restoring natural hydrologic functions.

- Minimize Impervious Cover

Virtually all rainfall that lands on impervious surfaces is converted to runoff, and so opportunities to reduce impervious cover should always be considered first. When rainfall lands on an impervious surface, it is heated to the temperature of the surface, picks up pollutants, and runs off to storm sewer systems and, ultimately, to natural water bodies. This runoff can damage natural waterways and alters the natural hydrologic cycle by preventing rainfall from being transpired by vegetation and permeating through soils to recharge groundwater. Development of land generally creates impervious surfaces, such as buildings, sidewalks, and streets. Even open spaces, such as lawn or turf, can act similarly to impervious surfaces if their soils are compacted during construction.

In all new projects, impervious surface areas should be built with the smallest footprint feasible. In order to achieve this, design techniques, such as stacking parking or building it beneath buildings, using porous pavements, and minimizing soil compaction, should be implemented. When retrofitting existing areas of development, reorganizing the site use, removing unnecessary impervious surfaces and replacing them with vegetation will reduce stormwater runoff from the site. This will reduce negative impacts like flooding, stream erosion and pollution, and groundwater recharge loss that are associated with impervious cover.

- Disconnect Impervious

Disconnecting impervious surfaces from conventional stormwater flow paths and instead, conveying the runoff to pervious areas reduces the burden on storm sewer systems and benefits the environment. Downspouts from roof areas can be directed to structural BMPs, such as: vegetated swales, rain gardens, or other vegetation to encourage absorption, evapotranspiration, and infiltration (However, care must always be taken to direct runoff away from basements or areas where it can cause flooding or damage). Roof runoff can also be captured and reused with rain barrels and cisterns. Impervious surfaces, such as parking lots, streets, and sidewalks can be graded towards vegetated areas rather than concentrating and convey it to inlets and pipes. Curb cuts and depressed curbs along road and sidewalk edges can be use to allow runoff to enter a vegetated system, such as a street bump-out, tree trench, or stormwater planter box. Dispersing stormwater runoff from impervious surfaces alleviates flooding, stream erosion, and water pollution.

Non-Structural Best Management Practices Continued

- Street Sweeping

FIG 3.14
Street Sweeper

Roadways are sources of several types of pollution that can impact water quality. Vehicles can leak oil, shed metals and emit soot onto streets. Trash and leaf-litter collects in gutters, and sediment can wash onto roads adjacent to construction areas. Typically, these pollutants are carried into the nearest inlet during rainfall events and eventually, they are transported through storm sewers to streams, wetlands, and other water bodies.

Street sweeping is a highly effective management practice to prevent water pollution, as it removes large and small debris from roadways. An effective street sweeping program should take seasonal variation, the road function, and varying pollutant loads into account, as these factors will determine the necessary frequency of sweeping and the type of sweeping equipment that should be used. At Purdue, aggressive street sweeping at the end of the winter season significantly reduces the sand and sediment conveyed to the storm system.

There are several different types of street sweeping machines used in various applications and yielding a range of results. Purdue should consider its needs in terms of types of pollutant removals desired from street and parking lot surfaces, as well as the other tradeoffs, when selecting a street sweeping methodology.

Mechanical broom sweeping machines are the most commonly used street sweeping technology, but they are not necessarily the most efficient. Mechanical broom sweepers use brooms to sweep debris onto a conveyor belt, which then transfers debris to a containment hopper. These machines have many moving parts and are more expensive to maintain as a result. Mechanical broom sweepers are not very efficient at picking up small particles, and they can also generate a lot of fine particle dust, which is a risk to human health. However, these machines are very effective at picking up packed materials, such as road millings, as well as at cleaning sand and other abrasives in after winter snow applications.

Vacuum sweepers use brooms like a mechanical broom sweeper but a suction device rather than a conveyor belt to collect street-dirt. Although they are better than mechanical broom sweepers, vacuum sweepers do continually generate dust containing fine particulates. Vacuum sweepers have less moving parts, making them less costly to maintain, but they have small suction tubes (8-14 inches in diameter) that can be easily clogged. They are effective at curbside cleaning but do not work well for cleaning wide paths.

Regenerative air sweepers work by “blasting” air onto the street to loosen both large and small particles that are then picked up with a vacuum. Most versions of these machines use water for dust suppression, which greatly reduces the amount of air pollution generated. These machines are highly effective at cleaning the entire pavement surface covered, although the water used in dust suppression can leave some very fine particulates

dissolved in pavement cracks. These machines cost much less to maintain compared to other sweeper machines, and they pick up both large and small debris. However, these machines are not appropriate for very heavy-duty applications, such as picking up millings and abrasives used in winter snow applications.

High efficiency dry vacuum sweepers are the latest technology in street sweeping. These machines use filters that can capture particulates as fine as 2.5 microns (PM-2.5), which makes them far more efficient than any other street sweeping devices at picking up fine particles. However, these machines are difficult to maintain and repair and about twice the cost of other street sweeping machines. High efficiency dry vacuum sweepers would be most efficiently used where hazardous materials are found and the maximum pollutant removal is desired.

Another option for street sweeping is using different types machines in tandem. For example, mechanical broom or vacuum sweepers can be used to pick up very heavy debris with a regenerative air sweeper following close behind to pick up more fine particle pollutants.

- Reduce Fertilization, Pesticide Application, and Irrigation

Large turf areas such as golf courses, lawns, and athletic play fields, are usually heavily fertilized, covered in pesticides, and irrigated to maintain a lush vegetated cover. However, the impacts of excessive fertilization, pesticide application, and irrigation on water quality and quantity are significant. Fertilizers and pesticides are easily washed from the surface of turf during rainfall events and irrigation. Fertilizers increase nutrient loadings in water bodies, which can cause eutrophication and, ultimately, anaerobic conditions that severely limit biodiversity. Pesticides are made from a variety of different chemicals that can have a number of negative effects on the health of a stream and living organisms. The presence of these chemicals in water bodies provides the potential for them entering potable water used by humans as well. Irrigating uses large volumes of potable water, thus, depleting what is available for other human uses. Irrigation also exacerbates the runoff of fertilizers and pesticides and can cause the salinization of soils.

Wherever possible, the use of fertilizers, pesticides, and irrigation on vegetated areas should be reduced or eliminated. Also, in areas where some fertilizer and pesticide use is essential, the possibility of using earth-friendly products should be explored. Compost and compost teas offer a viable alternative solution. Compost teas are actively brewed with microbial food and catalyst sources added to the solution. The aim of the brewing process is to extract beneficial microbes from the compost itself, followed by growing these populations of microbes during the 24- to 36-hour brew period. The compost provides the source of microbes, and the microbial food and catalyst amendments promote the growth and multiplication of microbes in the tea. Brews can be made with higher contents of bacteria or fungi depending on source material and targeted application area. Some examples of microbial food sources: molasses, kelp powder, and fish powder. Some examples of microbial catalysts: humic acid, yucca extract, and rock dust. This type of fertilization has been very successful at other colleges such as Harvard and in intensely used urban spaces like Battery Park in NYC.

Additionally, developing a land maintenance program with guidelines on proper management techniques and schedule can assist in implementing these best management practices.

Structural Best Management Practices

- Porous Pavement with Infiltration Bed

Porous pavement consists of a porous (permeable) surface of asphalt, concrete, or pavers overlain on a sub-surface, open-graded stone storage/infiltration bed. The underlying stone storage bed has a minimum void space of 40% and is a critical component of any porous pavement system.

