STORMWATER MITIGATION FOR ARCHITECTS AND DEVELOPERS

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Introduction

Stormwater runoff is rainwater that is not absorbed into the soil or evaporated into the atmosphere, but rather runs off the surface of the land into streets, storm drains, rivers or other conduits that ultimately feed into coastal ocean waters. As rain falls, it picks up pollutants from air, and then from the surfaces over which it flows. This water and its constituent pollutants are conveyed to receiving waters untreated, causing serious impairments to water quality. Because this runoff pollution comes from many disperse sources, it is termed non-point source pollution. But contaminated rainwater is not the only source of non-point source pollution of surface waters - normal daily activities such as landscape watering, agricultural irrigation, driveway washdown, automobile washing, and others can create polluted runoff even in the absence of rain. In highly developed areas, this type of pollution is often called **urban runoff**.

One of the most serious problems associated with land development is that it changes the rate and amount of stormwater runoff reaching streams and rivers. Both urbanization and agricultural development affect an increase in overland flow, resulting in greater magnitude and frequencies of peak flows on our water bodies (Marsh, 1991). In urban areas such as Los Angeles, this increase is due to the greater proportion of impervious surfaces. The impact can be serious, both financially and environmentally: property damage from flooding is increased, water quality is reduced, channel erosion is accelerated, and habitat is degraded.

Responsible planning and management of the landscape depend on accurate assessment of the changes in runoff brought on by land development. In most communities developers, architects and builders are required to address the situation in terms of providing analytical forecasts of the changes in overland flow, stream discharge and use of correct BMPs (Best Management Practices) related to particular projects.

The vast majority of runoff and pollutants are carried by the small, frequent rain events, not the larger, more publicized (and less frequent) events. In arid regions such as southern California, this situation is exacerbated by the fact that pollutants build up on surfaces during the extended periods between rain events, especially over the dry summer months. As a result, pollutant concentrations are highest in the first storms of the season, and also at the beginning of each rain event. This is often referred to as the "first flush" phenomenon. The concentration of the first flush is greatest in areas with highly impervious ground surfaces (Scheuler, 2000). Another characteristic of arid regions is greater movement of sediments during rain events because of sparser vegetation. Pollutant concentrations in stormwater runoff from arid watersheds are consistently higher than the national average (Caraco, 2000).

The Hydrologic Cycle
To understand the impacts of stormwater and urban runoff, it may be useful to review the hydrologic cycle. The hydrologic cycle is the continuous circulation of water through the earth's land, seas, and atmosphere. In it's natural condition, soil absorbs much of the rainwater that falls to the earth. This water infiltrates the soil and is used either for biological processes, or percolates into the groundwater supply. The water that is not absorbed runs over the surface of the land at a fairly slow pace, which allows much of the suspended particles to settle out. This runoff reaches receiving water bodies (lakes, rivers, oceans) with relatively few impurities. Moreover, water that infiltrates through the soil and into the groundwater is cleansed through various biological processes that occur in the soil. This groundwater can also enter surface waters through underground aquifers. Some water that remains on plant and soil surfaces will evaporate into the atmosphere to be recycled as rain again, and much of the water that percolates into the ground will be used by plants and animals.

Development and urbanization change the dynamics of the water cycle by allowing more water to run off the ground surface than normal. This is due to the fact that development usually causes compaction of soils, and greatly increases the amount of impermeable surfaces. The loss of vegetation and organic litter also contribute to changes in surface characteristics (Strom and Nathan, 1998). In a natural system only about 10% of rainwater runs off the soil, whereas an urban area with 75-100% impervious surface experiences about 55% runoff (Low Impact Development, 2000). Compacted soils, and those covered with impervious materials (such as concrete, asphalt, rubber or metal) absorb rainwater very poorly, or not at all. Thus, rainwater falling on these surfaces will quickly become stormwater runoff and flow to other areas. Cities such as Los Angeles instituted stormwater conveyance systems (storm drains that are connected to channels like Ballona Creek and the L.A. River) that carry all of this runoff directly to the ocean. In Los Angeles, the area covered by roads, sidewalks, parking lots and buildings is extensive - approximately 80% for downtown L.A. (Condon and Moriarty, 1999). Studies suggest that as little as 20% impervious cover results in degradation of water quality (Strom and Nathan, 1998). For example, a recent study in Perris Valley, CA determined that an increase in impervious cover from 9% to 22% resulted in peak flow rate increases of over 100% and runoff volume increases of up to 130% (Caraco, 2000; Guay, 1996).

In addition to the large input of freshwater into surface waters, stormwater runoff contains high concentrations of pollutants, many of which are toxic to both terrestrial and aquatic wildlife. The source of these pollutants is highly varied, from deposition of air pollutants, to oil and other hydrocarbons from motor vehicles, to fertilizers and pesticides used in landscaping.

Stormwater conveyance systems were originally designed to prevent flooding (the probability of which increases when rain does not percolate into the soil), and were therefore designed for large-scale storms. But the majority of runoff that enters these channels is from small-scale rain events. It is the runoff from these smaller storms that can most easily be prevented through design measures that help keep water on-site.

Best Management Practices for Stormwater
Best Management Practices (BMPs) are any procedure, protocol, structural device or site design that prevents or mitigates stormwater runoff. In low impact design, these are also referred to as integrated management practices. BMPs can be broadly categorized by whether they prevent stormwater pollution (source controls) or treat stormwater to make it cleaner (treatment controls). The aim of this report is to

provide architects, developers and contractors with a database of design guidelines and structural BMPs that may be incorporated into new and ongoing projects. The list of BMPs and guidelines illustrated have been assimilated and developed from various sources including stormwater management journals, research papers, product catalogues and design guides. Most of the graphical material of the structural BMPs has been developed with the help of landscape architects who have been researching this subject for a number of years. The report also summarizes a number of stormwater management products that are available in the market for use in construction related projects.

Source Controls

Source controls are BMPs that prevent pollution from contaminating stormwater runoff. Because almost all non-natural surfaces (including turf grass and other landscaping) are potential sources of pollutants, this in large part entails preventing stormwater runoff from occurring by retaining and infiltrating rain water on site. It also includes structural designs that prevent rainwater from coming in contact with potentially contaminated surfaces, such as parking spaces and waste storage areas, to keep contamination to a minimum. When possible, BMPs that prevent stormwater pollution should always be employed before considering those that clean contaminated stormwater through various treatment devices. Architects and developers can play a key role in designing a site that produces very little stormwater pollution.

Source control BMPs prevent pollutants from contaminating stormwater runoff or entering water bodies. Pollutants have never come in contact with the stormwater starting from the beginning, at the source area. Some source control BMPs are operational, such as reducing the frequency of a polluting activity, checking regularly for leaks and drips, and educating employees about site clean up procedures. Other source control BMPs use a structure to prevent rainwater from contacting materials that will contaminate stormwater runoff. Examples of these BMPs include enclosing and/or covering the pollutant source (a building or other enclosure, a roof over storage and working areas, temporary tarp, etc.).

Low Impact Development Strategies

Low Impact Development is an approach to stormwater management that focuses on creating hydrologically functional landscapes that mimic the natural hydrologic regime (Low Impact Development, 2000). To achieve this, it combines hydrologically functional site design with pollution prevention measures to compensate for land development impacts on water quality. Site design techniques are employed that store, infiltrate, evaporate and detain runoff. This approach concentrates on managing stormwater on each lot (source control), and emphasizes the use of many smaller integrated stormwater controls that are distributed throughout the site, near the source of each impact. Low impact development also incorporates multifunctional design elements that can serve more than one purpose.

Site Design

In arid regions, 90% of the rain events in a given year are less than 0.8 inches. Therefore, most stormwater runoff can be controlled on-site through better site design. The typical western or "California" development style espouses expansive buildings, wide streets, oversized driveways and large cul-de-sacs. Created especially for the "car culture" of the west, this design strategy produces more impervious cover per home or business than any other part of the country (Caraco, 2000). With an eye toward minimizing impervious cover, there are many measures that can be employed in the design and layout of a development site that will reduce stormwater runoff and pollution.

The first and most important consideration in site design is to fit the development to the topographic lay of the land. This includes designing roads to follow grades and ridgelines of sloped areas, as opposed to cutting roads perpendicular to a steep slope. It is also important to maintain the natural drainage pathways on the site as much as possible and use this natural drainage in the development design. This will likely help to increase the length of the flow path to increase the travel time and infiltration over conventional drainage designs. Highlighting natural features of the property will also create a more aesthetically pleasing landscape and help to identify areas appropriate for different land uses (such as parks, playgrounds and building sites). When grading, road cuts and construction of drainage systems is decreased, development costs could likely be lower as well (BASMAA, 1999; Low Impact Development, 2000).

Minimizing the footprint of the development is another best management practice for site design. Also referred to as clustering, or open space design, this technique aims to keep the built areas of a site to a practical minimum, thus maximizing the undeveloped open space of a property. This means spacing buildings closer together and building up vertically instead of spreading out horizontally. A related practice, which can also be a direct result of minimizing the footprint, is that the natural vegetation should be maintained as much as possible. Combined with the recommendations in the previous paragraph, construction should be located in areas of minimal vegetation or clay soils, carefully avoiding trees and shrubs which both add interest to a site and increase soil permeability with their deeper roots. A buffer zone or setback from natural drainage systems and water bodies should also be observed.

Parking lots are some of the biggest sources of stormwater runoff because of their large areas and impervious surface. But alternatives to both of these can be achieved. Vertical structure parking reduces both the footprint of the space, as well as reduces oil and grease runoff because it is covered. Bioretention areas (vegetated depressions that collect and infiltrate stormwater) are easily incorporated into parking lots, especially at the end of or between parking rows. Bioretention also incorporates aesthetic features into the usually drab parking lot design.

Another very important BMP in site design is to minimize the amount of directly connected impervious area. Directly connected impervious areas (DCIA) is the sum of all impervious surfaces that drain directly into the municipal storm drains. By making sure that all impervious surfaces drain to an adjacent well-designed permeable surface before entering the stormwater system, runoff from a site can be significantly reduced. One strategy is to break up a paved area with interspersed vegetated strips or perimeters, another is the use of materials such as flagstone or unit pavers that can be set in sand with pervious spaces in between. To be considered "disconnected," the area of the pervious surface must be at least one-half the area of the impervious surface from which the runoff is generated (BASMAA, 1999). Likewise, in the building and landscape design, consideration should be given to directing runoff from roofs onto pervious surfaces such as vegetation beds rather than driveways and walkways. While this can be accomplished through the use of gutters and downspouts to carry runoff onto pervious surfaces, it must be carefully designed to insure that an even sheet flow across the surface is attained to prevent erosion. Placing vegetation directly under the downslope of a roof is another alternative.

Infrastructure for the automobile accounts for the single largest source of impervious surface area in both rural and urban areas. High traffic flows in urban areas would make it difficult to use pervious materials for roadways. However, narrower roadways and shorter driveways in residential developments can help to reduce roadway runoff without significant effect to traffic flow. By reducing the width of a street from 36 to 24 inches (if permitted by zoning and planning laws), both stormwater runoff and construction costs can be reduced. Likewise, minimizing driveway widths and using shared driveways when possible will also provide stormwater and construction benefits.

In the site design stage of a development, another consideration for limiting the impact of the actual development of a site is construction phasing. Construction phasing is a technique for preventing erosion by disturbing only one portion of a site at any time to construct the infrastructure needed for that phase. Grading is performed only on the phase that is being constructed and subsequent phases are started only when the exposed soils of previous phases are stabilized. Also, attempts are made to match cut soils from one area with the fill requirements of another area. If designed carefully, a phased project can reduce the amount of sediment lost on a site by 40% over a mass-graded project site. (Clayton, 2000)

Xeriscaping

Xeriscaping is not only about water conservation. Altering the natural contours of yards during landscaping and planting with non-native plants that need fertilizer and extra water can increase the potential for higher runoff volumes, increase erosion, and introduce chemicals into the path of runoff. In contrast, xeriscape landscaping provides households with a framework that can dramatically reduce the potential for NPS pollution.

Xeriscape incorporates many environmental factors into landscape design -- soil type, use of native plants, practical turf areas, proper irrigation, mulches, and appropriate maintenance schedules. By using native plants that are well suited to a region's climate and pests, xeriscape drastically reduces the need for irrigation, fertilization and chemical applications. Less irrigation results in less runoff, while less fertilizer and chemical application keeps runoff clean. While xeriscaping can be more expensive in the initial stages of landscape design, it can help to reduce the long term costs of maintenance, irrigation and energy use (xeriscaping also includes the placement of shade plants around buildings to minimize energy needs for cooling).

A soil analysis should be conducted to determine the best plant types for the site and whether any amendments will be needed. Also, all topsoil that is graded from other parts of the site should be saved and used in landscaped areas to maintain soil consistency and decrease the need for added compost or fertilizers. The drainage capacity of the soil can be improved by adding gypsum or sand. For stormwater mitigation, consideration should be given to using plants that will grow and/or maintain their foliage during winter months. An efficient irrigation should also be a planned component of the overall landscape design to avoid over watering and therefore decrease site runoff.

Building materials:

Some building materials can contribute to stormwater pollution and consideration should be given to using benign materials in the constructing buildings and landscapes. For example, creosote or penta-treatment preservatives may leach out of woods during prolonged rain events. Recycled plastics, composite resins, and concrete materials are now available as substitutes for pressure-treated woods in some circumstances. Certain roofing materials, such as asphalt and galvanized metal, are also known to generate polluted runoff (Pitt et al., 1993). Roofs made of slate, steel, and terra cotta tiles are more benign than traditional materials, yet also durable and fireproof

Treatment Controls

Treatment BMPs are structures that treat the stormwater to remove the contaminants. Most treatment BMPs require elaborate planning, design and construction. No treatment BMP is capable of removing 100 percent of the contaminants in stormwater (http://dnr.metrokc.gov/wlr/dss/spcm/Chapter 3.PDF). It should also be noted that treatment BMPs in arid and semi-arid watersheds require greater pretreatment than in humid regions (Caraco, 2000).

