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Portsmouth Activated Carbon BMP Demonstration

THE CARBON/SAND FILTER:

AN ANALYSIS OF POLLUTANT REMOVAL EFFICACY

COASTAL RESOURCES MANAGEMENT PROGRAM
GRANT NO. NA47OZ0287-01 TASK #72

The City of Portsmouth, Virginia
Department of Engineering & Technical Services
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ABSTRACT

Ultra-urban environments, typically highly developed, downtown areas, are a significant source of pollution in stormwater runoff, with few pervious areas and a high concentration of vehicular activity. Lack of space and high property values make conventional Best Management Practices (BMPs), such as detention basins, unfeasible. This report investigates the pollutant removal effectiveness of a Carbon/Sand Filter, which in a space-saving effort, filters runoff in an underground concrete sand filter. The filter also includes activated carbon intended to help reduce pollution stemming from motor vehicle activity.

The report discusses the history of the ultra-urban environment and the pollutants associated with this environment and their potentially toxic effects on aquatic life. It details the design and construction of the Carbon/Sand Filter, an underground concrete structure approximately 34' x 10' x 8' that serves a parking lot in the downtown section of Portsmouth. It also discusses the stormwater monitoring and chemical analyses performed by the Hampton Roads Sanitation District (HRSD) for the project.

The report gives a detailed statistical analysis of the chemical analysis results and discusses the pollutant removal efficacy for fourteen chemical parameters. It also compares the pollutant removal of this BMP to the publishes efficiencies of BMPs in other regions. It concludes that the Carbon/Sand Filter is somewhat more efficient in removing many contaminants than a conventional sand filter, which was concurrently tested.

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1.0 INTRODUCTION

1.1 An Overview of the Carbon/Sand Filter Analysis.

Water quality studies over the last several decades have repeatedly demonstrated the deleterious effects of daily human activities on our nation's waterways. As recently as 1946, 30 million gallons per day of untreated domestic sewage were routinely routed directly to the lower Chesapeake Bay and the James, Elizabeth, and Nansemond Rivers and other estuaries as a means of disposal. These and other polluted discharges to receiving waters have significantly contributed to reductions of and restrictions on fish catches and shellfish harvesting in the Hampton Roads tributaries. Although many such practices have changed over the years, concern over the continuing deterioration of these vital resources has compelled both government agencies and environmental advocacy groups to further identify and address the problems of water pollution.

The study of receiving water quality focuses on two different sources of pollution: point sources and nonpoint sources. Point sources are those associated with industrial process wastewater and municipal sewage, while nonpoint sources generally refer to stormwater runoff. Federal, state, and local permitting programs have been designed to reduce pollutants in discharges from these sources. These permits have allowed federal, state, and local governments to better regulate commercial and industrial practices that adversely affect water quality and have encouraged governments to implement measures to reduce pollution from publicly owned facilities.

Although the initial efforts of water quality programs were aimed at reducing point source pollutant concentrations through effluent limits, more recent studies have indicated that contaminant levels from nonpoint sources can be significantly higher than those from point sources. Consequently, many industries and municipalities are required to address the quality of their stormwater runoff. The response has been to implement Best Management Practices (BMPs) to improve the quality of runoff before it reaches the Waters of the United States. These practices can be non-structural BMPs, which reduce pollutant sources before rainfall or runoff is introduced to them, structural BMPs, which remove pollutants already in a runoff stream, or a combination of the two.

The engineering and planning communities are continually challenged with developing less expensive and more effective BMPs. However, not all BMPs are applicable to every situation or land use. Practices used in suburban areas are not always suitable for a highly urbanized area. BMPs for agricultural land use are collectively very different than those for more urban areas. This study analyzes the pollutant removal efficacy and shows the dollar costs of an innovative stormwater structure, the Carbon/Sand Filter, designed for use in highly urbanized areas.

To better understand the purpose of analyzing this new BMP, a broader picture must be painted of issues and technologies concerning "ultra-urban" runoff, or that from highly urbanized, often "downtown," areas. The remainder of this section describes the development of the ultra-urban environment and the resulting problems for the quality of stormwater runoff. It will also highlight significant government regulations designed to address pollution in runoff and in receiving waters.

Subsequent sections will detail the pollutants in the ultra-urban setting, their potential environmental effects, and the processes through which they can be removed. This report will also describe the Carbon/Sand Filter Project, its design, construction, and monitoring for certain chemical parameters. It will conclude with a thorough analysis of the pollutant removal efficiency of the filter and provide data that will allow comparisons to other BMPs.

1.2 The Development of the Ultra-Urban Environment.

The colonization of the Virginia coastal region began over 300 years ago. Though much smaller in population, Portsmouth and Norfolk developed in much the same manner as cities such as New York and Boston. The Tidewater region was one of the first areas permanently settled by the British in the 17th century. Its comprehensive system of navigable waterways, including the James River and the Chesapeake Bay, and its proximity to the Atlantic Ocean facilitated colonization and allowed easy passage to Europe. Settlements were situated on the rivers and tidal estuaries primarily for trade purposes, although some rivers provided a fresh water source and a removal system for waste. Because the shipping trade and other associated industries thrived on the waterways, the population was concentrated in these areas. Workers had to live at or near their workplaces, as most had no means of transportation. Commercial businesses were, in turn, supported by this population. Figure 1-1 offers a glimpse of the Norfolk waterfront and shipping industry in the nineteenth century.

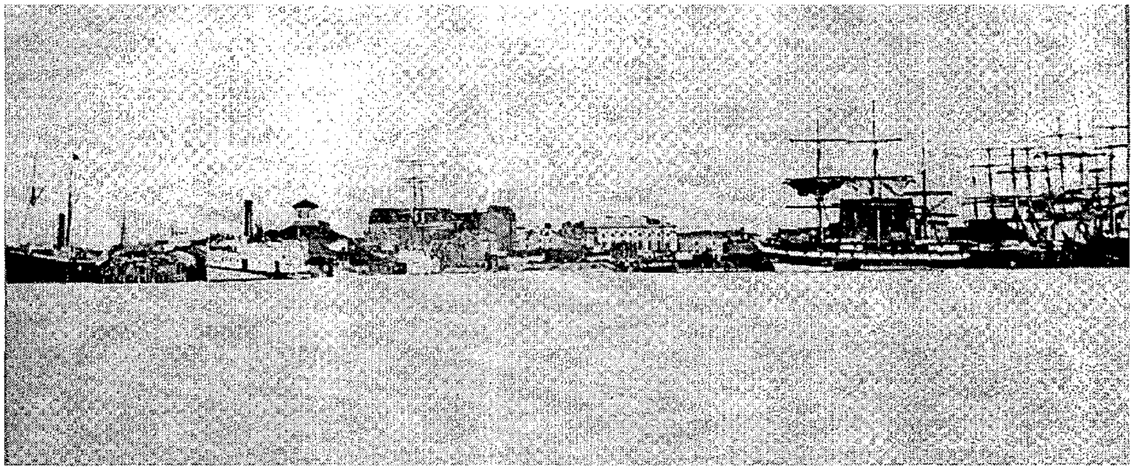


Figure 1-1. The Norfolk waterfront around 1875. This is one of the oldest known photographs of Norfolk (Walker, 1981).

As the population increased over time, the density of buildings, both residential and commercial, also increased. Eventually piping systems were installed to improve drainage, and, when indoor plumbing first became available, many raw sewage pipes were connected directly to the storm drainage system. These small cities did not at that time have the technology to treat sewage and, until the 1920's, did not appreciably understand the health problems associated with the discharge of sewage to the waterways. For the most part, this discharge did not immediately exceed the waste assimilative capacity of the receiving waters because the populations were relatively small and the waste discharge low. Figure 1-2 is a photograph of downtown Norfolk in 1922 that depicts how densely developed the area had become.

Figure 1-2. Downtown Norfolk, looking east, in 1922 (Walker, 1981).

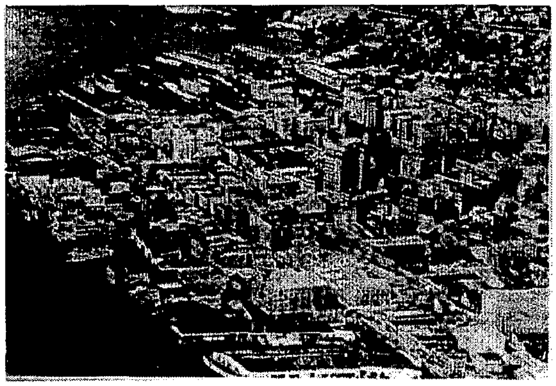


Figure 1-3(a). Downtown Norfolk, looking west, in 1925 (Walker, 1981).

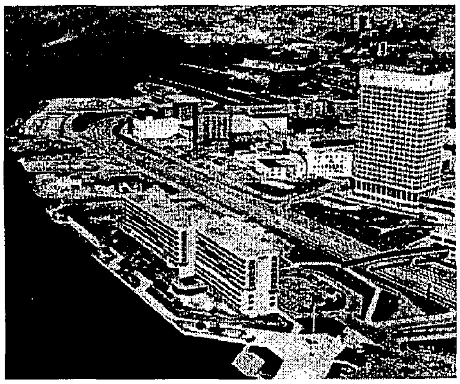


Figure 1-3(b). Downtown Norfolk from the same perspective, in 1980 (Walker, 1981).

Today, the areas that once constituted the entire city are now called the central business districts, or "downtown" areas. The expanding population radiated to the suburbs as the city's land mass grew. In many ways, the shipping trade is not as active as it was in the past, but other commercial industries and small businesses have filled the voids in the downtown areas. Now, in many cases, businesses are even more densely located, as high rise office buildings dot the waterfront. Downtown residential areas are also still densely populated. Wetland areas have all been destroyed in favor of urban land development. As sanitary sewage networks and treatment plants were created to treat wastewater, efforts were made to disconnect the older sewage pipes from the storm drainage system. Figures 1-3(a) and 1-3(b) illustrate these changes in the landscape.

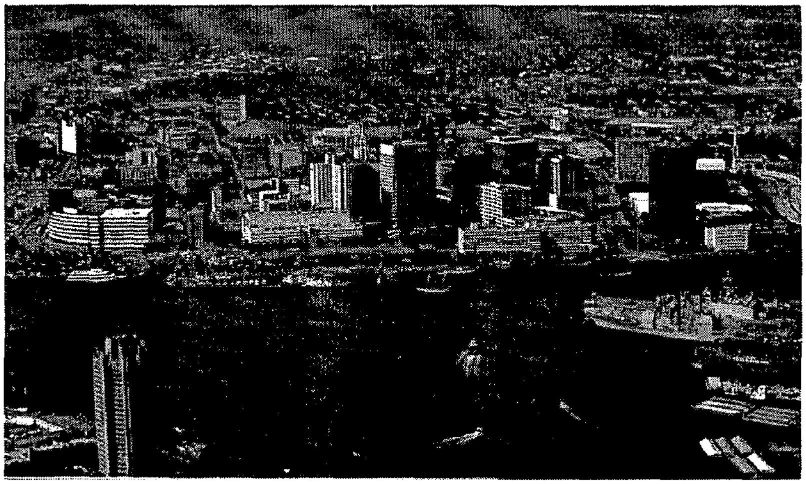


Figure 1-4(a). Downtown Norfolk, looking north, in 1995. The water body is the confluence of the Elizabeth River's southern branch, eastern branch, and main stem. The hi-rise at bottom left is in downtown Portsmouth (Marsala).

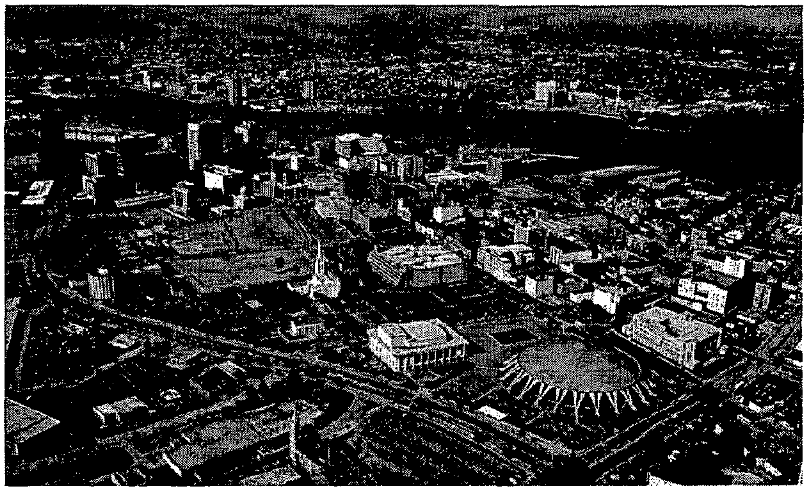


Figure 1-4(b). Downtown Norfolk, looking south, in 1995. The open parking area beyond the church in the center is the MacArthur Center mall site. Portsmouth lies beyond the Elizabeth River (Marsala).

The character of the downtown area, or ultra-urban setting, is one of much human activity and with a high concentration of the work force. Because many of these individuals drive automobiles, parking lots are installed where space is not already consumed by office buildings or road and sidewalk systems. As seen in Figures 1-4(a) and 1-4(b), impervious surface covers nearly all of the downtown area, and there is very little unused space. These characteristics make the ultra-urban environment a major concern for management of stormwater runoff quality. However, conventional BMPs, both structural and non-structural, are very difficult to implement in such an area. Chapter 2 will further investigate the problems associated with the ultra-urban setting.

1.3 Regulations Governing Water Quality.

Without regulations governing activities that affect water quality, there would likely be little impetus to implement management programs. Discharge of municipal sewage and industrial wastes clearly has a negative effect on water quality, and can promote the spread of waterborne diseases that harm humans. Other discharges can degrade water quality such that it harms aquatic life. Programs undertaken to improve water quality, however, are at a considerable expense to the public and to commercial businesses and industries. For this reason there will always be some debate over what degree of regulation is appropriate. The following discussion highlights the regulations that have the most significant impact on water quality in the Hampton Roads region.

The defining federal legislation in water quality management is the Federal Water Pollution Control Act (FWPCA) of 1956. This law established a program to provide funds for water pollution research and for construction of wastewater treatment facilities, as wastewater had been identified at that time as the primary source for waterborne diseases. The FWPCA has been amended a number of times since its inception, with different names assigned to essentially the same, but evolving legislation. Amendments in 1972 led to the law's more common name, the Clean Water Act, and created the National Pollutant Discharge Elimination System (NPDES), which established a system of permits through which the government can control discharges from a wide variety of pollutant sources.

The initial thrust of the NPDES program was to reduce pollutants from industrial process and municipal sewage discharges. Litigation during the late 1970's resulted in the legal definition of stormwater as a point source to be regulated under the NPDES program. The Water Quality Act of 1987 further amended the Clean Water Act to include schedules for reducing pollutants from stormwater discharges associated with industrial activities and from municipal separate storm sewer systems serving populations of 100,000 or more.

NPDES stormwater discharge permits require the implementation of a pollution prevention plan in the case of industrial stormwater discharges and a stormwater management program for municipal discharges. Each documents the proposed measures to be taken by the permittee to control, at the source, pollutants that may be picked up by stormwater, as well as proposed methods of removing pollutants that have already been picked up by the runoff. All municipal permits contain an array of measures, called Best Management Practices (BMPs), that are designed to achieve both goals.

Other laws have been passed at the state and local levels that further address water quality problems. In the Mid-Atlantic region, states have adopted legislation to reduce pollution in the Chesapeake Bay. The Chesapeake Bay Preservation Act was passed by the Commonwealth of Virginia in 1988. Localities, in turn, tailored the regulations to their communities to reduce the water quality impacts due to property development. Development and redevelopment of areas within Chesapeake Bay Preservation Areas must be accompanied by BMPs, both structural and non-structural.

Stormwater Management Regulations have been adopted at the state level in Virginia as well as in some local jurisdictions. Erosion and Sediment Control Regulations exist at both the state and local levels. These and other various laws have specific requirements that reduce the deleterious environmental effects of property development.

1.4 Response to Water Quality Regulations.

Water quality management methods have been implemented and are regulated on a number of levels. NPDES permits are approved and enforced at the federal level by the Environmental Protection Agency (EPA) or its designee, which in Virginia is the Virginia Department of Environmental Quality (DEQ). Stormwater discharge permits for both industrial facilities and municipal storm sewer systems are issued by DEQ based on the management methods proposed in each permit application, as well as any further measures required by DEQ.

In the case of permits for discharges related to industrial activities, a pollution prevention plan is required for the facility and is implemented at the cost of the business. Required for municipal permits is a stormwater management program detailing methods of reducing pollution in runoff. Many costs of the program, such as publicly owned detention basins, street sweeping, public education, and illicit discharge screening, are borne by the locality, but other elements entail further requirements on individual property developers, such as erosion and sediment control measures and privately owned detention basins.

Most environmental legislation applies to new construction and is seen as a cost of development to the developer or property owner. Under most circumstances, existing properties are "grandfathered" into such regulations as the Chesapeake Bay Preservation Act and the Virginia Stormwater Management Regulations. However, when a property undergoes new construction, even for a building addition, the newer regulations may apply to the whole facility. Depending on the criteria used in a certain locality, a developer could be required to install a sizable BMP, such as a detention basin for an addition to an existing parking lot.

These methods are generally designed to negate any additional impacts property development might have on a receiving water. More difficult is the effort to apply structural controls to an existing area where no new construction is planned. Such areas may still significantly contribute to pollution in runoff, but, without retroactive regulations to require controls on private property, the local government might be the only party to install such a control. With limited funding, the number of BMPs that can be retrofitted to many existing areas by the locality is insufficient. To successfully combat this problem, creativity in design must be used to devise more effective and cost-effective means of installing structural BMPs.

1.5 Conventional Best Management Practices.

1.5.1 Non-Structural BMPs.

Non-structural Best Management Practices have long been seen as the least expensive way to reduce pollution in stormwater runoff. Usually these practices entail changing the behavior of people who contribute, often unknowingly, to the problem. Elements that can be described as pollution prevention are generally the least expensive BMPs. The more a practice performs some mechanical function to eliminate pollutant sources, the more expensive the method becomes. The following discussion describes non-structural controls, beginning with more preventative measures.

Public education efforts are directed at controlling three major sources of pollution: motor vehicle maintenance, spills of toxic substances, and lawn care maintenance. It is estimated that 4.4

million gallons of used motor oil are improperly disposed of each year in Virginia (Hampton Roads Planning District Commission, 1993). Evidence abounds of disposal of grass clippings to the storm drain which end up in receiving waters. Fish kills in local lakes and ponds are most often attributable to the decay of organic matter, including algae blooms and other aquatic vegetation, which in turn depletes the water body of dissolved oxygen. In urban areas it is believed that these blooms are largely created by the runoff of excess fertilizer from homeowners' lawns.

Education efforts concentrate on encouraging the disposal of used motor oil, antifreeze, and other fluids at recycling centers rather than pouring them into storm drains. Routine car maintenance reduces fluid dripping while the vehicles are parked or in operation. Spill prevention is encouraged among homeowners and businesses so that toxic chemicals are not stored improperly where they may be accidentally knocked over or otherwise deposited to the ground and then the storm drain. Lawn care education teaches to bag or compost lawn clippings or to leave them on the newly cut grass. It also encourages soil testing to determine the proper application, if any, of fertilizer, so that no excess fertilizer remains to run off. It is hoped that these efforts are directed at citizens who do not realize that their behavior contributes to pollution in runoff and who will change their behavior accordingly.

Other effective non-structural BMPs include street sweeping, storm drain cleaning, illicit discharge inspection, and vegetative buffering. Street sweeping primarily removes trash and particulate contaminants from roadways that would eventually make their way into the storm drains. Storm drain cleaning removes trash, sediments, and organic materials, such as leaves and grass clippings, before they can be carried by runoff to receiving waters. Inspection for illicit discharges reveals any direct connections to the storm drain of wastewater that should be directed to the sanitary sewer. It also identifies areas where leaking sanitary sewers are seeping into the storm drain. Vegetative buffers are non-structural in the sense that they embody the effort to reduce the amount of impervious cover on a newly designed site and allow infiltration of rainfall into the ground, thus reducing the runoff stream that can carry pollutants.

While it is widely believed that non-structural methods are a very effective means of pollutant reduction, there is very little data to substantiate the claim. Effectiveness of street sweeping and storm drain cleaning can be measured in terms of tons of debris removed. However, public education offers no reliable means of tracking the amount of pollutants that will not be directed to receiving waters due to education efforts.

1.5.2 Structural BMPs.

The most common and more effective structural BMPs in this region include detention basins, infiltration facilities, and grass and biofiltration swales. The goal of these structures is to treat the water by removing some of the pollutants through plant uptake or through natural processes that take place in the underlying soil. Not all contaminants can be assimilated, though, and the result is a muck layer that must be removed and properly disposed of. Removal rates for these structures are most often measured in percent phosphorus removal, although other contaminants, such as nitrogen or suspended solids, are generally removed to a similar degree.

Detention basins are designed to accumulate runoff in a basin so that suspended pollutants have time to fall to the basin floor in a relatively quiescent environment. Dry detention basins remain dry when there is no rainfall and release stormwater more slowly than is accumulated during rainfall.

Wet detention basins, also called wet ponds, have a permanent pool of water and an overflow weir or riser that will release the excess stormwater when it reaches a certain level in the pond. During dry weather the permanent pool is reduced only by evaporation. Pollutant removal rates for these structures range from 10 percent to 60 percent depending on detention time (Center for Watershed Protection, 1996). Detention basins are more productive if they contain constructed wetlands, which, in turn, must be maintained and not over-burdened with pollutants. Short circuiting, in which the runoff travels directly from one end of the basin to the outflow structure, reduces the effectiveness of the BMP because the water does not have the benefit of a long detention time that allows the natural filtering process to take place.

Infiltration trenches and basins are built underground and allow stormwater runoff to infiltrate into the soil. They usually consist of layers of gravel and sand separated by filter cloth that provide void space for the runoff to fill as it seeps into the ground. Trenches are longer and narrower than basins and are usually used adjacent to parking lots. Removal efficiencies for infiltration devices range from 50 percent to 70 percent depending primarily on the amount and rate of infiltration into the ground (Center for Watershed Protection, 1996). Infiltration BMPs are often not the best alternative in the Hampton Roads region because high groundwater levels, and in some cases clayey soils, prevent proper infiltration of the runoff into the ground. They are also difficult to maintain because all of the material providing void space must be periodically removed and replaced to prevent clogging.

Biofiltration and bioretention facilities perform the same function as detention basins but are usually used for sheet flow runoff from a parking area. They cannot treat the same capacity of water as can a detention basin, but, because they are not inundated for long periods of time, they can be more attractively landscaped with trees and shrubs. Removal efficiencies are on the order of 50 percent (Center for Watershed Protection, 1996).

Porous pavement is a relatively new structural management device which allows stormwater to infiltrate into the pavement and ground below before it can create runoff. Therefore, this pavement is only effective with flat slopes. Porous pavement also has a removal efficiency range of 50 percent to 70 percent (Center for Watershed Protection, 1996). Porous pavement tends to clog in a relatively short time, requiring expensive vacuuming for maintenance.

It is virtually impossible to make numeric comparisons of non-structural and structural BMPs. The degree of efficacy for a structural control is measured by chemical sampling of flow streams into and out of a structure. Conversely, it is not practically feasible to measure the amount of pollutants that will not be introduced to stormwater because of proper lawn care techniques or proper maintenance of an automobile. Comprehensive stormwater management programs include combinations of structural and non-structural BMPs.

Each structural BMP has its own related deficiencies. The primary problem associated with the ultra-urban environment, however, is lack of space. Detention, infiltration, and grass swale structures all require a substantial amount of space to significantly reduce pollutants in runoff. Because of the density of buildings and population and degree of human activity in downtown areas, there is rarely enough space to implement a successful structural BMP. Chapter 2 will further investigate the problems unique to the ultra-urban environment.

2.0 REMOVAL OF ULTRA-URBAN POLLUTANTS FROM STORMWATER RUNOFF.

2.1 Pollutants in Stormwater Runoff.

Types of pollutants found in stormwater runoff depend heavily on the land use of the drainage area. The two major categories of land use considered for management of runoff are agriculture and urban areas. The character of runoff from these environments differs significantly because of the substances found on the ground surface that are exposed to rainfall. However, the urban environment can be further divided into industrial, commercial, residential and open/recreational land uses. To illustrate the challenges in managing pollution from urban areas, this study will compare the contaminants from suburban and ultra-urban land uses.

2.1.1 Agricultural Land Use.

Agriculture is responsible for much of the pollution in the Chesapeake Bay. Nutrients, sediment, animal wastes, and pesticides are the primary nonpoint source pollutants from agricultural lands. Nutrients are considered to be the most damaging to the Chesapeake Bay. The forms of nutrient transport to receiving waters is diverse.

Commercial fertilizer and manure contain the nutrients, nitrogen, phosphorus, and potassium, to promote crop growth. However, not all nutrients in fertilizer are used for plant growth. Often there are more nutrients than are needed for a crop in a season, and some forms of the nutrients will not even be available for plant uptake. Nutrients not used by plants either remain in the soil or are carried away by runoff.

In receiving waters, these nutrients have the same effect on aquatic plant life, spurring growth of algae in the water column as well as growth of other aquatic vegetation. When this organic material dies and is decomposed by bacteria, oxygen is consumed, reducing the dissolved oxygen available for higher order organisms. Increased turbidity in the water caused by excess algae can reduce sunlight penetration, thereby affecting submerged aquatic vegetation (SAV). Destruction of the SAV eliminates the food source and habitat for small and juvenile fish and can disrupt the food chain.

Nitrogen and phosphorus are available in soluble or particulate and organic or inorganic forms. Whether carried by stormwater in a soluble form or attached to sediment, both nitrogen and phosphorus can undergo chemical transformations in transport. Therefore, it is very difficult to correlate the nutrient chemical form at the source to what appears in the receiving water. Inorganic nitrogen and phosphorus are more readily available for uptake by algae. Although the growth-death-decay process presents the biggest problem for the aquatic environment, some forms of nitrogen can be toxic to both aquatic animals and humans. Ammonia is toxic to fish even in low concentrations, and nitrate, when converted to nitrite after ingestion by humans, can cause methemoglobinemia, a potentially fatal condition for infants.

Generally speaking, nitrogen is the limiting nutrient in marine environments, while phosphorus is the limiting nutrient for freshwater systems. In the absence of the limiting nutrient, plant growth is supported only by normal background levels of the nutrient in the water column. Introduction of the limiting nutrient to the receiving water by runoff can lead to an explosion in plant growth.

Sediment can have a number of effects on the aquatic environment. As it settles in the receiving water, it covers up SAV and fish spawning areas. In suspension it, like algae, reduces penetration of sunlight to the plant life at the bottom. It also can clog fish gills and filters of shellfish. As a particulate substance, other pollutants can adsorb onto sediment particles to be transported from the source to the receiving water.

Pesticides are designed to prevent damage to crops by insects and by other undesirable plants. These chemicals kill, repel, or alter reproductive cycles of unwanted pests. They also can be toxic to animals, including aquatic life. Small quantities may have serious effects on lower order organisms. However, through bioaccumulation, in which a chemical accumulates in the tissue of higher order organisms feeding on contaminated lower order organisms, chemical effects can be transferred up the food chain.

2.1.2 Suburban Land Use.

The primary pollutants associated with the suburban environment are nutrients, organics, suspended solids, hydrocarbons, and heavy metals. Nutrients, organic material, and suspended solids are primarily the result of property development and maintenance for many small individual properties, as opposed to the large properties in agricultural use. Hydrocarbons and heavy metals are related to automotive traffic as people travel within urban areas. Because there are many individually owned properties in urban areas, most stormwater management methods are very different than those for agricultural land use.

Much of the nutrients in suburban stormwater runoff come from fertilizers applied to homeowner lawns. It is fair to say that most homeowners who maintain their lawns are not trained in proper methods of fertilizer application. As a result, excess fertilizer is available for transport to receiving waters by stormwater runoff. Atmospheric deposition of nutrients onto impervious surfaces has also been identified as a source for nitrogen and phosphorus.

Organic material comes from the accumulation of leaves, grass clippings, animal waste, and other yard debris. If this material is not properly disposed of, it will often find its way to the storm drain system. After it is carried in runoff through the storm sewer, it decomposes in the receiving water, consuming dissolved oxygen in the water needed by other aquatic life.

Suspended solids are associated with erosion stemming from construction activities. Most undeveloped land on which new construction will occur lies in suburban areas. Although erosion and sediment controls are required for construction sites by government regulations, improperly maintained controls still lead to suspended solids carried in stormwater runoff. Smaller construction or maintenance activities conducted by homeowners are infrequently inspected by local officials and can result in delivery of suspended solids to receiving waters.

Hydrocarbons are found in all urban environments and represent the most significant difference between agricultural and urban runoff. These contaminants are found in high concentrations where there is a large volume of traffic. Major thoroughfares, parking lots for shopping areas, and automotive service and gas stations have the highest incidence of hydrocarbons in suburban areas (Schueler, 1994). Secondary roads in residential neighborhoods typically do not accumulate many hydrocarbons because they are not used as frequently by motorists and generally support traffic only from the nearby homes.

Heavy metals are also an indicator of automotive use, but these appear more where there is a good deal of stop-and-go traffic. While present in the suburban environment, heavy metals are more problematic in the ultra-urban environment and will be discussed in the following section.

2.1.3 Ultra-Urban Land Use.

The primary pollutants associated with the ultra-urban environment are hydrocarbons, heavy metals, suspended solids, animal wastes, and litter. Hydrocarbons and heavy metals appear as a result of vehicular activity, but in greater concentrations than in suburban areas because of a higher concentration of traffic. Suspended solids, animal wastes, and litter are not necessarily more prevalent than in suburban land uses. However, because there is a much greater degree of impervious area in densely developed downtown districts, these pollutants are carried in runoff, with fewer greenspaces available to filter the runoff stream.

