Section 5
Identification of Alternative Structural Control Measures

The impacts of urbanization within the Nine Mile Run (NMR) watershed have altered natural drainage patterns, altered natural rainfall-runoff-storage relationships, and added pollutants to storm water runoff and watershed streams. These urban impacts have resulted in a decline in the quantity and quality of aquatic and riparian habitat and limited opportunities for the public to enjoy the many benefits that water provides to the NMR watershed. The large percentage of impervious surfaces in the watershed, particularly in the upstream areas, has resulted in higher than natural storm water flow rates with decreased times of concentration and reduced runoff periods. The natural morphology of the stream has been altered significantly and siltation is occurring in the downstream reach of the stream.

Alternative structural municipal control measures can include removing illicit sewage discharge to storm drains, using porous pavement in lieu of traditional concrete and asphalt, rehabilitating aging sewage collection systems, and modifying catch basins and storm inlets to catch debris. Alternatives directed toward restoring the NMR watershed can include the enhancement and expansion of existing wetlands, the creation of additional water storage capacity, and the restoration of more natural flow conditions and habitat. Watershed restoration can also include the modification and stabilization of the stream channel, the creation of acceptable water quality, and reintroducing hydrologic variability. Restoration of the NMR stream will provide benefits to the ecosystem and the surrounding communities in an esthetically and ecologically improved natural area.

Section 4 discussed alternative non-structural source control measures that can be implemented within the NMR watershed to address the wide variety of problems typically related to urban runoff. Applying land use controls, public education programs, and non-structural municipal measures can have a significant impact on improving water quality and overall watershed protection. However, many structural tools are also available to address environmental degradation in urban watershed areas like NMR. In contrast to non-structural measures, structural alternatives typically require complex engineering analyses and construction to implement. This section, divided into the following topics, will discuss these alternative structural measures.

- Source Control Measures
- Remedial Measures for Existing Municipal Infrastructure
- New Regional Facilities

- Stream Erosion and Velocity Controls

5.1 Source Control Measures

A comprehensive storm water management program often requires certain structural source control measures be implemented on existing development. A wide-range of structural source control measures are available to address problems related to urban runoff. This section will examine alternative structural control measures in the following areas:

- Remove Illicit Wastewater and Industrial Connections to Municipal Storm Drain Systems
- Reconfigure Paved Surfaces to Decrease the Percentage of Impervious Area
- Use Porous Pavements to Promote Infiltration
- Construct Roof-Top Gardens Over Public and Private Buildings
- Capture Roof Runoff in Constructed Tanks or Cisterns for Irrigation

5.1.1 Removing Illicit Connections to Storm Water Systems

Due to indifference, ignorance, poor enforcement of ordinances, or other reasons, a storm water drainage system may have illegal connections from residential, industrial, or commercial facilities. These illicit non-storm water discharges to the storm water collection system may include process wastewaters, cooling waters, wash waters, and sanitary wastewater among others. Field investigations and laboratory analyses have confirmed that there are illicit connections to municipal storm drain systems within the NMR watershed. Removing these illicit connections could be an effective structural management measure to improve water quality in the NMR watershed.

The enforcement mechanism for detection and removal of these illicit connections comes from municipal wastewater ordinances. As a first step, municipalities within the NMR watershed should conduct a thorough review their existing ordinances and determine if adequate legal provisions are included to empower the municipalities to require the removal of illicit connections. Municipalities would then use the ordinances to implement an inspection plan to locate illicit connections. Control procedures for detection and removal of these existing illicit connections involve a multi-phased effort that is described below. To ensure that storm water system discharges into NMR contains only storm water, the following procedures should be conducted:

- Locate illicit discharges to the municipal storm sewer system:
    - Examine existing utility mapping and drawings
    - Conduct a comprehensive field investigation program
    - Isolate identified problem areas and work upgradient
- Develop a plan of action to eliminate illicit connections:
    - Replumb sewer lines
    - Plug illicit discharge points
- Document that non-storm water discharges have been eliminated by recording tests performed, methods used, and dates of testing

The first step for identifying existing illegal connections would be to research existing record drawings. A review of “as-built” pipeline schematics and paths of floor drains in older buildings should allow suspect illegal connections to the storm water collection system to be identified. This process is a good “first step”, but many municipalities and facilities do not have accurate, up-to-date schematic drawings available.

Once potential areas for illegal connections have been identified from record drawings, comprehensive field investigations should be conducted. Evidence of illegal connections is generally detectable at storm drain outfall (end-of-pipe) locations. The intent of the field investigation program is to identify outfalls that have characteristics of illegal connections during dry weather conditions. The initial phases of the field investigation program should involve notation of visual observations at suspect outfalls and sample collection for analytical testing of indicator parameters such as fecal Coliform bacteria, or Ecoli. Presence of dry weather flow or other suspect visual or odorous characteristics should be documented in field logbooks.

Storm drain investigations generally begin at suspect outfalls and work upgradient until either the source is identified or there is no evidence to warrant further investigation. The detection process may be expedited by field screening every other manhole, open channel outfall, or combination thereof to most quickly isolate the potential source. Bisecting watersheds and working up or down gradient, dependent on observed conditions, has also been used effectively to isolate the approximate location of an illegal connection. Isolation of an illegal connection within the storm drain piping requires utilization of one or more of the following location techniques:

Dye Testing - A dye test can be performed by releasing a visually detectable dye into the sanitary or process wastewater system and examining the discharge points from the storm water collection system for visual traces of the dye.

Smoke Testing - Smoke testing sometimes can detect connections between the sanitary sewer and storm drain systems. During dry weather, the storm water collection system is filled with smoke and then yard areas along sewer service laterals and cleanouts are examined for evidence of smoke.

Television Camera Inspection - TV inspections can identify illicit connections to the storm sewer using a closed-circuit video inspection camera. TV inspections are often conducted concurrently with dye testing to identify illicit connections.

Once illegal connections have been identified, municipal ordinance enforcement measures are implemented to require the property owner to disconnect the non-storm connection from the storm drainage system.

A program for sharing resources (TV inspection equipment, water truck for injecting dye, etc.) between municipalities can reduce the capital budget expenditures associated with this program. Capital outlays can be substantial if municipalities choose to procure equipment separately for the individual public works departments. Even with a resource sharing program, illegal connection location and removal techniques require a significant capital commitment in labor and equipment.

Public education will also aid in the monitoring of illegal connections by making individuals aware of the evidence of unwarranted discharges to the storm drain system. A community hotline for reporting such evidence can greatly supplement the storm water department's field screening efforts.

5.1.2 Reconfiguring Paved Surfaces to Reduce Impervious Area

An alternative structural management measure to consider for the NMR watershed would be to reconfigure existing and proposed paved surfaces to reduce the overall impervious area within the watershed. Imperviousness surfaces represent the imprint of land development on the landscape. They are comprised of two primary components: 1) the rooftops under which residents live, work, and shop, along with their ancillary patios, decks and walkways, and 2) the transportation system, including roads, driveways, and parking lots, that residents use to get from one roof to another. Previously in Section 4.2.7, a public education program was described as an alternative nonstructural management measure to encourage residents and business owners to reduce the quantity of impervious surfaces within their properties. This section will address a structural management measure to reduce the total impervious area within the NMR watershed by reducing the quantity of pavement.

The total area of the NMR watershed is 4,283 acres. The total impervious area within the watershed is 1,129 acres giving an overall percent impervious of 26%. Of the 1,129 acres of impervious area within the watershed, the transportation component (roads and parking) is 636 acres, or 56% of the total impervious area. This suggests that significant opportunities exist to reduce the share of impervious surfaces from the transportation component: driveways, parking areas, and roads.

For the most part, the opportunity for new development in the NMR watershed is limited. As a result, there are limited opportunities to reduce the share of imperviousness from the transportation component in new development projects. However, opportunities exist to decrease impervious area by reconfiguring existing paved surfaces through restorative redevelopment efforts. Some simple but effective strategies for communities to reduce the share of imperviousness from the transportation component include the following:

- Reduce the quantity of pavement within public parking areas
- Reduce the quantity of pavement area within residential lots
- Reduce the quantity of pavement area within street and alley rights-of-way
- Further reduce impervious area within public rights-of-way by narrowing sidewalks or removing redundant or unnecessary sidewalks

Reduce the quantity of pavement within public parking areas

There are limited opportunities for new commercial development projects within the NMR watershed. However, there are several existing large parking areas, like the Edgewood Plaza and East Hills Shopping Center, and many smaller commercial lots where restorative redevelopment techniques could be applied. Eventually existing parking areas will deteriorate and need to be replaced. Restorative redevelopment techniques can be applied when lots are resurfaced. Alternative measures to be considered and discussed include the following:

- Reduce the number of parking spaces, if possible
- Reduce the size of parking stall dimensions, where possible
- Eliminate unnecessary pavement areas and replace them with vegetated landscape islands
- Create new vegetative infiltration swales and infiltration ditches
- Use semi-pervious building materials, such as brick pavers, instead of asphalt

Most communities routinely build more public parking spaces than are needed to meet actual parking demands. This is a result of using outdated or overly generous local parking codes to determine minimum parking ratios. However, the parking areas that would be resurfaced or reconstructed under the principals of restorative redevelopment have already existed for a long time and actual parking demands are already known. Whenever an existing parking area is scheduled to be repaved, business owners should carefully evaluate their parking needs and reduce the number of unnecessary parking spaces. Even small reductions in parking can reduce the construction and storm water management costs that are accrued during these resurfacing projects.

Shared parking can allow adjacent commercial and/or industrial establishments to share parking lots if peak parking demands occur during different times of the day or week. Mass transit can reduce the number of vehicle trips, which translates directly into smaller parking lots.

Reducing the size of parking stall dimensions represents another opportunity to reduce impervious cover. During repaving projects, the length and sometimes the width of existing parking stalls can be reduced by a foot or more. Existing parking stalls can also be amended to provide a percentage of smaller stalls for compact cars. Parking areas for small businesses are often unlined. Without clearly defined and marked parking stalls, business patrons park anywhere in the lot, and the paved areas are inefficiently used. Existing unmarked parking areas should be lined to clearly define parking stalls, and unnecessary pavement areas should be removed.

Many existing commercial establishments within the NMR watershed have the entire area around their building paved. Often, a significant portion of this paved area is rarely trafficked, if at all. During repaving construction, these unused paved surfaces can be removed and replaced with vegetated landscape islands and/or infiltration ditches. Figure 5.1.1 shows a typical small commercial establishment within the NMR watershed. Large portions of this paved parking area are clearly unnecessary as they are rarely trafficked. This illustration provides a good example of a case where the unused pavement in the corners and around much of the perimeter of the site could be removed and replaced with vegetated areas.

Figure 5.1.1: Example of Unnecessary Paved Surfaces

Business owners should be encouraged to replace unnecessary pavement area with landscape islands, vegetative swales, and infiltration ditches. Vegetative swales are grassed channels designed to convey storm water, where pollutants are removed by filtration through settling and infiltration through the soil. Typically vegetative swales cost less to construct than paved areas and curbs. Infiltration ditches temporarily store runoff in a stone filled reservoir and exfiltrate the runoff through surrounding soil media. A vegetated buffer strip can complement the ditch to prevent the entrance of sediments.

When existing parking areas deteriorate to the point of needing reconstruction, business owners can be encouraged to replace the existing asphalt pavement with semi-pervious building materials such as brick pavers with sand-filled joints. While the initial cost of permeable surfacing materials can be more expensive to install, the ambiance and charm of brick pavers can add long-term value to the commercial site and often have a longer design life than asphalt. Special varieties of porous pavements that can be used will be discussed in Section 5.1.3.

<u>Reduce the quantity of pavement area within residential lots</u>

Significant opportunities are available to reduce overall imperviousness in residential areas by applying the principals of restorative redevelopment when existing driveways are repaved or reconstructed. Many of the existing homes and driveways within the NMR watershed are older and are or will be in need or repair or replacement. Encouraging residents to use permeable paving materials, narrow the driveway width, and eliminate unnecessary paved areas during restoration can have a significant impact on reducing total impervious area in the NMR watershed.

Pavement area can also be reduced in new development. Typical residential driveways are 12 feet wide for one car driveways and 20 feet wide for two. By specifying narrower driveways, promoting permeable paving materials, and allowing two-track driveways or gravel and grass surfaces, communities can sharply reduce the typical 400 to 800 square feet of impervious cover created by each driveway.

Many current subdivision codes have very strict requirements that govern lot geometry, including setbacks and lot shape. These criteria constrain site planners from designing open space or cluster developments that can reduce impervious cover. Smaller front and side setbacks, often essential for open space designs, are typically not allowed or require a zoning variance that may be difficult to obtain. Relaxing setback requirements allows developers to create attractive, compact lots that are marketable and livable. For example, side yard setbacks can be as close as five feet from detached housing without specific fire protection measures. Often, fears about fire safety, noise, parking capacity and site distance impairment are cited as impediments to shorter setbacks, but the reality is that these concerns can be overcome with careful design.

Due to the limited amount of anticipated development within the NMR watershed, the extent in which these alternatives are applicable is also limited. However, some opportunities for new subdivision development exist within the watershed, particularly in the municipality of Wilkinsburg. Figure 5.1.2 below shows a new housing development in Wilkinsburg. Creating narrower driveways, using permeable paving materials, and promoting more gravel and grass surfaces in developments such as this one can reduce the amount of impervious area generated from new development.

Figure 5.1.2: New Subdivision Development in Wilkinsburg

Reduce the quantity of pavement area within street and alley rights-of-way

Street widths within the NMR watershed range from 15 feet (alleys) to 50 feet (major highways). The average residential road ranges from 30 to 35 feet in width. In some areas, residential streets can be 32, 36, and even 40 feet wide, despite the fact they only serve a few dozen homes. These wide streets are the greatest source of impervious cover in existing neighborhoods and new subdivisions. Wide residential streets are created by blanket applications of high volume and high speed design criteria, the perception that on-street parking is needed on both sides of the street, and the perception that wide streets provide unobstructed access for emergency vehicles.

Communities with new expansion development have significant opportunities to reduce impervious cover by revising their street standards to widths of smaller residential access streets. Residential street widths should be designed to handle expected traffic volumes, provide adequate parking, and ensure access for service, maintenance, and emergency vehicles. Two strategies can help to narrow streets: using queuing streets and critically evaluating the need for on street parking on both sides of the street. Several national engineering organizations have recommended residential streets as narrow as 22 feet in width.

Many communities require the end of cul-de-sacs to be 50 to 60 feet in radius, creating large circles of needless impervious cover. There are several different planning options to reduce the impervious cover created by traditional cul-de-sacs. One option is to reduce the radius of the turnaround bulb. Several communities have implemented this successfully and the smaller radii can range from 33 to 45 feet. Since vehicles only use the outside of the cul-de-sac when turning, a second option is to create a pervious island in the middle of the cul-de-sac, creating a donut-like effect. A third planning option is to replace cul-de-sacs with loop roads and hammerheads.