Wet Ponds:

Also called retention basins, these are small shallow (3-9 feet deep) lakes with rooted wetland vegetation around the perimeter. Wet ponds are designed to permanently contain stormwater, and therefore provide both water quantity and quality control. The depth of the pooled water is determined by the elevation of the outlet above the basin floor at the far end of the pool, opposite the receiving inlet. Highly permeable soils are not suitable for wet ponds because of the potential for drying out in summer months. The minimum recommended length:width ratio is 3:1 to allow for level spreading of water over the entire basin and sufficient residence time of incoming stormwater. The permanent pool of water serves to provide continued settling of particulates and the vegetation enhances the removal of dissolved contaminants, including nutrients, and reduces the formation of algal blooms. In addition to stormwater mitigation, these ponds have other potential benefits such as aesthetic enhancement, increase in property value, recreational opportunities, and wildlife habitat. Specially designed wet ponds can also create evaporative cooling near buildings, resulting in potential energy savings (Daniels, 1997).

The side slope of wet ponds (the embankment) should be at least 4 horizontal: 1 vertical. However, in urban settings and cases where space is limited, vertical concrete retaining walls may be used, although this will not allow for rooted vegetation. If rooted vegetation is not possible, non-rooted vegetation may be retained around the perimeter. Some evidence suggests that non-rooted vegetation can remove dissolved nutrients and metals even better than rooted vegetation (Guntenspergen et al., 1991). Careful consideration of vegetation is important in California because most storms occur in the winter when plant growth is decreased. For this reason, wet ponds in California may not be as effective in removing dissolved contaminants as those reported on the east coast (Roesner and Walker, 1993). In addition, wet ponds in arid regions will almost certainly require some supplemental source of water to counter evaporation during dry periods and prevent dry down.

Constructed wetlands:

Large areas (1-2% of the tributary watershed) that have a significant percentage of the facility covered by wetland vegetation. The length to width proportions of a constructed wetland should generally be >3:1. These facilities have the added benefit of passive recreation and wildlife. Constructed wetlands are effective for both water storage and pollutant control, potentially achieving a higher removal of particulates and dissolved contaminants than other BMPs. However, they are not feasible for densely developed areas and high sediment load areas. Constructed wetlands also require a qualified wetland ecologist to design and install the wetland vegetation and require significant maintenance. The limitations mentioned earlier regarding storm events during periods when vegetation is dormant, and contamination of groundwater are also relevant here. Those interested in learning more about constructed wetlands should refer to the annotated bibliography, or consult a licensed landscape architect.

Extended detention basins:
This is a shallow basin that remains dry between storms, and temporarily stores water during and after a storm. These BMPs are designed primarily to reduce peak discharges by slowing down the conveyance of stormwater and therefore provide only limited removal of particulates. A detention basin is an elongated depression (preferably 3:1 length to width ratio) with an inlet at one end and outlet at the other; during a storm the basin fills and water is released slowly from an outlet to allow settlement of particulates and sediments. The outlet is on the bottom of the basin so that the basin drains completely dry between storms. Extended detention basins are suitable for any size development area, provided that the dimensions are appropriate. Basins can either be surface type ponds with banked sides and planted with turf forming (preferable native) grasses, or underground vaults with concrete retaining walls. They are useful in areas where a lack of water prevents the application of other "wet" BMPs. Detention basins are prone to erosion, resuspension of solids and clogging, especially in the absence of vegetation. Vegetation should be placed around the perimeter to the extent practicable, or the sides may be either paved or reinforced to abate erosion. Depending on whether sustainable irrigation is available, the bottom may also be vegetated with turf grass to remove some dissolved contaminants. Surface extended detention basins generally are more expensive than biofilters, but less expensive than wet ponds and wetlands. They have the added benefit of being a multiple land-use solution, offering recreational opportunities, as well as stormwater mitigation.

Cisterns:
Cisterns are a particular type of detention system in which the collected rainwater is then used on-site for irrigation, or even potable uses. Cisterns are one component of a rainwater collection system that includes: the catchment area; gutters and downspouts; leaf screens; the storage tank or cistern; a conveyance system; and a treatment system. These systems were originally designed as a substitute or alternative for municipal water or groundwater. However, the beneficial applications in controlling stormwater runoff are obvious as rainwater that is harvested and utilized for landscape irrigation has the opportunity to infiltrate the soil. The catchment area, the area from which rainwater and/or storm runoff is collected, should be made of a non-porous material such as galvanized steel or aluminum if the collected water is intended for any potable use (Beers, 2001). Typically, the roof of a building is used as the catchment area. As a rough estimate, for every 1000 square feet of roof area, about 600 gallons of water can be collected per inch of rain (Grahl, 2000). Leaf screens or gutter guards are 1/4 to 1/2 inch mesh cloth put over the gutters to keep out large organic debris such as leaves and twigs. If the water is to be used as potable, then roof washers should also be installed (Texas Guide to Rainwater Harvesting, 1997). Cisterns can be placed above or below ground, or can even be incorporated into the building facade as a "cistern wall" (Condon and Moriarty, 1999). Cisterns typically represent the greatest cost of a rainwater harvesting system and are often not economical substitutes for municipal water. However, they can be cost-effective for reducing stormwater runoff compared to other constructed treatment systems, and will reduce overall water costs (and reliance on municipal water) for tenants in the long run. Integrating cisterns systems into new construction projects is more cost-effective than retrofitting a system into an existing building. Harvested rainwater can also be used to cool buildings in various ways (Daniels, 1997).

Infiltration systems:
This type of BMP includes infiltration basins, infiltration trenches, dry wells, porous pavement and modular pavement. Infiltration basins are either open surface ponds or underground vaults. Trenches

are underground (either open or covered) chambers filled with rock or gravel. While basins may be used for areas up to 5 acres, the other systems are suitable only for small sites of less than 2-3 acres. Underground systems must be 2.5 times greater than the desired water volume to account for an approximate 60% loss of void space by rock fill. Infiltration is a method to completely retain a desired volume of stormwater onsite by allowing it to percolate into the substrate. Therefore, infiltration reduces the volume of stormwater flow, which also leads to a reduction in the peak flow rate. Infiltration systems may be considered where dissolved pollutants are of concern, but removal efficiencies will depend on the type of soil, with loamy soils providing the greatest efficiencies. Sandy soils have been used in areas (central California and Long Island, NY) where the primary objectives are ground water recharge and flood control, not water quality. The three major concerns with infiltration systems are clogging, accumulation of metals, and contamination of ground water. The bottom of infiltration trenches are assumed to clog quickly and therefore considered impervious; design plans for infiltration trenches should take into consideration that only the sides will allow percolation of stormwater. Long deep trenches provide the most efficient percolation because of the high surface area on side walls. Clogging becomes even more likely in finer soils.

To minimize the potential for groundwater contamination, the system should be separated from the seasonal high ground water level by at least 3 feet, and from the bedrock by at least 4 feet (greater distances are required in coarse soils). According to a USEPA report (1983), infiltration and percolation can successfully remove 45%-65% of stormwater pollutants over the long-term without adverse contamination of groundwater. However, highly soluble pollutants such as nitrate and chloride have been shown to be capable of migrating into groundwater (USEPA, 1991). Therefore, if contamination of groundwater is a concern, pretreatment with filters or other methods should be considered. Also, infiltration systems are not recommended for areas with industrial activity or high vehicular traffic without effective pre-treatment, regardless of soil type or water table depth. Dry wells, a vertical type of infiltration system in which the depth is generally greater than the width, are often used to successfully treat roof runoff.

Porous pavement can infiltrate or treat runoff from up to 70-90% of all storm events (WEF Manual, 1998). Porous pavements can be made of either asphalt or cement, or porous modular blocks. As with other infiltration systems, the groundwater level should be at least 3 feet below the bottom of the pavement. While porous concrete and asphalt have a tendency to clog and seal between 1-3 years, modular blocks are less prone to sealing and work well under a variety of conditions (Urbonas and Stahre, 1993), although they are not recommended for vehicular traffic other than parking. If clogging does occur, the soil or sand between the blocks can be cleaned out and replaced with new material. Walkways, courtyards and overflow parking lots are suitable applications for modular porous pavements.

In considering the size of an infiltration system, the system must be large enough to hold the desired volume of water, and shallow enough to limit the time required for water to soak into the soil (the ponding time). The maximum depth is a function of the ponding time: the shorter the ponding time, the shallower the depth must be (and therefore the larger the area needed). The precise volume and area needed for an infiltration system, as well as other design considerations, can be determined by following the protocol in the California Storm Water Best Management Practice Handbooks (1993). Guidance for the use of infiltration systems, including their limitations, can be found in "Potential Groundwater

Contamination from Intentional and Non-Intentional Stormwater Infiltration" (USEPA Report No. EPA/600/R-94/051, 1994).

Biofilters:
There are two basic types of biofilters:
grassy swales – a vegetated channel that treats concentrated runoff flow
grassy strip – a vegetated strip that treats sheet flow; placed parallel to the impervious surface.
While these BMPs are limited to treating a few acres, their performance can be comparable to wet ponds and constructed wetlands. Biofilters work best in fertile, porous soils that will support healthy vegetation and allow adequate infiltration. The presence of vegetation allows greater treatment of stormwater than with infiltration basins. Turf grasses are the preferred vegetation, and native species should be used whenever possible. If native species are not available, choose vegetation that is best suited to the region, climate and soils. A slope of 1-2% in the direction of flow is considered ideal to slow the flow of water sufficiently enough to allow infiltration and settling of sediments (the maximum flow velocity should not exceed 0.3 m/s). When designing biofilters, sizing is important: the minimum recommended length for strips is 10 feet, and for swales an area of 1000-1200 sq. ft. per acre of impervious surface is recommended in the L.A. region (Roesner and Walker, 1993). Irrigation may be necessary during the summer months to keep the vegetation healthy. Filter strips and swales can provide an attractive and functional alternative to concrete between buildings, as parking lot medians, roadside shoulders, and as buffers between buildings and streets.

Another innovative biofilter is a green roof (Scholz-Barth, 2001). Green roofs are categorized as either intensive or extensive. Intensive green roofs are multi-layer structures that require at least one foot of soil depth to create a park-like garden with trees, shrubs and manicured landscapes. These constructions are deemed attractive amenities and are used as recreational or park areas for larger building complexes, in addition to their stormwater mitigation functions. Intensive green roofs do however add considerable weight load to a building (80-150 lbs/sf) and also require intensive maintenance, thus adding significant cost.

Extensive green roofs are more appropriate and less expensive if environmental management is the exclusive goal, since these structures are not designed for public use (but can be accessed for routine maintenance). Extensive green roofs are covered with a thin soil layer (1-5 inches) and vegetation. The vegetation can vary from sod or grass turf to succulent plants, but should be chosen according to the geographical area and maintenance requirements. In new buildings, the roof should be built with a slope of between 5 and 20 degrees to allow for sufficient drainage of water away from the root zone. Buildings with large roof areas such as factories, single-story office buildings, shopping malls, schools and churches are appropriate applications for green roofs. The total construction costs for extensive green roofs are $15-$20 per square foot, but could reduce to $8-$15 in the next several years. Green roofs provide the additional benefit of energy efficiency.

Media Filtration:
Media filters consist of a settling basin, followed by a filter mechanism. The most common filter media is sand. These types of filters can only remove particulate contaminants. Other media include peat/sand mixtures, activated carbon and leaf compost, which are also capable of removing some dissolved pollutants, as well as oil and grease (Richman, 1997). Filters are suitable for areas of <1 to 50 acres and often used in highly urbanized settings. They can also be located underground if space or aesthetics are

an issue and are considerably smaller than retention and infiltration systems. They have a removal efficiency of suspended particulates that is comparable to wet ponds and extended detention basins, but are prone to clogging if upstream soil erosion is a problem. Another advantage is that they do not require a supplemental water source and can be used with almost any soil type. Effective pre-settling basins are important for removing sediments that can clog filters. An alternative that may be particularly useful for industrial sites are filters that are inserted into catch basins, which can remove particulate and dissolved pollutants, but may need to be cleaned or replaced frequently due to the lack of a pre-settlement basin. Of interest to architects is that filter systems can be integrated into the actual design of the building from conception.

Oil-Water Separators:
Oil/water separators are appropriate at locations where petroleum products and/or byproducts cannot be effectively controlled with source-control BMPs. An oil/water separator can be a simple tee section in a catch basin that traps floating materials, or a complex unit that is more expensive and maintenance-intensive. Most of these units are manufactured systems that use hydrodynamic designs (and sometimes filtration) to separate and contain oil and grease, as well as debris and sediments, from stormwater. Lighter materials such as oil and some trash will float, and heavier materials such as sediments will sink. Oil/water separators should be used for targeted pollutant removal in heavily oiled areas rather than as an all purpose stormwater treatment facility. The separator will function more efficiently and require less maintenance if the amount of stormwater passing through is limited. Only runoff that has been exposed to high oil activity areas should be directed through the oil/water separator. The specific design considerations will not be discussed here because these systems are purchased from manufactures that specialize in custom designs for specific uses. In order to work properly, they must be cleaned regularly to remove contaminants from the retention chambers. See the section on Stormwater Treatment Products for specific references.

Other Treatment Technologies:
Several other types of procedures are also available to treat stormwater. These include flocculation, coagulation and floatation. These technologies require both a structural component in which to carry out the procedure, as well as a chemical or physical component that achieves the separation. For more information on these technologies, see: Bernard et al., 1995; Harper and Herr, 1992; Heinzmann, 1994; and Laine et al., 1998.