Stormwater drains through the surface, is temporarily held in the voids of the stone bed and then slowly drains into the underlying, uncompacted soil mantle. The system is designed with an overflow outlet so that the water level will rise in the stone bed, but at no time does the water level rise to the pavement level. A layer of non-woven geotextile filter fabric separates the stone aggregate from the underlying soil, preventing the migration of fine particulate matter into the bed. The bed bottoms should be level and uncompacted. Porous pavement beds should not be placed on compacted fill material as infiltration will not occur.

Porous pavements reduce stormwater runoff by creating hardscape surfaces that are pervious, allowing rainfall to drain directly through pavement into a subsurface stormwater storage/infiltration bed. Runoff from roofs and other areas can also be directed into the stormwater bed. This reduces stormwater volume and pollutant loads, such as total suspended solids, metals, and oil and grease, from surfaces that are normally impervious. Porous asphalt and concrete surfaces provide better traction for walking paths in rain or snow conditions and are applicable to install to replace most roads, parking areas, walks, and other paved surfaces.

Purdue has a number of built examples of porous pavement including but not limited to; a parking strip on the west side of North Beering Drive, the new Marching Band Practice Field, the circular drop-off area behind the Horticulture Building, and the parking lot at Third and Russel.

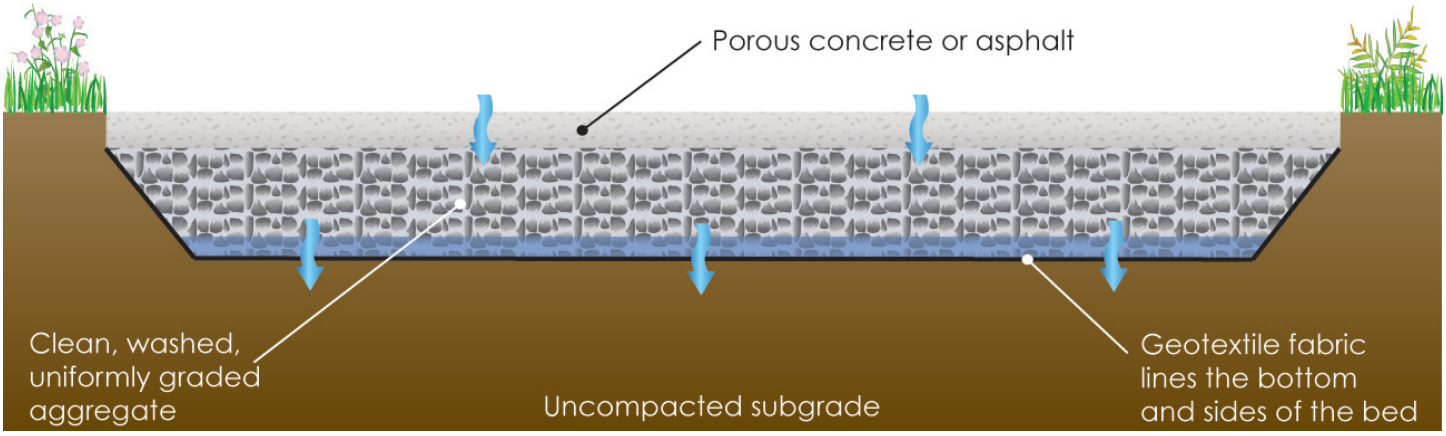


FIG 3.15
Porous Pavement with Infiltration Bed

Structural Best Management Practices Continued

- Subsurface Infiltration Bed

Subsurface infiltration beds are used for the temporary storage and infiltration of stormwater runoff and consist of a vegetated pervious soil layer or impervious pavement layer placed above a uniformly graded aggregate bed. Subsurface infiltration beds can be used in a variety of areas to reduce stormwater runoff and improve water quality but are especially suited for expansive generally flat opens spaces downhill from impervious areas. However, subsurface infiltration beds can be used on a slope if the beds are terraced or stepped. It is crucial though that the base of the bed remains level in all situations.

Subsurface infiltration beds are constructed by excavating to the necessary storage capacity while avoiding compaction of the bottom and sides of the bed so as not to affect infiltration rates. The beds are filled with clean-washed aggregate with a minimum of 40% void space wrapped in non-woven geotextile filter fabric to prevent fine soil particles from clogging the system. An outlet control structure is commonly used to provide control in the beds, usually in the form of an inlet box with an internal weir or a low-flow orifice. Also, detention basins may be eliminated or significantly reduced in size because the subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates.

Subsurface infiltration beds capture, store, and infiltrate/slowly release stormwater from impervious surfaces. Depending on the subsoil properties, runoff also has the potential to permeate through subsoils to reduce stormwater volume and pollutant loads, improving water quality. Another major benefit of subsurface infiltration beds is the preservation or creation of open space. Subsurface infiltration beds can be built beneath conventional impervious surfaces, porous pavements, athletic play fields, and many other surfaces. Also, because the infiltration system is below the frost line subsurface infiltration beds provide stormwater control year round. It is important that runoff directed to Subsurface Infiltration Beds be relatively clean (such as roof runoff) or be treated first through vegetation or structural measures to reduce sediment (which could clog beds over time).

