5 Drainage Systems

Conventional drainage systems are designed to achieve a single objective — flood control during large, infrequent storms. This objective is met by conveying and/or detaining peak runoff from large, infrequent storms. Drainage systems designed to meet a single flood control objective fail to address the environmental effects of increases in runoff volume and velocity caused by development, as well as flow peaks. Increased runoff from small, frequent storms erodes urban streams and washes eroded sediment and other constituents from the urban landscape into downstream receiving waters, often damaging adjoining property and impairing their use by people and wildlife.

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality. To do this, designers must integrate conventional flood control strategies for large, infrequent storms with three basic stormwater quality control strategies for small, frequent storms:

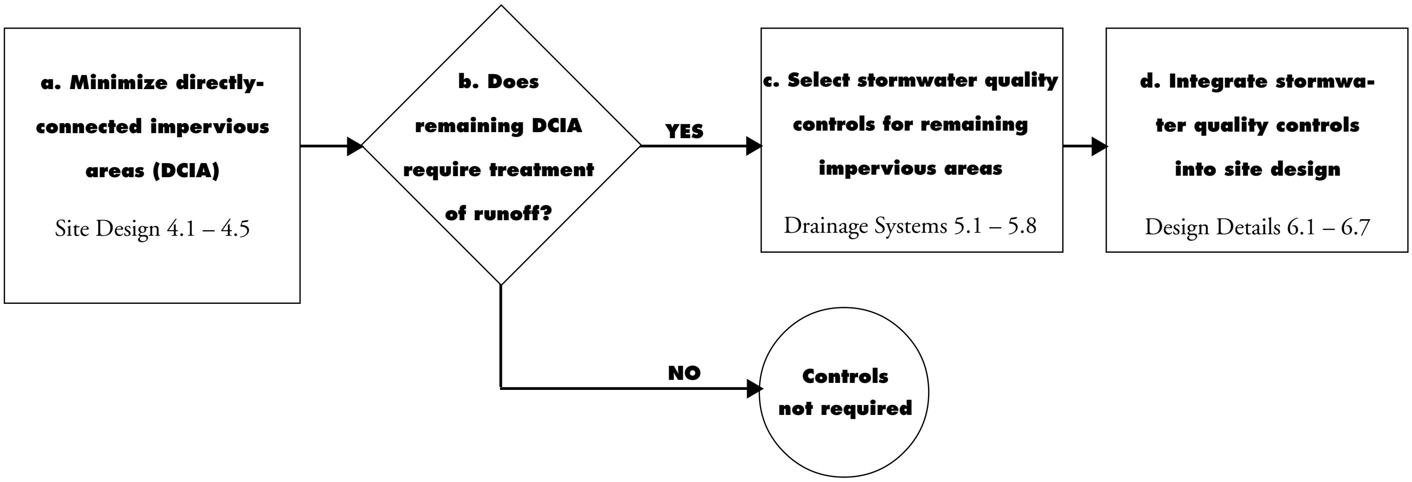
- *infiltrate runoff into the soil,*
- *retain/detain runoff for later release,*
- *convey runoff slowly through vegetation.*

Integrated flood control/stormwater quality control designs must meet a variety of engineering, horticultural, aesthetic, functional, economic, and safety standards. This chapter briefly outlines methods and criteria for drainage system design.

Drainage Systems

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality.

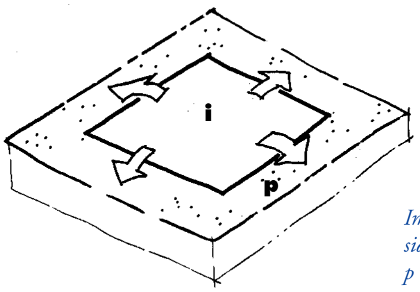
5.1 Drainage system design process



5.1 Drainage system design process. The simple design process described below establishes the foundation of a drainage system for stormwater quality.

a. Minimize directly connected impervious area (DCIA). Using the concepts and site planning strategies outlined previously, design a project to minimize directly connected impervious area.