Design of Treatment BMPs:
Stormwater mitigation must be designed with the budget, site, and regulatory constraints of a given development. The process should be an iterative one, in which feasible BMPs are narrowed down from a variety of potential options. The actual design of each BMP will depend on the role of that BMP in the overall stormwater mitigation plan for the site. Elements that should be considered in BMP selection and design include space requirements/limitations, soil types, slopes, depth of the water table, existing building foundations, and maintenance. Detailed guidelines for the design of specific BMPs can be found in *Low Impact Development Design Strategies* (2000), *Start at the Source* (BASMAA,1999), and *Guidance Manual for On-Site Stormwater Quality Control Measures* (SSMP, 2000).

Rational Method:
In order to design a stormwater BMP, one must know the amount of runoff that will need retention or treatment. Because direct measurement of runoff volume and flow rate is usually not practical, models

for estimating these parameters are frequently used. The size and features of a BMP will depend on the **design storm** that is chosen, which is the largest amount of rainfall in any single event that the BMP will be able to handle. Design storms are often referred to in years, such as a "10-year storm", which indicates a storm of sufficient size that it will occur on average only once in 10 years. Alternatively, there is a 10 percent chance in any given year that single storm will be of that magnitude. For stormwater mitigation, design storms are typically in the 1 to 2-year range because most of the stormwater pollution will be carried in these smaller events.

One simple runoff model that is used for on-site stormwater facilities is called the "rational method." This method calculates the peak runoff rate for a given drainage area that is subject to a given rainfall intensity over a specified duration. Basically, the equation is:

Qp = c © a

Where: *Qp* is the peak rate of runoff
- *a* is the drainage area
- *c* is the drainage area runoff coefficient (see table below)
- © is the rainfall intensity at a selected design storm and duration. The duration should be equal to the time that it takes for water from the farthest point in the drainage area to reach the collection point.

Although the equation gives units of acre-inches/hour (*c* is unitless), the units normally applied to runoff rates are cubic feet/second (cfs). However, the correction factor is 1.008 and the units of the rational method equation are usually equated directly to *cfs* without any correction. Other methods for determining peak flow rate and storage volumes are also available (*Low Impact Development Hydrologic Analysis*, 2000; *Guidance Manual for On-Site Stormwater Quality Control Measures*, 2000).

Table of runoff coefficients (*c*) used in the rational method: The following table is taken from the Urban Drainage Design Manual from the U.S. Department of Transportation (Brown et al.,1996), but also contains values (*) taken from Ferguson (1987).

Type of Drainage Area	Runoff Coefficient ©
Business:	
Downtown areas	0.70 – 0.95
Neighborhood areas	0.50 – 0.70
Residential:	
Single-family area	0.30 – 0.50
Multi-units, detached	0.40 – 0.60
Multi-units, attached	0.60 – 0.75
Suburban	0.25 – 0.40
Apartment dwelling areas	0.50 – 0.70
Industrial:	
Light areas	0.50 – 0.80
Heavy areas	0.60 – 0.90
Parks, Cemeteries	0.10 – 0.25
Playgrounds	0.20 – 0.40
Railroad yard areas	0.20 – 0.40
Unimproved areas	0.10 – 0.30
Lawns:	
Sandy soil, flat, 2%	0.05 – 0.10
Sandy soil, average, 2-7%	0.10 – 0.15
Sandy soil, steep, 7%	0.15 – 0.20
Heavy soil, flat, 2%	0.13 – 0.17
Heavy soil, average, 2-7%	0.18 – 0.22
Heavy soil, steep, 7%	0.25 – 0.35
Streets:	
Asphalt	0.70 – 0.95
Concrete	0.80 – 0.95
Brick	0.70 – 0.85
Drives and Walks	0.75 – 0.85
Roof	0.75 – 0.95
Bare earth*	0.20 – 0.90
Turf or Meadow*	0.10 – 0.40
Cultivated Field*	0.20 – 0.40
Forest*	0.10 – 0.30

New Regulations

In February, 2001, the Standard Urban Stormwater Mitigation Plan came into effect in Los Angeles County (LARWQCB, 2000). This plan requires that new developments (and some redevelopments) to infiltrate or treat the volume of runoff from a 0.75 inch storm event (the "design storm"), or 85% of the runoff volume from each 24-hr storm event. The actual mitigation volume will depend on the imperviousness of the development site. If impervious areas are drained to pervious areas for infiltration, then the impervious area needs to be able to percolate both the rainwater falling directly on it, plus the rainfall flowing onto it from the impervious area. For directly connected impervious areas (see section on Site Design), the entire first 0.75 inch of rain onto that area would require mitigation. Using the 0.75 inch regulation, a property with one-half acre of directly connected impervious area would need to mitigate approximately 10,400 gallons of runoff per storm event. This does not include any potential runoff from other pervious or semi-pervious areas, which could possibly generate runoff if the soils are bare, heavy or compacted. In such cases, the runoff generated from these areas during the first 0.75 inch of rain would also need to be mitigated. These new regulations make it imperative that architects and designers familiarize themselves with stormwater mitigation theories and practices, and begin to incorporate these into their building designs. EPA is scheduled to issue guidance on developing measurable goals in the near future. For more information regarding specific regulations for various development categories, as well as recommended BMPs for each, refer to the L.A. County Standard Urban Stormwater Mitigation Plan (2000).

Case Studies/Examples

This section will highlight some BMP examples for several different types of developments. These examples were taken from various sources (BASMAA, 1999; Condon and Moriarty, 1999; Lehner et al.,1999) as case studies and should be viewed only as suggestions, not as endorsements by this author. Neither should this list be considered exhaustive or comprehensive. The actual stormwater BMP plans and designs for a particular site must be developed for the specific needs of that site.

Residential Single-family:

- Cisterns to collect and detain stormwater for either infiltration or irrigation.
- Depressed lawn areas can function as mini-detention basins, allowing rainwater to percolate into the soil between storms. (For safety, these depressed areas should not be greater than 6 inches deep.)
- Permeable pavement on walkways, patios or driveway (but see discussion above under Treatment Controls for considerations of groundwater contamination).
- Shared driveways between adjacent homes
- Sloped driveway to direct runoff onto permeable surface
- Vegetation planted under roof dripline
- Dry-well connected to roof downspout

An outstanding example of a stormwater-sensitive residential development is Village Homes in Davis, CA. Built in the 1970's this site utilizes common drainage areas with a series of vegetated swales and percolation beds that infiltrate rainfall, as well as provide aesthetic amenities to the development. Streets are only 20-24 feet wide with 3-foot easements on either side, reducing impervious cover while still providing emergency access and walking room. Additionally, the use of a surface drainage system saved $800 per lot in infrastructure costs over traditional subsurface sewer system (Lehner et al., 1999).

Residential Multi-family

- Same suggestions as above
- Clustered design of separate units to minimize driveways and other impermeable surfaces
- Covered parking with vine-covered trellis (and direct parking lot runoff into trellis planter basins
- Vegetated swales or strips in between buildings and parking lot rows

Commercial

- Interrupted curbs that drain into infiltration basins between parking aisles
- Covered or underground main parking

- Pervious surfaces on overflow parking
- Covered outdoor loading and maintenance areas
- Cisterns for irrigation of on-site vegetation (underground or against exterior walls)
- Green roofs for stormwater retention and energy conservation

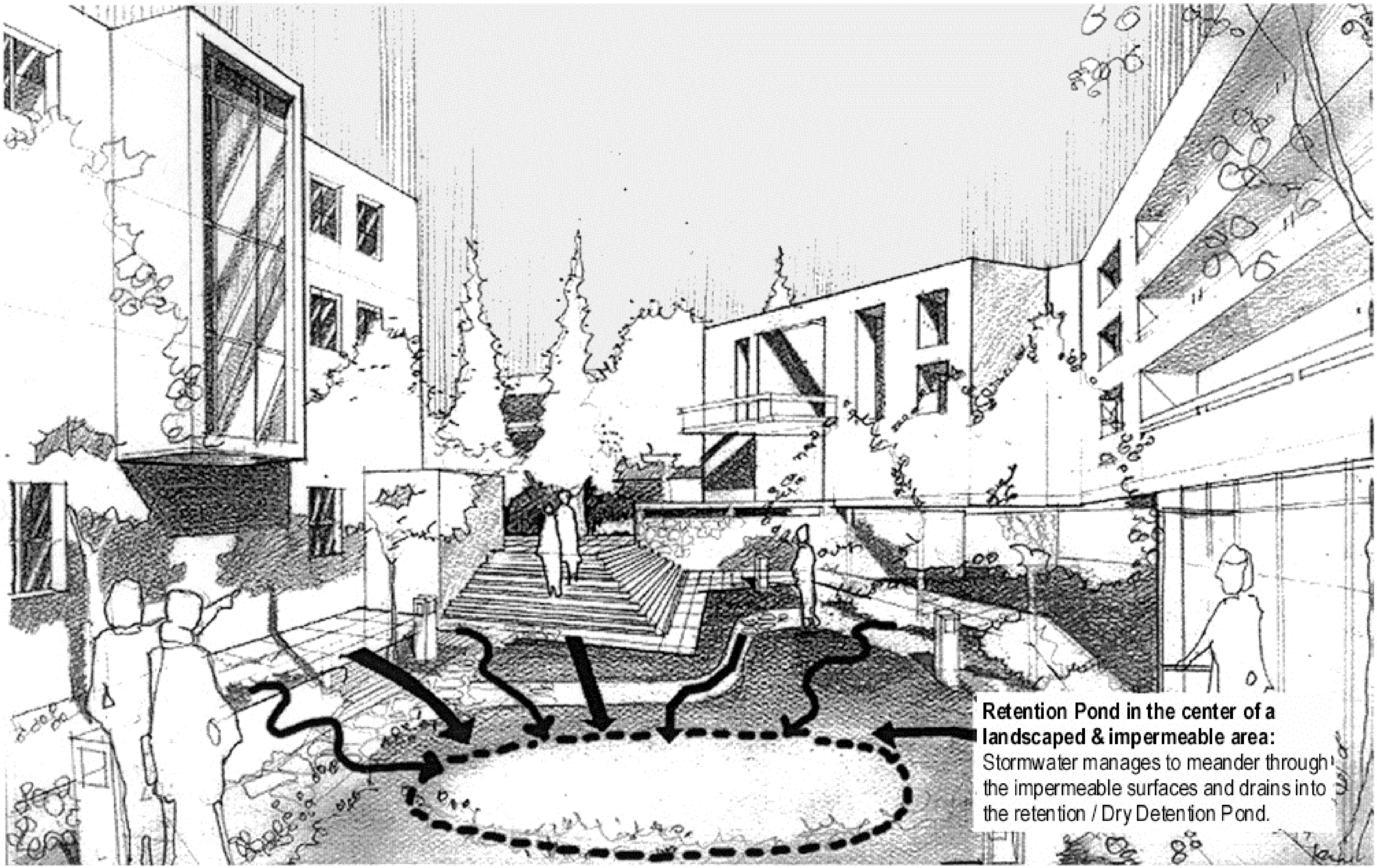
Industrial

- Incorporate mixed-use design: industrial, recreational and agricultural (e.g. a parking lot orchard)
- Cluster buildings to maximize open space
- Covered maintenance yard, service, and loading dock areas
- Curbed and/or covered garbage areas
- Vegetated swales and concave landscaping to hold stormwater
- Permeable pavement on all walkways
- Cisterns for irrigation of vegetated areas
- Building location and orientation for energy efficiency
- Shade trees for natural cooling and infiltration of roof/walkway runoff