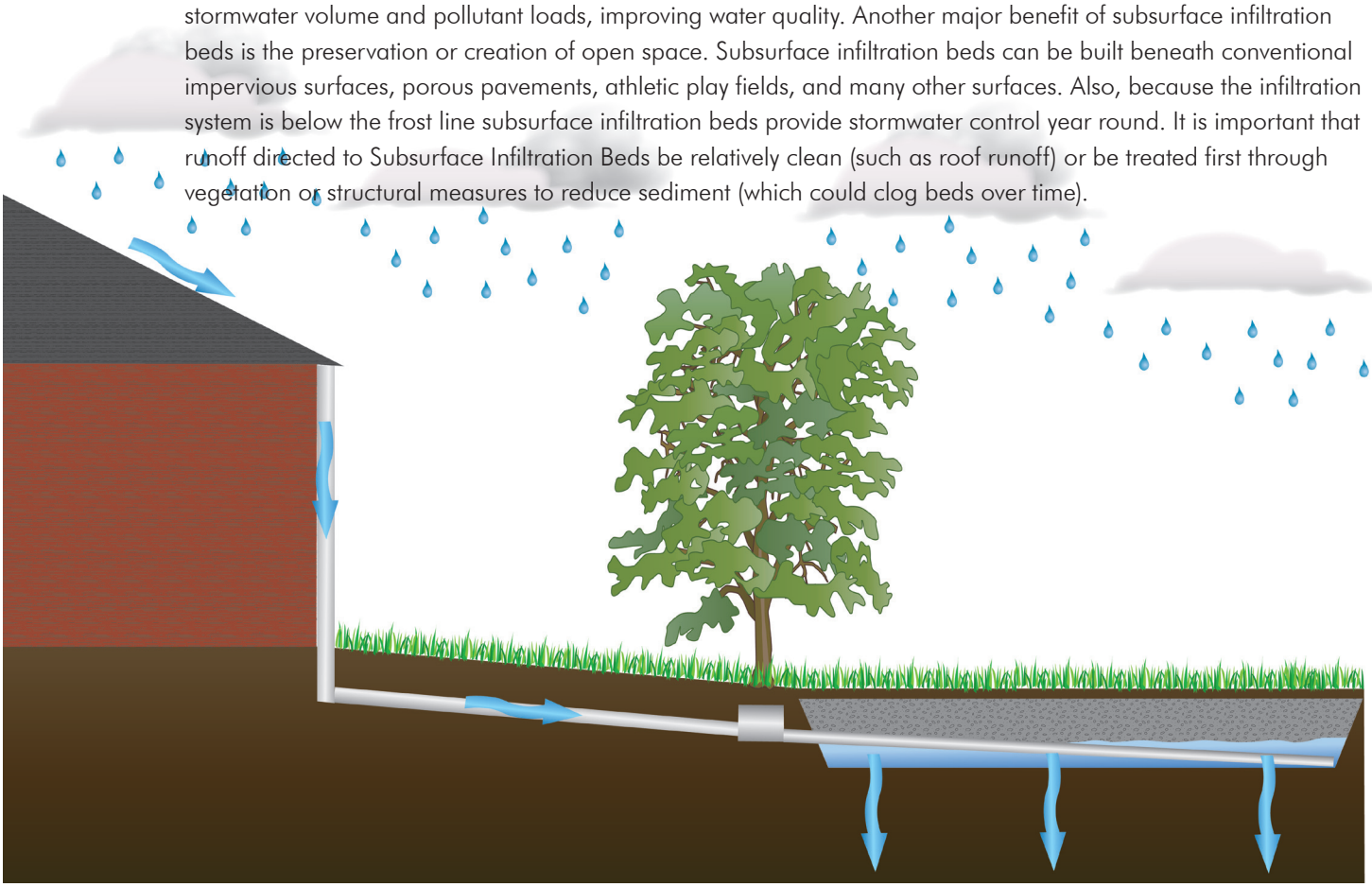


FIG 3.17
Subsurface Infiltration Bed

Structural Best Management Practices Continued

- Infiltration Trench

An infiltration trench is a perforated pipe in a level, linear stone trench that is used to capture, store, and infiltrate stormwater runoff. Infiltration trenches should be installed along a contour and typically consists of clean-washed, uniformly graded aggregate wrapped in non-woven geotextile filter fabric surrounding a perforated pipe. Infiltration trenches may be installed below a vegetated swale system to enhance the volume capacity provided that the infiltration rate of the soil is adequate. The bottom of an infiltration trench should be flat or very gently sloping, and the trench can be benched in sections to achieve a level trench bottom. Impervious drainage areas can be directed to an infiltration trench to distribute stormwater runoff.

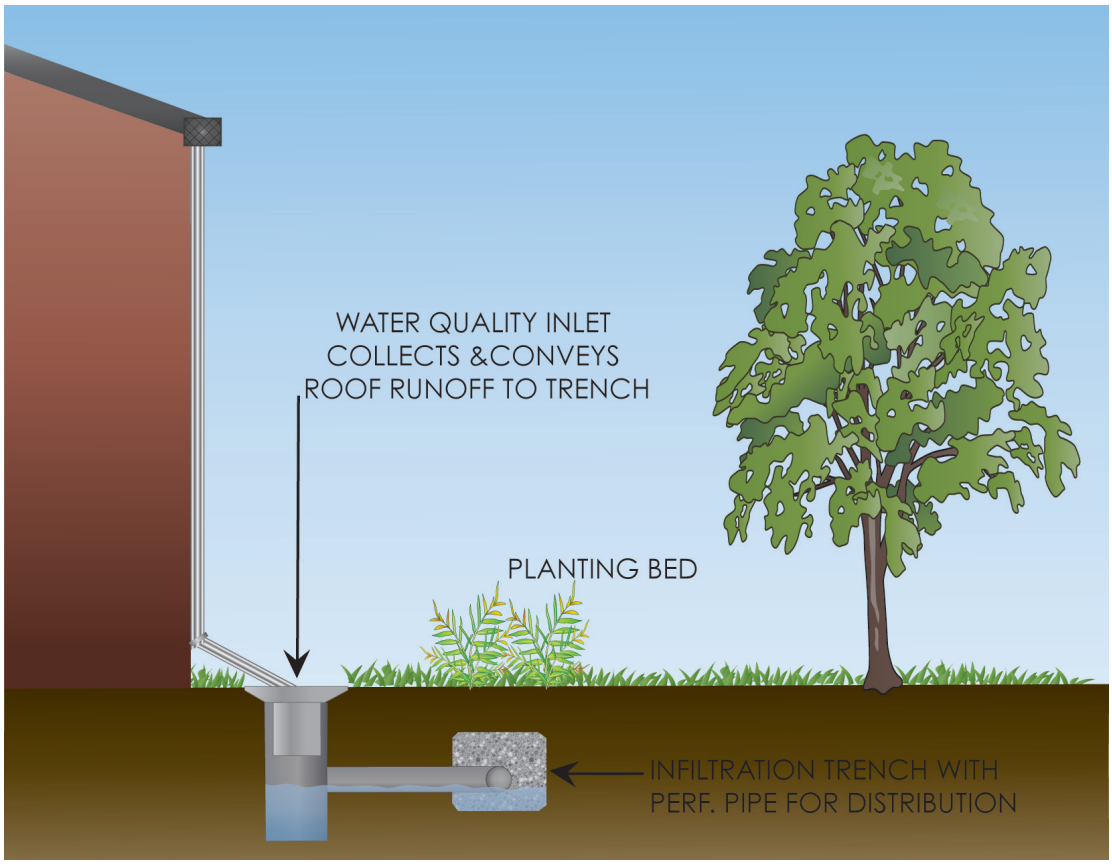


FIG 3.18
Infiltration Trench with Perforated Pipe

Structural Best Management Practices Continued

- Rain Garden or Bioretention

A rain garden, also called a bioretention area, is a shallow depression, filled with several feet of amended soils, that is planted with native vegetation to manage stormwater runoff from small drainage areas. The vegetation planted in rain gardens should be tolerant of salt (if receiving road and parking runoff), wet conditions, and dry conditions. Rain gardens manage small storm events and consist of inflow areas, shallow ponding areas over planting soil, a mulch layer, vegetation, and an overflow mechanism to take larger rainfall events to the stormwater system or other stormwater management features. Rain gardens can be constructed with a subsurface sand or gravel bed if additional stormwater storage capacity is required.

Rain gardens can be placed in lawn areas, in islands of paved areas, along roadways, and in other small open spaces adjacent to impervious surfaces. A rain garden can be sized and shaped to fit landscape restraints, and multiple bioretention areas can be placed throughout a site to capture runoff from various surfaces. If rain gardens are placed in areas that would be landscaped under a conventional stormwater plan, the additional cost of this type of feature is minimal.

Rain gardens provide a number of benefits. As runoff ponds at the surface, pollutants settle out, water filters through soils and vegetation, and water quality is improved. The volume of runoff is reduced through surface ponding, soil storage, evapotranspiration, and infiltration. Runoff velocity is also reduced when it enters a rain garden. Additionally, rain gardens enhance the aesthetics of a site and can provide habitat.