Many of the above-mentioned alternatives to reduce street coverage apply to new development. Due to the limited opportunities for new development within the NMR watershed, the applicability and benefit potential of these alternatives is also limited. For the most part, the existing street layout within the watershed is the typical urban layout with blocks and alleyways. Only a few residential streets end in cul-de-sacs, and most are dead end or hammerhead streets. However, opportunities to reduce street cover exist during street rehabilitation efforts as the majority of the existing roads within the watershed are older and will need to be repaved or reconstructed.

One application that can be considered while restoring existing streets is the use of porous pavements. Either the entire width of existing streets could be replaced with porous pavement, or just the on-street parking areas that line the traffic cartway. Local soils, frost depths, freeze-thaw cycles, and traffic loads all need to be carefully assessed so that selected porous pavement materials are suitable for local conditions. Alternative materials include masonry pavers with open joints, a bituminous mix with open-graded aggregate, or compacted gravel. The use of porous pavements to promote infiltration will be discussed in more detail in Section 5.1.3.

In addition, street widths can be evaluated with current traffic volumes when existing streets are scheduled to be reconstructed. Evaluating the need for on street parking on both sides of the street in many of the residential areas within the watershed can be evaluated as well. Reducing current street widths and on-street parking provides opportunities for the communities within the NMR watershed to reduce impervious cover.

<u>Further reduce impervious area within public rights-of-way by narrowing sidewalks</u>

Additional opportunities exist within the NMR watershed to reduce impervious area by modifying existing sidewalks. In most watershed neighborhoods, sidewalks exist on both sides of residential streets, are constructed of impervious concrete or asphalt, and are four to six feet wide. While these construction practices were intended to promote pedestrian safety, they often result in unnecessary sidewalk areas that could be eliminated. For example, a sidewalk on one side of the street often is sufficient. In fact, in a study of pedestrian accidents associated with sidewalks, there was a negligible difference in accident rates when sidewalks were reported on just one side of the street versus sidewalks on both sides of the street (NHI, 1996).

In older neighborhoods, like those found in the NMR watershed, many of the older concrete sidewalks will need to be replaced. During this process, the existing concrete sidewalks can be replaced with semi-permeable pavement systems that will promote infiltration. When sidewalks are being replaced, the watershed communities should also consider reducing sidewalk widths to four feet and placing them further from the street. Sidewalk design should emphasize the connections between neighborhoods, schools, and shops, instead of merely following the road layout. In addition, replacement sidewalks could be regraded to drain toward pervious front yard vegetation rather than the street. These alternatives could reduce impervious cover and provide safe, practical, and attractive travel paths. Almost every existing residential neighborhood in the NMR watershed has sidewalks on both sides of the street. These sidewalks could be examined to determine if the width of the sidewalk can be reduced or if it is even needed at all. In either case, opportunities become available to reduce the amount of impervious area generated from the sidewalk.

5.1.3 Using Porous Pavements to Promote Infiltration

The use of permeable pavement systems in lieu of traditional asphalt and concrete pavement is an alternative structural control measure to improve water quality within the NMR watershed. Permeable pavements systems can be used to reduce the imperviousness of trafficked surfaces such as patios, walkways, driveways, fire lanes, and parking areas for the purpose of reducing surface runoff and increasing infiltration. The permeable paving systems also are used as inlets and covers for infiltration trenches. Permeable pavements can be effective in helping to reduce peak surface runoff rates or in improving the groundwater recharge characteristics of developed sites.

Permeable pavement requires moderately permeable soil and the depth to the seasonal high water table or bedrock being greater than 3 feet below grade. Because of the large area over which infiltration occurs, permeable pavement minimizes the potential for groundwater mounding or concentrated discharges to groundwater. Because permeable pavements recharge surface runoff directly to groundwater, they should not be used where there is significant concern for contamination of surface runoff with dissolved pollutants. In particular, to prevent contamination of drinking water supplies, they should not be installed in highly permeable sand or gravel seams that are directly connected to aquifers. The NMR watershed is characterized by clay soils that tend to percolate more slowly.

Permeable pavements are typically installed in proximity to runoff-generating surfaces. The best performance is achieved when the up-gradient drainage area is minimized. One strategy is to alternate areas with impervious and permeable pavement. In these instances, conventional impervious pavement would be reserved for the most heavily trafficked corridors. A wide variety of alternative concrete and brick paving systems are available and can be combined with conventional pavements to achieve functional and aesthetically pleasing designs.

Permeable paving systems are prone to clogging by suspended solids. To reduce the likelihood of clogging, permeable pavement should not be used in areas that receive significant amounts of sediment, including mud tracked onto the surfaces during wet weather and sand or cinders used in snowy conditions. To preserve the long-term performance of permeable pavement, it is important to control sources of suspended solids in storm water before the water is discharged onto the paved surfaces.

Two factors must be considered when designing permeable pavement: runoff collection and percolation.

Runoff collection is controlled by the infiltration of the surface layer (e.g. brick, gravel, or concrete) and by the storage capacity of the pavement base. For most permeable paving systems, the surface infiltration rate is large enough that this factor can be ignored as a design consideration. However, the surface infiltration rates of compacted graded aggregate or topsoil may be limiting. The infiltration potential of paving systems that use these materials should be established by field-testing. Table 5.1.1 presents typical ranges for long-term surface infiltration rates for a variety of alternative paving materials.

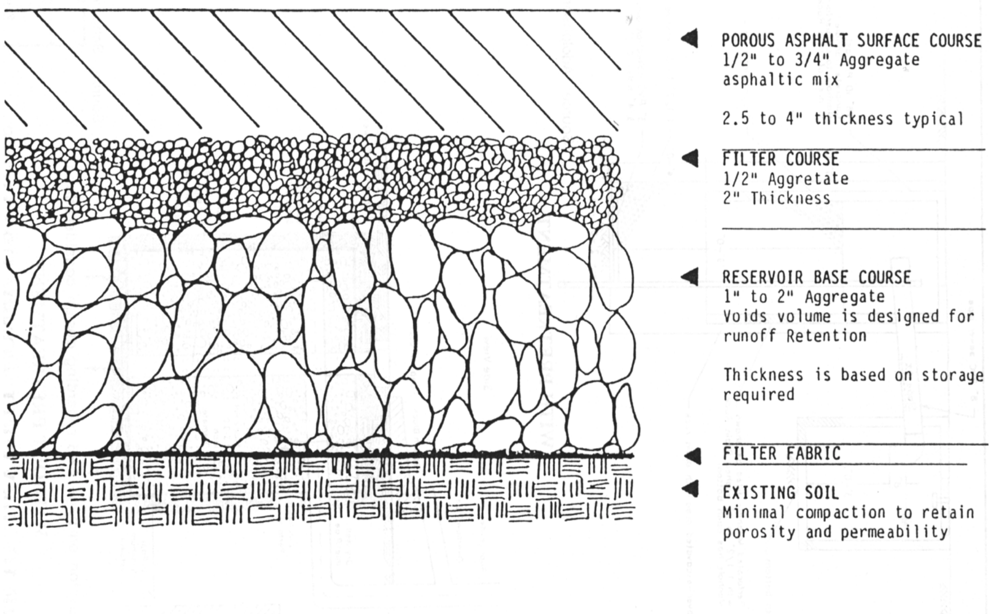
Permeable paving systems require a porous base that provides a sufficient percolation rate to the groundwater table. Because of the structural stability and large porosity, uniform (open-graded) crushed stone is preferred as a base material. Water will continue to infiltrate freely through the permeable pavement until the voids in the base fill with water. After the base fills with water, the residual surface infiltration rate will be dependant on the permeability of the underlying soil subgrade, which is usually less than the surface infiltration rate. Therefore, it is good practice to design the base layer to store 100 percent of the volume of water that will infiltrate. The depth of the base layer, therefore, will depend on the infiltration requirement for the paved surface. To compute the storage capacity of the base, the porosity of the compacted base material must be known. To preserve the storage potential of the base, a geotextile should be installed between the base and subgrade. The geotextile will minimize the tendency for soil to migrate upward into the base.

Table 5.1.1: Infiltration Rates for Various Paving Materials

Pavement Type	Surface Infiltration Rate (inches/hour)
Permeable interlocking concrete paving blocks bedded in coarse aggregate, no vegetation (15 percent open cell area)	4.5 to 6.3 *
Compacted uniform gravel or crushed stone (uniformity coefficient < 2)	2.0 to 6.3 *
Concrete grid pavers bedded in sand, surface treatment with topsoil and vegetation (25 percent open cell area)	0.63 to 2.0
Compacted dense graded aggregate (uniformity coefficient > 10)	0.2 to 0.63
* Initial infiltration rates may exceed 150 inches/hour	

A typical section of porous asphalt paving is shown in Figure 5.1.3 and a brief description of the characteristics and maintenance requirements of various paving materials follows.

Figure 5.1.3: Porous Asphalt Paving Typical Section



Source: City of Rockville, Maryland

Perforated Brick Pavers and Concrete Grid Pavers

This type of pavement is best suited to areas that carry pedestrian or light vehicular traffic. Areas surfaced with pavers can be damaged by snowplows or loader buckets that are set too low to the ground. Therefore, care must be used when removing snow from these surfaces, especially in areas where differential settlement may have caused "lipping" of the pavers. If mud or sediment is tracked onto the surface, it should be swept away as soon as possible.

For best performance and longevity of the pavement, the pavers should be imbedded in concrete sand. Vegetation that colonizes the open cells or perforations should be removed. Semi-annual maintenance to remove vegetation should be adequate. Herbicides that persist in the environment should not be used to control vegetation.

For practical or aesthetic reasons, the designer may choose to fill the open cells of the pavers with topsoil and vegetation. In these cases, the vegetative layer must be maintained as any other grassed open area. Deep-rooted woody plants, which can disrupt the pavement and reduce permeability, should be prevented from colonizing the surface.

Permeable Interlocking Concrete Paving Blocks

These pavements are designed to accommodate more constant traffic and higher tire loads than concrete grid pavers or perforated brick pavers. These are comparatively easy to maintain and have long service lives. Permeable interlocking concrete paving systems should be bedded in coarse aggregate. The open cells can be filled with pea gravel to further enhance the appearance of the finished surface.

Colonization of the open cells by vegetation should be discouraged. Semiannual maintenance to remove vegetation should be adequate. Herbicides that persist in the environment should not be used to control vegetation. If mud or sediment is tracked onto the surface, it should be swept away as soon as possible.

Compacted Gravel

Gravel-surfaced areas are suited to areas with very light vehicular traffic, such as overflow parking areas and service roads. Gravel surfaces are generally not recommended for pedestrian paths, because they can be difficult for older pedestrians or handicapped individuals to negotiate. The effectiveness of gravel-surfaced areas in infiltrating rainfall is variable and depends primarily on the contribution of fine particles to the mix. Only open-graded mixtures that contain very few fines will be associated with high surface infiltration rates. Dense graded road aggregate, which is commonly used to surface roads, is not appreciably more permeable than conventional pavement. As appropriate, the surface gravel course may consist of decorative materials such as pea gravel or slag.

Unlike areas surfaced with pavers or porous bituminous concrete, sweeping or washing of graveled areas is impractical. Therefore, gravel-surfaced areas are prone to clogging by sediment. In particular, fine sediment tends to become incorporated in the loose gravel or stone in the uppermost layer of the pavement. Penetration of sediment into the base can be prevented by separating the surface course and base layers with a geotextile. The upper surface of the pavement may need to be scraped off and replaced with fresh material to restore the functioning of graveled surfaces if the surface infiltration rate decreases significantly. The longevity of gravel surfaces is generally shorter than for other types of permeable pavement in the same setting.

5.1.4 Rooftop Gardens Over Public and Private Buildings

Rooftops are perhaps an urban watershed’s greatest untapped resource. Sloped or flat, large or small, industrial or residential, the possibilities for urban greening, air cleaning, community building, and food production can be numerous. Constructing rooftop gardens over public and private buildings can be an effective structural management measure to reduce urban runoff and its associated pollutants to the watershed.

Theoretically, any roof surface can be greened - even sloped or curved roofs can support a layer of sod or wildflowers. Switzerland has just passed a bylaw which states that new buildings must be designed to relocate the green space covered by the building's footprint to their roofs - even existing buildings - including historical buildings - must now green 20% of their rooftops. This has created an increased demand for research and material/product design, which has transpired to North American markets.

In reality, the technology and the know-how required to grow plants and trees on elevated structures has existed in the United States for a long time; an example being all the underground parking garages that support landscaped courtyards. The difference here is that these gardens are at ground level, mimicking a natural situation so a difference is not perceived. These gardens were given structural consideration during the initial design phase - not after the fact - whereas most of the roof gardens that people are interested in installing now will be retrofits to existing buildings.

Covering a rooftop with plants will allow several goals to be achieved:

- Environmentally, by increasing the biomass of the urban neighborhood, oxygen levels in the air are increased- and the amount of CO_2 produced by cars and other fuel burning technologies is decreased. In addition, dust and air-borne particulates are reduced since plants act as natural filters. Also, the local climate is altered because plants absorb rather than reflect heat and because roots hold and absorb water. Every time it rains, the roof is retaining storm water runoff, thereby decreasing the load on storm drain and combined sewer systems.

- Home and building owners will benefit financially. Layers of soil and foliage have excellent insulating qualities, keeping buildings warmer in the winter and cooler in the summer thereby reducing energy bills. Because of significant temperature swings, and therefore the expansion and contraction experienced by the roof, the life span of the roofing membrane will increase due to these insulating qualities. Since the roofing will be covered, the membrane will be protected from harmful UV rays, and everyday wear and tear.

- A safe, private, outdoor space in the heart of the watershed can be created without having to buy extra land. Residents get a more aesthetically pleasing view, property value is increased, and the public is educated on the environment.

There are several issues that should be considered when creating a rooftop garden:

Loading: Soil, decking, people, planters - and where they are placed on the roof deck - all have an impact on the existing structural carrying capacity of the roof, as well as that of the rest of the building. It is important to have a structural engineer confirm the additional weight that the existing roof can accommodate. One cubic foot of wet "earth" can weigh over 100 pounds, creating additional stresses on the rooftop. However, remember that earth is not soil - and adding compost, mulch, and other fillers will decrease the weight. Heavy planters can be placed strategically over bearing walls or columns; grasses do not need more than 3 inches of growing medium; some plants will grow in gravel... a lot of options available. This is particularly important in the NMR watershed as many of the existing homes and buildings are older and may have limited structural capacity for the additional structural loading.

Safety: The second consideration is safety. How is the roof accessed? How do materials and water get up to the roof? Who will be using the roof? Is there a railing? Requirements, solutions, and costs will vary depending on whether the garden is on a private residence, an apartment tower, or a public library. Building Codes have specific regulations regarding structural, health, and safety issues as they relate to new and existing buildings that need to be followed.