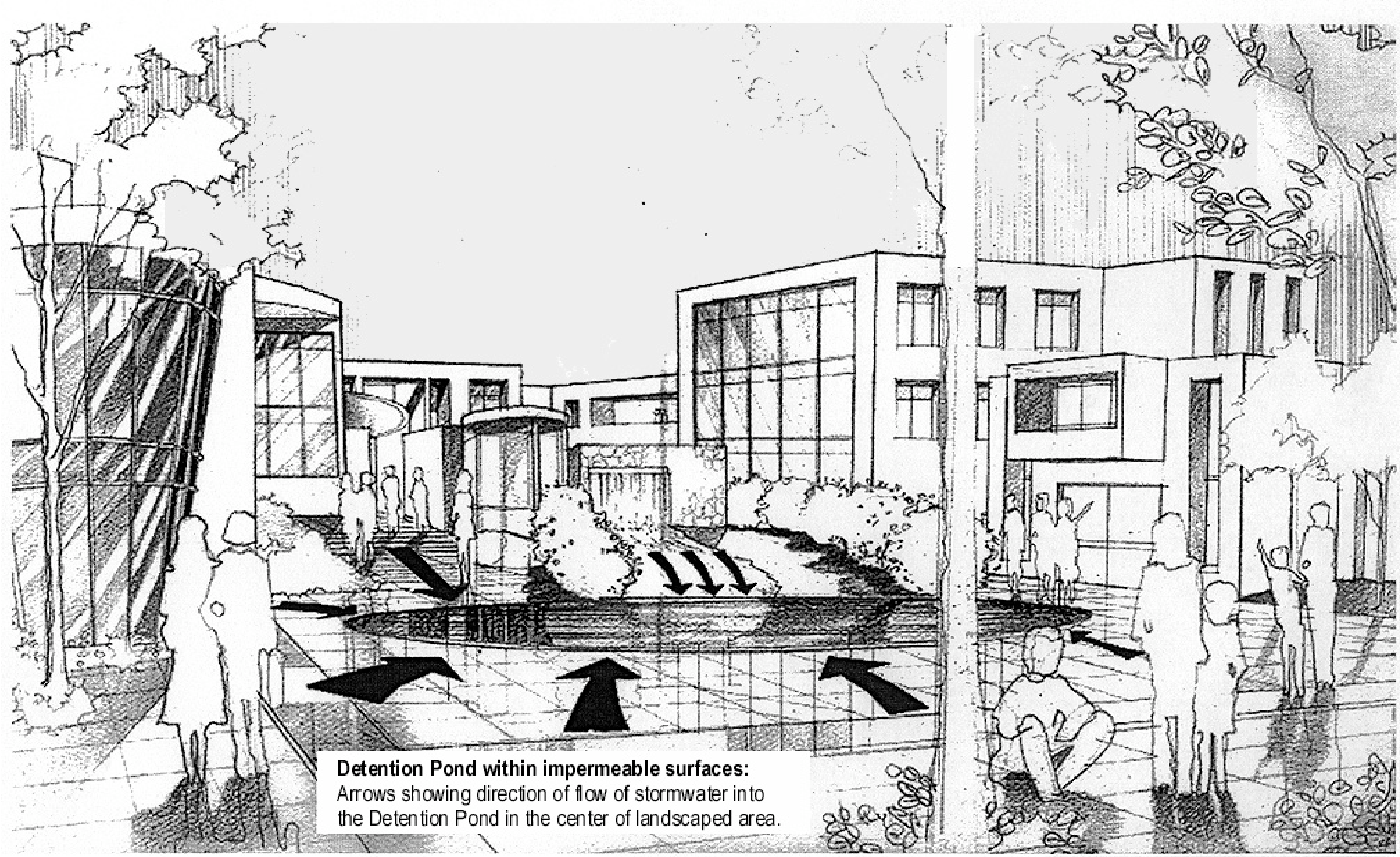
Conclusions

Urban and stormwater runoff are the largest sources of pollution to water bodies in Los Angeles. Impervious surfaces created by development increase both runoff rates and volumes, resulting in higher pollutant loads. A basic understanding of hydrologic principles can help architects and developers to incorporate stormwater mitigation principles into development designs. A combination of systems, including both source and treatment controls, should be considered for the most effective mitigation. Well-designed stormwater BMPs not only add value to a development, but also may reduce construction costs. Integrating effective stormwater BMPs into building and site designs will require close cooperation and planning among architects, engineers and landscape architects.

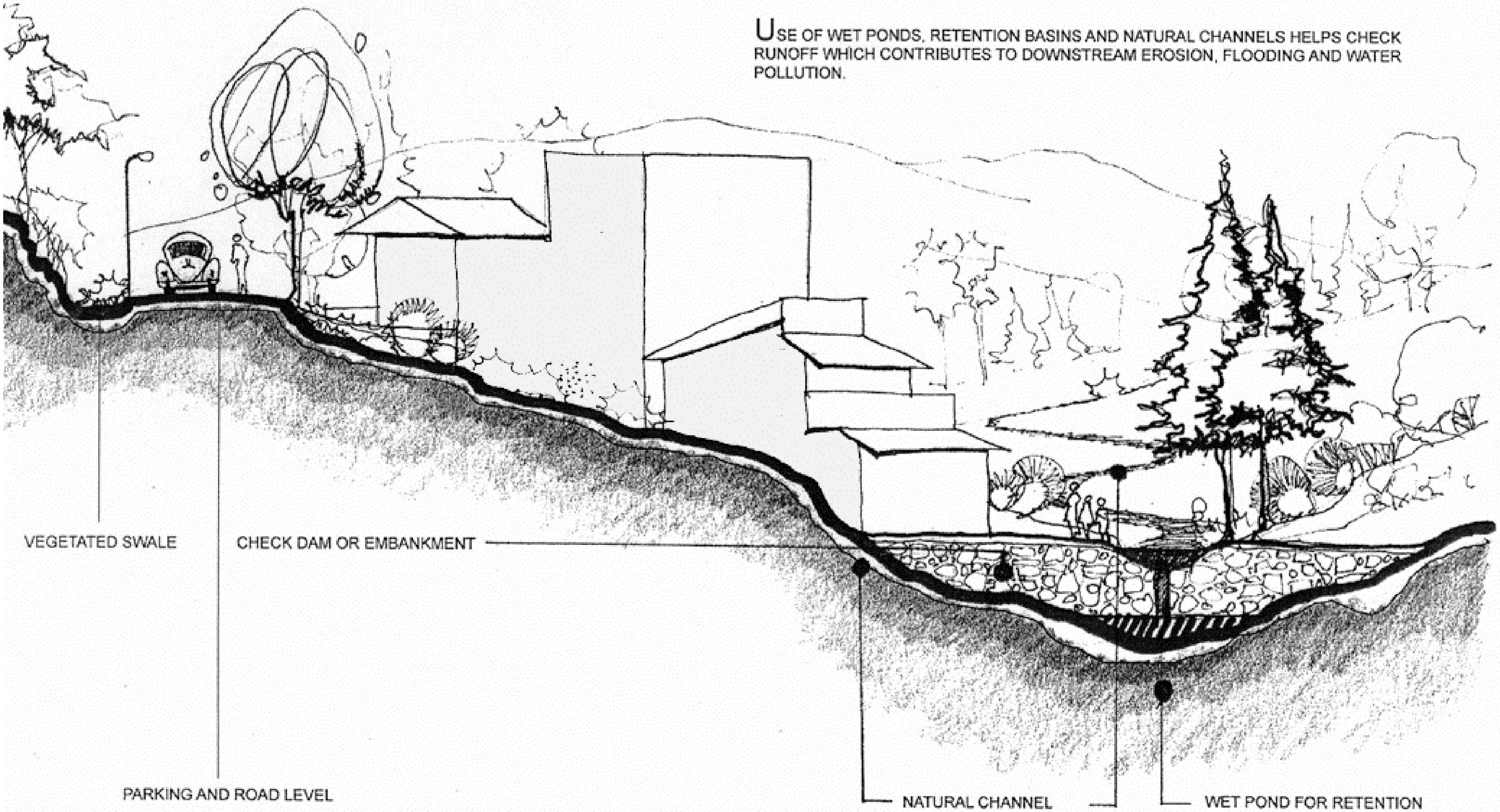
Illustrated Examples of Selected BMPs



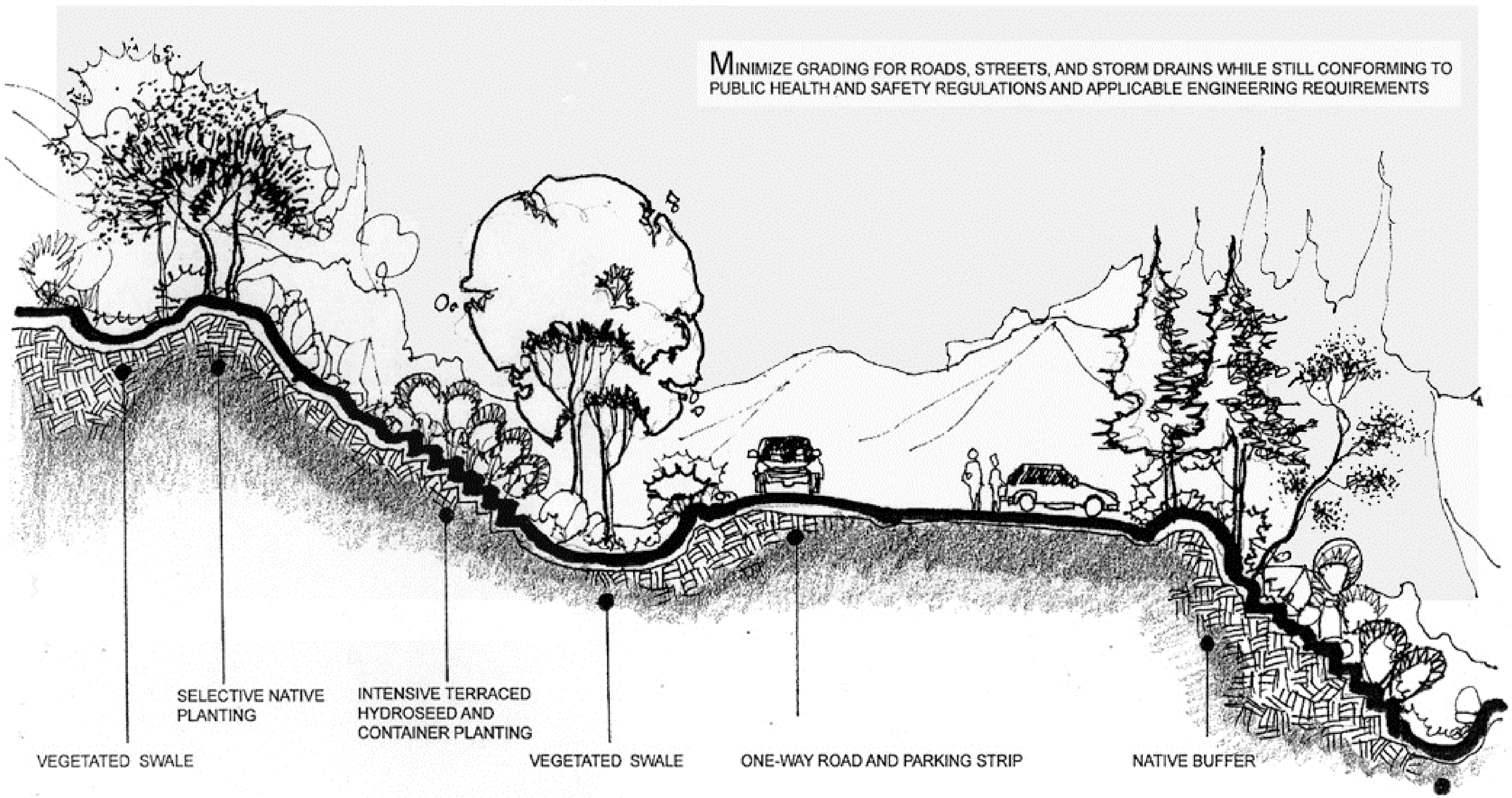
Retention / Dry Detention Basin as a part of residential urban landscape



Use of Detention Ponds in urban landscaped areas.



Design guidelines for grading and stormwater retention – section shows gradation of land and use of wet ponds, channels and check dam.

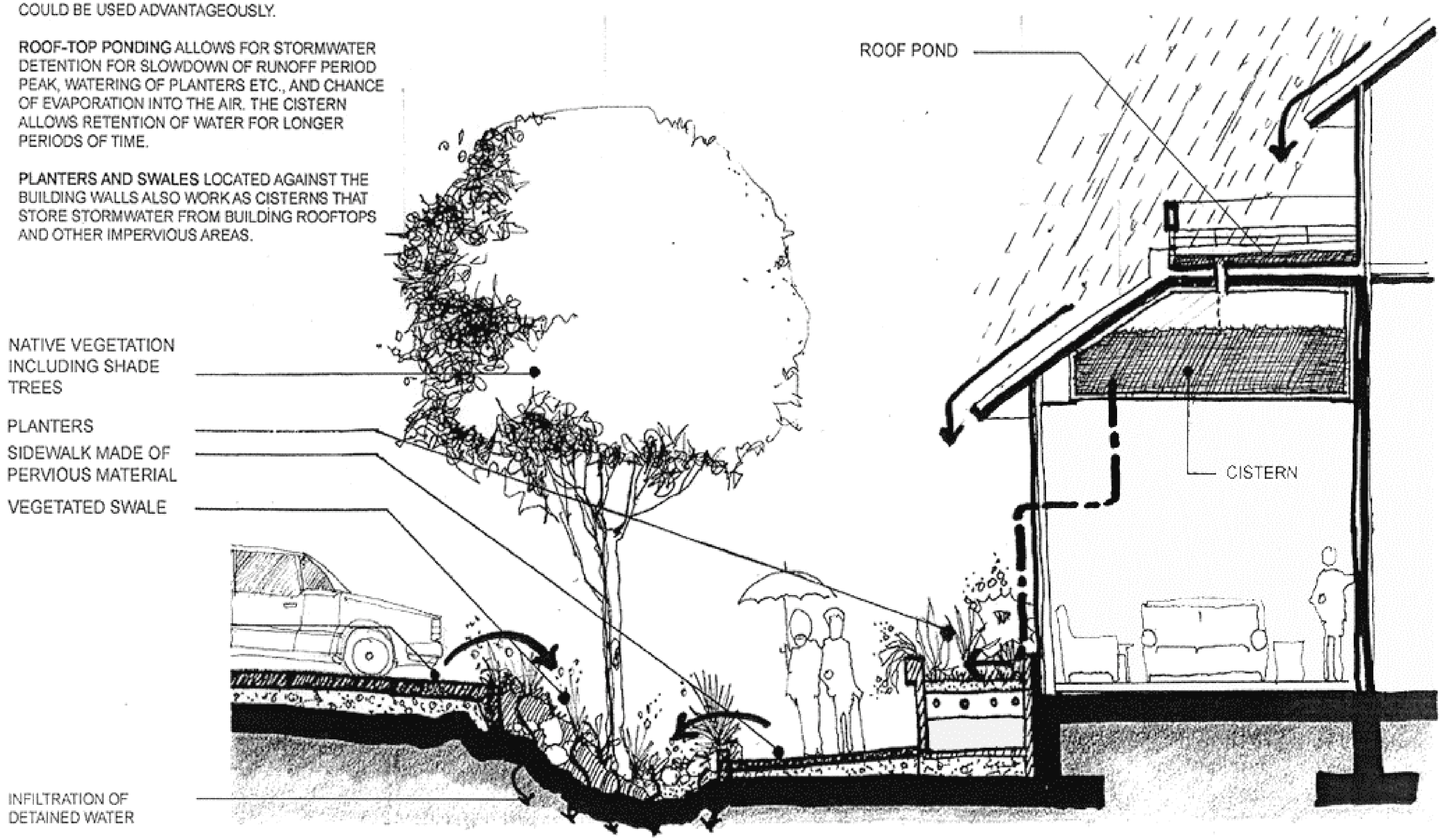


Design guidelines of landform grading - use of vegetated swales and selective planting.

