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Stormwater Management: Rain Gardens to Bioretention Areas

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Stormwater Management: Rain Gardens to Bioretention Areas

Minnesota residential rain garden (photo by Lynda Ellis)

As a natural stormwater management system, rain gardens are increasing in popularity and are delineated by a number of different names, based on purpose and location. Rain gardens, or rainwater gardens, are generally residential and are located on a depression or downside of a slope. A rain garden collects stormwater and helps filter out pollutants. A larger, more complex rain garden is referred to as a bioretention facility, which treats stormwater before it is infiltrated or discharged. A third water management system, the bioswale (ditch) or bioslope (slope), moves stormwater from one area to another, in addition to filtering out sediment and pollutants.

Rain Garden

A rain garden is a modest-sized, residential area created specifically to capture and treat water runoff from rain storms or melting snow. A rain garden may also be referred to as a stormwater marsh, bioretention pond (or cell), or planted swale. Landscaping a depression or slope as a rain garden adds beauty to a yard as well as serving as a sanctuary for butterflies, birds, and bees. Also, a strategically placed rain garden will help prevent erosion by holding soil in place with the deep roots of the plants. Most importantly, it allows rainwater runoff to infiltrate naturally through the soil, preventing the flow across such impermeable surfaces as roofs, driveways, and roads, from draining directly into lakes, streams or ponds. Runoff from impenetrable surfaces is a source of numerous pollutants, including oil, pesticides, herbicides, trace metals, hydrocarbons, and volatile organic compounds. Additionally, a rain garden is a method to optimize use of rainfall, thus reducing or avoiding the need for added irrigation. Another benefit is the decrease in ambient air and runoff temperature accomplished by a rain garden.

Residential rain gardens were first developed in 1990 by Dick Brinker, a developer building a new housing subdivision in Somerset, Maryland. He decided to replace the traditional stormwater management pond with residential rain gardens. Each house's property included a 300-400 square foot rain garden in place of curbs, sidewalks, and gutters, which would have cost $400,000. This system was highly cost-effective and functionally efficient – the planted rain gardens cost $100,000 to install, and flow monitoring showed they resulted in a 75-80% reduction in stormwater runoff during a normal rainfall.

Before constructing a rain garden, it's best to **check local municipal and county regulations**. For example, some cities have specific distance requirements for placing a rain garden near a lot line. Of critical importance is to avoid locating the garden over any utilities, underground irrigation lines, a septic tank, a wellhead, or inground irrigation lines. The national number for locating utilities is 811; for Minnesota, call Gopher State One Call, 1-800-252-1166. For modest-sized rain gardens (usually less than 1,000 square feet), a permit is generally not required. There may also be local regulations on maintaining the garden, such as the type of vegetation or appropriate seasonal cutting. Some cities or counties offer financial assistance or other incentives for installation of rain gardens, and some offer site assessment services (e.g. Anoka Conservation District).

A rain garden should be **located** in a depression or on a slope at least 10 feet from a house or other structure and should be fed by one or two downspouts (Fig. 1). If located on a slope, the decline of the site should be 2-12% and will require a berm on the downhill side to protect the ponding area on top of the garden. A rain garden may be designed and planted for sunny or shady areas but is not recommended for wet spots that retain water for extended periods. If there are trees in the area of the rain garden, it is important to ensure that they can tolerate wet soil conditions for lengthy periods of time.