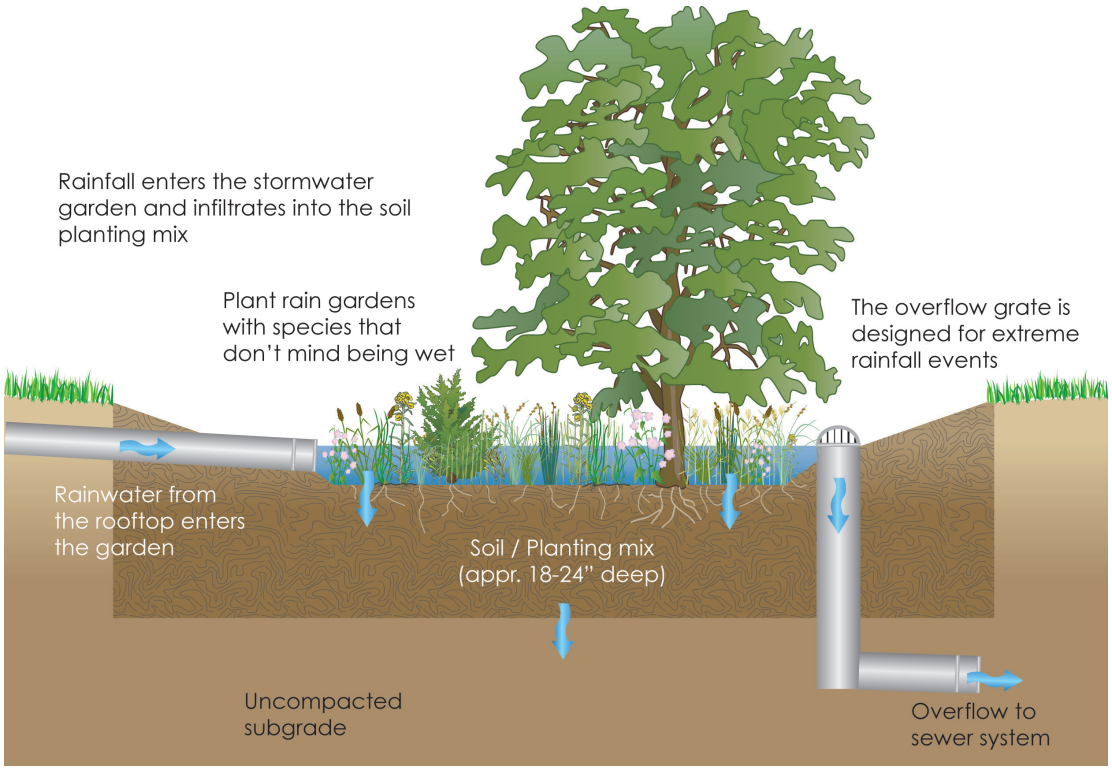


FIG 3.19
Raingarden

Structural Best Management Practices Continued

- Dry Well

A dry well is a small, subsurface infiltration pit or chamber that is used to collect roof runoff from the downspouts of individual buildings. A dry well can consist of an excavated pit filled with clean-washed aggregate wrapped in non-woven geotextile filter fabric, or it may be constructed from prefabricated storage chambers. Dry wells may be located under planting areas, paths, or other uses, and can be incorporated into the footprint of project disturbance. Dry wells can be used at any site where there is a structure with roof leaders, soils with a sufficient infiltration rate, and adequate space to place the dry well away from structure foundations.

Dry wells are meant to temporarily store and slowly infiltrate stormwater runoff. These systems can reduce the volume of runoff and rate entering the stormwater infrastructure system by disconnecting impervious roof surfaces. The infiltration of this runoff also recharges groundwater.

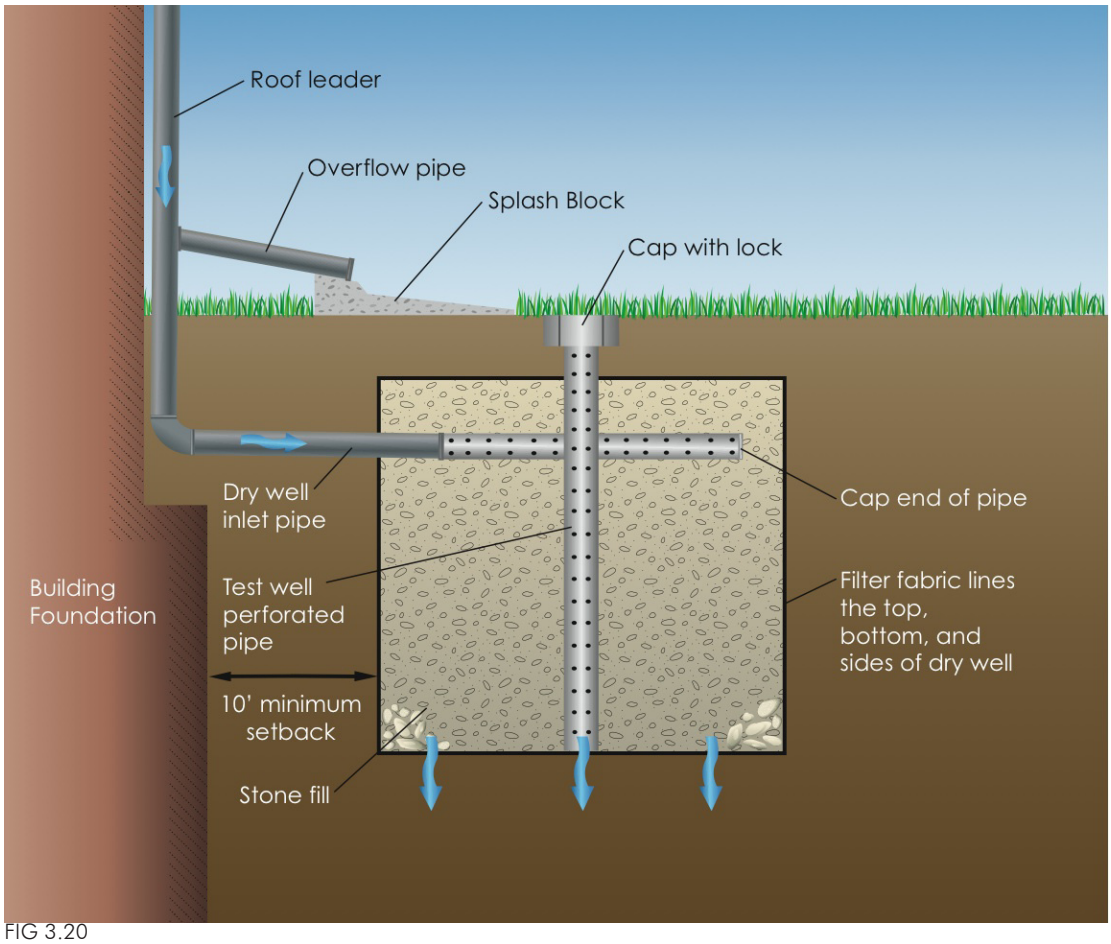


FIG 3.20
Dry Well

Structural Best Management Practices Continued

- Vegetated Swale

A vegetated swale is an uncompacted, densely vegetated, earthen channel that is generally shallow. The bottom of a vegetated swale should be at least 2 feet wide, and the side slopes should generally not exceed 3:1. Vegetated swales reduce the flow velocity and volume of stormwater, as well as improve water quality, and they can be used as a pretreatment mechanism that conveys runoff with fewer pollutants and at a slower rate to other stormwater management practices that are designed to manage greater stormwater volumes.

Vegetated swales are appropriate in areas with linear open space adjacent to impervious surfaces, such as around buildings, roadways, sidewalks, and parking lots. The limiting factor to implementing a vegetated swale is the availability of a long strip of land that is at an appropriate grade to convey stormwater runoff without erosion.

Natural, gently sloping low areas of a site usually make ideal areas to locate a vegetated swale; however, infiltration potential in these areas may not be as high as other areas. Vegetated swales are a desirable alternative to curbs and gutters along parking lots and roads.