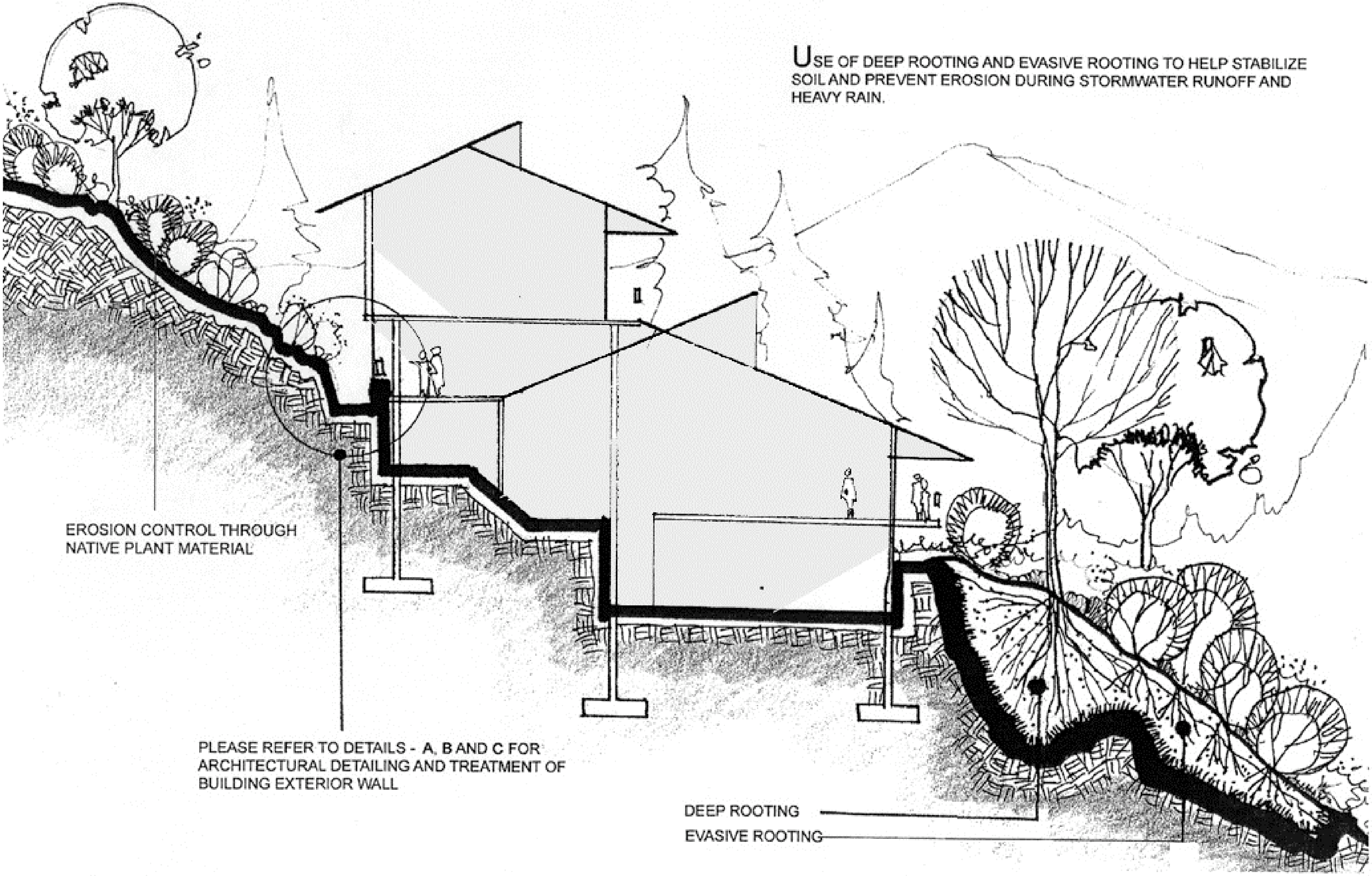
THIS CROSS-SECTION SHOWS HOW RETENTION / DETENTION OF STORMWATER RUNOFF FROM ROOFTOPS AND IMPERVIOUS AREAS COULD BE USED ADVANTAGEOUSLY.

ROOF-TOP PONDING ALLOWS FOR STORMWATER DETENTION FOR SLOWDOWN OF RUNOFF PERIOD PEAK, WATERING OF PLANTERS ETC., AND CHANCE OF EVAPORATION INTO THE AIR. THE CISTERN ALLOWS RETENTION OF WATER FOR LONGER PERIODS OF TIME.

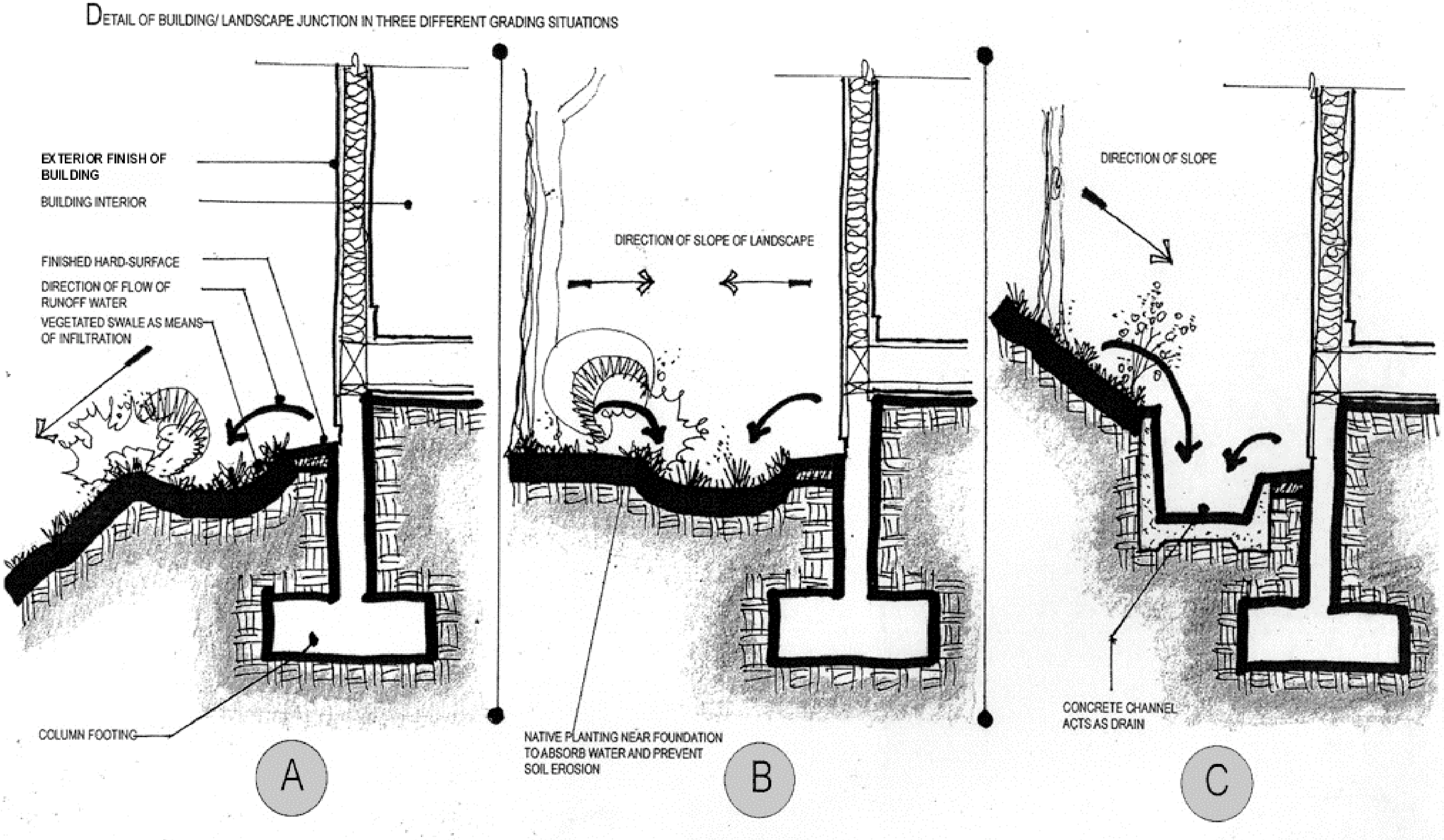
PLANTERS AND SWALES LOCATED AGAINST THE BUILDING WALLS ALSO WORK AS CISTERNS THAT STORE STORMWATER FROM BUILDING ROOFTOPS AND OTHER IMPERVIOUS AREAS.



. Section of residential street and house showing alternate methods of channeling stormwater runoff and use of cisterns/ roof ponds in a house.



Design guidelines for grading and stormwater retention – section shows use of proper plantation and treatment of the adjacent exterior of the building.



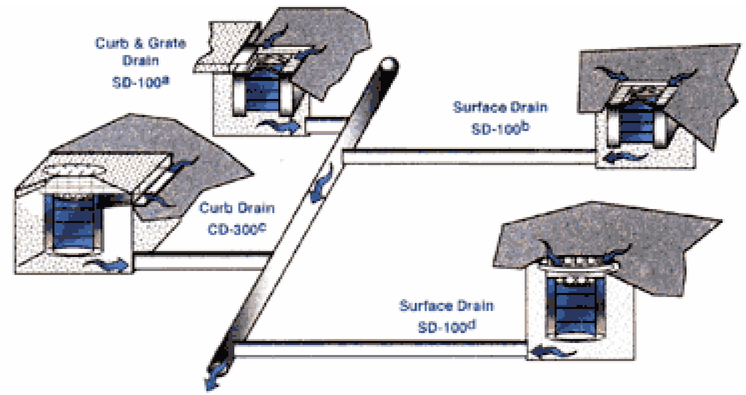
Design guidelines for Building/ Landscape junction – Details A, B and C .

Stormwater Treatment Products

*Disclaimer: All of the information contained in this section has been taken directly from the manufacturers and has not been validated by the authors.

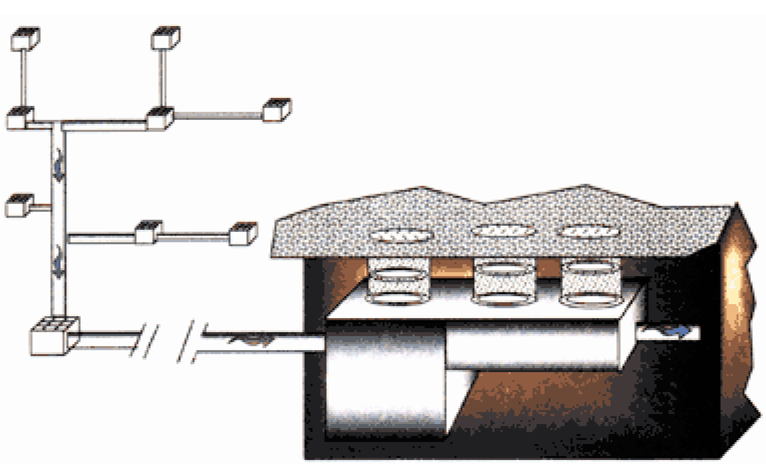
AquaShield™.

Remedial Solutions has the solution for the treatment of wastewater and stormwater discharges. The *AquaShield*™ for surface drain catch basins (SD-100) is made of stainless steel because of its superior ability to withstand harsh conditions that are encountered where various chemicals could degrade other possible construction materials. Our system is compatible with most any size or shape catch basin to allow ease of use in variable site conditions.



The SD-100 can be installed in surface openings of stormwater dry wells or leaching pools designed as detention basins. An adaptor directs the water entering the catch basin into the filtration system without restricting the normal surface flow. The filter stages can be added or removed from the system depending on the specific needs of the site and the size of the basin.

The ***AquaShield™*** CF-200 series is capable of accommodating the flow from several surface drains connected to a single discharge point. The CF-200 is installed down stream of the convergence of the surface drains and connects to the existing drain piping. Installation is as simple as for a normal pre-cast catch basin structure with a manway opening at the surface. The CF-200 is also in use at vehicle maintenance centers because of its high performance removal of oil/grease, heavy metals, and total suspended solids.



The ***AquaShield™*** CF-200 series provides multiple filter stages and channels to control the flow pattern of water to maximize the contaminant removal. The CF-200 is equipped with overflow areas to allow continued water travel and not cause backup on the surface during periods of prolonged and increased drainage. The filter stages and sediment area are easily serviced from the ground level.

http://www.remedialsolutions.com/aqua_shield/index.html

BaySaver Separation System
Since 1996, BaySaver systems have been installed in commercial, industrial, institutional, and residential applications. They are ideal for use in:

- high traffic parking lots
- industrial maintenance facilities
- gas and service stations
- highway stormwater runoff
- pretreatment for subsequent BMPs

BaySaver systems can easily be incorporated into new designs or retrofitted for existing infrastructure.

http://www.baysaver.com/bss/apps/apps.html

CONTECH® Underground Stormwater Detention Systems
Management of runoff and stormwater discharge from developed property. Such systems maximize property usage, lower development costs, and offer the safety and efficiency of underground storage.

http://www.contech-cpi.com/productpages/_stormwater.html

CONTECH® Slotted Drain
CONTECH® Slotted Drain™ quickly removes runoff from roadways, parking lots, and other paved surfaces through a continuous high-performance inlet that installs flush with the surface. It intercepts and removes sheet flow without requiring complex grading and surface contouring, and it eliminates the need for water channeling devices such as asphalt dikes, berms, and curbs.