The DCIA is measured by adding together the square footage of all impervious surfaces that flow directly into a conveyance stormwater system. These impervious surfaces are principally comprised of rooftops and conventional pavements. Impervious surfaces that are not directly connected to a conveyance system are not included in the calculation of DCIA. However, to be considered “disconnected,” intervening pervious areas receiving runoff (p) must be at least one half the size of impervious surface areas generating runoff (i). The pervious area must also be of appropriate width, location and slope, and design to effectively manage runoff.[20]



Impervious areas are considered “disconnected” if: $p \geq 1/2\ i$

b. Identify DCIA requiring treatment. In some areas, a site’s DCIA coverage may not require stormwater controls if the required treatment is based on other factors (e.g. if site is located upstream from existing or regional treatment facilities, or if it is an infill development in an existing urbanized watershed). If site DCIA coverage is not treated in another manner, some form of stormwater quality control on-site is probably needed.

c. Select stormwater quality controls for remaining impervious areas. There are three stormwater quality controls appropriate for the Bay Area: infiltration, detention/retention, and biofilters. Using these approaches, alone or in combination depending on site conditions and soils, drainage systems can be designed to reduce flows and manage pollutants.

d. Integrate stormwater quality controls into site design. The Design Details section (Chapter 6) describes the many opportunities available to site designers for reducing DCIA and incorporating stormwater quality controls into site design. Local municipalities and developers can evaluate their particular opportunities and constraints to determine practical solutions within the framework presented here. Chapter 8 has more detailed information on each of these design details.

5.2 Site conditions

5.2 Site conditions. Site designers and municipal site plan reviewers must understand site conditions and use these as the basis for selecting appropriate stormwater quality controls.

a. Local climate. The Bay Area is distinctive for its widely varied local climates. Local climate will influence selection of controls for a specific site. For example, controls that rely upon vegetation to stabilize soils and filter pollutants may be appropriate in coastal areas with more moisture and/or moderate temperatures, while pervious pavements may be better in hotter, drier portions of the Bay region where vegetation must be more heavily irrigated.

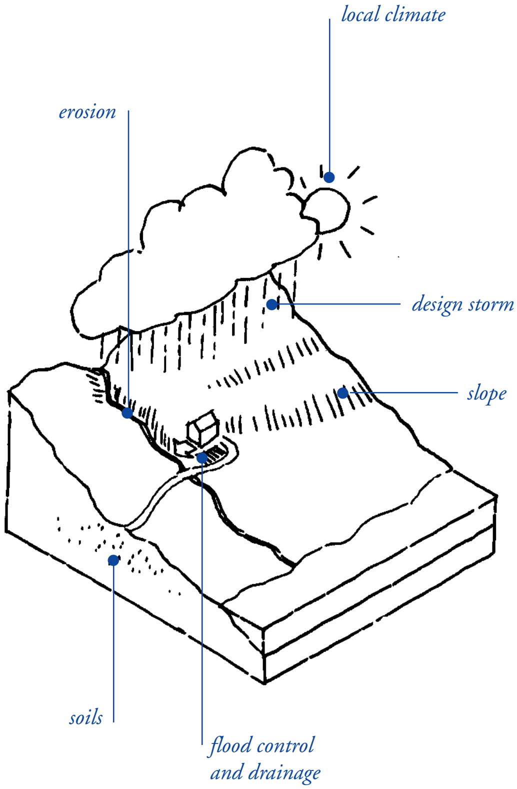
b. "Design storm" size. Design storms used to size stormwater quality controls are significantly different than those used for conventional drainage and flood control facilities. Stormwater quality design storms generally are based on the capture of a certain fraction of the average annual runoff from the site or development. The rainfall analysis presented in the California Storm Water Best Management Practices Handbook indicates that the most "cost-effective" level of stormwater quality protection occurs when about 75 to 85 percent of the annual rainfall is captured and held long enough to allow about 80 percent of the suspended solids to settle (between 12 and 40 hours). This design storm volume ranges between 1 and 1.6 times the average storm volume of about 0.05 feet (0.6 inches) in the Bay Area.[21] The actual design storm volume within this range depends on the drawdown time of the selected stormwater quality control.

c. Soils. Site designers must know the soils at the site when considering infiltration measures including pervious pavements. Soil conditions will determine whether a site is suitable for infiltration, or if a detention/retention system is required. See 5.3 Soils.

d. Erosion. Erosive soils impair the effectiveness of most stormwater quality controls, and must be stabilized before installing these controls. Excessive sediment clogs infiltration devices, rapidly fills detention basins, and covers vegetative measures.

e. Slope. Most stormwater quality controls are sensitive to the slope of local terrain. Biofilters and infiltration basins cannot be used in steep terrain, while detention basins usually can be made to work on any reasonably sized land parcel, as long as the area is not subject to landslides.

f. Flood control and drainage. Stormwater quality controls are sized to capture runoff from storms much smaller than those used to size drainage and flood control systems. Site developers should first consider an integrated system that achieves both stormwater quality and flood control objectives. In these integrated systems, runoff from small storms and the first portion of larger storms enters the stormwater quality control system. Flows exceeding the runoff volume of the stormwater quality control system are either bypassed into a separate drainage/flood control system or accommodated within the stormwater quality control system (as long as these larger flows do not "flush out" the pollutants captured from smaller storms).



