Description

A manufactured biotreatment BMP is a modular stormwater treatment system with vegetation and engineered media that has been optimized and standardized to provide consistent performance and simplified installation. Biotreatment systems are typically housed in a precast vault, although cast-in-place systems are available to accommodate irregular footprints. Some systems can also be installed in a lined pit with no concrete container required. Vegetation type depends on the filter media type and bed size and may include shrubs planted in media (Figure 1) wetland plants or other vegetation common to conventional biofiltration systems (TC-32).

Design Considerations

- Drainage Area Size
- Potential Pretreatment Requirements

Targeted Constituents	Removal
Sediment	High
Nutrients	Med
Trash	High
Metals	Med
Bacteria	Med
Oil and Grease	High
Organics	Low

California Experience

There are currently over 1,000 installations in California.

Advantages

- Standardized media provides consistent performance.
- Simplified design and procurement with most systems provided to the site pre-assembled with all components and media included.
- Compact footprint resulting in more site flexibility, lower maintenance costs and lower irrigation demand where irrigation is required.
- No standing water in the biotreatment area between storms minimizing opportunity for mosquito breeding.
- Can be incorporated into the landscaping of the development.
- Provides modest habitat for insects and other small invertebrates which in turn provide food for birds and other small animals.
- Rigorous independent performance assessments are available for some biotreatment systems.

Limitations

- Individual systems typically not suitable for drainage areas greater than a few acres due to treatment flow rate limitations.
- May require irrigation during the dry season.
- Depending on drawdown time, may be a breeding ground for mosquitoes.
- Reduced evapotranspiration and infiltration potential as a result of a compact footprint.

Suitability and Design

Biotreatment consists of a modular unit that contains vegetation and media. Tree boxes typically consist of a single tree incorporated into a storm drain inlet to ensure stormwater is filtered through the media and root system. Subsurface wetland units also typically contain vegetation (e.g., trees, shrubbery) and media to allow for filtration of stormwater and may be used in conjunction with a media filter cartridges (MP-40) for flow entering the storage from a curb inlet.

Source: City of Fremont
Figure 1. Tree-well filter designed by the City of Fremont

Biotreatment devices are appropriate in ultra-urban environments where a compact treatment system footprint is desired or where reliable sources of conventional bioretention materials are unavailable. These modular systems can be integrated into the existing development or redevelopment to provide removal of particulate pollution as well as some dissolved constituents.

Design should consider local government requirements for detention and flow control. Where detention is incorporated upstream or downstream, drawdown characteristics of the biotreatment system must be compatible with the detention system.

Although many biotreatment systems exist as proprietary products, not all are. The City of Fremont has developed their own 'tree-well filter' that receives street runoff (Figure 1). This unit is designed to receive the 0.2 inch per hour intensity storm, and allows stormwater to filter through 3 inches of mulch and 18 inches of soil media before draining to a 12 inch rock layer with a raised collection pipe that leads to the storm drain network.

Construction/Inspection Considerations

Refer to manufacturer guidelines.

Performance

Biotreatment pollutant removal during a storm is primarily a result of sedimentation and physical filtration, with some media types providing significant cation exchange or other sorptive functions that can remove dissolved pollutants. Over time, between storm events, plant uptake, microbial activity, decomposition and volatilization processes transform and sequester captured pollutants.

There are numerous biotreatment design variations and media types commercially available. Performance depends primarily on the hydraulic loading rate of the media bed and the media composition. Additionally, the presence or absence of pretreatment components and mulch can affect performance. Biotreatment systems can be combined with infiltration and detention systems to reduce runoff volume.

Protocols for testing and verifying the performance of innovative stormwater treatment systems have been developed by the Washington State Department of Ecology and the New Jersey Department of Environmental Protection. Both programs provide certification or approval of treatment systems following independent verification that those systems meet certain performance targets. Both programs have been endorsed by numerous states and public agencies including EPA and the Water Environment Federation (WEF) and have been supported by the Stormwater Equipment Manufacturers Association (SWEMA).

The Technology Assessment Protocol – Ecology (TAPE) from the Washington State Department of Ecology program requires full-scale field testing and has performance standards for sediment removal (Basic Treatment), phosphorus (Phosphorus Treatment), dissolved metals (Enhanced Treatment) and hydrocarbons (Oil Treatment). All are applicable to biotreatment performance evaluation although the Oil Treatment standard is intended for influent concentrations higher than 10 mg/L which are more common at industrial sites than sites regulated by municipal stormwater permits. A list of technologies, including some biofilters that have met these treatment standards can be found on the Ecology web page for emerging technologies at: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html.

The New Jersey DEP laboratory protocol for filter devices is applicable to biotreatment systems. It requires 80% removal of a TSS gradation with a mean particle diameter of 75 microns and an 80th percentile particle diameter of 8 microns. A list of technologies, including some biofilters that have met this standard can be found on the NJ DEP web page for Stormwater Manufactured Treatment Devices at: http://www.njstormwater.org/treatment.html.

To ensure acceptable biotreatment performance and operational feasibility, selection of biotreatment systems that have been verified by the Ecology and/or NJ DEP programs is recommended. Furthermore, design and sizing should be consistent with approvals issued by those programs.

Siting Criteria

Biotreatment systems typically receive runoff from the surface through a curb inlet or curb cut. Some systems can also accept an inlet pipe. As with other vegetated systems, deep installations should be avoided. Typical sites are a fraction of an acre to a few acres per system. Irrigation is typically required at least until plants are fully established.

Maintenance

Manufacturer's guidelines vary depending on system design and must be followed to ensure proper operation and performance. In general, to maximize the pollutant removal benefits of vegetation and to maintain aesthetic appeal and hydrologic function, vegetation must be harvested each growth season. For trees and shrubs, leaf litter should be removed. Other general maintenance activities may include replacement of mulch, maintenance of pretreatment components and removal of trash, debris and invasive plants.

Cost

Manufacturers' cost vary widely depending on design and size of the biotreatment. Installation costs are generally on the order of 50 to 100% of the manufacturer's cost.

Cost Considerations

- Treatment with fewer larger systems is typically more cost effective than using multiple smaller systems.

References and Sources of Additional Information

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Metcalf and Eddy, Inc., 2002, Wastewater Engineering: Treatment, Disposal, Reuse, McGraw-Hill, New York, New York. Minton, G.R., 2002, Stormwater Treatment: Biological, Chemical, and Engineering Principles, RPA Press, Seattle, Washington, 416 pages.

Netzer, A., and D.E. Hughes, 1984, Adsorption of copper, lead, and cobalt by activated carbon, Water Res., 18, 927. Shapiro and Associates and the Bellevue Utilities Department, 1999, Lakemont stormwater treatment facility monitoring report, Bellevue, Washington.

New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Filtration Manufactured Treatment Device: http://www.njstormwater.org/pdf/filter-protocol-1-25-13.pdf

New Jersey Department of Environmental Protection, Stormwater Manufactured Treatment Devices: http://www.njstormwater.org/treatment.html

New Jersey manufactured stormwater devices' performance verification database: http://www.njcat.org/verification-process/technology-verification-database.html

Washington State manufactured stormwater devices' performance verification: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html

Figure 2. Tree box incorporated into a storm drain inlet in San Diego, CA

Description

Stormwater media filters typically include a pretreatment settling basin and a filter bed or cartridge in a subsurface vault or manhole structure (Figure 1). Cartridge filters or beds may filter water through a media bed comprised of sand, perlite or an absorptive filtering media, or may filter water through a thin fabric membrane with a large surface area. Coarser solids settle out in the pre-settling area and then finer particles and other pollutants are removed as stormwater flows through the filter membrane or media.

Media filters do not contain vegetation and can accept flow from a curb inlet, grate inlet or inlet pipe. They are exceptionally versatile and can be integrated into most sites while allowing the overlying land to be used for most non-building purposes including vehicular or pedestrian traffic or landscaping.

California Experience

There are currently over 2,000 manufactured filter systems in operation in California.

Advantages

- Requires a smaller area than standard flatbed sand filters, wet ponds, and constructed wetlands.
- Media capable of removing dissolved pollutants can be selected.
- Simplified design and procurement with most systems provided to the site pre-assembled with all components and media included.
- Rigorous independent performance assessments are available for many media filter systems.
- Well suited for installation downstream of detention systems.
- Captures and holds solids, oil and trash out of public view and out of contact with wildlife, native soils and groundwater.

Figure 1. Stormwater media filter vault, mid-construction.

Source: Contech Engineered Solutions

Design Considerations

- Design Storm
- Media Type
- Maintenance Requirement

Targeted Constituents	Removal
Sediment	High
Nutrients	Low
Trash	High
Metals	Med
Bacteria	Low
Oil and Grease	Med
Organics	Low

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Limitations

- As with all filtration systems, use in catchments that have significant areas of non-stabilized soils can lead to premature clogging.

Design and Sizing Guidelines

Design of media filters is typically flow-based with the size and/or quantity of units increasing as the design water quality flow rate increases. Most filters have a characteristic hydraulic loading rate expressed as flow rate per filter surface area that is associated with a specific targeted pollutant concentration reduction or effluent concentration. In some filters this is converted to a design flow rate per cartridge or filter module for standard sizes. Sizing most commonly simply entails dividing the design water quality flow rate by the design flow rate per cartridge to get a total number of filter cartridges required.

Alternatively, where a specific maintenance interval is targeted, the filters can be sized based on a mass loading assessment where the number of cartridges required is equal to the pollutant load expected to be retained during the service period, divided by the load capacity of each cartridge. This approach is most common when the media filter is installed downstream of detention since the number of cartridges required to treat the discharged flow rate may be very low. Where a mass load-based sizing approach is pursued, a check of flow-based sizing must also be conducted with the number of cartridges specified being the greater of two approaches.

As with all filters, maintenance interval, hydraulic loading rate, and pollutant removal performance are inextricably linked with an increase in any one factor necessarily requiring a reducing in at least one other factor.

Construction/Inspection Considerations

Some media filter systems are shipped without the cartridges installed or with a construction bypass in place to prevent the filters from being fouled by construction stormwater runoff. Once the construction phase is complete the cartridges must be installed and/or the construction bypass components must be removed to activate the system. Most stormwater filtration systems are installed below grade with access provided by manhole openings or hatches. Entry into the systems during construction, activation, inspection, or maintenance may require OSHA confined space entry protocols to be followed.

Performance

The mechanisms of pollutant removal are essentially the same as with sand filters (TC -40) if of a similar design. Whether removal of dissolved pollutants occurs depends on the media. Perlite and fabric do not remove dissolved pollutants, whereas for example, zeolites, compost, activated carbon, and peat have this capability.

There are numerous media filter design variations and media types commercially available. Performance depends primarily on the hydraulic loading rate of the media bed and the media composition. Additionally, the presence or absence of pretreatment components can affect performance and longevity.

Protocols for testing and verifying the performance of innovative stormwater treatment systems have been developed by the Washington State Department of Ecology and the New Jersey Department of Environmental Protection. Both programs provide certification or approval of treatment systems following independent verification that those systems meet certain performance targets. Both programs have been endorsed by numerous states and public agencies including EPA and the Water Environment Federation (WEF) and have been supported by the Stormwater Equipment Manufacturers Association (SWEMA).

The Technology Assessment Protocol – Ecology (TAPE) from the Washington State Department of Ecology program requires full-scale field testing and has performance standards for sediment removal (Basic Treatment), phosphorus (Phosphorus Treatment), dissolved metals (Enhanced Treatment) and hydrocarbons (Oil Treatment). All are applicable to media filter performance evaluation although the Oil Treatment standard is intended for influent concentrations higher than 10 mg/L which are more common at industrial sites than sites regulated by municipal stormwater permits. A list of technologies, including several media filters that have met these treatment standards can be found on the Ecology web page for emerging technologies at: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html

The New Jersey DEP laboratory protocol for filter requires 80% removal of a TSS gradation with a mean particle diameter of 75 microns and an 80^{th} percentile particle diameter of 8 microns. A list of technologies, including several media filters that have met this standard can be found on the NJ DEP web page for Stormwater Manufactured Treatment Devices at: http://www.njstormwater.org/treatment.html

To ensure acceptable media filter performance and operational feasibility, selection of media filters that have been verified by the Ecology and/or NJ DEP programs is recommended. Furthermore, design and sizing should be consistent with approvals issued by those programs.

Siting Criteria

Media filters can receive runoff from the surface through a curb inlet, grate inlet, or through one or more inlet pipes. They can be installed under vehicular or pedestrian traffic areas or under landscaping. Maintenance typically requires a vacuum truck so media filters should be located where they can be accessed without unduly disrupting traffic flow or site operations.

Additional Design Guidelines

Follow guidelines provided by the manufacturer.

Maintenance

- Maintenance activities and frequencies are specific to each product. Annual maintenance is typical.
- Manufactured filters, like standard filters (TC-40), require more frequent maintenance than most standard treatment systems like wet ponds and constructed wetlands, typically annually for most sites.

- Pretreatment systems that may precede the filter unit should be maintained at a frequency specified for the particular process.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 25 to 50% of the manufacturer's costs.

Cost Considerations

- The modularity of the manufactured systems allows the design engineer to closely match the capacity of the facility to the design storm, more so than with most other manufactured products.
- Treatment with one larger systems is typically more cost effective than using multiple smaller systems.
- Installation of media filters downstream of detention systems can significantly reduce the flow rate treated and the size and cost of the required system.

References and Sources of Additional Information

Minton, G.R., 2002, Stormwater Treatment: Biological, Chemical, and Engineering Principles, RPA Press, 416 pages.

Wet Vault MP-50

Description

A wet vault is a vault with a permanent water pool, generally 3 to 5 feet deep. The vault may also have a constricted outlet that causes a temporary rise of the water level (i.e., extended detention) during each storm. This live volume generally drains within 12 to 48 hours after the end of each storm.

Design Considerations

- Hydraulic Capacity
- Sediment Accumulation

Targeted Constituents	Removal
Sediment	High
Nutrients	Low/Med
Trash	High
Metals	Low
Bacteria	Low
Oil and Grease	Low/Med
Organics	Low

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California Experience

There are several hundred stormwater treatment facilities in California that use manufactured wet vaults.

Advantages

- Internal baffling and other design features such as bypasses may increase performance over traditional wet vaults and/or reduce the likelihood of resuspension and loss of sediments or floatables during high flows.
- Head loss is modest.

Limitations

- Concern about mosquito breeding in standing water.
- The drainage area served is limited by the capacity of the largest models.
- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- Does not remove dissolved pollutants.
- An export of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

There are two general configurations of wet vaults currently available, differing with the particular manufacturer.

The first system consists of two standard precast manholes, the size varying to achieve the desired capacity. Stormwater enters the first (primary) manhole where coarse solids are removed. The stormwater flows from the first to the second (storage) manhole, carrying floatables where they are captured and retained. Further sedimentation occurs in this second manhole. The off-line manhole serves as a storage reservoir for floatables as stormwater flows though at flow rates less than the design flow. A device controls the flow into the storage manhole. All flows above the stated treatment flow rate bypass through the device. The bypass prevents resuspension or loss of sediment and floatables that have accumulated in the second manhole. It is important to recognize that as storage of accumulated sediment occurs directly in the operating area of the manholes; treatment efficiency will decline over time given the reduction in treatment volume.

This type of system exists in a number of treatment capacities (flow rate above which bypass occurs), approximately 2.4 - 21.8 cfs. The hydraulic capacities range from 10 to 100 cfs. As such, all stormwater achieves at least partial treatment through essentially all but the most extreme storm flows since some settling occurs in the first manhole. The manufacturer provides information on the total system (water) volume, sediment capacity, and floatable capacities. Footprints of this system ranges from about 200 to 350 ft^2, with heights of about 11.5 to 13.5 feet (excluding minimum soil cover and access port extenders), depending on the model. Head loss ranges from 5 to 12 inches, depending on the model. Sediment and floatable capacities range up to 201 cf and 150 gallons, respectively. The recommended point of maintenance is when about 25% of the wet vault volume is supplanted by sediment.

Another wet vault design can incorporate internal baffles. Included is an entrance baffle, to reduce the energy of the flow entering the unit. Baffles are also affixed to the floor, to reduce resuspension of settled sediments improve performance. A floating sorbent pad may be placed near the outlet to remove free oil floating on the surface. This design includes both a permanent wet pool, 3 feet in depth, and live storage volume that is filled during each storm. The live storage volume is accomplished by restricting the outlet. The system is modular: that is, it consists of standard units that are added to increase the length, thereby providing the desired volume. Presumably for very large sites there is a practical total length.

Construction/Inspection Considerations

Refer to guidelines provided by the manufacturer.

Performance

A manufactured wet vault can be expected to perform similarly to large catch basins in that its wet volume (dead storage) is similar to that determined by methodology provided in TC-20 for wet ponds. Hence, the engineer should compare the volume of the model he or she intends to select to what the volume of a constructed wet vault would be for the site. Conceivably, manufactured vaults may give better performance than standard catch basins, given the inclusion of design elements that are intended to minimize resuspension. Given this benefit, it could be argued that manufactured wet vaults can be smaller than traditional catch basins to achieve similar performance. However, there are no data indicating the incremental benefit of the particular design elements of each manufactured product. Specific performance information should be obtained from the manufacturer. The designer is cautioned when reviewing bench scale performance information as it may be a poor proxy for prototype scale performance.

Siting Criteria

There are no unique siting criteria. The size of the drainage area that can be served by a manufactured wet vault is directly related to the capacities of the largest models.

Additional Design Guidelines

Refer to guidelines of the manufacturers.

Maintenance

Maintenance consists of the removal of accumulated material with a vacuum and water jetting equipped-truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product. Annual maintenance is typical.

It is important to recognize that as storage of accumulated sediment occurs directly in the operating area of the wet vault, treatment efficiency will decline over time given the reduction in treatment volume. Whether this is significant depends on the design capacity. If the total volume of the wet pool is similar to that determined by the method on TC-20, the effect on performance is minor.

Maintenance Requirements

- Each manufacturer provides storage capacities with respect to sediments and floatables, with recommendations on the frequency of cleaning as a function of the percentage of the volume in the unit that has been filled by these materials.
- The recommended frequency of cleaning differs with the manufacturer, ranging from one to two years. It is prudent to inspect the unit twice during the first wet season of operation, setting the cleaning frequency accordingly.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100% of the manufacturer's cost.

Cost Considerations

- The different geometries of the several manufactured separators suggest that when comparing the costs of these systems to each other, that local conditions (e.g., groundwater levels) may affect the relative cost-effectiveness.
- Subsurface facilities are more expensive to construct than surface facilities of similar size. However, the added cost of construction is in many developments offset by the value of continued use of the land.
- Some of the manufactured vaults may be less expensive to maintain than public domain vaults as the former may be cleaned without the need for confined space entry.
- Subsurface facilities do not require landscaping, reducing maintenance costs accordingly.

References and Sources of Additional Information

Manufacturers' literature.

Description

Hydrodynamic separators: (alternatively, gravity separator, oil and grit separators, swirl concentrators or vortex separators) are typically manhole or vault based systems employing flow shaping features to enhance gravitational separation of floating and sinking pollutants. Compared to conventional wet vaults, hydrodynamic separators can typically provide the desired pollutant removal performance within a more compact system. Unlike a rectangular wet vault a hydrodynamic separator is round and directs incoming stormwater in a circular fashion, separating suspended sediments, trash and attached pollutants with centrifugal force. There are practical limitations to performance of most designs, where a certain minimum flow rate must be maintained, below which flow shaping features are ineffective and the system operates more as a simple gravity separator. In practice hydrodynamic separators are usually not designed to target sediment particles finer than about 50 microns.

Design Considerations

- Service Area
- Settling Velocity
- Appropriate Sizing
- Inlet Pipe Diameter

Targeted Constituent	Removal
Sediment	Med/High
Nutrients	Low
Trash	High
Metals	Low/Med
Bacteria	Low
Oil and Grease	Med
Organics	Low

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There are currently over 5,000 installations in California.

Advantages

- May provide the desired sediment and oil removal performance in a smaller footprint compared to conventional wet vaults.
- Scalable designs can treat a wide range of flow rates from <1 cfs to >100 cfs.
- Functions as a cost effective pre-treatment device.
- May provide significant spill protection.
- Captures and holds solids, oil and trash out of public view and out of contact with wildlife, native soils and groundwater.
- Subsurface design allows overlying land to be used for pedestrian or vehicular traffic or for landscaping.

Limitations

- As some of the systems have standing water that remains between storms, there is concern about mosquito breeding.
- It is likely that vortex separators are not as effective as wet vaults at removing fine sediments, on the order 50 to 100 microns in diameter and less.
- Does not remove dissolved pollutants.

- An export of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

Stormwater enters the separator, typically below the effluent line, tangentially into the basin, thereby imparting a circular motion in the system (Figure 1). Due to centrifugal forces created by the circular motion, the suspended particles move to the wall of the device, and fall along the wall to the bottom. Trash accumulates in the low pressure area of the center of the vortex.

Figure 1. Looking down a hydrodynamic separator from the top where stormwater tangentially enters the unit.

There are a wide variety of system designs commercially available with treatment capacities ranging from less than 1 cfs to more than 100 cfs. Some designs include internal screens suitable for capturing neutrally buoyant materials. Some incorporate internal bypass features that direct peak flows exceeding the design water quality flow rate around the separation zone. Many systems can accommodate multiple inlet pipes, grate inlets or curb inlets. Most systems are designed within standard manhole or utility vaults and can support HS20 loading, with additional reinforcement for greater loads available as an option.

Design of hydrodynamic separators is flow-based with the system size increasing as the design water quality flow rate increases. Some hydrodynamic separators have a characteristic hydraulic loading rate expressed as flow rate per system volume or separation chamber surface area that is associated with a specific targeted pollutant concentration reduction or effluent concentration. Sizing most commonly entails dividing the design water quality flow rate by the hydraulic loading rate to get a minimum system size.

Most, if not all commercially available systems also have sizing tables available for standard models listing the maximum treatment flow rate for a particular model and target performance level. It should be noted that the default target particle diameter and removal rate varies widely between manufactured systems so direct comparison of different models can be difficult. In most cases, a specific system can also be scaled larger or smaller to achieve a greater or lesser performance target at a particular flow rate. Results of full scale field monitoring or standardized laboratory testing with a standard sediment gradation are available for many hydrodynamic separators and should be the basis for selection and sizing decisions.

Construction/Inspection Considerations

No special considerations.

Performance

The primary mechanism of pollutant removal is gravitational separation for all hydrodynamic separators, with some models also employing screens to capture neutrally buoyant materials such as trash. There are numerous hydrodynamic separator design variations commercially available with performance of a particular design depending primarily on the residence time within the system.

Protocols for testing and verifying the performance of innovative stormwater treatment systems have been developed by the Washington State Department of Ecology and the New Jersey Department of Environmental Protection. Both programs provide certification or approval of treatment systems following independent verification that those systems meet certain performance targets. Both programs have been endorsed by numerous states and public agencies including EPA and the Water Environment Federation (WEF) and have been supported by the Stormwater Equipment Manufacturers Association (SWEMA).

The Technology Assessment Protocol – Ecology (TAPE) from the Washington State Department of Ecology program has a "Pretreatment" standard that is applicable to hydrodynamic separators. It is intended to achieve 50% removal of fine (50 micron-mean size) and 80% removal of coarse (125-micron-mean size) total suspended solids.

A list of technologies, including several hydrodynamic separators that have met this treatment standard can be found on the Ecology web page for emerging technologies at: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html

The New Jersey DEP laboratory protocol for hydrodynamic separators requires 50% removal of a TSS gradation with a mean particle diameter of 75 microns. A list of technologies, including several hydrodynamic separators that have met this standard can be found on the NJ DEP web page for Stormwater Manufactured Treatment Devices at: http://www.njstormwater.org/treatment.html

To ensure acceptable hydrodynamic separator performance and operational feasibility, selection of systems that have been verified by the Ecology and/or NJ DEP programs is recommended. Furthermore, design and sizing should be consistent with approvals issued by those programs.

Siting Criteria

Hydrodynamic separators can be configured to receive runoff from the surface through a curb inlet, grate inlet, or through one or more inlet pipes. They can be installed under vehicular or pedestrian traffic areas or under landscaped areas. Maintenance typically requires a vacuum truck so hydrodynamic separators should be located where they can be accessed without unduly disrupting traffic flow or site operations.

Additional Design Guidelines

Hydrodynamic separators may be susceptible to washout if flows significantly higher than the design treatment capacity are directed through the separation chamber or the sediment storage zone. Therefore, it is important that the system either be designed in an off-line configuration where peak flows are routed around the treatment system, or that the peak flow rate does not exceed the rate at which significant resuspension of previously captured materials will occur. For most designs, the maximum flow rate that the system can handle without resuspension is significantly higher than the design treatment flow rate for particles in the range of 100 microns. The New Jersey DEP protocol for hydrodynamic separator testing includes scour testing which is used to establish the maximum allowable hydraulic loading rate prior to bypass.

Maintenance

Maintenance consists of the removal of accumulated material with a vacuum truck which should be performed annually unless experience indicates the need for more or less frequent maintenance. It may be necessary to remove and dispose of the floatables separately due to the presence of petroleum product.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 25 to 50% of the manufacturer's cost. For most sites the units are cleaned annually.

Cost Considerations

- Treatment with one larger systems is typically more cost effective than using multiple smaller systems.

References and Sources of Additional Information

Field, R., D. Averill, T.P. O'Connor, and P. Steel, 1997, Vortex separation technology, Water Qual. Res. J. Canada, 32, 1, 185

New Jersey manufactured stormwater devices' performance verification: http://www.njcat.org/verification-process/technology-verification-database.html

New Jersey Department of Environmental Protection Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device: http://www.njstormwater.org/pdf/hds-protocol-1-25-13.pdf

Washington State manufactured stormwater devices' performance verification: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html

Drain Inlet Inserts MP-52

Description

Drain inlet inserts are manufactured filters placed in a drop inlet to remove sediment and debris. There are a multitude of inserts of various shapes and configurations, typically falling into one of three different groups: socks, boxes, and trays. The sock consists of a fabric, usually constructed of polypropylene. The fabric may be attached to a frame or the grate of the inlet holds the sock. Socks are meant for vertical (drop) inlets. Boxes are constructed of plastic or wire mesh. Typically a polypropylene "bag" is placed in the wire mesh box. The bag takes the form of the box. Most box products are one box; that is, the setting area and filtration through media occur in the same box. Some products consist of one or more trays or mesh grates. The trays may hold different types of media. Filtration media vary by manufacturer. Types include polypropylene, porous polymer, treated cellulose, and activated carbon.

Design Considerations

- Use with other BMPs
- Fit and Seal within Inlet

Targeted Constituents	Removal
Sediment	Low/Med
Nutrients	Low/Med
Trash	High
Metals	Low/Med
Bacteria	Low
Oil and Grease	Low/Med
Organics	Low

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California Experience

The number of installations is unknown but likely exceeds a thousand. Some users have reported that these systems require considerable maintenance to prevent plugging and bypass.