Slotted Drain improves the safety of pavement surfaces and increases the utilization of such areas quickly after rainfall events. A standard 20' length of *Slotted Drain* can intercept up to 50% more runoff than most 2' x 2' grate inlets. Slanted inlet plates improve discharge efficiency for faster water removal. The trapezoidal slot opening minimizes accumulation of debris while avoiding interference with pedestrian or small vehicle traffic.

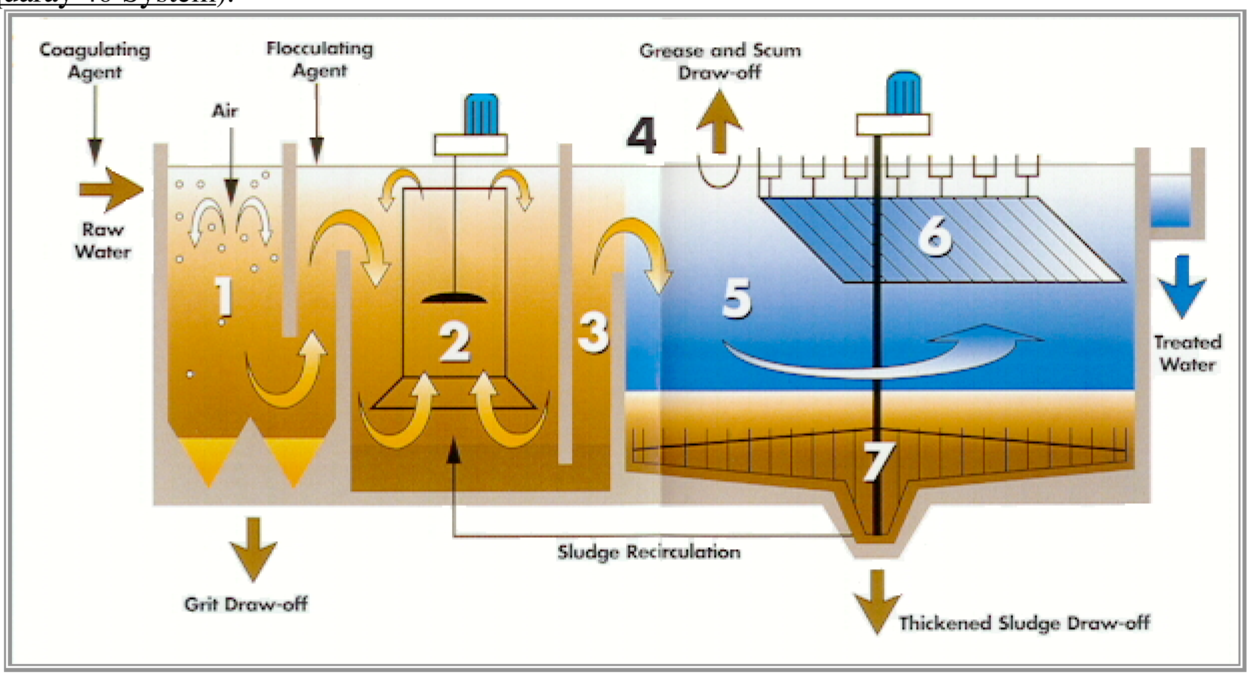
http://www.contech-cpi.com/productpages/_slotteddrain.html

DensaDeg 4D

The *DensaDeg 4D* Stormwater Treatment Process **by Infilco Degremont** is a compact, high-performance treatment process to handle stormwater flows. The *DensaDeg* can reach full capacity rapidly in response to storm events. The process is able to start up automatically without operator attention. The *DensaDeg 4D* provides four functions in one process:

- Grit Removal
- Grease and Oil Removal
- Clarification
- Sludge Thickening

The *DensaDeg's* non-ballasted, slurry recirculation technique eliminates the need for an external source of particulate matter for flocculation. This well-proven process will produce sludge concentrations in the range of 4 to 8 %. The *DensaDeg 4D* Stormwater Treatment unit can be coupled with debris removal (Climber Screen) and/or with UV disinfection
(Aquaray 40 System).



Area 1: Grit removal/coagulation

The raw water enters an aeration zone where grit removal is performed and a coagulating agent introduced. The coagulant is dispersed through the water by the aeration.

Area 2: Flocculation, first stage

The water then flows into a second area, mixed by an axial-flow turbine. Here, a flocculating agent is added and the thickened sludge is returned to the reactor. The combined flow is recirculated through a draft tube. The recirculated sludge accelerates the flocculation process and ensures the formation of a dense floc.

Area 3: Flocculation, second stage

This area handles the transition to the settling stage. It uses a plug-flow reactor, where the flocculation process continues and the grease and scum start to separate out.

Area 4: Grease and scum removal

Grease and scum are collected at the surface and removed

Areas 5 and 6: Pre-settling and lamella settling

Flocculated water enters a pre-settling area (area 5), where most of the suspended flocculated matter is separated directly. This is followed by a tube settler polishing zone (area 6) to remove the residual flocs. Uniform flow is maintained by water collection launders.

Area 7: Sludge densification and thickening

The settled sludge is thickened in area 7, after which part is recirculated and the remainder drawn off in concentrated form.

http://www.enquip.com/CSO-SSO.htm

Draincore^2

Designed to achieve large area subsurface drainage efficiently by gravity movement of water to a collection point. The 2.5 cm (1") depth of ring moves large volumes of water quickly and easily over an impervious membrane.

Collect water under parking lots, golf courses, drainage areas, or athletic fields of all types. *Draincore^2* can be used with your drainage soil mix or with our custom InvisibleTurf system, which as a specific drainage composition for maximum porosity and highest quality growing medium. Subsurface aeration is also available.

http://www.invisiblestructures.com/DC2/draincore.htm

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ecoSTOP

ecoStop is a Petroleum Spill Control System for any facility or site, where the potential for a petroleum spill exists (gasoline stations and other fueling facilities, electrical transformers, generators, oil storage areas, transportation fueling systems). The system is installed in-line and downstream from any segregated petroleum containment drainage area. ecoStop is available pre-installed in a standard precast concrete manhole or in an ecoSep Oil/Water Separator. It can also be retrofitted to an existing drainage system.

EcoTOP
ecoTop is an above grade oil/water separator that produces consistently superior removal efficiencies for effluent oil content in a portable stainless steel vessel (hydrocarbon concentration in the effluent <5 ppm according to the European Standards DIN 1999 and EN-858). A two-step separation process, gravity separation and removal of small oil particles by specially designed coalescing media elements, produce high removal efficiencies. The separated oil is automatically removed from the water surface and collected in an internal or external oil recipient.

http://www.ecotechnic.at/Ecostop/index_ecostop.html

EEC OIL-SEP
The *EEC OIL-SEP* oil and water separator is a single-stage device designed to separate and remove insoluble oil, solids, and entrained air from oily water. The system processes oily water at its rated capacity, and is designed for continuous and intermittent operation without the need for chemicals or other additives. After the system has been started, it is capable of automatic operation.

EEC OIL-SEP (0.5 - 10m3/h) The system design incorporates a mechanical rotating coalescing fiber and stationary polishing pack to provide the most efficient and effective means for separating oil from water and eliminating the need to change or replace filters or filtering media.

EEC OIL-SEP (10 - 200 m3/h) The fabricated vessel contains a series of matrix plate pack assemblies which are fitted in a vertical position to enhance solid removal. Each plate assembly is fabricated from corrugated, rigid, PVC sheets. Unlike conventional modular sheet media, no flat sheets are used in the fabrication of the plate packs. The result is greatly increased contact time between the oily water and the corrugated sheets, accelerating the coalescing process.

http://www.eecusa.com/html/newpage32.htm

Fossil Filter

Catch basin filtration is the placement of catch basin insert devices that contain a filtering medium (a sorbent) just under the grates of the stormwater system's catch basins. The water runoff flows into the inlet, through the filter where the target contaminants are removed, and then into the drainage system.

The devices must be capable of effectively filtering the first flush of stormwater runoff from a rain event and provide an overflow capability sufficient to prevent the system from becoming clogged. The sorbent filter medium must be a nonleaching inert blend of minerals that contain non-hazardous ingredients, as defined by the Federal EPA, OSHA and WHO.

The system must be capable of removing and containing sediment, debris, trash and petroleum hydrocarbons (oil and grease from fossil fuels) from the runoff. In addition, some heavy metals will be removed by virtue of being attached to the silt fines.

Fossil Filter™ and Fossil Rock™, its installed adsorbent, comprise a catch basin filtration system and satisfy the above criteria. Fossil Filter™ is a cost-effective alternative to large underground oil/water separators and other water filtration systems.

It is adaptable to both new and post construction, is easy (and economical) to install and maintain and is available in a variety of models, sizes and shapes to fit most drainage systems and structures.

Its most obvious applications are motor vehicle parking lots, corporation yards, service stations, washracks and the like where fossil fuel pollution is a problem. These products help you conform to the EPA Clean Water Act.

http://www.kristar.com/fosys.html

Garden Roofs®

Developed by Hydrotech in conjunction with ZinCo GmbH of Germany, the Garden Roof® assembly is backed by over 35 years of combined experience in premium waterproofing and green roof technologies. The Garden Roof® provides building owners and tenants with many ecological, technical and economic benefits. Some of the advantages of the Garden Roof® assembly include:

* Enhances building's appearance
* Adds space for tenant use and recreation
* One answer to the "Urban Heat Island" problem
* Stormwater management - retain 50%-90% of a typical rain fall on the roof
* Improves building's energy efficiency
* Processes airborne toxins and re-oxygenates the air

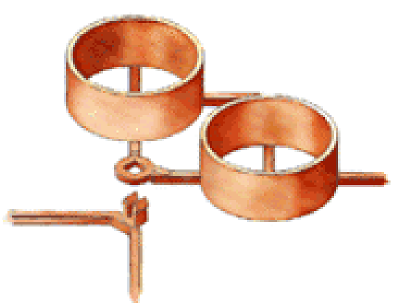
* Creates therapeutic and peaceful environments
* Total assembly warranted, from the deck up

The **Extensive Garden Roof®** is ideally suited for locations that will receive little or no maintenance, or where structural capabilities are a concern. Recommended plants include sedum, herbs, grasses and other vegetation that can withstand harsh growing conditions. The soil mixture, composed primarily of mineral materials mixed with organic medium, can be very shallow (as little as three inches). The entire system is very light, weighing little more than a traditional ballast roof, allowing for safe installation on almost any existing roof.

The **Intensive Garden Roof®** incorporates plants that require regular maintenance, such as watering, fertilizing and mowing. The variety of plants possible is numerous, including sod grass lawns, perennial and annual flowers, shrubs, and even small trees. When used in conjunction with Hydrotech's full line of hardscape elements, such as architecturally finished pavers and precast items, the system is ideal for roofs and plazas that will serve as pedestrian recreational areas.

http://www.hydrotechusa.com

Grass Pave



This horticultural difference means longevity and the best chance for durability and recovery under stress. The grass roots will penetrate the sandy gravel roadbase required for all pavements regardless of product choice.

http://www.invisiblestructures.com/GP2/grasspave.htm

Gravel Pave

Gravelpave² has been used for high traffic porous parking areas since 1993 -- banks, fast food restaurants, colleges, and residential driveways. 100% recycled plastic rings are molded onto non-woven geotextile filter fabric. The rings become invisible or camouflaged by the decorative gravel, which is "contained" for a smooth, well-dressed finish. Large rolls of *Gravelpave²* make installation of trails or parking lots quick and easy.

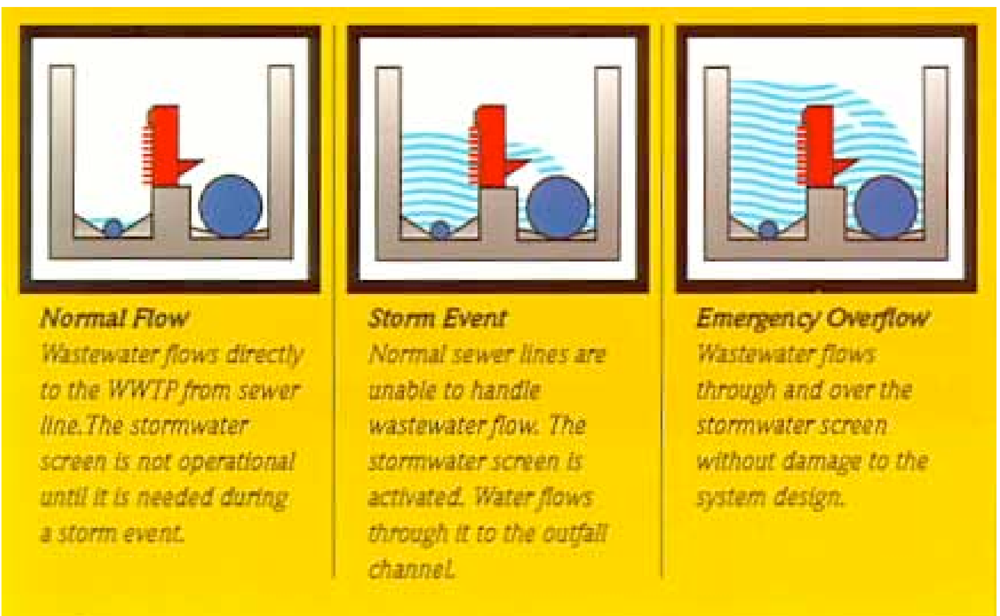
Gravel base course, depth specified by a soils engineer, is laid underneath to bear vehicle loading, *Gravelpave²* is unrolled and fastened together with washers in clouded, then filled with decorative gravel of minus 5mm (3/16") using a front end loader and rakes. Settling of fill gravel can be done by either compacting with a roller or irrigating with water.

http://www.invisiblestructures.com/GV2/gravelpave.htm

Hycor® Romag Screen

Automatically activated, self-cleaning screen - Ideal for remote locations. Functions as an emergency overflow weir to keep solids in the wastewater channel or direct toward solids collection pit.