Roofing: Roofing is also an issue. What kind is it and what condition is it in? Can it be walked on or should it be protected? Will plant roots penetrate the membrane or should planters be elevated? How and where does it drain? If it needs to be replaced or repaired within 5 years, can it be done without disrupting the established garden? Again, there are as many solutions as there are restrictions and regulations governing these issues.

Microclimate: Then there is the specific microclimate of the roof itself. Gardening up on a roof is quite different from gardening at grade. It is very sunny, sometimes windy, and the temperatures are often extreme. This will have a direct effect on what will grow well, how often watering needs to be done, and whether the plants can survive through the winter. The effects of heat, cold, and dryness can be tempered by using containers that retain moisture (i.e. plastic vs. terra-cotta; by insulating planters; by using mulch; by mixing moisture retaining additives into the soil; by layering or interplanting the plants; or by sticking to plants that thrive in these conditions). It is likely to be an ongoing experiment.

Another question is how to keep the soil from washing away while the plant roots grow enough to hold the soil. Plants can grow in a medium of gravel. Rainwater is sufficient to keep the plants alive. It depends on how the garden is to be used, what is intended to grow, and how often the roof needs accessed. Certainly, a flat roof, with level ground conditions, would seem to be the easiest to work with and on.

The following specific issues need to be addressed in the design and construction of a rooftop garden.

- Occupancy and the size of the garden as they relate to and impact adjacent or superimposed occupancies and occupant load (i.e. the number of people allowed to occupy the garden)
- Occupant load as it relates to and impacts structural loading and exiting requirements
- Exiting requirements such as types of exits allowed and number of exits required, the distance between exits and travel distance to exits, the sizes of exits and areas defined as "access to exits", fire separations between exits and the rest of the floor area, and possible requirements for fire alarms, exit lights, emergency lighting
- Handicapped accessibility and Barrier Free Design, either as a Code requirement or as a Client/User requirement
- Requirements for enclosures (i.e. guards, railings, parapets, walls around rooftops, terraces, and balconies) such as required heights, the placement of elements such as planters adjacent to enclosures which may reduce their effective height, climability of enclosures, and the loading and structural stability of guards and railings
- Specific requirements for structures/buildings on roofs relating to the effect on overall building height, the fire rating of structural members, and exiting
- Other applicable issues might include possible modification of window washing anchors on the roof, possible upgrading of washroom and service requirements, and possible upgrading of drainage and water-proofing requirements

In summary, there are two central elements that need to be considered when developing a rooftop garden: 1) the new loading exerted by the garden (the size and distribution of which can be altered by altering the layout of the garden) and 2) the load carrying capacity of the structure (which can be enhanced by increasing the strength of existing load bearing members or by adding new ones). When designing a roof garden, a licensed engineer should be consulted regarding the load carrying capacity of the building and to ensure that the garden design and the structural capacity are compatible.

Many of the existing homes and buildings within the NMR watershed have steeply sloped rooftops and are not eligible for the construction of a rooftop garden. In addition, the majority of the existing homes and buildings within the watershed are older and may not have the structural capacity for the additional structural loading of a rooftop garden. However, for homes and buildings with flat rooftops that have adequate structural capacity, rooftop gardens provide a viable option for retaining storm water runoff.

5.1.5 Capturing Roof Runoff in Tanks or Cisterns for Irrigation

In many urban watersheds like NMR, storm water from rooftops is often piped into a storm drain that leads to either a combined sewer system or a municipal storm drain system. One of the best ways to mitigate the impacts of urban runoff is to manage rooftop runoff on site instead of moving storm water through a conveyance system. Redirecting rooftop runoff can an effective management measure for reducing downstream impacts and can significantly decrease annual runoff volumes.

Rainwater harvesting - capturing and storing rainwater for later use - is a key element in storm water management. Diverting rooftop runoff into storage tanks, and ground runoff into mulched planting areas, utilizes rain to its fullest potential. Water harvesting can range from the simple to the complex, depending on need and budget. Water harvesting can be incorporated into plans for building a new home, designing a major subdivision, or, in the case of the NMR watershed, restorative redevelopment efforts. Nonstructural management measures, such as installing rain barrels to existing downspouts, are discussed elsewhere in the watershed management plan. This section will address alternative structural control measures.

Rainfall can be a valuable resource as rainwater harvesting not only helps reduce the quantity of urban runoff, but also decreases the community’s dependence on public water supplies for non-domestic uses. Unlike groundwater or tap water, rainwater is remarkably pure with virtually no dissolved salts or minerals. Because of this, rainwater is suited for rainwater irrigation and many other applications. Using rainwater to irrigate plants, for instance, flushes salt buildup from the soil and produces vigorous, healthy plants. By utilizing rainwater and reducing storm water runoff, a valuable water resource can be put to work.

The following lists additional advantages of harvesting rainwater:

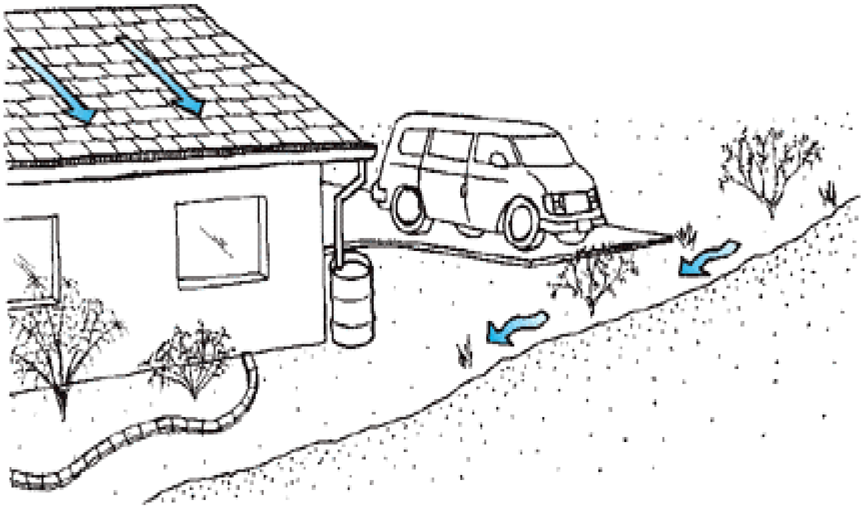
- Provides more self-sufficiency with a water supply
- Offsets the need for pumping groundwater
- Reduces energy needed for deep well pumping and water softening
- Provides very high quality water (in most areas), soft and low in minerals
- Reduces mineral deposits on fixtures, pipes and water heaters
- Plants respond many times better to rainwater than tap water
- Reduces erosion and flooding typically created by runoff
- Reduces silting and contamination of waterways from runoff
- Encourages appreciation for and conservative use of water

A rainwater harvesting system has four main components:

- Rainwater collection
- Storage
- Distribution
- System Maintenance

Rainwater collection

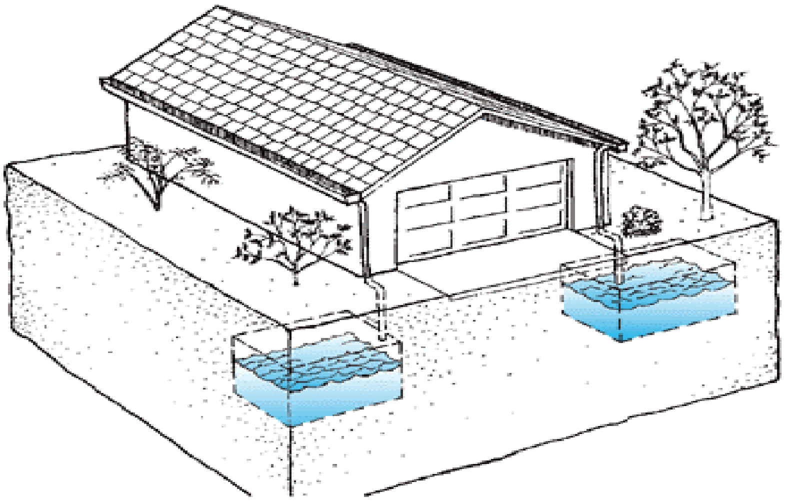
Rainwater can be captured from rooftop areas or any other impermeable surface. The amount of water that can be harvested depends on the size of the catchment area. It is important that the collected water is kept at least three feet away from the foundation of a home.



Storage

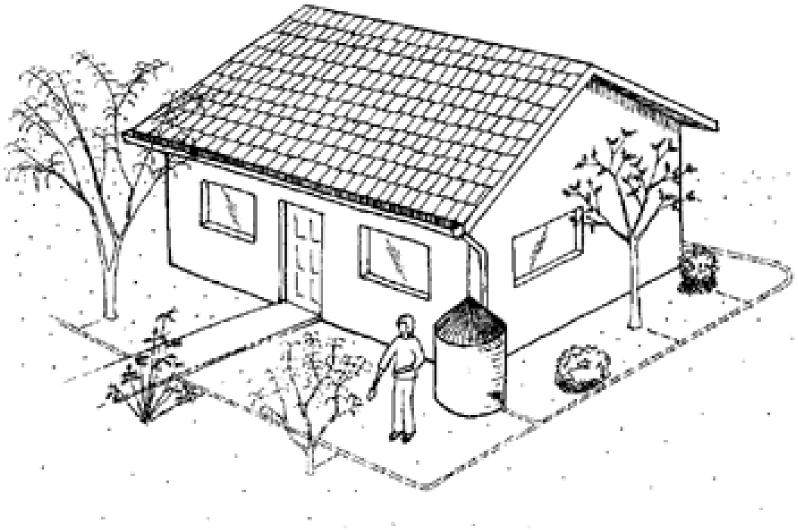
Storage systems can vary in complexity depending on need and catchment area. An effective system can involve nonstructural measures such as a drum or rain barrel fed by rooftop gutters and downspouts. A more involved system might include structural controls such as buried cisterns, plumbing, and a timed watering system. Types of pre-fabricated storage tanks and cisterns include galvanized steel, fiberglass, polyethylene, polypropylene, and PVC bladders. Partially pre-fabricated storage devices include a series of drums, cans, or barrels. Types of site-built storage tanks and cisterns include Ferro cement, stone, poured concrete, mortared block, and rammed earth.

Debris and leaves should be filtered before storing the water by placing screens over gutters or downspouts. Water kept in tanks or cisterns should also be covered to minimize algae growth and eliminate the potential for mosquito breeding. Placing floating lids on storage tanks is an effective solution.



Distribution

Gutters and downspouts can be designed to catch rainwater and distribute it directly to landscape plants or into tree wells. Rainwater can also be directed to rock-lined trenches or perforated pipes and allowed to infiltrate into the soil. Another option is to store the harvested rainwater and then later distribute it through a regular drip irrigation system.



System Maintenance

Rainwater harvesting systems require occasional maintenance. Debris screens over gutters should be cleaned periodically and storage tanks should be drained and cleaned on a fairly routine basis.

5.1.6 References for Section 5.1

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5.2 Remedial Measures for Existing Municipal Infrastructure

One management alternative to reduce the amount of water that enters sewer systems is through rehabilitation efforts. A major focus of rehabilitation is to minimize the effects of extraneous flow on the collection system. It is an expensive proposition to upsize the collection system piping to the wastewater treatment plant. It is often more cost effective to tighten up the collection system, exclude the extraneous water, and disconnect impervious surfaces. Extraneous water that enters the sewer collection system is divided into two categories: infiltration and inflow.

Groundwater that leaks into the system through underground cracks and joints is called infiltration. Surface water, storm water, snowmelt, rain, and runoff that enter into the sewer system is called inflow. This non-wastewater that enters the collection system consumes valuable capacity. Sewer rehabilitation can plug infiltration, upgrade capacity, and improve system hydraulics. This, in turn, will reduce the frequency, duration, and volume of combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs). Reduction in CSO and SSO discharges will reduce pollutants, solids, and floatable materials from entering the stream. By diverting storm water out of the sewers, downstream overflows and sewage pollution can be reduced. Groundwater that is diverted to streams rather than conveyed through sewers can augment dry weather stream flow. Separating storm water drainage from sanitary sewage conveyance is a basic and essential task for restoration of old urban watersheds like NMR.

The NMR stream corridor was used, beginning in the 1920’s, for construction of interceptor sewers serving Pittsburgh, Swissvale, Wilkinsburg, and Edgewood. These sewers generally followed the stream (as shown in Figure 5.2.1) in parallel alignments to a point near its confluence with the Monongahela River where they discharged storm water and sanitary sewage. In the late 1950’s when the ALCOSAN interceptor was installed, the City of Pittsburgh’s (now PWSA) NMR interceptor was connected to the ALCOSAN interceptor via a regulator structure in Duck Hollow. Later, in 1982 and 1983, Swissvale and Wilkinsburg tied into the upstream portion of the NMR interceptor. Still later yet, Edgewood tied into the NMR interceptor just downstream of Commercial Avenue.

Figure 5.2.1: NMR Interceptor along Stream Corridor

Two different types of sewer systems were constructed in the NMR watershed. Combined sewers that convey both storm water runoff and sanitary wastewater through a common piping system serve many of the neighborhoods within the City of Pittsburgh. Of the developed portion of the watershed, approximately 748 acres, or 27%, are served by combined sewers. Neighborhoods located within Edgewood, Swissvale, and Wilkinsburg are served by separate sewer lines that convey only sanitary wastewater. Of the developed portion of the watershed, approximately 2,044 acres, or 73%, are served by separate sewers.

A number of alternative structural measures are available to address the existing municipal infrastructures within a watershed. This section will discuss remedial measures that can be implemented within the NMR watershed regarding the following issues.

- Elimination of Sanitary Sewer Overflows
- Reduction in Combined Sewer Overflows
- Modification of Storm Drains to Trap Floatable Materials and Trap Floatable Materials

5.2.1 Elimination of Sanitary Sewer Overflows

Sanitary sewer overflows, or SSOs, are discharges of raw sewage from municipal sanitary sewer systems. SSOs can release untreated sewage into basements or out of manholes and onto neighborhood streets, playgrounds and into streams before it can reach a treatment facility. SSOs are primary caused by poor sewer collection system management and can pose a substantial health and environmental challenge.

SSOs occasionally occur in almost every sewer system, even though systems are intended to collect and contain all the sewage that flows into them. When SSOs happen frequently, however, it means something is wrong with the system and structural rehabilitation measures are often required.