Hydrocarbons and heavy metals are both deposited to a greater degree in areas where there is much stop-and-go traffic and where cars are parked. Because downtown areas are more congested than other areas and have a higher concentration of traffic signals, vehicles at lower average speeds spend more time on each linear section of road surface than on roads where they can move more freely. This extra time allows for additional deposition of pollutants. In downtown parking lots or on-street parking areas that serve retail businesses, vehicles have frequent turnover. In such conditions more oil and other fluid drippings are deposited to the ground while vehicles are warm.

Heavy metals are also more prevalent on road and parking lot surfaces in the ultra-urban environment. Automotive traffic has been identified as responsible for over fifty percent of copper, cadmium, and zinc in urban runoff streams (Schueler, 1994). Copper, which can be acutely toxic to aquatic organisms, originates from brake pad wear. Atmospheric deposition, of which automobile emissions are a source, is also a contributor to copper loadings in urban runoff. Cadmium and zinc appear as the result of tire wear.

Lead, chromium, silver, and mercury in runoff are also attributable to vehicular activity. Unlike copper, cadmium, and zinc, which are deposited directly and immediately to the pavement surface, these other metals appear as a result of atmospheric deposition originating in large part from diesel automobile emissions (Schueler, 1994). Many of these pollutants can also appear as the result of industrial activity, if there is such activity occurring in a particular downtown area. Although not the focus of this study, industrial areas can sometimes constitute an ultra-urban environment themselves.

Animal wastes are the result of both pet and bird droppings. Litter occurs not only as an intentional discarding of waste but also from overflowing trash receptacles. Suspended solids can come from a myriad of sources in the ultra-urban setting. All three of these pollutants, however, reach the receiving waters because the ultra-urban environment provides few filtering mechanisms. In other land uses suspended solids and animal wastes in small quantities can be trapped by grass or other vegetation. Litter is generally heavy enough to resist very light stormwater flows, but man-made drainage patterns create shallow concentrated flows capable of transporting litter.

2.2 Effects of Ultra-Urban Pollutants on the Aquatic Environment.

Studies on the effects of pollution from stormwater runoff on the aquatic environment are limited. This is primarily due to the difficulty in simulating the episodic nature of storm events rather than a lack of biotoxicity research. Laboratory studies that investigate the effect of a contaminant on a particular species perform either chronic or acute toxicity tests. Chronic toxicity tests introduce the contaminant in a low concentration and record the long-term biological and behavioral effects on the species. Acute toxicity tests examine the short-term effects of a stronger concentration of the toxicant.

Delivery of stormwater runoff, however, will result in a pollutant spike in the receiving water that is quickly diluted by the comparatively large volume of the receiving water. The spike is a result of first flush runoff, in which the majority of the pollutants on the ground surface are washed away in the beginning stages of a storm event. Although the degree of dilution depends on a number of variables, it is usually significant and rapid enough to limit the duration of exposure to an organism such as to rule out acute toxicity exposure. For certain specific habitats, such as a permanently inundated wetland for a juvenile fish species, the physical extent of the habitat may be limited, and the organism might not be able to avoid a toxic runoff stream. Storm events and pollutant delivery are too sporadic to be considered chronically toxic.

Despite the lack of data on the specific effects of stormwater runoff pollution, it is generally accepted in the scientific field that these pollutants do have some biological and behavioral effects on aquatic organisms. Assuming this to be the case, it is important to identify the potential fate of a contaminant during its delivery from source to receiving water. One must also consider those chemical forms of the contaminant that are bioavailable to aquatic species. Because many forms of an individual pollutant might not be toxic in the aquatic environment, it is more appropriate to concentrate on only those that can have a detrimental effect on a species.

2.2.1 Heavy Metals.

Heavy metals are found in the aquatic environment in a variety of chemical forms. Not all of these forms are bioavailable, and therefore toxic, to aquatic organisms. Additionally, the three major taxonomic groups, fish, invertebrates, and aquatic plants, and even species within these groups, exhibit varying responses to different contaminants. To detail the effects of the many chemical forms of metals on the many aquatic species is beyond the scope of this study. Rather, it will point out those chemical forms that are most consistently toxic to a number of species.

According to Welch (1980), the toxicity of heavy metals to aquatic life depends in a general sense on the solubility of the compound in which it is bound. Insoluble or low-soluble compounds are not readily available for uptake by aquatic organisms and therefore are not a direct threat to biota. Soluble compounds are readily available for uptake, but the ionized form of the metal does not move easily across membrane surfaces and is therefore not a direct threat to the organism. Compounds of intermediate water solubility appear to be the most toxic to aquatic organisms. Metal complexes with organic material are easily taken up and cause high body concentrations even when the concentration of the metal is low in the water. It is also important to note that many metal forms that are toxic to aquatic life do not appear that way in stormwater runoff, but rather are the result of biologically-mediated reactions or other chemical reactions in the receiving water or the bottom sediments.

Herricks et al (1994) identified a wide range of toxic effects that heavy metals may have on integrative ecosystem responses, including lethal, sublethal, and bioaccumulation effects. Extreme sensitivity to particular metals can result in the elimination of a species, which would not only reduce the biodiversity of an ecosystem but could also create an imbalance in the food web structure. Metals are toxic at several levels in the biological hierarchy, which includes enzymes, cells, organs, organ-systems, and organisms. In many species enzymes are created that bind metal cations so as to inhibit any toxic effects. Once the metal concentrations overtake the enzyme production, however, the metals become toxic to individual cells and can have severe detrimental effects on organs and organ-systems.

The sublethal effects of metals can be felt within the ecological hierarchy, from organism to species/population to community to ecosystem. Basic physiological functions, such as heart rate, respiration and ventilation rate, muscular movement, and metabolically derived bioluminescence, can be altered as can the growth of an organism. Subtle changes in organism behavior can also effect its survival. Changes in swimming patterns and predator avoidance in individual organisms and dispersal and migration of communities have been noted due to toxic levels of heavy metals. Genetic diversity can also be altered by metal toxicity.

Kadlec and Knight (1996) and URS Consultants, Inc (1995) have detailed in their respective studies the chemical forms of heavy metals found in receiving waters and their potential effects on aquatic life. Some heavy metals serve as micronutrients for aquatic biota in very low concentrations. Copper and zinc assist in the growth of aquatic animals and plants and chromium assists in the growth of animals. However, at slightly higher concentrations, copper and zinc become toxic to many aquatic species. Cadmium, lead, mercury, and silver are also toxic to aquatic life at low concentrations.

2.2.1.1 Cadmium.

Cadmium is most often found in its divalent state, Cd(II), in surface waters and is most soluble at low pH levels. In its ionic state it is bioavailable. It is also found as a complexed, soluble compound that can be easily adsorbed onto organic particulates and become biologically unavailable. There is conflicting information as to whether cadmium has the potential to bioconcentrate in aquatic organisms. The toxic effects of cadmium are acute mortality, reduced growth, and inhibited reproduction.

2.2.1.2 Chromium.

Chromium can be found in its trivalent, Cr(III), and hexavalent, Cr(VI), states in surface waters, although Cr(VI), which is the more toxic form, is chemically unstable and converts to Cr(III) where organic material is present. Because Cr(III) hydroxides and chlorides are relatively insoluble, they are not bioavailable to aquatic life. There is a wide range of sensitivity to chromium but little evidence of biomagnification among animals. Mortality and decreased growth have been attributed to exposure to chromium. These effects are more commonly found in plants than fish.

2.2.1.3 Copper.

Copper occurs in surface waters as chelated compounds of Cu(I) and Cu(II). When complexed with hydroxides, phosphates, sulfides, or carbonates, copper is insoluble and easily transported to sediments, but it is relatively soluble when chelated with certain organic compounds. At very low levels copper is a micronutrient necessary for protein synthesis. It is often used as an algicide because it is toxic at low levels to some forms of algae, but not to most macroinvertebrates or fish. However, changes in growth and smoltification, the physiological changes in fish in preparation for the transition from freshwater to saltwater, have been noted in some fish species.

2.2.1.4 Lead.

Lead is found in surface waters in its divalent state, Pb(II). It is not bioavailable, except under reducing conditions, because it readily forms insoluble salts and its ionic form is adsorbed onto particulates suspended in the water column. While plants seem to be relatively insensitive to lead, other organisms, especially gastropods, are sensitive to it. When biologically available, though, it can biomagnify in aquatic organisms.

2.2.1.5 Mercury.

Mercury is found in three primary oxidation states. Elemental Hg(0), found in reduced sediments, is volatile and easily transported throughout the environment. Hg(I) is relatively insoluble, whereas Hg(II) is soluble. Mercury is most toxic when methylated by bacteria in an anaerobic environment, but this form is not abundant.

2.2.1.6 Silver.

Silver is the most toxic heavy metal and is toxic to all organisms, although plants seem to be less sensitive than animals. The monovalent form, Ag(I), is found in surface waters. As an insoluble sulfide or when adsorbed onto organic matter, silver is not bioavailable.

2.2.1.7 Zinc.

Zinc is a micronutrient essential for respiratory function in animals and for plant photosynthesis and DNA synthesis. At more concentrated levels zinc becomes toxic, but aquatic organisms show a wide range of sensitivities to it. It is most commonly found in surface waters in its divalent state, Zn(II), where it forms ionic hydrates, carbonates, and complexes with organics, and highly insoluble sulfides. Zinc does not biomagnify in aquatic organisms.

2.2.2 Hydrocarbons.

Petroleum hydrocarbons derive from oil products. In the ultra-urban environment, the primary source of hydrocarbons is from drippings from automotive vehicles. Oil and grease contain many different hydrocarbon compounds. A hydrocarbon is a compound of hydrogen and carbon. The most commonly studied hydrocarbons in environmental engineering are polynuclear aromatic hydrocarbons (PAHs), which possesses several fused benzene rings and are composed only of carbon and hydrogen. PAHs are the result of incomplete combustion of organic compounds with insufficient oxygen (URS Consultants, 1995).

Hydrocarbons have a low water solubility, particularly those of higher molecular weight. For this reason, hydrocarbons are difficult to detect in water, and results of water quality studies often show PAHs below detection limits (URS Consultants, 1995). Hydrocarbons tend to adsorb to particulate material and settle to the sediment layer. In this layer hydrocarbons can persist indefinitely and have a continuing effect on benthic organisms. Some microorganisms have the ability to decompose hydrocarbons, but there is usually insufficient oxygen in the sediment layer to sustain such activity.

Many PAH compounds are known carcinogens and are very toxic to aquatic animals. While finfish appear to have the ability to assimilate hydrocarbons in tissues to some degree, shellfish do not have this capacity to the same extent. Because of the potential for accumulation in shellfish, consumption poses a health risk for humans. There are a number of symptoms of exposure to PAHs, including diminution of immune system activity, tumors and lesions, and organ tissue erosion.

2.2.3 Animal Wastes and Other Organic Material.

Organic material originating from the ultra-urban environment has the same effect on the receiving water as from any other land use, but to varying degrees. As organic material is decomposed by microorganisms, dissolved oxygen is used. The risk for the aquatic environment is that excessive decomposition of the material could result in oxygen deprivation of other organisms.

There are fewer animals and less vegetation in downtown areas, but where animal waste and dead leaves are deposited to the ground in this environment, there are fewer spaces with vegetative cover on which the material can collect and decompose. With no other place to go, this material is washed into the storm drain and into the receiving water.

Pathogens present in animal wastes pose an additional danger to the aquatic environment. Bacterial contamination has led to restrictions on shellfish harvesting in a number of areas in the United States. High bacterial levels can also limit recreational use of waterways by humans.

2.2.4 Suspended Solids.

Suspended solids carried in stormwater runoff usually originate from construction sites. In an extensively developed downtown area, there are fewer opportunities for new development, so the sources for suspended solids are more limited. As is the case for animal waste and organic material, however, there are few opportunities for trapping these solids before they are carried to the receiving water. Therefore the amount of material that reaches the receiving water can be as much as that in suburban areas where more construction activity occurs.

Erosion and sediment controls are required for construction sites in downtown areas, just as for suburban construction. Proper controls will greatly reduce solids carried in stormwater runoff. Also, downtown areas are more often targeted for street sweeping measures in order to keep the central business district clean. Many of the sediments that accumulate on the streets and in the gutters are removed by street sweeping and prevented from entering the storm drains.

Suspended solids cause the same problems found in water bodies draining agricultural land uses. In the water column it can clog fish gills and shellfish filters and reduce penetration of sunlight to the plant life at the bottom. As it settles to the bottom, it covers SAV and fish spawning areas. Suspended solids also serve as a vehicle for transport of other pollutants that adsorb to the individual particles.

2.2.5 Litter.

Litter is more of an eyesore than a significant threat to the aquatic environment. It can harm aquatic animals through ingestion and can disturb the habitats of certain plants and animals as it accumulates on the bottom or on the shoreline. Ironically, despite the relative insignificance of litter as an environmental threat, it is the high visibility to humans that raises the consciousness of pollution problems in receiving water bodies.

2.3 Mechanics for Ultra-Urban Pollutant Removal.

It is physically possible to remove nearly every pollutant in ultra-urban stormwater runoff to satisfy current water quality standards. However, it is not economically feasible to construct the equivalent of a small wastewater treatment facility at every outfall, which is what would be required to remove all of these pollutants. The function of ultra-urban BMPs is to remove, in an economical fashion, those pollutants of the highest concern for water quality. Conventional BMPs rely on natural chemical and biological processes to remove pollutants as they settle out in a quiescent environment. Ultra-urban BMPs must use a different technology to remove a somewhat different set of contaminants, while at the same time conserving space.

2.3.1 Conventional BMPs.

The three basic mechanisms used to treat stormwater runoff are detention, infiltration, and filtration. Most conventional BMPs rely on detention and infiltration, although some use filtration. All ultra-urban BMPs use filtration as its primary mechanism for pollutant removal.

Detention facilities impound stormwater runoff to reduce flow velocities. When the velocity of a flow is relatively low, there is not enough energy to keep particles in suspension. These suspended solids, and any pollutants adsorbed onto these particles, will settle to the bottom of the basin, where they accumulate over time. Nutrients in the runoff flow will nourish the vegetation that grows on the bottom and the banks of the basin. Other pollutants can be assimilated by both aquatic plants and animals.

Most detention basins have two or more outlet structures. One is a smaller orifice or weir that detains a certain volume of runoff and releases it at a controlled rate. It is possible to have more than one of these control devices. The other primary outlet structure is a larger spillway that serves as an overflow device to prevent flooding of the surrounding area. Detention facilities can be designed to have a permanent pool or to remain dry during dry weather. Those that have a permanent pool are generally called wet ponds and have a volume of water whose surface level is at the bottom of the lowest outlet structure. Figures 2-1(a) and 2-1(b) show two detention basins with permanent pools. These facilities are commonly called wet ponds.

Figure 2-1(a). Stormwater wet pond at the Hampton Roads Regional Jail in Portsmouth.

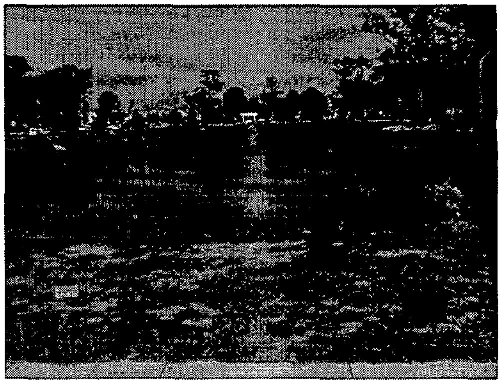


Figure 2-1(b). Stormwater wet pond at the Middletown Arch subdivision in Norfolk.

Infiltration facilities divert stormwater runoff to percolate into the ground, where natural filtration and biological processes can occur. Infiltration is a viable alternative only when soils are permeable and when the groundwater table is far enough below the structure to allow a natural filtration process. If the water table is too high, there is a risk of contamination of the groundwater from the stormwater runoff.

Filtration in conventional BMPs is usually an attempt to approximate, or even enhance, a naturally occurring infiltration process. The most common conventional filtration BMP is the filter strip, or biofilter. This type of filter includes a vegetative layer of grass and other plants on the surface, with an underlying layer of sand to promote filtration. Perforated collector pipes are often included beneath the sand layer to collect the filtered runoff and reroute it to the storm drain. Other designs simply allow the water to percolate into the ground.

2.3.2 Ultra-Urban BMPs.

Ultra-urban BMPs are designed to filter runoff in a confined area. Sand is usually the medium of choice, although some BMPs use peat or compost, or a combination of media. To save space the filter is located underground, most often in a self-contained concrete vault. The structure can then be designed to accommodate any type of activity above it on the ground surface. Most commonly, the area above the filter structure is used for parking, but the BMP can also be incorporated into a building design.

If the filter is contained completely underground, there can be no comprehensive use of vegetation as a natural pollutant filter because there is insufficient sunlight for the plants. Filters using peat or compost must have a vegetative surface, usually grass, and in order to have exposure to sunlight, must be located above ground. Storage of the Water Quality Volume (WQV), the first flush of stormwater runoff that is most heavily laden with pollutants, can occur underground, however, as it awaits transport to the filtering portion of the structure.

Most ultra-urban BMP designs also include a sedimentation chamber at the front end of the structure to allow heavier suspended solids to settle out of the runoff stream before reaching the filter section. Suspended solids, if not removed before filtration, can cause premature clogging of the filter media. Some designs also provide a water seal, accomplished through use of a concrete baffle, to trap hydrocarbons on the surface of the sedimentation chamber. This oil and grease must be periodically removed from the water surface or it will remain indefinitely.

2.3.3 The Carbon/Sand Filter.

The Carbon/Sand Filter uses three mechanical processes by which to remove pollutants from the runoff stream: sedimentation, mechanical straining, and adsorption. Figure 2-2 shows a schematic drawing of the Carbon/Sand Filter that illustrates the different process chambers through which the stormwater must flow. This BMP, like most ultra-urban BMPs, is designed as an off-line facility, so that the WQV will pass through the structure but much of the stormwater flow will be diverted to the primary storm drainage system. Chapter 3 will discuss more comprehensively the design features of the Carbon/Sand Filter.

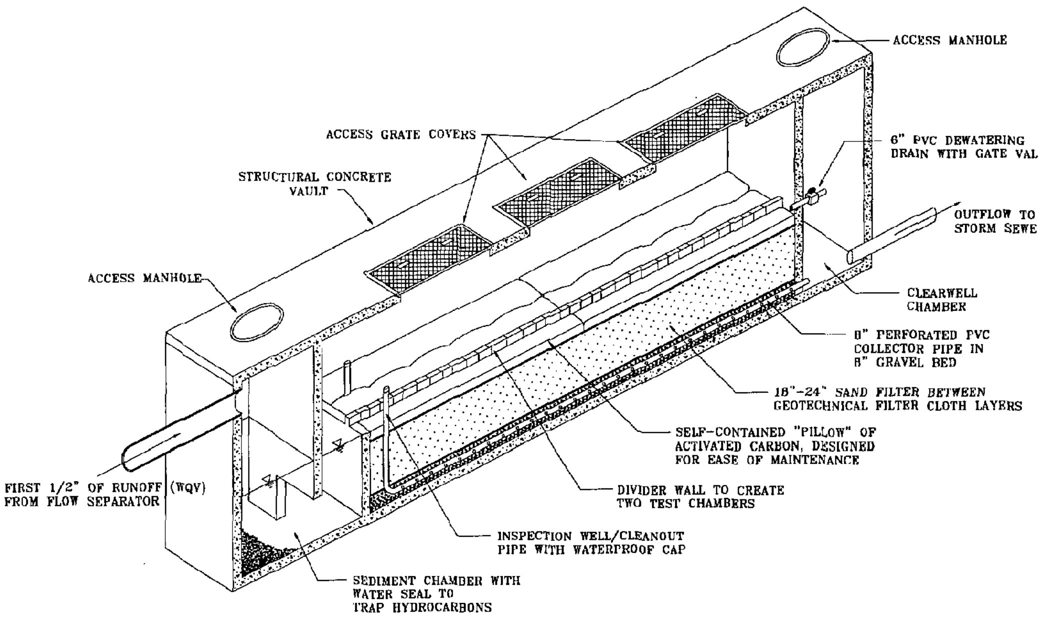


Figure 2-2. Schematic of the Carbon/Sand Filter.

Sedimentation occurs in the sedimentation chamber that holds most of the WQV as it awaits treatment by the filter media. The water volume must pass through a layer of filter fabric, designed to remove larger particles and trash that were not trapped in the sedimentation chamber, that lays on top of the filter bed. The filter bed consists of six inches of activated carbon, to which soluble metals and organic material can adsorb, and twelve inches of sand, which mechanically strains particulate material from the stormwater flow.

2.3.3.1 Sedimentation.

Sedimentation is the process used to remove particulate material from a liquid solution. Any suspended particles that are heavier than the solution, in this case water, settle downward by gravitational forces. The smallest size particle that will settle depends largely on the amount of energy of the flow stream. The energy created by stormwater flow into the filter structure will cause the resuspension of most of the particles that have settled on the chamber floor in previous storms. As seen in Figure 2-1, there is a significant elevation difference between the permanent pool in the sedimentation chamber and the invert of the pipe that channels stormwater flow into the structure.

There is a concrete baffle, a wall with a rectangular opening at the bottom, that serves as an energy dissipater in the sedimentation chamber. While particles are continually resuspended by the turbulence in the front portion of the chamber, the back side of the chamber remains relatively quiescent. The chamber as a whole prevents larger particles from flowing over the spillway into the filtration chamber.

The sedimentation chamber must be periodically cleaned to prevent excessive buildup of sediments. If too much sediment remains in this chamber, it is more likely that it will pass through to the filtration chamber.

2.3.3.2 Filter Fabric.

The filter media in the filtration chamber is covered with a layer of filter fabric (not shown in Figure 2-2), which allows the passage of water flow and most particulates but traps larger objects on the surface. Most street litter and leaves that will make their way into the storm drain and then the BMP are light material, the litter usually a paper product, and are easily carried by the runoff stream. In the turbulent environment of the sedimentation chamber, they can pass under the baffle and float to the surface on the back portion of the chamber. They then pass over the spillway and onto the filter surface.

Excessive amounts of this debris can cause premature clogging of the filter. The filter fabric represents a planned-failure plane, where the potential for this type of clogging is recognized, and the design accounts for maintenance needs. In the Carbon/Sand Filter maintenance crews can simply lift out the filter fabric with the debris on its surface and replace it with another piece of fabric. This type of periodic maintenance is much simpler than removing debris from the filter media itself, having to scrape away layers of sand or activated carbon and then replacing them.

2.3.3.3 Sand.

In the Carbon/Sand Filter the top portion of the filter, with which the stormwater will come into first contact, is the activated carbon, and the lower medium is the sand. This order was chosen for ease of maintenance, so that the activated carbon could be easily maintained and manipulated for testing purposes. It would be more appropriate to have the sand layer on the top to perform mechanical straining of particulate matter, and the activated carbon layer below it to remove soluble contaminants through adsorption. For illustrative purposes, it is easier to explain the pollutant removal processes by discussing the sand filter medium first.

Sand filtration has been used in water and wastewater treatment for over one hundred years. In a sense, the Carbon/Sand Filter is treating a wastewater stream, and this BMP is serving as a small, crude wastewater treatment facility. The primary mechanism for pollutant removal by sand is the use of meniscus forces to trap larger particles in the pore spaces between sand grains (Knutson, 1994). The void space available to hold this particulate matter is limited. As the upper region of the sand layer fills with particulates, the burden to remove additional particles from the stormwater stream falls to lower regions of the sand layer that still have free void space. Eventually, all void space will be used up, and breakthrough, when no further filtration is possible, will occur.

An ancillary treatment process that occurs during sand filtration is biological treatment. Bacteria present in the sand layer are capable of removing organic material from the stormwater stream. The stormwater actually serves as the substrate, or food, for these microorganisms. As long as there is a sufficient food source and sufficient oxygen, the bacteria will thrive until they die naturally. Because of the intermittent nature of storm events, however, there is not a steady stream of substrate on which the bacteria can feed.

Conversely, there have been some reports of sand filters containing a permanently inundated sand layer that offered a proper aerobic environment with a substrate abundance but that subsequently became anaerobic as the dissolved oxygen was used up by the microorganisms (Bell, 1994). This process of nitrification and denitrification is important in wastewater treatment in the conversion of ammonia to nitrogen gas. However, it is unrealistic to assume that biological treatment is sustained for long periods in ultra-urban BMPs unless such treatment is planned and accounted for in the structure design to provide a continuously proper living environment for the microorganisms.

2.3.3.4 Activated Carbon.

Activated carbon, like sand, is also used in water and wastewater treatment. The primary purpose in both treatment processes is to remove soluble organic matter from the water. In water treatment, filtration systems can only remove organic material to a degree. The remaining material, however, even at low concentrations, can cause taste and odor problems in drinking water, and in some cases can lead to toxic disinfectant byproducts, such as trihalomethanes. In wastewater treatment, activated carbon is used as a polishing agent to further remove soluble organic material before the treated wastewater is discharged back to the environment.

Activated carbon can remove this dissolved material because of its superior adsorptive capacity. Adsorption using activated carbon occurs at the liquid-solid interface and is the process of collecting a soluble substance, in solution, on a solid surface. The best adsorptive products are those that provide the most surface area. In the case of activated carbon, carbonaceous material, such as nut shells, wood, and coal, is heated to a red heat with insufficient oxygen to sustain combustion. The material is then activated by introducing an oxidizing gas, which creates a very porous structure inside the char. The activated carbon, therefore, has a very high internal surface area for a relatively small amount of material. Activated carbon can have a surface area of up to 1400 square meters per gram (Nyer, 1992).

Adsorption is a mass transfer process that occurs in three steps (see Figure 2-3). The first step is the advection and diffusion of the molecule through the liquid phase to the solid phase, or the carbon surface. The second step is the diffusion of the molecule through the macropore system of the carbon to the adsorption site within the micropores. The final step is the adsorption of the molecule, the adsorbate, onto the carbon surface, the adsorbent.

According to Nyer (1992), the adsorption step can occur as a physical or chemical process. In physical adsorption a molecule is held at the solid surface by the surface tension of the solid. Chemical adsorption involves the actual chemical bonding of a molecule at the solid surface. Adsorption to activated carbon is a physical process.

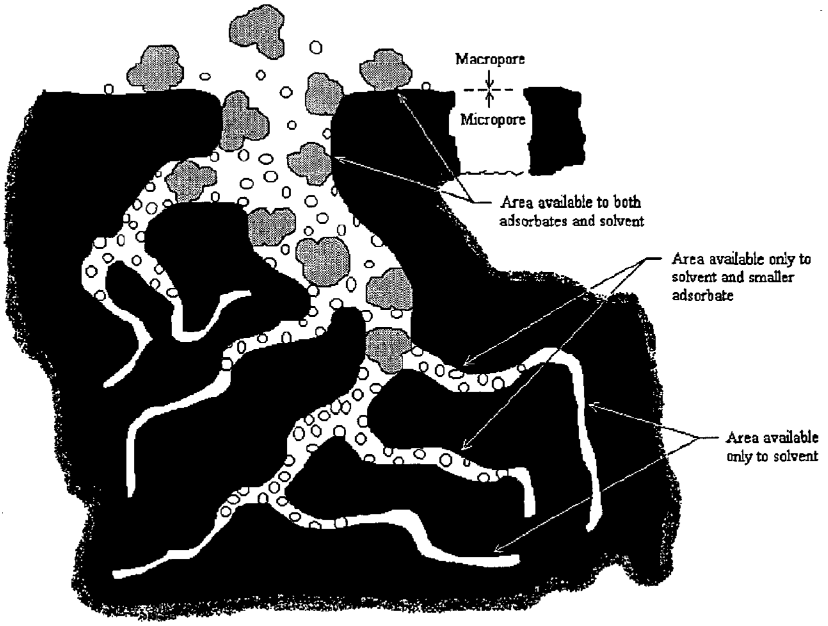


Figure 2-3. Internal structure of activated carbon (Adapted from Nyer, 1992).

Molecules can adsorb to the macropore surfaces of the carbon particle as well as to the micropores, but the degree of adsorption at these sites is relatively small compared to that in the micropores. As shown in Figure 2-3, larger molecules cannot penetrate the micropore structure as can smaller molecules. Kinetics of the adsorption process are dependent on certain characteristics of the molecules. Large molecules move more slowly through the micropores, and the adsorption process is slower. Less soluble molecules will adsorb more quickly to the carbon surface.

Activated carbon products come in two forms, granular activated carbon and powdered activated carbon. Granular activated carbon is approximately the same consistency as sand. The product used in this study was Filtrasorb 300, a granular activated carbon product provided by Calgon Carbon Corporation, Inc. Calgon Carbon reports that this product is effective in removing benzene and toluene, two organic components associated with automotive fluids, as well as other many other dissolved toxic organic chemicals (Calgon Carbon Corporation, Inc., 1988).

3.0 SYNOPSIS OF THE CARBON/SAND FILTER PROJECT

3.1 Problem Identification.

The original plan to develop the Carbon/Sand Filter was conceived out of the need to encourage the use of stormwater management BMPs in the downtown Portsmouth area. The City of Portsmouth applied for a VPDES Municipal Stormwater Discharge Permit in May, 1993 and in it proposed a Stormwater Management Program through which to comply with the federal regulations of the Clean Water Act. The City began to implement many elements of the Program upon submittal of the Permit application. To fund the Program, a Stormwater Management Utility was created, whereby each property owner would pay for his property's contribution to stormwater runoff.