5.2 Site conditions

5.3 Soils

5.3 Soils. The USDA Natural Resources Conservation Service (NRCS) [formerly the Soil Conservation Service (SCS)], classifies a soil's hydrologic effects into four Hydrologic Soil Groups (HSG), labeled A through D. Group A and B soils possess the greatest infiltration rates (unless soils are compacted during construction) and are generally best suited to stormwater infiltration. However, the Bay Area has a relatively high concentration of Group C and D soils, which possess lower infiltration rates that generally limit use of infiltration-based stormwater management systems.

Some soils have compound classifications, such as A/D. This indicates that the natural soil is in group D because of a high water table which impedes infiltration and transmission, but following artificial drainage using such methods as perforated pipe underdrains, the soil's classification is changed to A, making it more appropriate for infiltration with proper site design.

For a specific site, the HSG designation can be obtained by referring to a local soil survey, by consulting the complete national listing given in NRCS Technical Release 55, or by performing an on-site investigation. The accompanying table presents soil infiltration rates for each soil group determined by laboratory studies and measurements. Site designers should compare the design runoff volume with the available soil storage volume to determine if infiltration is feasible, and then use the infiltration rates to determine if the design runoff volume can infiltrate within a reasonable time (generally 24 to 48 hours). For sites with Group C and D soils, retention- and detention-based strategies are often more feasible than infiltration designs.

Hydrologic soil groups (HSG)[22]

Group A: Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well-drained sands or gravels. These soils have a high rate of water transmission.

Group B: Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained sandy loam soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C: Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of silty-loam soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D: High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Typical soil infiltration rates.[23]

Soil Type	*Min. Infiltration Rate (inches per hour)*
A	0.30 to 0.45
B	0.15 to 0.30
C	0.05 to 0.15
D	0 to 0.05

5.4 Pollutants

5.4 Pollutants. In a natural state, water is not chemically pure. It contains sediment, minerals, and other impurities depending on the surrounding geology and climate. These impurities do not often arrive at lakes, streams, and bays (known as "receiving waters") in concentrated form, because rainfall can infiltrate slowly into the soil, where it is cleansed by natural biologic processes. When rain falls faster than it can infiltrate, runoff flows over the surface. In most natural conditions, this runoff travels slowly through vegetation, and suspended particles settle or are filtered, sending cleaner runoff to receiving waters.

The impervious surfaces associated with urbanization prevent water from infiltrating and increase the rate of runoff. One can see rain fall on urbanized impervious surfaces – streets, rooftops, parking lots, trash and fuel handling areas, and pervious surfaces such as lawns, playfields, and exposed construction sites. Less visible are the foreign constituents that runoff carries as it flows quickly across urbanized surfaces and empties into its final receiving water. Understanding what pollutants are and where they come from can aid in designing effective stormwater treatment controls.

Constituents[24]

Sediment. Roads, parking lots, and roofs are common sources of sediment due to wear. Unstabilized landscaped areas, stream banks, unprotected slopes and denuded dirt areas also contribute. Sediment is a main component of total suspended solids (TSS), and is detrimental to aquatic life. Sediment also transports pollutants such as trace metals, nutrients, and hydrocarbons that attach to each particle.

Organic Compounds. These compounds are derived from automotive fluids, pesticides, and fertilizers. Organic compounds often attach to soil particles. Removal of soil particles from runoff via sedimentation or filtration will likely reduce the surface water pollution potential of organic compounds as well.

Nutrients. Nutrients include nitrogen, phosphorus, and other organic compounds which can be found in organic litter, fertilizers, food waste, sewage and sediment. Excess nutrients impact creek health and impair use of water in lakes and other water supply sources by promoting excessive growth of algae or vegetation (i.e. eutrophication).

Metals. Sources of trace metals (copper, lead, cadmium, chromium, nickel, and zinc) can include motor vehicles, roofing and construction materials, and chemicals. Trace metals can be toxic to aquatic organisms and, in accumulated quantities, can contaminate drinking water supplies. Removal of sediment from runoff via sedimentation combined with surface infiltration will reduce the amount of metals that reach receiving waters.

