Stormwater Runoff

BEST MANAGEMENT PRACTICES FOR MARINAS:

A Guide for Operators

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Stormwater Runoff Best Management Practices for Marinas: A Guide for Operators

Source-Control BMPs

Stormwater Treatment BMPs

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"Stormwater runoff" and "Best Management Practices," or BMPs, are terms being used more and more to discuss environmental protection and water quality. They are also terms marina owners and operators are hearing more frequently in relation to their facilities. But what do these terms mean and how do they relate to marina operations from a practical perspective?

This guide discusses why stormwater runoff management is important at marinas and what facility owners can do to address potential problems. The guide is designed to familiarize readers with the options available and help them determine which options could be applied at a specific site. Although intended primarily for marina owners and operators, this information should also be of interest to others involved with boating facilities and environmental management including government and agency officials, planners, consultants and the public.

Stormwater Runoff, Hull Maintenance and BMPs — They All Go Together

Stormwater runoff is simply rainwater that flows across the land. This water picks up pollutants and carries them into wetlands, creeks and estuaries where they can degrade water quality and threaten aquatic habitats. Any type of development can increase the amount of stormwater runoff, alter natural drainage patterns and increase the concentration and types of pollutants carried by runoff.

Runoff is a concern for marinas in areas used for boat hull maintenance. The materials and compounds used to repair boats, control fouling and corrosion, and the wastes generated by sanding, scraping, painting, varnishing and fiberglassing can contain metals, solvents, hydrocarbons and other contaminants.

Preparing a vessel for painting can generate paint chips, dust and particles that may contain metals such as copper, zinc and lead. Although some of these metals are relatively harmless on land, improper handling can allow them to get into the water. Even at very low levels, these metals can be toxic to marine life. (Toxic levels are so low that harmful concentrations are often measured in terms of parts per billion). Because many contaminants tend to attach themselves to solid particles, even soil and fine debris in hull maintenance areas can pick up potentially harmful materials. In addition to adversely affecting marine life, material washed into the water from hull maintenance areas can also contaminate sediments (sand and mud) in the marina basin, posing problems for dredging and the disposal of dredged material. Finally, allowing pollutants to seep into the ground can eventually contaminate the site itself, posing problems if the marina is ever sold.

It is easy to see why it is important to keep a close eye on hull maintenance areas to ensure that the associated wastes do not get into the water. Under the Federal Coastal Nonpoint Source Pollution Control Program, each state is required to develop plans to reduce pollution from stormwater runoff from a variety of sources, including marinas. This program seeks ways to reduce the total amount of solids in runoff from boat maintenance areas in existing marinas. The question is, how best to do this?

Even relatively simple practices can help reduce potential pollution from hull maintenance areas.

This is where stormwater **Best Management Practices** come in. Simply put, BMPs are anything a marina owner or operator can do to help prevent or reduce the amount of pollutants coming from their facility. Which BMPs are really "best" for a particular facility depends on the marina and the activities that occur there.

BMPs can involve a wide range of activities including:

- Building new structures,
- Using new or different equipment or products,
- Changing operating procedures and improving housekeeping practices.

Different Marinas, Different BMPs

When evaluating BMPs for use at a site, it is important to remember all marinas are different and, in some respects, unique. Marinas in different parts of the country can vary tremendously in terms of their size, services offered and operating characteristics because of differences in boat use, number and size. Even in relatively small geographic areas there can be a great deal of variation in these facilities. Marinas in coastal North Carolina range in size from 11 to 400 slips.

Obviously, the diversity in size and type of marinas make it difficult to generalize about BMPs for these facilities. A BMP that works well at one marina might be inappropriate for another because of location, site, economic or operational considerations. Each marina must be examined on a site-specific basis to ensure that the most effective and suitable BMPs are selected.

Although there is no "one size fits all" set of BMPs for marinas, there are a number of BMPs often suggested for reducing potential stormwater pollution from hull maintenance areas. Chances are one or more of the BMPs discussed here would be suitable for most facilities.

BMPs often fall into two categories commonly known as **source-control BMPs** and **stormwater treatment BMPs**. Source-control, or non-structural, BMPs focus on keeping stormwater from coming into contact with pollutants. Stormwater-treatment BMPs usually involve building structures or installing devices to treat or manage runoff. Source-control BMPs are generally preferred because they usually cost less and can keep most, if not all, pollutants out of the water.

SOURCE-CONTROL BMPS

Indoor Maintenance Areas

One of the most effective ways to reduce contaminated stormwater runoff is to move maintence and repair work indoors or under roofs where it is shielded from rainfall. However, it may also be one of the most impractical alternatives for many marinas due to cost, size, space limitations or zoning restrictions, especially when traditional structures are used.

For marinas with enough room, temporary work enclosures can be a relatively inexpensive way to protect maintenance areas from rain while also extending the work season. The enclosures are pre-fabricated structures made of heavy-gauge polypropylene plastic stretched over a tubular metal frame. Although the plastic has a life expectancy of three years, the structure pictured below is seven years old and has survived a hurricane and a number of severe "nor'easter" storms without major damage.

Planning Considerations

- Indoor work areas should have hard floors to facilitate clean up. Floor drains should be avoided or covered while work is being done.
- Temporary enclosures come in various sizes up to 100 feet long, 30 feet wide and 23 feet high. Usually, enclosures come as a kit with materials and assembly instructions. The marina must supply the labor to actually build the structure. Construction does not usually require special tools or skills, but it can be time consuming.

Temporary work enclosure located on Shelter Island, New York.

- Because temporary structures do not have permanent foundations and are portable, they may not require permits or zoning approvals in some locations and may also be exempt from capital improvement taxes. Check with your local building department regarding the laws and regulations in your area.

Moving certain types of work, such as painting, indoors or into enclosed areas may require the use of special ventilation equipment, protective clothing, respirators and safety equipment to meet requirements and regulations of the Occupational Safety and Health Administration, Clean Air Act and local fire safety laws.