Advantages

- Does not require additional space as the drain inlets are already a component of the standard drainage systems.
- Easy access for inspection and maintenance.
- As there is no standing water, there is little concern for mosquito breeding.
- A relatively inexpensive retrofit option.

Limitations

- Performance is likely significantly less than treatment systems that are located at the end of the drainage system such as ponds and vaults.
- Usually not suitable for large areas or areas with trash or leaves than can plug the insert.
- Distributed maintenance compared to centralized treatment devices.

Design and Sizing Guidelines

Drain inserts come in a variety of configurations but are generally a polypropylene fabric installed around a grate, box or tray. Some products can consist of one or more trays, boxes or grates and can hold different types of media. Filtration media vary with the manufacturer: types include polypropylene, porous polymer, treated cellulose, and activated carbon. Manufacturer's specifications can be referred to for more detail.

Construction/Inspection Considerations

The stormwater must enter the unit and not leak around the perimeter. Leakage between the frame of the insert and the frame of the drain inlet can easily occur with vertical (drop) inlets.

Performance

Few products have performance data collected under field conditions.

Siting Criteria

It is recommended that inserts be used only for retrofit situations or as pretreatment where other treatment BMPs presented in this section area used.

Additional Design Guidelines

Follow guidelines provided by individual manufacturers.

Maintenance

Likely require frequent maintenance, on the order of several times per year.

Cost

- The initial cost of individual inserts ranges from less than $100 to about $2,000. The cost of using multiple units in curb inlet drains varies with the size of the inlet.
- The low cost of inserts may tend to favor the use of these systems over other, more effective treatment BMPs. However, the low cost of each unit may be offset by the number of units that are required, more frequent maintenance, and the shorter structural life (and therefore replacement).

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Water Quality Inlet MP-53

Description

Water quality inlets (WQIs), also commonly called trapping catch basins, oil/grit separators, or oil/water separators, are devices that consist of one or more chambers that settle out coarse materials and separate free oil from stormwater. Some WQIs also contain screens to help trap trash as well. A typical WQI consists of a sedimentation chamber, an oil separation chamber, and a discharge chamber. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs).

Design Considerations

- Area Required

Targeted Constituent	Removal
Sediment	Med
Nutrients	Low
Trash	High
Metals	Low
Bacteria	Low
Oil and Grease	Med
Organics	Low

California Experience

Experience in California and throughout the country indicates these devices are appropriate for capturing hydrocarbons spills, but provide very marginal sediment removal and are not very effective for treatment of stormwater runoff.

Advantages

- Can provide spill control, and water quality treatment.

Limitations

- WQIs generally provide limited hydraulic and residuals storage, therefore, WQIs do not provide substantial stormwater improvement.
- Standing water in the devices can provide a breeding ground for mosquitoes.

Suitability and Design

- Water quality inlets are most effective for spill control and should be sized accordingly.
- Designs that utilize covered sedimentation and filtration basins should be accessible to vector control personnel via access doors to facilitate vector surveillance and controlling the basins if needed.
- Can be fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and resuspending settled pollutants.
- Generally, off-line units are designed to handle the first 1.3 centimeters (0.5 inches) of runoff from the drainage areas. Upstream isolation/diversion structures can be used to divert the water to the off-line structure (Schueler, 1992). On-line units receive higher flows that will likely cause increased turbulence and resuspension of settled material, thereby reducing WQI performance.

Construction Considerations

- Any construction activities within the drainage area should be completed before installation of the WQI, and the drainage area should be revegetated so that the sediment loading to the WQI is minimized.

- WQIs are available as pre-manufactured units or can be cast in place. Reinforced concrete should be used to construct below-grade WQIs. The WQIs should be water tight to prevent possible ground water contamination.

Performance

WQIs are primarily utilized to remove sediment from stormwater runoff. Grit and sediment are partially removed by gravity settling within the first two chambers. A WQI with a detention time of one hour may expect to have 20 to 40 percent removal of sediments.

To better understand the performance of water quality inlet (and other proprietary BMPs), many states such as New Jersey, Virginia and Washington State have created specific field and laboratory testing procedures for manufactured BMPs. The State-developed procedures allow for all BMP types be rated on the same criteria and better rate relative pollutant removal. See References for links to some State program websites.

Pollutant removal in stormwater inlets can be somewhat improved using inserts, which are promoted for removal of oil and grease, trash, debris, and sediment. Some inserts are designed to drop directly into existing catch basins, while others may require extensive retrofit construction.

Siting Criteria

Prior to WQI design, the site should be evaluated to determine if another BMP would be more cost-effective in removing the pollutants of concern. WQIs should be used when no other BMP is feasible. The WQI should be constructed near a storm drain network so that flow can be easily diverted to the WQI for treatment (NVPDC, 1992).

WQIs are most effective for small drainage areas. Drainage areas of 0.4 hectares (1 acre) or less are often recommended. WQIs are typically used in an off-line configuration (i.e., portions of runoff are diverted to the WQI), but they can be used as on-line units (i.e., receive all runoff).

Maintenance

Typical maintenance of WQIs includes trash removal if a screen or other debris capturing device is used, and removal of sediment using a vactor truck. Operators need to be properly trained in WQI maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of GIS systems to track sediment collection and to optimize future catch basin cleaning efforts.

When sediment fills greater than 60 percent of their volume, catch basins can reach steady state. Storm flows can then resuspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of stormwater flows.

Depending on frequency and severity of events WQIs should be cleaned regularly. Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda

County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the total sediment removed by catch basins on an annual basis (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semi-annual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds). These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency.

BMPs designed with permanent water sumps, vaults, and/or catch basins (frequently installed below-ground) can become a nuisance due to mosquito and other vector breeding. Preventing mosquito access to standing water sources in BMPs (particularly below-ground) is the best prevention plan, but can prove challenging due to multiple entrances and the need to maintain the hydraulic integrity of the system. BMPs that maintain permanent standing water may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production.

Cost

A typical pre-cast catch basin costs between $2,000 and $3,000; however, WQIs can be much more expensive. The true pollutant removal cost associated with WQIs, however, is the long-term maintenance cost which will require appropriate equipment, i.e., vactor trucks, and the staff to conduct the maintenance.

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Design Considerations

- Accumulation of Metals
- Clogged Soil Outlet Structures
- Vegetation/Landscape Maintenance

Targeted Constituent	Removal
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	Med

Description

An infiltration trench is a rock and media-filled trench with no outlet that receives stormwater runoff. Runoff is stored in the void space between the media and infiltrates through the sides and bottom and into the soil matrix. Infiltration trenches perform well for elimination of surface runoff up to their design capacity. Pretreatment using buffer strips, swales, or detention basins is important for limiting sediment from entering the trench which can clog and render the trench ineffective.

California Experience

Caltrans constructed two infiltration trenches at highway maintenance stations in Southern California. Of these, one failed to operate to the design standard because of average soil infiltration rates lower than that measured in the single infiltration test. This highlights the critical need for appropriate evaluation of the site. Once in operation, little maintenance was required at either site.

Infiltration trenches have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water Boards. Additionally, the Water Boards have determined that infiltration trenches can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- 100% reduction in the load discharged to surface waters.
- Can achieve pre-development hydrology by infiltrating a significant portion of the average annual rainfall runoff.

Limitations

- Have a high failure rate if soil and subsurface conditions are not suitable, or if there is a high sediment loading to the trench.
- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C or D.

Performance

Infiltration trenches eliminate the discharge of the water quality volume to surface receiving waters and consequently can be considered to have 100% removal of all pollutants within this volume. Actual pollutant removal in the subsurface would be expected to vary depending upon site-specific soil types (Table *1*).

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Sediment	High (90%)	9.9 mg/l	Settling, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Stander and Borst 2010; Maniquiz, 2010; Scholes, 2007
Metals	High	TCd: 0.07 µg/L, TCr: 0.35 µg/L, TCu: 5.33 µg/L, *TFe: 1027 µg/L,* TPb: 0.19 µg/L, *TNi: 4.53 µg/L,* TZn: 12.0 µg/L	Settling with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012; Maniquiz, 2010

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Hydro-carbons	High (90-97%)	N/A	Volatilization, sorption, and degradation in mulch layer.	1 foot	Hong et al. 2006; Hunt et al. 2012; Barraud et al 1999; Dierkes and Geiger, 1999; Mikkelsen et al. 1997; Hong et al. 2006. Hsieh and Davis 2005; Pitt et al. 1999
Total phosphorus	High (-240% to 99%)	*0.240 mg/l*	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010; Maniquiz 2010
Total nitrogen	High (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.92 mg/l, TKN: 1.34 mg/l, $NO_{2,3}$-N: 0.37 mg/l	Sorption and settling (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009; Maniquiz, 2010; Winiarski et al. 2006
Bacteria	High	*Enterococcus*: 235 MPN/ 100 mL, *E.coli*: 101 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010
Trash	High	*N/A*	Filtration	1.5 feet of media	Barrett et al. 2013

[1] Concentrations are based on bioretention performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Groundwater contamination concerns exists for infiltration trenches (Lind and Karro, 1995; Datry et al., 2004; Pitt, 1999) but pollutant concentrations in the soil column have been shown to decrease rapidly with depth (within the first 6 to 18 inches) (Dechesne, M. et al., 2004; Dierkes and Geiger, 1999; Mikkelsen et al., 1997; Datry et al., 2004). However, pollutant concentrations can be of concern as deep as 10 feet, preferential flow pathways are suspected as the means of transport in some geologic settings (Winiarski et al. 2006). These observations warrant a 10 foot minimum between infiltration trench bottom and seasonal high water table.

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which an infiltration trench meets (see Section 5.6.1 for FCS details).

Suitability and Design

The use of infiltration trenches may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics, such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock, can also preclude the use of infiltration trenches. The constraints of each site dictate the appropriate siting and footprint. Fundamental infiltration trench design components are as follows:

- Infiltration rate assessed on-site by a licensed geotechnical engineer or soil scientist.
- Unsuitable if known soil contamination is present, or if upstream drainage area uses or store chemicals or hazardous materials that could drain to the trench.
- 10 feet of separation between bottom of the trench and seasonal high water table.
- Drainage area that has been fully stabilized, plus use of a pretreatment BMP (e.g. grassed swales) at the entry point to ensure longevity.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.

Infiltration trench design is highly dependent on the constraints of the considered site. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation		Requires infiltration rate > 0.5 in/hr. When excavating ensure that subgrade compaction is minimized. Design for 6 to 18 inches average ponding depth. Trench should contain entire upstream WQV. After final grading, till the infiltration surface deeply
Without underdrains	\$2.75–\$5.00/ft^2	
With underdrains	\$3.90–\$6.15/ft^2	
Soil Media		

Component	Cost	Design Consideration
Recommended mix	$2.90–$4.30/ft^2	1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and rooting depths) at minimum 5 in/hr infiltration. Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil. Organic Matter Content < 5% by weight. 65% sand, 20% sandy loam, and 15% compost (from vegetation-based feedstock) by volume.
With engineered media	$3.60–$5.40/ft^2	
Soil Media Barrier		
Geotextile	$0.45/ft^2	When incorporating an underdrain, separate media from native soil with a geotextile layer, 2 to 4 inches of washed sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Washed sand (2-inch layer)	$0.20/ft^2	
No. 8 aggregate (min 2 inches thick)	$0.28/ft^2	
No. 57 stone (1.5 + feet)	$2.49/ft^2	
Hydraulic Restriction Layer		
Filter fabric	$0.45/ft^2	May use hydraulic restriction layer on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.
Clay	$0.65/ft^2	
30-mil liner	$0.35/ft^2	
Concrete barrier	$12.00/ft^2	
Landscape	$0.20–$3.50/ft^2	Armor surface with cobble or vegetation. If planted (optional), install native, deep rooting, and drought tolerant plants.

To provide adequate drainage the bottom surface area can be calculated to drain the trench within 72 hr by dividing the WQV by the infiltration rate. Where:

$$d = \frac{WQV + RFV}{SA}$$

d	=	Trench depth
WQV	=	Water quality volume
RFV	=	Rock fill volume
SA	=	Surface area of the trench bottom

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The infiltration trench must be configured to allow trash to enter the system and for trash to remain in the BMP until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in an infiltration trench. An open curb cut is recommended for high traffic areas (Figure 1). A minimum 2 inch drop from the gutter line of the curb to the inlet is recommended as demonstrated in Figure 1 to ensure that flow is routed into the infiltration trench and trash will not clog the inlet.

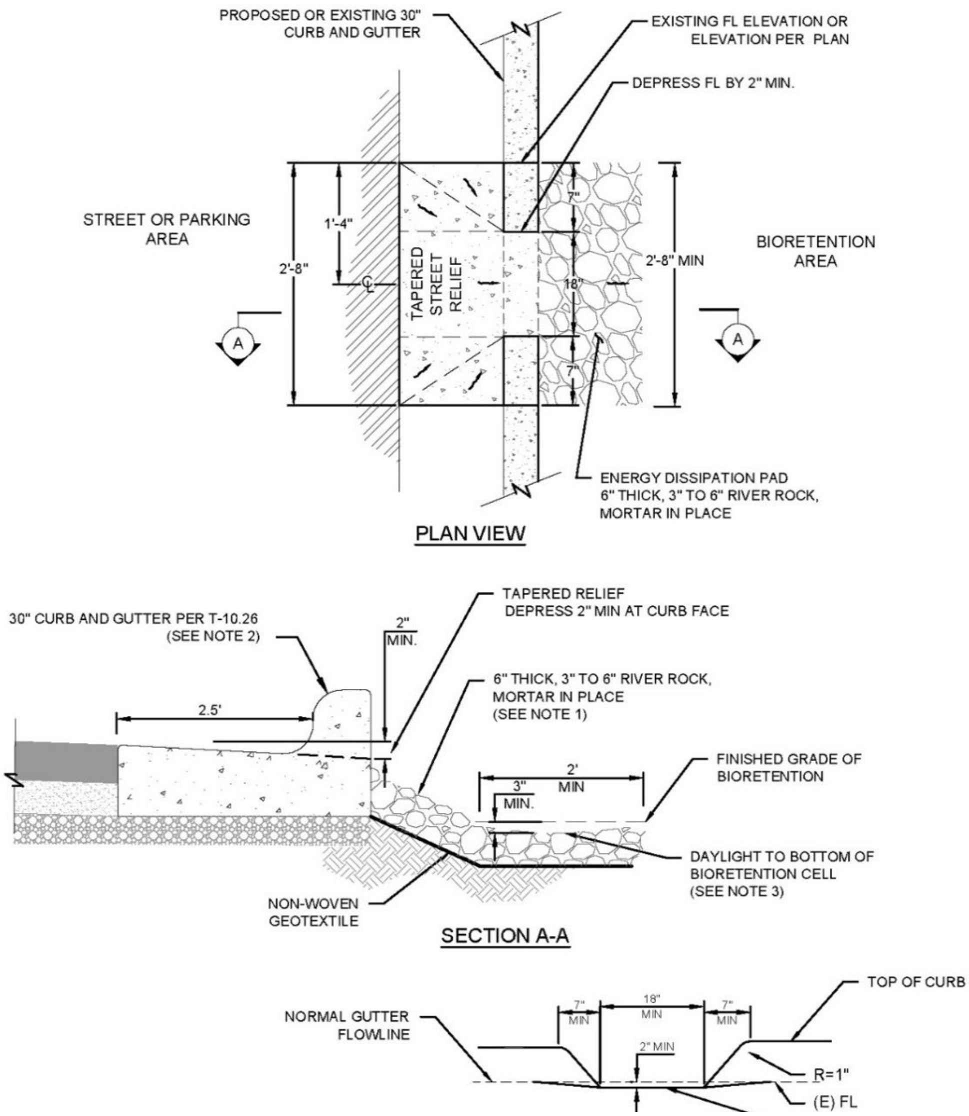


Figure 1. Example Inlet Detail

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. A forebay (Figure 2), filter strip (Figure 4), or mortared cobble inside the curb cut (Figure 3) can slow flow and allow trash and gross solids to settle out while

Figure 3. Example of a forebay as pretreatment

Figure 2. Example of mortared cobble for pretreatment with a curb cut.

Figure 4. Example of filter strip as pretreatment

consolidating at the edge of the infiltration trench area to make it easier for maintenance crews to collect and remove.

Trash Containment

Once trash has been captured in an infiltration trench it must be contained so trash does not escape the infiltration trench. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or
- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Figure 5 shows an example of an outlet with a screen to contain trash.

Maintenance

Infiltration trenches required the least maintenance of any of the BMPs evaluated in a Caltrans study, with approximately 17 field hours spent on the operation and maintenance of each site. Inspection of the infiltration trench was the largest field activity, requiring approximately 8 hr/yr (Caltrans, 2002).

Figure 5. Example of an outlet with 5 mm screen.

Clogged infiltration trenches reduced water quality performance but can also enable standing water to become a nuisance due to mosquito breeding. If the trench takes more than 72 hours to drain, then the rock-fill should be removed and all dimensions of the trench should be increased by 2 inches to provide a fresh surface for infiltration. To mitigate failure, ensure particulate loading of the stormwater is minimal, or is reduced with an adjacent pretreatment (Figure 1 through Figure 4). Reducing particulate loading enables the soil's infiltrative capacity to remain high and functional. Table 3 provides maintenance activity details, frequency, and costs.

Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Pruning and mowing overgrown vegetation that interferes with access, or safety (if applicable).
Routine (small)	$7.62/ft^2	
Routine (medium)	$1.91/ft^2	
Routine (large)	$1.91/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$10.52/ft^2	
Replacement (medium)	$10.17/ft^2	
Replacement (large)	$10.11/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

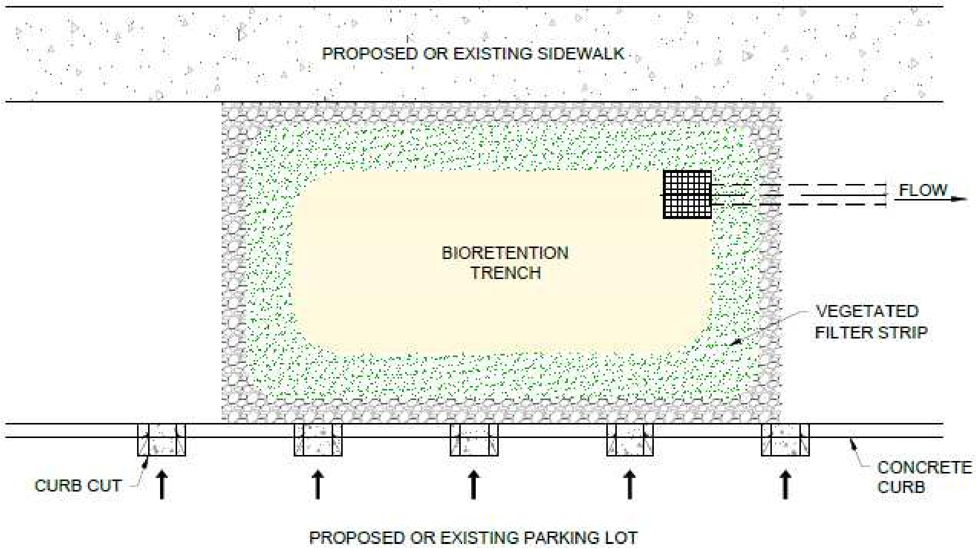
Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

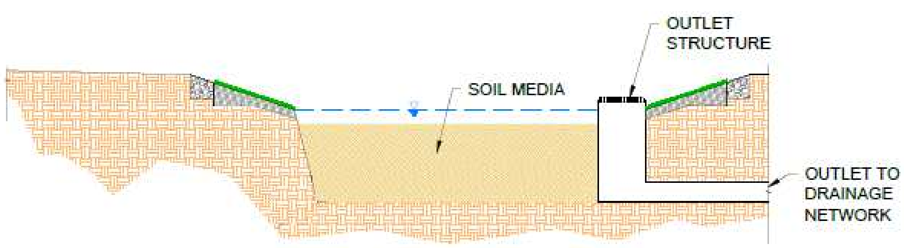
For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Infiltration Trench Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the infiltration trench in the subsequent rain events (see Table 3). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event.

Trash maintenance not only plays a role in the functionality of the infiltration trench but also in the aesthetics and public perception of infiltration trenches (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance. The appropriate maintenance interval is best determined through observation of the trench over an average water year.

Schematic



A - INFILTRATION TRENCH - PLAN VIEW
NOT TO SCALE



A - INFILTRATION TRENCH - SECTION
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Design Considerations

- Soil for Infiltration
- Slope
- Aesthetics

Targeted Constituent	Removal
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

Description

An infiltration basin is a relatively large impoundment that is designed to infiltrate stormwater. Infiltration basins use the natural filtering ability of the soil to remove pollutants in stormwater runoff. Infiltration facilities store runoff until it gradually exfiltrates through the soil and eventually into the water table. This practice removes surface flow and associated pollutants through infiltration and can also help recharge groundwater, thus helping to maintain low flows in stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

CALIFORNIA STORMWATER QUALITY ASSOCIATION®

California Experience

Infiltration basins have a long history of use in California, especially in the Central Valley. Basins located in Fresno were among those initially evaluated in the National Urban Runoff Program and were found to be effective at reducing the volume of runoff, while posing little long-term threat to groundwater quality (EPA, 1983; Schroeder, 1995). Proper siting of these devices is crucial as underscored by the experience of Caltrans in siting two basins in Southern California. The basin with marginal separation from groundwater and soil permeability failed immediately and could never be rehabilitated. The Water Augmentatoin Study (LASGRWC 2010) perfomred in the Los Angeles region showed no negative impact to ground water from infiltrating stormwater through infiltration practices treating stormwater from sites ranging from 0.5 acres to 7.4 acres.

Infiltration basins have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water Boards. Additionally, the Water Boards have determined that infiltration basins can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- 100% reduction in the load discharged to surface waters.
- Can achieve pre-development hydrology by infiltrating a significant portion of the average annual rainfall runoff.

Limitations

- Have a high failure rate if soil and subsurface conditions are not suitable.
- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C or D.

Performance

As water migrates through porous soil and rock, pollutant attenuation mechanisms include precipitation, sorption, physical filtration, and bacterial degradation (Table 1). Vegetation establishment may improve water quality performance and decrease residence time (i.e., increase water losses). If functioning properly, this approach is presumed to have high removal efficiencies for particulate pollutants and moderate removal of soluble pollutants. Actual pollutant removal in the subsurface would be expected to vary depending upon site-specific soil types. This technology eliminates discharge to surface waters except for the very largest storms; consequently, complete removal of all stormwater constituents can be assumed.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Sediment	High (90%)	9.9 mg/l	Settling, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Stander and Borst 2010; Maniquiz, 2010; Scholes, 2007

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit projector a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Metals	High	TCd: 0.07 µg/L, TCr: 0.35 µg/L, TCu: 5.33 µg/L, *TFe: 1027 µg/L,* TPb: 0.19 µg/L, *TNi: 4.53 µg/L,* TZn: 12.0 µg/L	Settling with sediment and sorption to organic matter and clay in media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2012; Maniquiz, 2010
Hydro-carbons	High (90-97%)	N/A	Volatilization, sorption, and degradation in mulch layer.	1 foot	Hong et al. 2006; Hunt et al. 2012; Barraud et al 1999; Dierkes and Geiger, 1999; Mikkelsen et al. 1997; Hong et al. 2006. Hsieh and Davis 2005; Pitt et al. 1999
Total phosphorus	High (-240% to 99%)	*0.240 mg/l*	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	2 feet	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; Li et al. 2010; Maniquiz 2010
Total nitrogen	High (TKN: -5% to 64%, Nitrate: 1% to 80%)	TN: 0.92 mg/l, TKN: 1.34 mg/l, $NO_{2,3}$-N: 0.37 mg/l	Sorption and settling (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006; Hunt et al. 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009; Maniquiz, 2010; Winiarski et al. 2006

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Bacteria	High	*Enterococcus*: 235 MPN/ 100 mL, *E.coli*: 101 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet	Geosyntec Consultants and Wright Water Engineering 2012; Hathaway et al. 2009; Hathaway et al. 2011; Hunt and Lord 2006; Hunt et al. 2008; Hunt et al. 2012; Jones and Hunt 2010
Trash	High	*N/A*	Filtration	1.5 feet of media	Barrett et al. 2013

[1] Concentrations are based on bioretention performance data. Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Groundwater contamination concerns exists for infiltration basins (Lind and Karro, 1995; Datry et al., 2004; Pitt, 1999) but pollutant concentrations in the soil column have been shown to decrease rapidly with depth (within the first 6 to 18 inches) (Dechesne, M. et al., 2004; Dierkes and Geiger, 1999; Mikkelsen et al., 1997; Datry et al., 2004). However, pollutant concentrations can be of concern as deep as 10 feet, preferential flow pathways are suspected as the means of transport in some geologic settings (Winiarski et al. 2006). These observations warrant a 10 foot minimum between infiltration basin bottom and seasonal high water table.

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which infiltration basin meets (see Section 5.6.1 for FCS details).

Suitability and Design

The use of infiltration basins may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics, such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock, can also preclude the use of infiltration basins. The constraints of each site dictate the appropriate siting and footprint. Fundamental infiltration basin design components are as follows:

- Infiltration rate assessed on-site by a licensed geotechnical engineer or soil scientist.
- Unsuitable if known soil contamination is present, or if upstream drainage area uses or store chemicals or hazardous materials that could drain to the basin.
- 10 feet of separation between bottom of the basin and seasonal high water table.

- Drainage area that has been fully stabilized, plus use of a pretreatment BMP (e.g. grassed swales, gravity separator) at the entry point to ensure longevity.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.

Basin design is highly dependent on the constraints of the considered site. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation		Requires infiltration rate > 0.5 in/hr. When excavating ensure that subgrade compaction is minimized. Design for 6 to 18 inches average ponding depth. Basin should contain entire upstream WQV. After final grading, till the infiltration surface deeply
Without underdrains	\$2.75–\$5.00/ft^2	
With underdrains	\$3.90–\$6.15/ft^2	
Soil Media		1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and rooting depths) at minimum 5 in/hr infiltration. Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil. Organic Matter Content < 5% by weight. 65% sand, 20% sandy loam, and 15% compost (from vegetation-based feedstock) by volume.
Recommended mix	\$2.90–\$4.30/ft^2	
With engineered media	\$3.60–\$5.40/ft^2	
Soil Media Barrier		When incorporating an underdrain, separate media from native soil with a geotextile layer, 2 to 4 inches of washed sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Geotextile	\$0.45/ft^2	
Washed sand (2-inch layer)	\$0.20/ft^2	
No. 8 aggregate (min 2 inches thick)	\$0.28/ft^2	
No. 57 stone (1.5 + feet)	\$2.49/ft^2	
Hydraulic Restriction Layer		May use hydraulic restriction layer on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.
Filter fabric	\$0.45/ft^2	
Clay	\$0.65/ft^2	
30-mil liner	\$0.35/ft^2	
Concrete barrier	\$12.00/ft^2	

Subsurface Option (Figure 1)		Constructing a subsurface facility includes excavating to depth, installing concrete unit, overdig, and backfill. Concrete unit height assumed here: 11' 4". *Requires* pretreatment BMP to capture trash and debris.
Excavation, Installation, and Backfill	$9.20/ft^2	
Concrete Unit	$59.93/ft^2	
Landscape	$0.20–$3.50/ft^2	Armor surface with cobble or vegetation. If planted (optional), install native, deep rooting, and drought tolerant plants.

Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.

Basin invert area should be determined by the equation. Where:

$$A = \frac{WQV}{kt}$$

A	=	Basin invert area (m^2)
WQV	=	water quality volume (m^3)
k	=	0.5 times the lowest field-measured hydraulic Conductivity (m/hr)
t	=	drawdown time (48 hr)

Design Variations

When traditional surface basins are infeasible because of land constraints, subsurface extended detention basin are ideal (Figure 1). Open space parks (e.g., baseball fields, etc.) are an example of where a subsurface infiltration basin is ideal because the park's purpose as a recreational area is not compromised. Additionally, recreational areas typical lack large structures, therefore the issue of overhead weight over the subsurface unit is not a concern.

Figure 1. Subsurface design of an infiltration basin, mid-construction.

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The infiltration basin must be configured to allow trash to enter the system and for trash to remain in the basin until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in an infiltration basin. An open inlet with a forebay is recommended.

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. A forebay with mortared cobble is one example of incorporating pretreatment in the inlet (Figure 2). This configuration can slow flow and allow trash and gross solids to settle out while consolidating at the edge of the infiltration basin to make it easier for maintenance crews to collect and remove.

Figure 2. Example of a forebay as pretreatment for an infiltration basin.

Trash Containment

Once trash has been captured in an infiltration basin it must be contained so trash does not escape the infiltration basin. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or

Figure 3. Example of an outlet with 5 mm screen.

- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Maintenance

A considerable cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate. Thus, it may be necessary to replace the basin with a different technology after a relatively short period of time. To mitigate failure, ensure particulate loading of the stormwater is minimal, or is reduced with an adjacent pretreatment (i.e. vegetated buffer strip). Reducing the particulate loading enables the soils infiltrative capacity to stay high and functional.

Clogged infiltration basins reduced water quality performance but can also enable standing water to become a nuisance due to mosquito breeding. If the basin takes more than 48 hours to drain, then the rock fill should be removed and all dimensions of the basin should be increased by 2 inches to provide a fresh surface for infiltration. To mitigate failure, ensure particulate loading of the stormwater is minimal, or is reduced with an adjacent pretreatment (Figure 2). Reducing particulate loading enables the soil's infiltrative capacity to remain high and functional. Table 3 provides maintenance activity details, frequency, and costs.

Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Pruning and mowing overgrown
Routine (small)	$7.62/ft^2	

Frequency	Cost	Activity
Routine (medium) Routine (large)	$1.91/ft^2 $1.91/ft^2	vegetation that interferes with access, or safety (if applicable).
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small) Replacement (medium) Replacement (large)	$10.52/ft^2 $10.17/ft^2 $10.11/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

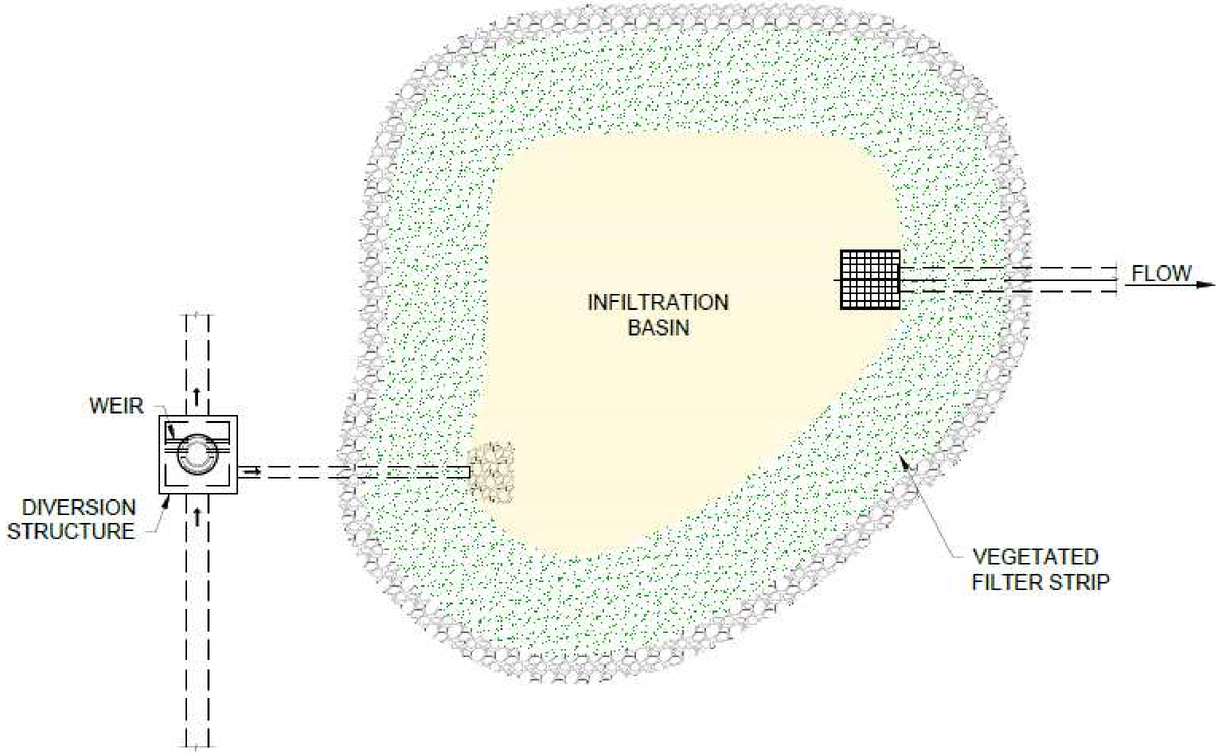
Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

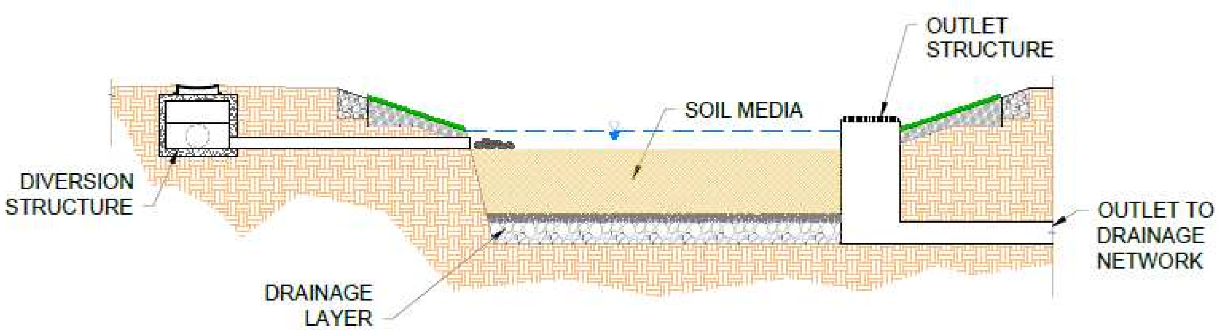
For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Infiltration Basin Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the infiltration basin in the subsequent rain events (see Table 3). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance frequency is best determined by site observation over an average water year.

Trash maintenance not only plays a role in the functionality of the infiltration basin but also in the aesthetics and public perception of the infiltration basin (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic



A - INFILTRATION BASIN - PLAN VIEW
NOT TO SCALE



A - INFILTRATION BASIN - SECTION
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Design Considerations
■ Soil for Infiltration
■ Area Required
■ Slope
■ Environmental Side-effects

Targeted Constituent	Removal
Sediment	Med
Nutrients	Med
Trash	High
Metals	Med
Bacteria	Low
Oil and Grease	High
Organics	Low
Flow Control	Med

Description

Harvest and Use refers to the capture of stormwater runoff in a tank and subsequent use of the captured volume (e.g. irrigation, indoor use). Capture of stormwater can be accomplished with above or below-ground cisterns or rain barrels to drain an entire roof or a partial area. For increased effectiveness, real-time controls (RTC) can be installed to integrate precipitation forecasts into the decision process. RTC allows the tank to be drawn down to ensure the anticipated storm volume can be held; what would have been overflow of the tank is drained in advance of the storm, and infiltrated (Tetra Tech, 2016).

California Experience

The RTC analysis cited above installed five residential cistern across LA County. Each residence was equipped with RTC and their implementation and efficacy was monitored (Figure 1). Installation of these systems validated their ability to be integrated into residential irrigation as well as the construction, permitting and implementation aspects of harvest and use. A water harvesting system at the San Diego Zoo is used to offset potable water use in irrigating the exhibits (Figure 2).

Additionally, the Water Boards have determined that harvest and use can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

BMP or the design of a planned BMP to meet the FCS definition. See the "Full Trash Capture Compliance" section and "Trash FCS" subsections in this fact sheet for more information.

Advantages

- Pollutant removal rates are assumed 100% in the captured and used stormwater volume.
- When RTC is integrated, stormwater can be drained across a regional network of intelligently controlled conveyances to a downstream regional BMPs or water reclamation facility.

Figure 1. Water harvesting at a private residence in Los Angeles.

Figure 2. Water harvesting demonstration at the San Diego Zoo.

Limitations

- Harvest and Use can be a relatively expensive technology due primarily to mechanical systems, power requirements, and high frequency maintenance needs.
- Stormwater from Harvest and Use may be accessible to mosquitoes and other vectors for breeding.

Performance

Generally, pollutant removal for cisterns is provided by a downstream BMP, although stormwater volume reduction can reduce total pollutant loads if rainwater is used. When equipped with RTC there is significant potential for harvest and use to improve water quality and augment the water supply (e.g. infiltrating stormwater, potable offset, and stormwater routed to a reclamation facility) (Tetra Tech, 2016). The cost-effectiveness of harvest and use can vary broadly depending on geologic and climatologic considerations of their location as well as RTC subscription costs (when applicable, Table 1).

Table 1. Cost efficiencies for Zinc removal and supply augmented in LA County

RWH scheme	$/lb of zinc removal	$/ac-ft of water augmented
RWH + standalone RTC license	$68,479	$36,119
RWH + enterprise RTC license (100,000+ subscribers)	$23,348	$11,826

While the majority of water quality benefits gained from harvest and use is due to infiltration, there are some water quality benefits that can be garnered from the storage tank. Sedimentation as well as sorption, precipitation, and chemical process can be attributed to reduce pollutant concentration in storage tanks (Despins et al., 2009). Percent change in pollutant concentrations between entrance and exit of four RWH systems from 2011 to 2012 with 100+ water quality samples are shown in Table 2 (Debusk and Hunt, 2014).

Table 2. Median reduction roof runoff concentration for sediment and nutrients

	TSS	Total Phosphorus	Total Nitrogen	TKN	$NO_2 + NO_3$
Median reduction in runoff concentration	44.8%	15.4%	50.0%	47.9%	62.1%

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which Harvest and Use meets (see Section 5.6.1 for FCS details).

Suitability and Design

Cisterns should be placed near a roof downspout, and the outlet (overflow and low-flow) should be directed to a pervious surface capable of infiltrating the water quality volume within 48 hours (e.g., bioretention cell). Infiltration requirements must follow those outlined in the Bioretention Fact sheet (TC-32). Fundamental harvest and use design components are as follows:

- Design of the runoff storage facility should be consistent with local regulatory guidelines.
- All inlets and outlets must be covered with a 1-millimeter mesh to prevent mosquito entry.
- Irrigation should not begin within 12 hours of the end of rainfall so that direct storm runoff has ceased and soils are not saturated.
- Can offset non-potable water supplies such as toilet flushing, car washing, street sweeping, and other uses.

Table 3. Cost of design components and associated considerations

Component	Cost	Design Consideration
Tanks/Cisterns	\$0.60–\$2.25/gal	Tanks should typically be opaque to prevent algal growth. Runoff should be conveyed to the cistern such that no backwater onto roofs occurs during the 100-yr event.
Rain Gutter and Gutter Guard	\$23/ft	If feasible direct all roof runoff to cistern with new or additional gutters and gutter guard. Downspout pipes should be sized to convey the 100-year discharge without causing any backwater on the roof.
Irrigation Pump, Controller and Piping	\$400-\$800	Pump apparatus applicable when hydraulic head from tank is insufficient to irrigate. All pipes conveying harvested rainwater should be Pantone color #512 and be labeled as "reclaimed water."
Filter	\$40.00–\$400.00	Self-cleaning inlet flow-through filter to strain out large debris on conveyance configuration. A first-flush diverter to capture the first wash-off of sediment, debris, and pollen during a rainfall event. If drainage area greater than 1,500 ft^2, use bypass capable filter
Foundation No. 57 gravel (assume 6-in. depth) Concrete (assume 6-in. depth)	 \$0.75/ft^2 \$13.50/ft^2	Gravel foundation if weight of the cistern at capacity is less than 2000 pounds, otherwise a concrete foundation is required.
Sign		Signage indicating: "Caution: Reclaimed Water, Do Not Drink" (preferably in English and Spanish) must be provided anywhere cistern water is piped or outlets.

Many municipalities across California offer rebates to residences for rain barrels (\$75) and cisterns (up to \$350) to incentivize their implementation (MWD).

Indoor and Potable Use

Significant treatment, including filtration and UV treatment, will be necessary for potable use. Local building codes and health standards should be consulted for indoor and potable use.

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting

BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The harvest and use system must be configured to allow trash to enter the system and for trash to remain in the cistern until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system. A screen is not required if the capture system has capacity to treat either of the design flows through media filtration or infiltration into native or amended soils.

Trash Containment

Once trash has been captured in the harvest and use system it must be contained so trash does not escape the bioretention area. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or
- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Maintenance

Relatively frequent inspection and maintenance is necessary to verify proper operation of these facilities. For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Harvest and Use Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. Below-ground cisterns may not provide complete dewatering, which increases the chances of water standing for over 72 hours and becoming a breeding place for vectors. Table 4 provides maintenance activity details, frequency, and costs.

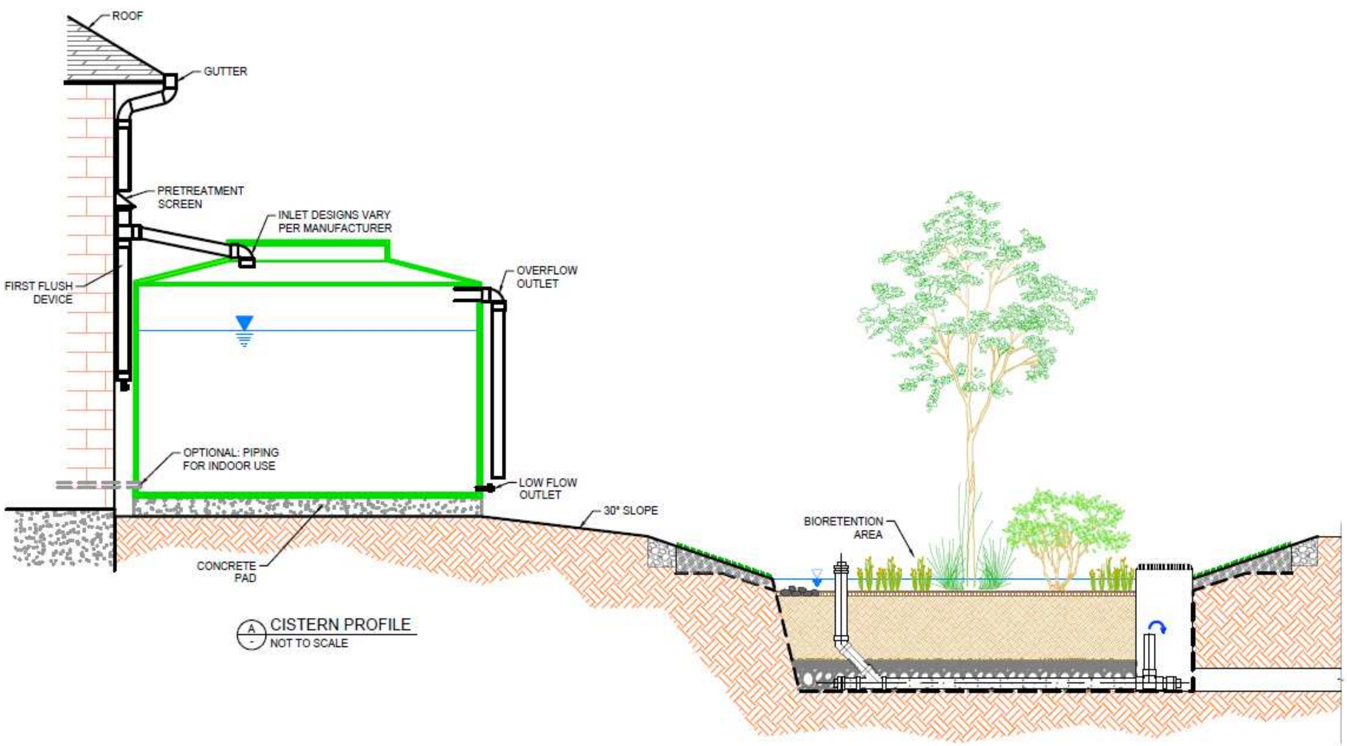
Table 4. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Clean gutters, debris screen, and roof of debris that have accumulated. Check pipe, valve connections, and backflow preventers for leaks.
Routine (small)	$2.85/ft^2	
Routine (medium)	$0.92/ft^2	

Frequency	Cost	Activity
Routine (large)	$0.52/ft^2	Check cistern for stability, anchor system if necessary.
End of Life Replacement (service life of 20 years)		
Replacement (small)	$0.6-2.25/gal	
Replacement (medium)	$0.6-2.25/gal	
Replacement (large)	$0.6-2.25/gal	
Note: Small System = 200 gal; Medium System = 600 gal; Large System = 1000 gal		

O&M costs for harvest and use systems are high because of the need for frequent inspections, and the reliance on mechanical equipment. When RTC is utilized an annual subscription is required that ranges from $1000 for a single residence but could be reduced by greater than 80% if 100,000's of residences subscribe in a regional program.

Schematic



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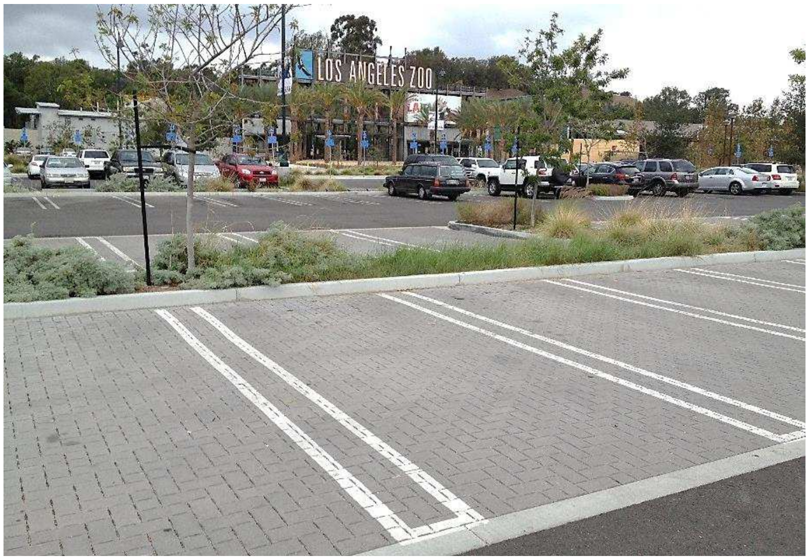


Design Considerations

- Accumulation of Metals
- Clogged Soil Outlet Structures

Targeted Constituent	Removal
Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	Med
Oil and Grease	Med
Organics	Low
Flow Control	Med

Description

Pervious (Permeable) Pavement describes a system which combines a load-bearing, durable surface with an underlying layered storage structure. Stormwater is temporarily stored prior to infiltration or discharge through an underdrain to a controlled outlet. The system can infiltrate water across the entire surface or through the spaces between impermeable blocks. Pervious paving may permit groundwater recharge where appropriate, or if unsuitable may be lined to discharge to an underdrain.

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION®

California Experience

Pervious pavement has been widely implemented across California in a variety of configurations to meet a full suite of regulatory requirements including in the Los Angeles Zoo parking lot (image above), incorporated in a green street in San Diego (Figure 1), and to create permeable plazas in San Francisco (Figure 2).

Figure 1. Pervious concrete parking lane in San Diego

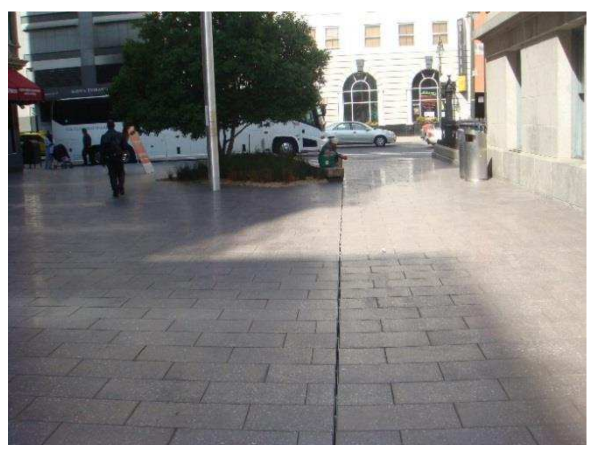


Figure 2. PICP plaza in San Francisco.

Advantages

- Offers a valuable stormwater management solution in spatially constrained urban areas which also serves as transportation infrastructure.

Limitations

- Permeable pavement can become clogged if improperly installed or maintained.
- Limited to paved areas with low traffic volumes, axle loads and speeds.

Performance

Attenuation of flow is provided by the storage within the underlying structure of the pavement. Volume reduction primarily depends on the drainage configuration and subsoil infiltration capacities. Systems installed without underdrains in highly permeable soils can achieve practically 100% volume reduction efficiency (Bean et al. 2007). Systems installed in restrictive clay soils can still give significant volume reduction (Tyner et al. 2009; Fassman and Blackbourn 2010). The volume reduction can be further enhanced by treating the subgrade with scarification, ripping, or trenching (Tyner et al. 2009; Brown and Hunt 2010), by omitting underdrains (where practicable), or by incorporating an internal water storage layer by upturning underdrain inverts to create a sump (Wardynski et al. 2013). Materials should create neutral or slightly alkaline conditions and they should provide favorable sites for colonization by microbial populations.

Peak flow can be also effectively attenuated by permeable pavement systems by reducing overall runoff volumes, promoting infiltration, and increasing the lag time to peak discharge (Collins et al. 2008). Table 1 details expected effluent concentrations and removal processes for each pollutant constituent.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High[2] (32% to 96%)	24.9 mg/L	Settling on surface and in reservoir layer.	Bean et al. 2007; CWP 2007; Fassman and Blackbourn 2011; Gilbert and Clausen 2006; MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Scholes, 2007; Geosyntec Consultants and Wright Water Engineering 2012

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Metals	High (65% to 84%)	TAs: 2.50 µg/L, TCd: 0.25 µg/L, TCr: 3.89 µg/L, TCu: 7.52 µg/L, TPb: 0.40 µg/L, TNi: 1.71 µg/L, TZn: 10.5 µg/L	Removal with sediment and possible sorption to aggregate base course.	Bean et al. 2007; Brattebo and Booth 2003; CWP 2007; Dierkes et al. 2002; Fassman and Blackbourn 2011; Gilbert and Clausen 2006;MWCOG 1983; Pagotto et al. 2000; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Geosyntec Consultants and Wright Water Engineering 2012
Hydro-carbons	High (92% to 99%)	N/A	Removal in surface course and aggregate layer.	Roseen et al. 2009, 2011
Total phosphorus	Low (20% to 78%)	0.100 mg/L	Settling with sediment, possible sorption to aggregate, and sorption to underlying soils.	Bean et al. 2007; CWP 2007; Gilbert and Clausen 2006; MWCOG 1983; Roseen et al. 2009, 2011; Rushton 2001; Schueler 1987; Toronto and Region Conservation Authority 2007; Geosyntec Consultants and Wright Water Engineering 2012; Yong et al. 2011
Total nitrogen	Low (-40% to 88%)	TKN: 1.00 mg/L *$NO_{2,3}$-N: 1.35 mg/L*	Settling, possible denitrification in IWS, sorption in underlying soils (TKN).	Collins et al. 2010; CWP 2007; MWCOG 1983; Schueler 1987; Geosyntec Consultants and Wright Water Engineering 2012
Bacteria	Medium	N/A	Sedimentation, filtration, sorption, desiccation, and predation in surface course and reservoir layer.	Myers et al. 2009; Tota-Maharaj and Scholz 2010;
Thermal load	Medium	58–73 °F	Heat transfer at depth, thermal buffering through profile, and thermal load reduction by volume reduction (infiltration). IWS enhances thermal load reduction.	Wardynski et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

[2] Run-on from adjacent surfaces with high sediment yield can cause premature clogging of the surface course or subsurface interface. Permeable pavement should not be used to treat runoff from pervious surfaces or other areas with high sediment yield

Suitability and Design

If the grades, drainage characteristics, and traffic conditions are suitable, permeable paving may be substituted for conventional pavement on parking lots or other areas with light traffic. Car parking areas along residential streets, parking lots, and other lightly trafficked or non-trafficked areas are appropriate siting locations. The suitability of a pervious system should also consider loading criteria required of the pavement; if the area is to be used by heavy vehicles (e.g. garbage truck on residential street), there is a need to increase structural design. Fundamental design components are as follows:

- Geotechnical investigation required to identify soil infiltration rate and to design the subgrade to support the anticipated traffic load. If known soil contamination is present, infiltration is not allowed.
- When infiltrating, 10 feet of separation between bottom of bed and seasonal high water table.
- Materials should be able to sustain traffic loading without excessive deformation or cracking.
- Contain sufficient void space for storage of sediments to limit the period between maintenance.
- The sub-base and capping will be in contact with water, the strength and durability of the aggregate particles when saturated and subjected to wetting and drying should be assessed.

Pervious pavement design is highly dependent on the constraints of the considered site and local regulations. Permeable pavement is often considered self-treating with no run-on allowed while some municipalities do allow consideration of run-on from surrounding areas for treatment purposes. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation	$1.10–$2.25/ft^2	Underdrain required if subsoil infiltration rate < 0.5 in/hr. Provide orifice at underdrain outlet sized to release water quality volume over 2–5 days. Surface ponding should be provided (by curb and gutter) to capture design storm
Surface Course Pervious asphalt Pervious concrete PICP Plastic grid pavers	 $2.00/ft^2 $6.00/ft^2 $3.00/ft^2 $2.50/ft^2	Pervious concrete, porous asphalt, and permeable interlocking concrete pavers (PICP) are the preferred types of permeable pavement because detailed industry standards and certified installers are available.
Underdrain Pipe Includes drainage stone, assumes 5-foot spacing	$3.60/ft^2	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Bedding/Reservoir Layer No. 8 aggregate (min. 2 in. thick) No. 57 stone (min. 6 in. thick)	 $0.22/ft^2 $0.83–$1.67/ft^2	Use a 2-inch bedding course of ASTM No. 8 stone on top a base layer of washed ASTM No. 57 stone (washed

Component	Cost	Design Consideration
		ASTM No. 2 may be used as a subbase layer for additional storage).
Hydraulic Restriction Layer 30-mil liner Concrete barrier	 $0.35/ft^2 $12.00/ft^2	Subgrade slope should be 0.5% or flatter. Baffles should be used to ensure water quality volume is retained. Use hydraulic restriction layer on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities; also prevents soils from entering aggregate voids.