Bacteria and viruses. Sources include animal excrement (found in areas where pets are often walked), sanitary sewer overflow, and trash handling areas (dumpsters). Bacteria and viruses may pose public health and safety concerns if they are present in drinking water reservoirs or recreational water bodies.

Oil and Grease. Sources of oil and grease include motor vehicles, food service establishments, and fueling stations. Oil and grease act as carriers for heavy metals and contain hydrocarbon compounds, which even at low concentrations may be toxic to aquatic organisms.

With proper maintenance of stormwater management systems, pollutants infiltrating into the soil do not usually pose a risk of contaminated soil or groundwater. Risk is greater when there is a concentrated source of pollutants, such as in a heavy industrial site or in the case of illegal disposal.

A case study by the USGS of a groundwater recharge basin in Fresno showed that a wide variety of urban runoff pollutants were removed by sorption within the top 1.5 inches of sediment in the basin, but no pollutants were found in the sediment at depth greater than six inches. This shows that the pollutants have not traveled more than six inches deep – well above the level of groundwater wells.[25]

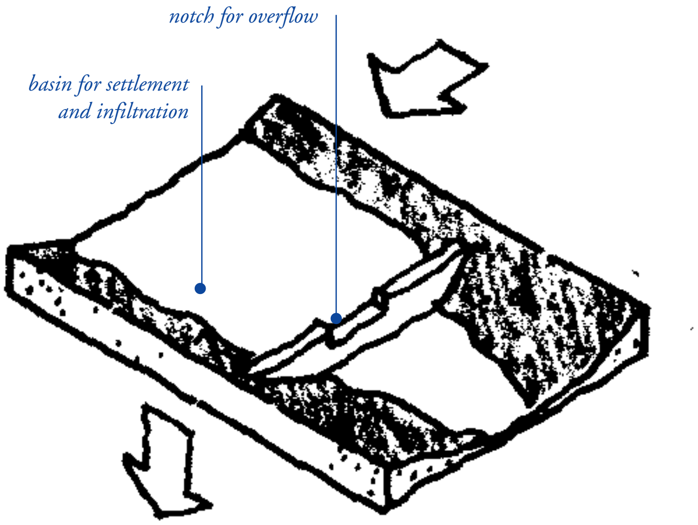
Pollutants, continued

Residential developments present the least potential of contamination of groundwater or soil from infiltration systems, according to a recent study completed by the EPA.[26] This is because residential developments generally have low concentrations of pollutants, and the pollutants that are present have low solubility and mobility. High concentrations, when they occur, such as nitrates and pesticides or an oil spill in a driveway, are localized and small. Based on recent EPA analysis of groundwater protection and infiltration, the Santa Clara Valley Water District, for example, is currently considering revising their policy to permit infiltration basins 10 feet or less in depth.[27]

Risk of groundwater contamination from residential infiltration systems is further minimized by findings that metals tend to remain within the upper one foot of soil depth. Organics such as petroleum hydrocarbons migrate slowly downward– allowing natural degradation to occur. Furthermore, drinking water is typically drawn from significantly greater depths. In the Santa Clara Valley, for example, wells pumped for drinking water supply are deeper than 50 feet by ordinance. In some portions of the valley, water companies pump from in the range of 400 feet, much deeper than the potential migration of most common pollutants. [28]

Some pollutants, such as nitrates and solvents, can migrate to depths that can ultimately threaten water supply wells. Illegal dumping of waste oil, pesticides, herbicides, paint, paint thinner and other chemical products into any type of infiltration device presents additional risk to groundwater. Local water districts and other agencies generally have policies and strategies to protect groundwater supplies from these threats. These policies are an attempt to balance the environmental benefits of infiltration with the compelling need to protect soil and groundwater supplies.

5.5 Drainage system elements



5.5a Infiltration basin

5.5 Drainage system elements. Drainage systems can achieve stormwater management goals by using one of three basic elements, either alone or in combination, depending on site and other conditions: infiltration, retention/detention, and biofilters.

5.5a Infiltration. Infiltration is the process where water enters the ground and moves downward through the unsaturated soil zone. Infiltration is ideal for management and conservation of runoff because it filters pollutants through the soil and restores natural flows to groundwater and downstream water bodies. Infiltration systems are designed to infiltrate the majority of runoff from small storms into the soil rather than discharging it into a surface water body. Infiltration basins can range from a single shallow depression in a lawn, to an integrated swale, pond, and underground storage basin network.