Cost

Unless a building is already available, it is not feasible for most marinas to build a structure solely for maintenance activities. Typical costs for temporary work enclosures range from $3 to $5 per square foot for materials. This does not include labor.

Outdoor Maintenance Areas

Usually, it is not practical for a marina to do all of its maintenance work under a roof. If work must be done outdoors, it should be done over dry land in specially designated areas that are designed for such purposes and are away from the water's edge. These areas should be clearly marked with signs. Customers and staff should be prohibited from performing maintenance work outside these areas.

Planning Considerations

- Locate maintenance areas as far away from the basin and waterways as possible to prevent contaminants from getting into the water.
- Maintenance areas should have a hard, impermeable surface that can be easily vacuumed or swept to remove contaminants. Concrete floors are particularly easy to clean, and they are resistant to solvents and petroleum products.
- Maintenance areas should be swept or vacuumed regularly and the collected wastes disposed of properly (check with your local solid waste agency on how to dispose of paint chips safely). Special attention should be paid to weather conditions, with cleanups being done more frequently if there is a chance of material being dispersed by wind or rain. Avoid hosing down the work area.

Concrete work pads are raised and surrounded by permeable gravel to control runoff.

Outdoor work area with paved, impervious surface.

- Care should be taken to ensure that stormwater runoff from other parts of the marina does not flow over the maintenance area. This can be done by proper siting or by using berms or curbs to divert water from the area.
- If the maintenance area cannot be properly cleaned, rainwater falling on it should be directed to a stormwater treatment device before it flows into the marina basin. These devices are discussed in the latter half of this document (see page 9).
- Maintenance areas should be located away from storm drains. If storm drains are nearby, they should be covered when work is being done to prevent material from being carried into the water.
- If blasting or painting is done outdoors, vertically hung tarps or enclosures should be used to contain dust, abrasive grit and/or paint. Work should be monitored (especially on windy days) to ensure that paint, dust or blasting grit is contained or stopped if conditions prevent containment.

Cost

Costs for hull maintenance areas vary widely depending on the specific marina. In some cases, existing infrastructure such as parking lots or other paved surfaces may be converted to maintenance areas with minimal expenditures. Constructing a new concrete pad with appropriate runoff controls capable of handling large boats can cost $10,000 or more in coastal North Carolina.

Work Outside of Designated Hull Maintenance Areas

In some marinas, it may not be possible to have a designated work area for all hull maintenance activities due to space limitations or cost. If work must be done outside a designated area, precautions should be taken to contain waste and debris and prevent them from entering the water. Tarps may be used to contain paint chips and dust from hull maintenance activities.

Planning Considerations

- In areas without a sealed or impervious surface, perform all work over tarps or drop clothes. Ideally, tarps should be placed beneath the cradle or boat stand.

Tarps should be used to contain paint chips and dust from hull maintenance activities.

- Tarps should be cleaned frequently by vacuuming or sweeping. Special attention should be paid to weather conditions — clean tarps immediately if there is the possibility of rain or wind. Work should be avoided on windy or rainy days.
- If customers are allowed to do maintenance work on their boats, they should be required to clean up the area when done working. Separate, covered and labeled containers should be provided for waste materials. Have tarps available for customer use to assure that the wastes are collected properly.
- When maintenance work has to be done near water, consider the use of additional BMPs such as the innovative paint removal techniques and dustless vacuum sanders described below.

Innovative Paint Removal Techniques

Different paint removal technologies can be used as BMPs to eliminate or at least contain paint chips and dust associated with hull preparation activities. Special equipment, products or procedures can also reduce the amount of waste material generated and ensure it does not get into the environment.

Plastic Media Blasting

New abrasive hull blasting technologies are being used in other states and may become available in North Carolina. These technologies utilize a process to reclaim and reuse media made of plastic. In this procedure, the boat containment area must be completely enclosed to trap the media and paint waste. The collected mixture is fed into specialized equipment (see truck in photograph on page 7) that sifts and separates most of the paint dust and chips from the media. The plastic media can then be reused. In addition to containing paint dust and chips, this process can significantly reduce the amount of material that has to be disposed of when stripping a hull. For example, the plastic media stripping of a 19-foot boat produced a total of 200 pounds of waste and media. The equipment recovered 185 pounds of reusable media (containing a small amount of paint), leaving only 15 pounds of paint for disposal.

Boat enclosed for plastic media hull blasting.

Planning Considerations

- Specialized equipment and training is required for plastic media blasting. Some companies have mobile equipment and will perform this service on site for a set fee.
- Clean up and disposal costs can be reduced by recovering the media and containing dust and debris.

Mobile equipment used to separate and recover plastic blasting media.

- Because the media cannot remove anything harder than itself, these techniques may not be effective for preparing all surfaces. For example, plastic media may not remove corrosion or barnacles from props, shafts or rudders. However, it will remove paint without damaging sound gel coat, rubber, chrome or glass surfaces.
- Some softer media may not work well on very durable, pliable paints (such as coal or tar epoxies). Paint around edges may have to be removed by hand. Sanding is usually required before painting a blasted hull.
- Be careful when blasting boats with damaged or blistered gel coats. Blasting may open blisters or voids that will have to be filled before painting. Even sound gel coats may contain small voids that may have to be filled after blasting.

Cost

Equipment costs for a blasting system that incorporates media recovery and reclamation start at $25,000, not including training or the media. Contractors with their own mobile equipment will blast hulls with plastic media on site for approximately $17 to $18 per foot. Length is calculated as the length of the boat at the waterline plus one-half the beam. (Approximate cost for blasting a “typical” 30-foot powerboat is about $630.) Discounts may be available for volume work.