Surface Course Types

A number of surface course types are available for implementation. Porous asphalt and pervious concrete are similar in that they utilize the same mixing and application equipment as their traditional (i.e. non-pervious) counterparts. Permeable Interlocking Concrete Pavement (PICP) and grid pavers are other options that allow infiltration in void spaces between impervious components.

Figure 3. Example of porous asphalt.

Porous Asphalt

Porous asphalt is a bituminous-bound pavement composed of fine and coarse aggregate. To offer increased void space (typically 15-20% total) and flow-through of stormwater as compared to traditional asphalt, a gap graded aggregate is used. This layer is placed over a bedding/reservoir layer as described in Table 2. Percolating stormwater is held in the reservoir before infiltration, or if non-infiltrating is directed to the underdrain structure. The particular design specifications of porous asphalt hinge on the materials used and the compaction procedures, should adhere to the National Asphalt Pavement Association (NAPA) Porous Asphalt Pavements for Stormwater Management (NAPA 2008).

Figure 4. Example of pervious concrete.

Pervious Concrete

Pervious concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water-to cementitious material ratio is typically 0.35–0.45 to 1 such that the mixture displays a wet metallic sheen without the paste flowing from the aggregate (NRMCA 2004). Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space (GCPA 2006). An admixture improves the bonding and strength of the pavements. The pavements are typically laid with a 4- to 8-inch (10 to 20 cm) thickness over a gravel reservoir (depth varies according to water volume capture requirements), typically a washed No. 57 stone. Pervious concrete is a rigid pavement and therefore does not require an aggregate base course for structural support. Pervious concrete will typically exhibit a coarser surface texture than impervious concrete but is ADA compliant.

Permeable Interlocking Concrete Pavement (PICP)

PICP is available in many different shapes and sizes. When lain, the blocks form patterns that create openings through which rainfall can infiltrate. Orientation of rectangular pavers is important for structural purposes—herringbone patterns tend to provide the most efficient structural design, especially where vehicle stopping and turning are expected. ASTM C936-13 specifications state that the pavers be at least 2.36 inches (60 mm) thick with a compressive strength of 55 MPa (8,000 psi) or greater. Typical installations consist of the pavers and crushed aggregate fill, a 1.5- to 3.0-inch (38 to 76 mm No. 8) fine aggregate bedding layer, and an aggregate base-course, typically a washed No. 57 stone, storage layer (Smith 2011). If greater storage is required, a reservoir subbase layer of No. 2 stone can be included.

Figure 5. Example of PICP.

Grid Pavers

Grid systems, also called geocells, turf pavers, or turf reinforcing grids, consist of flexible-plastic, interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turf grass. Similar to PICP, a 1–2 inch sand bedding layer and gravel base course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space depends on the fill media (Ferguson 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa (2,000 psi)

Figure 6. Example of a grid paver.

(Invisible Structures 2001). That value increases up to 38 MPa (5,500 psi) when filled with various materials (Invisible Structures 2001). If sand is used, a geotextile should be used between the sand course and the reservoir media to prevent the sand from migrating into the stone media.

Maintenance

The maintenance requirements of a pervious surface is determined by its design (i.e., when an underdrain is incorporated, it must be inspected). The chief maintenance concern is prevention of clogging of the pervious surface. The factors to be considered when defining maintenance requirements must include: type of use, ownership, level of traffic, the local environment and any contributing catchments.

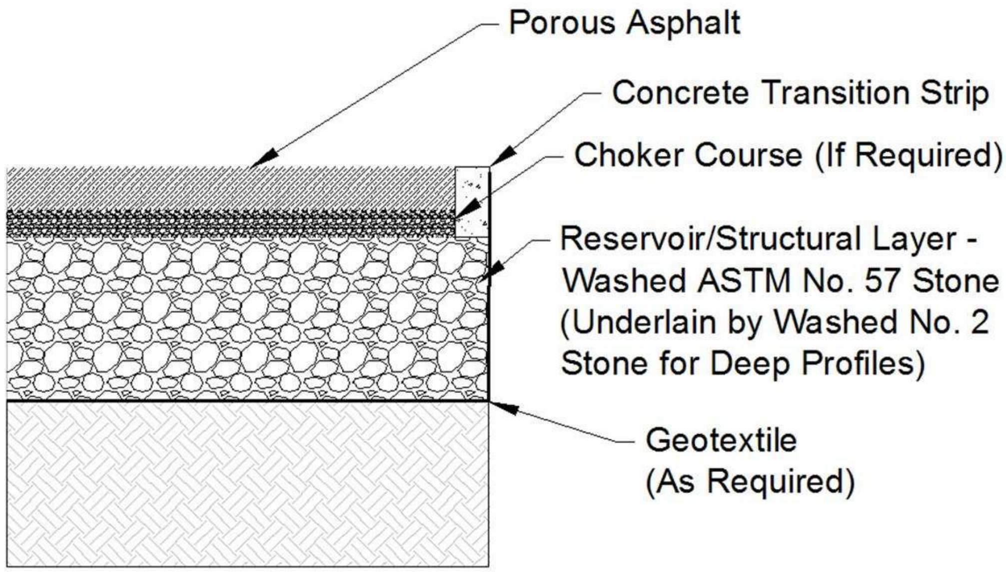
Table 3. Typical maintenance activities and associated costs and frequency

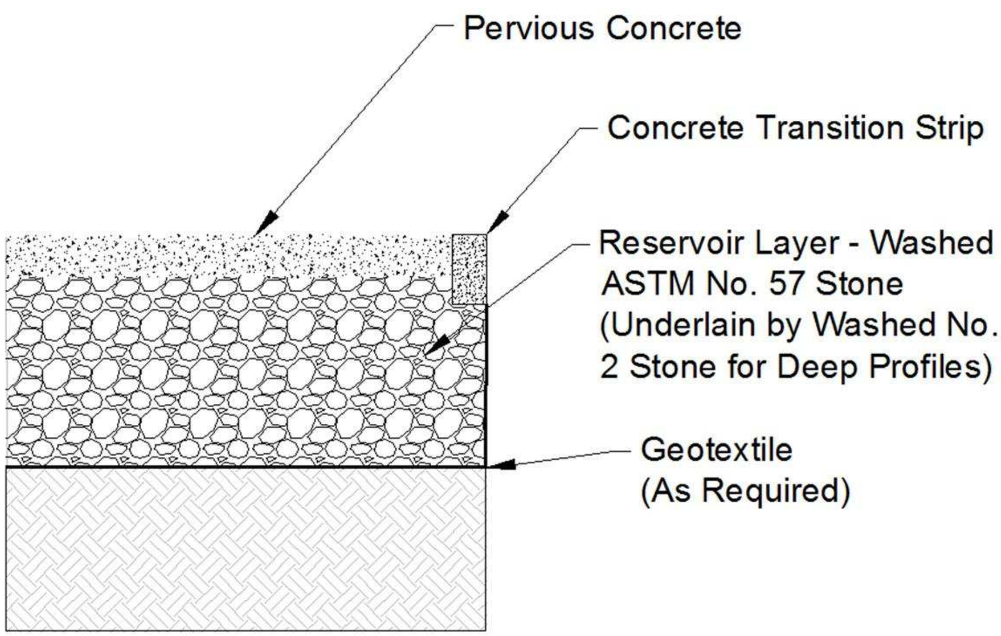
Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment and debris adjacent impervious surfaces and in voids/joints of permeable pavement. Check for and stabilize erosion. Pavement should be swept with a vacuum power or regenerative air
Routine (small)	$5.32/ft^2	
Routine (medium)	$1.33/ft^2	
Routine (large)	$0.67/ft^2	
Intermediate Maintenance (required every 6 to 10 years)		For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping replace bedding fill material to keep fill level with the paver surface.
Intermediate (small)	$3.71/ft^2	
Intermediate (medium)	$1.85ft^2	
Intermediate (large)	$1.85/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$6.50–$9.50/ft^2	
Replacement (medium)	$6.50–$9.50/ft^2	
Replacement (large)	$6.50–$9.50/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

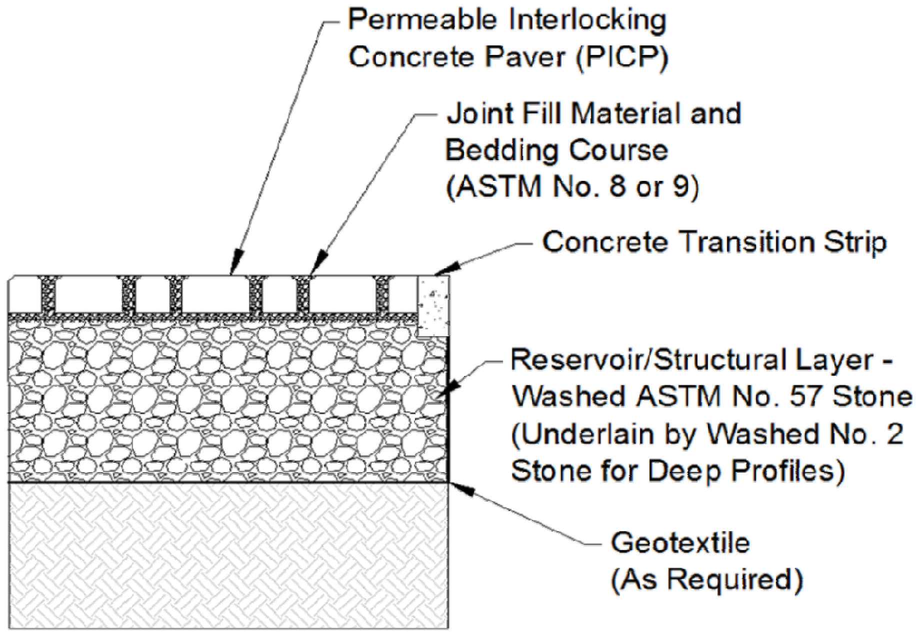
Redeveloping Existing Installations

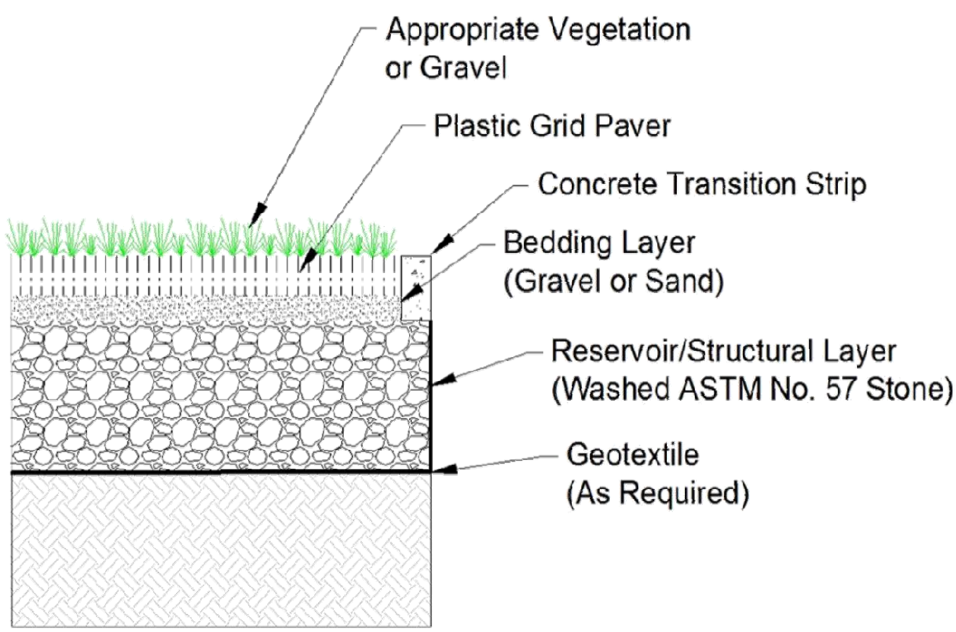
Various jurisdictional stormwater management and mitigation plans (SUSMP, WQMP, etc.) define “redevelopment” in terms of amounts of additional impervious area, increases in gross floor area and/or exterior construction, and land disturbing activities with structural or impervious surfaces. The definition of “redevelopment” must be consulted to determine whether or not the requirements for new development apply to areas intended for redevelopment. If the definition applies, the steps outlined under “designing new installations” above should be followed. Permeable pavement can be implemented to reduce the overall imperious area of a newly developed or redevelopment site. Many jurisdictions consider permeable pavement areas to be self-treating areas with some allowing some amount of run-on for treatment.

Schematic


Porous Asphalt
Concrete Transition Strip
Choker Course (If Required)
Reservoir/Structural Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)


Pervious Concrete
Concrete Transition Strip
Reservoir Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)


Permeable Interlocking Concrete Paver (PICP)
Joint Fill Material and Bedding Course (ASTM No. 8 or 9)
Concrete Transition Strip
Reservoir/Structural Layer - Washed ASTM No. 57 Stone (Underlain by Washed No. 2 Stone for Deep Profiles)
Geotextile (As Required)


Appropriate Vegetation or Gravel
Plastic Grid Paver
Concrete Transition Strip
Bedding Layer (Gravel or Sand)
Reservoir/Structural Layer (Washed ASTM No. 57 Stone)
Geotextile (As Required)

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Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Targeted Constituents	Removal
Sediment	High
Nutrients	Med
Trash	High
Metals	Med
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

Description

Wet ponds (stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from constructed wetlands primarily in having a greater average depth. The primary removal mechanism is settling as stormwater runoff resides in this pool, but limited pollutant uptake, particularly of nutrients, also occurs to some degree through biological activity in the pond.

California Experience

Caltrans constructed a wet pond in northern San Diego County (I-5 and La Costa Blvd.). The most significant issues at this site were related to vector control, vegetation management, and concern that endangered species would become resident and hinder maintenance activities.

Some reduction of many of the pollutants regulated by the State and Regional Water Boards is possible in wet ponds.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements.
- Can provide substantial aesthetic, recreational value and wildlife habitat.
- When incorporated, a permanent wet pool can provide water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients.
- Offers significant channel protection by preventing the discharge of damaging peaks and volume from impervious area.

Limitations

- Mosquito and midge breeding is likely to occur in ponds.
- A large footprint is often required; depending on volume and depth, pond designs may require approval from the State Division of Safety of Dams.
- Pose a risk to cold water systems because of their potential for stream warming.

Performance

The observed pollutant removal of a wet pond is highly dependent on two factors: the volume of the permanent pool relative to the amount of runoff from the typical event in the area and the quality of the base flow that sustains the permanent pool. A Caltrans study indicated that when the permanent pool is much larger than the volume of runoff from an average event, then displacement of the permanent pool by the wet weather flow is the primary process. A statistical comparison of the wet pond discharge quality during dry and wet weather shows that they are not significantly different. Consequently, there is a relatively constant discharge quality during storms that is the same as the concentrations observed in the pond during dry weather conditions. Table 1 below details expected effluent concentrations and removal processes for each pollutant.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median effluent concentration[1]	Removal processes	References
Sediment	High (75-95%)	11.5 mg/L	Settling, and sorption	Geosyntec Consultants and Wright Water Engineering 2012; Barrett 2008; Scholes 2007; Pettersson et al. 1999
Metals	Medium	TAs: 0.89 µg/L, TCd: 0.20 µg/L, TCr: 1.37 µg/L, TCu: 4.39 µg/L, TFe: 265 µg/L, TPb: 2.87 µg/L, TNi: 2.23 µg/L, TZn: 21.67 µg/L	Removal with sediment, sorption	Geosyntec Consultants and Wright Water Engineering 2012; Fassman 2012; Scholes 2007
Total phosphorus	Medium (-55-100%)	0.091 mg/L	Sorption, and settling. Can be a net source or sink via breakdown or uptake of plant material	Geosyntec Consultants and Wright Water Engineering 2012; Dietz and Claussen 2005, 2006; Wu et al. 1996; Barrett 2008; Burton 2002
Total nitrogen	Medium (50-75%)	TN: 1.20 mg/L, TKN: 1.01 mg/L, $NO_{2,3}$-N: 0.13 mg/L	Plant uptake if sufficient vegetation, denitrification	Geosyntec Consultants and Wright Water Engineering 2012; Barrett 2008; Collins 2010

Pollutant	Typical Removal	Median effluent concentration[1]	Removal processes	References
Bacteria	High	E. coli - 100 (MPN/100 mL) Fecal Coliform - 581 (MPN/100 mL)	Microbial degradation, photolysis, sorption, settling	Geosyntec Consultants and Wright Water Engineering 2012; Scholes 2007; Struck 2006
Trash	High	*N/A*	Filtration (Media treatment depth of 1.5 feet) and/or screened outlet	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Suitability and Design

Wet ponds are best suited to drainage areas greater than approximately 10 acres and where base flow rates or other channel flow sources are relatively consistent year-round. Several different versions of the wet pond design exist, the most common (and recommended) variant is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff and promote settling. The constraints of each site dictate the appropriate siting and footprint. Fundamental wet pond design components are as follows:

- Capture volume determined by local requirements or 85 percent of the annual runoff volume.
- Include energy dissipation in inlet design and a sediment forebay to reduce resuspension of accumulated sediment and facilitate maintenance (typically 10 percent of the permanent pool).
- If applicable, permanent pool volume equal to twice the water quality volume.
- The outlet structure should be designed to drain the water quality volume over 72 hours.

In addition, Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component/Activity	Cost	Design Consideration
Excavation	\$5.00–\$15.00/ft^2	Water depth not to exceed 8 ft. Side slopes of the basin should be 3:1 or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice
Soil Media Topsoil	 \$1.35/ft^2	Apply 1 to 4 inches to support plant growth. Depth depends on specified plantings and underlying soil characteristics. Natural, friable soil representative of productive, well-drained soils in the area. Low phosphorus (TP < 15 ppm) with pH 5.5–7.
Hydraulic Restriction Layer Filter fabric Clay 30-mil liner Concrete barrier	 \$0.45/ft^2 \$0.65/ft^2 \$0.35/ft^2 \$12.00/ft^2	If inter-storm rate of water loss exceeds supply from groundwater, baseflow, or runoff ensure water is maintained in permanent pool by use of hydraulic restriction layer
Vegetation	\$1.25–\$3.50/ft^2	Primarily annual and perennial wetland plants specific to the water depth they would experience. Vegetation occupying no more than 25% of surface area

Wet ponds can be designed as either on- or off-line facilities. For on-line facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant specifications for small dams. When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1 foot of freeboard along pond side slope.

A non-clogging outlet (e.g., reverse-slope pipe) or weir outlet with a trash rack is recommended to minimize the occurrence of clogging. Outlet structures and piping should also be installed with collars to prevent water from seeping through the fill and causing structural failure. Additionally, a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes.

Road access should be provided along at least one side of BMPs that are seven meters or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of seven meters should have perimeter road access on both sides or be designed such that no parcel of water is greater than seven meters from the road.

Pond Configuration

Some design features do not increase the volume of a pond, but can increase the amount of time stormwater remains in the device and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1, where feasible. The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. After the first large storm verify desired residence time has been met.

Wet ponds with greater amounts of vegetation often have channels through the vegetated areas and contain dead areas where stormwater is restricted from mixing with the entire permanent pool, which can lead to less pollutant removal. Consequently, a pond with open water comprising about 75 percent of the surface area is preferred. The perimeter of all permanent pool areas with depths of 4.0 feet or greater should be surrounded by an aquatic bench. This bench should extend inward 5-10 feet from the perimeter of the permanent pool and should be no more than 18 inches below normal depth. The area of the bench should not exceed about 25% of pond surface. The depth in the center of the basin should be 4–8 feet deep to prevent vegetation from encroaching on the pond open water surface.

A sediment forebay should be used to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation. An emergency spillway should be provided to safely bypass extreme flood flows.

Construction costs associated with wet ponds vary considerably. Much of this variability can be attributed to the degree to which the existing topography will support a wet pond, the complexity and amount of concrete required for the outlet structure, and whether it is installed as part of new construction or implemented as a retrofit of existing storm drain system.

Vegetation

A plan should be prepared that indicates how aquatic and terrestrial areas will be stabilized with vegetation. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. A list of some wetland vegetation native to California is presented in Table 3. Climatic considerations local to the wet pond should indicate which native vegetation is most appropriate.

Table 3. List of wet pond vegetation native to California

Botanical Name	Common Name
Baccharis Salicifolia	Mule Fat
Frankenia Grandifolia	Heath
Salix GoodingII	Black Willow
Salix Lasiolepis	Arroyo Willow
Samucus Mexicanus	Mexican Elderberry
Haplopappus Venetus	Coast Goldenbrush
Distichis Spicata	Salt Grass
Limonium Californicum	Coastal Statice
Atriplex Lentiformis	Coastal Quail Bush
Baccharis Pilularis	Chaparral Broom
Mimulus Longiflorus	Monkey Flower
Scirpus Californicus	Bulrush
Scirpus Robustus	Bulrush
Typha Latifolia	Broadleaf Cattail

Figure 1. Example forebay. Also note other components of the pond: earthen berm and native vegetation

Maintenance

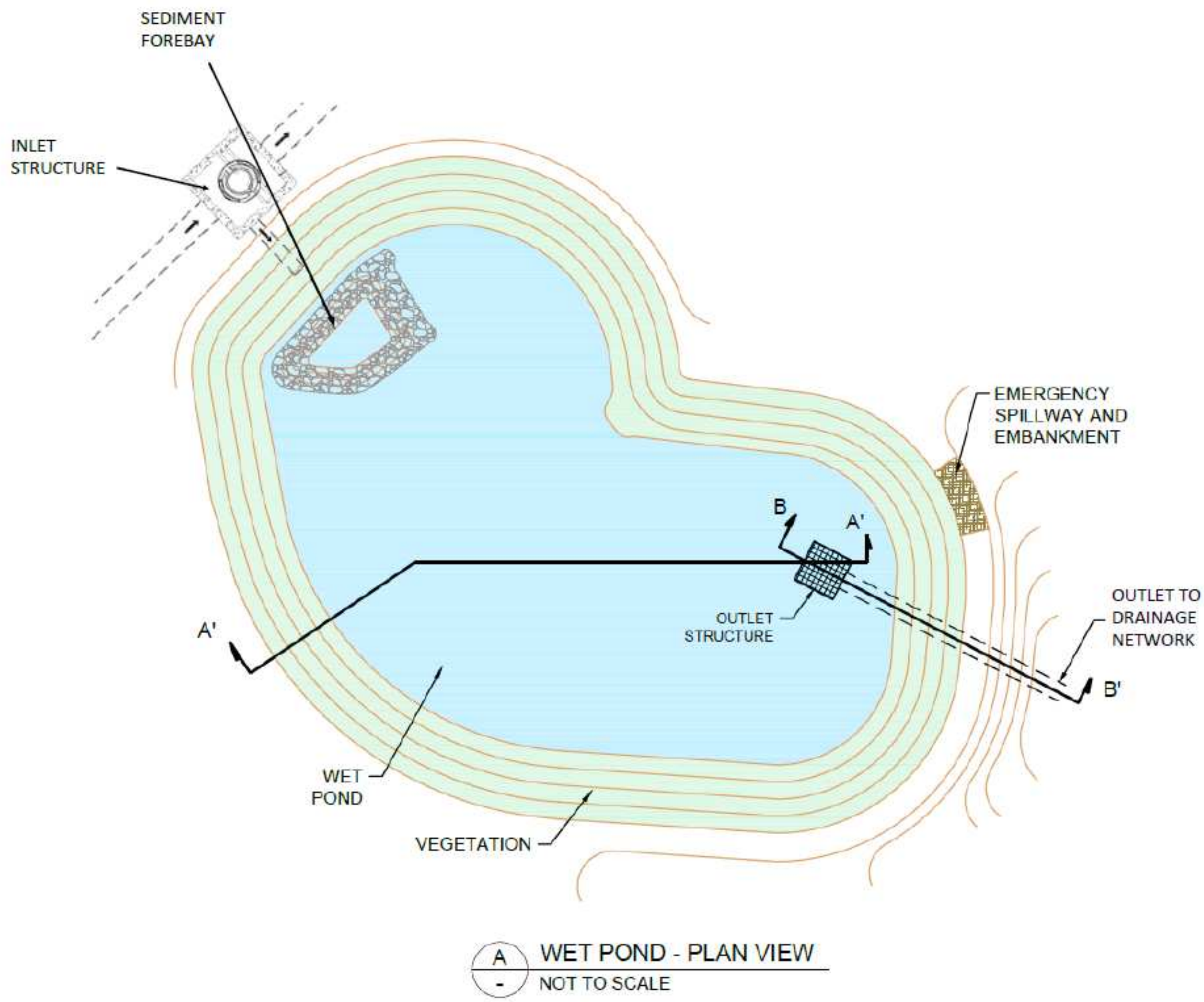
Regular maintenance activity ensures the wet pond functions capacity to remove pollutant load and provides hydrologic benefits is maximized. Typical maintenance involves caring for the pond's vegetation and removing debris. Table 4 provides recommended frequencies and associated costs.

- Where permitted by the Department of Fish and Game or other agency regulations, stock wet ponds/constructed wetlands regularly with mosquito fish (*Gambusia spp.*) to enhance natural mosquito and midge control.

Table 4. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Pruning and mowing overgrown vegetation that interferes with access, or safety. Removing and replanting dead vegetation
Routine (small)	$0.44/ft^2	
Routine (medium)	$0.34/ft^2	
Routine (large)	$0.24/ft^2	
Intermediate Maintenance (required every 6 to 10 years)		Remove accumulated sediment in the forebay and regrade (when the accumulated sediment volume exceeds 10 percent of the basin volume)
Intermediate (small)	$1.47/ft^2	
Intermediate (medium)	$1.41/ft^2	
Intermediate (large)	$1.40/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$8.19/ft^2	
Replacement (medium)	$6.43/ft^2	
Replacement (large)	$5.99/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

Schematic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WET POND - PLAN VIEW
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Constructed Wetlands

Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Targeted Constituents	Removal
Sediment	High
Nutrients	Med
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

Description

Constructed wetlands are engineered, shallow-water ecosystems designed to treat stormwater runoff. Stormwater should never be diverted into a natural wetland. Natural wetlands should be protected from the adverse effects of development, including impacts from increased stormwater runoff. Natural wetlands provide stormwater and flood control benefits on a regional scale. Constructed wetlands are effective in terms of pollutant removal and they also offer aesthetic and habitat value.