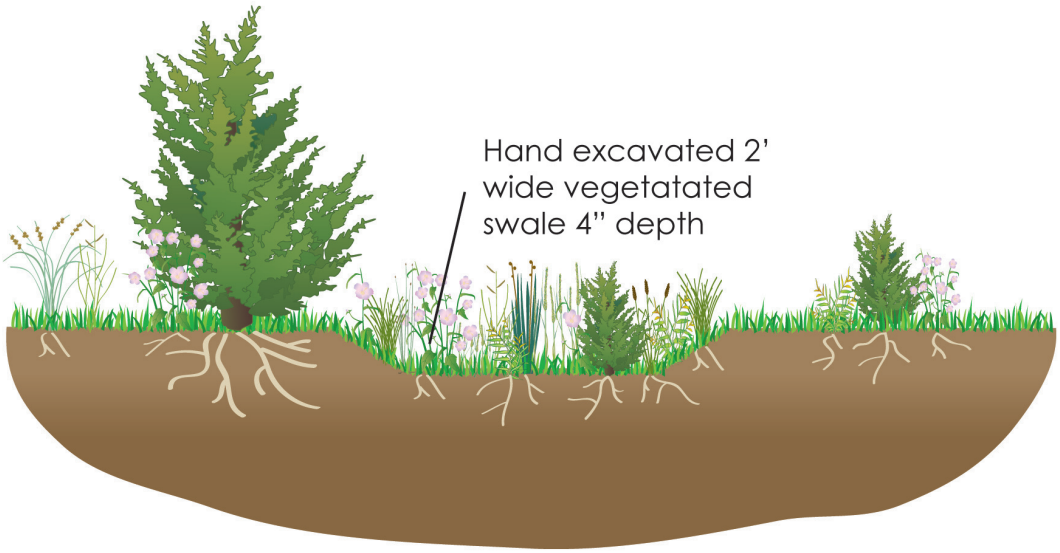


FIG 3.21
Vegetated Swale

Vegetated swales should be planted with native grasses, shrubs, and/or trees that are drought and salt tolerant and that have a high potential for water and pollutant uptake. Swale soils should be appropriate to support dense vegetation, infiltration, and pollutant removal. If the desired swale area lacks adequate soils, they should be removed and replaced with loamy to sandy amended soils with a high alkalinity. Check dams constructed from wood, concrete, or stone in a vegetated swale can slow the rate of flow, preventing erosion and providing temporary detention to improve the performance of the system. They also improve the performance of the swale in terms of runoff quantity and quality mitigation.

Structural Best Management Practices Continued

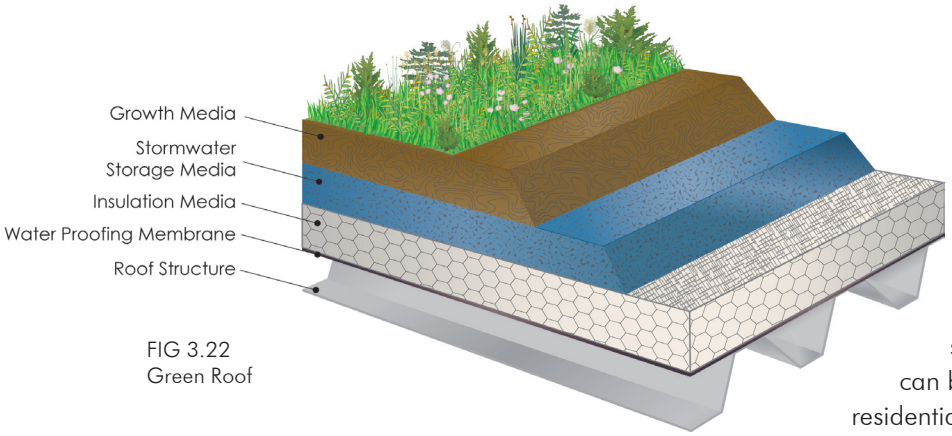


FIG 3.22
Green Roof

- Green Roof

Green roofs are engineered, vegetated systems installed on roofs to control stormwater, mitigate pollution, reduce urban heat island effect and provide habitat and aesthetics. Green roofs can be established on both existing and new roofs. This depends mainly on the structural capacity of the building. They can be implemented in all areas including residential, commercial, and industrial sites. The strength of the supporting structure, as well as the size, slope, height, and directional orientation of the roof, are critical factors that must be assessed before installation of a green roof.

Green roofs fall into two categories. Extensive green roofs consist of thin layers of soil and lightweight plantings (.8"- 6") suited to thin media like sedums, grasses and other small plants and are un-irrigated. Intensive green roofs consist of deeper layers of soil (6" or more) that can support larger plants including trees and shrubs and are often irrigated.

Green roofs provide many benefits, such as controlling stormwater runoff, trapping dust and breaking down air-borne pollutants, and creating wildlife habitat. Green roofs also mitigate urban heat island effects, recycle carbon, and conserve energy by stabilizing the indoor temperature and humidity of buildings.

- Capture and Reuse

Rooftops generate a large volume stormwater runoff that has the potential to be detained and reused. There are a number of storage options available for capturing rooftop runoff for reuse. Cisterns, rain barrels, and other vertical storage structures are simply large containers that store precipitation draining via the external

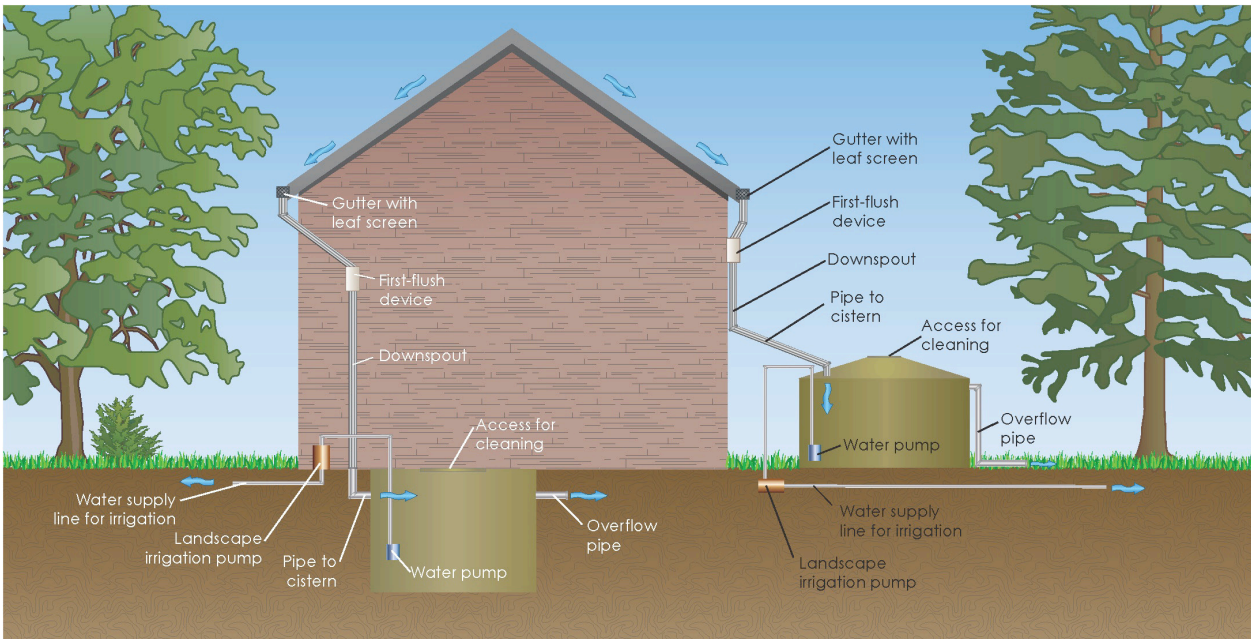


FIG 3.23
Rainwater Capture and Reuse Systems

roof leaders of buildings. This stored runoff can then be used for passive irrigation, fire protection, or grey water reuse, such as flushing toilets. Reusing runoff reduces the burden on stormwater sewer infrastructure by reducing the volume of stormwater runoff generated from buildings and other impervious surfaces. In turn, the demand for potable sources of water for uses such as irrigation and toilet flushing is reduced.