“Environmentally-Sensitive” Chemical Paint Strippers

Chemical paint strippers can actually eliminate paint chips and dust associated with sanding, scraping and blasting. There are now less toxic and less hazardous alternatives to strippers that use methylene chloride and other organic solvents. New products are non-chlorinated, biodegradable, have low volatility and are not listed as hazardous. Some of the more environmentally-sensitive strippers may be water based and use less toxic materials (look for dibastic esters, semi-aqueous terpene-based products, detergents and C9 to C12-based hydrocarbon strippers). Although the new strippers themselves may be considered non-hazardous, metals and chemicals from the paint they remove may be hazardous. Therefore, all residue and wash water must be collected and disposed of properly (contact your local solid waste agency for how to properly dispose of wastes).

Planning Considerations

- Environmentally-sensitive paint strippers are usually made without toxic or caustic chemicals, so they do not burn skin and will not release harmful fumes like some of the more aggressive chemical strippers. This can reduce or eliminate the need for special ventilation equipment and associated costs.

Chemical paint stripper and covering cloth applied to boat hull.

- These environmentally-sensitive strippers may require more experience and expertise to apply correctly, as well as more time to work effectively. Some may have to remain on the hull for two to 24 hours depending on the condition of the hull and the air temperature. Lower temperatures require more time, and some products do not work well below 32°F.
- When stripping, place plastic around and under the work area to catch any drips. Some products come with a special paper that is placed over the stripper after it has been applied. The paper helps contain the chemicals and dissolved paint.
- Strippers may not work on all paints, such as 2-part epoxies or chlorinated rubbers. Check with the manufacturer for specific applications.
- Machines are used to pressure wash and collect washwater in one step from a chemically stripped hull. Stripping residue and washdown water may be contaminated by paint and must be collected and disposed of properly, possibly as a hazardous waste.

Machine used to pressure wash and collect washwater in one step from a chemically stripped hull.

- Special machines that pressure wash the hull and collect the washwater in a one-step process are available for this purpose. It is estimated that a 30-foot boat would generate approximately 30 gallons of waste, including washdown water.

Cost

Cost will vary depending on the product used, conditions and layers of paint to be removed. Non-toxic, water-based strippers can cost $40 to $60 per gallon. According to one manufacturer, a gallon of their product covers an average of 50 square feet of hull so the estimated cost of materials is one dollar per square foot. A 30-foot boat may require five to six gallons. The manufacturer also estimates disposal cost for the residue is about $30 per boat depending on size. Complete pressure washing/vacuum collection systems cost $5,000. Cost can be reduced if the marina has an existing pressure washer and/or vacuum system.

Dustless Vacuum Sanders

Dustless vacuum sanders are sanders (or grinders) attached to a vacuum system that starts automatically when the sander is turned on. These units can trap up to 98 percent of the dust generated by hull sanding, making them particularly suitable for situations where work must be done near the water.

Planning Considerations

- By containing dust, vacuum sanders keep work areas and workers clean, saving time and money in clean up.
- To recover costs, some marinas rent the sanders to customers for use on their own boats for fees ranging up to $15 per hour.
- Advertising and training are necessary to encourage use.
- Studies indicate that sanders may collect an average of two ounces of dust per foot of boat sanded (3.75 pounds for a 30-foot boat). This material must be collected and disposed of properly.

Cost

Vacuum sanders vary depending on size and features. Typical costs range between $1,100 and $1,400.

Dustless vacuum sander. Vacuum unit is at lower right.

STORMWATER TREATMENT BMPS

Stormwater treatment BMPs are structural devices constructed to manage and treat runoff contaminated with pollutants. In some cases, these BMPs are also used to divert runoff away from areas where pollutants may occur. These devices normally work in one of three ways: capturing runoff and allowing it to filter into the ground (infiltration); holding the runoff long enough for pollutants to settle out (detention/retention); or some combination of these two processes. Some devices are designed to be aesthetically pleasing.

When considering treatment BMPs, a good understanding of the site's drainage patterns and the rate, direction and volume of water coming from different areas is key to designing an effective system. In many cases, the services of a professional engineer or landscape architect may be required to provide this analysis. The information provided here is intended to help operators and owners evaluate and begin screening alternatives for potential applicability at their sites. It should not be considered a design manual or a substitute for professional engineering guidance. See page 19 for a listing of more technical publications on this topic.

In general, marinas should try to reduce the total amount of runoff coming from the entire facility by using permeable material such as special pavers or washed marl outside of maintenance areas. Permeable coverings slow runoff and allow water to filter into the ground rather than run directly into the basin. Redirecting slopes away from the shoreline can also help.

In many marinas, much of the runoff comes from offsite so it may not be practical to capture and treat all of the runoff. However, structural BMPs should be sized to collect and treat at least the first 1 to 1.5 inches of rainfall from impervious work areas. This is often called the "first-flush" because it usually contains most of the pollutants. To prevent premature failure, BMPs should also incorporate provisions for handling overflow from storms greater than the design rainfall.

There are many stormwater treatment BMPs but not all of them are applicable to marinas because of space, cost and site conditions. High groundwater tables, limited space and aesthetic and safety concerns are just a few of the factors that may limit the type of BMPs that can be employed at existing marinas. The BMPs discussed here do not cover the full range of practices available. However, the BMPs in this guide are generally considered most suitable for conditions commonly found in marinas and for retrofitting existing boating facilities.

Stormwater treatment BMPs are structural devices used to manage and treat runoff contaminated with pollutants. Types of stormwater treatment BMPs that may work at marinas include:

- Vegetated Filter Strip
- Infiltration Trench
- Dry Well
- Vegetated Swale
- Rain Garden or Bioretention Area
- Water Quality Inlet Insert
- Water Harvesting
- Permeable Pavement
- Retention/Infiltration Chamber

Vegetated Filter Strip

What It Is

Vegetation, either grass or a combination of trees and shrubs, planted as a buffer along the water's edge to filter stormwater runoff and remove contaminants and soil particles before they reach surface waters. Filter strips can be particularly effective at removing large particles, such as paint chips.

How It Works

The vegetation slows runoff carrying sediments, chemicals and nutrients. This causes the particles to settle out before reaching the surface water. In some cases, nutrients or chemicals in the runoff may be taken up by the vegetation, rather than going into the surface water.

Vegetated filter strip in Wilmington, NC.