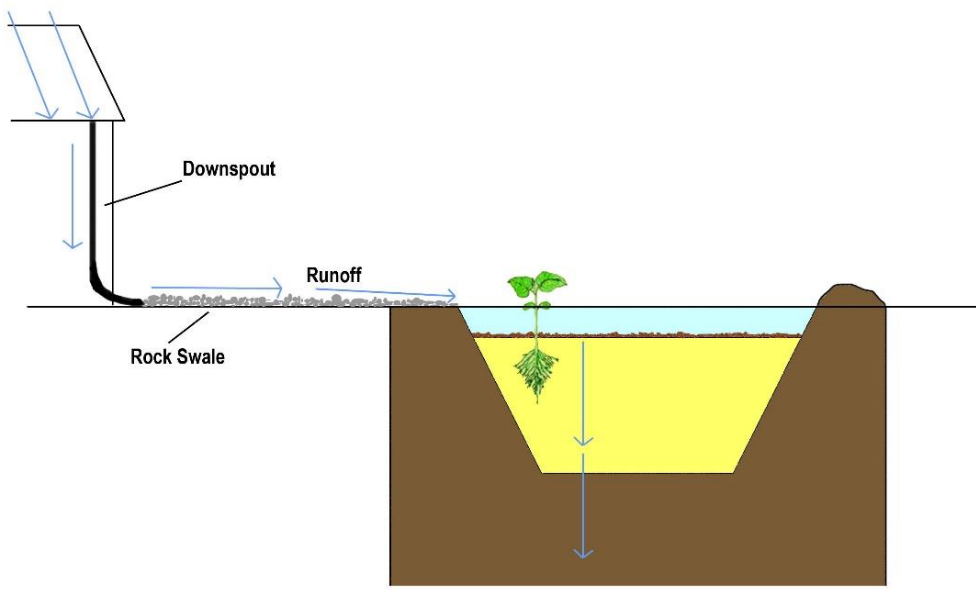


Fig 1. Cross-sectional diagram of a residential rain garden.

Maximum channelling of storm water to the rain garden may be accomplished by building a trough lined with rock (swale) or vegetation (bioswale) from a downspout or by an underground PVC pipe. Rainfall enters the rain garden via a defined inlet with a flow-attentuation mechansim in the basin to minimize soil erosion. A rock-lined overflow will disperse excess water during a heavy rain event and will prevent erosion, particularly during the first years when the vegetation has not yet matured.

Rain gardens designed to capture street runoff may include a curb-cut, a break in the curb which allows stormwater to enter the garden from the street. This can include a pretreatment chamber to collect debris and sediment from the street and addition of a retaining wall on the side opposite the curb to maximize the volume of water stored in the garden. The landowner should check with local government to determine the process for creating a curb-cut rain garden and, in many cases, the construction costs are covered by municipal funds.

The suggested **area** of a residential rain garden is approximately 20-30% of the size of the driveway, patio, or roof that is draining into it. A typical size is 100-400 square feet, but a rain garden of any size can have an impact on stormwater control. The ideal shape is oblong and positioned perpendicular to the slope of the land, allowing it to capture the maximum amount of rainfall.

Water **inlets and outlets** for a rain garden need to be stabilized to prevent erosion. For water entering a garden via a downspout, pipe or bioswale, a level spreader is used to distribute inflow evenly. If water velocity into the garden is less than 1-2 feet per second, there is little chance for erosion. Excess water will leave the ponding area from the backside of the basin. This works well if the perimeter is undisturbed soil with a turf cover; if the surrounding soil has been altered, rocks or turf reinforcement mats (polypropylene net) can be used to line the outlet area. A 2005 study of rain garden effectiveness found that a surrounding berm (in this case, six inches) was likely the most critical feature for controlling runoff and providing infiltration of the soil.

The **depth of the underground filtering area** of a rain garden is normally 2-3 feet. The ponding area is typically 6-12 inches deep but should not be more than 18 inches deep in order to prevent plants from being totally submerged after a rain event. The base of the water-capturing basin needs to be level to allow drainage into the filtering area and then into native soil below. The bottom of the filtering area should be at least 2-5 feet above the water table; if you are unsure of the depth of the water table, it is suggested that an eight-foot-deep soil boring be done to determine this. If the water table is shallower than 2 feet, an underdrain is needed for the rain garden to function correctly.

The **composition of the filtering area** of a rain garden needs to allow water to pass through quickly, ideally draining in 24-48 hours. Native soil types vary, so a soil test is recommended. An infiltration or ribbon soil test may be performed, but a simple method recommended by the University of Minnesota Extension Service is to fill a hole, 6 inches deep and 12 inches across, with water and ensure that it drains in 24 hours. If water drains within 24 hours, a rain garden may be added to a depression or slope by tilling the native soil 6-12 inches in depth (Fig. 2). If the water in the test hole does not drain in 24 hours, it is suggested to replace the top 2-3 feet of soil with a "rain garden mix" (Fig. 3): 50-60% sand, 20-30% topsoil (no clay), 20-30% compost.

Alternatively, the *Minnesota Stormwater Manual* recommends a special engineered medium consisting primarily of sand plus some clay and compost. The sand allows rapid water drainage while the clay and compost support the plants as well as adsorb pollutants. Recommended filtering media in other areas of the country will vary, some including gravel or hardwood bark.