California Experience

The City of Laguna Niguel in Orange County has constructed several wetlands, primarily to reduce bacteria concentrations in dry weather flows. The wetlands have been very successful in this regard. Even though there is not enough perennial flow to maintain the permanent pool at a constant elevation, the wetland vegetation has thrived. The Los Angeles County Department of Public Works successfully implemented a constructed wetland on the banks of the Los Angeles River that restores wildlife habitat and improves water quality. The Dominguez Gap Wetland is able to maintain a permanent pool by diverting low flows from the Los Angeles River.

Constructed wetlands provide some reduction for many of the pollutants regulated by the State and Regional Water Boards.

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Figure 1. Dominguez Gap Constructed Wetland in Los Angeles, CA.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements.
- Can provide substantial wildlife habitat and recreational/educational opportunities.
- Offers significant water quality improvement across a broad spectrum of constituents including dissolved nutrients.
- Typically support mosquito predation, therefore require fewer vector control efforts.

Limitations

- Limited use in semi-arid climates where supplemental water would be required to maintain water levels.
- Can occupy large footprint; depending on volume and depth, pond designs may require approval from the State Division of Safety of Dams.

Performance

The processes that impact the performance of constructed wetlands are essentially the same as those operating in wet ponds and similar pollutant reduction would be expected. One concern about the long-term performance of wetlands is associated with the vegetation density. If vegetation covers the majority of the facility, open water is confined to a few well defined channels. This can limit mixing of the stormwater runoff with the permanent pool and reduce the effectiveness as compared to a wet pond where a majority of the area is open water. Dense vegetation can reduce nutrient reductions after the first several years of operation (Faulkner and Richardson, 1991). Table 1 below details expected effluent concentrations and removal processes for each pollutant constituent.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High (70-90%)	9.4 mg/L	Settling, sorption, filtration	Geosyntec Consultants and Wright Water Engineering 2012; Scholes 2007; Backstrom, 2003
Metals	Medium	TCd: 0.17 µg/L, TCu: 3.38 µg/L, TPb: 1.32 µg/L, TZn: 20.0 µg/L	Removal with sediment, sorption	Geosyntec Consultants and Wright Water Engineering 2012; Struck 2006; Hafeznezami 2012
Total phosphorus	Medium	0.093 mg/L	Settling, sorption, plant uptake if sufficient vegetation	Geosyntec Consultants and Wright Water Engineering 2012; Scholes 2007; Burton 2002
Total nitrogen	Medium (44-77%)	TN: 1.19 mg/L, TKN: 0.82 mg/L, $NO_{2,3}$-N: 0.09 mg/L	Plant uptake if sufficient vegetation, denitrification	Geosyntec Consultants and Wright Water Engineering 2012; Hammer and Knight 1994; Scholes 2007
Bacteria	High	Enterococcus - 390 (MPN/100 mL) E. coli - 637 (MPN/100 mL) Fecal Coliform - 1031 (MPN/100 mL)	Microbial degradation, sorption, filtration, predation	Geosyntec Consultants and Wright Water Engineering 2012; Scholes 2007; Ellis et al. 2003; Davies 2000; Arias 2001
Trash	High	*N/A*	Filtration (media treatment depth of 1.5 feet) and/or outlet screen	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Suitability and Design

Constructed wetlands are best suited to drainage areas greater than approximately 5 acres and where base flow rates or other channel flow sources are relatively consistent year-round. Wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared with other stormwater management practices. In areas where land value is high, this may make wetlands an infeasible option. The constraints of each site dictate the appropriate sizing and footprint. Fundamental constructed wetland design components are as follows:

- Capture volume determined by local requirements or 85 percent of the annual runoff volume.
- Incorporate a multi-pool design, including energy dissipation in inlet design and a sediment forebay to reduce volume over 24 to 72 hours.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation	$5.00–$15.00/ft^2	Multi-zone design to incorporate: deep pool (15–20% of area), transition area (10-15%), shallow pool (40%), temporary ponding (30-40%), and optional upland storage area. Water depth not to exceed 4 feet.
Fine Grading	$0.25/ft^2	The minimum length-to-width (L:W) ratio should be 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible.
Soil Media		Apply 1 to 4 inches to support plant growth. Depth depends on specified plantings and underlying soil characteristics. Soil representative of productive, well-drained soils in the area. It shall be free of material detrimental to plant growth (e.g. stones > 1 inch diameter). Low phosphorus (TP < 15 ppm) with pH 5.5–7.
Topsoil	$1.35/ft^2	
Hydraulic Restriction Layer		If inter-storm rate of water loss exceeds supply from groundwater, baseflow, or runoff ensure water is maintained in permanent poolsby use of hydraulic restriction layer
Filter fabric	$0.45/ft^2	
Clay	$0.65/ft^2	
30-mil liner	$0.35/ft^2	
Concrete barrier	$12.00/ft^2	
Vegetation	$1.25–$3.50/ft^2	Rich with vegetation (no more than 50% of surface area). Primarily annual and perennial

Component	Cost	Design Consideration
		wetland plants specific to the water depth they would experience.

Constructed wetlands can be designed as either on-line or off-line facilities. For on-line facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant specifications for small dams. When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond side slope.

Pond Configuration

Effective wetland design displays complex micro-topography (i.e., multi-zone design, Figure 4). Multi-zone design can be broken down according to depth:

A. Deep Pools: 15–20% of wetland surface area (including forebay), 18 to 36-inches deep.

B. Transition: 10–15% of wetland surface area, transition between deep pool and shallow water, 12–18 inches deep, maximum slopes of 1.5:1.

C. Shallow Water: 40% of wetland surface area, 3- to 6-inches-deep, flat or 6:1 slope (at least 6-foot radius around all deep pools to provide safety shelf).

D. Temporary Ponding: 30–40% of wetland surface area, up to 12-inches-deep, 3:1 slopes.

E. Detention Storage/Upland: Additional ponding depth can be provided for peak flow mitigation, as needed. Depth should generally not exceed 4 feet above the permanent pool elevation. The minimum length-to-width (L:W) ratio should be 2:1, but L:W should be maximized by creating a sinuous flow path and placing the outlet as far from the inlet as possible.

If the entire design volume cannot be stored in a single location or if utility conflicts are apparent, wetland pockets can be distributed between several locations and connected with vegetated channels and/or buried conduit. An emergency spillway should be provided to safely bypass extreme flood flows.

A sediment forebay (i.e., pretreatment) should be used to isolate gross sediments before they reach the large permanent pool to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 10% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation. Ponds should be designed with a maintenance access to the forebay. In addition, ponds should generally have a drain to draw down the pond for vegetation harvesting or the more infrequent dredging of the main cell of the pond.

Construction costs associated with constructed wetlands vary considerably. Much of this variability can be attributed to the degree to which the existing topography will support a constructed wetland, the complexity and amount of concrete required for the outlet structure, and whether it is installed as part of new construction or implemented as a retrofit of existing storm drain system.

Vegetation

Constructed wetlands generally feature relatively uniformly vegetated areas with depths of one foot or less and open water areas (25-50 percent of the total area) no more than about 1.2 m (4 feet) deep, although design configuration options are flexible. Wetland vegetation is comprised generally of a diverse, local aquatic plant species. A list of some wetland vegetation native to California is presented in Table 3. Climatic considerations local to the wet pond should indicate which native vegetation is most appropriate.

Table 3. List of Wetland Vegetation native to California

Botanical Name	Common Name
Baccharis Salicifolia	Mule Fat
Frankenia Grandifolia	Heath
Salix GoodingII	Black Willow
Salix Lasiolepis	Arroyo Willow
Samucus Mexicanus	Mexican Elderberry
Haplopappus Venetus	Coast Goldenbrush
Distichis Spicata	Salt Grass
Limonium Californicum	Coastal Statice
Atriplex Lentiformis	Coastal Quail Bush
Baccharis Pilularis	Chaparral Broom
Mimulus Longiflorus	Monkey Flower
Scirpus Californicus	Bulrush
Scirpus Robustus	Bulrush
Typha Latifolia	Broadleaf Cattail

Maintenance

Inspect facility after first large storm to determine whether the desired residence time has been achieved. Vegetation harvesting in the summer is recommended. In certain cases, more frequent plant harvesting may be required by local vector control agencies. Where permitted by the Department of Fish and Game or other agency regulations constructed wetlands may be stocked with mosquito fish (Gambusia spp.) to enhance natural mosquito and midge control.

Figure 2. Constructed wetland inlet.

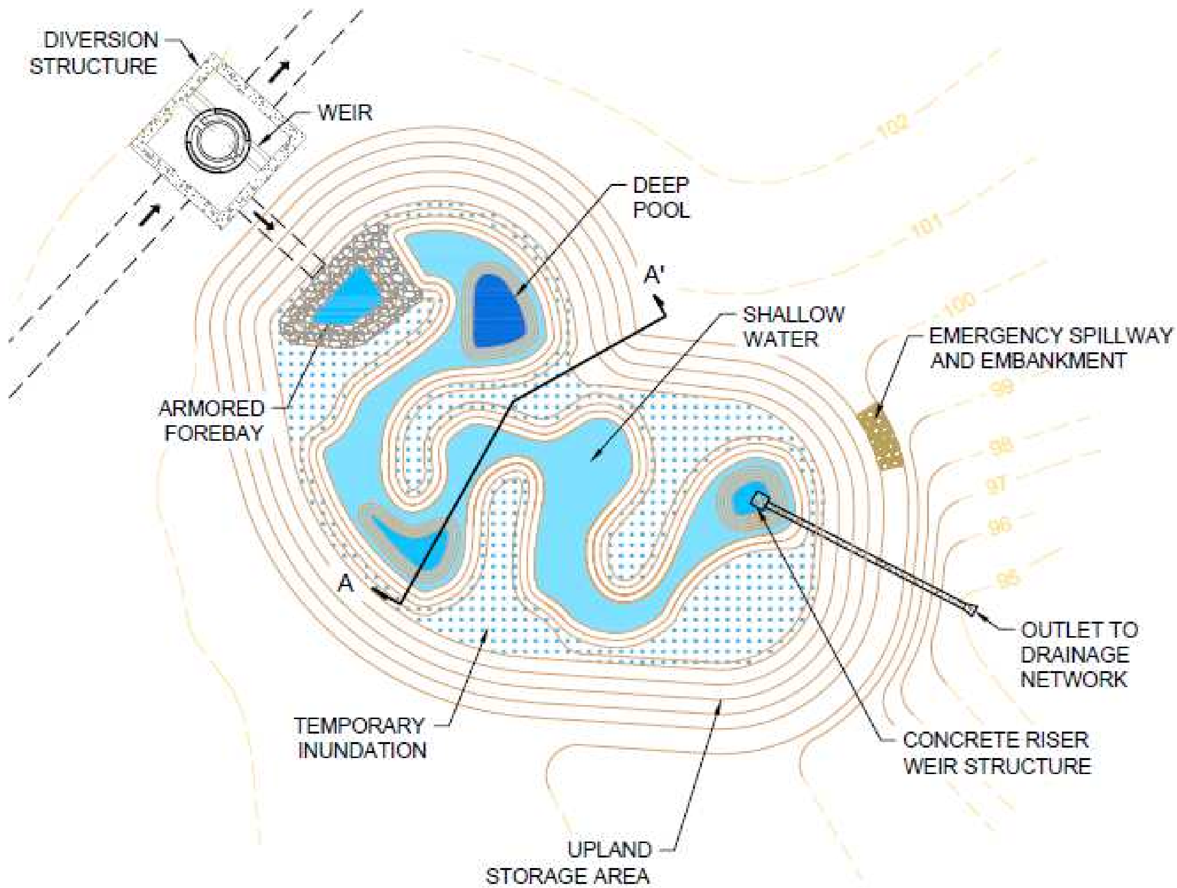
Figure 3. Example of a forebay as pretreatment for a constructed wetland.

Table 4. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Pruning and mowing overgrown vegetation that interferes with access, or safety. Inspect structural integrity of the outlet
Routine (small)	$0.44/ft^2$	
Routine (medium)	$0.34/ft^2$	
Routine (large)	$0.24/ft^2$	
Intermediate Maintenance (maintenance required every 6 to 10 years)		Remove accumulated sediment in the forebay and regrade when accumulated sediment exceeds 10 percent of the basin volume.
Intermediate (small)	$1.47/ft^2$	
Intermediate (medium)	$1.41/ft^2$	
Intermediate (large)	$1.40/ft^2$	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$8.19/ft^2$	
Replacement (medium)	$6.43/ft^2$	
Replacement (large)	$5.99/ft^2$	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

Trash maintenance not only plays a role in the functionality of the constructed wetland but also in the aesthetics and public perception of the constructed wetland (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic



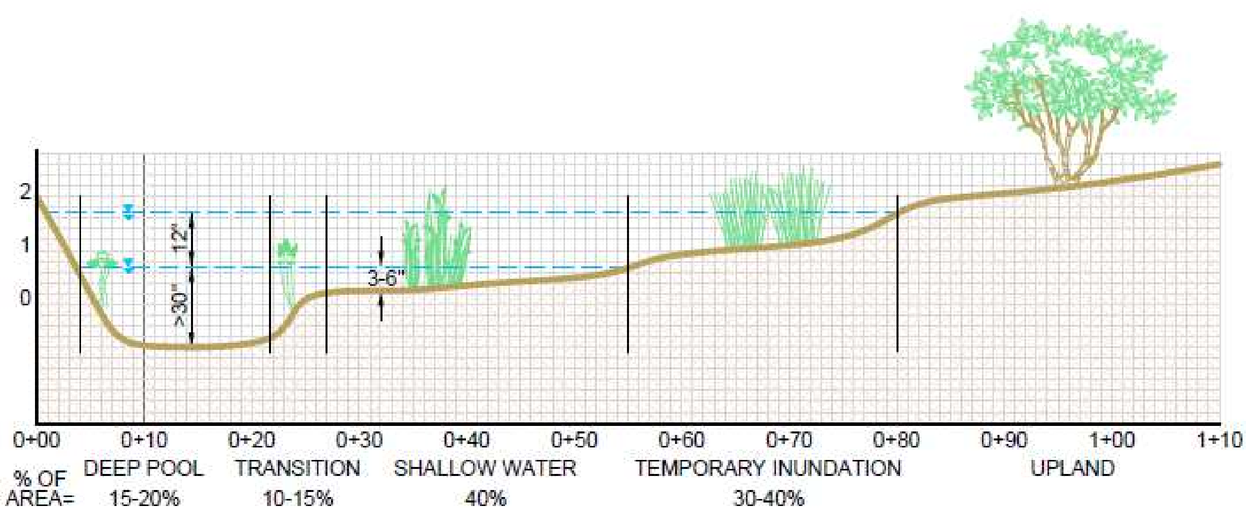


Figure 4. Constructed Wetland Schematic.

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Extended Detention Basin TC-22

Design Considerations
■ Tributary Area
■ Area Required
■ Hydraulic Head

Targeted Constituent	Removal
Sediment	Med
Nutrients	Low
Trash	High
Metals	Med
Bacteria	Med
Oil and Grease	Med
Organics	Med
Flow Control	High

Description

Extended detention basins (dry ponds, dry extended detention ponds, detention ponds, extended detention ponds) are basins whose outlets have been designed to detain the stormwater runoff from a water quality design storm for some minimum time (typically 48 hours) to allow particles, trash and associated pollutants to settle. Unlike wet ponds, these facilities do not have a large permanent pool. They can also be used to provide flood control by including additional flood detention storage.

California Experience

Caltrans constructed and monitored five extended detention basins in southern California with design drain times of 72 hours. Four of the basins were earthen, less costly and had substantially better load reduction because of infiltration than the concrete basin. The Caltrans study reaffirmed the flexibility and performance of this conventional technology. Extended detention basins, while not as effective as systems that provide filtration such as bioretention areas or sand filters, have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water Boards. Additionally, the Water Boards have determined that extended detention basins can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Advantages

- Extended detention basins can have a simple, low-cost design, and meet hydromodification management requirements and the full capture system definition for trash control.
- Widespread application can provide significant control of channel erosion and flood management.

Limitations

- The recommended minimum orifice diameter of 0.5" may be too large in drainages less than 5 acres.
- Dry extended detention basins are relatively ineffective at removing soluble pollutants.
- Can detract from property value due to the aesthetics of dry and bare areas.

Performance

The primary purpose of most detention basins is flood control, but they can also garner pollutant removal performance (Table 1). Variations in design can vary this performance, for example vegetated detention basins provide improved pollutant removal when compared to concrete basins. An optional micropool at the basin's outlet can be incorporated to increase performance of soluble pollutants.

Table 1. Typical pollutant removal and removal processes for constituents

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	Med/High 50-99%	23.3 mg/L	Settling in pretreatment, filtration	Geosyntec Consultants and Wright Water Engineering 2012; Barrett 2008; Harper 1999; Revitt 2004; Scholes 2007
Metals	Medium TCd: 88% TCu: 46-96% TCr: 95% TPb: 92% TZn: 35-95%	TAs: 1.71 µg/L TCd: 0.24 µg/L TCr: 2.55 µg/L TCu: 4.99 µg/L TPb: 3.86 µg/L TNi: 2.73 µg/L TZn: 21.3 µg/L	Removal with sediment, sorption	Geosyntec Consultants and Wright Water Engineering 2012; Barrett 2008; Scholes 2007
Total phosphorus	Low	0.197 mg/L	Settling with sediment, sorption, biological uptake	Barrett 2008; Harper 1999; Geosyntec Consultants and Wright Water Engineering 2012; Walker 1987
Total nitrogen	Low	TN: 1.60 mg/L, TKN: 1.49 mg/L, $NO_{2,3}$-N: 0.27 mg/L	Settling with sediment, sorption, filtration, biological uptake	Barrett 2008; Harper 1999; Geosyntec Consultants and Wright Water Engineering 2012

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Bacteria	Medium	E. coli – 429 (MPN/100 mL) Fecal Coliform - 727 (MPN/100 mL)	Sorption, microbial degradation, settling, photolysis	Geosyntec Consultants and Wright Water Engineering 2012; Barrett 2008, Harper 1999; Scholes 2007
Trash	High	N/A	Filtration (Media treatment depth of 1.5 feet) and/or outlet screen	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data.

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which extended detention basins meet (see Section 5.6.1. for FCS details).

Suitability and Design

Dry extended detention basins are among the most widely applicable BMPs and are especially useful in retrofit situations where their low hydraulic head requirements allow them to be sited within the constraints of the existing storm drain system. Fundamental extended detention basin design components and suitability are as follows:

- Drawdown time of 48 hours is required for vector control, but design should also incorporate long flow paths, promote the establishment of low velocities, for improved water quality.
- A facility's drawdown time is regulated by an orifice or weir; with minor design adjustments in outlet design, extended detention basins are applicable in all soils and geology.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.

Extended detention basin design is highly dependent on the constraints of the considered site and costs vary accordingly with design. An optional micropool at the basin's outlet can be incorporated to increase performance of soluble pollutants. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation	$5.00–$15.00/ft^2	Capture volume determined by local requirements or sized to treat runoff produced by the 85th percentile storm. Length to width ratio of 1.5:1 if feasible. Basin depth of 2 to 5 feet is optimal. Include energy dissipation

Component	Cost	Design Consideration
		in the inlet design to reduce resuspension of sediment. Incorporate maintenance access to the basin design
Vegetation Sod (buffalo) Seeding	 $0.67/ft² $0.15–$0.22/ft²	Turf grasses (not bunch grasses) should be maintained on the surface to prevent erosion and improve treatment. Water and spot fertilize during first year.
Subsurface Option (Figure 3**)** Excavation, Installation, and Backfill Concrete Unit	 $9.20/ft² $59.93/ft²	Constructing a subsurface facility includes excavating to depth, installing concrete unit, overdig, and backfill. Concrete unit assumed here: 11' 4". Requires pretreatment BMP to capture trash and debris.
Outlet Structure		No more than 50% of the water quality volume drains within the first 24 hours.

Outlet Design

Design of the outflow structure is crucial in successful operation of the basin. Outlet design can include an outlet riser with orifices sized to discharge the water quality volume, and riser overflow height set to the design storm elevation. A trash rack (i.e. stainless steel screen) should be implemented to prevent clogging at the entrance to the outflow pipes. Screens should have a mesh smaller than 5 mm to meet the full capture requirement for trash. An image with these design components is presented in Figure 1. Alternative outlet design includes a separate riser or broad crested weir for overflow of runoff for the 25 and greater year storms. Figure 2 shows an example of an outlet that provides a variable flow as outlet flow increase with depth.

Figure 1. Example of outlet structure.

Figure 2. Variable flow outlet structure.

Outlet design should also ensure that no more than 50% of the water quality volume drains within the first 24 hours. Discharge through a control orifice is calculated from:

$$Q = CA(2gH\text{-}H_o)^{0.5}$$

Where:

Q = discharge (ft³/s)

C = orifice coefficient

A = area of the orifice (ft^2)

g = gravitational constant (32.2)

H = water surface elevation (ft)

H_0= orifice elevation (ft)

Recommended values for C are 0.66 for thin materials and 0.80 when the material is thicker than the orifice diameter. This equation can be implemented in spreadsheet form with the basin stage/volume relationship to calculate drain time. To do this, use the initial height of the water above the orifice for the water quality volume. Calculate the discharge and assume that it remains constant for approximately 10 minutes. Based on that discharge, estimate the total discharge during that interval and the new elevation based on the stage volume relationship. Continue to iterate until H is approximately equal to H_0. When using multiple orifices the discharge from each is summed.

Subsurface Option

Subsurface extended detention basin are ideal when a surface detention basin is infeasible because of land constraints (Figure 3). Open space parks (e.g., baseball fields, etc.) are an example of where a subsurface extended detention basin is ideal because the park's purpose as a recreational area is not compromised. Additionally, recreational areas typically lack large structures, therefore the issue of overhead weight over the subsurface unit is not a concern.

Figure 3. Subsurface design of an extended detention basin, during construction.

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The extended detention basin must be configured to allow trash to enter the system and for trash to remain in the system until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the 1 year 1 hour design storm and solids that would be retained by a 5 mm screen or mesh must remain in the system. Preventing trash migration may require modifications to the inlets, and outlets.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in an extended detention basin. In general, an open inlet is recommended to allow for flow and trash to enter the extended detention basin unrestricted (Figure 4). A forebay or other pretreatment configuration is recommended to consolidate trash collection in the basin.

Figure 4. Example inlet structure.

Trash Containment

Once trash has been captured in an extended detention basin it must be contained so trash does not escape the extended detention basin. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or
- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Figure 5 shows an example of an outlet with a screen to contain trash. A larger grate on the top of the structure allows larger flows to safely flow out of the system.

Figure 5. Outlet structure with a 5mm screen.

Maintenance

Routine maintenance activity consists primarily of sediment, trash, and debris removal, but also mowing the turf to meet aesthetic and flow routing design of the basin. Vector control can also a significant investment of maintenance hours when poor drainage exists or stilling basins are installed as energy dissipaters.

Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Mowing overgrown vegetation that interferes with access, or safety.
Routine (small)	$0.44/ft^2$	
Routine (medium)	$0.34/ft^2$	
Routine (large)	$0.24/ft^2$	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$8.19ft^2$	
Replacement (medium)	$6.43/ft^2$	
Replacement (large)	$5.99/ft^2$	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the SWRCB's maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Extended Detention Basin Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the extended detention basin or being washed out of the system in the subsequent rain events. Trash can also clog the inlet and the surface of the limiting the flow into the basin and reducing the surface infiltration capacity. Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance interval is best determined by observing the BMP in operation for a wet season.

Frequent trash maintenance not only plays a role in the functionality of the extended detention basin but also in the aesthetics and public perception of the extended detention basin (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematics

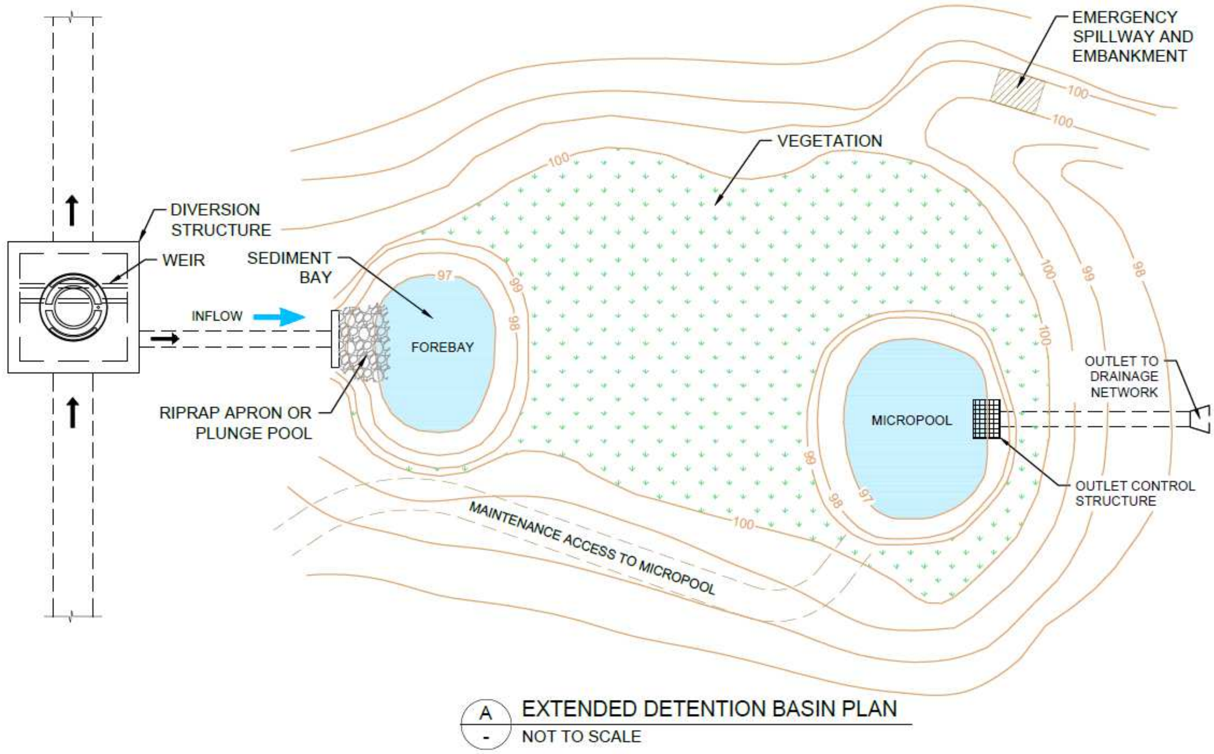

Figure 6. Schematic of an extended detention basin.