Potential Benefits

- Helps prevent pollutants from entering waterways, protecting water quality and keeping sediments in the marina basin free from contaminants that may impact future dredging operations.
- Can help reduce sediment deposition in the marina basin, reducing the need for dredging.
- Creatively landscaped strips can provide aesthetic and recreational amenities at a marina, such as picnic areas, if such activities do not disturb the vegetation.

Planning and Technical Considerations

- Filter strips must be a minimum of 5 feet wide to be effective. Wider strips, up to 30 feet, are better for filtering sediment and pollutants.
- Filter strips are most effective on slopes of 5 percent or less and will not function well on slopes greater than 15 percent. Steeper slopes require wider strips. As a general rule, an additional 4 feet of width should be added for each additional one percent of slope.
- A given filter strip can only handle runoff from relatively small areas (one to two acres). Be careful to ensure that all of the water from the upland area passes through the strip and cannot bypass it. Often, concentrated flow will need to be dispersed on grade by using a level spreader, such as a shallow stone trench that spreads the flow evenly at the edge of the strip. Because water has to flow evenly over the strip for it to be effective, the landward edge of the strip must be at a constant elevation (no dips, depressions or gullies).

Level spreader constructed of concrete.

- Plants suitable for the particular area and climate must be used. In marine areas, salt-tolerant species such as salt meadow cord grass (*Spartina patens*) or needle rush (*Juncus roemerianus*) should be considered. Your local Cooperative Extension Service or Soil and Water Conservation District office can provide information on the best species for your location.
- Strips require regular maintenance. Reseeding, watering, fertilization and some mowing may be required to maintain the necessary dense growth of vegetation. Annual inspections should be conducted. Rills, gullies and channels should be repaired as soon as possible.

Cost

Filter strips are one of the least expensive stormwater runoff control measures to implement. Seeding costs range from $20 to $100 per 1,000 square feet. The cost for sod is about $125 per 1,000 square feet ($0.40 to $6.25 per linear foot for a 20- to 50-foot wide strip) depending on site conditions. Level spreaders range from $5 to $50 per linear foot, depending on construction materials used.

Infiltration Trench

What It Is

A shallow trench, usually 3 to 8 feet deep, filled with stone to create an underground reservoir that holds runoff and allows it to slowly percolate through the bottom of the trench into the surrounding soil.

How It Works

Polluted runoff is diverted to the trench before it reaches surface waters. The trench retains all or some of the runoff, depending on the design. The stormwater slowly filters through the soil, and pollutants are removed by adsorption, sedimentation, and decomposition by bacteria. This practice is particularly effective in the sandy soils of coastal North Carolina, provided the local water table is not near the surface.

Potential Benefits

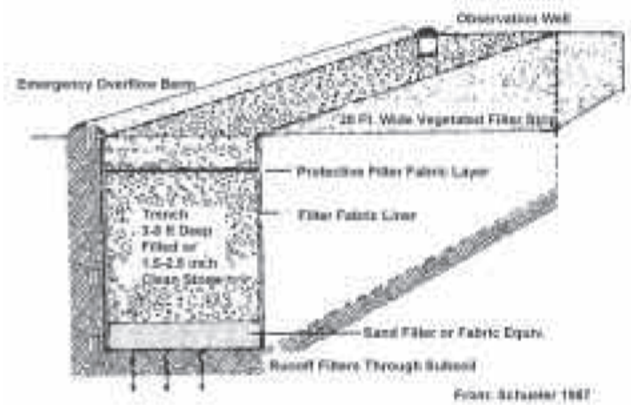
- Helps prevent pollutants from entering waterways, protecting water quality and keeping sediments in the marina basin free from contaminants that may impact future dredging operations.
- When properly designed and maintained, trenches can provide effective treatment for dissolved pollutants as well as particulate matter.
- Relatively easy to fit into margins and around perimeters of developed areas with limited space.

Planning and Technical Considerations

- Trenches are only feasible where soils drain well (sandy). The bottom of the trench should be at least 3 feet above the seasonal high groundwater table. An infiltration trench measuring 2 feet deep will require the seasonally high water table to be 5 feet from the surface. This requirement restricts the use of an infiltration trench at many locations.
- Infiltration trenches, like filter strips, are most easily used on one to two acre drainage areas. Ideally, these practices will be placed in relatively flat areas, but they can be constructed to be long and narrow to minimize costs on sloped areas.
- Trenches can be designed to collect all or some of the expected stormwater runoff. “Water quality” trenches that are designed to catch only the “first flush” of stormwater, which contains most of the pollutants, may be the only trenches suitable for many marinas because of space considerations. (Example: every acre of impermeable surface generates 3600 cubic feet of first flush runoff. This translates into an infiltration trench that is 2 feet deep, 200 feet long and 20 feet wide. Deeper trenches require proportionally less surface area.)
- Because they are susceptible to clogging, infiltration trenches should only be used in conjunction with vegetated filter strips or some other method that traps coarse sediments.
- Clean, washed 1.5- to 2.5-inch stone should be used to fill the trench to prevent clogging. Crusher run should never be used. A layer of filter fabric placed 6 inches below the surface helps trap sediment before it clogs the entire trench, reducing maintenance costs.
- Shallow, wide trenches (as opposed to narrow, deep trenches) enhance pollutant removal. The stone fill should extend below the frost line so the trench functions in cold weather. In coastal North Carolina, the frost line ranges from 4 to 6 inches deep.
- Trenches should be sited away from building foundations. If the trench is down slope, it should be a minimum of 10 feet from the building. If the trench is up slope, it should be 100 feet away from the building.
- Trenches should be designed to hold water for at least six hours after it rains and to drain completely within three days after a storm. A perforated PVC pipe should be installed as an observation well. Before a trench is installed, a soil test should be performed to verify soil type and seasonally high water table.

Cost

Infiltration trenches are one of the most economical stormwater BMPs for small sites. Cost varies depending on the site and the specific design. In sandy soils, constructing infiltration trenches will typically cost $5 to $10 per square foot.