It is necessary to consider the volume of water coming off of a drainage area and the reuse demand for stored water in order to properly size a storage device. Another consideration in reusing runoff is that the stored water must be used or discharged before next storm event. Also, an overflow or bypass of large storm events must be provided on the storage device, and screens, covers, or other measures should be implemented to prevent breeding of mosquitoes and other insects. Ideally, rain barrels and cisterns should be placed up-gradient of reuse areas may reduce or eliminate pumping needs. Stormwater runoff is not suitable for reuse as potable water unless adequate water quality treatment is provided but can be used for irrigation.

- Tree Trench

A tree trench is a linear stormwater management feature consisting of trees planted in several feet of amended planting soils designed to capture runoff from adjacent impervious areas. Tree trenches are applicable in linear areas with limited space to manage stormwater, such as along streets. In addition to managing stormwater, tree trenches enhance aesthetics by providing greening, improve air quality, and reduce the urban heat island effect.

Tree trenches should be designed with a shallow surface depression and several feet of absorbent planting soils. Subsurface stone storage beds can also be place below the planting soils for additional storage capacity. Small drainage areas can be conveyed to tree trenches surficially, through curb cuts or trench drains, or piped directly into the planting soils and stone bed. Overflow structures should be provided within the tree trench to both bring runoff into the soil and stone beds and to overflow the entire tree trench system to another stormwater management feature or sewer system to prevent system failure in large storm events. Tree trenches are one of the most effective stormwater measures in highly developed areas and along roads. By providing greater soil availability than a standard tree pit, tree trenches facilitate healthier trees.

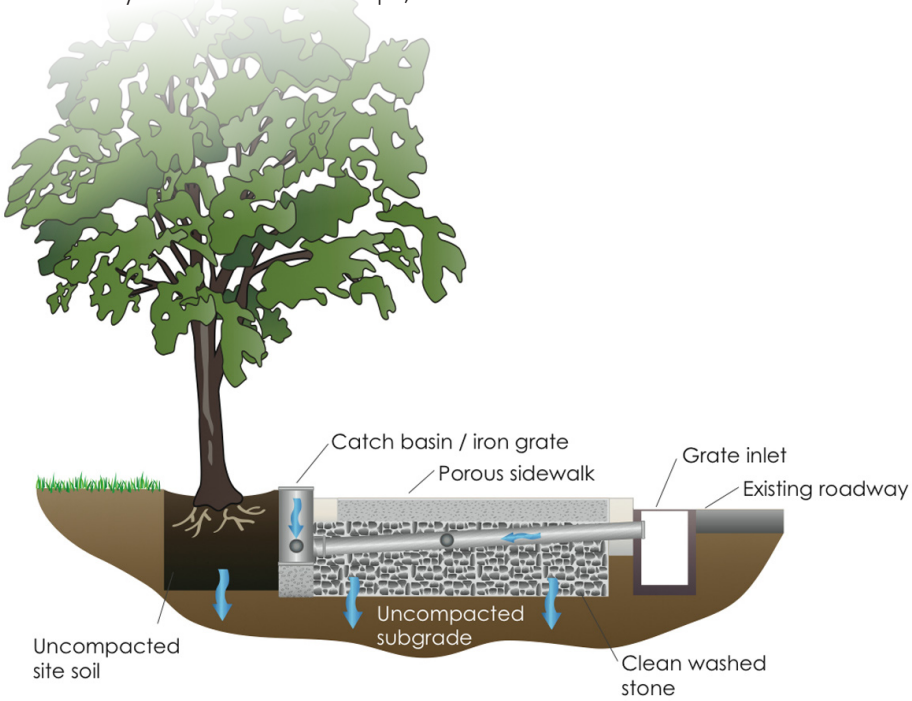


FIG 3.24
Tree Trench

Structural Best Management Practices Continued

- Water Quality Best Management Practices

Water quality best management practices (BMPs) are filters, structures, products, or surface features that improve the quality of stormwater runoff by removing pollutants, such as sediment, oil, leaves, and litter from stormwater runoff. Several different methods and products are available to remove pollutants from stormwater runoff. Water quality BMPs are useful for pre-treating stormwater before it is conveyed to other downstream stormwater BMPs, such as infiltration beds or vegetated systems. If runoff is cleaned before coming into these systems, it will enhance their functioning and lifespan.

Water quality inserts are placed inside of existing stormwater inlets where runoff enters the inlet. These BMPs, also called catch basin inlets, can be in the form of a tray, bag, or basket. These filters prevent large debris from entering the inlet, which prevents clogging.

Conventional stormwater inlets may also be modified to create a settling sump by lowering the bottom of the inlet below the invert of the outlet pipe. These sumps allow sediment and other particles to passively settle out of runoff. Weep holes should be placed at the bottom of the settling sump to prevent excessive storage of stormwater. Also, sediment forebays, which are small surface depressions that allow sediment to settle out of stormwater, can be used to improve water quality.

There are several other manufactured products available that filter stormwater, such as a Vortex separator that mechanically separates pollutants from runoff by centrifugal force. The use of these measures should be carefully evaluated in terms of anticipated flow rates and pollutant removal, as other vegetated measures may be more cost effective.

The type and size of water quality insert needed for a particular drainage area should be chosen based on expected pollutant loadings and runoff volumes. These methods may not be necessary in all areas but should be used in pollution "hot spots," such as roadways, parking lots, industrial and commercial sites and other areas that have particularly high pollutant loads. All water quality BMPs must be regularly maintained to ensure proper functioning and should be installed in the last phase of construction to avoid clogging with excessive sediment and other pollutants generated from construction activities.

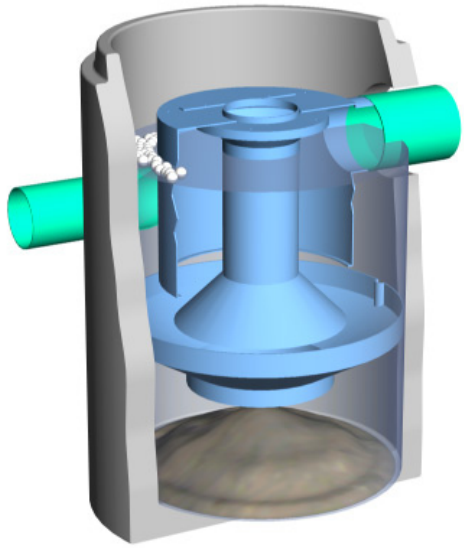


FIG 3.25
Vortex Separator - www.hydro-international.biz

Structural Best Management Practices Continued

- Street Bump-outs

A street bump-out, or curb extension, is an extension of typical curb that creates an open space that is used to temporarily store, filter, and potentially infiltrate runoff. Street bump-outs reduce stormwater flow velocity and volume, as well as improve water quality. A street bump-out can be implemented in any street of adequate width but are often most effective at intersections to collect as much runoff as possible while improving pedestrian conditions. In addition to enhancing street aesthetics and providing stormwater management, street bump-outs provide traffic calming, which improves pedestrian safety.