In locations where water infiltration is excessively slow, for example, where the content of native soil is high in clay (>40%), an underdrain may be added to the bottom of the filtering area (Fig. 4). Most of the water captured by this type of rain garden enters the underdrain; this filtered water is discharged into the storm sewer system, while a modest amount infiltrates into the native soil. If native soil is high in clay, it is recommended that the sandy bioretention mixture not be combined with the surrounding soil because clay particles can settle in between sand grains, forming a concrete-like substance. An alternative to addition of an underdrain is to construct a rain garden in which the ponding depth is shallower than 12 inches to maintain a manageable volume of captured water or addition of a drywell (a pit filled with gravel or other debris) at the lowest spot of the water basin.

It is recommended to lay no more than 3 inches of mulch on the bottom of the ponding area. Hardwood mulch is better than pine bark or chips as it does not float away. Mulch breakdown over time has been shown to contribute to improved soil structure.

Additional suggestions for design of a rain garden include a dry riverbed composed of medium-sized rock, which gives it structure when dry. A weir, or small barrier, can be included to increase the ponding volume and manage a sloped area; water pools behind the weir, flowing steadily over the top of the barrier.

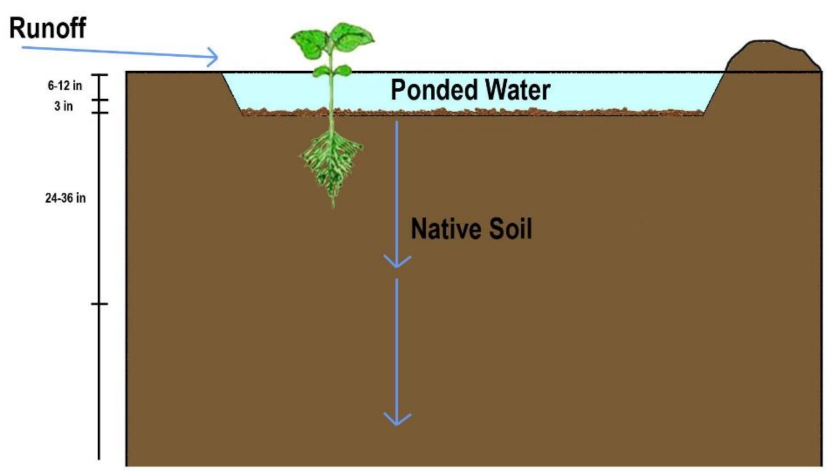


Fig 2. Rain garden with tilled but not amended soil (native soil infiltrates water quickly)

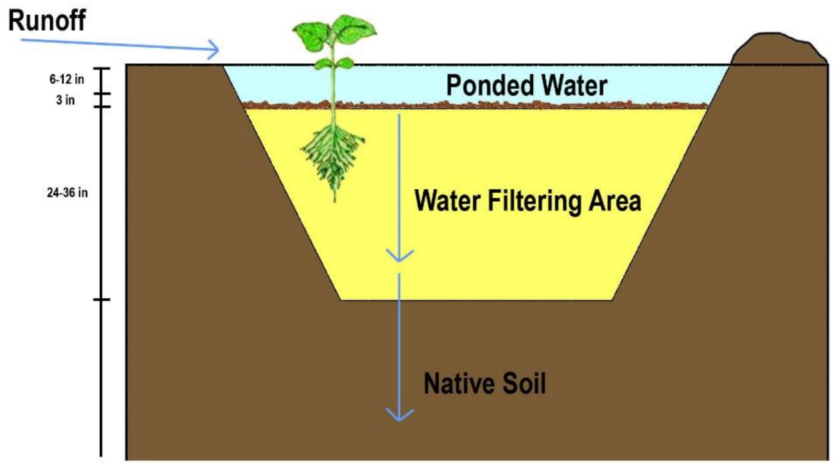


Fig 3. Rain garden with amended soil or addition of filtering media (native soil infiltrates water slowly)