Dry Well

Important Notice:

Due to improper use of dry wells for waste disposal that can cause serious groundwater contamination, dry wells as stormwater drainage wells are currently illegal in North Carolina according to North Carolina Administrative Code (15A NCAC 2C .0209(e)(2)(B)). They are also prohibited for most other disposal purposes under General Statute 143-214.2(b).

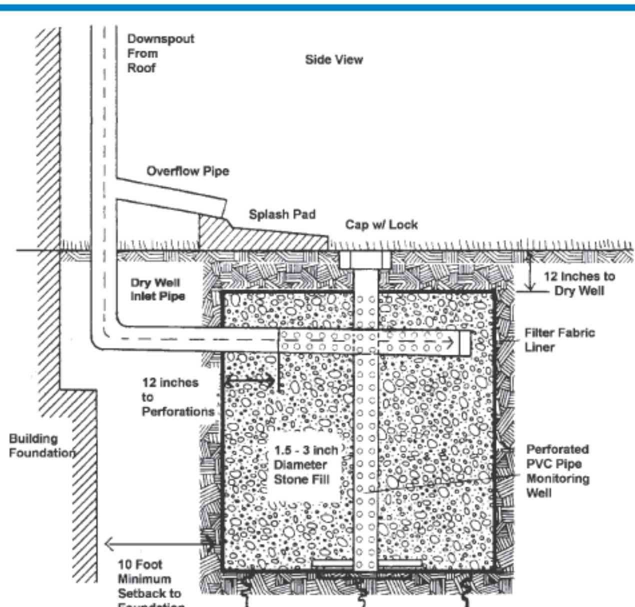
Additionally, G.S. 87-88(j) requires a permit from the Environmental Management Commission before using a well for any other type of recharge or injection. For updates on regulations or policy affecting use of dry wells, refer to **http://h2o.enr.state.nc.us/aps/gpu/uic/index.htm.**

What It Is

An excavated pit filled with clean stone (typically 3 to 12 feet deep) that is usually designed to collect and store stormwater from rooftops or other relatively "clean" runoff.

How It Works

Runoff enters the dry well through an inflow pipe (such as a roof gutter downspout) and from surface infiltration. The water then infiltrates down through the subsoil rather than running over land. This technology works best when there is not a seasonally high water table.



Adapted From: Schueler 1987

Potential Benefits

- Dry wells can be used to manage peak discharges from storms and reduce the overall volume of stormwater runoff from a marina site. This may help eliminate the need for other stormwater management measures or reduce the size required.
- Because dry wells normally collect relatively clean water, they can provide good quality groundwater recharge.

Planning and Technical Considerations

- Dry wells are only suitable for sites where soils are well drained (sandy) and the well can be designed so the bottom is a minimum of 3 feet above the seasonal high groundwater table, bedrock or other impervious surface (clay). Thus their use is limited in coastal North Carolina, where water tables often are much closer to the surface.
- Wells are susceptible to clogging and possible failure from sediment. They should not be used where they will receive runoff that carries high sediment loads. This is almost never a problem when treating rooftop runoff.
- To prevent clogging and promote infiltration, the well should be filled with 1- to 3-inch diameter clean (washed) stone and lined with filter fabric.
- Locate wells a minimum of 10 feet away from building foundations.
- Dry wells should be designed to capture, at minimum, roof runoff from a first flush rain (1 to 1.5 inches). An inch of rain on a 1,000-square foot roof generates 600 gallons of runoff. The dry well must store a corresponding amount of water.
- An observation well should be installed in each dry well to make sure it drains properly. A perforated PVC pipe installed vertically in the well can be used for this purpose. The pipe should have a removable cap on top and be anchored with rebar at the bottom.

Cost

The cost for a dry well varies depending on the site and design specifications. Because dry wells and infiltration trenches are similarly constructed, the cost of a dry well should be close to — or perhaps slightly higher than — the cost of a trench.

Vegetated Swale

What It Is

A vegetated channel that looks similar to a ditch but is wider. The channel has a gentle slope designed to transport and treat stormwater runoff. Vegetated swales are sometimes called "biofilter" swales and are commonly used as a substitute for curb and gutter systems.

How It Works

Surface water is directed to a vegetated channel where gentle slopes and dense vegetation (typically grass) slow water flow. The reduced flow combined with the vegetation provides moderate removal rates of particulate pollutants from runoff. The pollutants are trapped, filtered and infiltrated into the soil.

Potential Benefits

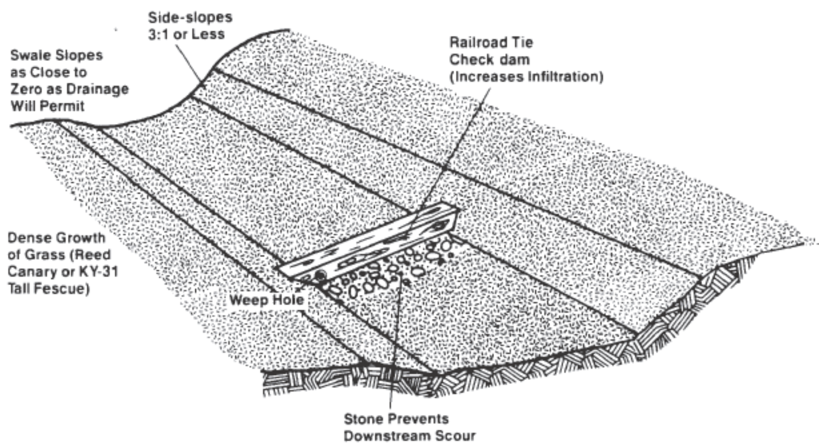
- Protects water quality by removing more pollutants from runoff than gutters, pipes, ditches or other conveyances.
- Diverts runoff from areas that may be contaminated with pollutants, such as hull maintenance areas.
- Less expensive than curb and gutter drainage systems and simple to construct.
- Enhances the natural landscape and provides aesthetic amenities.