Screen openings: 4mm
Hydraulic capacity: to 100 MGD for a single unit.

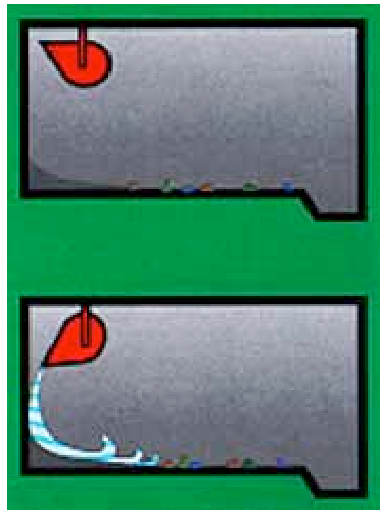


http://www.parkson.com/NEWPROD_hycor_romag_screen.htm

Hycor® Vollmar Tipping Bucket for Automatic Stormwater Tank Flushing

Completely maintenance free tank cleaning. Buckets tip automatically when the water level mechanically unbalances the load. Any water source may be used: ground water, river water, gray water or potable water.

Lengths from 3' to 19.5' for single buckets - buckets may be used in parallel for extremely long tanks.



http://www.parkson.com/NEWPROD_hycor_tipping_bucket.htm

HYDRO-CLEAR® Rapid Sand Filter

The Hydro-Clear® filter features a unique underdrain system and a shallow bed (10 inches deep) of single-media, fine-grained sand. These innovations permit the filter surface to be "pulsed" or regenerated periodically, prolonging filter runs and keeping the filter on-line, despite unpredictable changes in solids loadings and solid characteristics. The unique features also allow the filter to be backwashed efficiently with significantly less power and water than is required with other types of filters.

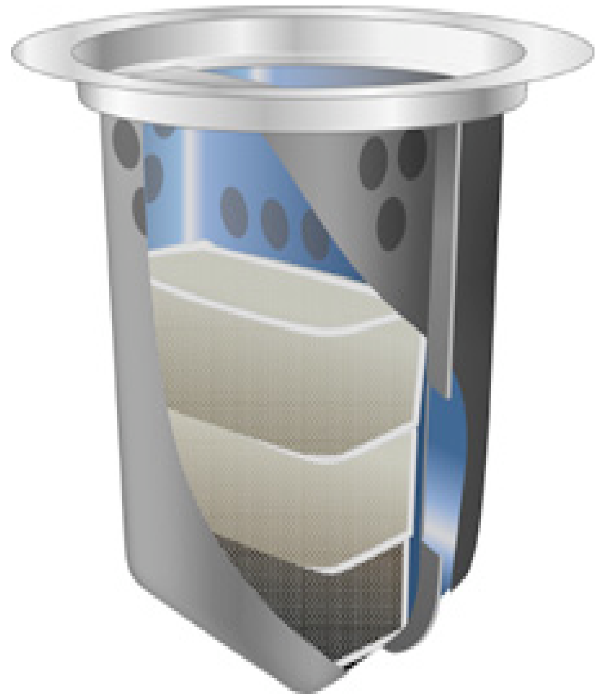
Hydro-Clear® filters come as prefabricated package units, steel modular systems, or as component systems to be installed in concrete tanks. The package systems are available in two and three cell models. The modular systems and component systems installed in concrete tanks may consist of any number of filter cells and various arrangements, depending on the amount of flow.

Applications
Hundreds of customers worldwide use Hydro-Clear® filters for the following applications: municipal tertiary treatment, wastewater reclamation; reuse; stormwater filtration; Primary Effluent Filtration (PEF); commercial and institutional treatment, housing developments.

http://www.zimpro.com/hydroclr-muni.htm

Hydro-Kleen

The patented Hydro-Kleen Filtration System is a cost-effective technology for use with storm water catch basins and drains to trap hydrocarbons, metals, sediments, and other contaminants contained in storm water and other surface runoff.



The multi-media filtration system contains design features that effectively filter out hydrocarbons and other contaminants while alleviating concerns with water flow.

The Hydro-Kleen Filtration System is an effective Best Management Practice (BMP) to assist end users in complying with meeting NPDES Storm water permit and other regulatory requirements for protecting surface water quality

http://www.hydrocompliance.com/

Infiltrator Chambers

Infiltrator Systems Inc. is the world leader in the manufacture of plastic drainage chambers for on-site septic and stormwater management. Infiltrator® chambers have revolutionized the septic and stormwater industries, providing cost-effective, efficient methods for handling residential and commercial wastewater. Infiltrator septic chambers replace conventional stone and pipe leachfields. The subsurface Infiltrator stormwater system replaces retention ponds, large diameter pipe and stone, and other stormwater designs. Infiltrator Systems Inc. is the world leader in the manufacture of plastic drainage chambers for on-site septic and stormwater management. Infiltrator® chambers have revolutionized the septic and stormwater industries, providing cost-effective, efficient methods for handling residential and commercial wastewater. Infiltrator septic chambers replace conventional stone and pipe leachfields. The subsurface Infiltrator stormwater system replaces retention ponds, large diameter pipe and stone, and other stormwater designs.

http://www.infiltratorsystems.com/overview.htm

Oil Skimmers, Inc.

The Model 6-V oil recovery system removes all kinds of floating oil from water. A closed-loop collector tube floats on the water surface, attracting oil but not water as it slowly snakes over and around debris. The tube is raised out of the water and drawn through scrapers that remove the oil. The clean tube is returned to the water surface to gather more oil.

The Model 5-H oil skimmer is used to remove oil, fat or grease from solutions in above ground tanks or basins where the skimmer is mounted less than 2 feet above the liquid surface. Being compact in design, it is used where space is limited. It can be installed on either open or closed top tanks.

http://www.oilskimmersinc.com/our_products/products.html

Rainstore 3 (RS3)

Invisible Structures, Inc., (ISI) has created a new class of subsurface water storage system, ***Rainstore3 (RS3).*** It is not pipe or arched chamber, but a structure with strength throughout its shape. The unique design places the plastic entirely in compression rather than bending or tension resulting in H-25 loading, and high void storage volume of 94%! Minimum cover is only 0.3 meter (12”).

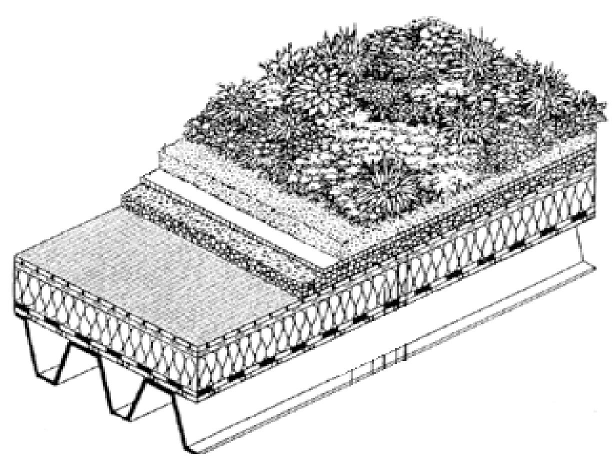
The structure can be as shallow as 0.1 meter (4") or as deep as 2.5 meters (94"), length and width in 1 m (40") increments. Rainstore3 eliminates site restrictions by conforming to custom project requirements. RS3 does not require any stone backfill between structures. Calculating the void (storage) volume is as simple as dividing storage demand by 94%. This means significant savings in amount of excavation, soil transport, imported stone, installation time, and labor. Rainstore3 can be utilized for long-term water storage for irrigation, fire protection, and potable applications by encasing the structures in an impervious liner. Porous lining materials around RS3 offer 100% surface area coverage for water infiltration/exfiltration.

http://www.invisiblestructures.com/RS3/rainstore.htm

Roofscapes, Inc.

Roofmeadow® vegetated roof covers are tailored to the specific requirements for:

* Runoff management
* Load
* Appearance
* Energy conservation



The mission of Roofscapes, Inc. is to introduce, design, and install advanced measures for the control of urban runoff and for the preservation of air and water quality. In addition to green roofs, these include bioretention systems and created wetlands. We accomplish our mission by furnishing up-to-date consulting advice and construction services through our network of licensed landscape contractors.

Roofscapes, Inc. maintains a national network of highly-regarded landscape contracting companies that are licensed to install the Roofmeadow® family of green roof systems.

http://www.roofmeadow.com

SAGES system

A new stormwater management technology, the SAGES system, which can be used in existing or new stormwater management systems, can reduce the volume of stormwater and the contaminant load reaching receiving bodies. A portion of the stormwater is captured a diverted to groundwater. It is diverted at the point of origin; say at the catch basin, from the system into the ground. The system offers a means to decrease stormwater peaks, to cut off stormwater peaks, and to decrease stormwater pollution reaching surface water bodies.

The system includes easily removable filters, a support grate, a well-like device, and extraction chains. The filters are graded from coarse to fine in the direction of flow, thereby removing successively finer contaminants and resisting premature caking at any filter interface. The graded design removes successively finer contaminants. The support grate allows the filters to rest on a flat surface, thereby spreading the media to fill the entire unit at depth.

The SAGES units use mechanical and adsorption filters to remove contaminants. Mechanical filtration occurs by various mechanisms, including interception, inertia, gravity, diffusion and hydrodynamic trapping.

http://www.egmondassociates.com/eric.htm

SNOUT

SNOUT is an affordable, hooded outlet cover to install in sumped catch basins and other water quality structures that prevents oil and floatables from being drawn downstream. From Best Management Products, Inc.

- Oil-Water-Debris Separator for Stormwater
- Effective, inexpensive, easy to install
- For retro-fit or new construction
- Durable, yet lightweight, plastic composite
- Anti-siphon vent and watertight access port
- Stock sizes 12" - 96" (up to 84" pipe)

http://www.bestmp.com/

Stormceptor

The Stormceptor is a simple but revolutionary patented stormwater quality treatment device that efficiently removes oil and suspended solids and stores them for safe and easy removal. *Stormceptor* is manufactured in the United States by the leader in concrete products - CSR Hydro Conduit.

Stormceptor is unique in the market because it will not release trapped pollutants between servicing, even in periods of peak water flow. Designed to replace more costly conventional water quality inlets, and tested in laboratory and field application, *Stormceptor* offers other benefits beyond front-line pollution control.

The precast concrete *Stormceptor* is manufactured from easily assembled concrete components that are preengineered for traffic loading. The *Stormceptor* can be installed in road allowances similar to standard manhole structures.

*Stormcepto*r is applicable in a variety of situations:

- Industrial applications
- Commercial parking lots
- Automobile service stations
- Mass transportation facilities, such as train stations, bus depots, and airports
- New residential developments
- Re-development in the urban core
- Power/Utility Stations
- Gas Stations
- Shopping Centers

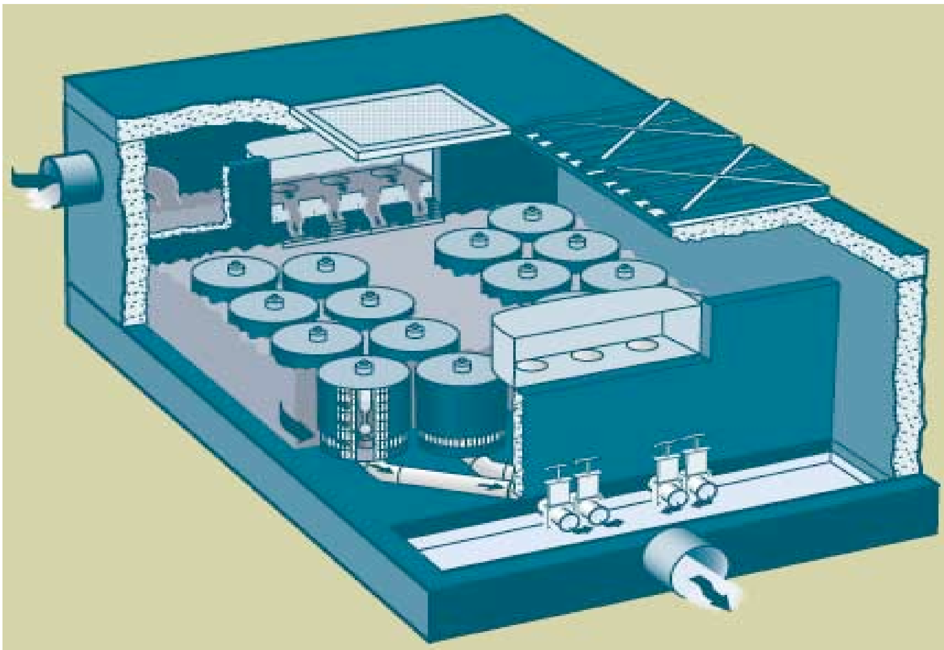
The *Stormceptor* is a simple but revolutionary stormwater quality treatment device that efficiently removes free oils and suspended solids. Normal flows are diverted into the lower treatment chamber where oil and other liquids with a specific gravity less than water rise and become trapped beneath the fiberglass insert while suspended solids settle to the bottom of the chamber by gravity and centrifugal forces. During high flow conditions, the by-pass chamber conveys water to the downstream sewer directly circumventing the lower chamber and preventing the resuspension and scour of settled pollutants.

http://www.stormceptor.com/

StormFilter®

The *StormFilter®*, is a premier filtration system, widely recognized as a versatile Best Management Practice for removing a variety of pollutants. The *StormFilter* cartridges are filled with an array of media, selected to treat the specific pollutant loadings at each site. These site-specific media options give the system the ability to remove high levels of stormwater pollutants such as sediments, oil and grease, soluble heavy metals, organics and soluble nutrients. It is unique in its ability to meet current and future pollution challenges. No other system offers this degree of excellence and versatility.