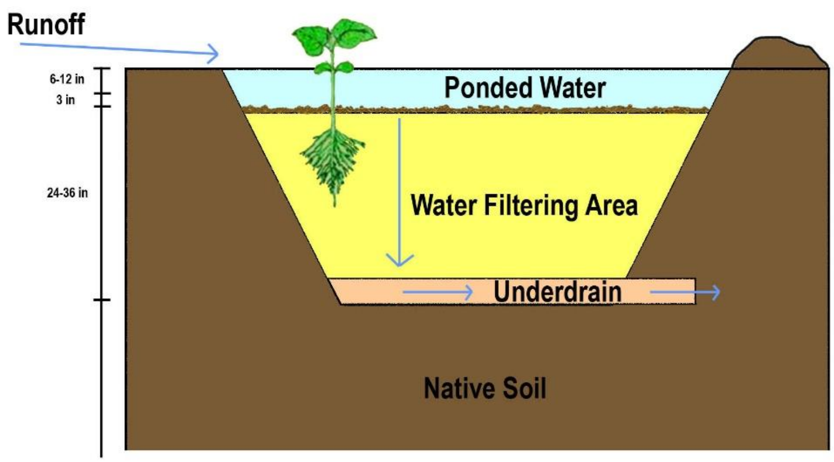
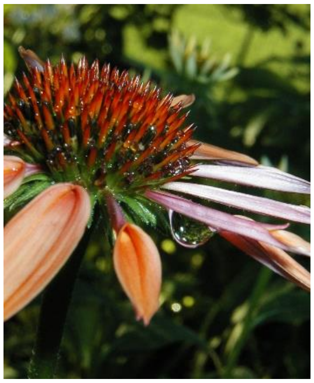


Fig 4. Rain garden with amended soil or addition of media plus an underdrain (native soil infiltrates water very slowly)

The **plants** for a rain garden need to tolerate periods of wet, as well as dry, conditions. Ideal plants are those native to the area (Fig. 5) which have deep root systems that renew annually, thus providing additional aeration and water drainage pathways. Deep roots also support the microbes that help break down organic pollutants, remove nitrogen, and transport oxygen to the soil.

If native plants are used in the rain garden, no fertilizer or pesticides are required as they are resistant to local pests and disease. Native flowering perennials and grasses are good choices, but experimentation is encouraged. When purchasing plants, choose those labeled “average to moist” water requirements for the central deep areas of the garden. Plants labeled “average to dry” conditions can be planted around the inside perimeter of the garden. Local city and extension services often have a list of suggested perennials for rain gardens, and the National Wildlife Federation has a database of native plants (https://www.nwf.org/NativePlantFinder/Plants), searchable by state. In Minnesota, at least 40% of the vegetation is recommend to be sedges and grasses to provide dense root masses. Young plants or plugs are recommended for a rain garden; they are easiest to plant and maintain and mature faster than planted seeds.

Rain gardens may be **planted** in the fall, when growth has slowed and plant energy is directed towards the roots, or in the spring, when tilling the soil is easiest and rain is most abundant. For a curb-cut rain garden, it is suggested to plant in spring or early summer, not in the fall.



Coneflower

Pagoda Dogwood

Liatris

Honeysuckle

Fig 5. Examples of plants usable in residential rain gardens in Minnesota.

The estimated **cost** of a residential rain garden is $3-10 per square foot. A typical residential rain garden with 150 square feet of surface area may cost $450-1,500, depending on soil conditions, location, type/number of plants, and addition of an underdrain. The overall cost is increased, of course, if the garden is constructed by a professional contracter.

Maintenance of a residential rain garden is minimal, especially if native plants are utilized (Fig. 6). Fertilizing the vegetation is not recommended. While the plants are becoming established, occasional watering may be needed. Occasional plant trimming or mowing of grasses will be necessary. Regular weeding is needed initially, but once the plants are mature, they will out-compete the weeds; vigilance is required to ensure that any invasive plant species are promptly removed. If the rain garden has inlets and outlets, particularly a curb-cut, debris and sediment need to be cleaned out. In the fall, removal of excess leaves, which can form a mat and slow water infiltration, is required. In most cases, the planted vegetation will need to be replaced every ten years. Mulch will break down over time and should be refreshed every couple of years.

For locations unsuitable for an in-ground rain garden, a **stormwater planter** is an option. A stormwater planter can manage roof runoff and function like a rain garden inside the planter, which utilizes layers of soil (18 inches) and stone (10 inches) inside constructed walls. The planter can be located close to buildings, raised or flush with the ground, and occupies minimal space. The same plants used in rain gardens can be used in a stormwater planter. The planter can serve either as an infiltration mechanism, allowing water to seep into the native soil below, or as a cleansing mechanism, filtering water through its layers and allowing it to drain into a subdrainage system. If the native soil has low permeability, as in many urban lots, the latter design is recommended. Moving water from an impermeable surface to the planter can be done with a rain chain or a downspout. A splash block (concrete pad) or collection of stones at the exit point will allow water to disperse as it flows into the planter. A stormwater planter requires an overflow mechanism, which will direct water away from structures, sending it directly to the subdrainage system.