Problems that can cause chronic SSOs include:

- Infiltration and Inflow: Too much rainfall or snowmelt infiltrating through the ground into leaky sanitary sewers not intended to hold rainfall or to drain property, and excess water inflowing through roof drains connected to sewers, broken pipes, and poorly connected sewer service lines

- Undersized Systems: Sewers have inadequate capacity to carry sewage from developed subdivisions or commercial areas

- Pipe Failures: Blocked, broken, or cracked pipes; tree roots growing into the sewer; sections of pipe that settle or shift so that pipe joints no longer match; sediment and other material builds up causing pipes to break or collapse

- Sewer Service Lateral Connections: Excessive infiltration can occur at sewer service lateral connections to houses and buildings

- Deteriorating Sewer Systems: Improper installation and inadequate system maintenance

For a number of years, municipal sewer systems within the NMR watershed have experienced problems. The Pennsylvania Department of Environmental Protection (PA-DEP) at several locations has documented significant fecal coliform bacteria levels. As a result, consent orders were issued by PA-DEP to PWSA and to the three other contributing municipalities in the watershed. One cause for these high levels of bacteria is known SSO outfalls from municipal sanitary sewer systems. The consent orders require the three municipalities with separate sewer systems to rehabilitate their sanitary collector sewers and eliminate existing SSO discharges.

Widespread problems can be expensive to fix. Some municipalities have found severe problems necessitating multi-million-dollar correction programs. Often communities have to curtail new development until problems are corrected or system capacity is increased.

Because SSOs contain raw sewage they can carry bacteria, viruses, protozoa (parasitic organisms), helminths (intestinal worms), and borroughs (inhaled molds and fungi) and can be a serious threat to water quality. The diseases they may cause are shown in Table 5.2.1 below and range in severity from mild gastroenteritis (causing stomach cramps and diarrhea) to life-threatening ailments such as cholera, dysentery, infections hepatitis, and severe gastroenteritis.

Table 5.2.1: Pathogens In Raw Sewage and Their Resulting Ailments

ORGANISMS	DISEASES AND SYMPTOMS
Bacteria	Chlorea, salmonellosis (food poisoning), typhoid fever, bacillary dysentery, gas-troenteritis (including diarrhea and abdominal pain)
Viruses	Hepatitis, meningitis, pneumonia, fever, common colds, paralysis, encephalitis, gastroenteritis, diarrhea, respiratory infections
Protozoa	Gastroenteritis, acute enteritis, giardiasis (including diarrhea, abdominal cramps, and weight loss), dysentery, toxoplasmosis, crypotosporidiosis
Helminths	Digestive and nutritional disturbances, abdominal pain, vomiting, restlessness, coughing, chest pain, fever, abdominal pain, diarrhea, anemia, weight loss, fever, muscle aches, nervousness, insomnia, anorexia, hookworm disease, taeniasis
Bioaerosols	Allergic reactions (such as asthma), Legionnaire's disease

People can be exposed to raw sewage and its adverse impacts through:

- Sewage in drinking water sources
- Direct contact in areas of high public access such as basements, lawns or streets, or to waters used for recreation
- Shellfish harvested from areas contaminated by raw sewage.

Many avoidable SSOs are caused by inadequate or negligent operation or maintenance practices. These non-structural management measures were described in Section 4.3. Chronic SSOs are usually caused by excessive infiltration and inflow entering an aging sewer system, inadequate system capacity, and improper system design and construction. These chronic SSOs usually require structural measures such as the following:

- Reducing infiltration and inflow through system rehabilitation and repairing broken or leaking service lines

- Enlarging or upgrading sewer, pump station, or sewage treatment plant capacity and/or reliability

- Construction of wet weather storage and/or treatment facilities to treat excess flows

Sewer rehabilitation, renovation, upgrade, and repair are accomplished with a variety of construction methods ranging from excavation and replacement to trenchless technologies. Some methods are restricted for use depending on pipe size, structural condition, hydraulic capacity, and physical condition of the sewer system components (pipeline segments, manholes, and service connections).

Figure 5.2.2 shows a picture of a cracked pipe found in the NMR sewer system that was discharging raw wastewater into the stream. Through routine inspections, problems such as this one were observed and repaired, eliminating the exfiltration of raw sewage into receiving streams.

Figure 5.2.2: Cracked Pipe in the NMR Sewer System

Pipeline Rehabilitation

Pipeline rehabilitation uses the existing host structure to form part of the new pipeline or to support a new lining. Various pipeline rehabilitation techniques are available. The communities within the NMR watershed will choose which method(s) are best suited for their sewer rehabilitation needs.

Rehabilitation systems can be divided into three categories:

- Pipe linings
- Segmental linings
- Structural and nonstructural coatings

Sewer pipe linings have been installed in continuous and short lengths over the past 30 years. The following alternative methods are used for rehabilitating various sizes and cross sections of sewer piping:

Sliplining – a new, smaller diameter polyethylene liner is slid into the old, defective pipe. The pipe ends are melted and held together, making an extremely strong "butt fusion" joint that withstands the stresses of being winched in place.

Cured-in-place – a flexible, resin-saturated lining is inserted to the sewer using an inversion process or a winching process. A flexible carrier bag is used to evenly line the host pipe with a thermosetting resin that, when cured, becomes a strong pipe within a pipe.

Deformed pipe – is commonly referred to as U-Liner / Nu-Pipe or Rolldown / Swagelining. The process involves inserting U-shaped HDPE or PVC thermoplastic pipe. The liner is expanded inside the sewer to form a tight fit with the existing sewer.

Spiral wound pipe - is fabricated at the bottom of the manhole or access shaft. A sheet of PVC is pulled through a winding machine that rolls and forms the pipe to a specified size. A continuous joint results from the fabrication.

Segmental linings are suitable for larger than 36-in diameter sewers and are available in a variety of shapes. Segmental linings may be installed through existing manhole chambers or through specifically constructed access shafts. Flow diversion pumping is usually required. The annular space between the lining and existing sewer is grouted. Segmental linings provide flexibility to accommodate variations in grade, slope, cross section, and deterioration. They are made from an assortment of materials and typically consist of prefabricated panels that are manufactured in various lengths that overlap at the circumferential and longitudinal joints. Segmented rings are anchored on spacers and, after final assembly, the annular space is cement grouted.

Reinforced Shotcrete and cast-in-place concrete are typical coating materials for manholes and sewers larger than 48-inches in diameter. Shotcrete and gunite coating is the application of concrete or mortar that is conveyed through a hose and pneumatically projected at a high velocity onto the interior surface of the host pipe. There are two alternative processes: a wet-mix and a dry-mix method. Shotcrete usually refers to the wet process. The dry mix process typically is usually referred to as gunite. Shotcrete and gunite processes usually contain steel or mesh reinforcing to reduce cracking and add structural strength. Various additives such as latex polymers can be added to improve bond strength, reduce absorption and permeability, and increase chemical resistance. Shotcrete mixes are typically designed to have low shrinkage and up to twice the in-place density of cast or hand-placed structural concrete.

Cast-in-place (CIP) concrete lining is also an effective rehabilitation method. CIP can be placed with or without reinforcing using slip or fixed form for concrete placement. CIP steel reinforcement is attached to the existing pipe using threaded inserts. Forms are positioned to provide the finished wall section before the concrete is placed. CIP walls can vary in thickness, depending on structural or nonstructural design. Corrosion additives and cements can be added to the mix design and segmental liners can be incorporated for further protection. Precast invert panels are often required for proper forming.

Excavation and Replacement

Excavation and replacement of deteriorated sewer pipelines was once the most common rehabilitation practice, but is becoming more limited due to the availability of trenchless technologies. Excavation and replacement of defective pipe segments is normally undertaken under the following conditions:

- The structural integrity of the pipe has deteriorated severely
- The pipe is significantly misaligned
- Additional pipeline (hydraulic conveyance) capacity is also needed
- Trenchless rehabilitation methods that would be adequate to restore pipeline structural integrity would produce an unacceptable reduction in service capacity
- Point repair where short lengths of pipeline are too seriously damaged to be effectively rehabilitated by other means
- Entire reaches of pipeline are too seriously damaged to be rehabilitated

- Removal and replacement is less costly than other rehabilitation methods

Sewer pipeline replacement through open-trench excavation can be carried out by removing the existing pipe and placing a new pipeline in the same alignment. Pipeline replacement also can be performed by parallel replacement where the existing pipeline is abandoned and replaced by a new pipe in either parallel alignment adjacent to the existing line or functionally parallel alignment along a different route. Pipeline replacement materials include traditional materials such as reinforced concrete, clay, ductile iron, and a variety of plastics.

Manhole Rehabilitation

As with pipelines, manholes need to be rehabilitated to correct structural deficiencies, address maintenance concerns, and eliminate infiltration and inflow. Many alternative rehabilitation methods are currently available and new product and application technologies are continually being developed.

As part of the NMR sewer evaluation conducted by PWSA for the City of Pittsburgh, 847 manholes were located, inspected, and surveyed. The results of the manhole inspection program revealed that overall conditions of the manholes ranged from fair to poor. Deteriorated joints, cracked walls, and missing bricks were among the list of observed defects. Figure 5.2.4 below shows a manhole along the NMR trunk sewer with structural deficiencies. Similar manhole inspection programs are being conducted in the three separate sewer communities.

Figure 5.2.3: Manhole in NMR with Structural Deficiencies

Structural deficiencies vary with manhole material composition, shape, and size. Movement and displacement or corrosive environments typically cause these deficiencies. Where freeze-thaw cycles are common such as in NMR, vertical and horizontal separation and movement of the frame seal, chimney, and top portion of the manhole cone can occur. Three-dimensional movement can also occur to manhole structures from settlement and movement of the surrounding ground causing cracks and fractures.

Concrete surfaces will deteriorate structurally when sulfides are present and released from the wastewater stream. Factors controlling sulfide generation include velocity, pH, air temperature, and oxygen availability. In extreme conditions, structural degradation of unprotected precast areas can occur in fewer than 5 years.

Alternative rehabilitation methods for manholes can be grouped into the following categories:

- Chemical grouting
- Coating systems
- Structural linings
- Corrosion protection
- Manhole frame, cover, and chimney renovation

Chemical grouting – used to fill voids, stabilize soil, plug holes, hold bricks in place, and prevent infiltration. Chemical grout is not a structural repair but does a nice job of stabilizing the surrounding soil and preventing groundwater infiltration. The success of chemical grouting depends on soil and groundwater conditions, injection patterns, gel time and grout mixture, containment of excessive grout migration, and selection of proper materials including acrylamide, acrylate, urethane foam, and urethane gel.

Coating systems – used for restoration of manhole structures and are ideally suited for brick structures that show little or no evidence of movement. Coatings are generally comprised of cement, mineral fillers, and chemical additives applied in layers by mechanical or trowel-on methods. Most coating systems provide both mechanical and chemical bonding and can be used to coat the entire manhole, including reconstruction of the bench and invert.

Structural linings – can restore the structural integrity of a manhole through in-situ nondestructive methods. Structural reconstruction methods include cast-in-place concrete, prefabricated reinforced plastic mortar, prefabricated fiberglass reinforced plastic, spiral-wound liner, and cured-in-place linings. Structural linings should be designed to withstand external water pressures.

Corrosion protection – a non-cement type coating is applied for protection from corrosive atmospheres. A variety of plastic, polymer, and epoxy coatings are effective in protection from sulfuric acid corrosion.

Frame, cover, and chimney rehabilitation – used to prevent leakage from surface waters entering the manhole through holes in manhole covers, between the cover and the frame, and spacing beneath the manhole frame. Manhole covers can be sealed by replacing them with new watertight covers, by sealing existing covers with rubber cover gaskets and rubber vent and pick hole plugs, or by installing watertight inserts under the existing manhole covers. Manhole frame and chimney joint areas can be sealed by installing a flexible manufactured seal or by applying a flexible material to either the surface chimney and frame, or between the adjusting rings and under the frame.

Sewer rehabilitation to reduce or eliminate SSOs can be expensive, but the cost must be weighed against the value of the collection system asset and the added costs of this asset if it is allowed to further deteriorate. Ongoing maintenance and rehabilitation adds value to the original infrastructure investment by maintaining the system's capacity and extending its life. The costs of rehabilitation and other measures to correct SSOs can vary widely by community size and sewer system type. Those being equal, however, costs will be highest and ratepayers will pay more in communities that have not put together regular preventive maintenance or asset protection programs in place.

Due to the consent order issued to PWSA by PaDEP, and the similar orders issued to the three other contributing municipalities, extensive sewer rehabilitation efforts will take place within the NMR watershed. The existing deteriorated sewers will undergo rehabilitation, renovation, upgrade, and repair. As a result, the discharge of raw wastewater into receiving streams can be corrected. It is important that the communities within the NMR watershed follow-up rehabilitation efforts with routine preventive maintenance and inspection programs to prevent SSOs and the problems associated with them.

5.2.2 Reduction In Combined Sewer Overflows

Structural measures could be implemented to reduce CSO discharges to receiving waters and the environmental impacts of elevated concentrations of fecal coliform and other substances associated with sanitary sewage and storm water. A number of structural alternatives are available to reduce the frequency, duration, and volume of CSO discharges and their associated pollutants, solids, and floatable materials. Previously, in Section 4 of this watershed management plan, a number of non-structural measures for CSO reduction (i.e. proactive maintenance and inspection program) were discussed. These are generally short-term solutions and usually do not require detailed engineering studies or major construction. However, long-term solutions often require alternative structural measures.

Combined sewer systems (CSS) are wastewater collection systems designed to carry sanitary sewage (consisting of domestic, commercial, and industrial wastewater) and storm water (surface drainage from rainfall or snowmelt) to a treatment facility. In dry weather, all flows are diverted by a regulator structure and are conveyed to the wastewater treatment plant (WWTP). In periods of rainfall or snowmelt, total wastewater flows can exceed the capacity of the regulator structure and only a fraction of the flow is conveyed to the WWTP. When this occurs, the CSS is designed to discharge the excess flow directly to surface water bodies. These overflows, called combined sewer overflows (CSOs), can be a significant source of pollution in communities served by CSSs. Combined sewers serve approximately 27% of the developed area within the NMR watershed. A map of these areas was provided in Figure 4.3.1.

A number of alternative structural controls could be implemented to reduce CSO occurrences and impacts. Some structural measures to increase the storage capacity of the CSS are described below. More elaborate structural measures are also available.

Upsize Sewer Pipes - By upsizing sewer pipes, the hydraulic capacity of the sewer system can increase and the frequency, duration, and volume of CSO discharges can be reduced. The capacities of the major interceptor(s) within the system should be determined and segments with inadequate capacity should be identified and upsized. Pipe upsizing is a structural alternative to the non-structural alternative of routine maintenance and inspection to increase sewer capacity.

Make Trunk Sewers Watertight – Many of the combined sewer trunks in the watershed were constructed along creek beds at elevations below the ground water table. By using one of the structural rehabilitation measures described in Section 5.2.1 to seal all pipe joints and cracks, ground water infiltration from the steam into the trunk sewer can be eliminated, greater pipe capacity is made available for sewage, and stream flows during dry weather are significantly increased.