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Vegetated Swale TC-30

Design Considerations

- Tributary Area
- Area Required
- Slope
- Water Availability

Targeted Constituent	Removal
Sediment	Med
Nutrients	Low
Trash	High
Metals	Med
Bacteria	Low
Oil and Grease	Med
Organics	Med
Flow Control	Med

CASQA
CALIFORNIA STORMWATER QUALITY ASSOCIATION®

Description

Vegetated swales are open, shallow channels with vegetation covering the side slopes and bottom that collect and slowly convey runoff flow to downstream discharge points. They are designed to treat runoff by filtering through vegetation in the channel, the subsoil matrix, and/or infiltration into the underlying soils. Swales can be natural or manmade. They trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of stormwater runoff. Vegetated swales typically provide conveyance and can serve as part of a stormwater drainage system to replace curbs, gutters and storm sewer systems in conjunction with other treatment control BMPs such as bioretention areas.

California Experience

Caltrans constructed and monitored six vegetated swales in southern California. These swales were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the sites. The gophers created mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- If properly designed, swales can serve as an aesthetic, potentially inexpensive urban development or roadway drainage conveyance measure with significant water quality benefits.

Limitations

- Swales are more susceptible to failure (excessive erosion, channelization) than other BMPs. Grass cover must be properly maintained.
- Not appropriate for areas with concentrated runoff (i.e. locations where spills may occur).
- Cannot treat large areas, but large areas can be divided and treated using multiple swales.
- Can be restricted by law, some municipalities require curb and gutter systems in residential areas.

Performance

Vegetated swales represent a practical and potentially effective technique for controlling urban runoff quality (Table 1). Check dams, slight slopes, permeable soils, dense grass cover, increased contact time, and small storm events all contribute to successful pollutant removal by the swale system.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High (20% to 98%)	13.6 mg/L	Sedimentation and filtration.	Deletic and Fletcher 2006; Yu et al. 2001; Bäckström 2002, 2003, 2006; Geosyntec Consultants and Wright Water Engineering 2012; Scholes 2007; Barrett, 2008; Caltrans 2002
Metals	Medium (37%-93%)	TAs: 1.17 µg/L, TCd: 0.31 µg/L, TCr: 2.32 µg/L, TCu: 6.54 µg/L, TFe: 86 µg/L, TPb: 2.02 µg/L, TNi: 3.16 µg/L, TZn: 22.9 µg/L	Removal with sediment.	Fassman 2011; Geosyntec Consultants and Wright Water Engineering 2012; Backstrom, 2003; Barrett, 1998, 2008; Scholes, 2007; Caltrans 2002
Total phosphorus	Low (18%-63%)	*0.19* mg/L	Settling with sediment and plant uptake.	Deletic et al. 2006; Geosyntec Consultants and Wright Water Engineering 2012; Yu, 2001; Scholes, 2007; Barrett, 1998;
Total nitrogen	Low (20%-67%)	TN: 0.71 mg/L, TKN: 0.62 mg/L, $NO_{2,3}$-N: 0.25 mg/L	Settling, sedimentation (TKN) and plant uptake.	Deletic et al. 2006; Geosyntec Consultants and Wright Water Engineering 2012; Caltrans 2002; Barrett, 1998; Yu, 2001
Bacteria	Low (typically exports pathogens)	E. coli: 4190 MPN/100 mL, Fecal coliform: 5000 MPN/100 mL	Limited sedimentation, desiccation, predation, and photolysis at surface.	EPA 2012; Geosyntec Consultants and Wright Water Engineering 2012; Barrett, 1998

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 17 meter (50 foot) increments along their length. These dams maximize the retention time within the swale, decrease flow velocities, and promote particulate settling. Finally, the incorporation of vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale.

Suitability and Design

The suitability of a swale at a site will depend on land use, size of the area serviced, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the swale system (Schueler et al., 1992). The constraints of each site dictate the appropriate sizing and design considerations. Fundamental bioretention design components are as follows:

- Flow rate based design determined by local requirements or sized so that 85% of the annual runoff volume is discharged at less than the design rainfall intensity.
- Identify natural topographic lows and natural drainage courses as ideal locations (Young et al., 1996).
- BMP footprint approximately 10-20% of the drainage area, drainage area less than 2 acres.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.
- Minimum residence time of 10 minutes.
- Maximum design flow velocity of 1 foot per second or less to minimize erosion.
- Availability of irrigation to maintain the vegetation.

Table 2 details a number of core construction components and corresponding design considerations. Retrofitting can increase costs because of demolition of existing pervious surfaces.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation	$0.80/ft^2	2 to 8 ft wide. If greater than 8 ft, channel dividers may be necessary to prevent meandering. Flow depth during the water quality treatment event should not exceed 2/3 the height. Flow depth (100-yr) should be fully contained within the swale.
Fine Grading	$0.24/ft^2	1% to 6% overall slope (1% to 2% optimum). Slopes greater than 2.5% should incorporate check dams. Side slopes: 3:1 (H:V) or flatter to prevent bank erosion. Swale should not be less than 100 feet in length
Vegetation		Swales must be thickly vegetated. Turf grasses (not bunch grasses) should be maintained on the surface to prevent erosion and improve treatment. Water and spot fertilize during first year
Sod (buffalo)	$0.67/ft^2	
Seeding	$0.15-$0.22/ft^2	

Vegetation

It is best to install swales at the time of the year when there is a reasonable chance of successful establishment without irrigation. When seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season. If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the swale or strip. Use a roller on the sod to ensure that no air pockets form between the sod and the soil.

When sustaining regular vegetation is infeasible, earthen swales are a viable alternative (Figure 1), however, a reduction in performance related to the absence of vegetation may result.

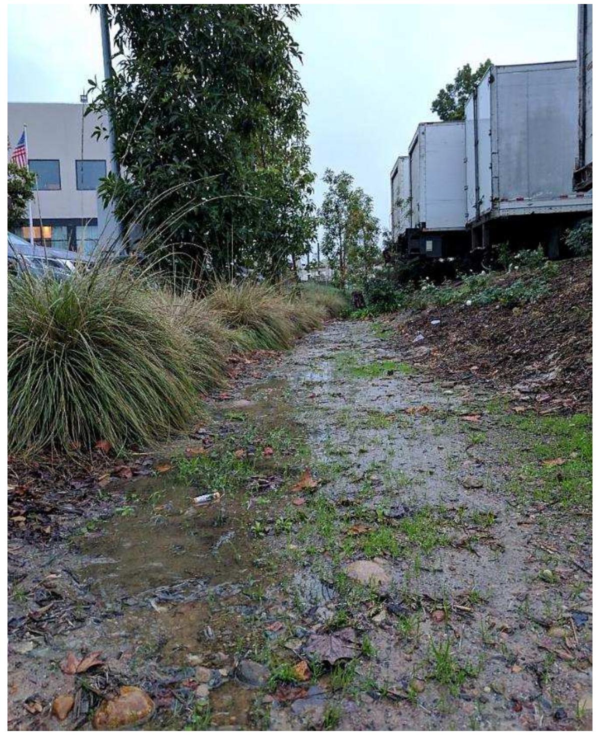


Figure 1. Earthen swale conveying stormwater in San Diego, CA

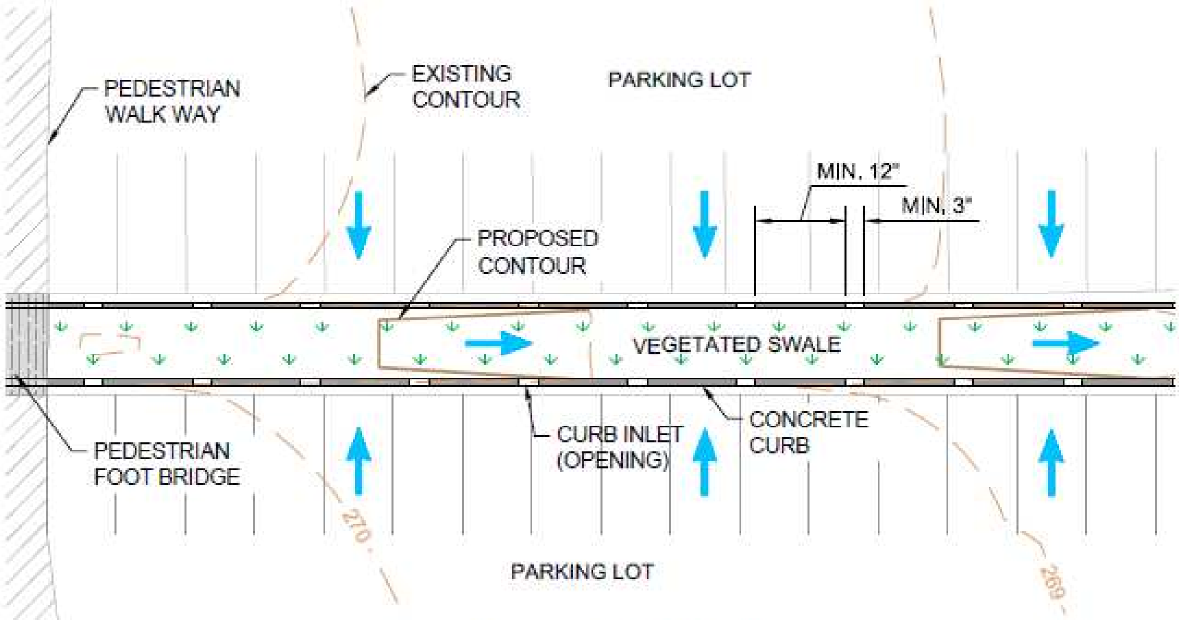
Maintenance

If properly designed and regularly maintained, vegetated swales can last indefinitely. The maintenance objectives for vegetated swale systems include keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover. Accumulated sediment should be removed manually to avoid concentrated flows in the swale. The application of fertilizers and pesticides should be minimal. Table 3 offers general maintenance activities, costs and frequencies.

Table 3. Typical maintenance activities and associated costs and frequency

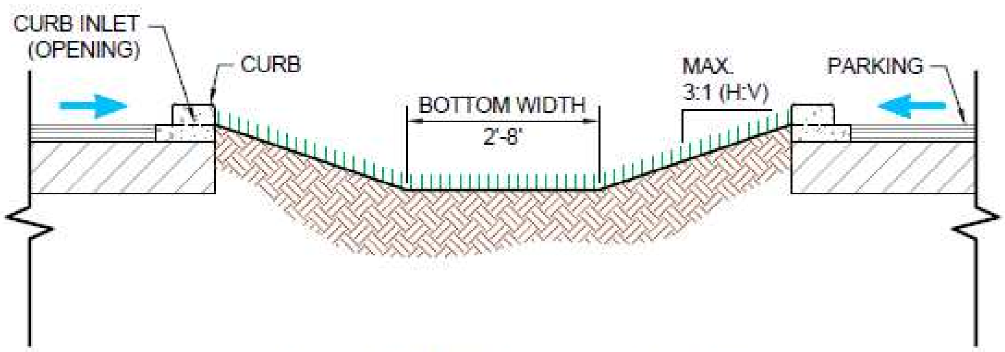
Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for sediment accumulation and erosion. Mow once or twice yearly. Inspect for ponding water to mitigate vector breeding. Repair holes created by rodents.
Routine (small)	$3.73/ft^2	
Routine (medium)	$1.40/ft^2	
Routine (large)	$1.01/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$4.17/ft^2	
Replacement (medium)	$2.33/ft^2	
Replacement (large)	$2.02/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

Schematic



VEGETATED SWALE - PLAN VIEW

NOT TO SCALE



VEGETATED SWALE - SECTION VIEW

NOT TO SCALE

VEGETATED SWALE NOTES

1. IF BOTTOM WIDTH GREATER THAN 8 FT., CHANNEL DIVIDERS SHOULD BE INSTALLED TO PREVENT MEANDERING AND LOW-FLOW CHANNEL FORMATION.

2. FLOW DEPTH: WATER QUALITY FLOW DEPTH SHOULD NOT EXCEED 2/3 THE HEIGHT OF THE VEGETATION. 100-YR FLOW DEPTH SHOULD BE FULLY CONTAINED WITHIN THE SWALE.

3. LONGITUDINAL SLOPE: 1% TO 6% OVERALL SLOPE (1% TO 2% RECOMMENDED). SLOPES GREATER THAN 2.5% SHOULD INCORPORATE GRADE CONTROL TO MAINTAIN AN AVERAGE SLOPE OF 2.5% OR LESS. SLOPES FLATTER THAN 0.5% MAY RESULT IN POOR DRAINAGE AND STANDING WATER. FLOW VELOCITY SHOULD NOT EXCEED 3 FT./S IN GRASSED SWALES

4. GRADE CONTROL: PROVIDE 6 IN. TO 18 IN. GRAVEL, WOOD, OR CONCRETE CHECK DAMS WITH GRAVEL SPLASH PADS (ASTM NO. 57 STONE) ON THE DOWNSLOPE SIDE TO MAINTAIN 2.5% SLOPES OR FLATTER.

5. PRETREATMENT: PROVIDE VEGETATED FILTER STRIP (SHEET FLOW) OR COBBLE ENERGY DISSIPATER WHERE PRACTICABLE.

6. VEGETATION: SEE VEGETATION SPECIFICATIONS

7. CURB CUTS AND INLETS SHOULD BE ARMORED

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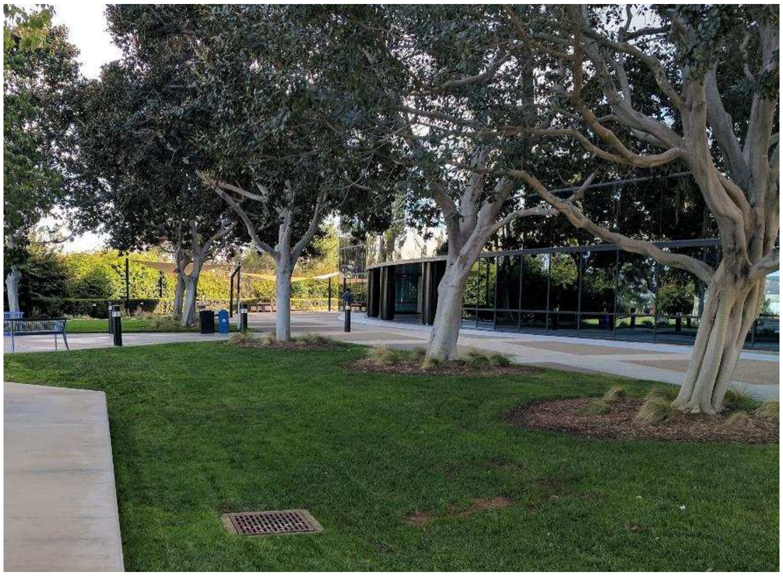
Vegetated Buffer Strip TC-31



Design Considerations

- Tributary Area
- Slope
- Water Availability
- Aesthetics

Targeted Constituents	Removal
Sediment	High
Nutrients	Low
Trash	Med
Metals	Med
Bacteria	Low
Oil and Grease	Med
Organics	Med
Flow Control	Low

CALIFORNIA STORMWATER QUALITY ASSOCIATION

Description

Vegetated buffer strips (grassed buffer strips, vegetated filter strips, filter strips, and grassed filters) are vegetated surfaces that are designed to treat sheet flow from adjacent surfaces. Filter strips function by reducing runoff velocities and allowing sediment and other pollutants to settle and by providing some infiltration into underlying soils. Filter strips were originally used as an agricultural treatment practice and have more recently evolved into an urban practice. With proper design and maintenance, filter strips can provide moderate pollutant removal and are often incorporated as pretreatment in more effective treatment control practices such as bioretention areas or permeable pavement.

California Experience

Caltrans constructed and monitored three vegetated buffer strips in southern California. These strips were generally effective in reducing the volume and mass of pollutants in runoff. Even in the areas where the annual rainfall was only about 10 inches/yr, the vegetation did not require additional irrigation. One factor that strongly affected performance was the presence of large numbers of gophers at most of the sites. The gophers created mounds, destroyed vegetation, and generally reduced the effectiveness of the controls for TSS reduction.

Advantages

- Buffers require minimal maintenance activity (generally erosion prevention and mowing).
- When properly designed and operated, buffer strips can provide reliable water quality benefits in conjunction with high aesthetic appeal.
- Flow characteristics and vegetation type and density can be closely controlled to maximize BMP effectiveness.

Limitations

- Not appropriate for areas with concentrated runoff (i.e., locations where spills may occur).
- A thick, properly maintained vegetative cover is needed to function properly.
- Provides limited treatment for dissolved constituents (except when infiltrated into the soil).
- Does not provide significant attenuation of the increased volume and flow rate of runoff.

Performance

Vegetated buffer strips provide similar treatment of stormwater runoff as vegetated swales but have fewer tendencies for channelization or erosion. Table 2 documents the pollutant removal vegetated filter strip from a variety of references.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High (-195% to 91%)	19 mg/L	Sedimentation and filtration.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011; Scholes 2007
Metals	Medium	TAs: 0.88 µg/L, TCd: 0.18 µg/L, TCr: 2.63 µg/L, TCu: 7.19 µg/L, TFe: 616 µg/L, TPb: 1.88 µg/L, TNi: 2.95 µg/L, TZn: 24.3 µg/L	Removal with sediment.	Knight et al. 2013; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-126% to 40%)	*0.173* mg/L	Settling with sediment, can be a net source or sink via breakdown or uptake of plant material	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Total nitrogen	Low TN: -17 to 40% TKN: -18 to 39%, $NO_{2,3}$-N:-18 to 43%	TN: 1.13 mg/L, TKN: 1.10 mg/L, $NO_{2,3}$-N: 0.19 mg/L	Settling, sedimentation (TKN) and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Bacteria	Low (likely exports pathogens)	N/A	Limited sedimentation, desiccation, predation, and photolysis at surface.	US EPA 2012

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Filter strips also exhibit good removal of litter and other floatables because the water depth in these systems is below the vegetation height and consequently these materials are not easily transported through them. Unfortunately little attenuation of peak runoff rates and volumes (particularly for larger events) is normally observed, depending on the soil properties. Therefore it may be prudent to follow the strips with another practice than can reduce flooding and channel erosion downstream.

Some treatment practices (e.g., wet ponds) can warm stormwater substantially, filter strips do not increase stormwater temperatures. Thus, they are good practices for protection of cold-water streams.

Suitability and Design

Filter strips require minimal design because they are essentially a grassed slope. Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion. They are best suited to treat runoff from roads and highways, roof downspouts, and small parking lots. They are also ideal components of the "outer zone" of a stream buffer or as pretreatment to a downstream BMP.

- Flow depth should not exceed 2/3 the height of the vegetation.
- Width should be the same as the tributary area.
- Flow length should allow a 10 minute hydraulic residence time.
- Maximum design storm velocity of 1 foot per second to minimize erosion.
- Use of low growing, drought tolerant, native vegetation.
- Irrigation must be available to support the vegetation.
- Sheet flow conditions must exist entering the strip.

Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Fine Grading	$0.24/ft^2	Limited to gently sloping areas where shallow flow characteristics are possible. 1% to 6% overall slope (1% to 2% optimum).
Vegetation Sod (buffalo) Seeding	 $0.67/ft^2 $0.15-$0.22/ft^2	Filter strips must be thickly vegetated. Turf grasses (not bunch grasses) should be maintained on the surface to prevent erosion and improve treatment. Water and spot fertilize during first year

Vegetation

It is best to install filter strips at the time of the year when there is a reasonable chance of successful establishment without irrigation. When seeds are used, erosion controls will be necessary to protect seeds for at least 75 days after the first rainfall of the season. If sod tiles must be used, they should be placed so that there are no gaps between the tiles; stagger the ends of the tiles to prevent the formation of channels along the swale or strip. Use a roller on the sod to ensure that no air pockets form between the sod and the soil.

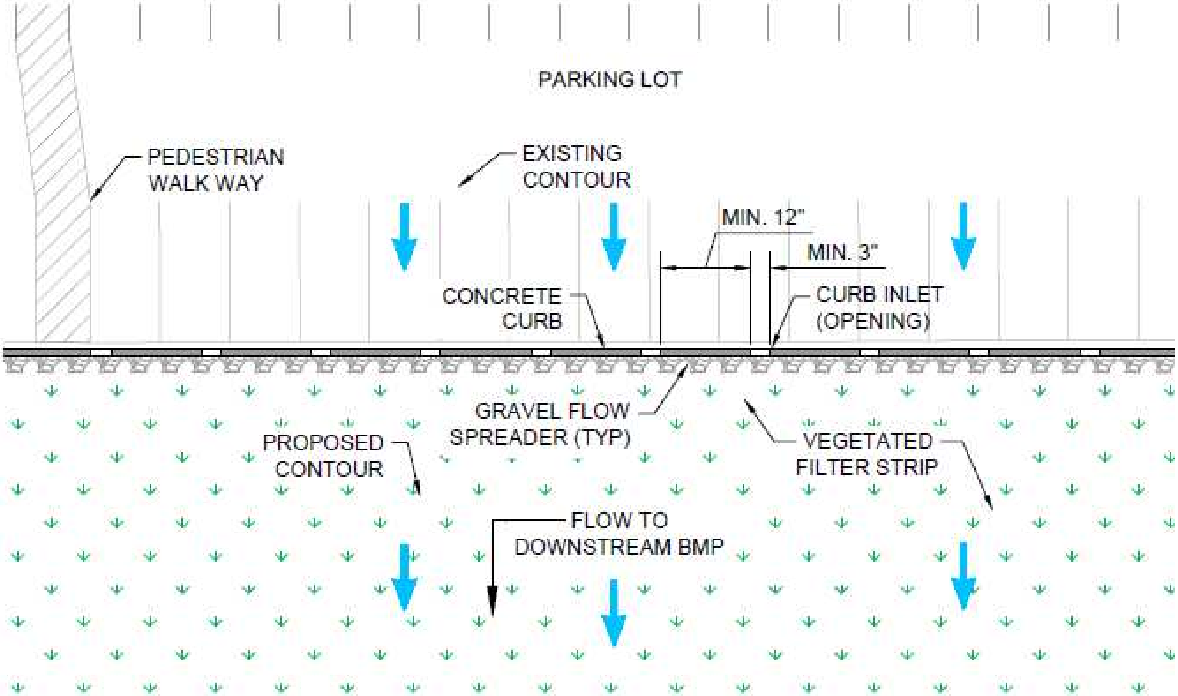
Maintenance

Filter strips require mainly vegetation management; therefore little special training is needed for maintenance crews. Typical maintenance activities and frequencies are included in Table 3.

Table 3. Typical maintenance activities and associated costs and frequency

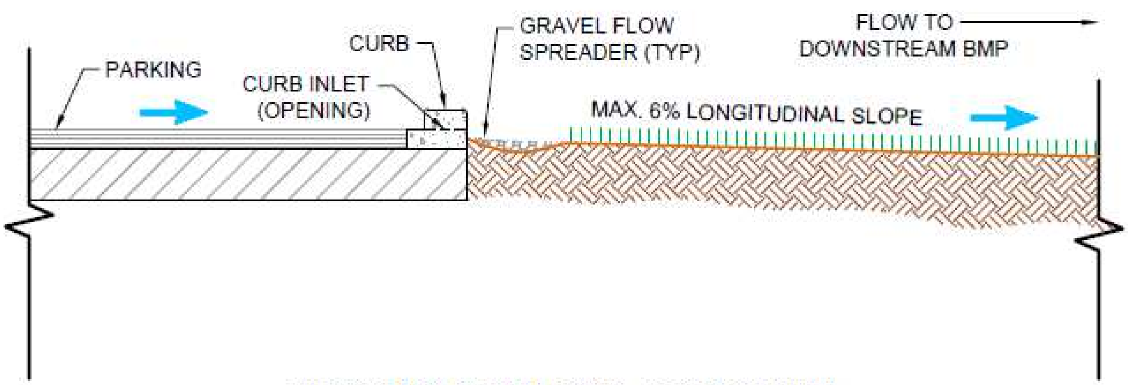
Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for sediment accumulation and erosion. Mow once or twice seasonally. Inspect for ponding water to mitigate vector breeding. Repair holes created by rodents.
Routine (small)	$3.73/ft^2	
Routine (medium)	$1.40/ft^2	
Routine (large)	$1.01/ft^2	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$4.17/ft^2	
Replacement (medium)	$2.33/ft^2	
Replacement (large)	$2.02/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

Schematic



VEGETATED FILTER STRIP - PLAN VIEW

NOT TO SCALE



VEGETATED FILTER STRIP - SECTION VIEW

NOT TO SCALE

VEGETATED FILTER STRIP NOTES

1. GRAVEL FLOW SPREADER: 6-IN. DEEP ASTM NO. 57 STONE
2. SIGNAGE SHOULD IDENTIFY FILTER STRIP AS A STORMWATER PRETREATMENT PRACTICE AND PROHIBIT FOOT TRAFFIC OR OTHER ACTIVITIES THAT COULD COMPACT OR RUT FILTER STRIP SOILS. SIGNAGE SHOULD INSTRUCT MAINTENANCE PERSONNEL TO MOW GRASS TO MOW GRASS NO SHORTER THAN 4-IN. AND MOW PERPENDICULAR TO FLOW PATH (FOLLOWING THE CONTOURS).
3. FLOW DEPTH SHOULD NOT EXCEED 2/3 THE HEIGHT OF THE VEGETETATION
4. FLOW LENGTH SHOULD ALLOW A 10 MINUTE HYDRAULIC RESIDENCE TIME
5. VEGETATION: SEE VEGETATION NOTES

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Design Considerations

- Soil for Infiltration
- Tributary Area
- Slope
- Aesthetics
- Environmental Side-effects

Targeted Constituent	Removal
Sediment	High
Nutrients	Med
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

CALIFORNIA STORMWATER QUALITY ASSOCIATION

Description

The bioretention cell functions as a soil and plant-based filtration device that removes pollutants, including trash, through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, ponding area, organic layer or mulch layer, planting soil, and native vegetation. Runoff velocity is reduced by passing over or through a buffer strip, which can increase sedimentation and debris capture in heavily trafficked areas. Stormwater is infiltrated through engineered media to the native soils or can be directed to an underdrain.

California Experience

Bioretention areas have been widely implemented across California in a variety of configurations to meet a full suite of regulatory requirements in Los Angeles, San Diego, San Francisco, and many of the surrounding areas. Bioretention areas have been implemented in the right-of-way as a green street, in medians in parking lots, and incorporated into landscaped areas. Figure 1 and Figure 2 show how bioretention areas have been implemented around the state.

Figure 1. Bioretention incorporated in a green street in San Diego, CA.

Bioretention areas have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water

Boards. Additionally, the Water Boards have determined that bioretention can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

Figure 2. Bioretention in the parking lot of the LA Zoo.

Advantages

- Bioretention provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape and aesthetic.
- Can be used in any soil type. When infiltration rates are too low, underdrains are installed.

Limitations

- Not recommended for areas with slopes greater than 20%.
- Bioretention is not suitable where the water table is within 3 feet of the ground surface.
- Creates an attractive habitat for mosquitoes and other vectors if drainage is insufficient.

Performance

Bioretention removes stormwater pollutants through numerous processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Media depth can have an impact on the removal of certain pollutants, particularly nitrogen and phosphorus (Hunt et al. 2012, Hunt et al. 2006; Hunt and Lord 2006). Table 1 below details expected effluent concentrations and removal processes for each pollutant constituent.