With the creation of the Stormwater Management Utility came increased expectations from both private citizens and business owners for practices to control pollution in stormwater runoff. Conventional BMPs, structural and non-structural, are relatively easy to plan in suburban areas. New requirements have been made of developers to implement BMPs at new construction sites. Where there is ample space, large borrow pits and lakes are being retrofitted as regional BMPs for existing developments to provide pollution control. Erosion and sediment controls, street sweeping, and other programs are also used to reduce the contaminants that can be transported by a runoff stream.

The central business district, however, poses a unique problem in planning for conventional BMPs. In the City of Portsmouth, as in many core urban areas, the central business district is almost completely developed with no space left for detention, infiltration, or other similar facilities. The argument can also be made that such facilities do not fit aesthetically into this ultra-urban landscape. High property values further preclude the use of conventional structural BMPs in the downtown area. It is simply not economically prudent to allocate such expensive land toward a detention basin when the land could be used to expand the footprint of a multi-story building. Under certain circumstances such a difference in land use might determine the long-term profitability of the development.

The Carbon/Sand Filter was the result of a brainstorm by the City of Portsmouth Public Works Department to devise and fund an unconventional means of removing pollutants in runoff that would also serve as a model BMP for future business development in the downtown area. With incalculable support and technical assistance from local, state, and federal government agencies and from a number of private companies, the City of Portsmouth showed that implementing a BMP in the ultra-urban sector of a Hampton Roads community was a feasible alternative to conventional BMPs.

3.2 BMP and Site Selection.

Preliminary research revealed that a number of municipalities have been attempting to address the same problems that Portsmouth is experiencing. Principal among these other localities were Alexandria, VA, Washington, D.C., Austin, TX, and the state of Delaware. The City of Alexandria in1993 prepared a document, "The Alexandria Supplement to the Northern Virginia BMP

Handbook," compiling all known information for constructing unconventional ultra-urban BMPs. This manual served as the starting point in the search for a demonstration BMP.

The City of Portsmouth considered for use in its downtown area all options included in the Alexandria document. Two significant factors of Portsmouth's ultra-urban environment affecting the decision were the relative flatness of the land and tidal intrusion in the storm drainage system. Also, because there were no City-administered construction projects planned at the time for the downtown section, the ultra-urban BMP had to be installed as a retrofit for an existing, City-owned, developed property. It was assumed that the most appropriate site from which to remove a range of ultra-urban pollutants would be a parking lot.

Ten different parking lots were considered for use for this project. Of these ten lots, four were eliminated from consideration because they have no internal drainage structures, but rather sheet flow to the adjacent City street. To install a new drainage system in one of these lots would have made the project cost prohibitive. Three of the remaining lots are parking garages, for which it was assumed that construction costs for a BMP structure would increase dramatically. One lot was removed from consideration because of known flooding problems due to tidal influence.

The two remaining lots both appeared to be good candidates for a retrofit BMP. One lot is behind the City Hall building and contains 23 spaces, mostly for use by City vehicles (see Figure 3-1). These spaces are for use by employees who need only temporary access to City Hall, and they do not serve as permanent parking for these vehicles. The parking area has only a moderate degree of turnover and is empty during the evenings and weekends. Stormwater runoff drains at a significant slope to a curb line on one side of the lot, then to a catch basin in the curb, and to an outfall to the Elizabeth River located approximately ten feet behind the curb line. The most appropriate BMP for this site is the Delaware Sand Filter which is designed to be incorporated into the curb and gutter drainage scheme. Figure 3-2 is a schematic drawing of the Delaware Sand Filter design.

Figure 3-1. Parking lot behind Portsmouth City Hall considered for the Delaware Sand Filter design. The catch basin that serves this lot is located beside the second vehicle on the right side. The filter would be located in the grass area adjacent to the Elizabeth River.

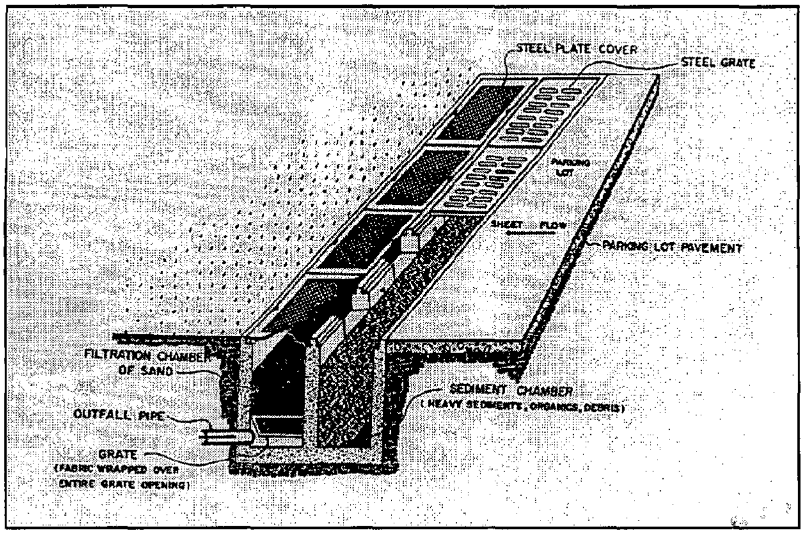


Figure 3-2. Schematic of the Delaware Sand Filter (City of Alexandria, 1993).

The other site considered was an 83-space lot on High Street rented to private citizens working in the downtown area (see Figure 3-3). The lot is nearly full during the week, but mostly empty in the evenings and on weekends. Half of this lot, including 44 spaces, is paved with a significant slope to a drop inlet in the middle of the lot. The other half of the lot, with 39 spaces, is gravel and has little apparent slope in any direction. A ridge line separating the two halves seems to prohibit flow from the gravel portion to the paved portion.

Figure 3-3. Parking lot on High Street considered for the D.C. Sand Filter design. The left half of the parking lot is asphalt with a drop inlet that can be seen just above the center of the photograph. The right half of the lot is gravel with no internal drainage structures.

For this drainage scheme, a D.C. Sand Filter was considered to be most appropriate. Figure 3-4 is a schematic representation of the original D.C. Sand Filter design, from which the Carbon/Sand Filter structure was derived.

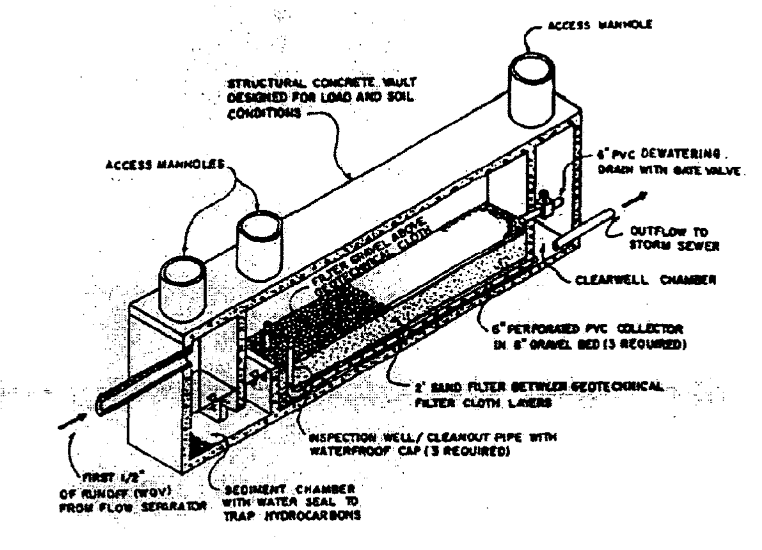


Figure 3-4. Schematic of the D.C. Sand Filter (City of Alexandria, 1993).

Because of the volume of permanently parked cars at the High Street lot, it was deemed a better site on which to construct the BMP. A field inspection revealed that there were considerably more oil and grease spots on the High Street lot than on the City Hall lot, perhaps indicating that the automobiles using the lot had not been serviced as regularly as are City vehicles. This was seen as an opportunity to further clean up a hotspot for ultra-urban pollution. Finally, unlike the City Hall lot, which is accessible to few people, the High Street lot is visible to those who either walk or drive along this commercial corridor. As a demonstration project, a primary goal is to publicize the use of a new technology to the maximum extent possible.

The High Street parking lot, although run by the City of Portsmouth Parking Authority, is actually owned by the Portsmouth Redevelopment and Housing Authority (PRHA). The Board of Commissioners for PRHA approved in the Spring of 1994 the use of this property for a stormwater BMP.

3.3 Project Funding and Design Objectives.

At the time that the need for a demonstration BMP for an ultra-urban atmosphere was realized, there were no additional funds available from the Stormwater Management Utility to finance the project. City staff searched for another funding source and found the Virginia Coastal Resources Management Program, administered by the Virginia Department of Environmental Quality (DEQ), the most likely to give grant support to the project. A grant application was prepared in June, 1994.

Further research into the mechanics of a D.C. Sand Filter resulted in several modifications to the original design to enhance its effectiveness for use in the City of Portsmouth. Staff from the City of Alexandria conducted a tour of a number of BMPs within its jurisdiction and provided insight for design alternatives based on some of their experiences with the BMPs. Discussions with URS Consultants, Inc. led to the inclusion of activated carbon in the filter bed of the proposed BMP to further remove a number of ultra-urban pollutants.

URS Consultants, Inc. agreed to provide engineering services for the structural design of the Carbon/Sand Filter as well as technical assistance in interpreting water quality monitoring results. Tarmac America, Inc. offered to supply the project with 64 cubic yards of 5000 psi concrete for the filter structure at a fifty percent reduced cost. It also donated 15 cubic yards of concrete sand to be used as filter material in the BMP. Calgon Carbon Corporation agreed to supply 3000 pounds of Filtrasorb 300 Granular Activated Carbon at no cost. The Hampton Roads Sanitation District (HRSD) also donated staff time in collecting samples for analysis at its laboratory. The member localities of the Hampton Roads Planning District Commission (HRPDC), through the Regional Stormwater Management Committee, drafted a letter of support for the project, declaring their interest in the results of the study.

The grant application, with evidence of corporate and public support, was submitted to DEQ for funding from the 1994 Virginia Coastal Resources Management Program. Grant funding was approved in the amount of $49,932 for the project to begin October 1, 1994 and to last for one year.

The objectives of the project as stated in the grant application were to: (1) increase the removal of heavy metals, hydrocarbons, and other pollutants associated with ultra-urban runoff; (2) maintain recognized efficiency for removal of suspended solids and nutrients that contribute to degradation of the Chesapeake Bay; (3) reduce maintenance time and costs through planned-failure design; and (4) provide a model BMP that can be used in urban areas both regionally and nationally.

3.4 Carbon/Sand Filter Design.

Once the site was selected for construction of the Carbon/Sand Filter, the site was surveyed by the City to record the topographic features of the lot. Figure 3-5 is a planimetric drawing from the City's Geographic Information System (GIS) that shows the configuration of the BMP within the parking lot and the drainage system layout for the surrounding area. The survey information was used in conjunction with the planimetric drawing to calculate the runoff volume to be treated by the BMP. It was assumed that only the paved portion of the entire lot would drain to the BMP.

Also determined, using criteria defined by the City of Alexandria, was the appropriate size and shape of the filter structure to fit within the profile of the existing storm drainage system. The Carbon/Sand Filter was designed as an off-line facility that would treat the Water Quality Volume (WQV), defined as the first half-inch of runoff from the impervious area of a drainage basin, and allow for the flow of any additional volume to the primary storm drain. The paved lot is 65 feet wide and 226 feet long. Equation 3-1 shows the calculation of the WQV.

$$\begin{aligned} \text{WQV} &= (\tfrac{1}{2}\text{-in runoff}) \times (65 \text{ ft width}) \times (226 \text{ ft length}) \times (1 \text{ ft}/12 \text{ inch}) \\ &= 612 \text{ cubic ft} \end{aligned} \qquad \textbf{(Eqn 3-1)}$$

Appendix A-1 shows the calculations for sizing the filter structure, using the worksheets provided in the Alexandria Supplement to the Northern Virginia BMP Handbook (City of Alexandria, 1993). The dimensions used in the calculations were subsequently changed slightly to accommodate field conditions.

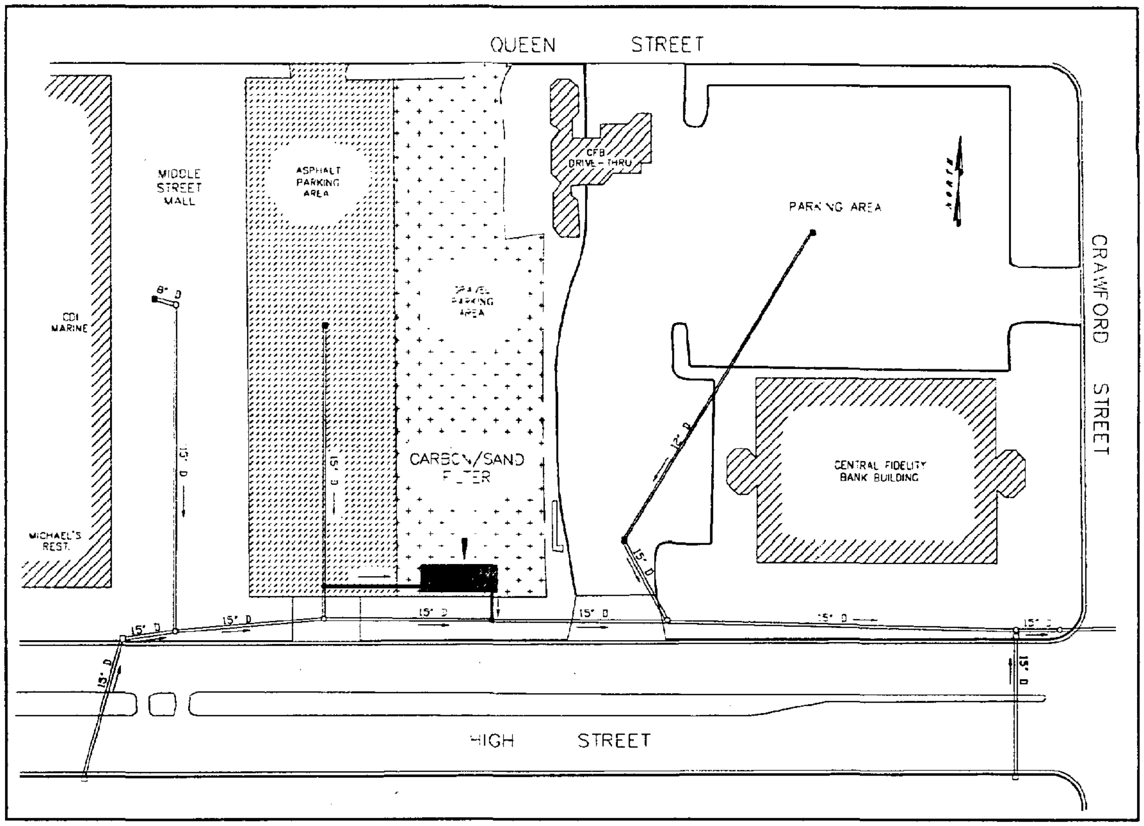


Figure 3-5. Site layout for the Carbon/Sand Filter.

It was calculated from survey data that the diversion manhole, a manhole with an internal weir to divert the WQV to the Carbon/Sand Filter, would have an invert elevation of 8.15 ft (City of Portsmouth Datum, Mean Sea Level = 0 ft). The top of the weir in the diversion manhole was set at an elevation of 9.61 ft. Calculations showed the invert elevation in the reentry manhole, where the effluent from the Carbon/Sand Filter is returned to the primary drainage system, to be 5.50 ft. Therefore, the maximum water surface elevation is slightly over four feet above the floor of the structure. This shallow depth requires the structure to be longer and wider than is normally designed in more hilly regions.

Appendix A-2 includes the actual design drawings, showing topographic features and elevations, pipe invert elevations, structure dimensions and layout, BMP structural design, and construction notes and details. These drawings have been formatted to fit into this text and are not to scale.

As seen in Figure 3-5, the Carbon/Sand Filter is positioned close to the right of way for High Street. This gives some degree of flexibility for future development of the property. A developer can use this BMP with a multitude of design layouts, or the BMP can be removed and placed elsewhere on the lot. The BMP is also situated so as to minimize the number of parking spaces temporarily displaced during construction and testing of the BMP.

The structural design was provided by URS Consultants, Inc. Their time and materials were donated to the project cause, allowing project funding to be used for construction and testing. The filter structure was designed to support a heavy traffic loading (AASHTO H15-44 Truck Load) in case a future entrance were to be located over the BMP. The structure would support loading from a large truck, such as an 18-wheel rig or a garbage truck.

Steel grates were specified for maintenance access to the filter chamber, so that a City work crew can remove the grates to change filter materials. Two manhole openings were included for pumpout access to the sedimentation chamber, and a single manhole opening was positioned over the clearwell chamber, which can be used for other maintenance needs.

The filter chamber was designed to have two parallel filter beds, separated by a concrete wall. This design element is unique to this demonstration project to allow simultaneous testing of two filter media with the same influent. When the stormwater flow passes through the sedimentation chamber and over the wall leading to the filtration chamber, it will filter through either the filter of sand or the filter of activated carbon and sand. The purpose of this feature is to be able to compare pollutant removal results of each chamber, rather than to compare the results of the Carbon/Sand Filter to those of another BMP in another locality or region.

Filter chamber #1, the chamber to the north, was filled with twelve inches of sand underneath six inches of activated carbon, separated by a layer of filter fabric. The activated carbon is contained in "pillowcases" of filter fabric, sewn inexpensively by a local upholsterer, in order to easily remove and replace the carbon medium. This feature allows a faster and simpler maintenance visit, accomplishing one of the goals of the Carbon/Sand Filter project. Filter chamber #2, to the south, was filled with eighteen inches of sand only. Both chambers have an underdrain system of eight-inch perforated PVC pipe, supported by coarse aggregate stone. The underdrain angles up and out of the filter bed to provide a cleanout for clogging.

3.5 Request for Proposals.

A request for proposals was advertised in The Virginian-Pilot on April 9, 1995 at a cost to the project of $189.24. A public bid opening was conducted on April 20,1995. Three bid proposals were received, and the lowest was offered by CPG, Inc in the amount of $39,630. It was originally estimated during planning stages that construction of the filter structure would cost about $29,000. After the design was completed, the City cost estimate for construction was $37,000. The lowest bid was seven percent above this estimate, and the other two bids were fourteen percent and eighteen percent higher than the City estimate. Appendix A-3 shows unit and total bid price tabulations for all three bidders.

Because the grant funding was only for $49,932, even the lowest construction price would only leave approximately $10,000 to perform the necessary stormwater sampling and chemical analysis. The City had estimated that these tasks would cost approximately $17,000. To reduce the need for additional funding from another source, the City approached the Contractor, CPG, Inc, to discuss ways in which to alter the design to reduce costs.

A number of design alternatives were considered to reduce construction costs. One of the primary changes proposed was to use concrete block for internal walls rather than formed, reinforced concrete. The Contractor countered that there would be no worthwhile savings if he had to hire a mason to perform this work. The Contractor suggested that some steel and concrete be cut back, but the structural engineer reiterated that the amount of steel and concrete was appropriate for the design loading.

It was agreed, however, to change the design for the internal wall separating the two filter chambers. The original design called for a reinforced concrete beam to support the interior of the filter structure and to have a small gap between the bottom of this beam and the wall separating the filter media of each chamber. The new design removed this beam and brought the internal wall up to the structure top. Even with this new design and with other minor suggestions, the Contractor was unwilling to discount more than $600 worth of changes. The City decided to proceed with the Contract to construct the Carbon/Sand Filter at the proposed cost and to identify additional funding for stormwater sampling and chemical analysis.

3.6 Carbon/Sand Filter Construction.

Construction began on May 30, 1995, with excavation of the site. Immediately, the Contractor encountered problems, uncovering old foundations of buildings that had long since been demolished. Most of the foundations were brick ranging from 18 inches to 48 inches in thickness, but could be removed easily by a backhoe. Some of the foundations, however, were concrete and required a jackhammer and an impactor for demolition. Figures 3-6(a) and 3-6(b) show the excavation for the filter structure and several exposed brick and concrete foundations. The Contractor also uncovered several utility lines of undetermined origin. After consulting City records and personnel from Virginia Power and Commonwealth Gas Services, constituting a delay in the Contractor's work, it was determined that these clay pipes were abandoned in place and could be removed.

Figure 3-6(a). Excavation of the filter structure location. Note the exposed brick foundation on the left and the concrete foundation just right of center. The wooden barriers in the background protect the reentry manhole.

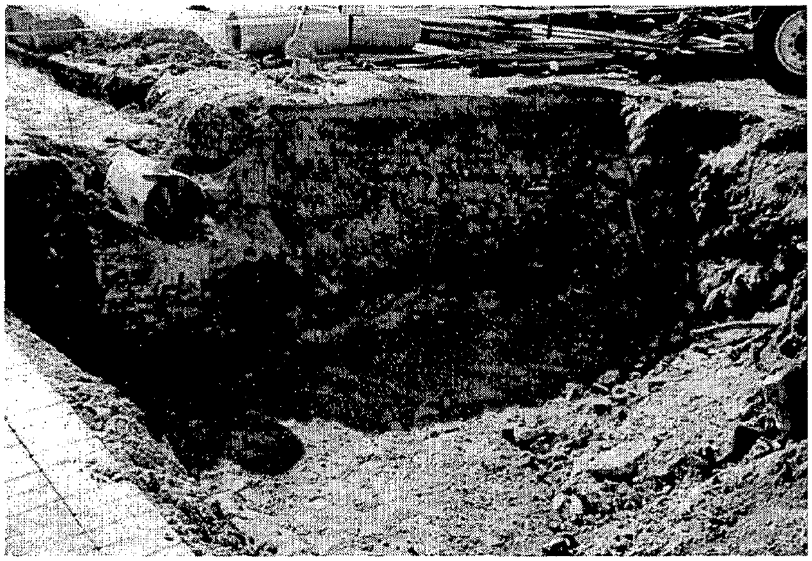


Figure 3-6(b). Excavated site of the filter structure. There are brick foundations exposed along this wall. The pipe to the left runs from the diversion manhole to the Carbon/Sand Filter.

The Contractor requested a Contract change order to be reimbursed for additional labor and equipment and for down time associated with foundation removal. The value for the additional work was calculated by the Contractor to be $3,073.26. The Contract, however, specified that the Contractor would bear the cost for any delays associated with utility conflicts. City of Portsmouth contracts also designate excavation as unclassified, meaning that the City makes no assurances as to the type of material that the Contractor must remove. Strictly interpreted, the Contractor must remove any and all materials in the prescribed area at no additional cost to the City. City staff, however, agreed that the concrete foundations did significantly and unexpectedly add to the required time for excavation and subsequently agreed to pay the Contractor for this extra work. The City did not pay additional money for removal of brick foundations because they were removed with relative ease by the backhoe.

Concurrent with excavation was the construction of the diversion and reentry manholes and laying of the pipe connecting these structures to the filter box. Figures 3-7(a), 3-7(b), and 3-7(c) show the sequence of construction of the diversion manhole. Excavation of this area also uncovered old foundations, as seen in Figure 3-7(a). A concrete footing was poured under the existing storm drain pipe and the brick walls built to form the manhole. The reinforced concrete diversion weir was constructed inside the manhole and the manhole rim and cover grouted in place at the final stages of the project.

Figure 3-7(a). Construction of the diversion manhole. The footing was poured under the original storm drain pipe carrying drainage from the asphalt parking lot. Note the exposed brick foundations.

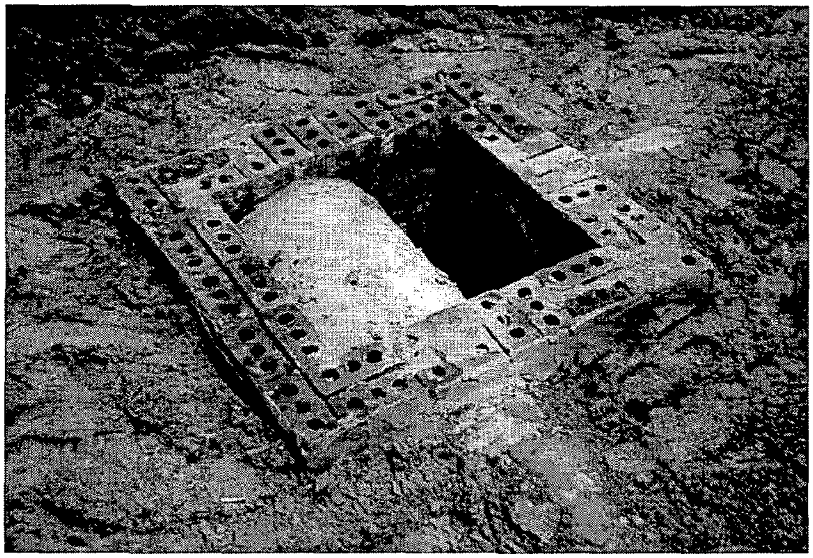


Figure 3-7(b). Brick walls of the diversion manhole were erected. The existing pipe was cut open and the diversion weir constructed at the latter stages of the project. The pipe opening shown leads to the Carbon/Sand Filter.

Another unforeseen problem arose in constructing the reentry manhole. Although shown on the construction plan, a Virginia Power conduit running parallel to the primary storm drain system under the High Street sidewalk was deeper and larger than expected. The conduit was eighteen inches wide by four feet deep and encased in concrete. Also uncovered was a terra cotta Bell Atlantic duct not shown on the plan, but located between the Virginia Power duct and the proposed location for the reentry manhole. It was never determined whether the Bell Atlantic line was active, so it was left in place. The bottom of the reentry manhole had to be lowered by eighteen inches to an elevation of 4.02 ft so that the PVC pipe from the Carbon/Sand Filter to the manhole would fit under the ducts. The manhole was then built with the ducts actually incorporated into the walls of the structure. Figures 3-8(a), 3-8(b), and 3-8(c) show excavation of the reentry manhole location, and the fully constructed manhole.

Figure 3-7(c). The view from the diversion manhole toward the Carbon/Sand Filter, not yet constructed.

Figure 3-8(a). Excavation of the reentry manhole location. The concrete Virginia Power duct can be seen in the center. The Bell Atlantic duct is behind the Virginia Power duct and cannot be seen from this angle.

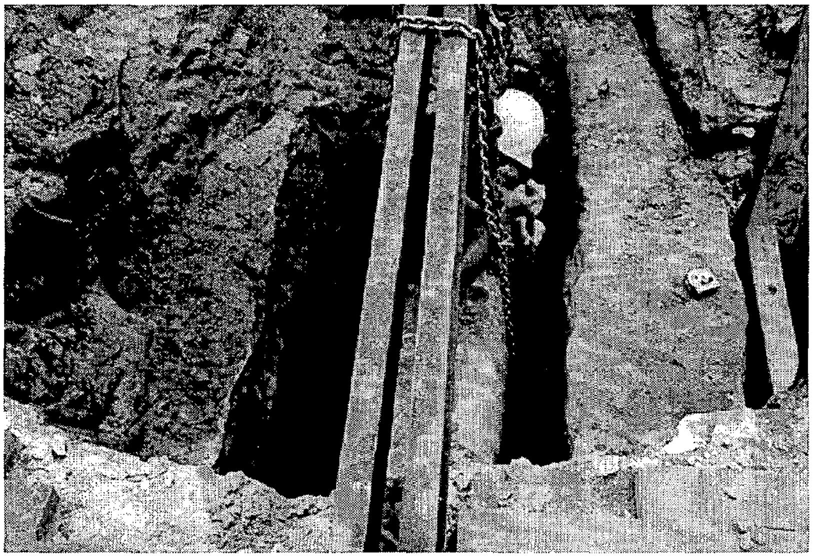


Figure 3-8(b). A view from above of the ducts conflicting with the reentry manhole. The terra cotta Bell Atlantic duct is in the center, beneath the steel support. The concrete Virginia Power duct is to the right. The existing storm drain, not yet uncovered in this photograph, is below and to the left of the Bell Atlantic duct.

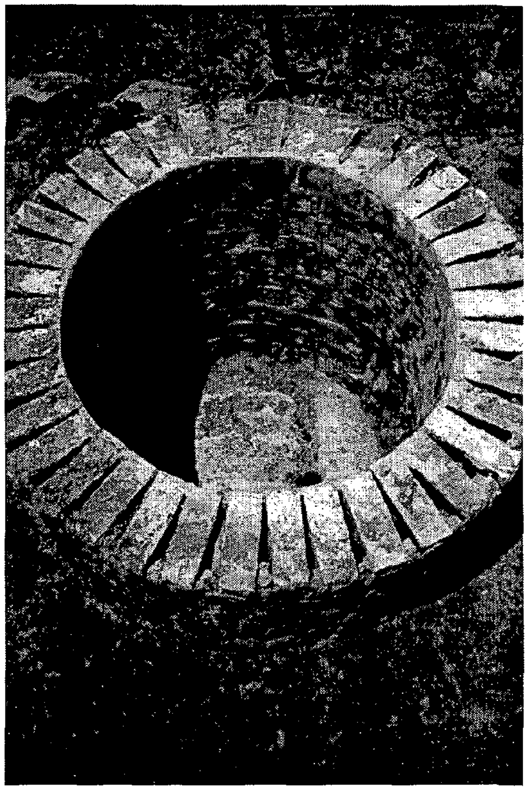
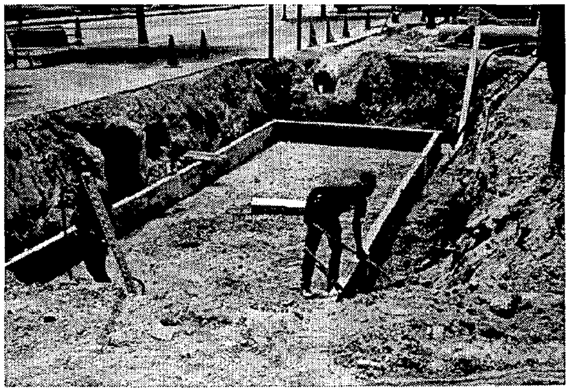


Figure 3-8(c). A view down into the finished reentry manhole. The existing storm drain pipe is to the left and has not yet been cut open in this photograph. The Bell Atlantic duct on the right can just be distinguished.