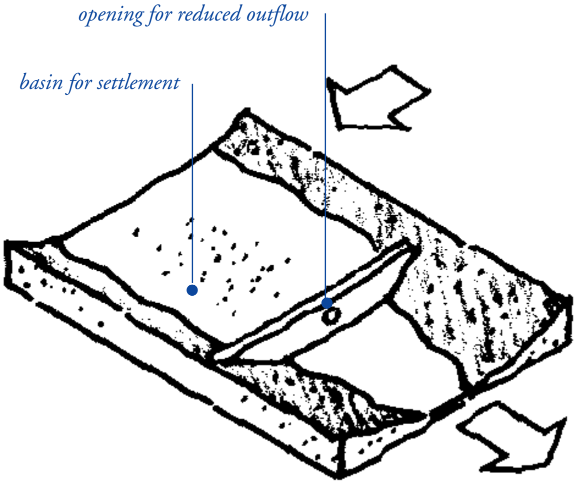
Site soil conditions generally determine if infiltration is feasible. In Soil Groups A and B (see 5.3) infiltration is usually acceptable, but it is severely limited in Soil Groups C and D. It is also limited where high groundwater, steep slopes, or shallow bedrock is present.

Infiltration basins can be either open or closed. Open infiltration basins, which include ponds, swales, and other landscape features, are usually vegetated – the vegetation maintains the porous soil structure and reduces erosion. Closed infiltration basins can be constructed under the land surface with open graded crushed stone, leaving the surface to be used for parking or other uses. Subsurface, closed basins are generally more difficult to maintain and more expensive than surface systems, and are used primarily where high land costs demand that the land surface be reclaimed for economic use.

Other design considerations include clogging that may occur in very fine or poorly drained soils and impacts on slope stability of hillside sites. Infiltration basins are best installed at the end of construction, after the site is fully stabilized. If installed early, bypass flows until the site is stabilized, as construction-related runoff may contain a high proportion of silts which can clog the basin floor.

Infiltration systems have been used by Caltrans and local jurisdictions in California for about three decades[29], though heavy Bay Area soils sometimes limit their local application. The basic

Drainage system elements, continued



5.5b Retention/detention basin

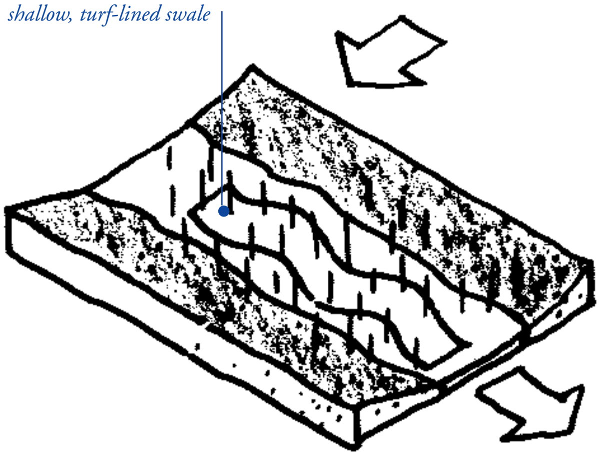
design goal of infiltration systems is to provide opportunities for rainwater to enter the soil. This is generally accomplished by retarding the flow of runoff, and by bringing it in contact with the soil, either by holding it in ponds or moving it slowly along the ground surface. Infiltration basins are most economical if placed near the source of runoff, but they should be avoided on steep, unstable slopes or near building foundations.

5.5b Retention and detention. Retention and detention systems differ from infiltration systems primarily in intent. While infiltration systems are intended to percolate water into the soil, retention/detention systems are designed primarily to store runoff for later release. Detention systems store runoff for one to two days after a storm and are dry until the next storm. Retention systems usually have a permanent pool that retains the runoff volume until it is replaced during the following storm. Properly designed retention/detention systems release runoff slowly enough to reduce downstream peak flows to their pre-development levels, allow fine sediments to settle, and uptake dissolved nutrients in the runoff where wetland vegetation is included. Retention/detention systems are most appropriate for areas where soils percolate poorly, that is, C/D soils.