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	Treatment Depth	References
Sediment	High	9.9 mg/L	Settling in pretreatment and mulch layer, filtration and sedimentation in top 2 to 8 inches of media.	1.5 feet of media	Hatt et al. 2008; Hunt et al. 2012; Li and Davis 2008; Geosyntec Consultants and Wright Water Engineering 2012; Stander and Borst 2010
Metals	High	TCd: 0.07 µg/L, TCr: 0.35 µg/L, TCu: 5.33 µg/L, *TFe: 1027 µg/L,* TPb: 0.19 µg/L, *TNi: 4.53 µg/L,* TZn: 12.0 µg/L	Removal with sediment and sorption to organic matter and clay in media.	2 feet of media	Hsieh and Davis 2005; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012
Hydrocarbons	High	N/A	Removal and biodegradation in mulch.	3 inches of mulch	Hong et al. 2006; Hunt et al. 2012
Total phosphorus	Medium -240% - 99%	*0.240 mg/L*	Settling with sediment, sorption to organic matter and clay in media, and plant uptake. Poor removal can result from media containing high organic matter or high background concentrations of phosphorus.	2 feet of media	Clark and Pitt 2009; Davis 2007; Geosyntec Consultants and Wright Water Engineering 2012; Hsieh and Davis 2005; Hunt et al. 2006; Hunt and Lord 2006; ; Li et al. 2010
Total nitrogen	Medium TKN: -5% - 64%, Nitrate: 1% - 80%	TN: 0.92 mg/L, TKN: 1.34 mg/L, $NO_{2,3}$-N: 0.37 mg/L	Sorption and settling (TKN), denitrification in IWS (nitrate), and plant uptake. Poor removal efficiency can result from media containing high organic matter.	3 feet of media	Barrett et al. 2013; Clark and Pitt 2009; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2006, 2012; Kim et al. 2003; Li et al. 2010; Passeport et al. 2009
Bacteria	High	*Enterococcus*: 235 MPN/ 100 mL, *E.coli*: 101 MPN/100 mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in mulch layer and media.	2 feet of media	Hathaway et al. 2009, 2011; Hunt and Lord 2006; Hunt et al. 2008, 2012; Jones and Hunt 2010; Geosyntec Consultants and Wright Water Engineering 2012
Trash	High	*N/A*	Filtration	1.5 feet of media	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Performance Considerations

Bioretention areas provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most sediment removal occurs in pretreatment practices, in the mulch layer, and in the top 2 to 8 inches of soil media (Hatt et al. 2008; Li and Davis 2008; Stander and Borst 2010). Metals are commonly sediment-bound and are removed in the top 8 inches of media (Hsieh and Davis 2005; Hunt et al. 2012).

Nitrogen and phosphorus removal is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal). The significant increase is suspected to be the result of excessive phosphorus levels in the furnished soil media (Hsieh and Davis 2005; Hunt et al. 2006; Davis 2007). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 parts per million (ppm) (Hunt and Lord 2006). A study in Texas indicated that nutrient export can also occur when bioretention soils are amended with excessive compost (Li et al. 2010). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). Total Kjeldahl nitrogen (TKN) has been found to vary between a 5 percent increase and 64 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate in the planting soil to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Nitrate removal can be improved by incorporating a saturated layer in the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009).

Bioretention represents a technology to mitigate pathogens from urban watersheds (especially when volume reduction is considered), although limited data exist for bacteria, virus, and protozoa removal. Most scientists and engineers agree that bacteria die-off occurs at the surface where organisms are exposed to solar radiation and dry (desiccating) conditions; dense vegetation in the bioretention area can limit the penetration of sunlight, but it can provide habitat for bacterivores and other beneficial pathogen predators (Hunt and Lord 2006; Hunt et al. 2008; Hathaway et al. 2009). Microbes are also sequestered by sedimentation and sorption; therefore, 2 feet minimum media depth and slower infiltration rates (1–2 in/hr) are recommended to enhance pathogen removal (Hathaway et al. 2011; Hunt et al. 2012).

In addition to chemical and biological pollutant removal, bioretention can be designed to reduce thermal loading to waterways. Thermally enriched runoff can increase stream temperatures and have adverse impacts on stream biota and dissolved oxygen (Booth et al. 2013; USEPA 1986). Research suggests that deep media beds (generally four feet or greater) can buffer extreme temperatures and that infiltration of stormwater can decrease overall thermal loading (Hunt et al. 2012; Jones and Hunt 2009; Winston et al. 2011; Wardynski et al. 2013). Thermal mitigation can likely be enhanced by shading bioretention areas with tree canopy cover and including IWS (Hunt et al. 2012; Jones et al. 2012).

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which bioretention meets (see Section 5.6.1 for FCS details).

It is worth noting that the numerous treatment processes provided by bioretention, particularly filtration, means bioretention performance far exceeds the 5 mm or greater FCS definition for particle trapping. So bioretention systems are not only trapping all particles of 5 mm or greater but effectively all particles less than 5 mm, including microplastics and “nurdles” (pre-production plastics).

Suitability and Design

Figure 1 and Figure 2 illustrate the flexibility of bioretention design in new or existing infrastructure. The constraints of each site dictate the appropriate siting and footprint. Fundamental bioretention design components are as follows:

- A fully stabilized drainage area of less than 20% slope.
- 2.5 to 3.5 inch minimum elevation difference in head between inlet and outlet.
- Typical ponding depth of 3 to 12 inches or more with 9 inches recommended.
- 10-ft setback from foundations, 100-ft from septic fields and water supply wells, and 50-ft from steep slopes.
- Geotechnical investigation required to identify soil infiltration rate. If known soil contamination is present, line restricting infiltration is not allowed.

Bioretention design is highly dependent on the constraints of the considered site. Costs will vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations. Retrofitting can increase costs because of demolition of existing pervious surfaces.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation		Underdrain required if subsoil infiltration rate < 0.5 in/hr or when contamination present. When infiltrating ensure that subgrade compaction is minimized.
Without underdrains (unlined)	\$2.75–\$5.00/ft^2	
With underdrains (lined)	\$3.90–\$6.15/ft^2	
Soil Media		1.5–4 feet (deeper for better pollutant removal, hydrologic benefits, and rooting depths) at minimum 5 in/hr infiltration. Total phosphorus < 15 ppm, pH 6–8, CEC > 5 meq/100 g soil. Organic Matter Content < 5% by weight. 65% sand, 20% sandy loam, and 15% compost (from vegetation-based feedstock) by volume.
Recommended mix	\$2.40–\$4.75/ft^2	
With engineered media	\$3.40–\$6.80/ft^2	
Soil Media Barrier		When utilizing an underdrain, separate media from underdrain with 2 to 4 inches of washed sand (ASTM C-
Geotextile	\$0.45/ft^2	

Component	Cost	Design Consideration
Washed sand (2-inch layer) No. 8 aggregate (min 2 inches thick) No. 57 stone (1.5 + feet)	$0.20/ft² $0.28/ft² $2.49/ft²	33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Underdrain Pipe (includes drainage stone, with 5-foot spacing)	$3.60/ft²	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Curb and Gutter	$18/ft	When installed adjacent to road, provide stabilized inlets at least 12 inches wide
Mulch Native hardwood	$0.24–$0.39/ft²	Dimensional chipped hardwood or triple shredded, well-aged hardwood mulch 3-inches-deep.
Hydraulic Restriction Layer Filter fabric Clay 30-mil liner Concrete barrier	 $0.45/ft² $0.65/ft² $0.35/ft² $12.00/ft²	If non-infiltrating, use hydraulic restriction layer. If infiltrating may use on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.
Vegetation	$0.20–$3.50/ft²	Native, deep rooting, drought tolerant plants. Apply one-time spot fertilization upon planting. Water until plants are established.

Vegetation

Vegetation is an integral component of bioretention and has been shown to provide some increase in metals reduction (Sun and Davis 2007, Li, et al. 2011) and a significant increase in nutrient reduction (Glaister, et al., 2014; Henderson, et al., 2007; Barrett, et al., 2013; Limouzin, et al., 2011; Li, et al., 2011; Houdeshel, et al., 2015). Three species each of trees, shrubs, and perennials are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For instance, a 15 foot (4.6 meter) by 40 foot (12.2 meter) bioretention area (600 square feet or 55.75 square meters) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1.

Figure 3. Bioretention in a landscaped area in San Diego, CA.

Drought tolerant native species are recommended and should be planted when conditions are most favorable. Vegetation should be watered at the end of each day for fourteen days following planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the bioretention area. The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures, such as providing a soil breach to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities.

The designers should evaluate the best placement of vegetation within the bioretention area. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site. Following placement of the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted at the beginning of the growing season. Mulch should be placed immediately after trees and shrubs are planted. Two to 3 inches (5 to 7.6 cm) of commercially available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion.

Figure 4 Bioretention in San Francisco, CA. Source: Jim Hook

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The bioretention area must be configured to allow trash to enter the system and for trash to remain in the bioretention area until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in a bioretention area. An open curb cut is recommended for high traffic areas (Figure 5). A minimum 2 inch drop from the gutter line of the curb to the inlet is recommended as demonstrated in Figure 6 to ensure that flow is routed into the bioretention area and trash will not clog the inlet.

Figure 5. Example of an open curb cut.

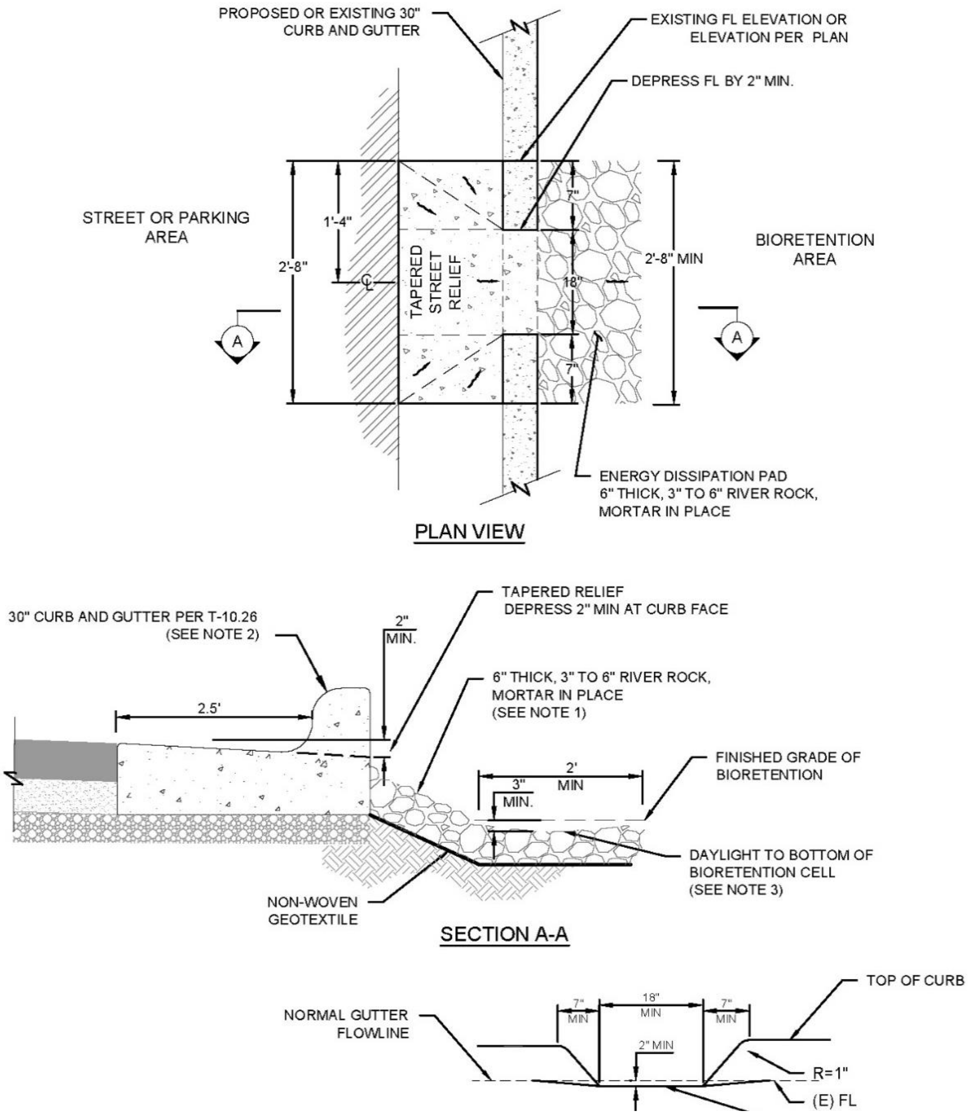


Figure 6. Example Inlet Detail

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. A forebay (Figure 7), filter strip (Figure 8), or mortared cobble inside the curb cut (Figure 9) can slow flow and allow trash and gross solids to settle out while consolidating at the edge of the bioretention area to make it easier for maintenance crews to collect and remove.

Figure 7. Example of a forebay as pretreatment for a bioretention area.

Figure 8. Example of filter strip as pretreatment for a bioretention area.

Figure 9. Example of mortared cobble for pretreatment in a bioretention inlet with a curb cut.

Trash Containment

Once trash has been captured in the bioretention area it must be contained so trash does not escape the bioretention area. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or

Figure 10. Example of an outlet with 5 mm screen.

- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Figure 10 shows an example of an outlet with a screen to contain trash.

Maintenance

The primary maintenance requirement for bioretention areas is inspection and repair or replacement of the treatment area's components. Appropriately selected plants will aid in reducing fertilizer, pesticide, water, and overall maintenance requirements. Bioretention system components should blend over time through plant and root growth, organic decomposition, and the development of a natural soil horizon. These processes will lengthen the facility's life and reduce the need for extensive maintenance. Maintaining soil porosity and basic housekeeping practices such as removal of debris accumulations and vegetation management are necessary to ensure that the system dewaters completely (recommended 72-hour or less residence time) to prevent creating mosquito and other vector habitats. If a bioretention cell has an underdrain, the functionality of the underdrain needs to be maintained to ensure that the drainage and drawdown of stormwater is not hindered. Bioretention requires monthly landscaping maintenance, including measures to ensure that the area is functioning properly, and irrigation during dry periods. In many cases, bioretention areas initially require intense maintenance, but less maintenance over time. Maintenance tasks can be conducted by a landscaping contractor, who might already be hired at the site. Additionally, a bioretention cell's efficacy to reduce pollutant loads and provide hydrologic benefits is severely diminished when frequent and complete maintenance is not conducted. For typical maintenance activities, Table 3 provides recommended frequencies and associated costs.

Table 3. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
As needed		• Irrigate area during dry periods. Make structural changes or repairs as needed to eliminate pools of water, particularly during the warmer months of the year. Coordinate with the local mosquito and vector control agency to control mosquitoes.
Biweekly, at project completion		Water plants daily for 2 weeks.
Routine Maintenance (required monthly to every 2 years)		<u>Remove excess sediment, trash, and debris across the surface, inlet, and outlet</u>. Check for and stabilize erosion. Pruning and mowing overgrown vegetation that interferes with access, or safety. Remove and replant dead or dying plants. Replace tree stakes and wires. If there is an underdrain, unclog drainage structure.
Routine (small)	$7.62/ft^2	
Routine (medium)	$1.91/ft^2	
Routine (large)	$1.91/ft^2	
Intermediate Maintenance (required every 6 to 10 years)		Remove and replace mulch upon decomposition. Replace soil media for areas receiving especially
Intermediate (small)	$5.62/ft^2	

Frequency	Cost	Activity
Intermediate (medium) Intermediate (large)	\$2.94/ft^2 \$2.50/ft^2	high pollutant loads. Repair erosion at inflow points and outflow structures.
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small) Replacement (medium) Replacement (large)	\$10.52/ft^2 \$10.17/ft^2 \$10.11/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

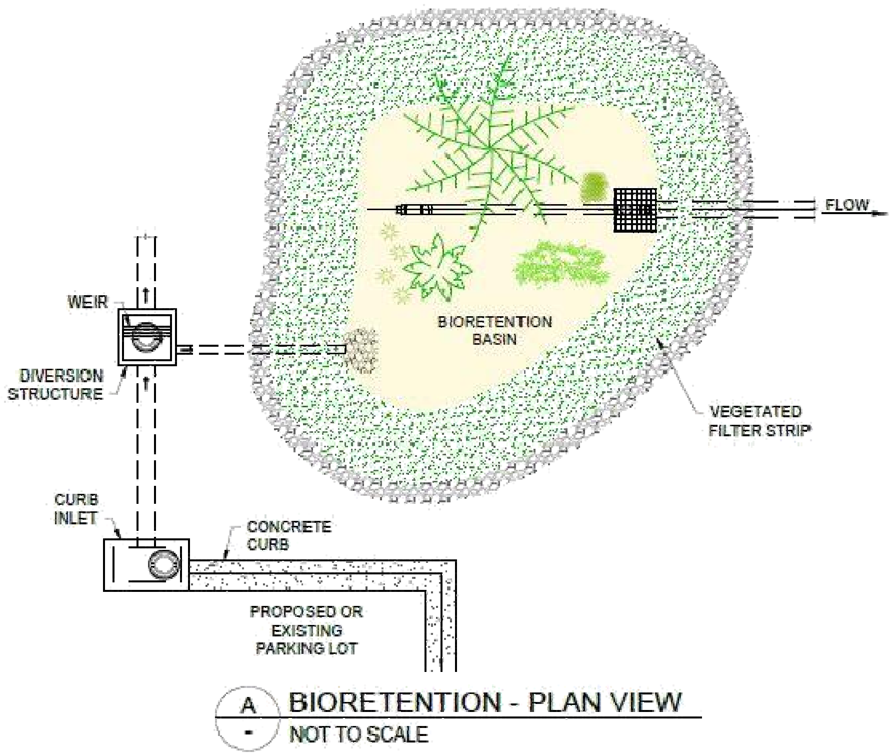
Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Bioretention Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the bioretention area in the subsequent rain events (see Table 3). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance interval is best determined by observing the BMP in operation for a wet season.

Trash maintenance not only plays a role in the functionality of the bioretention area but also in the aesthetics and public perception of the bioretention area (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic



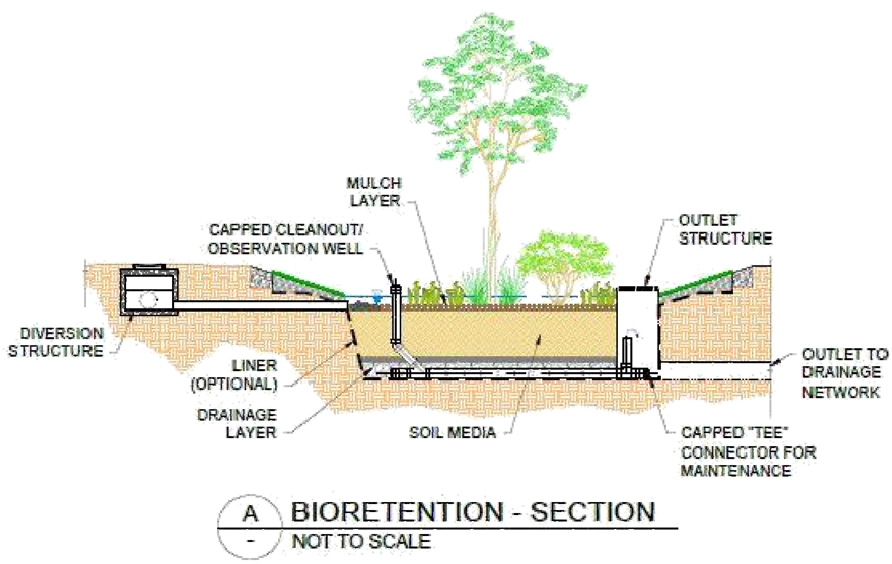


Figure 11. Schematic of a Bioretention Area.

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Design Considerations

- Roof Strength
- Climate
- Maintenance Access

Targeted Constituent	Removal[1]
Sediment	
Nutrients	
Trash	
Metals	
Bacteria	
Flow Control	

Description

Green roofs (vegetated roofs) are vegetated areas installed on gently sloped or flat rooftops. Green roofs are able to reduce stormwater runoff and improve water quality by intercepting rainfall that would otherwise be routed to a downspout; instead stormwater is filtered through the media, or evapotranspired by the vegetation. Two design styles exist to incorporate a wide variety of building types: extensive, media depth between 4 and 6 inches, and intensive, media depth greater than 6 inches. Extensive green roofs are most common because of the structural requirement, particularly for redevelopment. Intensive green roofs are most often incorporated into new development.

California Experience

Green roofs have been implemented for new development and redevelopment areas to accomplish a number of goals including regulatory requirements, aesthetics, and economics. The San Diego County Operations Center incorporates an extensive green roof to enhance visual aesthetics and provide an inviting roof top environment for employees and guests (Figure 1). The Vista Hermosa Park Ranger Station and Facility Buildings also incorporated an extensive green roof to reduce the impervious area and footprint of the park (Figure 2). An extensive green roof at the California Academy of Science in San Francisco provides an example to patrons and converts an otherwise unusable space into an additional recreational opportunity and makes the academy more sustainable by increasing the insulation and reducing energy lost through the roof (Source: www.calacademy.org) (Figure 3). Finally, Kaiser Center created an intensive green roof with a park-like setting in Oakland (Figure 4).

[1] Pollutant removal generally occurs through stormwater volume reduction

Figure 1. Extensive Green roof at the San Diego County Operations Center.

Figure 2. Extensive Green roof at the Vista Hermosa Park Ranger Station and Facility in Los Angeles, CA

Source: www.calacademy.org

Figure 3. Extensive Green roof at the Academy of Science in San Francisco, CA

Source: kaisercenterroofgarden.com

Figure 4. Intensive green roof at the Kaiser center in Oakland, CA

Advantages

- Vegetated roofs may improve property values and provide air quality benefits.
- Can extend expected roof-life and reduce building energy demand.
- Reduces heat island effect and provide passive recreation areas.

Limitations

- Roof structure must be able to support additional weight from soil and vegetation.
- May require irrigation in arid and semi-arid climates.

Performance

Hydrologic and water quality performance of green roofs varies with footprint, media depth, roof angle and vegetation type but an average of 45-75% of annual runoff can be expected to be retained (Berndtsson 2010). In comparison, unplanted soil media has been observed to offer significantly reduced rooftop retention capability (Berndtsson 2010; Schroll et al. 2011; Wolf and Lundholm 2008). Studies investigating the quality of stormwater discharging from green roofs is limited, but in general it is expected that phosphorus and nitrogen concentrations are exported from green roofs (Berndtsson 2010). Table 1 below details expected effluent concentrations and removal processes for each pollutant.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High (-195% to 91%)	19 mg/L	Sedimentation and filtration.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011; Scholes 2007
Metals	Medium	TAs: 0.88 µg/L, TCd: 0.18 µg/L, TCr: 2.63 µg/L, TCu: 7.19 µg/L, TFe: 616 µg/L, TPb: 1.88 µg/L, TNi: 2.95 µg/L, TZn: 24.3 µg/L	Removal with sediment.	Knight et al. 2013; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-126% to 40%)	*0.173* mg/L	Settling with sediment, can be a net source or sink via breakdown or uptake of plant material	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Total nitrogen	Low TN: -17 to 40% TKN: -18 to 39%, $NO_{2,3}$-N:-18 to 43%	TN: 1.13 mg/L, TKN: 1.10 mg/L, $NO_{2,3}$-N: 0.19 mg/L	Settling, sedimentation (TKN) and plant uptake.	Geosyntec Consultants and Wright Water Engineering 2012; Knight et al. 2013; Winston et al. 2011;
Bacteria	Low (likely exports pathogens)	N/A	Limited sedimentation, desiccation, predation, and photolysis at surface.	US EPA 2012

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

Suitability and Design

Green roofs can be installed on a wide range of buildings. Structures that do not traditionally incorporate heavy overhead loads (e.g. residential homes) can utilize an extensive green roof which incorporate a shallow soil depth (between 4 to 6 inches) thus a lower weight. Alternatively, intensive green roofs can be utilized on buildings with greater strength, allowing for greater soil depth (greater than 6 inches), deeper rooting vegetation, and increased water quality and stormwater volume benefits. Typical static loading per unit area for intensive green roofs is 15 to 55 pounds per square foot, and 75 to 150 pounds per square foot for extensive (Tolderlund 2010). Regardless of design type fundamental green roof design guidelines include:

- Structure evaluated by a qualified structural engineer to ensure proper support exists.
- Sized to fully capture the local regulatory requirements.
- Incorporate watertight liner to prevent rainwater from intruding the underlying structure.

Table 2 details a number of core construction components and corresponding design considerations for an intensive green roof. An extensive design will also likely incorporate a drip irrigation system, and walkways for foot-traffic.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Soil Media Recommended mix	$2.00–$4.75/ft^2	Minimum 4 inches of media: 80–90% lightweight inorganic materials such as expanded slates, shales, or pumice. No more than 20% organic materials (potential for leaching nutrients).
Soil Media Barrier No. 8 aggregate (min 2 inches thick) Filter Fabric Root Barrier	 $0.28/ft^2 $0.45/ft^2 $2.25/ft^2	Clean washed synthetic or inorganic aggregate material such as no 8 stone or suitable alternatives. Filter fabric prevents migration of the media into the soil media barrier. Needled, non-woven, polypropylene geotextile. Root barrier placed directly above waterproof liner to protect from roots.
Underdrain Pipe (includes drainage stone, with 5-foot spacing)	$3.60/ft^2	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Hydraulic Restriction Layer 30-mil liner	$0.35/ft^2	Protect the roof deck and underlying structure from intruding stormwater.
Vegetation	$1.50–$3.50/ft^2	Low-lying, drought tolerant species which can thrive without supplemental irrigation. Construct on slopes from 1% to 30%. Slopes approaching 30% require media

Component	Cost	Design Consideration
		retention practices (e.g. baffles or geo-grids). Should be able to withstand harsh rooftop environment

To protect the existing roof outlets (e.g., drains, scrubbers) 12 inch setbacks should be maintained and filled with washed no. 57 stone. A setback of 24 inches should be maintained between ventilation ducts and HVAC components. Additionally, sufficient access to the roof and around vegetation must be provided to allow routine maintenance.

Vegetation

Extensive green roof vegetation should consist of low-growing, highly drought-tolerant species that can survive in the harsh environment of a rooftop. Common vegetation types include grasses and succulents. There is greater flexibility in intensive green roof vegetation and should match the plant palate of the surrounding area. Irrigation may be required to maintain the vegetation.