After the manholes were complete and all pipe section laid, construction of the filter box began. Steel rebar was positioned and tied within wooden forms to provide reinforcement for the concrete floor of the structure. Once the concrete floor was poured and smooth finished, forms were constructed, steel tied, and concrete poured for the structure walls. Next, the forms and steel were set for the concrete top, as were the manhole cover frames and steel grate frames. After the concrete top was poured and cured, the outside of the structure was backfilled and graded to its previous elevation. The sections of the asphalt lot and the brick sidewalk that had been removed for construction of manholes and laying of pipe were returned to their original condition. Figures 3-9(a) through 3-9(l) illustrate the construction process.



(a)

Figure 3-9. Construction process for the Carbon/Sand Filter. Figs. 3-9(a)-(c) show construction of the floor, figs. 3-9(d)-(h) show construction of the walls, and figs. 3-9(i)-(l) show the construction of the top, backfilling, and the finished structure.

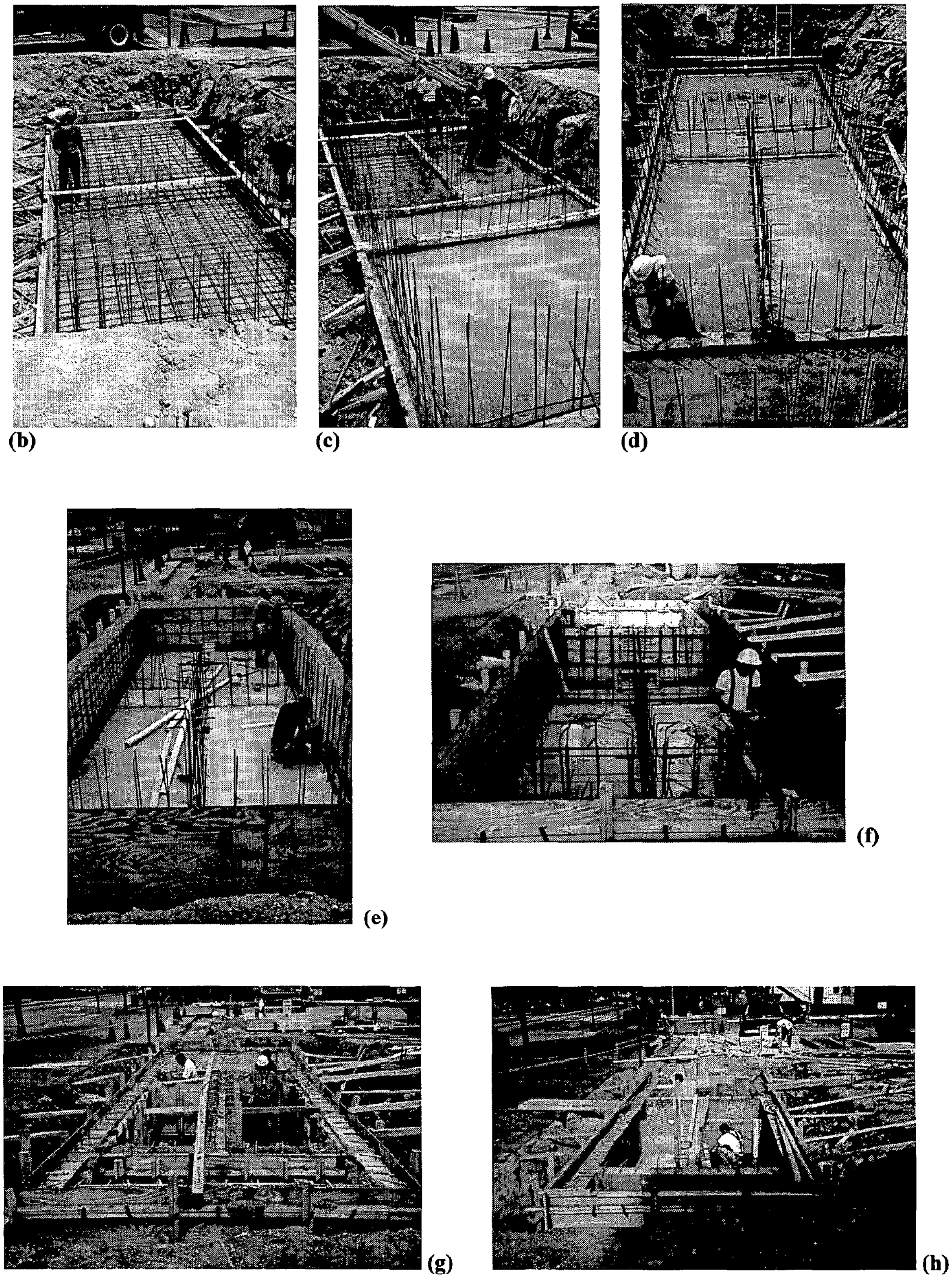


Figure 3-9 (continued).

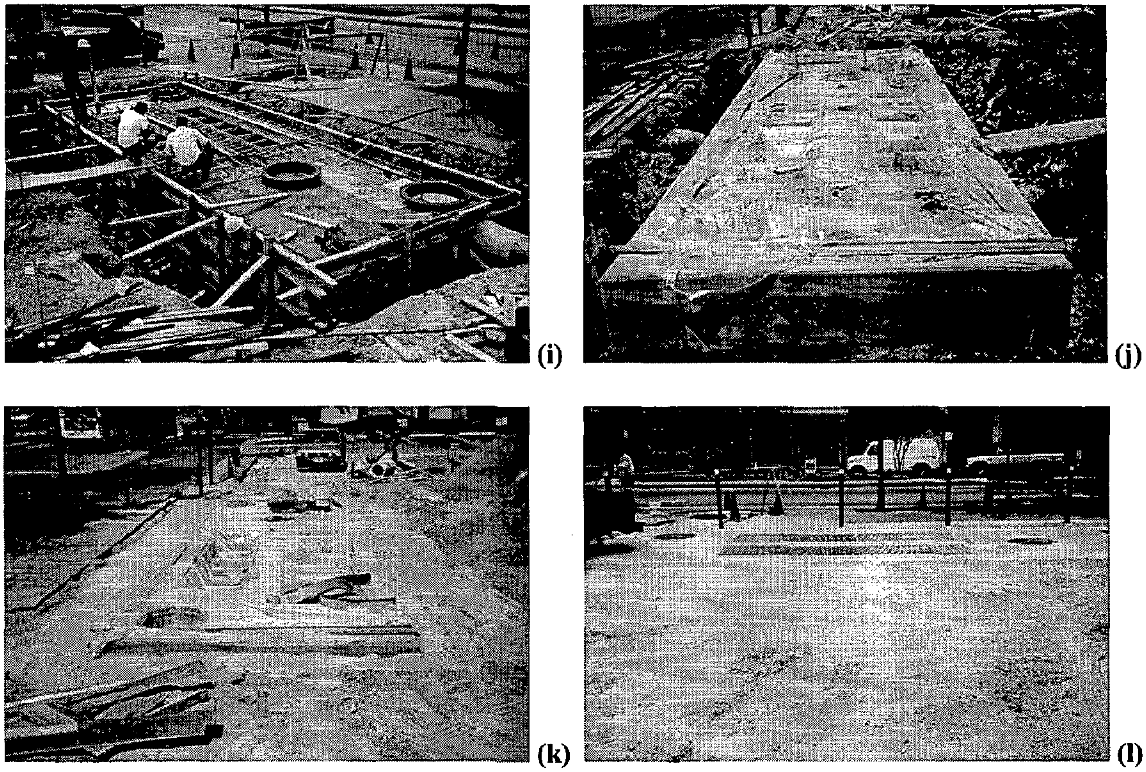
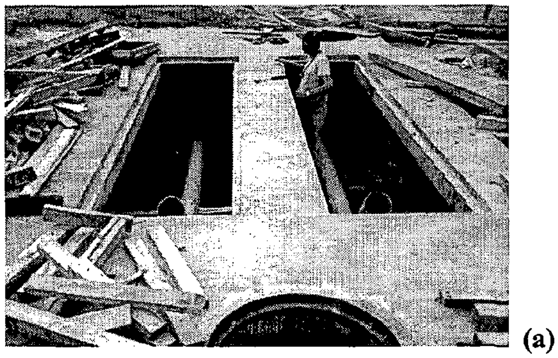
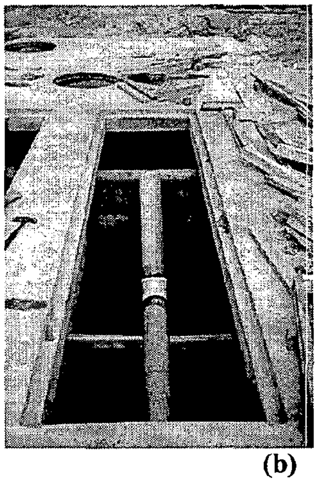


Figure 3-9 (continued).

After construction of the filter box was complete, the Contractor secured the perforated PVC underdrains on the floor of each filter chamber. Coarse aggregate stone was then placed around the collector pipes and covered with a layer of filter fabric, provided by Contech Construction Products, Inc, to contain the filter media above. A work crew from the City Public Works Department placed sand, donated by Tarmac America, Inc, to the specified depths for each chamber. Activated carbon, provided by Calgon Carbon Corporation, Inc in 55-pound bags, was poured by the crew into four "pillowcases" of filter fabric, each thirty inches wide and seven feet long, and positioned on top of the sand in filter chamber #1. Figure 3-10 shows the underdrain positioning, and Figures 3-10 shows the inside of a filter chamber at several stages of the media installation process.

Figure 3-10. These two photographs show how the underdrain pipes are situated and secured in the bottom of the filtration chambers.





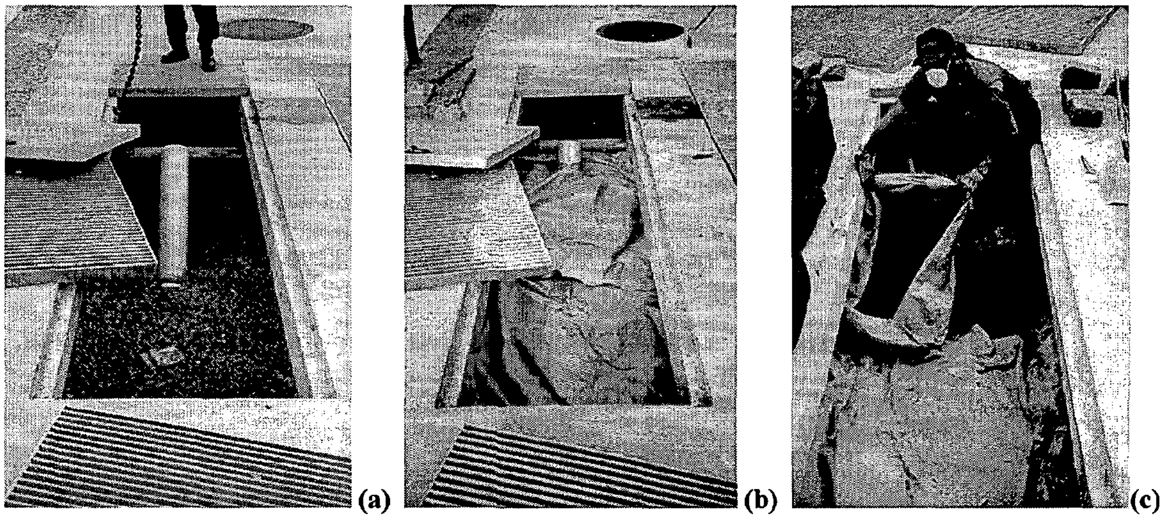


Figure 3-11. Fig. 3-11(a) shows the underdrain and cleanout in a stone bedding. Fig. 3-11(b) is chamber #2 filled with sand and covered with filter fabric. Fig. 3-11(c) shows the "pillowcase" being filled with activated carbon in chamber #1.

3.7 Stormwater Sampling and Chemical Analysis.

Stormwater sampling for the project was to be performed by URS Consultants, Inc (URS), with the chemical analysis contracted to the Hampton Roads Sanitation District (HRSD). Staff from URS visited the site to measure the internal dimensions of the structure and the pipes. The measurements were used to install the flowmeters and sampling devices inside the Carbon/Sand Filter. Three DataGator flow meters were used for the sampling, one inside the influent pipe entering the sedimentation chamber and one inside each of the two collector pipes leading to the clearwell chamber. The sampling devices, Sigma rotary samplers, were affixed to the walls of the structure. The samplers were connected to the flowmeters so as to collect flow-weighted samples during storm events.

URS personnel was present for the first storm event. The crew reported that the clearwell chamber was flooded with backflow coming from the direction of the reentry manhole. As a result, the sampling equipment was tossed about the chamber, and the samples were contaminated by the backflow. Because of the turbulent environment and the potential for irreparable damage to its valuable equipment, URS elected to discontinue sampling services.

The City of Portsmouth subsequently contracted HRSD to perform stormwater sampling in addition to the chemical analysis. HRSD installed a Marsh-McBirney flowmeter inside the influent pipe and inside one of the effluent pipes. The flowmeters were connected to ISCO 3710 Samplers that were stationed in steel drums on top of the filter structure. These samplers were programmed to siphon through a plastic tube a sample from inside the prescribed pipe at intervals determined by the volume of flow passing through the pipe. The samples were collected into one container to create a flow-weighted sample. Only one flowmeter was used to trigger a sample from each effluent pipe because it was assumed that the flow rates would be nearly identical for each effluent pipe.

To prevent further backflow into the Carbon/Sand Filter, a City Public Works crew cleaned the primary storm drain downstream of the reentry manhole to remove any material clogging the system. It was recognized at the time that tidal influence could be causing the backflow problem. In order to sample the filtered effluent, the backflow had to be completely eliminated. Otherwise, unfiltered stormwater from the primary system or possibly a mixture including water from the Elizabeth River would be collected.

At the first storm event sampled by HRSD, the sampling team witnessed further backflow into the clearwell chamber. HRSD proposed to install a spring-loaded flap gate as a backflow preventer, which was fabricated and installed prior to further sampling. Another problem was encountered in flow measurement. The Marsh-McBirney flowmeters use an electromagnetic field to sense stormwater flow velocity and a pressure transducer to measure flow depth inside the pipe. From these measurements are calculated the volumetric flow rates. At certain points during the storm event, when there was no backflow, the flow out of the effluent pipes was shallower in the pipe than could be measured by the flowmeter.

Subsequent storms revealed yet another problem with the flowmeters. Flow data downloaded from the meters yielded unusual flow patterns, including negative flow at times, for both flowmeters. It was expected that some unusual patterns would exist in the clearwell chamber because of the backflow preventer. However, the influent readings could not be explained. HRSD staff recalibrated the first meter, installed a replacement meter, and, when no further explanation could be offered, presented the case to a panel of experts at a Marsh-McBirney conference. The only conclusion that could be reached was that the Virginia Power duct paralleling the structure was interfering with the electromagnetic field used by the flowmeter.

HRSD tried two other flowmeters that used other measurement techniques. An ISCO Doppler Flowmeter, which uses an ultrasonic signal to measure flow velocity and a pressure transducer to measure depth, was inserted into the influent pipe. Unusual readings were obtained from this flowmeter as well and were considered to be unreliable. The final flowmeter used was an ISCO 3230 Bubbler Flowmeter, which uses a pressure transducer to measure the force needed to elicit a bubble from the device. This meter also measures flow velocity and depth, but was used at the weir structure leading from the sedimentation chamber to the filtration chamber. Data downloaded from this meter were also considered to be unreliable.

After months of delays and invalid data, it was decided to collect the samples manually. For each storm a crew from HRSD would determine whether there was enough flow to fill the sedimentation chamber and spill over into the filtration chamber. If a sample was to be taken, it was performed by turning on the ISCO Sampler to siphon samples from the influent and effluent pipes. This sampling procedure was considered to be less than ideal, but unavoidable, given the field conditions.

HRSD staff also recognized that a significant flow from the gravel parking area was flowing into the Carbon/Sand Filter through the grates above the filter chamber. The result was that stormwater flow carrying high levels of suspended solids was flowing into the filter but not being measured in the influent. This situation would create the appearance that there was a higher level of contaminants leaving the BMP than was entering. To solve this problem, City crews barricaded the area of the access grates with parking curb blocks and sandbags, which diverted the flow around the grates. This was performed prior to the second sampling event.

The sampling problems occurred from September to December of 1995. Valid samples were collected in the period from December, 1995 to July, 1996.

4.0 ANALYSIS OF POLLUTANT REMOVAL FOR THE CARBON/SAND FILTER.

4.1 Storm Event Sampling.

Samples were collected for chemical analysis according to the schedule in Table 4-1. Efforts were made to collect samples only for storm events preceded by three days of dry weather. Any storm that did not produce enough volume to fill the sedimentation chamber and pass over into the filtration chamber was not sampled. Without a flow through the filter, there is no effluent to collect from the underdrain system.

Table 4-1 also shows the high and low temperatures recorded for each day an event was sampled. Because the testing period lasted from December to July, there is a wide range of temperatures for the days on which storm events were sampled. A more comprehensive testing program could have evaluated the effects of temperature on runoff pollutant concentration and on filtering efficiency for both the sand and the activated carbon. To test a statistically significant number of storms for each season, however, would likely require more than a year to achieve representative results. Budgetary and time constraints preclude the study of temperature effects for this project.

Rainfall data is included in Table 4-1 as recorded by the Portsmouth Weather Records Service, located in the West Cradock section of Portsmouth, 2.8 miles south-southeast of the Carbon/Sand Filter site. Appendix A-4 includes complete climatological data from December 1, 1995 to July 31, 1996. An electronic rain gauge had been set up on the roof of the Children's Museum of Virginia building across High Street from the Carbon/Sand Filter site. Miscommunication between City of Portsmouth staff and URS Consultants, owner and operator of the rain gauge, resulted in a failure to record rainfall data for the duration of the stormwater monitoring.

Event Number	Date	Time	High Temperature (°F)	Low Temperature (°F)	Days of Antecedent Dry Weather	Rainfall (inches)
1	Dec 9, '95	9:00 AM	49	38	1[2]	0.62
2	Feb 21, '96	12:00 AM[1]	68	46	3[2]	0.68
3	Mar 6, '96	11:47 PM	66	58	3	0.36
4	Mar 19, '96	1:45 PM	71	46	1	0.19
5	Mar 28, '96	10:40 AM	48	40	5	1.19
6	Apr 24, '96	12:15 AM[1]	86	64	2	0.20[4]
7	May 16, '96	6:15 AM	69	56	0[3]	0.61
8	Jun 24, '96	10:00 PM	94	69	3	1.80[4]
9	Jul 3, '96	6:45 PM	87	64	2	0.76[5]
10	Jul 15, '96	5:00 PM	88	74	0	0.69[4]
11	Jul 18, '96	7:00 PM	93	71	2	2.53[5]
12	Jul 25, '96	7:00 PM	93	69	5	0.61[4]

1 = Previous day's data reported because of time of sampling.
2 = Previous precipitation was a snowfall event.
3 = Storm event began the previous evening.
4 = Thunderstorm(s).
5 = Heavy thunderstorm(s).

Table 4-1. Storm event data.

4.2 Chemical Parameters.

In developing the idea to construct and fund the Carbon/Sand Filter as a demonstration BMP, it was seen as necessary to be able to compare the testing results of this BMP to similar ones on other regions. The City of Alexandria, Virginia, at the time the idea of the Carbon/Sand Filter was conceived, was testing two of its new Delaware Sand Filters. It was decided to test for the same chemical parameters in the Carbon/Sand Filter as were tested in the BMPs in Alexandria.

According to the original project proposal, twelve parameters were to be monitored: total copper, total lead, total zinc, total petroleum hydrocarbons, total suspended solids, total phosphorus, nitrite + nitrate, total Kjeldahl nitrogen, ammonia, biochemical oxygen demand, total organic carbon, hardness, and pH. These were the parameters used for testing the Delaware Sand Filters in Alexandria. Budget constraints required that the set of parameters be scaled down to one that would still represent the pollutant removal capacity of the BMP.

It was postulated that, of the heavy metals being tested, lead would register the lowest reading from the parking lot site that drains to the Carbon/Sand Filter. Most automobiles now use unleaded gasoline, and a field survey revealed that few of those regularly parked in the lot had diesel fuel engines. Large trucks, which commonly use diesel fuel, rarely enter this parking area. Copper and zinc, however, are deposited by a broad spectrum of automobile types and could be expected to more prevalent at this site than lead. Lead was therefore removed as a pollutant parameter for testing of the BMP.

Total petroleum hydrocarbons (TPH) is a test that measures the concentration of hydrocarbons in a solution without attempting to further identify the concentrations of individual constituents. TPH is also not a test that is used at the HRSD laboratory and would have to be subcontracted to another laboratory at a significant cost. HRSD staff claimed that a more precise measurement of hydrocarbons in a solution could be attained by measuring the individual constituents. The most common tests are for benzene, toluene, ethylbenzene, and xylene, which together comprise a test commonly known as BTEX. This test and one for naphthaline were used to measure hydrocarbons for this project instead of the TPH test.

Nitrite + nitrate was also removed from the list of test parameters. Nitrite + nitrate, total Kjeldahl nitrogen (TKN), and ammonia (NH_3) all measure the amount of nitrogen in a solution, as present in different chemical forms. Ammonia is an important parameter to measure for this project because that contaminant can be very lethal to aquatic animals. TKN measures ammonia plus organic nitrogen and is important as an indicator of fresh pollution by delivery of organic matter by stormwater (Krenkel and Novotny, 1980). Nitrite + nitrate measures nitrogen that is undergoing or has undergone a biologically mediated transformation. It is more a measure of "older" pollution and is not as great a threat as the nitrogen forms measured by TKN (Krenkel and Novotny, 1980).

The removal of pH as a testing parameter was not by design but rather a result of miscommunication. In the original project proposal, City staff was to perform the sample collection and submit the samples to the HRSD laboratory. pH was to be measured in the field by the sampling crew and not at the laboratory. When the sampling services were later contracted to HRSD, it was never specified for the HRSD sampling crew to test for this parameter. Nearly all twelve storm events had been sampled when it was recognized that pH had not been routinely measured.

pH, a measure of the hydrogen ion concentration in a solution, is an important factor in many chemical reactions. pH affects the toxicity of a number of substances, including ammonia, which, in its free form, increases in toxicity as the pH increases (Krenkel and Novotny, 1980). Because most receiving waters are typically well-buffered, pH does not fluctuate greatly. Water quality sampling results published by the EPA recorded the pH of the Elizabeth River, in the vicinity of downtown Portsmouth, at 7.56 (City of Portsmouth, 1992). Results from stormwater testing performed for the City of Portsmouth's VPDES Permit indicate that the pH for stormwater runoff from a broad set of land uses, including the commercial use into which category this BMP site falls, ranges only from 5.22 to 7.07, with an average pH of 6.19 (CH2M Hill with Woolpert Consultants, Inc., 1993). pH can theoretically range from 0 to 14, with 7 being a neutral solution. A study of pollutant pathways and transformations from source to and in receiving water would necessitate the measurement of pH, but this study can make broader conclusions without its measurement.

4.3 Chemical Analysis Results.

Table 4-2 provides technical information for the chemical analyses of each pollutant parameter used for testing of the Carbon/Sand Filter. It includes the units of measurement, the chemical analysis method, and the method detection limits (MDL). For certain parameters the practical quantitation limits (PQL) are used in place of the MDL. Also, the VPDES quantitation limits (VPDES QL), used for judging the confidence of a result for use in reporting for VPDES permit requirements, are given for total recoverable copper and total recoverable zinc.

Any figure below the MDL or the PQL should be considered suspect as to its exact value. For statistical analysis, the reported values will be used for this study, but HRSD staff indicated that in such situations it often uses a zero value for averaging purposes. A value below the VPDES QL is considered negligible for reporting analysis results in accordance with municipal VPDES permits.

Parameter	Units	Method	MDL	PQL	VPDES QL
Total Suspended Solids (TSS)	mg/L	S.M. 2540 E	1		
Total Phosphorus (TP)	mg/L	EPA 365.4	0.05		
Total Kjeldahl Nitrogen (TKN)	mg/L	EPA 351.2	0.05		
Ammonia (NH3)	mg/L	EPA 353.1	0.05		
Biochemical Oxygen Demand (BOD)	mg/L	S.M. 5210 B	1		
Total Organic Carbon (TOC)[1]	mg/L	EPA 415.1	0.5		
Total Recoverable Copper (Cu)	µg/L	EPA 200.7	6		10.0
Total Recoverable Zinc (Zn)	µg/L	EPA 200.7	2		20.0
Hardness	mg/L	EPA 200.7	1		
Benzene	µg/L	EPA 624		5.0	
Toluene	µg/L	EPA 624		5.0	
Ethylbenzene	µg/L	EPA 624		5.0	
Xylene	µg/L	EPA 624		5.0	
Naphthaline	µg/L	EPA 624		5.0	

1 = Analysis performed by Applied Marine Research Laboratory (AMRL) of Old Dominion University (ODU).

Table 4-2. Specifications for chemical analyses performed for this project. Blank values indicate that the category is not applicable.

Table 4-3 gives a complete listing of chemical analysis results, as provided by HRSD. The following sections describe the methods of data analysis and then group the pollutant parameters into five categories to analyze the results. These sections describe each parameter in more detail, note any unusual results obtained from the laboratory analysis, and statistically analyze the interpretive significance of the data. More general conclusions about the analysis results will be given in Section 4.6.

Site	Date	TSS (mg/L)	TP (mg/L)	TKN (mg/L)	NH3 (mg/L)	BOD (mg/L)	TOC (mg/L)	T.R. Cu (ug/L)	T.R.Zn (ug/L)	Hardness (mg/L)	Benzene (ug/L)	Toluene (ug/L)	Ethylbenze (ug/L)	Xylene (ug/L)	Naphthaline (ug/L)
Influent	Dec 9, '95	10	0.11	0.12	<0.05	<1	1.98	13	41	2.00	NQ	NQ	NQ	NQ	NQ
	Feb 21, '96	37	0.08	0.40	0.05	3	1.64	20	32	1.49	NQ	NQ	NQ	NQ	NQ
	Mar 6, '96	15	0.11	0.75	0.36	5	7.80	25	35	2.25	NQ	NQ	NQ	NQ	NQ
	Mar 19, '96	138	0.19	1.04	0.11	5	5.09	68	96	6.89	NQ	NQ	NQ	NQ	NQ
	Mar 28, '96	14	0.06	0.37	0.12	3	7.09	18	41	2.11	NQ	NQ	NQ	NQ	NQ
	Apr 24, '96	8	0.26	0.90	0.13	7	5.06	39	69	2.70	NQ	NQ	NQ	NQ	NQ
	May 16, '96	7	0.06	0.26	<0.05	3	4.05	8.0*	59	1.71	NQ	NQ	NQ	NQ	NQ
	Jun 24, '96	7	0.11	1.00	0.44	4	30.08	36	90	4.62	NQ	8.3**	NQ	NQ	NQ
	Jul 3, '96	19	0.13	0.76	0.17	11	10.26	32	65	7.36	NQ	NQ	NQ	NQ	NQ
	Jul 15, '96	13	0.1	0.39	<0.05	4	6.58	23	77	4.58	NQ	NQ	NQ	NQ	NQ
	Jul 18, '96	9	0.09	0.52	0.12	5	6.91	18	73	5.68	NQ	NQ	NQ	NQ	NQ
	Jul 25, '96	8	0.09	0.60	<0.05	6	10.22	28	115	4.14	NQ	NQ	NQ	NQ	NQ
Sand Filter Chamber Effluent	Dec 9, '95	93	0.13	1.13	<0.05	<2***	1.26	29	78	29.0	NQ	NQ	NQ	NQ	NQ
	Feb 21, '96	6	<0.05	0.27	0.13	3	2.72	21	59	1.87	NQ	NQ	NQ	NQ	NQ
	Mar 6, '96	28	0.09	0.45	0.11	2	4.70	22	79	14.5	NQ	NQ	NQ	NQ	NQ
	Mar 19, '96	100	0.11	0.54	0.1	2	3.26	21	158	11.3	NQ	NQ	NQ	NQ	NQ
	Mar 28, '96	4	0.11	0.64	0.19	7	5.36	30	193	11.5	NQ	NQ	NQ	NQ	NQ
	Apr 24, '96	6	0.18	0.80	0.08	4	7.89	36	32	32.8	NQ	NQ	NQ	NQ	NQ
	May 16, '96	4	0.13	0.56	0.05	4	5.99	15	84	34.8	NQ	NQ	NQ	NQ	NQ
	Jun 24, '96	42	0.24	1.96	0.44	34	40.98	37	272	17.4	NQ	16.0**	NQ	NQ	NQ
	Jul 3, '96	7	0.07	0.63	0.15	7	16.08	58	366	22.4	NQ	NQ	NQ	NQ	NQ
	Jul 15, '96	4	0.07	0.12	<0.05	2	3.20	7	110	9.14	NQ	NQ	NQ	NQ	NQ
	Jul 18, '96	3	0.06	0.36	<0.05	3	4.21	13	128	11.1	NQ	NQ	NQ	NQ	NQ
	Jul 25, '96	2	0.06	0.61	0.06	3	6.68	16	179	17.6	NQ	NQ	NQ	NQ	NQ
Carbon/Sand Filter Chamber Effluent	Dec 9, '95	64	0.19	2.34	1.56	4	2.74	13	112	14.0	NQ	NQ	NQ	NQ	NQ
	Feb 21, '96	12	<0.05	0.30	0.14	2	1.90	21	64	6.01	NQ	NQ	NQ	NQ	NQ
	Mar 6, '96	61	0.09	0.48	0.29	2	4.50	25	63	8.59	NQ	NQ	NQ	NQ	NQ
	Mar 19, '96	20	0.05	0.39	<0.05	2	1.60	16	116	17.8	NQ	NQ	NQ	NQ	NQ
	Mar 28, '96	3	<0.05	0.41	0.09	3	2.95	11	132	19.2	NQ	NQ	NQ	NQ	NQ
	Apr 24, '96	6	0.17	0.85	0.11	6	2.38	46	45	26.5	NQ	NQ	NQ	NQ	NQ
	May 16, '96	5	0.09	0.25	<0.05	3	6.11	11	86	35.9	NQ	NQ	NQ	NQ	NQ
	Jun 24, '96	36	0.22	1.85	0.31	29	41.71	30	220	21.3	NQ	11.1**	NQ	NQ	NQ
	Jul 3, '96	8	0.08	0.67	0.14	6	7.18	54	362	20.5	NQ	NQ	NQ	NQ	NQ
	Jul 15, '96	5	<0.05	0.13	<0.05	<1	7.05	<6.0	112	10.0	NQ	NQ	NQ	NQ	NQ
	Jul 18, '96	4	<0.05	0.27	<0.05	2	10.07	11	122	14.4	NQ	NQ	NQ	NQ	NQ
	Jul 25, '96	3	0.05	0.45	0.05	3	8.48	9	147	23.7	NQ	NQ	NQ	NQ	NQ

NQ = Sample concentration below quantitation.