Retard Inflows – By using special gratings or Hydrobrakes (or comparable commercial devices), municipal operation and maintenance (O&M) staff can modify catch basin inlets to restrict the rate at which surface runoff is permitted to enter the system. Slowing inflow will enable the CSS to transport more flow overall by spreading out the flow over time. Eliminating the direct connection of roof drains and sump pumps to the collection system is also possible where sufficient land area is available for drainage.

Upstream Detention - By storing storm water upstream in holding tanks and controlling the rate at which it enters the CSS can alleviate overflow pollution. Storage concepts include the conventional concrete holding tanks and earthen basins, and the minimum land requirement concepts of: tunnels, underground containers, underground “silos”, natural and mined underground formations, and the use of abandoned facilities and existing sewer lines. More innovative storage may be provided by modifying the existing Fern Hollow box culvert to maximize its storage potential. The flow rate from storage facilities can be controlled and designed to discharge at a constant rate compatible with the downstream sewerage system capacities and water quality objectives.

An example of implementation of a structural measure to reduce CSOs can be found in Detroit. The city of Detroit installed inflatable dams in two long, large-diameter lines that extend from the collection system to the shoreline discharge point. The system layout prevented any risk of upstream adverse effects, and installation was relatively straightforward and inexpensive. Detailed monitoring data are not available to quantify the benefits, but these devices are often effective in completely containing overflows from smaller storms and can reduce the number of overflows. Maintenance is minimal because contained flows drain back into the collection system following the storm, and no real-time operation of the devices is necessary. The dams simple provide more effective use of existing excess capacity within the system.

Additional structural controls are available to reduce, if not eliminate, visible floatables and solids. Simple devices including baffles, screens, and racks can be used to remove coarse solids and floatables from combined sewage, and devices such as booms and skimmer vessels can help remove floatables from the surface of the receiving water body. A description of each of these devices is given below. More elaborate structural methods are also available.

Baffles – Floatables can be captured relatively easily within the collection system with baffles placed over at overflow locations. The effectiveness of baffles will depend on the specific design of the diversion points for the overflows. Baffles are generally simpler than screens and other methods, and have lower capital and O&M costs. Their removal effectiveness is likely to be lower, however, because turbulence in the flow stream tends to entrain floatables, especially those that are relatively close to neutral buoyancy.

Trash Racks – A trash rack is a set of vertical bars designed to remove coarse and floating debris from CSOs. Trash racks are usually used to prevent floatables from existing storm water detention ponds and from entering and clogging the pond outlet pipes. Trash racks can be used in a similar manner for CSO floatables, as long as enough outfall pipe or land space is available for a small structure and the outfall is high enough above the receiving water to facilitate regular maintenance.

Static Screens – Static screens (usually vertical bar racks) are manually cleaned screens similar to trash racks. Static screens are typically used in sewage treatment plants for preliminary treatment and at pump stations for the removal of debris to protect facility pumps and other internal working areas. They can also be used to control course solids and floatables in areas where adequate construction space exists and where the outfalls are above the water level of the receiving water body to facilitate maintenance.

End-of-Pipe Nets – Nets can be used to separate floatables from CSOs. In general, simple placement of a net across the face of an outfall is not practical because factors such as discharge velocity and receiving water currents can threaten the integrity and influence efficiency of a netting system. Usually, a netting installation takes the form of an in-water containment area deflecting CSO flow through a set of netted bags. Floatables are retained in the bags and removed for disposal. The containment system should be sized to handle the volume and source of the CSO. Nets have the potential to work well in lake, tributary, or quiescent estuarine waters at least a few feet deep with an outfall at or close to the level of the water surface.

Outfall Booms – Simple vinyl oil collection booms, or more elaborate containment systems with specially fabricated floatation structures and suspended curtains, can be placed in the water around outfalls to contain materials with positive buoyancy (which remain on the surface even in turbulent pipeline flows) and materials with neutral buoyancy (which will surface only under the relatively quiescent conditions of the containment zone). Once contained behind booms, the floatables can be removed by hand or vacuum trucks.

A number of the alternative structural measures described in this section can be implemented in the NMR watershed to reduce the frequency, duration, and volume of CSO discharges. Upsizing existing sewer pipes, upstream detention of storm water, making trunk sewers watertight, and devices to remove floatables and solids can alleviate overflow pollution. These structural alternatives combined with the non-structural measures described in Section 4 (i.e. proactive maintenance and inspection programs) can be used to reduce CSOs and the pollutant discharges associated with them.

5.2.3 Modification of Catch Basins and Storm Inlets

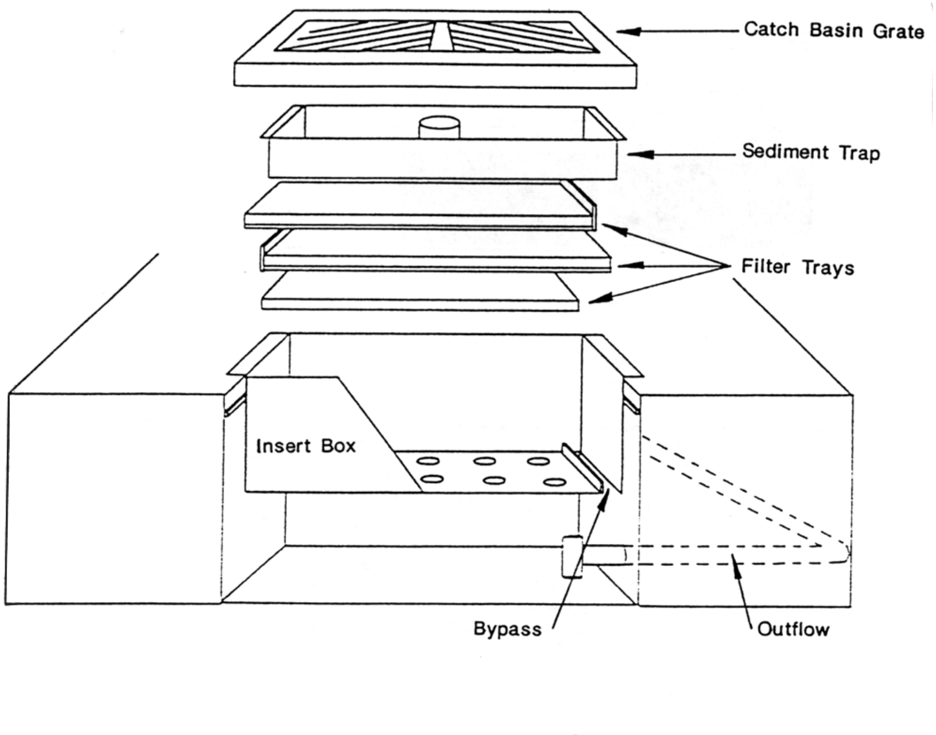
Modifying existing catch basins (in combined sewer areas) and storm inlets (in separate sewer areas) to increase the capture of sediments and floatable materials can be an effective structural management measure. Structural controls are often implemented coincidentally with nonstructural management measures, like those described previously in Section 4.3.2, for optimal watershed benefits. Wherever possible, structural measures should be taken to modify municipal storm inlets and catch basins to trap floatable materials and sediment and prevent their discharge into waterways.

Modification of Catch Basins

Many of the existing catch basins within the City of Pittsburgh portion of NMR are currently equipped with sewer hoods to trap sewer gasses and prevent them from escaping, capture floatables, and settle some solids. If hooded outlets are inspected and maintained, and if catch basins are cleaned systematically on a regular schedule, trash, floatable debris, and most solids should be prevented from being discharged into watershed streams. However, some of the existing catch basins do not have a sewer hood. A comprehensive inspection program could identify these catch basins and new sewer hoods can be retrofitted into the existing structures.

A variety of other products, known as "catch basin inserts", may also be used to filter runoff entering the catch basin. There are two basic types of catch basin inserts. One insert option consists of a series of trays, with the top of the tray serving as an initial sediment trap, and the underlying trays comprised of media filters. Another option uses filter fabric to remove pollutants from storm water runoff. These devices have a very small volume compared to the volume of the catch basin sump, and would typically require very frequent sediment removal. An example of a catch basin filter is shown in Figure 5.2.4.

Figure 5.2.4: Typical Catch Basin Filter



Source: McPherson (1992)

Catch basins can also be resized to accommodate the volume of sediment that enters the system. Pitt et al. (1997) proposed a sizing criteria based on the concentration of sediment in storm water runoff. The catch basin is sized, with a factor of safety, to accommodate the annual sediment load to the catch basin. This method is preferable where high sediment loads are anticipated or observed, and the optimal design described above is suspected to provide little treatment.

The performance of catch basins is related to the volume of sump (i.e. the storage in the catch basin below the outlet). Lager et al. (1997), described an "optimal" catch basin sizing criteria, which relates all catch basin dimensions to the diameter of the outlet pipe (D): Dimensions are:

- The diameter of the catch basin should be equal to 4D
- The sump depth should be at least 4D. This depth should be increased if cleaning is infrequent or if the area draining to the catch basin has high sediment loads
- The top of the outlet pipe should be 1.5D from the inlet to the catch basin.

Modification of Storm Inlets

The municipalities of Edgewood, Swissvale, and Wilkinsburg are served by separate sewer systems where storm water runoff is captured by storm inlets with no litter traps. Many of the existing inlets have a combination of a horizontal slotted grate and a vertical curb inlet. This typical storm inlet configuration was shown in Figure 4.3.3. The slotted grate generally traps most trash and floatables; however, the curb inlet allows the debris to pass right through into the inlet, through the municipal storm drain system and into the receiving stream. Several commercially available devices can be added to existing curb inlets to allow storm runoff to pass through while capturing trash and floatables.

For example, a variety of filtering devices are available to capture oil, grease, trash, and sediment from storm water runoff before it enters the storm sewer system. A typical filtering device is shown in Figure 5.2.5. Filtered water passes through the unit and the basket configuration enables capture of waterborne sediment, trash, and debris that passes through into the inlet. Devices such as these are relatively easy to install and maintain. The basket configuration allows for easy, periodic cleanouts using a vactor truck.

Figure 5.2.5: Typical Storm Inlet Filter

Catch basins and storm drains receiving sediment-laden runoff, trash and floatables should be protected. Devices of various designs are available which either detain sediment-laden runoff and floatables within the structure or prevent them from entering into a storm inlet. Exploring these structural alternatives for the storm drains within the NMR watershed, along with non-structural measures such as routine maintenance and cleaning, is vital for preventing dirt, debris, floatables, and associated pollutants from being discharged into receiving streams.

5.2.4 References for Section 5.2

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5.3 New Regional Facilities

A number of systems are available whereby storm water runoff is collected, temporarily stored, and percolated through the soil. These systems include wet or dry ponds, detention basins, dry wells, infiltration basins, and constructed wetlands. These facilities are typically designed to fit aesthetically into the open space landscaping of new development sites. Often, these facilities are fragmented in that individual basins are sited within individual development plans, but regional basins can be constructed to provide storm water management for an entire sub-watershed area. In the Nine Mile Run (NMR) watershed, the opportunity for new development is minimal but these structural alternatives can be considered on a regional level. Selection of these structural alternatives is dependent upon the desired level of particulate and dissolved pollutant removal, groundwater recharge, and storm water runoff flow control

Whenever possible, priority should be given to source control alternatives. Source control measures are generally (but not always) less expensive than the regional facilities that will be described in this section. Also, these new regional facilities would not remove all pollutants in storm water from urbanized areas, and their removal efficiencies would be difficult to predict due to the limited understanding of the relationship between facility design criteria and performance. However, while source control measures should be given a higher priority, the construction of new regional facilities needs to be considered in new development projects and, in the case of the NMR watershed, retrofitted into existing development. This section will discuss:

- Factors to consider when selecting structural facilities to increase storm water storage and/or infiltration and control stream flow
- Constructing wet or dry ponds, detention basins, dry wells, and infiltration ditches to collect runoff, temporarily store it, percolate it through the soil, and increase the base flow to watershed streams
- Constructing ponds and wetlands to collect storm water runoff, detain it, and remove pollutants through settling, filtration, absorption, microbial decomposition, and vegetative uptake

5.3.1 Factors to Consider

There are general factors that are taken into consideration when selecting structural measures that increase storm water storage and/or infiltration. In every case, all structural measures must be compatible with existing flood control and storm water management objectives.

- Slope: Certain facilities cannot be placed on or near steep slopes as the ponding of water or velocity of flow may cause instability or excessive erosion.
- Area Required: Most regional facilities require considerable area, although some can be placed underground
- Soil: Infiltration systems must be located on suitable soils; vegetation requires good soils; wet pond bottoms require impermeable soils
- Water Availability: Facilities using vegetation for pollutant removal may require water during dry seasons
- Aesthetics and Safety: Where accessible or visible to the public, aesthetics and/or safety may be a concern with some of these measures
- Hydraulic Head: A few facilities may require a drop in hydraulic gradient or water elevation, which site topography may not provide
- Environmental Side Effects: Considerations are needed to control mosquito breeding and groundwater contamination, as well as opportunities to enhance aquatic wildlife and passive recreation

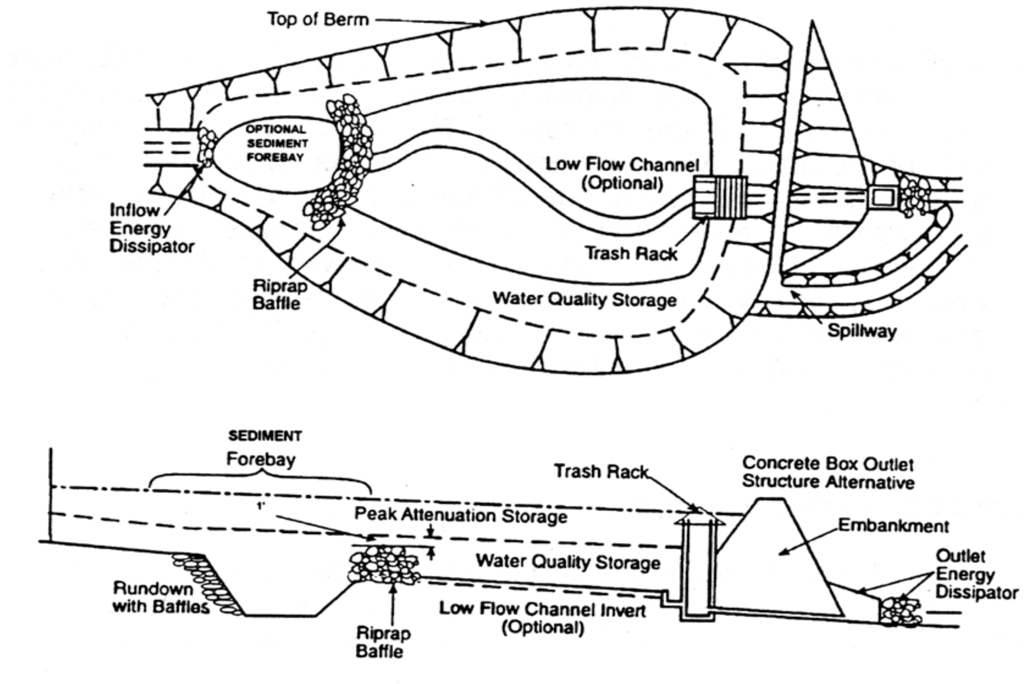
5.3.2 Extended Dry Detention Ponds, Wet Ponds, Dry Wells, and Infiltration Basins

Extended Dry Detention Ponds: Extended dry detention ponds provide flow equalization to mitigate impervious area. They can be site-specific or regional. These devices are able to store storm water runoff until it can be discharged, either by overflow, a pipe system, groundwater infiltration, or by evaporation and transpiration. Extended dry detention ponds temporarily store storm water runoff and promote the settling of solids and pollutants attached to the solids. Discharge is designed to be slow to provide time for sediment to settle. These ponds are typically designed to completely discharge the detained runoff over a twenty-four to forty-eight hour period. To enhance sediment removal, the ponds are often designed with a sediment forebay, which captures debris and larger sized sediment entering the facility. The finer particles settle out in the bottom stage of the pond.