The permanent pool of a retention system and the storage volume in a detention basin are both sized equal to the runoff volume from the stormwater quality design storm, plus an additional 20 percent of this volume for sediment storage. Detention system outlets are generally sized to release 50 percent of this volume within 12 to 16 hours, and the remainder in another 24 to 32 hours.

Outlets of detention systems may clog easily if not properly designed and maintained. Retention system outlets must both maintain the permanent pool and slowly release runoff during each storm. Retention times in the permanent pool commonly are set at one to three days for removal of fine sediments, and up to two weeks for removal of dissolved nutrients through biological uptake by wetland vegetation. Common outlet designs are orifices, perforated risers, and V-notch weirs, with an emergency spillway provided to safely convey storms larger than the stormwater quality design storm.

5.5c Biofilters. Biofilters, also known as vegetated swales, are vegetated slopes and channels designed and maintained to transport shallow depths of runoff slowly over vegetation. Biofilters



5.5c Biofilter

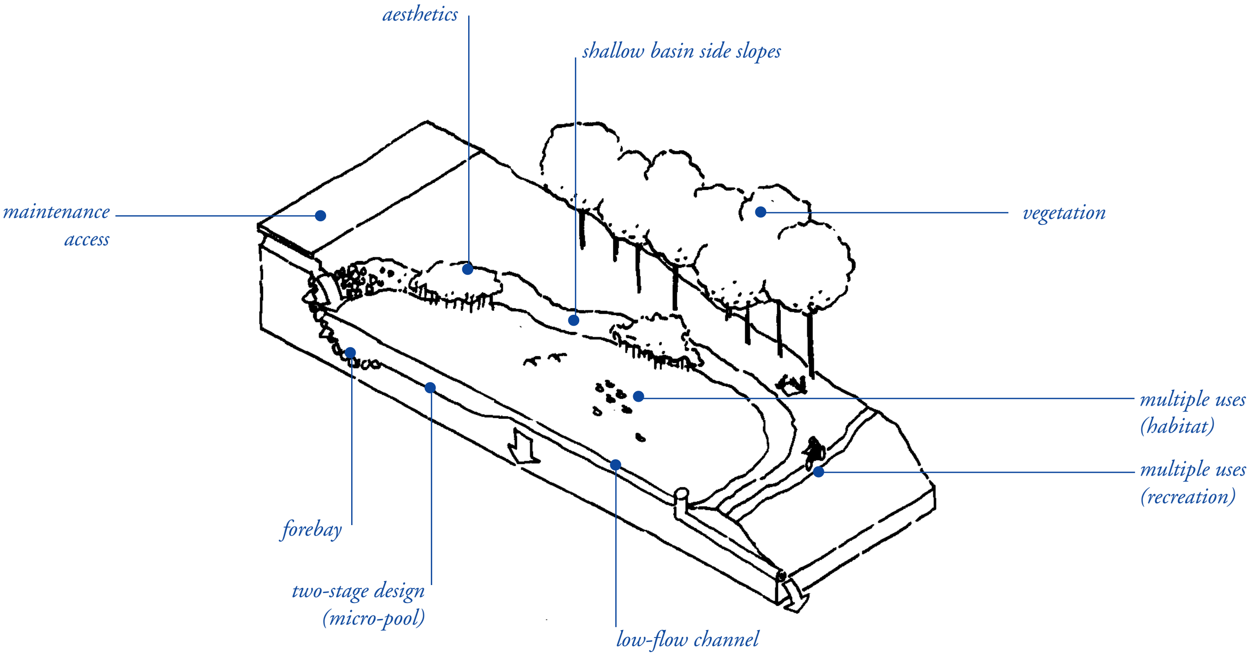
are effective if flows are slow and depths are shallow. This is generally achieved by grading the site and sloping pavement in a way that promotes sheet flow of runoff. For biofilter systems, features that concentrate flow, such as curb and gutter, paved inverts, and long drainage pathways across pavement, must be minimized. The slow movement of runoff through the vegetation provides an opportunity for sediments and particulates to be filtered and degraded through biological activity. In most soils, the biofilter also provides an opportunity for stormwater infiltration, which further removes pollutants and reduces runoff volumes.

Slow, shallow sheet flow is maintained in the biofilter by constructing it with gently sloping sides (3:1 slope max.), minimal longitudinal slope (1 to 2% recommended, with check dams for steeper slopes), and a flowpath length of at least 10 feet. The key concept is to move water slowly through the vegetation. The most common ground cover material is turfgrass, which must be irrigated through the dry season. For a turfgrass lined biofilter to work effectively, the turf must be mowed regularly and the cuttings removed.[29] Where slopes are less than 1% or where groundwater is high, wetland vegetation can be used in biofilters. Clay soils, or soils where vegetation are inhibited, are generally not appropriate for biofilters.