* Values below quantitation should not be used for compliance decisions concerning Water Quality Standards because of a high degree of uncertainty.

** QC Data obtained indicative of contamination (Blank Value = 4.13 ug/L) Analysis contracted to Reeds & Associates Lab.

*** Due to sample volume limitation, value reported is higher than MDL level.

Table 4-2. Chemical analysis results of Carbon/Sand Filter testing.

4.4 Statistical Methods Used for Data Analysis.

The results of each pollutant parameter are statistically examined in three ways. The first is an examination of the sample means for each monitoring station: the influent, the sand filter effluent, and the carbon sand filter, abbreviated CSF for this analysis, effluent. The means are compared iteratively as data from certain storm events are scrutinized and screened for irregularities. The second method tests the groups of data for each monitoring station to determine if there is a statistically significant difference in the readings between the influent and sand filter effluent, the influent and the CSF effluent, and the sand filter effluent and the CSF effluent. The final method examines the correlation between the data groups. A correlation between two groups assigns a numerical value to the propensity of the sample data of one group to increase as that of another group increases. The results can indicate a tendency toward a positive relationship, a negative relationship, or no apparent relationship.

4.4.1 Sample Means.

There are several steps in the evaluation of the sample means. First, the mean is calculated over all storm events for the sample pollutant concentrations. The influent and each filter chamber effluent each have a mean value. Next, any data that was the result of a known flaw in the filtering or sampling process is removed from the data set. The data points are then examined for extreme outliers that indicate an unusual and unrepresentative occurrence in the normal filtering or sampling process. As these points are considered for removal from the data set, care is taken to remove only those data points indicative of a process flaw and not points that are merely unexpected. Finally, the calculated means are tabulated and compared to analyze the effects of removing the data of selected storm events. The means are used to point out indications of pollutant removal by either or both of the filter chambers and pollutant removal advantages of one filter chamber over the other.

4.4.2 Paired T-test for Significance of Results.

Although the sample means might indicate a difference in pollutant concentration between monitoring groups, the difference may be due to variability in the sample data and not a true indication of pollutant removal. The data, exclusive of storms that were removed as flawed data, are tested for statistical significance in pollutant removal, using a paired t-test. The paired t-test method compares two monitoring groups at a time, for instance the influent data to the sand filter effluent data, subtracting the effluent data point from the influent data point for each storm. These differences are tabulated and analyzed to see if there is a significant disparity that would indicate true pollutant removal. As explained by Devore (1987), the t-test tests the hypothesis that the mean difference in pollutant concentration is zero versus the alternative hypothesis that the mean difference in pollutant concentration is positive, indicating true pollutant removal. This is represented statistically by

$$H_o : \mu_D = 0,$$
$$H_a : \mu_D > 0,$$

where μ_D = the mean of the differences in pollutant concentration.

This test assumes that the differences being examined are normally distributed for the entire population, meaning all storm events in which stormwater passes through the filter, as well as for the sample data. Because the alternative hypothesis is $H_a : \mu_D > 0$, and not $H_a : \mu_D \neq 0$, the t-test is a one-tailed test. All tests are performed at a 90 percent confidence level.

The test statistic used is

$$t_{paired} = \bar{d} / (s_D / \sqrt{n}), \qquad \textbf{(Eqn 4-1)}$$

where $\bar{d}$ = sample mean value of difference in concentration, and
s_D = sample standard deviation for difference in concentration.

To determine $\bar{d}$, the data points for each data set, grouped by monitoring station, are paired by storm event. The data points from the set hypothesized to have lower values are subtracted from the other data points. More specifically, the hypothesis of this study is that each filtration chamber effluent should have lower pollutant concentrations than the influent and that the Carbon/Sand Filter effluent should have lower pollutant concentrations than the sand filter effluent. Therefore, for the case of the influent to sand filter comparison, the sand effluent concentration data point, the lower expected value, is subtracted from the influent concentration, the higher expected value. That is,

Storm event #1: d_1 = (influent concentration) - (sand effluent concentration)
Storm event #2: d_2 = (influent concentration) - (sand effluent concentration)
Storm event #i: d_i = (influent concentration) - (sand effluent concentration) ...
:
:
Storm event #n: d_n = (influent concentration) - (sand effluent concentration)

where $\bar{d} = \Sigma d_i / n$, and **(Eqn 4-2)**

$$s_D = \sqrt{s_D^2} = \sqrt{\left(\Sigma d_i^2 - (\Sigma d_i)^2/n\right)/_{n-1}}. \qquad \textbf{(Eqn 4-3)}$$

If $t_{paired} > t_{\alpha,\, n-1}$, where $\alpha = (100 - 90)\% = 10\% = 0.10$, then H_0 is rejected at a 90 percent confidence level, meaning the evidence that there is an advantage in pollutant removal is statistically significant. Otherwise, the random variation on the data cannot be ruled out as causing the difference between sample means.

This test procedure is used for each comparison of monitoring groups, meaning that the influent data is compared to the sand effluent data, the influent data is compared to the Carbon/Sand Filter effluent data, and the sand filter effluent data is compared to the Carbon/Sand Filter data. The same procedure is followed for each pollutant parameter. Section 4.5.1 Total Suspended Solids (TSS) gives detailed calculations for this methodology to illustrate the process. Subsequent sections that analyze the results of other pollutant parameters only discuss the results of the statistical analysis. Actual calculations performed in an Excel spreadsheet format can be referenced in Appendix A-5.

All formulae and methodology used in this section are common in statistical practice but, as represented here, are adapted from Devore (1987).

4.4.3 Correlation of Monitoring Data.

The third statistical method used to analyze the sample data is the calculation of the sample correlation coefficient. This coefficient measures the relationship between two sets of data. It gives statistical relevance to the tendency of one data set to increase or decrease as the other data set increases or decreases. It will reflect a lack of any such behavior as well.

The sample correlation coefficient, r, is given by the following formula:

$$r = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{\sqrt{n\Sigma x_i^2 - (\Sigma x_i)^2}\ \sqrt{n\Sigma y_i^2 - (\Sigma y_i)^2}}, \qquad \textbf{(Eqn 4-4)}$$

where x_i and y_i are data points, each related to a particular storm event, within the monitoring groups that are being compared, such as the influent to the sand filter effluent.

The value of r ranges from -1, which indicates a strong negative relationship, to 1, which indicates a strong positive relationship. For instance, a sample correlation coefficient of 1 in the example above would indicate a strong propensity for the pollutant concentration in the sand filter effluent to increase as the concentration in the influent increases and for it to decrease as the influent concentration decreases. An r value of 0 indicates no relationship between the data sets.

Devore (1987), on whose work this discussion is based, reports that for $0 \le |r| \le 0.5$, the correlation is weak. For $0.8 \le |r| \le 1$, the correlation is considered to be strong. As for the test for significance in the sample mean differences, Section 4.5.1 Total Suspended Solids (TSS) thoroughly illustrates the calculation procedure, whereas subsequent sections relate only the results of the calculations for each parameter. Appendix A-5 can be referenced for detailed calculations in an Excel spreadsheet format.

4.5 Pollutant Data Analysis.

4.5.1 Total Suspended Solids (TSS).

Total suspended solids (TSS) are measured by filtering the solution through a filter of 2.0μm pore size and drying the filtered material in an oven (Eaton et al, 1995). Any material in solution that passes through the filter is considered to be dissolved solids and not suspended solids. This analysis measures any material of the minimum size and may include particulate forms of other parameters that are being tested, such as metals or organic material. It is used to give a general indication of contaminant content in water.

Table 4-4 provides the influent and effluent chemical analysis results for TSS. The first column gives the influent concentration data for each storm event. The second and third columns provide data for the sand filtration chamber and the CSF chamber, respectively. At the bottom are sample means for the entire data set and selected subsets of the complete data.

Previous mention has been made of the problems associated with the first storm event on December 9, in which flow passed from the gravel lot directly into the filter chambers, bypassing the influent sampling station. As seen in the data, the result was a significant increase in the TSS levels for the effluents from the two filtration chambers. The data for this storm event is removed for this analysis to prevent misleading results.

Total Suspended Solids
(TSS, mg/L)

Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	10	93	64
Feb 21, '96	37	6	12
Mar 6, '96	15	28	61
Mar 19, '96	138	100	20
Mar 28, '96	14	4	3
Apr 24, '96	8	6	6
May 16, '96	7	4	5
Jun 24, '96	7	42	36
Jul 3, '96	19	7	8
Jul 15, '96	13	4	5
Jul 18, '96	9	3	4
Jul 25, '96	8	2	3
Mean #1	23.8	24.9	18.9
Mean #2 (w/out 12/9)	25.0	18.7	14.8
Mean #3 (w/out 12/9, 3/19)	13.7	10.6	14.3

Table 4-4. Sample mean data for total suspended solids (TSS).

The storm event of March 19 also yields unusual readings. The influent concentration of TSS is extremely high, as is that for the effluent from the sand filter. The mean TSS concentration for the influent and for the sand filter effluent nearly doubles when the figures from this storm event are included (Table 4-4, mean #2 versus mean #3). The reading for the CSF effluent is slightly elevated but still relatively consistent with results from other storm events for that chamber.

Were the results of the influent alone elevated, it could be theorized that some sand or dirt material had been deposited in a large quantity on the lot. This condition could have occurred as a result of the recorded snow event of March 7, less than two weeks earlier, if sand or dirt were used to melt the snow and provide traction for vehicles and pedestrians. If the particles were large enough, such as heavier granules of sand, it is possible that they settled out to a significant degree in the sedimentation chamber and never reached the filtration chamber. Another possibility is that this type of material was trapped on top of the filter by the layer of filter fabric or by the filter itself. This would not, however, account for the elevated reading for the sand filter chamber effluent.

The prospect that sand or some other material could be deposited on the parking lot and that a finer material that could pass through the sand filter was deposited into the sand filter chamber through the access grates seems rather remote. Because the sand filter chamber is closer to the public sidewalk, however, it is possible that fine sand and salt spread on the sidewalk as a countermeasure to snow could have been swept into the access grates for the sand filter chamber but not into those of the carbon/sand filter chamber. This possibility, although seemingly unlikely, is the only reasonable explanation for the unusual chemical analysis results.

Eight of the remaining ten storm events yield results that would be expected of a filtration device. In these cases both effluent concentrations are consistently lower the influent concentration but not unexpectedly lower. The events of March 6 and June 24, however, show an increase in TSS concentration for both effluents over the influent. This result could be an indication of either of two possible conditions. First, there could have been some deposition of a material that entered the filter chambers through the access grates, while bypassing the influent monitoring station. This was the case for the December 9, 1995 storm in which stormwater flowed from the gravel lot into the filter chambers, but that problem was subsequently fixed. The chemical analysis data for the June 24 storm seem to indicate such a possibility because many of the parameters see an increase in concentration after filtration. The second possibility is that a residue from previously filtered stormwater remained in the filter and was flushed out by a more intense rain event that followed.

The sample mean data seem to indicate that there is a slight pollutant removal by the sand filter but that the effluent concentrations for the CSF are approximately the same as for the influent. After removing the December 9 and March 19 storm event data, the sand filter sees a 23 percent decrease in TSS while the CSF sees a four percent increase in TSS.

The next step in the data analysis is to test for significance the apparent decrease in TSS concentration for the sand filter and the apparent increase in TSS concentration for the CSF. Table 4-5 shows the mathematical differences between each monitoring group for each storm event. The sample mean difference, $\bar{d}$, is calculated using Equation 4-2 and the standard deviation of the sample differences is calculated using Equation 4-3. The results are shown at the bottom of Table 4-5. Also shown are the mean and standard deviation for sample differences when the March 6 and June 24 storm events are removed from the data set. There is no known or apparent flaw in either the filtering process or the sampling process for these storms, but because the readings are suspect, conclusions will be drawn with and without the data from these storms. The June 24 data for all chemical parameters is particularly indicative of some unusual circumstance.

Total Suspended Solids (TSS, mg/L) Date	Influent (1)	Sand Effluent (2)	CSF Effluent (3)	Influent - Sand Effluent (4) = (1) - (2)	Influent - CSF Effluent (5) = (1) - (3)	Sand Effluent - CSF Effluent (6) = (2) - (3)
~~Dec 9, '95~~	~~10~~	~~93~~	~~64~~	---	---	---
Feb 21, '96	37	6	12	31	25	-6
Mar 6, '96	15	28	61	-13	-46	-33
~~Mar 19, '96~~	~~138~~	~~100~~	~~20~~	---	---	---
Mar 28, '96	14	4	3	10	11	1
Apr 24, '96	8	6	6	2	2	0
May 16, '96	7	4	5	3	2	-1
Jun 24, '96	7	42	36	-35	-29	6
Jul 3, '96	19	7	8	12	11	-1
Jul 15, '96	13	4	5	9	8	-1
Jul 18, '96	9	3	4	6	5	-1
Jul 25, '96	8	2	3	6	5	-1
Mean difference, $\bar{d}$				3.1	-0.6	-3.7
Standard deviation, s_D				17.2	20.9	10.7
Exclusive of 3/6, 6/24 events						
Mean difference, $\bar{d}$				9.9	8.6	-1.3
Standard deviation, s_D				9.2	7.5	2.1

Table 4-5. Means and standard deviations for sample differences in total suspended solids (TSS) data.

The test statistic, t_{paired}, is calculated, using Equation 4-1, to test the null hypothesis that there is no significant difference in pollutant concentration between monitoring groups. The calculated values for t_{paired} for the ten valid storm event data sets are shown below with the tabular value for t at $\alpha = 0.10$ (a 90 percent confidence level) and $n-1 = 9$:

Influent to Sand Filter Effluent: $t_{paired} = 0.563$ $t_{0.10,9} = 1.383$
Influent to CSF Effluent: $t_{paired} = -0.091$ $t_{0.10,9} = -1.383$
Sand Filter Effluent to CSF Effluent: $t_{paired} = -1.086$ $t_{0.10,9} = -1.383$

The negative values indicate that the t-test is being evaluated at the lower end of the t distribution curve. In these cases the sample mean difference reflects the opposite of what would be the expected result of the filtration process, for instance that the pollutant concentration in the CSF effluent is actually higher than that of the influent. The t-test examines whether this result is due to variability in the individual data points. The absolute value of these figures is used to test the null hypothesis.

The statistical analysis of these results concludes that no rejection of the null hypothesis,

$H_o : \mu_D = 0,$ is warranted in favor of
$H_a : \mu_D > 0.$

That is, statistically, there can be no rejection of the possibility that the difference in sample means is due to variability of the data. This result does not mean that there is no difference between the monitoring groups, only that this cannot be concluded with statistical certainty.

For comparative purposes, Table 4-5 also includes figures to test the significance in sample data differences when the March 6 and June 24 storms are removed from the data set. This study will draw conclusions about TSS removal both with and without the data for these two storms. Although the data indicate a possible flow of polluted runoff through the filter that had bypassed the influent monitoring station, particularly for the June 24 storm, there is no overwhelming evidence that there was a flaw in either the filtering process or the sampling process for these storms. Because the values were somewhat unexpected, however, the t-test is used to show how the filters truly performed if indeed these data points were flawed.

The calculated values for t_{paired} for the data of the eight remaining storm events are shown below with the tabular value for t at $\alpha = 0.10$ (a 90 percent confidence level) and $n-1 = 7$:

Influent to Sand Filter Effluent: $t_{paired} = 2.597$ $t_{0.10,7} = 1.415$
Influent to CSF Effluent: $t_{paired} = 2.743$ $t_{0.10,7} = 1.415$
Sand Filter Effluent to CSF Effluent: $t_{paired} = -1.604$ $t_{0.10,7} = -1.415$

The statistical analysis of these results concludes that the null hypothesis,

$H_o : \mu_D = 0,$ should be rejected in favor of
$H_a : \mu_D > 0.$

At a 90 percent confidence level it can be concluded that the difference in sample means is not due to variability of the data but is indicative of a true difference in TSS concentration. It can be stated, in this case, that the sand filter and the CSF both remove TSS in the stormwater runoff and that the sand filter gives more TSS removal than the CSF. Table 4-6 summarizes the statistical analysis results.

Total Suspended Solids (TSS)			
Statistic	**Influent: Sand Effluent**	**Influent: CSF Effluent**	**Sand Effluent: CSF Effluent**
Exclusive of 12/9, 3/19 events			
Change in pollutant concentration	↓ 23%	↑ 4%	↑ 35%
Test statistic, t_{paired}	0.569	-0.091	-1.094
Tabular t-value, $t_{(0.10, 9)}$	1.383	-1.383	-1.383
Test conclusion	Do not reject H_0.	Do not reject H_0.	Do not reject H_0.
Interpretation	Difference could be variation in data.	Difference could be variation in data.	Difference could be variation in data.
Correlation coefficient, r	-0.14	0.03	0.84
Exclusive of 12/9, 3/19, 3/6, 6/24 events			
Change in pollutant concentration	↓ 69%	↓ 60%	↑ 28%
Test statistic, t_{paired}	3.040	3.252	-1.722
Tabular t-value, $t_{(0.10, 7)}$	1.415	1.415	-1.415
Test conclusion	Reject H_0.	Reject H_0.	Reject H_0.
Interpretation	True concentration difference.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.55	0.88	0.76

Table 4-6. Summary of statistical analyses for total suspended solids (TSS).

Table 4-6 also shows the sample correlation coefficient, r, for each monitoring group comparison, calculated using Equation 4-4. The coefficient shows no apparent behavioral relationship between the influent data and either of the effluent data but does show a strong tendency for the TSS concentration to increase or decrease in the CSF effluent as the concentration respectively increases or decreases in the sand filter effluent. When the March 6 and June 24 storm data are removed from the sets, there appears to be a weak positive relationship between the influent TSS concentrations and the sand filter effluent concentrations, a strong positive relationship between the influent concentrations and the CSF concentrations, and a relatively strong relationship between the sand filter and CSF effluents. The calculations illustrate the effect that the unexpected data results from these two storms have on the statistical analysis.

4.5.2 Nutrients.

Total phosphorus, total Kjeldahl nitrogen (TKN), and ammonia (NH_3) all measure types of nutrients in a solution. The effects of phosphorus and nitrogen have already been discussed. There are numerous chemical tests that measure different forms of nitrogen. Two forms that are important to this study are measured by total Kjeldahl nitrogen (TKN) and ammonia (NH_3), which are further discussed below.

4.5.2.1 Total Phosphorus (TP).

Phosphorus is one of the primary pollutants through which different BMPs are compared. In the Chesapeake Bay watershed, phosphorus is considered the "keystone" pollutant. In Virginia compliance with the Chesapeake Bay Preservation Act is predicated on meeting phosphorus removal requirements for a particular development site. If the Carbon/Sand Filter or any other innovative BMP design is to gain widespread use, it is imperative that its pollutant removal capabilities be documented, phosphorus foremost among them.

Total phosphorus (TP) is measured in a two-step process: first through digestion and then through colorimetry (Eaton et al, 1995). Digestion involves the oxidation destruction of any organic matter present in order to release phosphorus in the solution as orthophosphate. In colorimetry, a reagent is added to the sample that will react with the orthophosphate to form a colored acid. The intensity of the color change reflects the concentration of phosphorus in the sample.

Table 4-7 provides the influent and effluent chemical analysis results for TP. The first column gives the influent concentration data for each storm event. The second and third columns provide data for the sand filtration chamber and the CSF chamber, respectively. At the bottom are sample means for the entire data set and selected subsets of the complete data.

Because of flow from the gravel parking lot directly into the filter chambers through the access grates, the December 9 storm is removed from the data set. The June 24 storm data exhibits behavior reflective of conditions similar to those of the December 9 event. Statistical analysis is performed on the data, inclusive and exclusive of the June 24 storm.

Total Phosphorus
(TP, mg/L)

Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	0.11	0.13	0.19
Feb 21, '96	0.08	0.04	0.04
Mar 6, '96	0.11	0.09	0.09
Mar 19, '96	0.19	0.11	0.05
Mar 28, '96	0.06	0.11	0.04
Apr 24, '96	0.26	0.18	0.17
May 16, '96	0.06	0.13	0.09
Jun 24, '96	0.11	0.24	0.22
Jul 3, '96	0.13	0.07	0.08
Jul 15, '96	0.10	0.07	0.04
Jul 18, '96	0.09	0.06	0.04
Jul 25, '96	0.09	0.06	0.05
Mean #1	0.1158	0.1075	0.0917
Mean #2 (w/out 12/9)	0.1164	0.1055	0.0827
Mean #3 (w/out 12/9, 6/24)	0.1170	0.0920	0.0690

Table 4-7. Sample mean data for total phosphorus (TP).

The mean values for the influent TP concentration remain nearly the same for the data inclusive of all storms, exclusive of the December 9 storm, and exclusive of the December 9 and June 24 storms. The mean values for the data of both effluents, however, decrease as these storms are excluded from the data sets. Mean #2 and mean #3 in Table 4-7 are the more meaningful results. When the December 9 storm only is excluded, the sand filter recognizes a nine percent decrease in TP, while the CSF recognizes a 29 percent decrease. When both the December 9 and the June 24 storm events are excluded, the sand filter yields a 21 percent decrease in TP, while the CSF gives a 41 percent decrease.

As summarized in Table 4-8, the paired t-test, applied at a 90 percent confidence level, indicates that, for the data exclusive of the December 9 storm only, the difference in TP concentrations between the influent and the sand filter effluent could be the result of variability in the data. It cannot be conclusively said that there is a true TP removal for the sand filter. The test does indicate, however, that there is a significant difference in TP concentration between the influent and the CSF effluent and between the sand filter effluent and the CSF effluent. It can be concluded that the CSF does provide a significant TP removal and that the CSF provides significantly more TP removal than the sand filter.

When the June 24 storm event is also removed from the data set, there is, at a 90 percent confidence level, a significant difference in the TP concentration between the influent data and the effluent data. The conclusion is that the sand filter provides a true TP removal. Using this set of storm events, the CSF still provides a true TP removal and provides significantly more TP removal than does the sand filter.

Total Phosphorus (TP)

Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
Exclusive of 12/9 event			
Change in pollutant concentration	↓ 9%	↓ 29%	↓ 22%
Test statistic, t_{paired}	0.545	1.745	2.975
Tabular t-value, $t_{(0.10,\ 10)}$	1.372	1.372	1.372
Test conclusion	Do not reject H_0.	Reject H_0.	Reject H_0.
Interpretation	Difference could be variation in data.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.38	0.43	0.91
Exclusive of 12/9, 6/24 events			
Change in pollutant concentration	↓ 21%	↓ 41%	↓ 25%
Test statistic, t_{paired}	1.590	3.379	2.725
Tabular t-value, $t_{(0.10,\ 9)}$	1.383	1.383	1.383
Test conclusion	Reject H_0.	Reject H_0.	Reject H_0.
Interpretation	True concentration difference.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.61	0.70	0.79

Table 4-8. Summary of statistical analyses for total phosphorus (TP).

The normal expectation for correlation between the data sets would a positive one. It is expected that, although both filters should provide some pollutant removal, if the pollutant concentration in the influent for one particular storm event is higher than the concentrations for the other storm events, it give a higher reading in the effluent for that event than the readings for other events. A similar correlation between the sand filter effluent data and the CSF effluent data is expected. This test is used primarily to flag instances of zero or negative correlation between data sets. Either of these conditions does not necessarily connote unreliable results, but rather that the results should be thoroughly examined for unusual circumstances regarding the filtering or sampling process.

The sample correlation coefficients for each data set comparison are given in Table 4-8 for the different sets of storm events. Considering the data sets when the December 9 storm only is removed, the correlation between the influent and the sand filter effluent data and that between the influent and CSF effluent data each has a weak positive relationship. The relationship between the two effluent data sets is strongly positive, indicating that both have very similar filtering behavior with respect to TP. When the June 24 storm is also removed from the data sets, the positive relationship between the influent data and the data for each effluent is stronger, and the relationship between the sand filter effluent and the CSF effluent is slightly weaker, but still a strong one.

The results of these statistical analyses, considered together, lead to the conclusion that both the sand filter and the CSF appear to effectively filter phosphorus from stormwater runoff. Additionally, the CSF is somewhat more effective than the sand filter in removing phosphorus.

4.5.2.2 Total Kjeldahl Nitrogen (TKN).

TKN measures the total organic nitrogen and the total ammonia nitrogen in a solution. These unoxidized forms of nitrogen are important because they give an indication of the oxygen demand that will be created as oxidation occurs. Oxygen consumed in these chemical processes is then unavailable for higher order aquatic organisms. As mentioned in Section 4.2, TKN is a measure of "fresh" pollution that will exert a higher oxygen demand rather than nitrogen forms that are more stabilized in the receiving water (Krenkel and Novotny, 1980).

To measure TKN, the sample is digested with acid to convert all organic nitrogen to ammonia nitrogen (Eaton et al, 1995). Colorimetry is then used to measure the ammonia content of the solution. Table 4-9 provides the influent and effluent chemical analysis results and sample mean concentrations for TKN.

For the reasons given in the discussions of total suspended solids and total phosphorus, the December 9 storm event is removed from the data set. Statistical analysis of the data is given both with and without the June 24 storm events in the data sets. It remains unclear as to whether a flaw in the filtering process or the sampling process occurred during the June 24 event.

The mean influent concentrations are very close, regardless of whether the December 9 storm or the December 9 and the June 24 storms are excluded from the calculation. Both effluent concentrations, however, are lower when excluding the December 9 storm and are further reduced when both storms are removed from the data sets. When the December 9 storm is not considered, the sand filter gives a one percent removal rate while the CSF gives a 13 percent removal rate. The mean CSF effluent concentration of TKN is 13 percent lower than that of the sand filter. With both the December 9 and June 24 storms excluded, the apparent TKN removal rate is 17 percent for the sand filter and 30 percent for the CSF. The mean concentration for the CSF effluent is 16 percent lower than for the sand filter.

Total Kjeldahl Nitrogen
(TKN, mg/L)

Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	0.12	1.13	2.34
Feb 21, '96	0.40	0.27	0.30
Mar 6, '96	0.75	0.45	0.48
Mar 19, '96	1.04	0.54	0.39
Mar 28, '96	0.37	0.64	0.41
Apr 24, '96	0.90	0.80	0.85
May 16, '96	0.26	0.56	0.25
Jun 24, '96	1.00	1.96	1.85
Jul 3, '96	0.76	0.63	0.67
Jul 15, '96	0.39	0.12	0.13
Jul 18, '96	0.52	0.36	0.27
Jul 25, '96	0.60	0.61	0.45
Mean #1	0.5925	0.6725	0.6992
Mean #2 (w/out 12/9)	0.6355	0.6309	0.5500
Mean #3 (w/out 12/9, 6/24)	0.5990	0.4980	0.4200

Table 4-9. Sample mean data for total Kjeldahl nitrogen (TKN).

Total Kjeldahl Nitrogen
(TKN)

Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
Exclusive of 12/9 event			
Change in pollutant concentration	↓ 1%	↓ 13%	↓ 13%
Test statistic, t_{paired}	0.038	0.782	2.182
Tabular t-value, $t_{(0.10,\ 10)}$	1.372	1.372	1.372
Test conclusion	Do not reject H_0.	Do not reject H_0.	Reject H_0.
Interpretation	Difference could be variation in data.	Difference could be variation in data.	True concentration difference.
Correlation coefficient, r	0.57	0.65	0.97
Exclusive of 12/9, 6/24 events			
Change in pollutant concentration	↓ 17%	↓ 30%	↓ 16%
Test statistic, t_{paired}	1.300	2.871	1.908
Tabular t-value, $t_{(0.10,\ 9)}$	1.383	1.383	1.383
Test conclusion	Do not reject H_0.	Reject H_0.	Reject H_0.
Interpretation	Difference could be variation in data.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.44	0.66	0.80

Table 4-10. Summary of statistical analyses for total Kjeldahl nitrogen (TKN).