Critical site considerations for extended dry detention ponds include drainage area, land slope, and available treatment area. Drainage areas of 20 acres or less are recommended for storm drainage applications; drainage areas in excess of 20 acres may result in permanently wet conditions in part of the pond, which may be aesthetically undesirable. However, extended dry detention ponds are subject to other constraints such as minimum orifice diameter in the control structure and required length of detention time, etc. Similarly, a moderate slope is required for the pond sides and bottom, in order to maintain dry conditions in the pond between storm events. The required treatment area for the pond is typically between 0.5 and 2 percent of the tributary drainage area. Other factors such as soil permeability and depth to water table must be considered. High groundwater may contribute to the undesirable conditions of a permanently "wet" pond.

Proper maintenance of extended dry detention ponds includes periodic removal of sediment, seasonal mowing, removal of invasive vegetation/trees, and routine inspection for sediment removal, trash and debris removal, and structural repair and replacement. Sediment should be removed from the bottom stage of the pond every five to fifteen years. Sediment and debris should be removed from the forebay more frequently. Regularly scheduled mowing is encouraged to control weeds and pests.

Figure 5.3.1: Typical Extended Dry Detention Pond



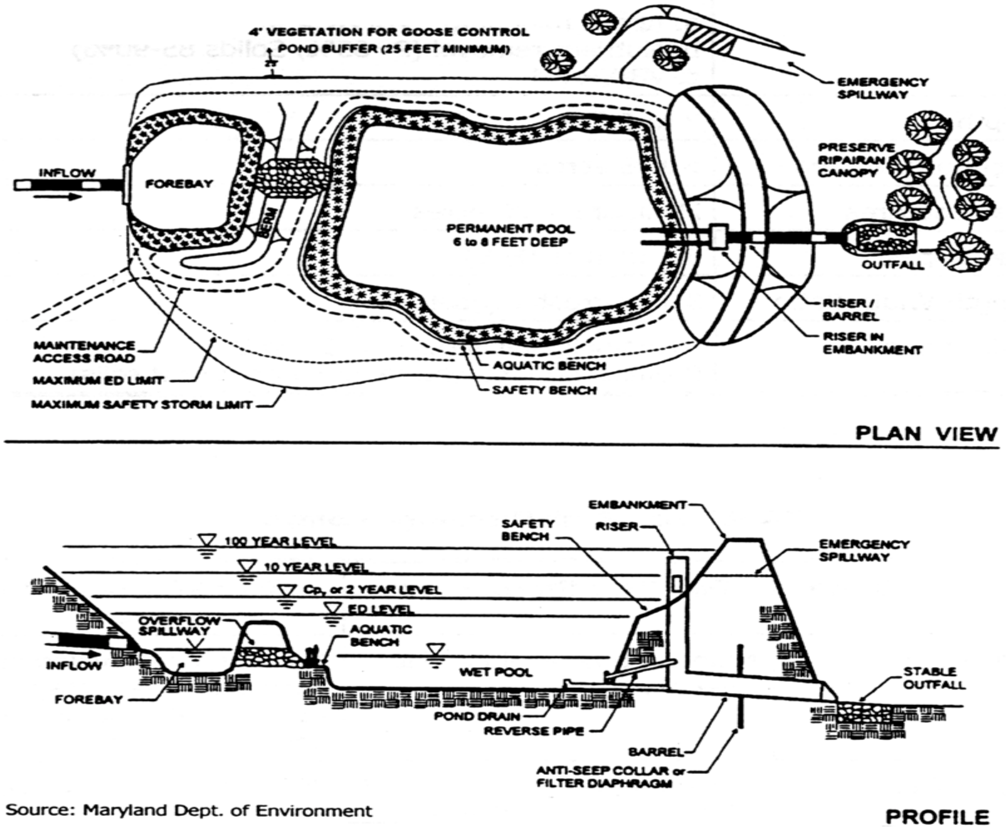
(Adapted from *Dam Design and Construction Standards*, Fairfax County, Virginia, 1991)

Wet Ponds: A wet pond (or retention pond) is similar to a dry pond except that a permanent pool of water is incorporated into the design. Like dry ponds, these ponds can be site-specific or regional. Wet ponds are typically located in the path of storm water runoff and maintain a permanent volume of water. Within the permanent pool, enhanced settling and biological processes promote removal of both particulate (e.g. sediment) and dissolved (e.g. nitrate, phosphate) pollutants. Wet ponds can also provide recreational/aesthetic benefits. If there is adequate space available, rooted wetland vegetation is typically found along the wet pond perimeter and within the extended littoral zone.

Critical site considerations for wet detention ponds include drainage area, soil permeability, land slope, and available treatment area. A wet pond should have a minimum tributary drainage area of 10 acres, and preferably 20 acres, to ensure that the permanent pool will have a sustained source of water during dry weather. Soil permeability must be limited to prevent the permanent pool from infiltrating into the subsoil. In areas with Soil Conservation Service (SCS) soil classifications of A or B, compaction of the pond bottom or construction of a bottom liner is recommended. Wet ponds cannot be located on steep, unstable slopes. The required treatment area for the pond is typically between 1 to 3 percent of the drainage area. Depth to water table must be considered.

Proper maintenance is required to maintain wet pond performance and prevent the ponds from breeding mosquitoes and becoming a public nuisance. Like dry ponds, maintenance activities should include regular sediment and debris removal, mowing, and inspections. Again, sediment and debris removal should be more frequent for the forebay (2 to 5 years) than for the permanent pool (5 to 15 years).

Figure 5.3.2: Typical Wet Pond



Source: Maryland Dept. of Environment

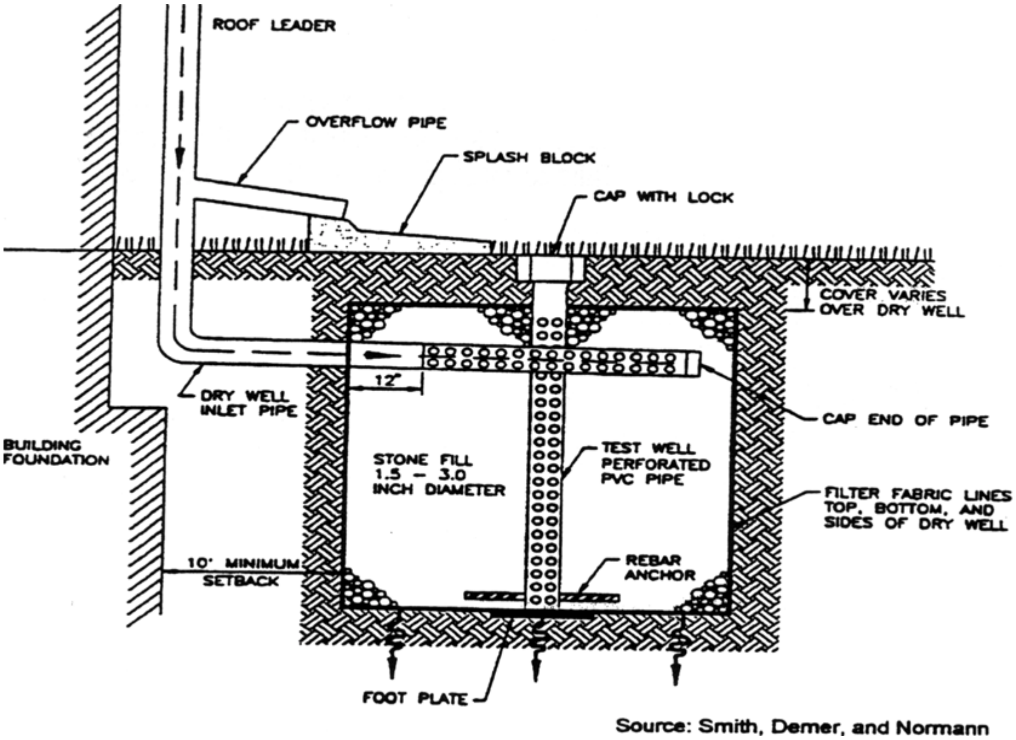
<u>Dry Wells:</u> A dry well is an excavated pit ranging from 3 to 12 feet that is filled with aggregate and receives storm water from roof drainage and direct surface runoff. Unlike dry and wet ponds, dry wells are usually only placed on individual properties.

A dry well is used to capture and store runoff from rooftops or areas with low sediment loading. The use of dry wells for storm water control is applicable where soil is sufficiently permeable to allow for a reasonable rate of infiltration. Soil permeability must be sufficient to drain the entire volume of the water quality design storm within 72 hours. The soil infiltration rate should be 0.5 inches per hour or greater. Suitable soil types include sand, sandy loam, loamy sand, and gravel. Surface soils within the NMR watershed are generally deposits of sand, gravel, and clay over sedimentary rock layers of shale, sandstone, limestone, claystone, and coal.

These devices are not applicable in large drainage areas, or areas where high pollutant or sediment loading without pretreatment is anticipated. If the runoff will contain toxic pollutants, infiltration facilities alone are not suitable because of the potential for groundwater contamination. The minimum design storm should be the one-year 24-hour water quality design storm. An overflow system is required unless the well can be demonstrated to handle the entire volume of the flood design storm. The minimum depth to the seasonal groundwater table or bedrock shall be three feet from the bottom of the structure.

A dry well should be inspected monthly to ensure it is functioning properly. The water level in the test well should be the primary means for measuring infiltration. Corrective measures shall be taken if the structure fails to infiltrate the design storm event.

Figure 5.3.3: Typical Dry Well

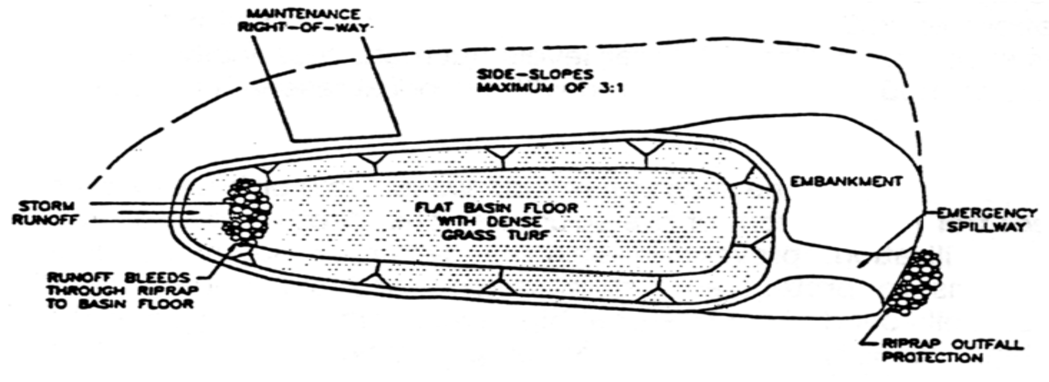


Source: Smith, Demer, and Normann

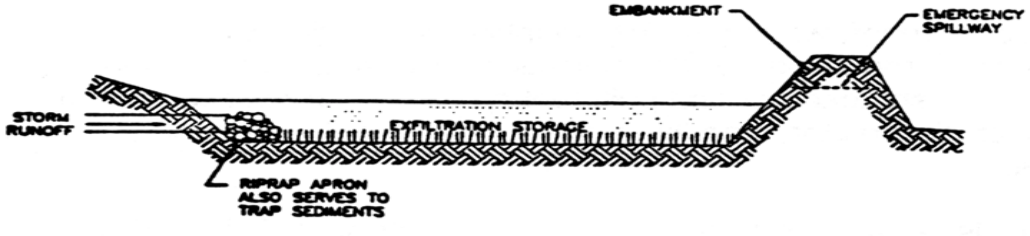
<u>Infiltration Basins:</u> An infiltration basin is a dry pond that captures first flush storm water and treats it by allowing it to percolate into the ground through the permeable pond bottom and/or side embankments. Like dry wells, infiltration basins are usually site-specific and not regional. As the storm water percolates into the ground, physical, chemical, and biological processes occur which remove both sediments and soluble pollutants. Pollutants are trapped in the upper layers of the soil, and the water is allowed to gradually exfiltrate into the subsoil. An underdrain piping system may also be used to collect the filtered storm water.

Critical site considerations include the drainage area, depth to water table, and soil permeability. Infiltration basins are generally recommended for drainage areas between 2 and 10 acres, with a maximum of 20 acres. For drainage areas greater than 10 acres, maintenance of the infiltration basin becomes difficult, and an extended dry detention pond or wet pond would be more appropriate. To guarantee the feasibility of infiltration, the bottom of the basin should be 3 to 4 feet above the seasonally high water table, and the soil should have a SCS classification of A or B. The NMR watershed is classified as having by clay soil. Only 42 percent of the watershed has a soil classification of B, while the rest is class C and D. The required treatment area for the basin is typically 0.5 to 2.0 percent of the drainage area. The use of sediment forebay may extend the functional capabilities of the basin by removing larger debris prior to entering the infiltration area.

Figure 5.3.4: Typical Infiltration Basin



TOP VIEW



SIDE VIEW

(Source: Smith, Damer, and Normann, 1983)

Maintenance of infiltration basins should include sediment and debris removal, regular mowing, and regular inspection. In addition, special considerations are required to maintain the exfiltration capability of the basin. Additionally, when sediment is removed from the basin, light equipment should be used to minimize compaction. In addition, tilling or mechanical aeration of the basin bottom may be required.

The facilities described above are typically designed to fit aesthetically into the open space landscaping of new developments. They are usually placed within individual development projects or lots. The majority of the NMR watershed consists of urbanized, residential and commercial areas. The undeveloped open space within the watershed primarily consists of parklands, cemeteries, and the Duquesne slag disposal area. Other areas of open space consist of highway right-of-ways or properties that are unlikely to be developed because of steep grades or other site-specific constraints. As a result, realistic opportunities to implement these alternatives are limited to on-lot restorative redevelopment and regional systems.