Planning and Technical Considerations

- Swales are most suitable for relatively small sites (less than five acres) that have low to moderate density development and less than 50 percent of impervious surface. Swales are also suitable for sites where the percentage of impervious cover is small. Finally, swales can be used in parking lots to break up the impervious cover.
- Because they have limited capacity to treat runoff from large storms, swales may have to be used in conjunction with other BMPs depending on site conditions and the level of runoff treatment required.
- The slope of the swale along its axis should be as close to zero as possible while still allowing drainage. It should never exceed four percent. Side slopes should be no greater than 3:1 (horizontal to vertical).
- The site should have well-drained soil. Because soil compaction can inhibit performance, swales should not be used for boat storage or parking. The bottom of the swale should be at least 1 foot above the seasonal high groundwater level.
- Swale slopes should be designed to prevent erosion during a two-year storm and sized to handle the flow from a ten-year storm. In coastal regions of North Carolina, these storms range from 4 to 6 inches. A stabilized outlet or level spreader should be provided at the down slope end to prevent scour and erosion.
- Check dams (such as railroad ties sunk halfway into the swale with a weep hole and stone on the downstream side) can be used to flatten slopes and promote infiltration.
- In cases where water flow is high and could cause erosion, the use of turf reinforced mats (TRM) is encouraged. These mats help anchor the grass roots, holding the grass in place during high flows. TRMS are available at most contractor supply centers.
- A dense cover of vegetation must be established and maintained. (Contact your local Cooperative Extension or USDA Natural Resources Conservation Service office for the best species for your location.) Vegetation should be kept at a height of at least 4 to 6 inches to promote infiltration.
- Maintenance is minimal and primarily involves periodic mowing, spot reseeding, debris removal and, if needed, watering.

Cost

Swales are relatively inexpensive. The cost for a 15-foot wide swale with 3:1 side slopes is approximately $7 to $13 per linear foot depending on the method of seeding.



Rain Garden or Bioretention Area

What It Is

Rain gardens, also called bioretention areas, are shallow depressions that collect water. Rain gardens are aesthetically pleasing because they are planted with vegetation, usually grasses or a combination of shrubs and small trees. The garden is designed to capture and infiltrate the first flush of runoff, reducing nutrient, sediment, oil, grease and bacterial pollution.

How It Works

Runoff is directed to the shallow depression. Water flows through the surface of the garden and, depending upon the surrounding soil type, either infiltrates to shallow groundwater or is collected by underdrains at the bottom that slowly release the water into the basin or an adjoining waterway. The vegetation removes some nutrients, and the soil removes metals. Bacteria trapped on the surface eventually die because they are exposed to air and sunlight. Water does not pond for more than one day, so mosquitoes are not an issue. (Mosquitoe larvae need a minimum of four days in water to hatch.)

Rain garden constructed at the NC Aquarium in Manteo. (Photo courtesy of NC Aquarium staff)

Potential Benefits

- Can be sited nearly anywhere on the property, provided the garden intercepts some runoff.
- Simple to construct in coastal North Carolina, and can be installed in all soil types provided there is not a high water table.
- Removes many pollutants at a very high rate.
- Aesthetically pleasing and can be integrated into the landscape.

Planning and Technical Considerations

- Rain gardens are best located in sandy soils, but can also be constructed in clay soil regions. Construction is more challenging and more expensive in clay soils.
- Bioretention areas work best when they receive runoff from very stable drainage areas, such as established grassy lawns, rooftops or asphalt parking lots. They clog easily if runoff from disturbed surfaces or dusty gravel parking lots drain to the garden. Individual rain gardens can easily treat drainage areas of two acres or less. However, there are instances where much larger drainage areas (up to five acres) could be treated by a single rain garden.
- A rain garden's size should be five to seven percent of the contributing drainage area. For example, a rain garden used to treat 10,000 square feet (nearly 0.25 acres) of parking lot and rooftop should have a surface area of 500 to 700 square feet, assuming a ponding depth of 7 to 9 inches. For more detailed information on sizing a rain garden, please refer to the rain garden website found at the end of this guide.
- When siting a rain garden in sandy soils, a shallow depression 9 to 12 inches deep is constructed to capture runoff. If shrubs and trees are planted, 2 to 4 inches of mulch is placed on the surface.
- A deeper basin is excavated in clay soils, often 4 feet deep. Underdrains and a gravel storage layer are placed at the bottom of the basin, and a special sandy soil media fills much of the remaining volume. As with sandy soils, 9 to 12 inches are

Installation of plants in a rain garden at Carolina Beach State Park Marina.

left unfilled by soil. Plants and mulch "top off" the rain garden. The underdrain will direct water to an adjoining waterway or the basin. During large storms, water will bypass the garden or flow out a designated point in the bioretention area.
- Some very attractive plants can tolerate rain gardens, including Virginia Sweetspire (*Itea virginica*), Southern Wax Myrtle (*Myrica cerifera*) and Sweet Pepperbush (*Clethra alnifolia*). Centipede or Bermuda grass can also tolerate the sometimes very wet or very dry conditions. As with vegetated filter strips, please consult your local cooperative extension office for advice on plant selection.
- As with all BMPs, maintenance is required. Common tasks include removing trash, pruning vegetation and replacing mulch. If the bioretention area is grassed, it will need to be mowed. Any debris or sediment that collects in the rain garden will need to be removed.

Cost
Bioretention areas can cost as little as $4 per square foot in the sandy soils of North Carolina. A good estimate for coastal plain rain garden construction is $5 to $6 per square foot. In Piedmont and mountain soils, the cost of a bioretention area will double at a minimum.

Water Quality Inlet Insert

What It Is
A fabric sock that is placed inside a stormwater inlet. It usually fits like a box just beneath the stormwater inlet grate.

How it Works
Trash, debris, sediment and associated metals, oil and grease are carried by water to inlets. The pollutants are trapped as runoff passes over the grate and through the blanket or other insert. It is imperative that the filter be replaced when it becomes saturated with pollution.