The paired t-test for the data exclusive of the December 9 event concludes that the difference in mean TKN concentrations between the influent and either effluent could be a result of variation in the sample data. The CSF effluent concentration, though, is significantly lower than the sand filter effluent concentration at a 90 percent confidence level, meaning that, based on this data set, there is an advantage in organic plus ammonia nitrogen removal for the CSF over the sand filter.

When the June 24 storm event is also removed from consideration, the decrease in TKN from the influent to the CSF effluent becomes significant. It is concluded in this case that the CSF provides true pollutant removal, and that there is still a TKN removal advantage for the CSF over the sand filter. The decrease in TKN between the influent and the sand filter effluent may still be due to variation in the sample data.

For exclusion of the December 9 storm or both storms, the sample correlation coefficients are very similar. As expected, there is a moderate positive relationship between the influent data and each effluent data set, and there is a strong positive relationship between the two effluent data sets. The statistical analysis results are summarized in Table 4-10.

Taken together, the analysis indicates a probable, but not irrefutable, removal of TKN for the sand filter and a stronger probability of TKN removal by the CSF. The CSF is conclusively more effective in removing TKN than the sand filter.

4.5.2.3 Ammonia (NH_3).

As microorganisms decompose organic matter, oxidizing carbon to obtain energy, the nitrogen remains unoxidized and is released to the water as ammonia (Davis and Cornwell, 1991). Ammonia can be processed to a certain degree by aquatic plants but is toxic to most other aquatic life. It is also used by some microorganisms in the presence of organic carbon to build cell tissue. When ammonia is oxidized to nitrate, an oxygen demand is exerted. The oxygen consumed in this process is no longer available for higher order organisms. Thus, ammonia is a contaminant of concern in aquatic chemistry.

Ammonia (NH_3), also written as ammonia nitrogen (NH_3-N), is analyzed in a similar but simpler fashion than TKN. It uses colorimetry to measure the ammonia content, but the organic nitrogen is not first converted to ammonia nitrogen as for the TKN measurement (Eaton et al, 1995). Colorimetry does not give the organic nitrogen content of the solution. Table 4-11 provides the influent and effluent chemical analysis results and sample mean concentrations for NH_3.

The December 9 storm is the only event removed from the data set for analysis of NH_3 removal by the BMP. None of the other readings appears to be unusually skewed as to warrant deletion from the data set. The June 24 storm data, which exhibits unusual behavior for many other pollutant parameters, does not give the significant increases in NH_3 as seen in previous analysis.

Exclusion of the December 9 storm changes the mean concentrations for all three monitoring stations, increasing the means slightly for the influent and sand filter effluent concentrations and decreasing the CSF effluent concentration dramatically. The NH_3 concentrations are 14 percent lower for the sand filter and 20 percent lower for the CSF than the influent concentrations. The CSF effluent concentration is seven percent less than that of the sand filter.

Ammonia **(NH_3, mg/L)** **Date**	**Influent**	**Sand Effluent**	**CSF Effluent**
Dec 9, '95	0.04	0.04	1.56
Feb 21, '96	0.05	0.13	0.14
Mar 6, '96	0.36	0.11	0.29
Mar 19, '96	0.11	0.10	0.04
Mar 28, '96	0.12	0.19	0.09
Apr 24, '96	0.13	0.08	0.11
May 16, '96	0.04	0.05	0.04
Jun 24, '96	0.44	0.44	0.31
Jul 3, '96	0.17	0.15	0.14
Jul 15, '96	0.04	0.04	0.04
Jul 18, '96	0.12	0.04	0.04
Jul 25, '96	0.04	0.06	0.05
Mean #1	0.1383	0.1192	0.2375
Mean #2 (w/out 12/9)	0.1473	0.1264	0.1173

Table 4-11. Sample mean data for ammonia (NH_3).

As summarized in Table 4-12, the t-test results conclude that the apparent NH_3 removal by the sand filter may be due to variation in the sample data, but that there is a true NH_3 removal provided by the CSF. There is no conclusive difference between the sample mean differences of the sand filter and of the CSF. The difference in means may also be the result of variation in the sample data. The sample correlation coefficients show moderate positive relationships between the influent data and the sand filter effluent data and between the sand filter and CSF effluent data. There is a very strong positive relationship between the influent data and the CSF effluent data. Together, these statistics suggest that the CSF provides definite NH_3 removal from stormwater runoff and that there is a strong possibility that the sand filter provides NH_3 removal, although somewhat less than the CSF.

Ammonia (NH_3) **Statistic**	**Influent: Sand Effluent**	**Influent: CSF Effluent**	**Sand Effluent: CSF Effluent**
Exclusive of 12/9 event			
Change in pollutant concentration	↓ 14%	↓ 20%	↓ 7%
Test statistic, t_{paired}	0.781	1.717	0.379
Tabular t-value, $t_{(0.10, 10)}$	1.372	1.372	1.372
Test conclusion	Do not reject H_0.	Reject H_0.	Do not reject H_0.
Interpretation	Difference could be variation in data.	True concentration difference.	Difference could be variation in data.
Correlation coefficient, r	0.75	0.92	0.73

Table 4-12. Summary of statistical analyses for ammonia (NH_3).

4.5.3 Oxygen Demand.

There are a number of chemical reactions, many biologically mediated, that require oxygen to occur. When this oxygen becomes chemically bound, it is no longer available to higher order organisms. Most oxygen demand is related to biodegradation of organic material, or carbonaceous demand, in a solution. Other sources of oxygen demand are the oxidation of inorganic material, such as sulfides or ferrous iron, and the oxidation of reduced forms of nitrogen, or nitrogenous demand.

There are many chemical analyses designed to measure the oxygen demand of these different reactions in a solution. The most common tests are for biochemical oxygen demand (BOD), chemical oxygen demand (TOC), and total organic carbon (TOC). The BOD and TOC analyses were used in this project. These two tests give a reasonably comprehensive indication of the oxygen demanding substances in the stormwater runoff being filtered, and are widely used in stormwater quality analysis. This allows the results from the Carbon/Sand Filter to be compared to those of other BMPs. Budgetary constraints prevented further chemical analysis of oxygen demand.

4.5.3.1 Biochemical Oxygen Demand (BOD).

Biochemical oxygen demand (BOD) measures carbonaceous demand and the demand created by the oxidation of inorganic material. The analysis most commonly used, and the one used for this project, is the 5-day BOD (BOD_5), in which the oxygen levels are monitored over a five-day period. In this discussion, BOD is meant to be BOD_5.

The BOD test measures the dissolved oxygen (DO) in a diluted sample at the beginning and at the end of the five-day period (Eaton et al, 1995). The sample is diluted in cases where the BOD might exceed the oxygen content of the sample over the course of the five-day test period. If there are likely too few microorganisms to oxidize the organic matter, the sample is seeded bacteria, and nutrients required by bacteria to carry out their functions can be added. The solution is incubated at a constant temperature.

Table 4-13 provides the influent and effluent chemical analysis results and sample mean concentrations for BOD. The exclusion of both the December 9 and the June 24 storm events most likely give the most accurate appraisal of how the filters remove oxygen demanding substances from stormwater runoff. The problems of the December 9 storm event have been well documented. The June 24 monitoring data once again exhibits highly unusual behavior. The BOD concentrations for both effluent streams are ten times higher for this single storm event than the average value of the remaining storm data. Although impossible to confirm, it is more likely that a foreign substance such as leaves and other organic material and debris were deposited directly onto the filter beds than there being a regularly occurring condition in the filtering process that would create an increase in BOD in the effluent. Because these data points are such extreme outliers, they are not considered for the analysis.

The removal of the data from these two storms causes a mild, ten percent increase in the mean influent BOD concentration. The reduction of the mean BOD concentrations for both effluents is more dramatic, decreasing 38 percent for the sand filter effluent and 43 percent for the CSF effluent. As apparent pollutant removal rates for oxygen demanding substances, there is a 29 percent decrease in BOD concentration between the influent and the sand filter effluent and a 43 percent decrease between the influent and the CSF effluent. The CSF appears to be 20 percent more effective in removing these contaminants than the sand filter.

Biochemical Oxygen Demand (BOD, mg/L)			
Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	0.5	0.5	4
Feb 21, '96	3	3	2
Mar 6, '96	5	2	2
Mar 19, '96	5	2	2
Mar 28, '96	3	7	3
Apr 24, '96	7	4	6
May 16, '96	3	4	3
Jun 24, '96	4	34	29
Jul 3, '96	11	7	6
Jul 15, '96	4	2	0.5
Jul 18, '96	5	3	2
Jul 25, '96	6	3	3
Mean #1	4.71	5.96	5.21
Mean #2 (w/out 12/9, 6/24)	5.20	3.70	2.95

Table 4-13. Sample mean data for biochemical oxygen demand (BOD).

The t-tests for the three flow comparisons all conclude that there is a significant difference in BOD concentration at a 90 percent confidence level. The sample correlation coefficients all show moderate to strong positive relationships between the data sets. These analyses are summarized in Table 4-14. The conclusion of the statistical analyses is that the sand filter and the CSF both provide true removal of oxygen demanding substances and that the CSF is more effective than the sand filter.

Biochemical Oxygen Demand (BOD)			
Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
Exclusive of 12/9, 6/24 events			
Change in pollutant concentration	↓ 29%	↓ 43%	↓ 20%
Test statistic, t_{paired}	1.928	4.301	1.567
Tabular t-value, $t_{(0.10, 9)}$	1.383	1.383	1.383
Test conclusion	Reject H_0.	Reject H_0.	Reject H_0.
Interpretation	True concentration difference.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.38	0.74	0.66

Table 4-14. Summary of statistical analyses for biochemical oxygen demand (BOD).

4.5.3.2 Total Organic Carbon (TOC).

The total organic carbon (TOC) test measures, as the name implies, the amount of organically bound carbon in a solution. Unlike BOD, TOC does not measure other organically bound elements, such as nitrogen and hydrogen, and inorganic material that can contribute to oxygen demand (Eaton et al. 1995). TOC is analyzed by breaking down the organic molecules, using heat and oxygen, ultraviolet irradiation, chemical oxidants, or combinations of these, and converting the carbon to CO_2, a form that can be quantitatively measured. Table 4-15 provides the influent and effluent chemical analysis results and sample mean concentrations for TOC.

As is the case for BOD, the exclusion of both the December 9 and the June 24 storm events most likely give the most accurate appraisal of how the filters remove organic carbon from stormwater runoff. The problems of the December 9 storm event have been discussed previously. The TOC concentrations for the June 24 storm are extremely high in all three stormwater samples, over five times higher for this single storm event than the average values of the remaining storm data. Whereas the BOD concentrations were high only in the effluent streams, the TOC is also high for the influent sample, indicating the presence of organic material passing completely through the filter. It is unusual, however, that there was no increase in the BOD influent concentration for this event. In a general sense, the BOD is expected to increase if there is an increase in TOC, although the reverse is not necessarily true. The high TOC level could be due to decaying leaves and other organic material that were present in the parking area. Because the TOC concentrations for this storm are far removed from the other readings, the analysis will be conducted both with and without the data for this event.

Total Organic Carbon (TOC, mg/L) **Date**	**Influent**	**Sand Effluent**	**CSF Effluent**
Dec 9, '95	1.98	1.26	2.74
Feb 21, '96	1.64	2.72	1.90
Mar 6, '96	7.80	4.70	4.50
Mar 19, '96	5.09	3.26	1.60
Mar 28, '96	7.09	5.36	2.95
Apr 24, '96	5.06	7.89	2.38
May 16, '96	4.05	5.99	6.11
Jun 24, '96	30.08	40.98	41.71
Jul 3, '96	10.26	16.08	7.18
Jul 15, '96	6.58	3.20	7.05
Jul 18, '96	6.91	4.21	10.07
Jul 25, '96	10.22	6.68	8.48
Mean #1	8.0633	8.5275	8.0558
Mean #2 (w/out 12/9, 6/24)	6.4700	6.0090	5.2220

Table 4-15. Sample mean data for total organic carbon (TOC).

The exclusion of the June 24 storm dramatically decreases the TOC concentrations for the influent and both effluents. This illustrates how greatly this particular storm skews the mean concentrations. The reduction in TOC is greater for the effluent concentrations than for the influent concentration. With all data included, the sand filter effluent realizes a six percent increase in TOC over the influent, and the TOC remains the same from the influent to the CSF effluent. The CSF effluent concentration are six percent lower than that of the sand filter. With the December 9 and June 24 storms excluded, the sand filter effluent concentration is seven percent lower and the CSF effluent concentration 19 percent lower than that of the influent. The TOC concentration for the CSF effluent is 13 percent lower than for the sand filter effluent.

Table 4-16 summarizes the statistical analyses of the TOC data. The t-tests for all three comparisons using the complete data set conclude that the differences in TOC readings between the influent and both effluents and between the sand filter effluent and the CSF effluent may be the result of variability in the sample data. This is partly a result of the June 24 storm data. A large number for one data point can significantly increase the standard deviation for the sample data if the other data points are small. This in turn increases the statistical likelihood that calculated differences between pollutant concentrations at different monitoring stations are due to variability in the data. It is more difficult to make a conclusion about the true filtering capacity of the BMP.

When the December 9 and June 24 storm data are removed, the t-test concludes that there is a true TOC reduction from the influent to the CSF effluent. The differences in TOC between the influent and sand filter effluent and between the sand filter and CSF effluent could still be due to sample data variability. It appears that the unusually high TOC readings for the July 3 storm event increase the standard deviation, thus decreasing the test statistic.

Total Organic Carbon (TOC)

Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
All events included			
Change in pollutant concentration	↑ 6%	0%	↓ 6%
Test statistic, t_{paired}	-0.367	0.006	0.414
Tabular t-value, $t_{(0.10, 11)}$	-1.363	1.363	1.363
Test conclusion	Do not reject H_0.	Do not reject H_0.	Do not reject H_0.
Interpretation	Difference could be variation in data.	Difference could be variation in data.	Difference could be variation in data.
Correlation coefficient, r	0.96	0.96	0.93
Exclusive of 12/9, 6/24 events			
Change in pollutant concentration	↓ 7%	↓ 19%	↓ 13%
Test statistic, t_{paired}	0.456	1.543	0.581
Tabular t-value, $t_{(0.10, 9)}$	1.383	1.383	1.383
Test conclusion	Do not reject H_0.	Reject H_0.	Do not reject H_0.
Interpretation	Difference could be variation in data.	True concentration difference.	Difference could be variation in data.
Correlation coefficient, r	0.58	0.59	0.25

Table 4-16. Summary of statistical analyses for total organic carbon (TOC).

The sample correlation coefficients for each comparison are extremely high when the complete data sets are used. This is because the TOC concentrations have a strong positive relationship, even as those of certain storms stray far from the other readings. Such strong positive relationships discourage the discounting of certain data points because the filtering process is behaving in an expected manner. When the questionable storm data is removed, the correlations remain positive but are not as strong.

The conclusion from these analyses is that both filters probably provide a mild degree of TOC removal but that the CSF does not provide significantly more removal than the sand filter.

4.5.4 Heavy Metals.

The sources of heavy metals and their potential toxic effects have been covered in previous discussion. Budgetary constraints limited the number of metal parameters that could be analyzed for this project. Copper and zinc were chosen to represent the metal group because of their relative abundance in the ultra-urban landscape. Hardness is a measure of lighter metals and would not normally be included in a category of heavy metals, but there is a correlation between hardness concentration and the toxicity of heavy metals in an aquatic environment. Hardness is also a common parameter in analysis of BMP efficiencies, so its inclusion for this project allows the Carbon/Sand Filter to be compared to other BMPs.

Total recoverable copper (Cu), total recoverable zinc (Zn), and hardness are all measured using the same analytical method, the Inductively Coupled Plasma (ICP) method. The samples are digested in acid to reduce interference by organic matter and to convert the metal associated with particulates to a form that can be recognized in ICP spectroscopy (Eaton et al, 1995). Total recoverable copper and total recoverable zinc are digested in a more dilute acid than is used analysis for total copper and total zinc. A controlled plasma is used to superheat the sample until the molecules are completely dissociated and an atomic emission is achieved. The light of this emission consists of many wavelengths, each measurable element having a different wavelength. The amount of energy present at each wavelength is proportional to the concentration of the element being measured.

4.5.4.1 Total Recoverable Copper (Cu).

Table 4-17 provides the influent and effluent chemical analysis results and sample mean concentrations for Cu. The data are very inconsistent in terms of an increase or a decrease in Cu concentration between the influent and either effluent. Considering this inconsistency, none of the data points seems to be an outlier or otherwise unusual. The data is analyzed with and without the December 9 storm because of the known problems during that event. The mean concentration values change very little for each of the three monitored flows.

The Cu concentration is seven percent lower for the sand filter effluent and 23 percent lower for the CSF than the influent when all storms are considered. The effluent concentration is 17 percent lower for the CSF than for the sand filter. When the December 9 storm is excluded, the Cu concentration is 12 percent lower for the sand filter effluent and 24 percent lower for the CSF than the influent. The effluent concentration is 13 percent lower for the CSF than for the sand filter. The apparent removal rates do not change much when excluding the December 9 event.

The t-tests reflect the steadiness in the mean Cu concentrations as the December 9 storm is excluded. The test indicates that the difference in Cu concentration between the influent and each of the effluents might be the result of variation in the sample data, although the test statistic t_{paired} is almost

Total Recoverable Copper (Cu, µg/L) Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	13	29	13
Feb 21, '96	20	21	21
Mar 6, '96	25	22	25
Mar 19, '96	68	21	16
Mar 28, '96	18	30	11
Apr 24, '96	39	36	46
May 16, '96	8	15	11
Jun 24, '96	36	37	30
Jul 3, '96	32	58	54
Jul 15, '96	23	7	5
Jul 18, '96	18	13	11
Jul 25, '96	28	16	9
Mean #1	27.3	25.4	21.0
Mean #2 (w/out 12/9)	28.6	25.1	21.7

Table 4-17. Sample mean data for total recoverable copper (Cu).

Total Recoverable Copper (Cu) Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
All events included			
Change in pollutant concentration	↓ 7%	↓ 23%	↓ 17%
Test statistic, t_{paired}	0.667	1.326	1.510
Tabular t-value, $t_{(0.10, 11)}$	1.363	1.363	1.363
Test conclusion	Do not reject H_0.	Do not reject H_0.	Reject H_0.
Interpretation	Difference could be variation in data.	Difference could be variation in data.	True concentration difference.
Correlation coefficient, r	0.22	0.33	0.87
Exclusive of 12/9 event			
Change in pollutant concentration	↓ 7%	↓ 19%	↓ 13%
Test statistic, t_{paired}	0.456	1.543	0.581
Tabular t-value, $t_{(0.10, 10)}$	1.372	1.372	1.372
Test conclusion	Do not reject H_0.	Do not reject H_0.	Reject H_0.
Interpretation	Difference could be variation in data.	Difference could be variation in data.	True concentration difference.
Correlation coefficient, r	0.26	0.30	0.89

Table 4-18. Summary of statistical analyses for total recoverable copper (Cu).

large enough in the influent to CSF effluent comparison to reject the null hypothesis and conclude a true Cu removal for the CSF. The concentrations for the CSF effluent, however, are significantly lower than those for the sand filter. In both sets of storm data the sample correlation coefficients show a weak positive relationship between the influent Cu concentration and each effluent Cu concentration. The positive relationship is very strong between the sand filter effluent data and the CSF effluent data. The statistical analysis results are summarized in Table 4-18.

The statistical analyses together suggest that there is likely a true Cu removal benefit for both the sand filter and the CSF and that the CSF gives a greater Cu removal benefit than the sand filter.

4.5.4.2 Total Recoverable Zinc (Zn).

Table 4-19 provides the influent and effluent chemical analysis results and sample mean concentrations for Zn. The data show an increase in Zn between the influent and each effluent for eleven of the twelve storm events. The data also shows no indication of the process flaws known to have occurred during the December 9 event. When the data for this storm are removed, the mean Zn concentrations increase for all three monitored flows.

Total Recoverable Zinc (Zn, μg/L) **Date**	**Influent**	**Sand Effluent**	**CSF Effluent**
Dec 9, '95	41	78	112
Feb 21, '96	32	59	64
Mar 6, '96	35	79	63
Mar 19, '96	96	158	116
Mar 28, '96	41	193	132
Apr 24, '96	69	32	45
May 16, '96	59	84	86
Jun 24, '96	90	272	220
Jul 3, '96	65	366	362
Jul 15, '96	77	110	112
Jul 18, '96	73	128	122
Jul 25, '96	115	179	147
Mean #1	66.1	144.8	131.8
Mean #2 (w/out 12/9)	68.4	150.9	133.5

Table 4-19. Sample mean data for total recoverable zinc (Zn).

A cursory review of the chemical analysis data clearly shows that there is zinc export from both filters. Because only one of the filter chambers uses activated carbon as a filtering medium, the carbon is not the sole source of the zinc in the effluent. Both filter chambers use sand as a filtering medium and have coarse aggregate stone as a bedding to support the underdrain system. Either of these materials could be a source of zinc. It would be expected that the zinc content would decrease over time as stormwater flows flush out the zinc. The data for the eight-month monitoring period show an increase in

Zn concentrations in the effluents, however. Further monitoring would be needed to affirm the assumption that the zinc comes from one or both of these materials in the filter chambers.

As summarized in Table 4-20, there is a 119 percent increase in Zn concentration for the sand filter effluent and a 99 percent increase for the CSF effluent over the influent. The concentration for the sand filter effluent is nine percent higher than for the CSF effluent, but in a relative sense this difference is meaningless. When the December 9 storm is excluded, there is a 121 percent increase in Zn concentration for the sand filter effluent and a 95 percent increase for the CSF effluent over the influent. The concentration for the sand filter effluent is 12 percent higher than for the CSF effluent.

The t-tests for all comparisons and scenarios conclude, as expected from looking at the raw data, that there is a true difference in Zn concentration. The effluent Zn concentrations are significantly higher than the influent concentration, and the sand filter effluent concentration is significantly higher than that of the CSF, a useless comparison given that both effluents are so dramatically higher in zinc than the influent.

Total Recoverable Zinc (Zn)

Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
All events included			
Change in pollutant concentration	↑ 119%	↑ 99%	↓ 9%
Test statistic, t_{paired}	-3.153	-2.737	2.124
Tabular t-value, $t_{(0.10, 11)}$	-1.363	-1.363	1.363
Test conclusion	Reject H_0.	Reject H_0.	Reject H_0.
Interpretation	True concentration difference.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.36	0.28	0.96
Exclusive of 12/9 event			
Change in pollutant concentration	↑ 121%	↑ 95%	↓ 12%
Test statistic, t_{paired}	-2.909	-2.499	2.275
Tabular t-value, $t_{(0.10, 10)}$	-1.372	-1.372	1.372
Test conclusion	Reject H_0.	Reject H_0.	Reject H_0.
Interpretation	True concentration difference.	True concentration difference.	True concentration difference.
Correlation coefficient, r	0.31	0.27	0.97

Table 4-20. Summary of statistical analyses for total recoverable zinc (Zn).

The sample correlation coefficients show weak positive relationships between the influent and effluent data. If the source of the zinc were in fact the sand or the stone in the filter chambers, there would not necessarily be a positive relationship between the influent data and the effluent data. There would be zinc export regardless of the influent Zn concentration. If it can be assumed that the amount of zinc export from the filter materials is reasonably constant over all of the storm events, the fluctuation in the influent Zn concentration might have a limited effect on the effluent concentration. This would account for the weak positive relationship. The correlation between the sand filter effluent data and the CSF effluent data is very strongly positive, indicating that their behavior is consistently similar for export of zinc.

4.5.4.3 Hardness.

Hardness is not a measure of heavy metals, but the hardness of a solution does affect the toxicity of heavy metals that are present in the solution to the aquatic environment. Technically, it is the sum of all polyvalent cations in a solution. Practically, it is a measure of the calcium and magnesium content of the water. It is measured using the ICP method to determine the calcium and magnesium content and then calculating the hardness as $CaCO_3$. Calcium and magnesium are considered to be lighter metals.

Water can be described as soft, moderately hard, hard, or extremely hard. Water with less than 75 mg/liter of is considered to be soft (Davis and Cornwell, 1991). To achieve the desired hardness concentration in drinking water of 75-120 mg/liter, a softening process, such as a lime-soda or an ion exchange process, can be used.

Hardness itself does not have a toxic effect on the aquatic environment, but it does affect the toxicity of other contaminants. Hardness has an antagonistic effect on the toxicity of heavy metals. As the concentration of $CaCO_3$ increases, aquatic species are less sensitive to the heavy metal in the water (Krenkel and Novotny, 1980).

Hardness
(as $CaCO_3$, mg/L)

Date	Influent	Sand Effluent	CSF Effluent
Dec 9, '95	2.00	29.0	14.0
Feb 21, '96	1.49	1.87	6.01
Mar 6, '96	2.25	14.5	8.59
Mar 19, '96	6.89	11.3	17.8
Mar 28, '96	2.11	11.5	19.2
Apr 24, '96	2.70	32.8	26.5
May 16, '96	1.71	34.8	35.9
Jun 24, '96	4.62	17.4	21.3
Jul 3, '96	7.36	22.4	20.5
Jul 15, '96	4.58	9.14	10.0
Jul 18, '96	5.68	11.1	14.4
Jul 25, '96	4.14	17.6	23.7
Mean #1	3.794	17.784	18.158
Mean #2 (w/out 12/9)	3.957	16.765	18.536

Table 4-21. Sample mean data for hardness (as $CaCO_3$), with data reported at three significant figures.

Table 4-21 provides the influent and effluent chemical analysis results and sample mean concentrations for hardness. Similar to the results for Zn, there is a dramatic increase in hardness between the influent and each effluent for every storm event. The data also shows no indication of the process flaws known to have occurred during the December 9 event. When the data for this storm are removed, the mean hardness concentrations increase slightly for the influent and the CSF effluent and decrease slightly for the sand filter effluent.

As is the case with Zn, the data clearly show that there is export of calcium and magnesium from both filters. The source of export for these elements is probably either the sand or the coarse aggregate stone. As discussed for zinc, it would be expected that the calcium and magnesium content would decrease over time as stormwater flows flush them out. The data support this theory somewhat for hardness, with the concentration peaking in the middle of the monitoring period and subsequently decreasing.

As summarized in Table 4-22, there is a 369 percent increase in hardness concentration for the sand filter effluent and a 379 percent increase for the CSF effluent over the influent. The concentration for the sand filter effluent is two percent lower than for the CSF effluent, but in a relative sense this difference is meaningless as it was for Zn. When the December 9 storm is excluded, there is a 324 percent increase in hardness concentration for the sand filter effluent and a 368 percent increase for the CSF effluent over the influent. The concentration for the sand filter effluent is 11 percent lower than for the CSF effluent.

Hardness (as $CaCO_3$)

Statistic	Influent: Sand Effluent	Influent: CSF Effluent	Sand Effluent: CSF Effluent
All events included			
Change in pollutant concentration	↑ 369%	↑ 379%	↑ 2%
Test statistic, t_{paired}	-4.528	-5.784	-0.195
Tabular t-value, $t_{(0.10, 11)}$	-1.363	-1.363	1.363
Test conclusion	Reject H_0.	Reject H_0.	Do not reject H_0.
Interpretation	True concentration difference.	True concentration difference.	Difference could be variation in data.
Correlation coefficient, r	-0.19	0.00	0.76
Exclusive of 12/9 event			
Change in pollutant concentration	↑ 324%	↑ 368%	↑ 11%
Test statistic, t_{paired}	-4.096	-5.379	-1.232
Tabular t-value, $t_{(0.10, 10)}$	-1.372	-1.372	-1.372
Test conclusion	Reject H_0.	Reject H_0.	Do not reject H_0.
Interpretation	True concentration difference.	True concentration difference.	Difference could be variation in data.
Correlation coefficient, r	-0.10	-0.04	0.88

Table 4-22. Summary of statistical analyses for hardness (as $CaCO_3$).

The t-tests strongly conclude, as expected from looking at the raw data, that there is a true difference in hardness concentration between the influent and each effluent. The effluent hardness concentrations are significantly higher than the influent concentration. The difference between the sand filter effluent concentration and that of the CSF may be due to variation in the sample data. The test results are the same regardless of whether the December 9 storm event is included in the data set.

The sample correlation coefficients show weak negative relationships or zero relationship between the influent and effluent data. This is due to the high variation of the effluent data with respect to the influent data, which have little relative variation because the concentration values are low compared to the effluent. It can be concluded from these coefficients that because the export of hardness is so great, the influent concentrations have no real effect on what leaves the filter chambers. The correlation between the sand filter effluent data and the CSF effluent data is strongly positive, indicating that their behavior is consistently similar for export of calcium and magnesium.

4.5.5 Hydrocarbons.

Hydrocarbons and their toxic effects to the aquatic environment were discussed in Section 2.2.2 Hydrocarbons. The chemical analysis commonly used to measure hydrocarbons is the total petroleum hydrocarbons (TPH) test. Because the HRSD laboratory does not perform this test, measurements were determined for individual organic constituents. The volatile organic compounds, benzene, toluene, ethylbenzene, and xylene, usually measured together in a test known as BTEX, and the polynuclear aromatic hydrocarbon, naphthalene were all measured using the purge and trap gas chromotographic/mass spectrometric (GC/MS) method.

In the GC/MS method, the sample is purged by bubbling an inert gas through the sample to vaporize the organic constituents, and the organics are collected on a sorbent trap (Eaton et al, 1995). The compounds are then desorbed, using the same inert gas, onto the gas chromotograph, which separates the compounds into stationary and mobile phases. The mass spectrometer ionizes the molecules into charged species to detect the compounds. BTEX and naphthaline concentrations are determined all in one test.