The **effectiveness** of rain gardens has been found to be excellent and it is stable over time; a well-constructed garden should drain from the basin at the rate of at least one-half inch per hour and can infiltrate 85-90% of annual stormwater runoff, improving the quality of the runoff and replenishing groundwater. A rain garden with a filtering area and no underdrain is very effective at capturing water and filtering out pollutants: It's been shown than they remove 95-98% of the metals (copper, zinc, lead) found in runoff and reduce phosphorus by as much as 80%. They can also reduce total nitrogen by 40% and nitrate-nitrogen by 15-75%. High phosphorus and nitrogen, primarily from animal manure and chemical fertilizers, have been shown to be a leading cause of the decline in the quality of surface water in urban settings. Excess nitrates in lakes and streams has been traced to septic systems, feed lots, industrial waste water, sanitary landfills, and garbage dumps. In addition, bottom-feeding fish, such as carp, stir up bottom sediment, adding phosphorus back into the water. Rain gardens also have been shown to remove 80% of sediments from rainwater runoff, allowing 30-40% more water to soak into the ground than a conventional lawn.

A rain garden with an underdrain is less effective because 80% or more of the runoff will be captured by the underdrain and returned to the storm sewer system. The remaining 20% will pass into native soil below the underdrain, where the filtered water will have about 85% of the total solids and 45% of the total phosphorus removed.

Additional positive results include that excess runoff from a rain garden will have a lower temperature and higher dissolved oxygen levels than will runoff from an impenetrable surface, thus reducing the impact on aquatic systems that receive the water. Rain gardens also reduce the load on municipal water infrastructure, delaying the runoff by several hours past peak.

Fig 6. Residential rain garden A) under construction and B) completed. Photo by Mary Nolte.

Bioretention Areas

Bioretention areas are larger than residential rain gardens and are used in commercial or agricultural settings; their design, location, and use need to satisfy local permit requirements (as opposed to residential rain gardens, which don't usually require a permit). Bioretention facilities are designed for water management and can treat stormwater runoff, groundwater, and in some cases, wastewater.

The mechansims for controlling the quantity and improving the quality of stormwater are the same as those for a residential rain garden: water in the ponding area infiltrates into the soil below until it reaches capacity and the basin begins to fill; water is captured by the plants and soil micropores. The pooled water, and that from plant and soil surfaces, then evaporates back into the atmosphere. Dust and other types of sediment settle out of the pooled water as it infiltrates into the bioretention facility filtering area and the soil below. Plants utilize some of the nutrients for growth or mineral storage, while the roots bind dissolved chemical substances, rendering them harmless. Soil microbes break down the remaining chemicals, decomposing pollutants into soil matter.

Inlets for bioretention facilities trap a large portion of runoff debris and sediment; inlet designs include a curb-cut, gravel or grass strips, a level spreader, and a sediment forebay. Outlets include a riser structure that can accept water exceeding maximum pond depth and convey it to underground storm drains. Underdrains are also used as an outlet, conveying runoff to an existing storm drain or into an above-ground bioswale or swale.

Typical landscaping designs for bioretention facilities include perennial gardens, turf plus trees, and trees plus shrubs. Herbaceous native plants, such as ground covers, help defray the cost of mulch.

Visual inspection of bioretention facilities needs to be accomplished during construction and continuing over its timespan to ensure proper functioning. Inspection during critical steps in construction is typically done by an engineer to ensure the facility meets the requirements of the local stormwater management review authority. Inspection of the physical characteristics of the finished bioretention facility and conduction of a full inundation test confirm that it is functioning as intended. Periodic inspection of completed biorentention areas is necessary because, as vegetation matures, the needs of the area may change (e.g., mature trees will add shade to the surrounding area).

Urban stormwater management is dependent on the pollution, soil characteristics, land use, and geographic/topographic characteristics of the area, but highly technological solutions are not necessarily optimal – instead, rain gardens can be used as a low technological solution. Used in a network, rain gardens have been increasingly recognized as a best management practice (BMP) for controlling stormwater runoff. A study that followed the functioning of a two-tier rain garden in Cincinnati, OH, determined the efficacy of the practice over a four-year period. Cincinnati has a humid continental climate pattern with approximately forty inches of annual precipitation. The two-tiered rain garden there received runoff from a hill slope, a roadway drainage system and from an asphalt parking lot. The gardens were planted with drought- and flood-tolerant perennials and grasses and included an underdrain imbedded in a bottom layer of gravel. A pipe conveyed water from the upper to the lower garden. When the upper garden was full with runoff, the excess drainage flowed to the lower garden. When the lower garden became full, the excess drainage was conveyed to the conventional sewer system of the adjacent street.