Potential Benefits
- Simple to install and typically very small.
- Best in situations where there is little to no land available to install any practices.
- Sometimes inlet filters are the only stormwater treatment option.
- An individual filter is relatively inexpensive. (However, the cost multiplies substantially if there are many inlet drains on the marina property or if the filters saturate with pollution quickly).

Planning and Technical Considerations
- The size of the inlet needs to be determined to verify that a given insert will fit. Inserts tend to treat relatively small drainage areas, often much less than 0.25 acres each.
- There are many such filters for sale by private companies. The cost and size of filters vary. Do not place an inlet filter in a drain that is in a paved area adjacent to a lot of loose sediment or debris, as the filter can clog very quickly. Filters should be inspected and replaced when they are visibly full of pollutants. The frequency of replacement depends upon the stability of the drainage area and the type of filter.
- In North Carolina, anecdotal evidence suggests filters need replacement as frequently as once per month. Other accounts indicate they may be used for nearly six months. The less polluted the drainage area, the longer a filter will last.

Cost
Filters will cost roughly $50 to $200 each, depending upon the manufacturer and the inlet size.

Stormwater inlet draining directly to marina basin.

Inlet filter slip being installed.

Water Harvesting

What it is

Containers used to capture runoff from rooftops, such as a marina office. The water is temporarily stored for later use, such as washing vehicles or boats, irrigation or toilet flushing. Cisterns are either high-density polyethylene chambers or metal containers resembling small silos. They often are accompanied by a pump and a water distribution system (valves, pipes and hoses).

How it Works

Gutters direct runoff from the rooftop into a cistern. The cistern stores the rainfall until it can be used for other purposes. The water is drawn down until a subsequent rainfall fills it again. The system works best when it rains on a periodic basis, such as one rain every three to four days. Much of the cost of the system is in the water distribution network (pumps) and in plumbing to connect the cistern to toilets. The effectiveness of such a system is best measured in the long term.

A 3,000 gallon cistern is installed in Craven County, NC to capture runoff from 2,500 square feet of rooftop. This water will be used to irrigate the surrounding lawn and landscaped area. (Photo by NCSU BAE)

Potential Benefits

- Provides a use for rainfall on the property.
- Can reduce potable water costs.
- Recent studies in North Carolina show that the payback period ranges from six to 50 years depending upon the application.
- Prevents rainfall-borne pollution (also called atmospheric deposition), such as nitrogen, from reaching the basin.
- Usable in areas with a high water table because cisterns can rest above ground.

Planning and Technical Considerations

To size the cistern, the roof drainage area must be determined to calculate the rainwater supply to the cistern. The supply is balanced by the water demand, which varies by the desired use. For example, vehicle washing may demand an average of 300 to 500 gallons per day, while the water demand for toilet flushing may only be 50 gallons per day. A cistern-sizing model can be used to evaluate various cistern combinations. A free cistern-sizing model is available from NC State University at:
www.bae.ncsu.edu/topic/waterharvesting.

- If there is a large and reliable demand for water, plan on a cistern of at least 500 gallons per 1,000 square feet of rooftop.
- Depending upon the demand, a pump and piping distribution network may need to be designed and installed. However, if the required use can be gravity fed (such as drip irrigation), a hose and sprayer are the only equipment needed.
- All water use options require constant operation and/or upkeep, including someone to activate the sprinkler system or to inspect the pump and fittings needed for plumbing.

Cost

The cost of a cistern system is estimated at $1 per gallon. Larger cisterns cost much less ($0.50 per gallon) to purchase. Installation times and costs are dependent upon the type of cistern selected. Polyethylene cisterns may take five person hours to install, while a metal cistern could take five days. The larger the cistern, the more difficult installation becomes.

Permeable Pavement

What It Is

Pavement that allows water to pass through its surface and enter the soil underneath. The pavement is best constructed in sandy soils, which allow easier infiltration. The pavement surface can be constructed from several materials, including concrete blocks filled with sand or pea gravel; permeable asphalt; permeable concrete; or plastic grid pavers filled with soil that allow grass to grow through it.

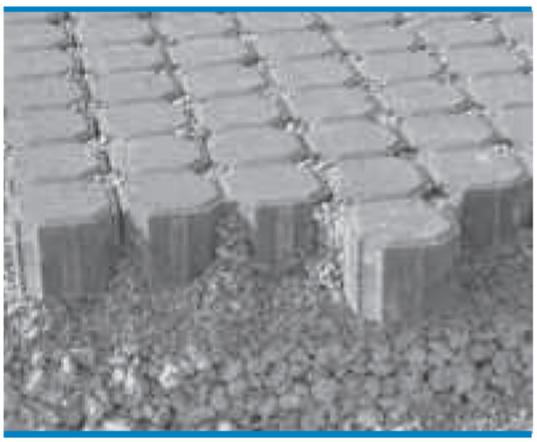
How it Works

Rain that falls onto the pavement flows through the surface and enters a temporary storage layer comprised of either washed 57 stone (nominal 0.75-inch to 1-inch in diameter) or washed marl (similar dimension).

The water slowly infiltrates into the surrounding soil. If installed in clay soils, an underdrain system is required to slowly remove water that passes through the pavement. Permeable pavement can dramatically reduce runoff and, if used on a large enough scale, will limit flooding. This in turn reduces erosion that can result from concentrated flow. Permeable pavement has been shown to remove some pollutants including copper, zinc and phosphorus. These pollutants are trapped along the interface of the pavement with the in-situ soil.

Potential Benefits

- Reduces flooding and adjacent erosion impacts.
- Removes some pollutants (some metals and phosphorus) before they reach the basin or adjoining waterways.
- Pavement has multiple uses, including parking, water quality and flood reduction. This is a good BMP to use when limited space is available.



Cut through of permeable pavement used in Swansboro, NC. The block pavers on the surface allow water to pass through and collect in the gravel layer at the bottom. From the gravel layer, the water will infiltrate the soil.