Biofilters are especially applicable to parking lots, as the long aisles can be sloped into linear grass swales to collect and treat runoff from pavement surfaces. Adjacent pavement elevations should be set slightly higher than the adjacent biofilter. If water enters at concentrated points, as opposed to sheet flow, erosion control should be included at inlets and outlets.[30]

Biofilters should be designed using the stormwater quality design storm. The peak depth of the hydrograph should be less than 3 inches and peak velocity less than 1 ft/second. Large storms should bypass the biofilter, or the biofilter should be sized to accommodate larger storms while meeting water quality criteria. The bottom width of the swale is generally 2 to 8 feet, with grass height of 4 to 6 inches and maximum water depth of less than 2 inches.

5.6 System design techniques



5.6 System design techniques. A variety of techniques are available to design stormwater management systems for water quality protection so that safety and aesthetics are maximized while minimizing maintenance. A key element of system design is to provide a means for managing the runoff from large storms – either a spillway or an embankment designed to withstand overtopping. The stormwater management system is usually comprised of a series of individual elements – basins, swales and pipes – in an interconnected, continuous system. Some of the techniques available to integrate these elements into the site plan and improve their functionality include:

a. Two-stage design. Place 15 to 25% of the volume at a lower stage to create a micro-pool that fills often, keeping the rest of the basin dry and sediment-free most of the time.

b. Basin side slopes. Set side slopes at 4:1 or flatter to prevent bank erosion and minimize risk of drowning.

c. Forebay. Design basins so that larger particles settle in depressions at basin inlets, and so inflows do not erode or resuspend materials in forebay. Plan for maintenance to remove trash, debris and sediment that collects in the forebay, as this is essential to protecting the aesthetic value of the basin and in reducing long-term maintenance costs.

d. Low flow channel. A low-flow channel conveys dry-weather flows and the last of captured volume to the basin outlet.

e. Vegetation. Plant vegetation to control erosion and enhance sediment entrapment.

f. Maintenance access. Access for maintenance must be included in the design of all elements. While most smaller basins and swales can be serviced by typical garden maintenance methods, larger basins may require stable vehicular access ways to forebays and outlets for periodic cleaning or dredging.

g. Multiple uses. Incorporate flood control, recreational facilities, landscaping, and/or wildlife habitat into system design.

h. Aesthetics. Integrate the basins and swales into the site to take advantage of the aesthetic qualities of water and plant materials.

Drainage Systems

5.7 Water quality volume

Stormwater systems are engineered to handle specific runoff volumes and flow rates. For flood protection, systems are designed with capacity for the expected peak runoff volumes and flow rates of a given design storm size. This is known as the "peak runoff volume." Peak runoff volumes and flow rates are calculated for various design storm sizes, depending on local conditions, codes, and the potential damage that can be caused by flooding. Large drainage systems flood very infrequently, but they are expensive to construct. Therefore, drainage systems are typically sized to balance flooding risk and cost. Street drainage systems are typically designed for a 10-year storm, meaning that there is a 10 percent chance in any given year that a storm will be large enough to overwhelm the drainage system and flood the street. Since the flooding of a street once every ten years, on average, is a minor inconvenience, designing streets for a ten year storm represents a generally accepted balance of protection and cost. Homes and buildings suffer more severe damage from flooding, and are typically designed to remain protected in the 100 year storm, meaning that the probability of flooding is one percent in any given year.

The same need to balance costs and benefits applies to drainage system design for stormwater quality protection. Many pollutants may be carried by small, frequent storms. Because of this phenomenon, the water quality protection component of a drainage system can be designed to manage a much smaller volume and flow rate of water than the flood protection component. Also, because most rainfall occurs in small, frequent storms, water quality systems with relatively small capacities can have a large impact in minimizing overall runoff and preserving base stream flows.

This amount of water that can be managed to protect water quality is called the "water quality volume (wqv)." The water quality volume can be managed through pollution prevention, infiltration, retention/detention, and biofiltration.

The wqv is the amount of runoff from impervious areas that must be managed before being released into the conveyance storm drain network or receiving water. As with flood control volumes, there are a variety of approaches and standards for defining the water quality volume:

- as a proportion of total annual runoff from impervious surfaces
- as a depth of rainfall
- as the runoff from impervious surfaces of a storm with a particular recurrence interval.