The *StormFilter* is offered in four different configurations: cast-in-place, precast, linear, and catch basin. The precast, linear and catch basin models use pre-manufactured vaults to ease the design and installation process. The cast-in-place units are customized for larger flows and may be either uncovered or covered underground units.



http://www.stormwatermgt.com/products/stormfilter_lg.shtml

StormTreat

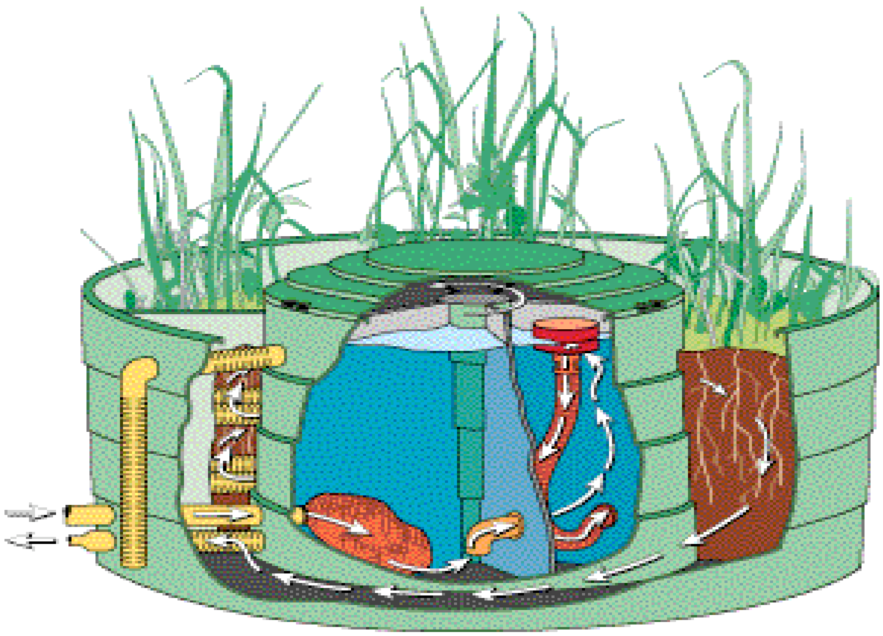
StormTreat's unique, multi-stage, stormwater treatment system, effectively reduces the broadest range of runoff pollutants including bacteria, heavy metals, nutrients, petroleum hydrocarbons, and suspended solids.

The *StormTreat* system meets EPA's recommended 80% removal rate for Total Suspended Solids (TSS), and can be configured to meet more stringent state standards in critical water resource areas.

The *StormTreat* system significantly reduces the need for unsightly and land-intensive detention facilities. It captures and treats the first half-inch of all of the smaller (routine) storms and treats the first flush of the large (less common) storms. Therefore, flood control can be accomplished by using landscape buffers and/or smaller detention facilities.

By providing highly efficient treatment of the first flush, the *StormTreat* system compares favorably with other stormwater BMPs on a "cost per-acre treated" basis.

Maintenance is simplified by standardized procedures and is limited to: a) Annual inspections (and replacement of grit filter bag); b) Sediment pumping once every three to five years using standard septic system pumper.



http://www.stormtreat.com/

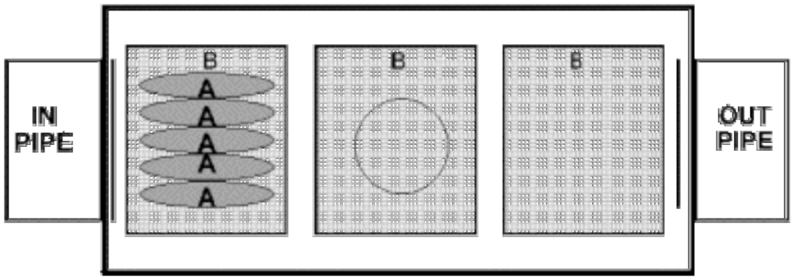
Suntree Technologies Baffle Box

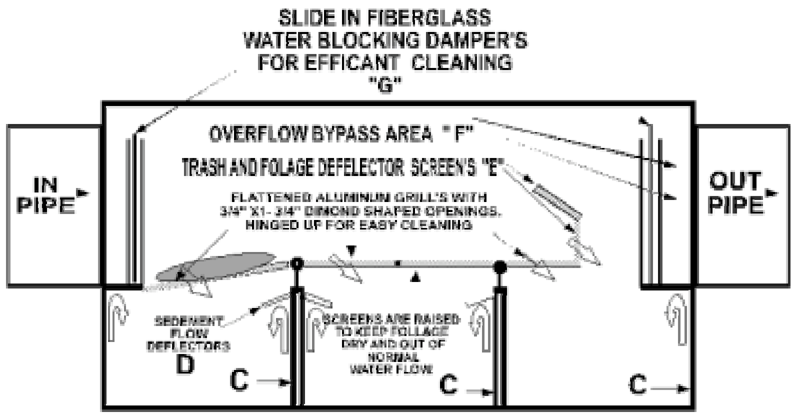
Baffle Box With Bypass Filter Separators And Oil Booms

Installs inline with stormwater drainpipe, usually at an outfall to a lake or pond.

Water enters laden with trash, grass clippings, tree limps, sand, gravel, and all types of sediments. The water first travels over the Oil Collections Booms (A) and then continues over the Aluminum Grills. The small sediment falls through the Aluminum Grills (B) and is retained behind Baffles (C). The Sediment Flow Deflectors (D) further help to keep the sediments from escaping out over the Baffles (C). All larger materials such as grass clippings, tree limbs, and other bio items are trapped above the Aluminum Grills (B). These foliage-type items are further contained by the Trash Deflector Screen (E), and kept in a dry or near dry state which keeps the nutrients and phosphates from leaching into the rivers and ponds. In the event the Baffle Box is not cleaned, the water still has clear passage through the Over-Flow Bypass Area (F) which is always an area that is far greater than that of the pipes entering and exiting the Baffle Box.

Suntree Technologies Baffle Box is equipped with flexible slide grates (G) to stop all water flow in both directions while cleaning. This feature is very important when the Baffle Box is installed below the water level or when there is a base flow. Also, all baffle boxes are flat on the bottom which makes them hard to clean; whereas *Suntree Technologies Baffle Box* is rounded on the bottom to allow for quick, easy cleaning, since the sediment is funneled to the middle of the box.

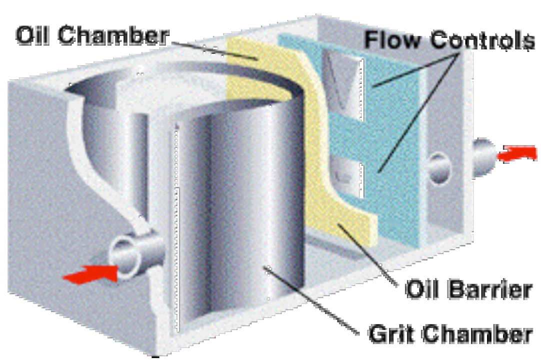




http://www.bafflebox.com/function.htm

Vortechs™ Stormwater Treatment System

A major advancement in oil and grit separator (OGS) technology, the Vortechs Stormwater Treatment System efficiently removes grit, contaminated sediments, heavy metals, and oily floating pollutants from surface runoff. This innovative design combines two unique treatment structures to eliminate turbulence within the system - ensuring proper physical separation and capture of oils.



The Vortechs System minimizes land area needed for stormwater treatment structures, and eliminates the liabilities of standing water such as ponds. Site owners will enjoy cost savings on maintenance due to the low water level, one-point access, and a design that prevents oils and other floatables from exiting the system during cleaning.

The Vortechs Stormwater Treatment System is constructed of precast concrete and features a compact, below-grade profile. The system incorporates a combination of unique treatment structures that efficiently remove pollutants from runoff at rates up to 25cfs without washing out. With its proven performance and low maintenance, the Vortechs System speeds up your permitting process and reduces site owners' post-construction clean-out costs. Now, follow the Vortechs™ System in action using our new animated phases of operation.

http://www.vortechnics.com/vortechs/

V2B1

The V2B1 is a structural stormwater treatment technology consisting of 2 standard precast manholes: An upstream swirl-chamber/vortex separator (first structure) and a floatables collection chamber and outlet chamber (second structure). Swirl-chamber technology combined with vortex design principles, effectively treat the stormwater by removing and retaining sediments and floatables from site runoff.

http://www.env21.com/

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This article discusses a stormwater management system that uses composted leaves as a filtration medium. It removes 80% of all suspended solids, metals, phosphorus, hydrocarbons and other pollutants.

(2) Bautista, F.M., Geiger, N.S., Wetlands for Stormwater Treatment, *Water Environment and Technology,* 5(7): 50, July 1993.

The authors describe a four-year water quality monitoring program to demonstrate that constructed wetlands can be effective biofilters that reduce nutrient and sediment loading. This article discusses existing water quality issues, criteria development, compliance, and performance evaluation.

(3) Bay Area Stormwater Management Agencies Association, *Start at the Source: Design Guidance Manual for Stormwater Quality Protection*. BASMAA, San Francisco, CA. 1999.

This manual focuses on maintaining the natural hydrologic cycle in planning and designing residential, commercial and industrial development projects. It covers basic stormwater management concepts and offers practical techniques for source control of stormwater runoff.

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Article discusses the use of air flotation at the treatment plant, which was divided into two stages. The first stage was coagulation/flocculation, and the second stage was flotation. This process was efficiency tested for suspended solids, chemical oxygen demand, and hydrocarbons.

(6) Booth, D.B., Leavitt, J., PLANNER'S NOTEBOOKS – Field Evaluation of Permeable Pavement Systems for Improved Stormwater Management, *Journal of the American Planning Association*, 65(3): 314, 1999.

The article explains that in urban landscapes, problems result from loss of water-retention in the soil, and states that traditional solutions are not successful. The article asserts that permeable pavement is a more promising approach to reducing the downstream affects of urban development. Runoff results from four different permeable parking surfaces are compared to those with traditional asphalt.

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This circular provides a comprehensive and practical guide for the design of storm drainage systems associated with transportation facilities. Guidance is provided for the design of storm drainage systems that collect, convey, and discharge stormwater flowing within and along the highway right-of-way. Procedures for the design of retention facilities and stormwater pump stations are also presented, along with a review of urban water quality practices. A summary of related public domain computer programs is also provided.

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This article describes the design of a cistern system, including material, location, size, catchment area, sanitation, and construction considerations.

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This article questioned residents of seven subdivisions with wet and dry stormwater basins to determine the role the basin played in the purchase of their homes. The authors found that wet basins contribute to the positive image of the subdivision, and made the lots more valuable.

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(48) Stormwater and Erosion and Sediment Control Best Management Practices for Developing Areas (Ch.6), in: *Florida Development Manual: A Guide to Sound Land and Water Management*. 1998.
A comprehensive summary of BMPs used for stormwater management and erosion and sediment control. BMPs are divided into structural and non-structural source controls, as well as recommended practices to prevent erosion and sediment loss during construction.

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The book establishes reasons for stormwater management, and discusses the fundamental ideas of probability and hydrograph procedures. It presents popular computer models for controlling peak discharge and volume. This book also extensively covers water quality issues and management alternatives for water quality improvement. Optimization procedures and erosion and sediment control for rural areas are also discussed.

(61) Water Environment Federation and American Society of Civil Engineers. *Urban Runoff Quality Management*. WEF no. 23/ASCE no. 87. 1998
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The author states that, "Water quality controls of stormwater runoff and infiltration should be a major part of a nonpoint source control program." The article argues the need to have coordination between surface runoff and groundwater control. The matrix method, where vulnerability of the area and harmfulness of pollutant sources both determine which BMPs are appropriate, is concluded to be the best approach.

(63) Zielinski, J.A. The Benefits of Better Site Design in Residential Subdivisions, in: *The Practice of Watershed Protection,* T.R Scheuler and H. K. Holland (eds.). Center for Watershed Protection, Ellicott City, MD. 2000
This article describes the use of open space design to reduce storm water runoff and pollutant export from residential developments. A nutrient output model is used for a comparative analysis between two subdivisions.

(64) http://h2osparc.wq.ncsu.edu/descprob/pointsrc.html#intro. WATERSHEDSS Point Sources webpage.

Contains introduction of history to point source regulation and pollutants, as well as best management practices. WATERSHEDSS is the, Water Quality Decision Support System – Water, Soil, and Hydro-Environmental Decision Support System. North Carolina State University, October 19, 2001.

"The two primary objectives of WATERSHEDSS are to:

1. transfer water quality and land treatment information to watershed managers in order to assist them in making appropriate land management and land treatment decisions to achieve water quality goals

2. assess and evaluate sources, impacts, and potential management options for control of nonpoint source pollution in a watershed based on user-supplied information and decisions." (http://h2osparc.wq.ncsu.edu/about.html).

(65) http://www2.lib.chalmers.se/cth/diss/doc/9900/PetersonThomas.html. Thomas Peterson, Stormwater Ponds for Pollution Reduction,

Chalmers University Department of Sanitary Engineering, 11/19/1999. From the Postgraduate Programme in Sanitary Engineering, Chalmers University of Technology.

(66) http://dnr.metrokc.gov/wlr/dss/spcm/Chapter 3.PDF. Website for King County, Washington's Department of Natural Resources – Water & Land Resources Division. Drainage Services Section. August 29, 2001.

Webpage contains link to the Stormwater Pollution Control Manual, and Chapter 3 is on Best Management Practices. This chapter consists of a series of information sheets listing the best management practices (BMPs) required for various activities conducted in unincorporated King County.

(67) http://www.chi.on.ca/bmpstructural.html. Part of the Computational Hydraulics Int. website (http://www.chi.on.ca/aboutchi.html).

CHI is a consulting engineering firm specializing in stormwater management. The webpage gives lists of BMPs divided into structural and non-structural categories, as part of the Highway Stormwater BMP questionnaire.