There are limitations to implementing these alternatives on a regional level. The regional facilities described above take up considerable land area because the side slopes of many of them are flat to allow for maintenance and to ensure public safety. In these cases where land availability is minimal as is the case in most of the NMR watershed, there are limited opportunities for regional facilities.

Hydrologic and hydraulic numerical simulation modeling was conducted to evaluate the response of the watershed, sewer system, and stream to various habitat restoration alternatives. The modeling studies showed that there is sufficient channel and overbank variability to provide wet weather storage. For 1-year and 2-year design storms, there is an actual decrease in peak storm flow. However, there is insufficient storage volume to attenuate larger storms and increases in peak along the NMR valley for 10-, 25-, and 100-year design storms.

There are also constraints in implementing on-site alternatives into existing development due to the characteristics of the NMR watershed. For example, a dry well can be used to capture and store runoff from existing residential and commercial rooftops. However, the use of dry wells to manage storm water is only applicable where soil is sufficiently permeable to allow for a reasonable rate of infiltration. The clay soils of the watershed prevent adequate infiltration rates.

5.3.3 Wetlands

There are several scenarios for the NMR watershed where wetland creation or expansion could be used to manage storm water and provide some pollutant removal. Constructed wetlands can increase wildlife habitat while decreasing the stream gradient and creating slow flow areas to regulate flow. Using wetlands to control the storm water flows with extra storage capacity and slower flow-through rates also will reduce bank erosion and increase the variability of stream morphology and hydrologic flow characteristics.

Constructed storm water wetlands are wetland systems designed to maximize the removal of pollutants from storm water runoff through wetland vegetation uptake, retention, and settling. Constructed storm water wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. Like detention basins and wet ponds, constructed storm water wetlands may be used in connection with other components, such as sediment forebays and micropools.

Constructed storm water wetlands should not be located within natural wetland areas. These engineered wetlands differ from wetlands constructed for compensatory storage purposes and wetlands created for restoration. Typically, constructed storm water wetlands will not have the full range of ecological functions of natural wetlands; constructed storm water wetlands are typically designed specifically for flood control and water quality purposes. For the NMR watershed, they could be designed for water quality enhancement.

Similar to wet ponds, constructed storm water wetlands require relatively large contributing drainage areas and/or dry weather base flow. Minimum contributing drainage areas should be at least ten acres, although pocket type wetlands may be appropriate for smaller sites if sufficient groundwater flow is available.

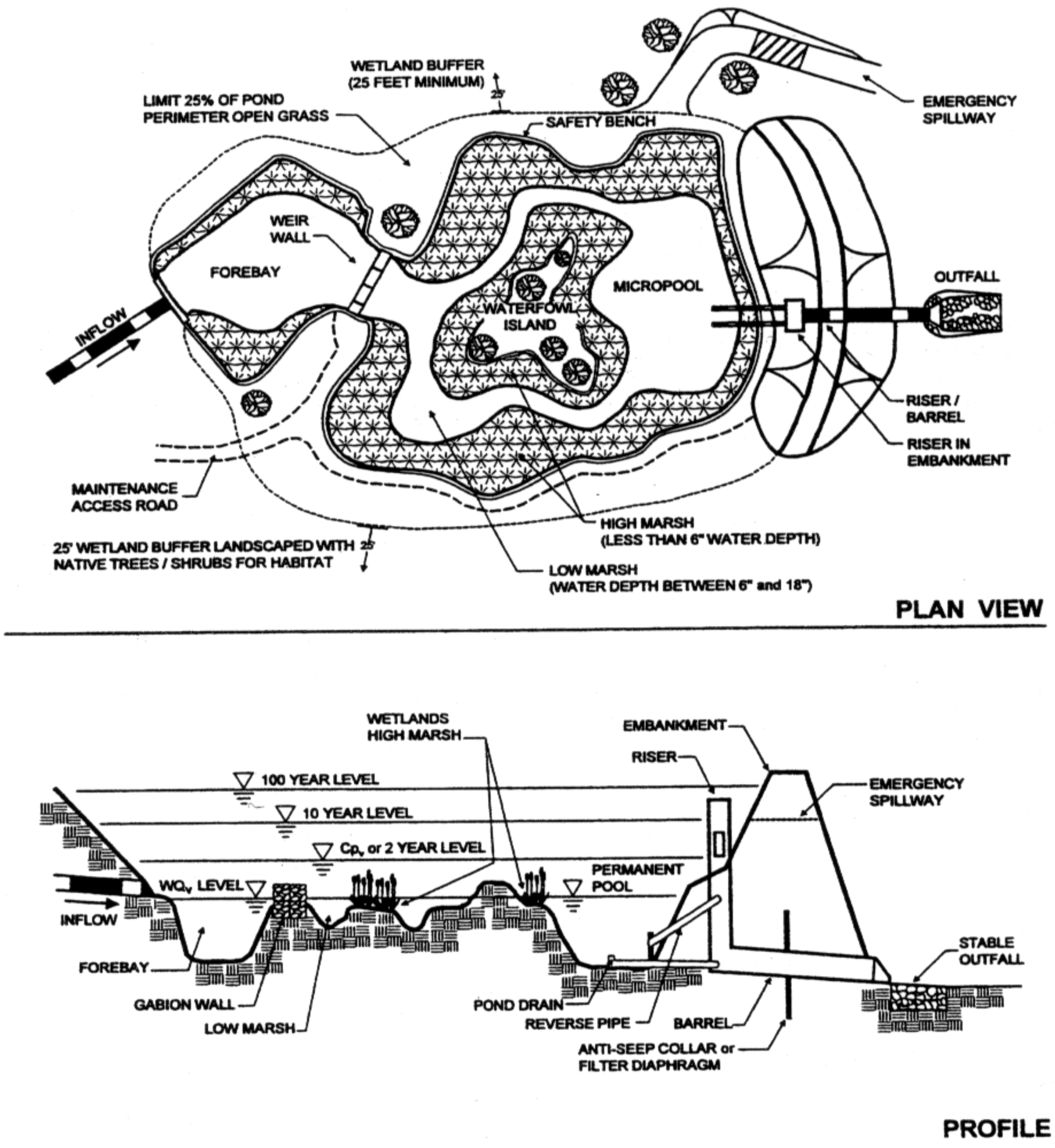
There are four basic constructed storm water wetland design types:

- Shallow marsh systems
- Extended detention wetlands
- Pond/wetland systems
- Pocket wetlands

Shallow Marsh Systems

Most shallow marsh systems consist of pools ranging from 6 to 18 inches during normal conditions. Shallow marshes may be configured with different low marsh and high marsh areas, which are referred to as cells. Shallow marshes are designed with sinuous pathways to increase retention time and contact area. Shallow marshes may require larger contributing drainage areas than other systems, as runoff volumes are stored primarily within the marshes, not in deeper pools where flow may be regulated and controlled over longer periods of time.

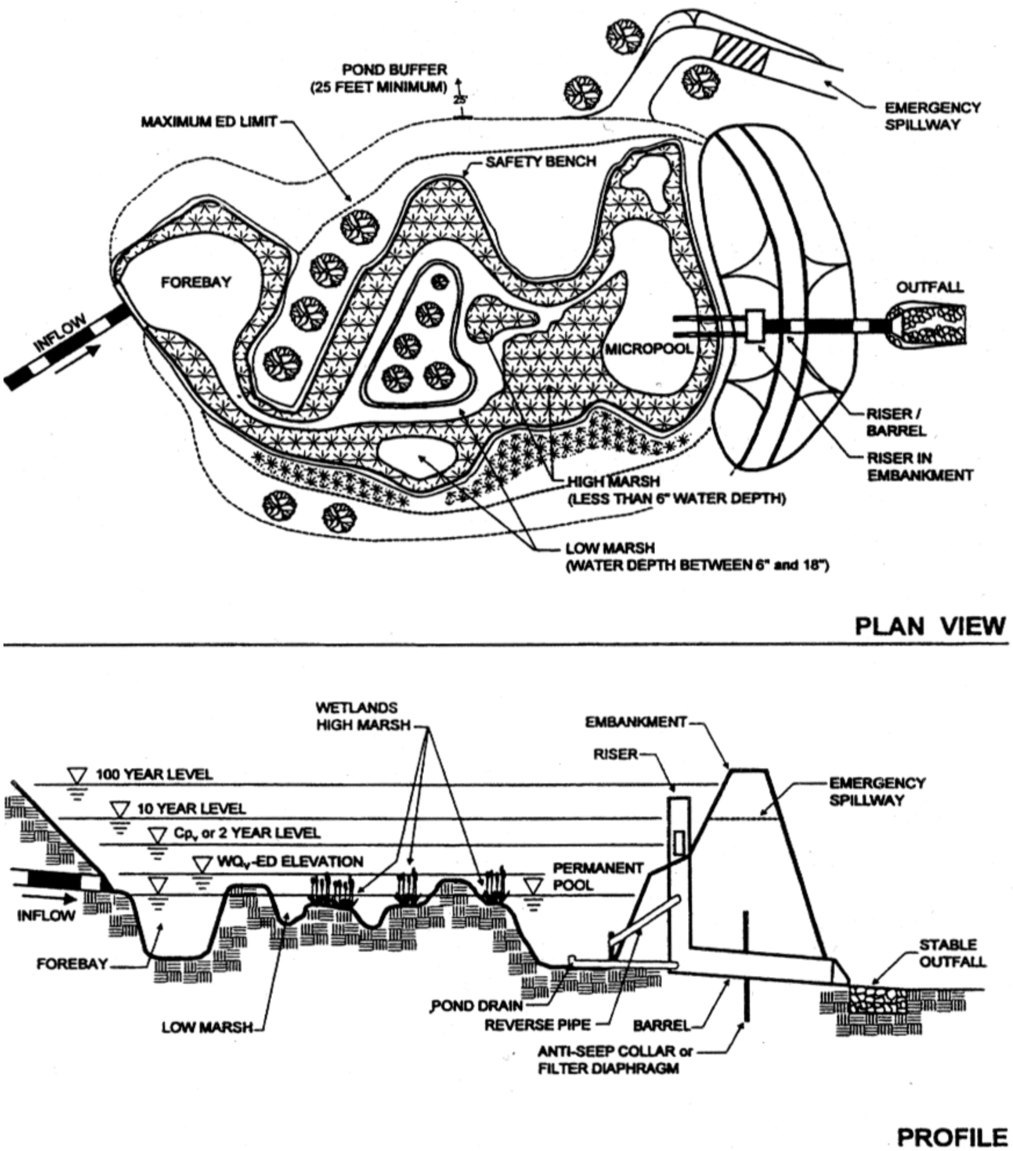
Figure 5.3.5: Typical Shallow Marsh System



Extended Detention Wetland

Extended detention wetlands provide a greater degree of downstream channel protection. These systems require less space than the shallow marsh systems, since temporary vertical storage is substituted for shallow marsh storage. The additional vertical storage area also provides extra runoff detention above the normal elevations. Water levels in the extended detention wetlands may increase by as much as three feet after a storm event and return gradually to normal within 24 hours of the rain event. The growing area in the extended detention wetlands expands from the normal pool elevation to the maximum surface water elevation. Wetland plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations.

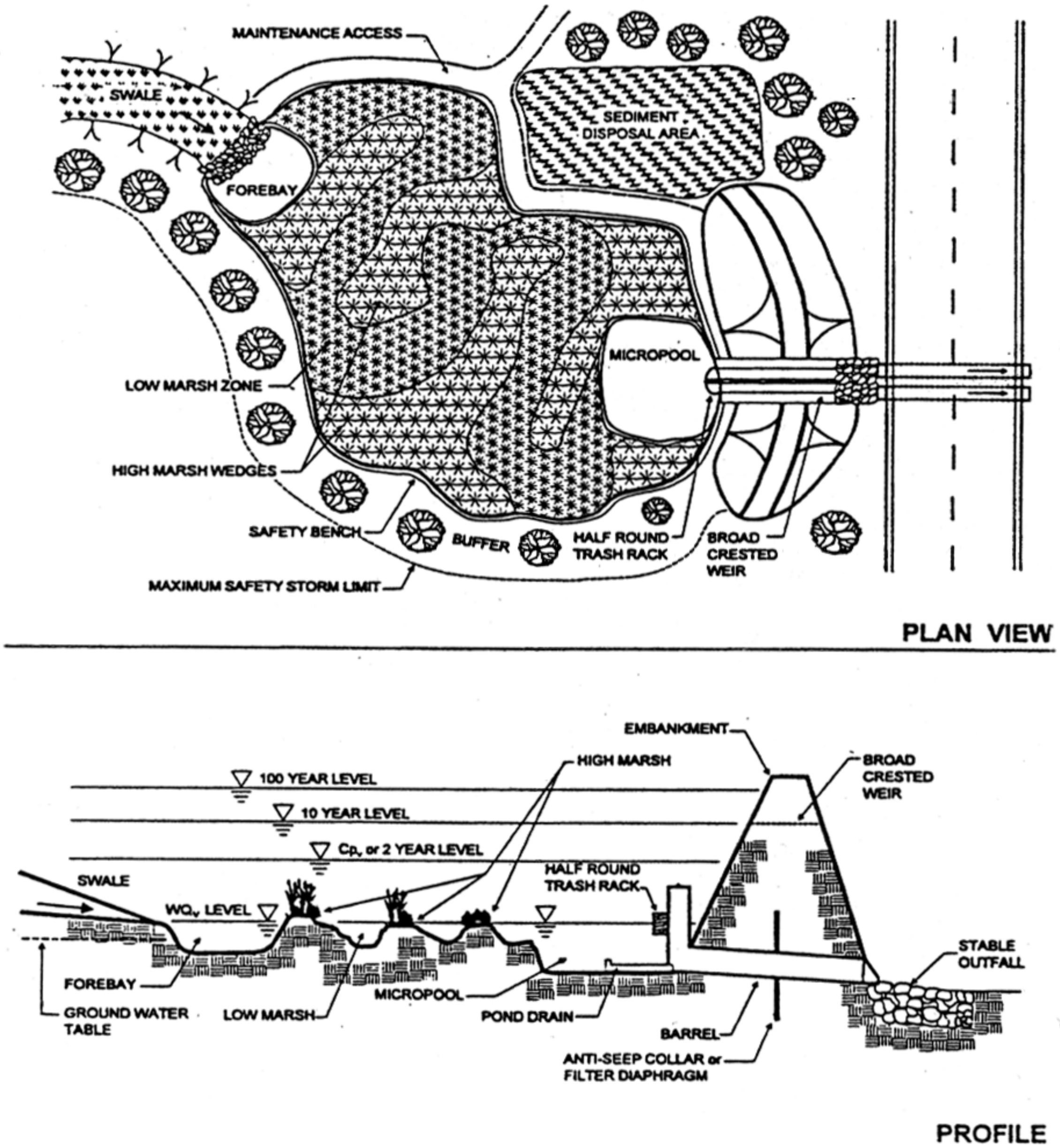
Figure 5.3.6: Typical Extended Detention Wetland



Pond / Wetland System

Multiple cell systems, such as pond / wetland systems, utilize at least one pond component in conjunction with a shallow marsh component. The first cell is typically the wet pond that provide for particulate pollutant removal. The wet pond is also used to reduce the velocity of the runoff entering the system. The shallow marsh provides additional treatment of the runoff, particularly for soluble pollutants. These systems require less space than the shallow marsh systems and generally achieve a higher pollutant removal rate than other constructed storm water wetland systems.