The concentrations for BTEX and naphthaline were below detection limits in nearly all samples. A toluene reading was registered for the June 24 storm event, but HRSD staff noted that the quality control blank was also measurable for this contaminant. It is concluded that an error occurred in the chemical analysis.

That the concentrations for these organic constituents were consistently below detection limits is surprising. It seems to refute the theory that the ultra-urban environment is a hotspot for hydrocarbons. Of course, the analyses are of stormwater runoff from but one parking lot in the downtown area. Although it is expected that the parking lot would be a source for hydrocarbons, it is possible that the lot is an unusually clean one. Perhaps the concentration of organic compounds would be higher in runoff from the adjacent roadway.

4.6 Discussion of Results.

Both the sand filter and the Carbon/Sand Filter provided pollutant removal for seven of the nine chemical parameters that had detectable concentrations in the samples. Of these seven parameters, the

CSF provided a higher pollutant removal than the sand filter for six, with varying degrees of confidence. Table 4-23 summarizes the results of the pollutant removal analysis.

	Sand Filter			Carbon/Sand Filter				
Pollutant Parameter (1)	Low Analytical Value (2)	High Analytical Value (3)	Confidence (4)	Low Analytical Value (5)	High Analytical Value (6)	Confidence (7)	Higher Pollutant Removal Efficiency (8)	Confidence (9)
TSS	23%	69%	Medium	-4%	60%	Medium	Sand Filter	Medium
TP	9%	21%	Medium	29%	41%	High	CSF	High
TKN	1%	17%	Low	13%	30%	Medium	CSF	High
NH_3	---	14%	Low	---	20%	High	CSF	Low
BOD_5	---	29%	High	---	43%	High	CSF	High
TOC	-6%	7%	Low	0%	19%	Medium	CSF	Low
Cu	7%	7%	Low	19%	23%	Low	CSF	High
Zn	-121%	-119%	High	-99%	-95%	High	Neither	---
Hardness	-369%	-324%	High	-379%	-368%	High	Neither	---

Table 4-23. Summary of pollutant removal efficiencies for the sand filter and the Carbon/Sand Filter.

For each filter type, Table 4-23 gives the high and low mean concentration difference (columns two and three and columns five and six, corresponding to data sets with different storms included. The confidence is given for each pair (low/high) of removal efficiencies (columns four and seven). A low confidence indicates that the t-tests for both the low and the high values concluded that the difference in sample means may be due to variation in the data. A medium confidence indicates that one of the t-tests made this conclusion, and a high confidence reflects a true concentration difference for both the low and high values. Column eight shows which filter had better pollutant removal results, and column nine indicates the degree of confidence that one filter truly outperforms the other. That confidence relates to the t-test results for the difference between the two effluent concentrations. Note that for zinc and hardness, neither filter is considered superior because they both export these contaminants.

Table 4-24 compares the pollutant removal efficiencies of the sand filter and the CSF to those of other BMPs. The comparison is only for those pollutants that are commonly reported in BMP effectiveness studies. The other BMPs listed are those that conceivably could be used in the ultra-urban landscape. The information for these other BMPs is derived from the "Urban Watershed Management: A Workshop for Innovative Urban Watershed Restoration and Protection" document, published by the Center for Watershed Protection. This agency is a source for the most current information on many kinds of BMPs, drawing information frequently from newly published studies.

The pollutant removal data for the Carbon/Sand Filter does not compare favorably to the reported values for other BMPs. Curiously, though, the pollutant removal efficiency for the sand filter tested in this study is much lower than the value reported for sand filters in the Center for Watershed Protection document. Because the design of the sand filter studied here is the same one used in other regions, perhaps there is a regional effect on how pollutants are transported and filtered. Because of the inherent difficulty in comparing BMPs tested under different weather conditions, the more meaningful comparison is that of the two filters tested for this project. The percentage difference in pollutant removal between this sand filter and the Carbon/Sand Filter can be applied to reported values for sand filters in other areas to see how a Carbon/Sand Filter would perform there.

BMP Pollutant Removals **BMP Type**	**Total Suspended Solids**	**Total Phosphorus**	**Total Nitrogen**
Carbon/Sand Filter	(-4) - 60	29-41	13-30
Sand Filter	23-69	9-21	1-17
Dry Extended Detention Pond	30	10	10
Dry Well	90	60	50
Conventional Infiltration Trench	90	60	50
Porous Pavement	90	60	80
Sand Filter (others)	85	50	35
Peat Sand and Compost Filters	90	40-70	20-50
Biofilters	80	45	25

Table 4-24. Comparison of pollutant removal efficiencies for different BMPs.

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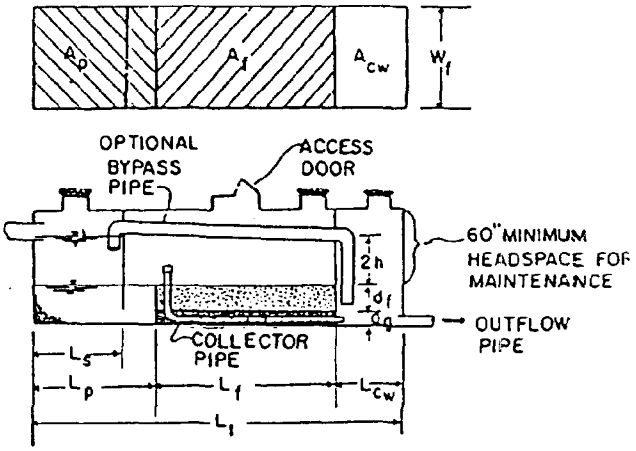
Appendix A-1

BMP Sizing Calculations

11/28/94

ALEXANDRIA, VIRGINIA
ULTRA-URBAN BMP COMPUTATIONS

WORKSHEET H1: COMPUTATIONS FOR D. C. SAND FILTER (ORIGINAL SINGLE POOL CONFIGURATION)



Part 4: Considering data on Worksheet E, select maximum ponding depth over filter:

$2h =$ 1.50 ft;

$h = \boxed{0.75}$ ft

From WORKSHEET E;

$I_a = \boxed{0.337}$ acres

$WQV = \boxed{612.4}$ ft^3

Outflow by gravity possible X

Effluent pump required ____

Part 5: Compute Minimum Area of Filter (A_{fm}):

$$A_{fm} = \frac{545 I_a d_f}{(d_f + h)}$$

$= [545 \times$ 0.337 $\times$ 2.0 $] / [$ 2.0 $+$ 0.75 $]$

$= \boxed{133.6}$ ft^2

Part 6: Considering Site Constraints, Select Filter Width (W_f) and Compute Filter Length (L_f) and Adjusted Filter Area (A_f):

$W_f = \boxed{10}$ ft;

$L_f = A_{fm} / W_f$

$=$ 133.6 / 10

$=$ 13.4, say $\boxed{14}$ ft

$A_f = W_f \times L_f =$ 10 $\times$ 14

$= \boxed{140}$ ft^2

Part 7: Compute the Storage Volume on Top of the Filter (V_{Tf})

$V_{Tf} = A_f \times 2h =$ 140 x 1.50

= $\boxed{210}$ ft^3

Part 8: Compute Storage in Filter Voids (V_v):

(Assume 40% voids in filter media)

$V_v = 0.4 \times A_f \times (d_f + d_g)$

= 0.4 x 140 x (2.0 + 0.5)

= $\boxed{140}$ ft^3

Part 9: Compute Flow Through Filter During Filling Period (V_Q):

(Assume 1-hour to fill per D.C. practice)

$V_Q = \frac{kA_f(d_f + h)}{d_f}$; use k = 2 ft/day = 0.0833 ft/hr

= $\overset{0.3333}{\cancel{[0.0833}}$ x 140 x (2.0 + 0.75)]/ 2.0

= $\boxed{64.2}$ ft^3

Part 10: Compute Net Volume to be Stored Awaiting Filtration (V_{st}):

$V_{st} = WQV - V_{Tf} - V_v - V_Q$

= 612.4 - 210 - 140 - 64.2

= $\boxed{198}$ ft^3

Part 11: Compute Minimum Length of Permanent Pool (L_{pm}):

$L_{pm} = \frac{V_{st}}{(2h \times W_f)}$ = 198 / (1.5 x 10)

= $\boxed{13.2}$ ft

Part 12: Compute Minimum Length of Sediment Chamber (L_{sm}) (to contain at least 20% of WQV per Austin practice)

$$L_{sm} = \frac{0.2WQV}{(2h \times W_f)} = \underline{0.2(612.4)} \; / \; \underline{(1.50)(10)}$$

$$= \boxed{8.2} \text{ ft}$$

Part 13: Set Final Length of Permanent Pool (L_p)

L_{sm} + 2ft = $\underline{8.2}$ + 2 = $\boxed{10.2}$ ft

If $L_{pm} \geq L_{sm}$ + 2ft, Make $L_p = L_{pm}$ = $\boxed{13.2}$ ft

If $L_{pm} < L_{sm}$ + 2ft, make $L_p = L_{sm}$ + 2ft = $\boxed{}$ ft

Part 14: Set Length of Clearwell (L_{cw}) for Adequate Maintenance Access (Minimum = 3 ft) and Compute Final Inside Length (L_{ti}):

L_{cw} = $\boxed{3}$ ft ;

Sum of ~~interior~~ partition thicknesses (t_{pi}) = $\boxed{5}$ ft

$$L_{ti} = L_f + L_p + L_{cw} + t_{pi}$$

$$= \underline{14} + \underline{13} + \underline{3} + \underline{5}$$

$$= \boxed{35} \text{ ft}$$

Part 15: Design Structural Shell to Accommodate Soil and Load Conditions at Site:

It may be economical to adjust final dimensions upward to correspond with standard precast structures or to round dimensions upward to simplify layout during construction.

Part 16: Design Effluent Pump if Required:

Since pump must be capable of handling flow when filter is new, use k = 20 feet/day = 0.833 ft/hr

$$Q = \frac{kA_f(d_f + h)}{d_f}$$

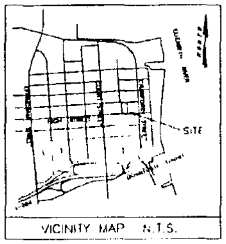
$$= [0.833 \times \underline{} \times (\underline{} + \underline{})]/\underline{}$$

$$= \boxed{} \text{ ft}^3\text{/hr} \; ; \; /3600 = \boxed{} \text{ cfs;}$$

$$\times 448.8 = \boxed{} \text{ gpm}$$

Appendix A-2

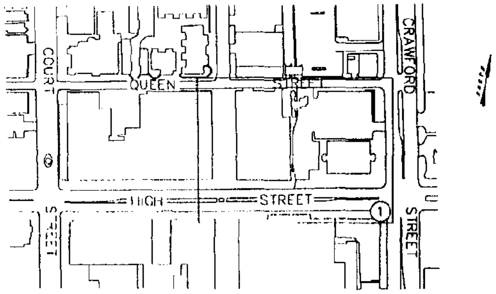
Construction Plans

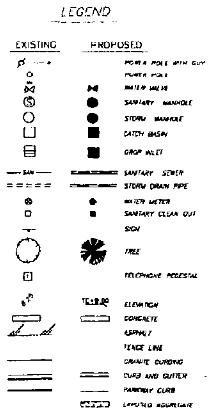


CITY OF PORTSMOUTH
ENGINEERING AND TECHNICAL SERVICES DEPARTMENT
PORTSMOUTH, VIRGINIA

PLAN AND PROFILE OF
STORMWATER MANAGEMENT BMP

PORTSMOUTH CARBON/SAND FILTER





INDEX OF SHEETS	
1	PLAN SHEET
S-1	STRUCTURAL & PROFILE SHEET
3	DETAIL SHEET

APPROVED : ______________________ ____________ ______________________ ____________

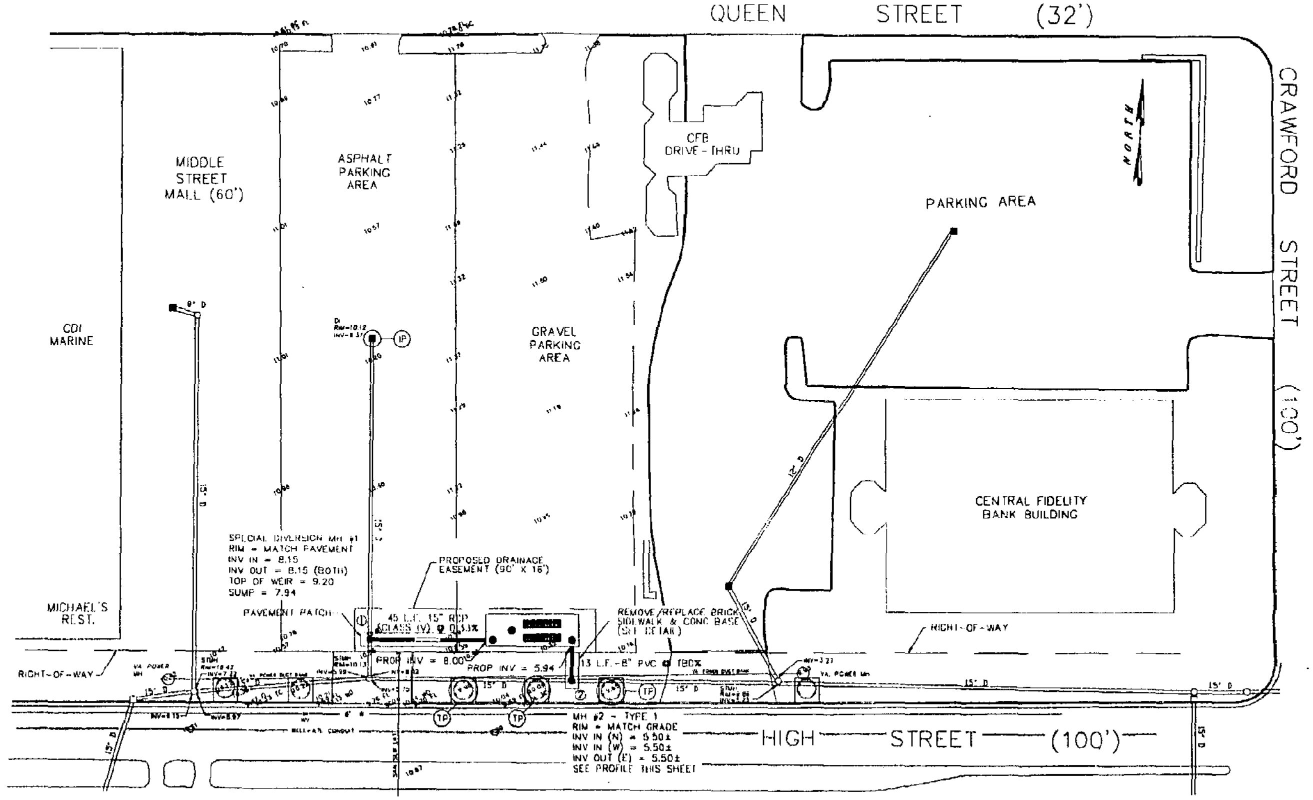
V. WAYNE ORTON
CITY MANAGER, CITY OF PORTSMOUTH

DATE

RICHARD A. HARTMAN, P.E.
CITY ENGINEER, CITY OF PORTSMOUTH

DATE

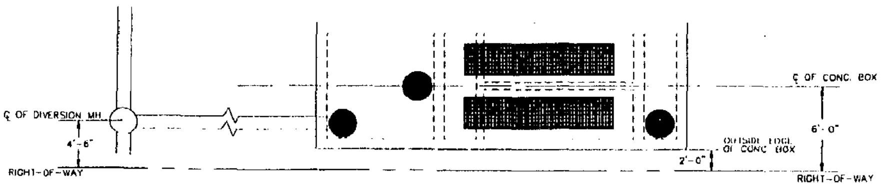
REV	REVISIONS DESCRIPTION	DATE	APPROVED



DRAWINGS NOT TO SCALE

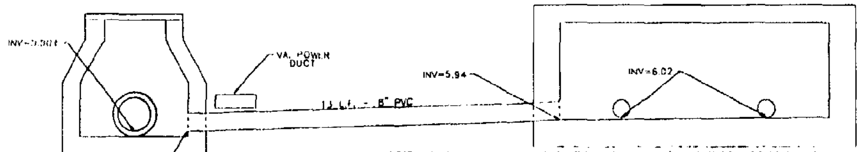
NOTES.

1. ALL BRICK & CONCRETE SIDEWALK TO BE REMOVED/REPLACED (SEE DETAIL) FOR STORM DRAINAGE TRENCH AND MANHOLE #2.
2. ANY EXPOSED CONCRETE TO BE REMOVED SHALL BE SAWCUT FOR REMOVAL.
3. CONTRACTOR RESPONSIBLE FOR REPLACING ANY DAMAGED CONCRETE OR BRICK OUTSIDE TRENCH.
4. SIDEWALK TO BE SWEPT WITH FINE SAND AFTER REPLACEMENT OF BRICK.
5. DO NOT DISTURB VIRGINIA POWER DUCT LINE.
6. SIDEWALK TO BE SWEPT WITH FINE SAND AFTER REPLACEMENT OF BRICK.
7. ALL BACKFILL SURROUNDING CONCRETE STRUCTURE AND FOR PIPE TRENCHING IN THE GRAVEL PARKING LOT SHALL BE SELECT FILL TOPPED WITH 6" OF CRUSHER RUN (MINIMUM) UP TO EXISTING GRADE
8. REMOVE & REPLACE ALL PARKING LOT POSTS AND PARKING SIGNS.
9. PROTECT ALL TREES ON HIGH STREET.
10. SIDEWALK, GUTTER, MANHOLES, AND STORM DRAIN TO BE CLEARED OF ANY SILT, SAND, OR DEBRIS UPON COMPLETION OF CONSTRUCTION.
11. 8" PERFORATED PVC PIPE TO BE PLACED IN EACH FILTRATION CHAMBER (SEE DETAIL, SHEET 3).



POSITIONING OF CONCRETE BOX & DIVERSION MANHOLE

SCALE: 1" = 5'



NOTE: THIS PROFILE IS BASED ON THE BEST INFORMATION AVAILABLE AS TO THE DEPTH OF THE VIRGINIA POWER DUCT. THE EXACT LOCATION AND DEPTH OF THE VIRGINIA POWER DUCT WILL BE DETERMINED BY THE CONTRACTOR IN THE FIELD. THIS INFORMATION WILL DETERMINE THE DEPTH OF THE MANHOLE AND THE INVERT AND GRADE OF THE PVC PIPE.

PROFILE OF EFFLUENT 8" PVC PIPE

SEE SECTION 2, SHEET S-1 SCALE: 1" = 2'

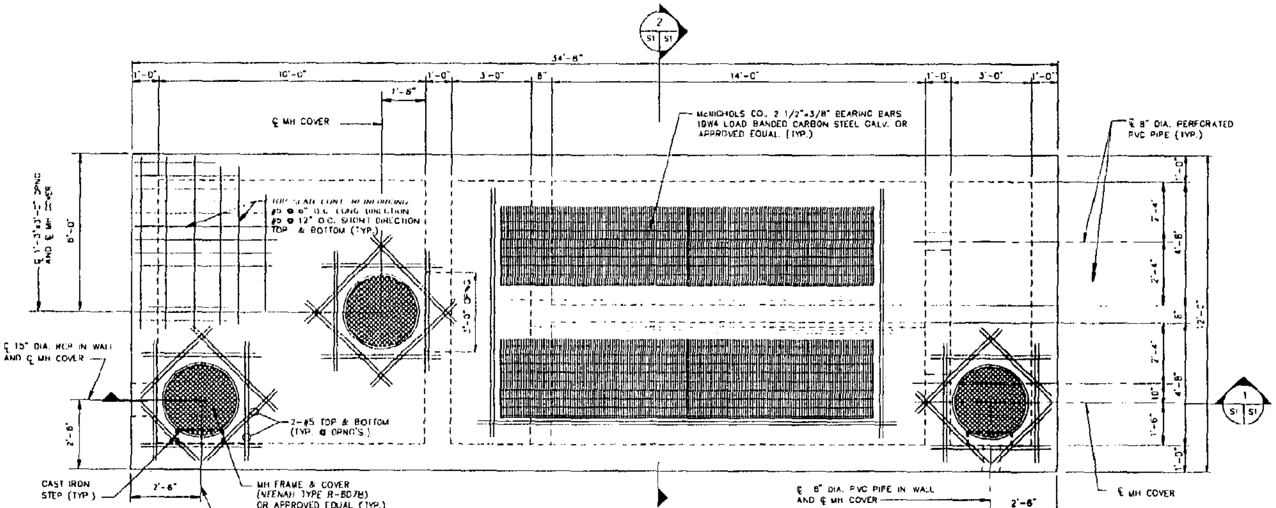
PROJECT	FILE	SHEET NO
CARBON/SAND FILTER	CARBPLAN.DWG	1

PLAN

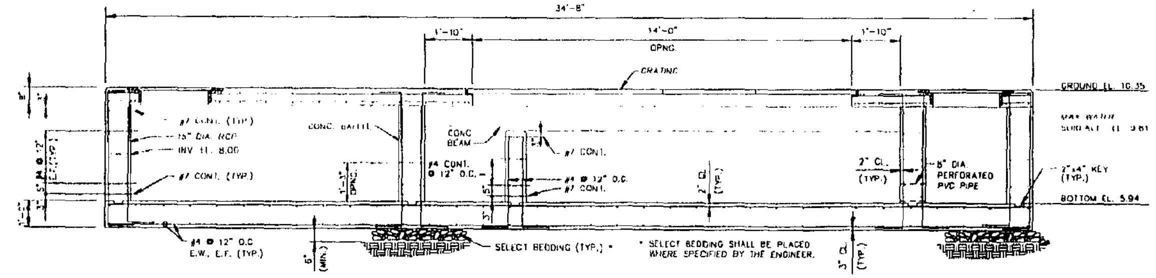
SURVEYED
PLOTTED
ALIGNMENT CHECKED
R/W CHECKED

CHECKED BY: R.A.H.

DESIGNED BY: J.S.K.



PLAN
SCALE: 1/2" = 1'-0"

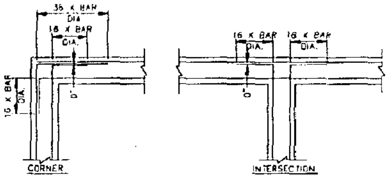


* SELECT BEDDING SHALL BE PLACED WHERE SPECIFIED BY THE ENGINEER.

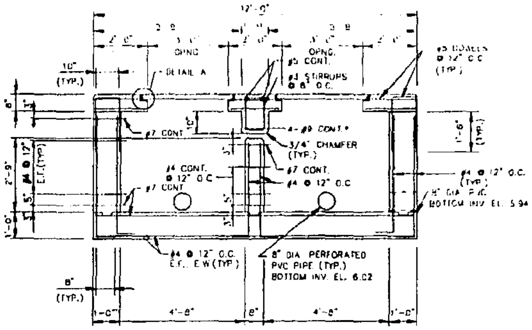
SECTION 1 S1 S1
SCALE: 1/2" = 1'-0"

GENERAL STRUCTURAL NOTES:

1. THE CONTRACTOR SHALL VERIFY THE REQUIREMENTS OF OTHER TRADES AS TO SLEEVES, CHASES, HANGERS, INSERTS, ANCHORS, HOLES, ETC. TO BE PLACED OR SET IN STRUCTURAL WORK.
2. DESIGN LIVE LOAD USED IN THE DESIGN OF THE TOP SLAB : AASHTO H15-44 TRUCK LOAD
3. PRIOR TO PLACING CONCRETE, FOUNDATION EXCAVATION SHALL BE INSPECTED BY THE ENGINEER TO EXPLORE THE EXTENT OF ANY LOOSE SOFT OR OTHERWISE UNDERSIRABLE MATERIAL SELECT BEDDING SHALL BE PLACED WHERE SPECIFIED BY THE ENGINEER
4. STRUCTURE IS DESIGNED IN ACCORDANCE WITH THE REPORTS AND SPECIFICATIONS OF THE "BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE" (ACI 318-89) AND "ENVIRONMENTAL ENGINEERING CONCRETE STRUCTURES" (ACI 350R-89).
5. ALL CONCRETE SHALL OBTAIN A 28 DAY COMPRESSIVE STRENGTH OF 5,000 PSI AND BE AIR ENTRAINED
6. REINFORCING STEEL SHALL CONFORM TO ASTM A-615 GRADE 60 (MINIMUM YIELD 60,000PSI)
7. ALL STRUCTURAL STEEL SHALL CONFORM TO ASTM A36
8. ALL REINFORCING MARKED CONTINUOUS (CONT.) ON THE PLANS AND DETAILS SHALL BE LAPPED 36x BAR DIAMETER AT SPLICES UNLESS OTHERWISE NOTED.
9. GENERAL DETAILS OF FABRICATION AND PLACING OF REINFORCING AND CONCRETE COVER FOR REINFORCING SHALL BE IN ACCORDANCE WITH ACI 318-89 AND ACI 350R-89 MINIMUM CONCRETE COVER FOR REINFORCING STEEL AS INDICATED ON THE DRAWINGS SHALL GOVERN WHEN IN CONFLICT WITH ACI 318-89 OR ACI 350R-89 SLOPE BASE SLAB CONCRETE TO DRAIN
10. ALL REINFORCING SHALL BE HELD SECURELY IN PLACE DURING POURING OPERATIONS TO PREVENT DISLOCATION. BAR SUPPORTS AND HOLDING BARS SHALL BE PROVIDED BY THE FABRICATOR FOR ALL REINFORCING STEEL TO INSURE MINIMUM CONCRETE PROTECTION (INDICATE SUCH ON REINFORCING SHOP DRAWINGS). BAR SUPPORTS SHALL BE PLASTIC TIPPED OR STAINLESS STEEL
11. ALL STEEL SHALL BE FABRICATED BEFORE GALVANIZING AND CONFORM TO ASTM A153.
12. NOTATIONS: E.W. = EACH WAY
    E.F. = EACH FACE

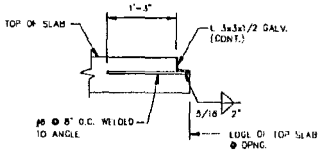


TYPICAL DETAILS SHOWING CONTINUOUS REINFORCING AT CORNERS & INTERSECTIONS
NOT TO SCALE



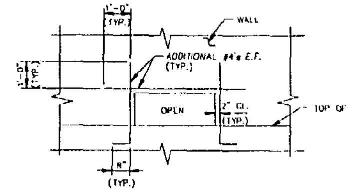
SECTION 2 S1 S1
SCALE: 1/2" = 1'-0"

* USE STD. 90° HOOKS FOR 2-#9 IN DEVELOPING BARS AT ENDS OF BEAM

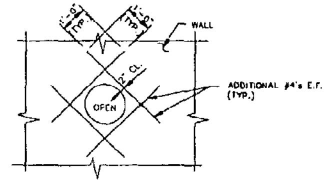


(GRATE & SLAB REINF. NOT SHOWN)

DETAIL A
GRATE SUPPORT FRAME
SCALE: 1" = 1'-0"

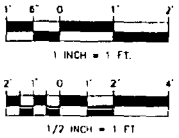


DETAIL FOR 3'-0"x1'-3" WALL OPNG.
SCALE: 1/2" = 1'-0"



TYPICAL REINFORCING DETAIL FOR WALL OPENINGS
NO SCALE

GRAPHIC SCALES



	BY	DATE
DESIGNED	SFT	1/95
DRAWN	PH	1/95
CHECKED	PBM	1/95

NO	DATE	REVISION

CITY OF PORTSMOUTH
ENGINEERING AND TECHNICAL
SERVICES DEPARTMENT

FILTER BOX
PLAN AND SECTIONS

URS CONSULTANTS
[illegible] VIRGINIA BEACH BLVD.
VIRGINIA BEACH, VIRGINIA 23462

SHEET NO. S 1

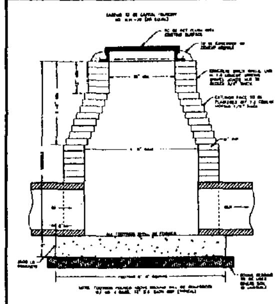
PLAN
FIELDBOOK
NO.
SURVEYED
PLOTTED
ALIGNMENT CHECKED
R/W CHECKED

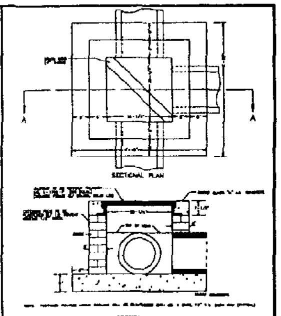
CHECKED BY: R.A.H.
DESIGNED BY: J.S.K.