A significant conclusion of this study was that 90% of all rainfall events were fully detained in the tiered rain gardens. For the 10% of storm events that drove the gardens to release runoff into the sewer system, flow was found to have been delayed off-peak for an average of 5.5 hours. A second primary factor in regulating flow was the amount of transpiration of the vegetation, which grew to maturity during the construction phase. It was suggested that composting of the mulch (replaced every other year) and subsequent improvement in the soil likely facilitated plant growth and spreading. It was also found that the upper rain garden functioned as a filter of fine sediment; the conclusion was that most of the sediment was dispersed near the inlet of the upper rain garden and incorporated into the organic surface soil, allowing the basin to maintain a normal infiltration rate over time. The operational stability of this rain garden network over four years was viewed as encouraging.

Bioswale/bioslope

A bioswale, or bioslope, is a depressed area that moves water from one area to another, allowing some, but not all, of it to infiltrate; “bioswale” is a term generally applied to larger municipal areas, although water from a house can also be transported to a rain garden via a bioswale. Bioswales are part of the practice of “low impact development (LID),” which mimics the natural flow of water in our historic landscape.

In practice, use of existing natural drainage swales enhanced with native plants, subgrade drains and/or amended soils, show the best results. A road ditch can serve as a bioswale. In the midwest, most annual preciptation is from frequent small rain events – bioswales provide infiltration and filtration of nearly all of this water. Bioswales also reduce streambank and channel erosion by reducing the surges of higher runoff flows and storm sewer discharges, and may, in turn, reduce flooding in the receiving body of water.

A grassed swale is a linear, shallow channel vegetated with flood-tolerant grass. The grassed swale represents a significant improvement to traditional drainage ditches in slowing the flow and reducing the pollution of rain water runoff. In this type of swale, stormwater velocity is reduced by stategic placement of check-dams, perpendicular areas of rock, which aid in ponding. This encourages infiltration, filtration and sediment deposit in the swale. Grassed swales are appropriate for most regions of North America and are low-cost and low-maintenance methods for improving the quality of stormwater runoff. Generally, grassed swales are used to treat drainage areas of five acres or fewer; in highly urban or highly impervious areas, grass swales are recommended to be constructed in series or to function as a pretreatment for other stormwater management practices. A grass swale may be dry or wet, the latter functioning as a linear wetland and recommended for use as a pretreatment method.

A research project on the rebuilding of Highway 169 in northeast Minnesota was an opportunity to understand whether local waste materials incorporated into the bioretention areas had the ability to filter runoff as efficiently as traditional filtering materials, which are often hauled long distances to a road construction site. The study was conducted by the Natural Resources Research Institute (NRRI) at the University of Minnesota from 2015-2018. The project was initiated with a small trial, capturing runoff from a parking lot; six plots were set up with different mixtures of filtering media. Mixtures of varying amounts of peat and natural soil, compost and natural soil, and compost and taconite tailings were used. The group analyzed effluent water for concentrations of metals and phosphorous. The NRRI was able to expand the test to a road site when 5.7 miles of Highway 169 were reconstructed in 2018. Peat that was excavated during construction was salvaged and combined with compost from Duluth's Western Lake Superior Sanitary District and local sand to produce a filtering medium. An underdrain was included in the bioretention area. It was found that the local, salvaged peat was a highly efficent roadside filtering medium. Mixtures of peat and compost were also effective but owing to high phosphorus levels in compost, it must be limited to a low proportion of the filtering medium. Taconite tailings have the potential to remove phosphorus from contaminated water, but the proportions must be controlled to prevent any metal release.

In conclusion, many existing "rain gardens" predate use of that term. Any planted shallow depression designed to attentuate rain flow is conceptually a rain garden. Now referred to as "bioswales," vegetated roadside drainage ditches served as bioretention areas in many parts of the globe long before concrete storm sewers became the conventional practice. What is new about this green technology is the emerging quantitative understanding of how bioretention practices, from rain gardens to bioswales to large-scale bioretention areas, make sustainable land use possible.

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