Note that the water quality volume applies only to impervious areas. It is not generally necessary to treat runoff from pervious areas. For this purpose, pervious areas are defined as those areas with a coefficient of runoff of 0.30 or less, meaning that 70% or more of the rainfall landing on a given surface infiltrates into the soil.

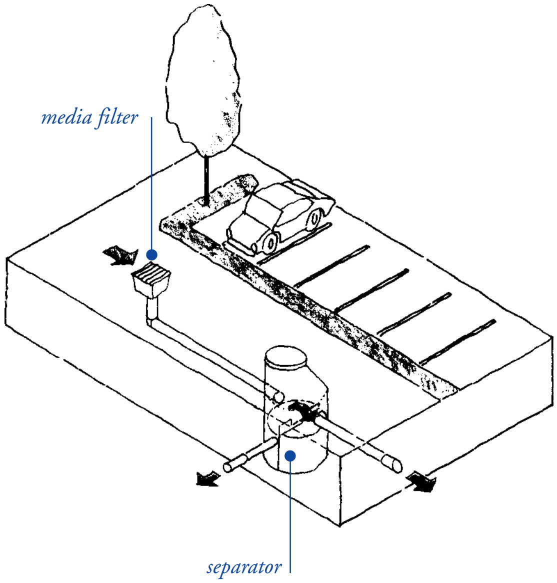
Because BASMAA is an association of several stormwater programs representing dozens of municipalities, each with different circumstances, this document does not establish specific hydrologic criteria or a specific water quality volume.

As with flood control, there are a variety of standards and approaches for quantifying how to manage stormwater for water quality protection. The California Storm Water Quality Task Force, in its *Storm Water Best Management Practice Handbooks* (1993), and the Water Environment Federation/American Society of Civil Engineers in their jointly published *Urban Runoff Quality Management* (1998) each adopted an 80% annual capture rate as a standard of practice for the water quality volume. In the San Francisco Bay Area, this translates into approximately the first 0.50-1.25 inches of rain, or a two-year recurrence interval storm.

The Center for Watershed Protection in Silver Spring, Maryland, a leading independent research center, recommends a 90% annual capture rate. Some jurisdictions, such as the City of Olympia (WA) and the Washington State Department of Ecology, have focused on reducing impervious land coverage, adopting impervious surface reduction targets rather than emphasizing a specific water quality volume.

Drainage Systems

5.8 Manufactured treatment systems



Some areas are so densely developed that streets, buildings and walkways provide almost complete impervious land coverage. Here, land values prohibit the use of landscape solutions such as biofilters, infiltration basins, or wet ponds. In addition, the soil conditions in these highly urbanized locations often do not support infiltration, further reducing the practicality of landscape stormwater quality systems.

In these areas, if treatment is required, manufactured treatment systems can be inserted into a conventional conveyance storm drain system. In some cases, these devices can supplement more integrative site planning and landscape strategies.

These devices are available from many manufacturers, and generally function to separate urban pollutants from runoff. They have minimal impact on reducing overall runoff volumes or mitigating peak flows. Other considerations include both initial expense and the cost of intensive, regular maintenance recommended by device manufacturers, which can include trash removal, replacement of filters, flushing cartridges, and vacuuming of sediment.

Though promoted by their manufacturers, these devices are considered experimental by the scientific community, and their efficacy is still under study. Though many proprietary designs are available, general product categories are presented here.

Catch basin or inlet inserts. Also referred to as inlet filters, catch basin inserts are trays or baskets containing filter and/or oil-absorbent materials installed on the inside of storm drain inlets to filter and capture pollutants. They work through filtration, settling, and absorption.

Separators. These devices (also called oil/grit or oil/water separators, water quality inlets, interceptors) are structures designed to remove pollutants from a wastewater stream based on physical differences between the pollutant and water. Lighter materials such as oil and buoyant trash will float to the surface and heavier materials such as sediments will sink.

Media filters. These devices use media to filter pollutants from urban runoff. Media includes sand, gravel, peat, compost, activated carbon, fabric, and resin.

In a watershed plan that employs clustered, dense development to preserve open space, on-site treatment in the more densely developed portion of the watershed may not be necessary. Dense or clustered development allows for significant areas to be preserved and remain undeveloped, reducing the need to mitigate throughout the entire watershed.