Street bump-outs are constructed out of formed concrete curb, adjacent to the standard curb line in a long narrow strip with rounded ends. The center area of the bump-out should be excavated and filled with modified soils. The bottom of the planting area can be lined with an under-drain if infiltration is not feasible at the site. The soil mix should be high in nutrients, organic matter, and absorptive properties. Plants, which may be grasses, shrubs, and/or trees, selected for a vegetated swale should be native, salt tolerant, and have a high potential for pollutant removal. Runoff can be directed into a street-bump out through a trench drain, sheet flow through curb cuts, or through storm pipe. An overflow/outlet is required to manage large storm events. Bump-outs are most cost effective for stormwater management along streets with minimal grade change (4% or less).

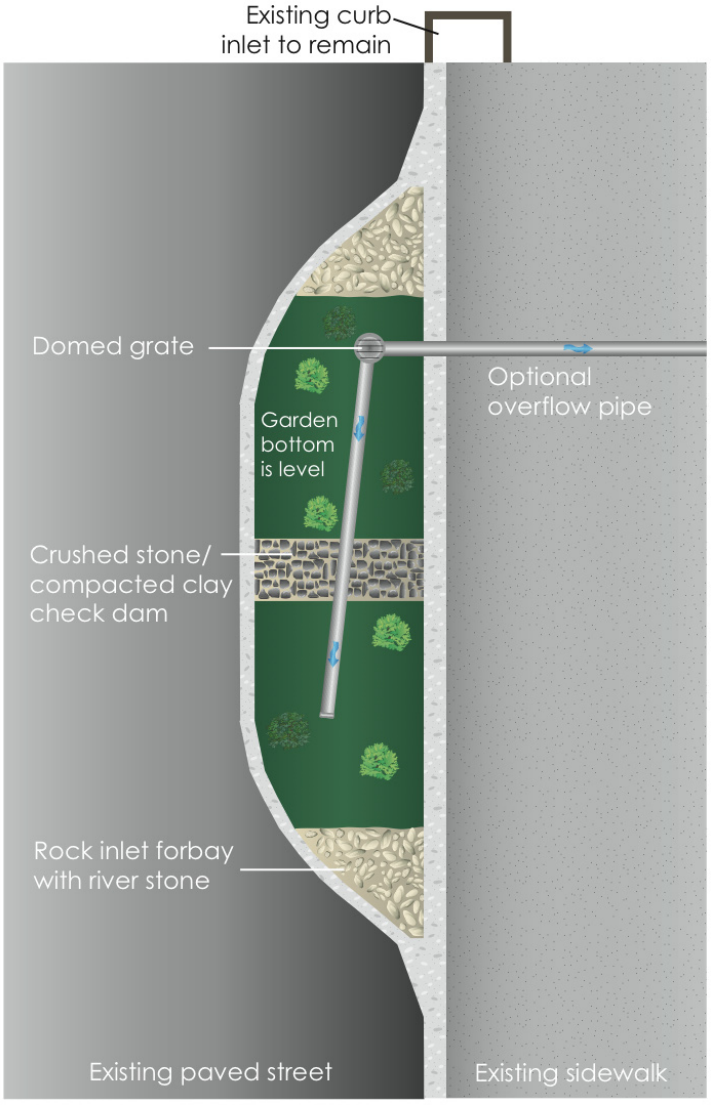


FIG 3.26
Street Bump-Out

Structural Best Management Practices Continued

- Stormwater Planter Boxes

A stormwater planter box is a structure, usually formed from concrete or brick, which is filled with absorbent soils and plants in order to temporarily store and treat rainwater. Planter boxes are placed adjacent to the external downspouts of a building to receive rooftop runoff. Planter boxes can be designed with open bottoms to infiltrate water, or they may be designed to discharge directly to the storm sewer system after temporarily detaining runoff. All planter boxes must be designed with an overflow connection to a secondary stormwater management system or storm sewer.

Planter boxes capture runoff from small storm events, usually from roof areas. Planter boxes provide water quality treatment, in addition to slowing and reducing the discharge of small rainfall events. Planter boxes provide an opportunity for stormwater management in densely developed areas. These aesthetic features can reduce stormwater peak rates and volume through capturing runoff from impervious surfaces. Additionally, they reduce the need for landscape irrigation. Planter boxes can be highly cost effective in very urban environments.

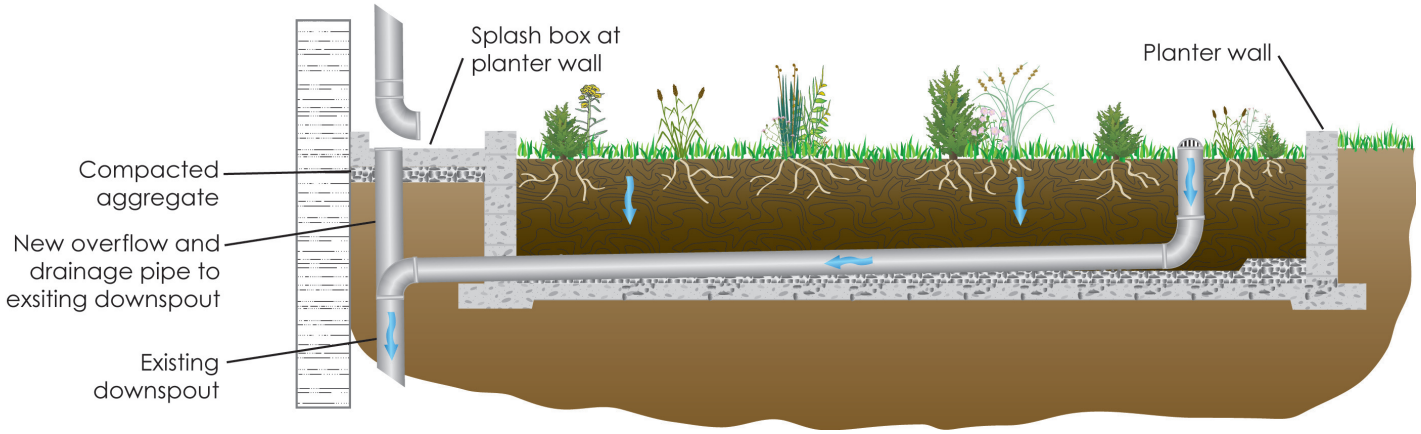


FIG 3.27
Storm Water Planter Boxes

3.4 Cost and Benefits

With any investment, there are costs and benefits leading to trade-offs that guide the decision making process. Investing in stormwater management measures is no different. There are numerous benefits to installing stormwater best management practices, but there are also expenses associated with their design, construction, and maintenance.

At Purdue, the decision on what stormwater elements are most desirable must be made on site-by-site basis and will be influenced by such things as space constraints, visibility of the site, location of the site within the greater campus context, the feasibility of construction, and, of course, the cost. From the perspective of cost effectiveness, tools for informing this decision making process are presented below.

In Figure 3.28, costs associated with various stormwater best management practices are shown. The costs in this table were derived from actual construction projects and reflect the cost per square foot of constructing the different stormwater elements. It should be noted that these unit costs are concept level estimates only that should be used for general decision making. A professional design team and cost estimator will be necessary for site specific design projects.