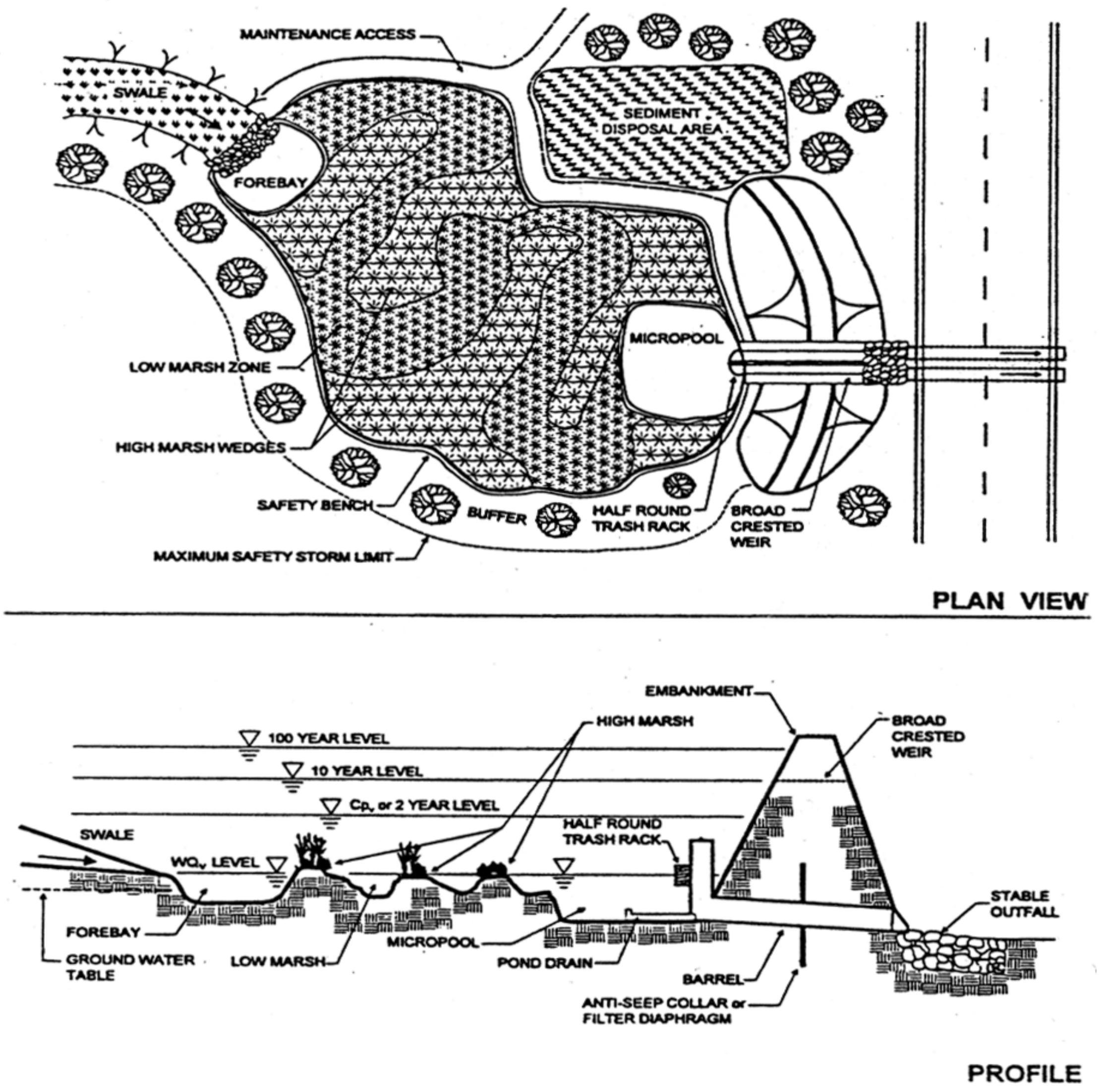
Figure 5.3.7: Typical Pond/Wetland System



Pocket Wetlands

These systems may be utilized for smaller sites of one to ten acres. To maintain adequate water levels, pocket wetlands are generally excavated down to the groundwater table. Pocket wetlands that are supported exclusively by storm water runoff generally will have difficulty maintaining marsh vegetation due to extended periods of drought. In urban settings, natural wetlands can be altered by increases in runoff volume. The existing functions and structure of the natural wetland can be altered severely when runoff becomes a major component of the natural wetland hydrologic regime (or water balance). Ultimately, natural wetlands that have been altered by runoff function more like constructed storm water wetland systems than natural systems.

Figure 5.3.8: Example of a Pocket Wetland



Sites must be carefully evaluated when planning constructed storm water wetlands. Soils, depth to bedrock, and depth to water table must be investigated before designing and siting constructed storm water wetlands.

A “pondscaping plan” should be developed for the creation of a storm water wetland. This plan should include hydrological calculations, a wetland design and configuration, elevation and grades, a site/soil analysis, and estimated depth zones. The plan should also contain the location, quantity, and propagation methods for the storm water wetland plants. Site preparation requirements, maintenance requirements, and a maintenance schedule are also necessary components of the plan.

Establishment and maintenance of the wetland vegetation is an important consideration when planning a storm water wetland. The following is a list of recommendations for creating wetlands:

- In selecting plants, consider the prospects for success more than the specific pollutant capabilities. Plant uptake is an important removal mechanism for nutrients, but not for other pollutants.
- Selection of native species should avoid those that invade vigorously. Since diversification will occur naturally, use a minimum of species adaptable to the various elevation zones within the storm water wetland.
- Give priority to perennial species that establish rapidly.
- Select species adaptable to the broadest ranges of depth, frequency, and duration of inundation (hydroperiod).
- Match site conditions to the environmental requirements of plant selections.
- Take into account hydroperiod and light conditions
- Give priority to species that have already been used successfully in constructed storm water wetlands that are commercially available.
- Avoid using only species that are foraged by the wildlife expected at the site.
- Establishment of woody species should follow herbaceous species.
- Add vegetation that will achieve other objectives, in addition to pollution control.

Constructed storm water wetlands require considerable routine maintenance, but do not require large, infrequent sediment removal, unlike conventional pond systems that require relatively minor routine maintenance and expensive sediment removal at infrequent intervals.

Careful observation of the system over time is required. In the first few years after construction, twice a year inspections are needed during both the growing season and non-growing season. Data gathered during these inspections should be recorded, mapped, and assessed. The following observations should be made during the inspections:

- Types and distribution of dominant wetland species in the marsh
- The presence and distribution of planted wetland species; the presence and distribution of volunteer wetland species; signs that volunteer species are replacing the planted wetland species
- Percentage of unvegetated standing water (excluding the deep water cells which are not suitable for emergent plant growth
- The maximum elevation and the vegetative condition in this zone; if the design elevation of the normal pool is being maintained for wetlands with extended zones.
- Stability of the original depth zones and the microtopographic features
- Accumulation of sediment in the forebay and micropool; and survival rate of plants in the wetland buffer

Regulating the sediment input to the wetland is the priority maintenance activity. The majority of sediments should be trapped and removed before they reach the wetlands either in the forebay or in a pond component. Gradual sediment accumulation in the wetlands results in reduced water depths and changes in the growing condition within the wetland that can destroy the wetland plant community.

The deeply incised valley of NMR presents limitations on the area of wetland that can be created and the use of a combination of the alternatives described may be necessary. Generally most of the alternatives involved with the habitat restoration of NMR are built around a pond / wetland system or extended detention wetland to provide sufficient storage for treatment of storm water and reduction of flow velocities. Storm water will need to be diverted from NMR to a constructed forebay to remove sediment and reduce flow velocities. Storm water flow from Fern Hollow needs be managed either in a separate pond, or within the same structure as the NMR flows.

In addition to the creation of wetlands, the restoration of the aquatic habitat of NMR will involve enhancement and expansion of existing wetlands. By providing improved and expanded wetland habitat, the stability of the NMR watershed ecosystem is increased as the impacts of the storm water flows are minimized and low flows are enhanced.

For example, the existing, expanded, and proposed wetland habitat areas above Commercial Avenue could be reconnected to the relocated stream channel as part of the improvements provided by the habitat restoration project. This could serve to improve natural routing and peak flow attenuation during storms. Design storm model runs that were conducted verified this, especially for high frequency storms (with 1 and 2-year return periods). However, modeled post-development peak velocities during these peak storms, although reduced, still will have an impact on stream stabilization and erosion. Fluvial geomorphology principals will be implemented to restore the meandering configuration of the channel, increasing over-bank flooding and storage volumes. Increasing over-bank flooding will slow velocities and control erosion. These principals will be discussed in Section 5.4.

5.3.4 References for Section 5.3

Camp Dresser & McKee (CDM), *et al*. 1993. *California Storm Water Municipal Best Management Practice Handbook.* Storm water Quality Task Force. Sacramento, CA.

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5.4 Stream Erosion and Velocity Controls

The use of structural stream restoration measures is an alternative control measure to remediate the negative impacts of watershed urbanization along watershed streams. There are several locations along the NMR stream channel where the stream channel and/or channel bank is unstable and eroding away. In stream restoration projects, alternative materials such as logs, root wads, and rock are used to control erosion, stabilize slopes, control stream gradients, create flow diversity, and provide aquatic habitat. They are used in areas for treating invert, toe, top of bank, and full bank erosion situations. Alternative remediation techniques include the use of: root wads, log vanes, rock vanes, J-hook vanes, cross vanes, step-pools, boulder bank stabilization, and rock grade control structures.

Root Wads

Root wads are a remediation measure that can be used for limited bank stabilization and aquatic habitat enhancement. Root wads are intact stumps taken from fresh, green, healthy parent trees. Hardwood trees are preferable, with the size depending on the stream size. Root wads are placed in the lower one third of the bank, oriented perpendicularly to the direction of flow. Footer logs are placed below and perpendicular to the root wads, at or below the stream invert. Bracing boulders are placed on each side of the root wad to help to hold it in place. There are several locations along the NMR channel where this remediation measure could be used to stabilize the channel. Figure 5.4.1 shows an example of how root wads can be used for channel stabilization.

Log Vanes

Log vanes are an alternative remediation measure that can be used for bank stabilization and the creation of flow diversity. Log vanes are single-arm structures whose tips are partially embedded in the streambed so that they are submerged even during low flows, and whose bank-ends are at bank-full elevation. Single logs or smaller logs banded together can be used. Support pilings are used to anchor the log structure to the streambed. Rods can be used for banded logs, and boulders can be used to stabilize the log vanes. Figure 5.4.2 shows a typical example of a log vane structure.

Figure 5.4.1: Root Wad Channel Stabilization

Figure 5.4.2: Typical Example of a Log Vane

Rock Vanes

Rock vanes can be used along with or instead of log vanes for bank stabilization and the creation of flow diversity. Rock vanes are single-arm structures that are partially embedded in the streambed such that they are submerged even during low flows. Vane rocks are placed in a line starting in the affected bank so that each rock is touching each adjacent rock to form a tight-fitted structure. Vane rocks are placed on top of footer rocks.

J-hook Vanes

J-hook vanes can be used for bank stability and creation of flow diversity.
J-hook vanes are single-arm structures whose tips are placed in a "J" configuration and partially embedded in the streambed such that they are submerged even during low flows. Vane rocks are places in a J-formation so that each rock is touching each adjacent rock to form a tight fit, with one to two rocks firmly anchored into the bank. Vane rocks are placed on top of footer rocks. Figure 5.4.3 shows a typical example of a J-hook vane that could be used in the Nine Mile Run stream channel.

Figure 5.4.3: Typical J-Hook Vane

Rock Cross Vanes

Cross vanes are an alternative measure can be used for aquatic habitat and channel grade control. When constructed and spaced properly, cross vanes can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits which fish can use as spawning grounds. Cross vanes are designed in a "U" shape from bank to bank such that the apex of the structure points upstream. All rocks should touch adjacent rocks to form a tight fit, and vanes should be placed on top of footer rocks. A typical example of a rock cross vane is shown in Figure 5.4.4.

Figure 5.4.4: Typical Rock Cross Vane

Step Pools

Step pools can be used for aquatic habitat and grade control. Step-pool channels have a succession of channel-spanning steps formed by large grouped boulders called clasts that separate pools containing finer bed sediments. Engineered steps can be made from boulders, logs, and large woody debris. Step rocks should be placed on footer rocks so that the step rock is offset in the upstream direction, and the footer rocks extend below the scour hole elevation. Figure 5.4.5 shows how a series of boulder step pools could be used along the Nine Mile Run stream channel.

Figure 5.4.5: Typical Step Pool Series in a Stream Channel

Boulder Bank Stabilization

Boulder bank stabilization can be used where channel banks are unstable due to steep slopes or stream erosion. There are several locations along the NMR channel where the existing channel banks are eroding away and need to be stabilized. Boulders are placed along the stream banks so that each is partially embedded in the stream bank and each rock touches each adjacent rock to form a tight fit. A typical example of the use of boulder bank stabilization is shown in Figure 5.4.6

Rock Grade Control Structures

Rock grade control structures are a remediation measure that can be used for grade control and erosion reduction. They reduce the longitudinal slope of the natural channel, limit the extent of channel-bed degradation, and improve downstream aquatic habitat.

Figure 5.4.6: Typical Example of Boulder Bank Stabilization

<u>Note:</u> BioHabitats, Inc provided the descriptions and photographs of the structural stream measures contained in this section.

5.5 Structural Controls for Leachate Discharges

Steel mill slag has been deposited over an area of 238 acres in the lower reaches of the NMR watershed. Storm water and ground water that percolates through the slag piles produces a leachate with a very high pH that discharges into the stream and significantly degrades aquatic habitat quality. The Urban Redevelopment Authority (URA) is currently under a Consent Order Agreement to develop and implement structural controls to eliminate these leachate seeps into the stream. The URA has procured an engineering consultant who developed and assessed alternative structural control measures to collect and treat the discharges. A leachate abatement plan and schedule has been submitted to DA-DEP for approval.