Planning and Technical Considerations

Permeable pavement is best used when the following guidelines are followed:

- Use only with low traffic volume.
  The exact amount and type of vehicles vary based upon climate and soil, but a standard traffic loading of 30-50 vehicles per day is a conservative upper limit for eastern North Carolina.
- Use in sandy or loamy sand in-situ soil.
  The soil must allow for water to exfiltrate the parking lot and must have low shrink-swell potential to ensure long term structural integrity. Any soil tighter than loamy sand probably fails on both counts, unless the site is "extra" engineered with underdrains and interior baffles.
- Seasonally high water table should be no closer than 36 inches from the surface. Water tables approaching the bottom of the pavement will not allow water to infiltrate the soil, causing structural damage to the pavement.
- No disturbed soils near pavement.
  Clay, silt or other particles can clog the open pores of permeable pavement. Construction adjacent to or near the permeable pavement could result in clogging.
- A washed and angular stone base is employed. Washed 57 stone is generally available throughout North Carolina. In some areas along the coast, washed marl is more readily available and can be an acceptable alternative. Do not use standard crusher run or rounded aggregate (stone). Standard crusher run will allow fine particles to clog the pores at the bottom of the pavement. Rounded aggregate (stone) is not a stable base as it allows rocking of block pavement.
- Proper construction technique is followed. The sub-base cannot be compacted during construction. Be careful not to smear the surface of permeable concrete or vibrate the concrete.
- The permeable parking is located in a relatively flat area. In general, the lot should not be sloped more than 0.5 percent. However, greater slopes are allowable with extra cost and engineering.
- It is critical that a maintenance plan be devised and followed. The surface layer will eventually clog even if properly designed and constructed. A vacuum street sweeper should run over the lot at least once or twice per year.

Cost

Permeable pavement is expensive. It is reasonable to expect most permeable pavements to cost an additional $5 per square foot of parking over traditional asphalt. This price includes extra materials and specialized labor. If permeable pavement is constructed over clay soils, the cost increases due to additional excavation and gravel bedding.

Retention/Infiltration Chamber

What it is

High-density polyethylene chambers designed to store runoff underground. The chambers have an open bottom and permeable sides to promote infiltration of the runoff into the surrounding soil. The units can be linked together to increase capacity and are designed or used in place of stone, pipe, surface ponds and dry wells.

How it Works

Runoff is directed to a catch basin or other suitable inlet connected to a chamber (or system of chambers) buried underground that retain some or all of the water, depending on the design. The open bottom and permeable sides allow the water to slowly filter through the soil. Bacteria in the soil remove pollutants by adsorption, straining or decomposition.

Potential Benefits

- Prevent pollutants from entering water ways, protect water quality and keep sediments in marina basin free from contaminants that may impact future dredging operations.
- Used as infiltration devices, chambers provide effective treatment for both dissolved and particulate pollutants.
- Can be installed under parking lots and work areas, freeing up surface space in marinas.
- Suitable for use in marinas with high water tables due to the unit's low profile (12 to 30 inches).

Planning and Technical Considerations

- In general, the chamber systems function in much the same way as infiltration trenches, and the same guidelines for site conditions, sizing and siting apply.
- Individual chambers come in various sizes but are generally 6 to 7 feet long, 3 to 4.3 feet wide and 1.3 to 2.5 feet high with capacities between 75 and 416 gallons. Units are lightweight (22 to 78 pounds) and can be installed by one or two people without the need for cranes or heavy equipment.
- Depending on size and design, systems may only require the excavation of a 3-foot wide, 3-foot deep ditch.
- With 18 inches of properly compacted backfill cover, the chambers are designed to withstand loads up to 32,000 pounds per axle, making them suitable for areas used for heavy equipment traffic and boat storage.
- A minimum of 3 inches of 0.75- to 1.5-inch diameter crushed, washed 57 stone should be placed under and along the sides of the chambers.
- To minimize maintenance, inlets should be equipped with a catch basin, sediment trap or similar device to intercept sediment and debris.
- Installations should be inspected once a year for sediment buildup. Sediment can be removed by re-suspension in water, or by pumping the chamber using access ports built into the units.

Cost

The cost for an individual chamber varies according to size. A 122-gallon unit costs about $50 to $60. Manual installation of the units can help cut the cost. At least one manufacturer estimates an installed system costs between $3 and $3.25 per cubic foot of runoff capacity.

Infiltration chambers being installed.

Area after chamber installation.

FOR MORE INFORMATION

For more detailed information on BMP siting, planning, selection and design, please refer to the publications listed below. Your regional NC Department of Environment and Natural Resources, Cooperative Extension Service, Natural Resources Conservation Service, County Soil and Water Conservation District or Sea Grant office can also provide additional information and assistance on stormwater BMP planning and design.

Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs (1987) by Thomas R. Schueler, available from the Metropolitan Washington Council of Governments, 777 North Capital Street N.E., Suite 300, Washington D.C. 20002-4201. Phone: (202) 962-3256

Reducing the Impacts of Stormwater Runoff From New Development (1992) by William B. Morton available from the Empire State Chapter of the Soil and Water Conservation Service, P.O. Box 1686, Syracuse, NY, 13201-1686.

NC DENR Stormwater Design Manual (2005). 512 N. Salisbury St. Raleigh, NC 27604 http://h2o.enr.state.nc.us/su/stormwater.html

Designing Rain Gardens/ Bioretention Areas (2001) by William F. Hunt and Nancy M. White. N.C. Cooperative Extension Factsheet Series. AG-588-3. Raleigh, NC, 27695. http://www.bae.ncsu.edu/cont_ed/bioretention/lecture/design_rain.pdf

Relevant Web sites:

Rain Gardens: http://www.bae.ncsu.edu/topic/raingarden/
Permeable Pavement: http://www.bae.ncsu.edu/topic/permeable-pavement
Water Harvesting: http://www.bae.ncsu.edu/topic/waterharvesting
Stormwater Coast*A*Syst: http://www.soil.ncsu.edu/assist/homeassist/stormwater

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