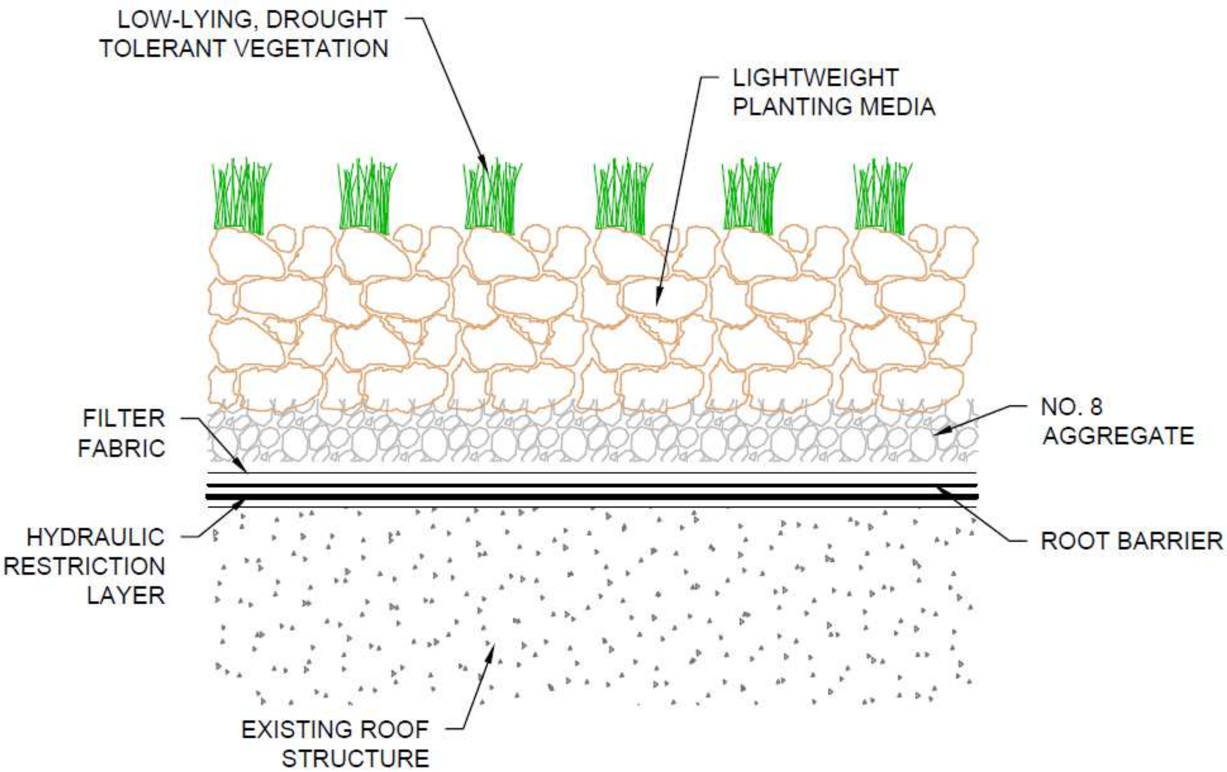
Maintenance

Maintenance tasks for green roofs consists primarily of maintaining vegetation and drainage structures.

Table 3. Maintenance tasks for green roofs

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Inspect and replace wind-scoured, and eroded media and vegetation. Inspect drains, gutters and downspouts for clogging. Inspect liner for leaks. Remove and replant dead or dying plants. Remove undesired vegetation.
Routine (small)	3.95/ft^2	
Routine (medium)	$1.13/ft^2	
Routine (large)	$0.79/ft^2	
End of Life Replacement (service life of 20 years)		Remove and replace plants, media, and replace the roof membrane.
Replacement (small)	$6.69/ft^2	
Replacement (medium)	$3.87/ft^2	
Replacement (large)	$3.53/ft^2	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2		

Schematic



INTENSIVE GREEN ROOF DETAIL

NOT TO SCALE

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Sand Filter TC-40

Design Considerations

- Aesthetics
- Hydraulic Head

Targeted Constituents	Removal
Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High
Flow Control	High

CALIFORNIA STORMWATER QUALITY ASSOCIATION®

Description

Stormwater sand filters exist in two general design styles, surface and subsurface, often referred to as the Austin and Delaware styles (respectively). They both remove pollutants by filtering stormwater vertically through a sand media. Surface sand filters operate similarly to infiltration basins, however can be lined and incorporate and underdrain structure. Subsurface filters are two-chambered devices consisting of a pretreatment settling chamber and a filter chamber filled with sand. Subsurface filters require less space than many LID BMPs and are therefore most often incorporated in ultra-urban areas.

California Experience

Caltrans constructed and monitored five surface sand filters and one subsurface design in southern California. Pollutant removal was very similar for both designs; however operational and maintenance aspects were quite different. The subsurface filters maintain permanent pools and consequently mosquito management was a critical issue. Removal of the top few inches of sand was required at three of the surface filters and the subsurface filter during the third year of operation; consequently, sizing of the filter bed is a critical design factor for establishing maintenance frequency.

Surface sand filters have been shown to be effective at reducing many of the pollutants regulated by the State and Regional Water Boards. Additionally, the Water Boards have determined that sand filters can qualify as a "Full Capture System (FCS)[1]" for trash. Accordingly, in addition to providing general specifications, this fact sheet includes trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. See the "**Full Trash Capture Compliance**" section and "***Trash FCS***" subsections in this fact sheet for more information.

Advantages

- Provides stormwater treatment and can be designed to meet hydromodification management requirements and the full capture system definition for trash control.
- Relatively high pollutant removal, especially for sediment and associated pollutants.
- Widespread application with sufficient capture can provide significant control of channel erosion.

Limitations

- Can be more expensive to construct and maintain than many other BMPs.
- Generally require more hydraulic head to operate properly (minimum 4 feet).
- Permanent pools in subsurface filters may enable mosquito and midge breeding.

Performance

Sand filters are effective stormwater management practices for pollutant removal. Conventional removal rates for all sand filters are presented in Table 1. With the exception of nitrates, which are always exported from filtering systems because of the conversion of ammonia and organic nitrogen to nitrate, they perform relatively well at removing pollutants.

Table 1. Typical pollutant removal for constituents and removal processes

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Sediment	High (74% to 95%)	8.7 mg/L	Settling in pretreatment and surface, filtration and sedimentation in media.	Barrett 2003, 2008, 2010; Bell et al. 1995; Geosyntec Consultants and Wright Water Engineering 2012; Horner and Horner 1995;

[1] Full Capture System (FCS): A treatment control, or series of treatment controls, including but not limited to, a multi-benefit project or a low impact development control that traps all particles that are 5 mm or greater, and has a design treatment capacity that is either: a) of not less than the peak flow rate, Q, resulting from a one-year, one-hour, storm in the subdrainage area, or b) appropriately sized to, and designed to carry at least the same flows as, the corresponding storm drain.

Pollutant	Typical Removal	Median Effluent Concentration[1]	Removal Processes	References
Metals	High (14% to 87%)	TAs: 0.87µg/L, TCd: 0.16µg/L, TCr: 1.02µg/L, TCu: 6.01µg/L, TPb: 1.69µg/L, TNi: 2.20µg/L, TZi: 19.9µg/L	Removal with sediment (optional: sorption to organic matter and clay amendments in media).	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Total phosphorus	Low (-14% to 69%)	0.09 mg/L	Settling with sediment (optional: sorption to organic matter and clay amendments in media). Poor removal efficiency can result from media containing high organic matter or with high background concentrations of phosphorus.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Total nitrogen	Low (20%)	TN: 0.82 mg/L, TKN: 0.57 mg/L, *$NO_{2,3}$-N: 0.51* mg/L	Sorption and setting (TKN) and denitrification in IWS (nitrate). Poor removal efficiency can result from media containing high organic matter.	Barrett 2008; Geosyntec Consultants and Wright Water Engineering 2012; Hunt et al. 2012;
Bacteria	High (fecal coliform: -70% to 54%, Fecal streptococcus: 11% to 68%	Fecal coliform: 542 MPN/100mL	Sedimentation, filtration, sorption, desiccation, predation, and photolysis in surface layer.	Barrett 2010; Geosyntec Consultants and Wright Water Engineering 2012
Trash	High	N/A	Filtration (treatment depth of 1.5 feet of media)	Barrett et al. 2013

[1] Underlined effluent concentrations were (statistically) significantly lower than influent concentrations, as determined by statistical hypothesis testing on the available sampled data. Effluent concentrations displayed in *italics* were (statistically) significantly higher than influent concentrations.

In addition to the relatively high pollutant removal in sand filters, these devices, when sized to capture the channel forming storm volume, are highly effective at attenuating peak flow rates and reducing channel erosion.

In general, when contamination of groundwater with conventional pollutants is of concern, sand filters are preferred over infiltration practices, such as infiltration trenches. In most cases, sand filters can be constructed with impermeable basin or chamber bottoms, which help to collect, treat, and release runoff to a storm drainage system or directly to surface water with no contact between contaminated runoff and groundwater.

Trash FCS

The Trash Amendments adopted by the State Water Board in April 2015 provide a performance standard for treatment of stormwater for trash in the form of the definition of FCS, which surface sand filters meet (see Section 5.6.1 for FCS details).

Suitability and Design

The selection of a sand filter design depends largely on the drainage area's characteristics. Subsurface filters typically treat runoff from drainage areas that are exclusively impervious (e.g., parking lots, loading docks, service stations, garages, airport runways/taxiways, and storage yards). Surface sand filtration systems are more suited for large drainage areas that have both impervious and pervious surfaces. This system is located at grade and is used to treat runoff from any urban land use. The constraints of the considered site dictate the appropriate style. Fundamental sand filter design and siting guidelines include:

Surface Sand Filter

- Drainage area that has been fully stabilized, plus use of a pretreatment BMP (e.g., grassed swales) at the entry point to ensure longevity.
- Geotechnical investigation required to identify soil infiltration rate. If known soil contamination is present, infiltration is not allowed.
- When infiltrating, 10 feet of separation between bottom of bed and seasonal high water table.
- Capture volume determined by local requirements and sized to treat the WQV.
- Sized to discharge the capture volume over a period of 12–48 hours.

Subsurface Sand Filter

- Sedimentation and filtration basins that are covered which are accessible to vector control personnel via access doors to facilitate vector surveillance and control.

Costs for both sand filter styles vary in accordance with the design. Table 2 details a number of core construction components and corresponding design considerations.

Table 2. Cost of design components and associated considerations

Component	Cost	Design Consideration
Excavation With underdrains	 \$2.80–\$5.05/ ft^2	Surface sand filters: installed in shallow depressions on surface. Underdrain required if subsoil infiltration

Component	Cost	Design Consideration
2 feet (min) to 3 feet	$3.90–$6.15/ft^2	rate < 0.5 in/hr. No greater than 8 feet ponding depth (shallower depth should be used in residential areas or near schools and parks). Subsurface sand filters: can be installed along the edges of roads.
Pretreatment		Surface: Provide stabilized inlets and energy dissipation. Install rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows to surface sand filters. For subsurface sand filters, use a sedimentation chamber.
Soil Media	$1.90–$5.05/ft^2	1 1.5–4 feet (deeper for better pollutant removal and hydrologic benefits). Total phosphorus composition < 15 ppm. Surface drawdown: 12–24 hrs.
Soil Media Barrier Geotextile Washed sand (2-inch layer) No. 8 aggregate (min 2 inches thick) No. 57 stone (1.5 + feet)	 $0.45/ft^2 $0.20/ft^2 $0.28/ft^2 $2.49/ft^2	When utilizing an underdrain, separate media from underdrain with 2 to 4 inches of washed sand (ASTM C-33), followed by 2 inches of choking stone (ASTM No. 8) over a 1.5 ft envelope of ASTM No. 57 stone.
Underdrain Pipe (includes drainage stone, with 5-foot spacing)	$3.60/ft^2	4-inch diameter minimum, schedule 40 PVC pipe with perforations (slots or holes) every 6 inches at 0.5% slope. Provide cleanout ports/observation wells for each underdrain pipe.
Hydraulic Restriction Layer 30-mil liner Concrete barrier	 $0.35/ft^2 $12.00/ft^2	If non-infiltrating, use hydraulic restriction layer. If infiltrating may use on vertical surfaces to restrict lateral flows to adjacent subgrades, foundations, or utilities.

Pretreatment is a critical element of sand filter design. Surface filters can utilize rock armored forebay for concentrated flows, gravel fringe and vegetated filter strip for sheet flows. In subsurface sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. Here the coarsest particles settle out and do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential for these sediments to clog the filter.

Additional Design Guidelines

Many guidelines recommend sizing the filter bed using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. The resulting equation, as derived by the city of Austin, Texas, (1996), is

$$Af = WQV\ d/[k\ t\ (h+d)]$$

Where:

Af = area of the filter bed (ft^2);

d = depth of the filter bed (ft; usually about 1.5 feet, depending on the design);

k = coefficient of permeability of the filtering medium (ft/day);

t = time for the water quality volume to filter through the system (days; usually assumed to be 1.67 days); and

h = average water height above the sand bed (ft; assumed to be one-half of the maximum head).

Typical values for k, are shown in Table 3.

Table 3 Coefficient of permeability values for stormwater filtering practices

Filter Medium	Coefficient of Permeability (ft/day)
Sand	3.5-10
Compost	8.7

The permeability of sand shown in Table 3 is extremely conservative, but is widely used since it is incorporated in the design guidelines of the City of Austin. When the sand is initially installed, the permeability is so high (over 100 ft/d) that generally only a portion of the filter area is required to infiltrate the entire volume, especially in a "full sedimentation" Austin design where the capture volume is released to the filter basin over 24 hours.

The preceding methodology results in a filter bed area that is oversized when new and the entire water quality volume is filtered in less than a day with no significant height of water on top of the sand bed. Consequently, the following simple rule of thumb is adequate for sizing the filter area. If the filter is preceded by a sedimentation basin that releases the water quality volume (WQV) to the filter over 24 hours, then

$$Af = WQV/18$$

If no pretreatment is provided then the filter area is calculated more conservatively as:

$$Af = WQV/10$$

Typically, filtering practices are designed as "off-line" systems, meaning that during larger storms all runoff greater than the water quality volume is bypassed untreated using a flow splitter, which is a structure that directs larger flows to the storm drain system or to a stabilized channel.

A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when 20% of the basin volume has been lost because of sediment accumulation.

Sedimentation Pond Outlet Structure: The outflow structure from the sedimentation chamber should be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. Gabion outflow structures should extend across the full width of the facility such that no short-circuiting of flows can occur. The gabion rock should be 4 inches in diameter. The receiving end of the sand filter should be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. When a riser pipe is used to connect the sedimentation and filtration basins (example in Figure 2), a valve should be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full. The riser pipe should have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers).

Full Trash Capture Compliance

This section provides trash-specific information to assist with upgrading either an existing BMP or the design of a planned BMP to meet the FCS definition. In addition to developing and adopting the Trash Amendments, the State Water Board provides implementation information on its Trash Implementation web page: https://www.waterboards.ca.gov/water_issues/programs/stormwater/trash_implementation.html.

The web page includes information on best management practices or Full Capture Systems, including lists of State-certified Multi-Benefit Trash Treatment Systems. So, when selecting BMPs for trash control, fact sheet users should refer to both this BMP fact sheet and the State Water Board's Trash Implementation web page.

Design Modifications to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

The surface sand filter must be configured to allow trash to enter the system and for trash to remain in the surface sand filter until it can be collected and removed. To meet the requirement, inlets must be designed to pass the peak flow produced by the one-year, one-hour design storm or the same flows as the capacity of the inlet storm drain and solids that would be retained by a 5 mm screen or mesh, must remain in the system.

Inlets

There are a multitude of inlet configurations that will allow trash to enter and be captured in a surface sand filter. An open inlet is recommended (Figure 2) to ensure that flow is routed into surface sand filters. A capture chamber is recommended for subsurface systems (Figure) that will allow smaller particles to enter the sedimentation chamber and larger gross solids to remain on top of the grate for collection.

Figure 1. Example subsurface inlet in parking lot.

Figure 2. Example surface sand filter inlet.

Pretreatment

Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. Pretreatment is beneficial to increase and consolidate trash capture while managing maintenance requirements. The diversion structure and gravel pad show in Figure 2 will slow flow and allow trash and gross solids to settle out while consolidating at the edge of the surface sand filter to make it easier for maintenance crews to collect and remove.

Trash Containment

Once trash has been captured in a sand filter it must be contained so trash does not escape the sand filter. Containment may be provided by one or more of these features:

- an external design feature or up-gradient structure designed to bypass flows exceeding the region-specific one-year, one-hour storm event; or
- the BMP having sufficient capacity to trap particles from flows exceeding those generated by the one-year, one-hour storm event; or
- the BMP having sufficient capacity to treat either the design flows or volumes through media filtration or infiltration into native or amended soils; or
- use of a maximum 5 mm mesh screen on all outlets.

Maintenance

Although sand filters are generally thought of as one of the higher maintenance BMPs, a California study indicated an average of approximately 49 hours a year were required for field activities. This was less maintenance than was required by extended detention basins serving comparable sized catchments.

Mitigating clogging is the greatest concern. The rate of clogging has been related to the TSS loading on the filter bed (Urbonas, 1999); however, the data is variable. Empirical observation of sites treating urban and highway runoff indicates that clogging of the filter occurs after 2–10 years of service. Presumably, this is related to differences in the type and amount of sediment in the catchment areas of the various installations. Once clogging occurs the top 2–3 inches of filter media is removed, which restores much but not all of the lost permeability.

Table 4. Typical maintenance activities and associated costs and frequency

Frequency	Cost	Activity
Routine Maintenance (required monthly to every 2 years)		Surface: Remove excess sediment, trash, and debris across the surface, inlet, and outlet. Check for and stabilize erosion. Subsurface: Remove accumulated material from sedimentation chamber, inspect for vector breeding.
Routine (small)	$1.87/ft^2$	
Routine (medium)	$0.62/ft^2$	
Routine (large)	$0.31/ft^2$	
End of Life Replacement (service life of 20 years)		Excavate to the depth of soil media. Test soil for excessive soil contamination of common stormwater pollutants (e.g. metals, nutrients). Continue to remove underlying soil if pollutants exceed standard for contaminated soil. Replace with clean soil.
Replacement (small)	$6.46/ft^2$	
Replacement (medium)	$5.21/ft^2$	
Replacement (large)	$4.90/ft^2$	
Note: Small System = 500 ft^2; Medium System = 2000 ft^2; Large System = 4000 ft^2 Underlined statement indicates that the activity may be required more frequently than shown in the table to meet the State Water Board maintenance criteria for Multi-Benefit Treatment Systems to be qualified as Full Capture Systems.		

Trash FCS

Maintenance to Prevent Trash Migration, Sustain Capacity, and Prevent Reduced Functionality

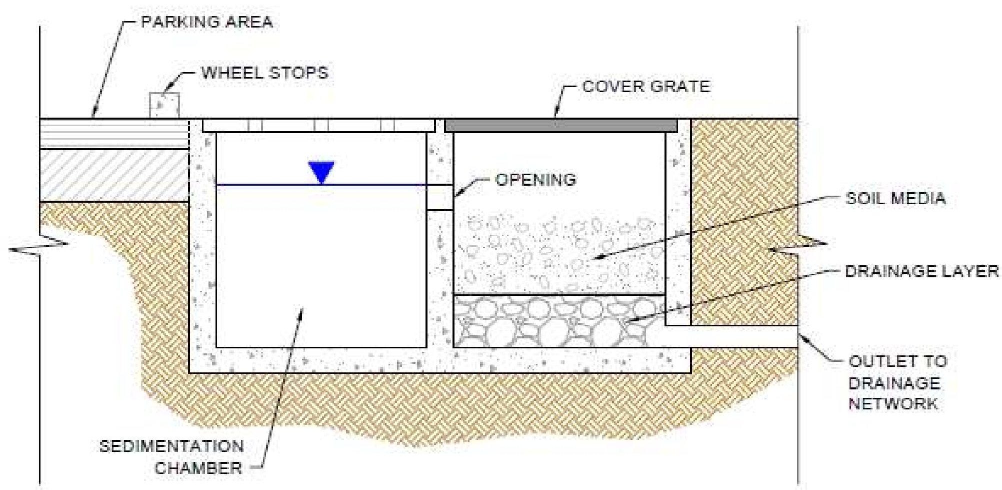
For Multi-Benefit Treatment Systems to be qualified as Full Capture Systems, the State Water Board requires regular maintenance to maintain adequate trash capture capacity and to ensure that trapped trash does not migrate offsite. Additionally, the State Water Board requires the BMP owner to establish a maintenance schedule based on site-specific factors, including the design trash capacity of the Sand Filter Multi-Benefit Trash Treatment System, storm frequency, and estimated or measured trash loading from the drainage area. To meet those criteria, it is likely that the frequency of trash and debris removal will have to be increased above the recommended monthly interval during the wet season to prevent trash from being blown from the BMP or being washed out of the surface sand filter in the subsequent rain events (see Table 4). Depending on the frequency and size of storms, and upstream pollutant characteristics, trash and debris removal can be as frequent as before and after every wet weather event. The optimum maintenance interval can best be determined by observing the BMP in operation for a wet season.

Trash maintenance not only plays a role in the functionality of the surface sand filter but also in the aesthetics and public perception of the surface sand filter (and of all BMPs). Part of maintaining positive perception among the public is the visibility of a well-maintained BMP. This positive perception can self-perpetuate further support for integrated stormwater management practices and therefore further investment in regular maintenance.

Schematic

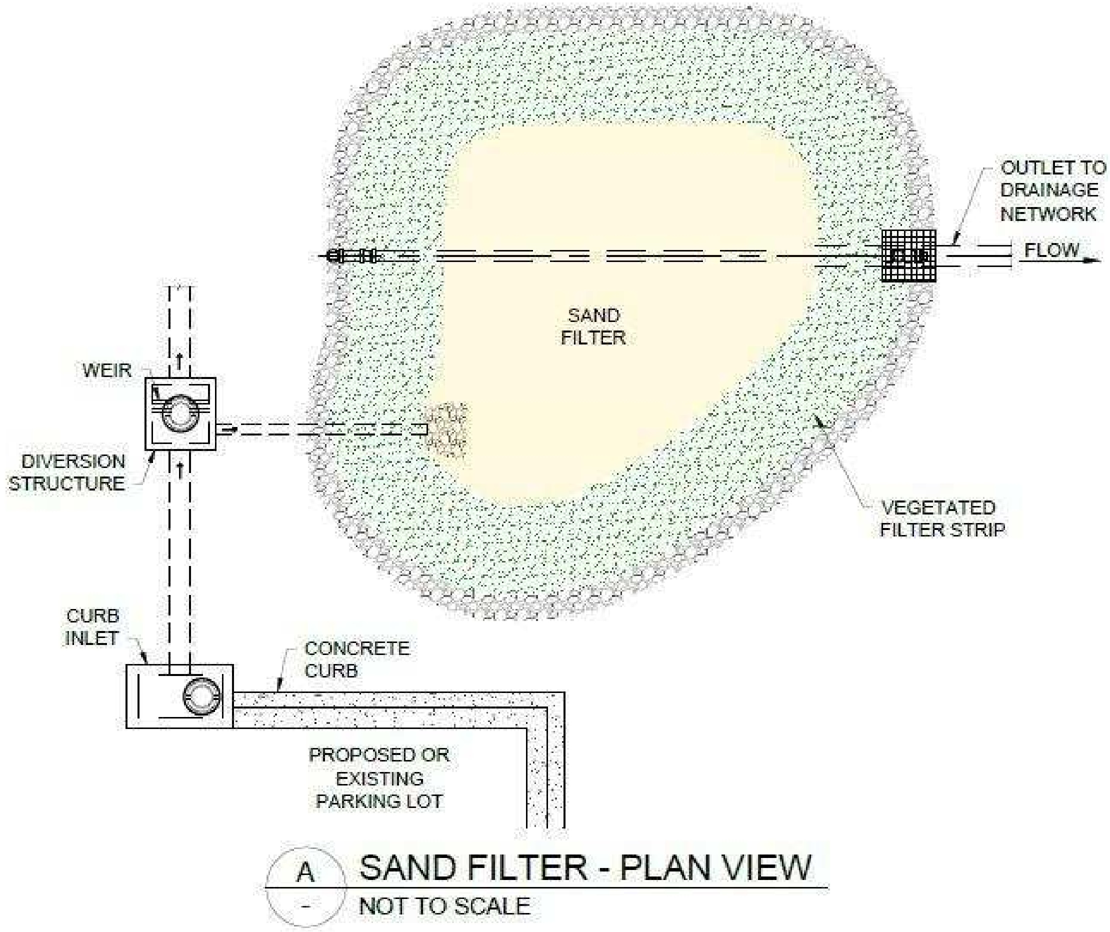
SUBSURFACE SAND FILTER
PLAN VIEW

NOT TO SCALE



SUBSURFACE SAND FILTER
CROSS SECTION

NOT TO SCALE


OUTLET TO
DRAINAGE
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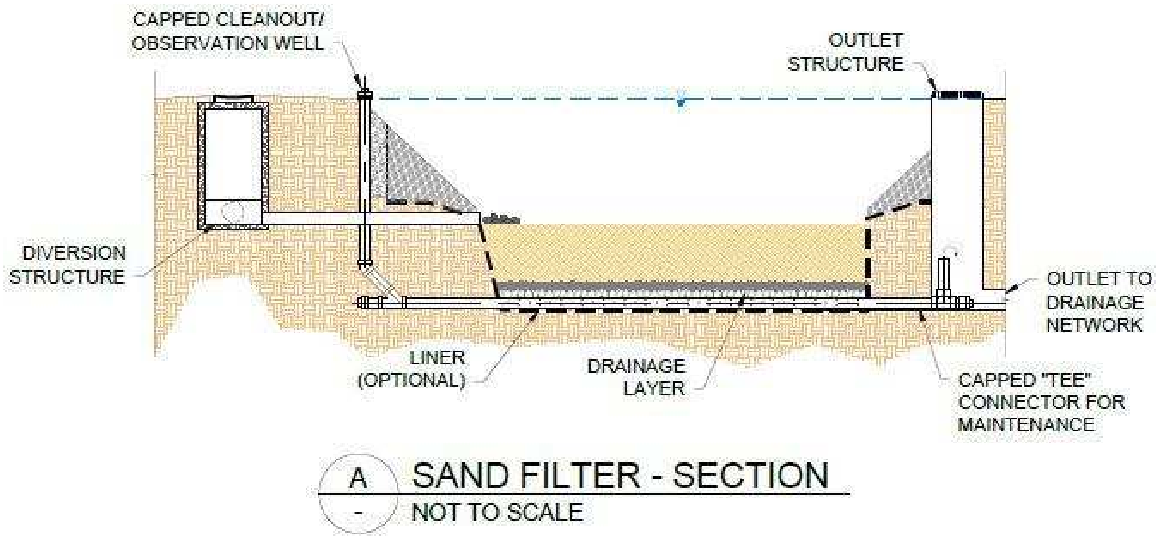
SAND FILTER - PLAN VIEW
NOT TO SCALE


CAPPED CLEANOUT/
OBSERVATION WELL
OUTLET
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DIVERSION
STRUCTURE
OUTLET TO
DRAINAGE
NETWORK
LINER
(OPTIONAL)
DRAINAGE
LAYER
CAPPED "TEE"
CONNECTOR FOR
MAINTENANCE
A
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SAND FILTER - SECTION
NOT TO SCALE

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