FIG 3.28
BMP Cost per Square Foot

		Stone Storage (40% Void Space)	Soil Storage (20% Void Space)	Surface Storage	Total		
BMP Type	Cost/SF BMP Area	CF Storage/SF BMP Area	CF Storage/SF BMP Area	CF Storage/SF BMP Area	CF Storage/SF BMP Area	$/CF of Storage	$/Acre of Drainage Area Captured
Porous Asphalt (18"-24" Aggregate Bed)	$8.51	0.8	0	0	0.80	$10.64	$38,621
Bioswale (24" Soil)	$8.88	0	0.4	0.33	0.73	$12.17	$44,164
Infiltration Trench (18" Aggregate)	$7.79	0.6	0	0	0.60	$12.98	$47,108
Porous Concrete (18"-24" Aggregate Bed)	$13.04	0.8	0	0	0.80	$16.30	$59,174
Tree Trench w/Stone (24" Soil, 12" Aggregate)	$14.57	0.4	0.4	0	0.80	$18.21	$66,097
Porous Asphalt (8" Aggregate Bed)	$5.00	0.27	0	0	0.27	$18.77	$68,149
Rain Garden w/Stone (24" Soil, 12" Aggregate)	$22.84	0.4	0.4	0.33	1.13	$20.21	$73,363
Porous Pavers (18"-24" Aggregate Bed)	$16.66	0.8	0	0	0.80	$20.83	$75,595
Rain Garden (24" Soil)	$15.87	0	0.4	0.33	0.73	$21.73	$78,898
Infiltration Planter Box (1' Stone, 2' Soil)	$26.53	0.4	0.4	0.33	1.13	$23.48	$85,240
Tree Trench w/o Stone (36" Soil)	$15.20	0	0.6	0	0.60	$25.33	$91,950
Infiltration Bed (12" Aggregate) w/Turf	$11.36	0.4	0	0	0.40	$28.39	$103,057
Vegetated Infiltration Bed (24" Aggregate Bed)	$24.41	0.8	0	0	0.80	$30.51	$110,765
Flow-Through Planter Box (0.5' Stone, 2.5' Soil)	$35.97	0.2	0.5	0.33	1.03	$34.93	$126,784
Porous Concrete (8" Aggregate Bed)	$9.53	0.27	0	0	0.27	$35.78	$129,869
Grass Pavers (8" Sub-base)	$8.27	0.20	0	0	0.20	$41.39	$150,258
Vegetated Infiltration Bed (12" Aggregate Bed)	$17.95	0.4	0	0	0.40	$44.88	$162,931
Porous Pavers (8" Aggregate Bed)	$13.15	0.27	0	0	0.27	$49.36	$179,182
Green Roof	$15.00	0	0.016666667	0	0.02	$900.00	$3,267,000

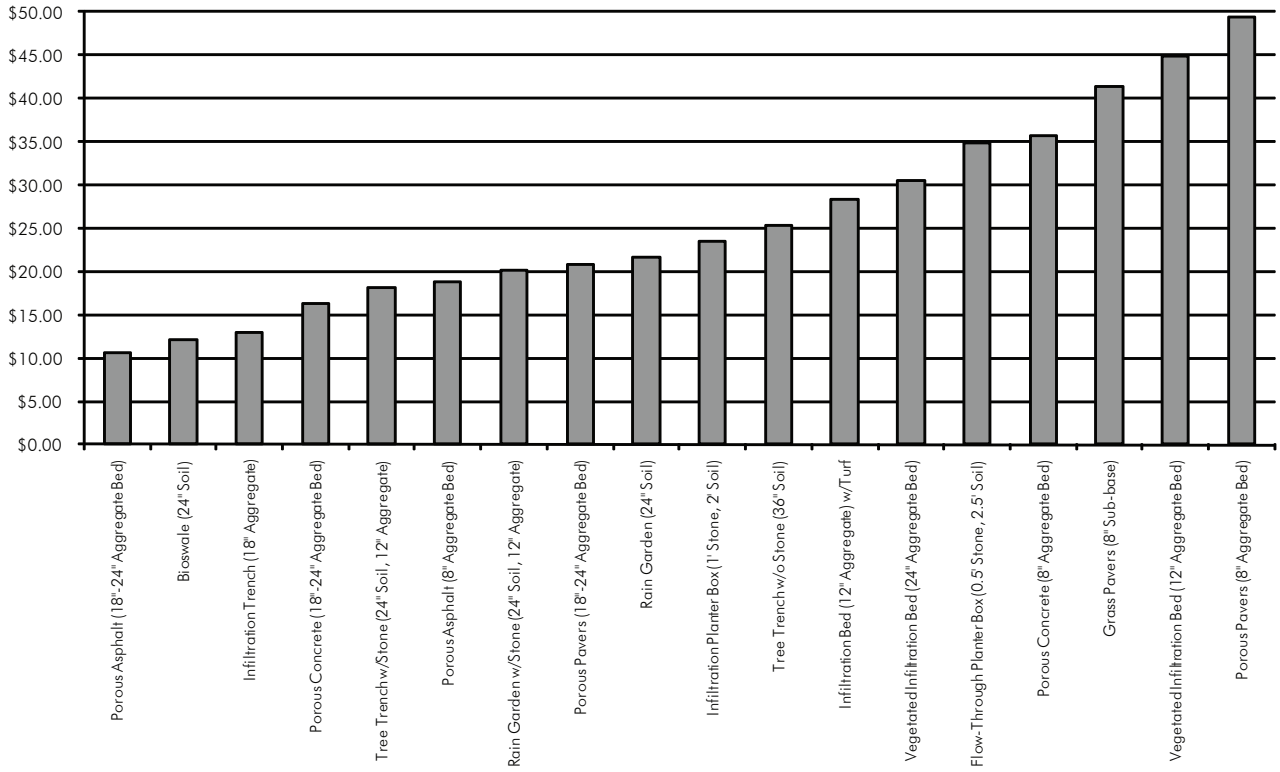
*Costs were originally derived from projects constructed in Pennsylvania and other Eastern states and adjusted to reflect costs for similar projects in Indiana.

Figure 3.29 shows the costs of BMPs based on the cost per cubic foot of stormwater runoff captured per square foot of BMP area. In calculating the volume of stormwater captured by each type of BMP, the volume of stone, soil, and surface storage per square foot of BMP area was calculated for each type. Some BMPs handle more water per square foot of area than others. Because water can only be stored in the void space provided by these materials, it was assumed that stone can store 40% of water per unit volume, soil can store 20% of water per unit volume, and surface storage is 100% per unit volume. Like the figure 3.28, this figure 3.29 is useful in deciding what stormwater elements are the most cost effective. However, this information should not be the only tool used in designing a site.

Every site imparts its own unique opportunities and challenges when it comes to integrating stormwater management practices into the design, so the least expensive BMPs according to the tables above, like porous pavements and bioswales, may not be applicable to construct in every area. For example, in space constrained areas in the Campus Core, small open spaces adjacent to buildings may lend themselves better to flow-through planter boxes or cisterns. Moreover, in areas that are needed for athletic activities, such as the practice fields near the Mackey Arena, it is not feasible to install rain gardens or planter boxes. Instead, these areas are ideal for installing subsurface infiltration beds.

When comparing the costs and benefits of stormwater BMPs, it is fairly straightforward to compare construction costs to BMP area or the volume of runoff captured. However, capturing stormwater runoff is not the only benefit that these measures provide. In addition to managing stormwater, measures such as rain gardens, planter boxes, bump-outs, bioswales, and tree trenches, enhance site aesthetics, improve the quality of life, provide traffic calming, reduce air pollution and the urban heat island effect. If these benefits could be quantified and included in this cost analysis, the cost of stormwater BMPs would look much smaller when compared to the benefits they provide.

FIG 3.29
BMP Cost per Cubic Foot of Stormwater Storage



New Plantings in front of Wiley Dining Court.