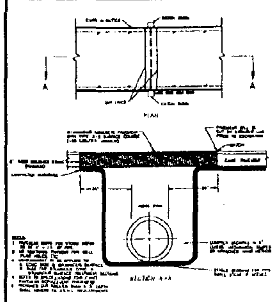
REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

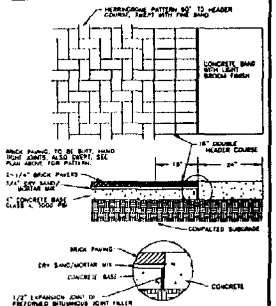
GENERAL NOTES

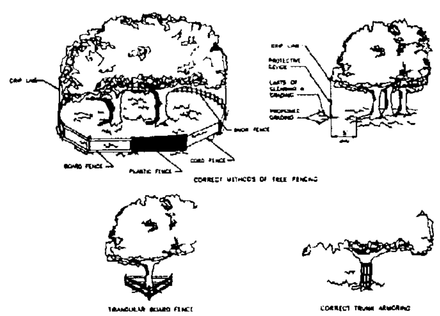
1. All materials and construction methods shall conform to the the City of Portsmouth Department of Engineering and Public Utilities, and any other applicable city ordinance or code.
2. *The Contractor is responsible for locating all public or* private utilities which lie in the construction area prior to any excavation or construction. The Contractor shall be responsible for repairing at his expense all existing utilities damaged during construction.
3. The Contractor shall use only approved material in the backfill of utility trenches.
4. All utility trenches shall be backfilled and compacted to within 0.33' of final subgrade elevation and graded to drain. Excess material shall be removed at the Contractor's expense. All finished slopes in utility easements or in right-of-way not subject to paving shall be topsoiled and seeded in accordance with the City of Portsmouth specifications and shall not exceed the maximum as follows - cut slope 3:1, fill slope 3:1.
5. The Contractor shall provide temporary drainage to relieve areas that may cause damage to the roadways, and erosion protection during construction as directed by the City of Portsmouth and Virginia State Erosion and Sedimentation Control Handbook.
6. All concrete shall be class "A3" air entrained (3,000 psi) unless noted otherwise.
7. All storm sewer pipe shall be as specified on the plan sheets and shall conform to current V.D.H.& T. and City of Portsmouth Standards. All pipe shall be reinforced concrete tongue and grove.
8. Prior to construction or excavation, the contractor shall call "Miss Utility" at 1-800-552-7001. In addition, the contractor shall call the offices of any and all other public or private utilities and request location of utilities that may exist and cross through the construction area, whether or not said utilities are shown on these plans. Utility companies shall be notified 48 hours in advance of any *excavation in the proximity of their utilities.* The contractor is responsible for repairing at his expense any damage caused to utilities during construction.
9. All storm sewer pipes, drop inlets and catch basins shall be cleaned of debris and eroded material at last stage of construction.
10. Straw bales shall be placed around all existing and proposed drainage inlets.
11. *Any defective, faulty, cracked, or broken sidewalks,* driveways, handicapped ramps or curb and gutter, as determined by the Inspector, shall be removed and replaced prior to final acceptance at no additional expense to the City.
12. Any items or instructions which are noted on the plans but are not included in the Bid Price Schedule shall not be paid for separately, but shall be included in other bid items. Frames and covers for sewer manholes and drainage structures shall be by Capitol Foundry, Dewey Brothers, or approvedequal.
14. All curb and sidewalk to be removed shall be taken out to the nearest joint.
15. Relocation of all signs shall be coordinated with the Department of Traffic Engineering.
16. All existing gravel drives shall be regraveled with 2" type 21 or 22 aggregate where disturbed by construction or as directed by the Engineer.
17. All conflicting utilities, (except sanitary sewer) lines and poles will be relocated by others.
18. Contractor shall adjust height of all water valve covers, cleanouts and manholes affected by construction.
19. Contractor shall relocate all mailboxes as required. (Non Pay item)
20. All concrete drives shall be 7" thick minimum. Valley gutter shall be 8" thick.
21. Elevations are based on M.S.L. =0.00 (City of Portsmouth Datum)
22. Proper traffic control devices and or flagmen shall be used at all times. All streets must be open to traffic at the end of each working day.
23. Tree removal will not be a pay item unless indicated.
24. *Disposal of all excess material is the responsibility of the* contractor. (City of Portsmouth's Craney Island Landfill is not available for this project).
25. *Contractor is responsible for coordinating closure of* driveways with individuals property owners and must maintain good access to the houses.
26. Contractor shall protect all trees and shrubs where possible.
27. Fire hydrants and water meters to be relocated (as required) by Public Utilities.
28. Contractor is responsible for final adjustment of all sewer clean-outs. (Final adjustment shall not be pay item).
29. Contractor is responsible for coordination of sewer main and sewer lateral replacements to avoid disruption in service.
30. Contractor is responsible for all required temporary plugging or pumping of sewer lines during construction.
31. All utilities and storm drain lines must be inspected by the Engineering department prior to backfilling.
32. Disposal of excess material within the City of Portsmouth shall require prior approval from the Engineer.
33. *Protection of water supplies shall be in accordance with* Sections 39.A and 39.B of the Virginia State Water Control Board.
34. Ductile iron laterals must be used (in R.O.W.) for ductile iron mains.
35. Prior to construction within any existing public right-of-way the contractor shall obtain a permit from the Engineering Division, City of Portsmouth, Virginia. A copy of the approved traffic control plan is to be submitted with the highway permit application.
36. The contractor shall be responsible for replacing with matching materials any pavement, driveways, walks, curbs etc. that must be cut or that are damaged during construction.
37. *When materials which are unsuitable for foundations,* subgrades, or other roadway purpose occur within the limits of street construction, the contractor shall be required to excavate such material below the grade shown on plans and the areas so excavated shall be backfilled with approved suitable materials. The extent of undercutting and backfilling to be determined by the Engineering division, City of Portsmouth, Virginia.
38. All pavement patches shall be Type A (see graphic detail, this sheet)


STANDARD MANHOLE I
STORM SEWER
NO SCALE

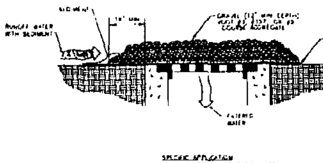

SECTION A-A
SPECIAL DIVERSION MANHOLE
NO SCALE


STORM DRAIN TRENCH DETAIL AND
PAVEMENT REMOVAL AND REPLACEMENT
NO SCALE


TYPICAL BRICK SIDEWALK CROSS SECTION
NO SCALE

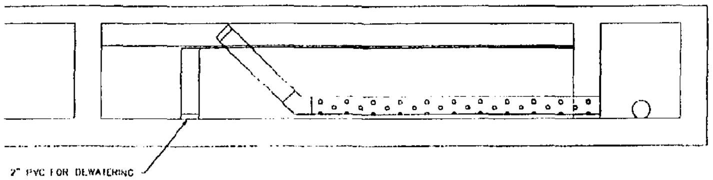


TP TREE PROTECTION DETAIL
NOT TO SCALE
TREEPROT DWG



SPECIFIC APPLICATION
THIS METHOD OF INLET PROTECTION IS APPLICABLE WHERE HEAVY [illegible] ARE EXPECTED, BUT NOT WHERE PONDING AROUND THE STRUCTURE MIGHT CAUSE EXCESSIVE INCONVENIENCE OR DAMAGE TO ADJACENT STRUCTURES AND UNPROTECTED AREAS.

IP INLET PROTECTION FOR DROP INLETS
NOT TO SCALE



POSITIONING OF PERFORATED PVC IN FILTRATION CHAMBER
SCALE: 1" = 5'

PAVEMENT PATCH TYPE A

DRAWINGS NOT TO SCALE

PROJECT	FILE	SHEET NO
CARBON/SAND FILTER	CARBPLAN DWG	3

Appendix A-3

Construction Bid Price Tabulations

				CPG		TMC		VIRTEXCO	
Item No.	Item	Quantity	Unit	Unit	Subtotal	Unit	Subtotal	Unit	Subtotal
1	Furnish & Install Reinforced Concrete Filter Box	1	lump sum	$29,976	$29,976	$31,680	$31,680	$31,000	$31,000
2	Furnish & Install Diversion Manhole	1	each	$1,200	$1,200	$1,800	$1,800	$2,875	$2,875
3	Furnish & Install Standard Manhole - Type 1	1	each	$1,200	$1,200	$1,950	$1,950	$2,875	$2,875
4	Furnish & Install 15" Reinforced Concrete Pipe, Class IV	45	linear feet	$40.00	$1,800	$49.00	$2,205	$28.75	$1,294
5	Furnish & Install 8" PVC Pipe	19	linear feet	$40.00	$760	$25.00	$475	$28.75	$546
6	Furnish & Install 8" Perforated PVC Pipe	30	linear feet	$20.00	$600	$18.00	$540	$28.75	$863
7	Furnish & Install Select Bedding	24	tons	$25	$600	$25	$600	$30	$720
8	Furnish & Install Select Fill	63	cubic yards	$18	$1,134	$19	$1,197	$29	$1,811
9	Furnish & Install Crushed Aggregate for Pavement Patch	19	tons	$20	$380	$28	$532	$30	$570
10	Furnish & Install SM-2A Asphalt Pavement for Patch	2	tons	$250	$500	$275	$550	$200	$400
11	Remove & Replace 7" Concrete Sidewalk Band	1	square yards	$400	$400	$125	$125	$65	$65
12	Remove & Replace 4" Concrete Base for Brick Sidewalk	6	square yards	$180	$1,080	$70	$420	$83	$498
	TOTAL				$39,630.00		$42,074.00		$43,516.75

Appendix A-4

Climatological Data

[redacted]

PORTSMOUTH WEATHER RECORDS SERVICE

Portsmouth, Virginia
36 degrees 50 minutes 07 seconds North
76 degrees 17 minutes 55 seconds West

Instrumentation:

Davis Weather Monitor II/WeatherLink Software: records time, temp, dew point, wind speed and direction; barometric pressure; rainfall; computes relative humidity, wind chill temp; records to memory high and low extremes of all readings aforementioned; graphs all aforementioned readings; real-time (PC visual) barometer trace; variable units (fahrenheit/celsius; knots, mph, kph, M/S; inches, MM, MB)

Standard cotton region shelter available for independent sensors

Gemware - Electro-V Psychrometer, Hand-Electric

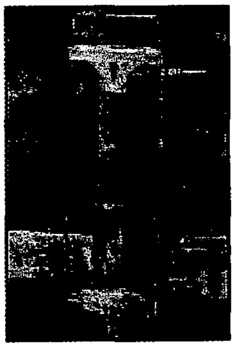
R. M. Young Aerovane Precision Electronic Anemometer

Maximum Gustmaster wind recorder (to 120 mph)

Downeaster Wind Direction and Speed Indicator (to 100 mph)

Airguide Aneroid Barometer (Compensated)

Pronamic Tipping Bucket Electronic Rainguage (one spoon; measures to .01")



All-Weather Raingage (4 inch diameter, 11 inch capacity; measures to .01") (NWS specification)

CompuTemp Plus electronic temperature sensor/display

Additional Software:

DOSFAX/WINFAX (fax transferrals/reception)
Talking Weather Station 3.23 interface with Davis Weather Monitor II
WeatherGraphix 3.4 graphics/data analysis system
WeatherBrief 3.2 text/visual data system
WeatherView 2.5B data/graphics system
Weathermation WeatherModem 2.2 data/visual system

"Radar" (old Steve Root program for plotting SD's on the subgridded Limited Fine Mesh I grid)
Hurrtrak 4.0 Professional Hurricane Tracking/Analysis System

Visibility: estimated (straightline visual) from 20 foot level

---

Database: (dating to July 1976)

Weather Eye (data storage and analysis)
Weather Eye Plus (data analysis and graphing)

Internet addresses:

71470.1535@compuserve.com
wtrotter@pen.k12.va.us
wtrotter@whro.org

PWRS Keyword Links:

ACON / Articles / Database / Forecast / Forecasts / Images / Instrumentation / Links / Mail / Marine / NC /
News / Observations / Radar / Records / Severe / Sun & Moon / Surface / Synopses / Tides / Time / Tropics

Return to PWRS' Home Page

Weather Data Denotations

DENOTATIONS (Weather/sky conditions)

A	Hail
AP	Small hail
B	Blowing
C	Cloudy
CL	Clear
D	Dust
F	Fog
FR	Frost
GF	Ground fog
GL	Glaze
H	Haze
IP	Ice pellets
K	Smoke
L	Drizzle
LTG	Lightning
PC	Partly Cloudy
R	Rain
RW	Rainshower
S	Snow
SG	Snow granules
SP	Snow pellets
SU	Sunny
TRW	Thundershower
T	Thunderstorm
X	Obscured Sky
Y	Spray
ZL	Freezing drizzle
ZR	Freezing rain

Intensity Markings
Precipitation:
- Light
+ Heavy
Sky Condition:
-Thin or Partial
Departures from Norms:
- below; + above

OTHER DENOTATIONS: NA, not available; NR, not recorded; TEMP, temperature; MAX, maximum; MIN, minimum; T, trace of precipitation; INOP, inoperative equipment; MPH, miles per hour; DN, departure from normal; DEP, departure; YR, year; NORM, normal; DST LTG, distant lightning; FROP or FROPA, frontal passage; AM morning; PM afternoon hours; EVE evening hours; E estimated; VBL, variable wind directions

---

COLUMN DENOTATIONS:

D	Date
HT	High Temperature
LT	Low Temperature
MT	Mean Temperature
DN	Departure from Normal of High, Low or Mean Temperature
HDD	Heating Degree Days
CDD	Cooling Degree Days
PREC	Precipitation
WS	Maximum Wind Speed (Gust)
WD	Direction of Maximum Wind Gust
HB	High Barometer Reading (Inches)
LB	Low Barometer Reading (Inches)
SC	Dominant Daily Sky Cover
WXR TYPES	Observed Weather Conditions and Remarks

NOTES: All temperatures are in degrees Fahrenheit. All precipitation measurements are in inches. All wind speeds are in miles per hour.

December, 1995

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of December, 1995. Time is EST.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	61	+3	33	-7	47.0	-2	18.0			SW	35	SU	BREEZY
2	55	-4	43	+4	49.0	0	16.0			N	22	SU	FROPA
3	70	+13	36	-2	53.0	+5	12.0			SSW	28	PC	MILD
4	57	0	38	0	47.5	0	17.5		0.01	NNE	23	PC	FROPA R-
5	58	+3	34	-3	46.0	0	19.0		T	S	19	PC	FROST (AM) F R--
6	54	-4	41	+4	47.5	0	17.5			NNE	23	PC	COOL
7	46	-9	29	-7	37.5	-8	27.5		0.34	NNE	30	PC	R IP S SG F FROPA 0.30" ACCUMULATION
8	42	-13	26	-10	34.0	-11	31.0			NE	19	SU	FR COLD
9	**49**	**-7**	**38**	**+2**	**43.5**	**-2**	**21.5**		**0.62**	**NW**	**25**	**C**	**R F FROPA**
10	40	-15	25	-10	32.5	-10	32.5			NW	27	SU	FROPA BLUSTERY COLDER
11	33	-17	22	-13	27.5	-15	37.5			WNW	27	-PC	COLD
12	42	-9	26	-9	34.0	-9	31.0			SW	14	PC	
13	50	-4	29	-8	39.5	-6	25.5			SE	14	C	
14	65	+12	40	+5	52.5	+9	12.5			SW	25	PC	
15	70	+15	47	+11	58.5	+12	6.5			ESE	17	PC	GF F MILD
16	57	+5	37	+1	47.0	+3	18.0		0.19	NW	33	PC	F R RW FROPA F (EVE)
17	42	-9	30	-4	36.0	-7	29.0			N	22	PC	F(AM) BREEXY
18	47	-4	29	-4	38.0	-4	27.0		0.05	ENE	14	C	F R- COLD
19	44	-6	37	+4	40.5	-1	24.5		0.54	NNW	20	C	F R L FROPA
20	37	-12	28	-6	32.5	-9	32.5		0.01	NNW	37	PC	RW-(AM) WINDY COLD
21	41	-9	24	-10	32.5	-10	32.5			NNW	26	PC	BREEZY COLD
22	39	-10	25	-7	32.0	-9	33.0			NNW	24	SU	BREEZY COLD
23	39	-15	25	-10	32.0	-13	33.0			NNW	21	SU	BREEZY COLD
24	38	-17	25	-10	31.5	-13	33.5			NNW	26	SU	BREEZY COLD
25	38	-12	23	-9	30.5	-10	34.5			W	15	PC	FROST- (AM) COLD
26	37	-9	26	-5	31.5	-7	33.5			NW	30	SU	FROPA
27	39	-6	24	-8	31.5	-7	33.5			NW	26	SU	BREEZY COLD
28	39	-14	25	-10	32.0	-12	33.0			NW	23	SU	BREEZY COLD
29	43	-7	28	-6	35.5	-7	29.5			N	22	SU	NOT SO COLD FR-(PM)
30	53	+5	26	-6	39.5	-1	25.5			SW	18	PC	FR (AM) NOT SO COLD
31	53	+2	43	+9	48.0	+6	17.0		0.02	SSE	12	C	R- L F+

SUMMARY OF DECEMBER 1995:

TEMPERATURE:

Monthly mean: High = 47.7 Low = 31.0 Mean = 39.4
Departure < Normal: High = -5.0 Low = -4.1 Mean = -4.5

Degree Days: Heating = 795.0 Cooling = 0.0
Number of Days Using: Heating = 31 Cooling = 0

Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 0
Days with minimum temperature <= 32: 19
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 1.78" Departure < Normal = -1.12"
Normal month = 2.90" or 61%
Average daily = 0.06" Normal daily = 0.09"
Number of days with measurable precipitation = 8

Year-to-date = 42.73" Departure = -3.84" 92% of normal

Maximum for December = 5.73" in 1983 --> (Since
Minimum for December = 0.76" in 1988 --> 1976)

Number of days with 0.01" or more: 8
Number of days with 0.10" or more: 4
Number of days with 0.50" or more: 2
Number of days with 1.00" or more: 0

Snowfall
December total = 0.30"
December maximum = 1.70"
in 1993

DAILY EXTREMES: Low temperature = 22 on the 11th
High temperature = 70 on the 3rd & 15th
Maximum daily precipitation = 0.62" on the 9th
Maximum 24-hour rainfall = 0.62" on the 9th
Maximum wind gust = NW 37 mph on the 20th
Maximum barometric pressure = 30.46" on the 29th
Minimum barometric pressure = 29.42" on the 19th

NUMBER OF:

Days Cloudy: 4
Days Partly Cloudy: 17
Days Clear/Sunny: 10
Days with Fog/Ground fog: 9

Days with thunderstorms: 0
Thunderstorms: 0
Days with some type of snowfall: 1

YEARLY TOTALS:

Temperatures

Mean maximum: 69.9 (+0.5)
Mean minimum: 51.3 (+0.4)
Mean monthly: 60.6 (+0.4)

Highest: 101, July 24th
Lowest: 13, February 6th and 7th
Days with maximum temperature >= 90: 48
Days with maximum temperature <= 32: 02
Days with minimum temperature <= 32: 52
Days with temperature <= 0: 00

Number of:
Days using Heating: 194
Days using Cooling: 166
Days Cloudy: 47
Days Partly Cloudy: 244
Days Clear/Sunny: 74
Days with fog/ground fog: 96

Degree Days

Heating: 3379.5
Cooling: 1782.5

Precipitation

Aqueous: 42.73" (DEP -3.84")
Maximum monthly: 8.08"/OCT.
Minimum monthly: 1.33"/AUG.

Snowfall: 0.50"
Maximum daily: 0.30"/DEC. 7
Maximum monthly: 0.30"/DEC.

Days with some type of snowfall: 6
Days with measurable precipitation: 107 or 29%

Days with thunderstorms: 20
Number of thunderstorms: 22

Greatest 24-hour period rainfall: 3.50"/Oct. 21st

Wind (Highest Recorded Wind Gust): West 52 miles per hour, NOV. 11
Barometer: Highest 30.60" on March 10th; Lowest: 29.33" on February 4th

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January, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of January 1996. Time is EST.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	45	-7	42	+5	43.5	-1	21.5		0.07	NE	15	C	F+ L R- DAMP
2	47	-2	42	+8	44.5	+3	20.5		0.25	NNW	14	C	F+ L TRW (PM)
3	56	+8	32	0	44.0	+4	21.0		0.05	N	28	PC	F+ RW (AM) RW FROPA (PM) ACCUMULATION: TRACE
4	37	-10	28	-4	32.5	-7	32.5		T	NW	27	PC	SW(AM) COLD FR(PM) ACCUMULATION: TRACE
5	40	-5	29	-2	34.5	-4	30.5		T	NW	22	PC	SW--(AM) COLD ACCUMULATION: NONE
6	31	-18	26	-4	28.5	-11	36.5		0.45	NNE	24	C	S COLD ACCUMULATION 4.5"
7	41	-10	22	-12	32.0	-11	33.5		1.24	NNE	31	C	S IP ZR R F ZL-FROPA SW- ACCUMULATION: 1.0"
8	30	-15	22	-9	26.0	-12	39.0		0.10	NW	35	PC	ZL- S SW WINDY **ACCUMULATION: 2.0"**
9	39	-7	18	-10	28.5	-8	36.5			WSW	24	PC	
10	40	-5	25	-4	32.5	-5	32.5			NNW	26	PC	FROPA COLD
11	29	-15	21	-7	25.0	-11	40.0			N	24	PC	COLD
12	43	-4	28	-2	35.5	-3	29.5		1.13	WNW	23	C	S IP R F FROPA S-- ACCUMULATION: TRACE
13	42	-5	26	-5	34.0	-5	31.0			WNW	22	SU	FROST+(AM)
14	52	+3	28	-2	40.0	0	25.0			WSW	18	SU	FR+(AM) MILDER
15	55	+8	37	+6	46.0	+7	19.0			NE	23	SU	FROPA
16	44	-2	33	+5	38.5	+2	26.5		.01	NNE	18	PC	RW-F-
17	62	+13	39	+11	50.5	+12	14.5			S	17	PC	F+(AM)
18	69	+19	44	+12	56.5	+15	8.5		.02	SE	40	PC	F(AM) RW- WINDY PM
19	70	+25	31	+1	50.5	+13	14.5		.55	SSE	64	PC	RW TRW FROPA
20	31	-16	22	-6	26.5	-11	38.5			NNW	24	PC	COLD
21	36	-9	29	0	32.5	-5	32.5		.02	N	19	C	R-S-F FROPA
22	38	-8	29	0	33.5	-4	31.5			NNE	16	PC	F
23	52	+3	29	-1	40.5	+1	24.5			SW	19	PC	F+(AM)
24	67	+14	41	+9	54.0	+12	11.0		.52	SSW	60	PC	WINDY RW+ FROPA
25	41	-9	30	-2	35.5	-6	29.5			W	23	SU	BREEZY COLDER
26	57	+8	25	-4	41.0	+2	24.0			ESE	24	PC	FR(AM)
27	64	+16	40	+10	52.0	+13	13.0		.77	ESE	47	C	R F WINDY
28	43	-4	31	+1	37.0	-2	28.0			SW	29	PC	FR- (PM)
29	44	-4	32	+3	38.0	-1	27.0		.22	ENE	18	C	FR- (AM) R F
30	49	0	37	+6	43.0	+3	22.0		.01	ESE	15	PC	RW- F
31	47	-2	30	-2	38.5	-2	26.5		.12	NE	28	C	R F FROPA

SUMMARY OF JANUARY 1996:

TEMPERATURE:

Monthly mean: High = 46.5 Low = 30.6 Mean = 38.5
Departure < Normal: High = -1.3 Low = 0.1 Mean = -0.7

Degree Days: Heating = 820.5 Cooling = 0.0
Number of Days Using: Heating = 31 Cooling = 0

Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 4
Days with minimum temperature <= 32: 22
Days with minimum temperature <= 0: 0

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PRECIPITATION:

    Total   month =    5.60"        Departure < Normal = +1.45"
    Normal month =     4.15"                               or 135%
    Average daily =    0.18"   Normal daily = 0.13"
    Number of days with measurable precipitation = 16

    Year-to-date =  5.60"   Departure = +1.45" 135% of normal

    Maximum for January   = 11.12" in 1987 --> (Since
    Minimum for December  =  1.07" in 1981 -->  1977)

    Number of days with 0.01" or more: 16            Snowfall
    Number of days with 0.10" or more: 10      January  total =  7.50"
    Number of days with 0.50" or more:  5    January  maximum =  8.90"
    Number of days with 1.00" or more:  2                      in 1980

 DAILY EXTREMES:   Low  temperature =  18 on the  9th
                   High temperature =  70 on the 19th
        Maximum daily precipitation = 1.24" on the  7th
           Maximum 24-hour rainfall = 1.69" on the  6th-7th
                  Maximum wind gust = SSE 64 mph on the 19th
        Maximum barometric pressure = 30.65" on the 26th
        Minimum barometric pressure = 29.38" on the  7th

                                NUMBER OF:

Days Cloudy:               10               Days with thunderstorms:  2
Days Partly Cloudy:        17                         Thunderstorms:  2
Days Clear/Sunny:           4       Days with some type of snowfall:  8
Days with Fog/Ground fog: 15
----------------------------------------------------------------------------
YEAR-TO-DATE:

Temperatures                  Degree Days     Precipitation

Mean maximum:   46.5 (-1.3) Heating:  820.5   Aqueous:    5.60" (DEP +1.45")
Mean minimum:   30.6 (-0.1) Cooling:    0.0     Maximum monthly:  5.60"/JAN.
Mean monthly:   38.5 (-0.7)                     Minimum monthly:  5.60"/JAN.

Highest:      70, January 19th                Snowfall:           7.50"
Lowest:       18, January  9th                  Maximum daily:  4.50"/JAN. 6
Days with maximum temperature >= 90:  0         Maximum monthly: 7.50"/JAN.
Days with maximum temperature <= 32: 22
Days with minimum temperature <= 32:  4         Days with some type of
Days with temperature         <=  0:  0           snowfall:       8
                                                Days with measurable
Number of:                                        precipitation: 16 or 50%
Days using Heating:          31
Days using Cooling:           0               Days with thunderstorms:  2
Days Cloudy:                 10               Number of thunderstorms:  2
Days Partly Cloudy:          17
Days Clear/Sunny:             4               Greatest 24-hour period
Days with fog/ground fog:    15                 rainfall: 1.69"/Jan. 6-7th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer:  Highest 30.65" on January 26th; Lowest: 29.38" on January 7th
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February, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of February 1996. Time is EST.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	34	-16	27	-3	30.5	-10	34.5			NE	23	C	COLD
2	35	-16	27	-6	31.0	-11	34.0		0.60	INOP		C	F ZR GL TRW ZL ACCUMULATION: 0.5"
3	28	-23	22	-9	25.0	-16	40.0		0.10	INOP		C	ZL IP+ S SW- FROPA ACCUMULATION: 1.0"
4	23	-27	12	-19	17.5	-23	47.5		0.25	INOP		PC	S SW COLD ACCUMULATION: 2.5"
5	23	-21	8	-20	15.5	-21	49.5			INOP		PC	COLD
6	31	-13	11	-17	21.0	-15	44.0			INOP		PC	F-K-FR(AM)
7	39	-5	13	-15	26.0	-10	39.0			S	19	PC	F-FR(AM) THAWING
8	54	+8	35	+6	44.5	+7	20.5		0.22	SW	26	C	RW
9	60	+11	35	+7	47.5	+9	17.5		0.01	WNW	25	PC	RW F FROPA
10	61	+13	29	+1	45.0	+7	20.0			SSW	24	SU	FR (AM)
11	**71**	**+20**	**44**	**+13**	**57.5**	**+17**	**7.5**			**WNW**	**37**	**PC**	**WINDY FROPA**
12	44	-3	30	+1	37.0	-1	28.0			WNW	23	PC	FROPA VIRGA BREEZY
13	38	-8	22	-7	30.0	-7	35.0			W	31	SU	WINDY COLD
14	51	-2	35	+2	43.0	0	22.0			SW	30	PC	WARMFROPA BREEZY
15	51	-3	37	+3	44.0	0	21.0		0.04	ENE	22	PC	RW-(AM)
16	38	-14	26	-8	32.0	-11	33.0		0.52	NNW	36	C	R IP S S+ BS FROPA ACCUMULATION: 4.0"
17	35	-15	19	-13	27.0	-14	38.0		T	NW	30	PC	S-(AM) COLD ACCUMULATION: TRACE
18	40	-10	26	-7	33.0	-9	32.0			NNW	21	PC	FROPA BREEZY
19	56	+2	27	-8	41.5	-3	23.5			SE	26	PC	FR(AM)
20	**68**	**+13**	**46**	**+10**	**57.0**	**+11**	**8.0**		**0.68**	**SSE**	**32**	**PC**	**F+(AM) RW F**
21	64	+6	49	+13	56.5	+10	8.5		0.10	SSE	21	PC	RW F+(AM)
22	68	+8	49	+11	58.5	+10	6.5		0.13	SE	16	PC	F+(AM) RW
23	56	-3	50	+9	53.0	+3	12.0			SE	17	C	RW (AM) F
24	68	+12	48	+10	58.0	+11	7.0			NW	36	PC	FROPA DRYING
25	70	+19	39	+5	54.5	+12	10.5			WNW	26	PC	
26	73	+24	51	+17	62.0	+20	3.0			NNE	17	PC	FROPA
27	72	+22	43	+11	57.5	+16	7.5			S	18	PC	GF K (AM) WARM FROPA(PM)
28	74	+21	51	+17	62.5	+19	2.5			W	29	PC	GF H (AM) K(AFT) FROPA
29	51	+2	30	+2	40.5	+2	24.5			N	28	PC	PC

SUMMARY OF FEBRUARY 1996:

TEMPERATURE:

Monthly mean:	High = 50.9	Low = 32.4	Mean = 41.7
Departure < Normal:	High = 0.0	Low = 0.0	Mean = 0.0

Degree Days:	Heating = 676.5	Cooling = 0.0
Number of Days Using:	Heating = 29	Cooling = 0

Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 4
Days with minimum temperature <= 32: 15
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 2.65" Departure < Normal = -0.72" or 79%
Normal month = 3.37"
Average daily = 0.09" Normal daily = 0.12"
Number of days with measurable precipitation = 10

Year-to-date = 8.25" Departure = +0.73" 110% of normal

Maximum for February = 6.32 in 1989 --> (Since
Minimum for February = 1.20" in 1991 --> 1977)

Number of days with 0.01" or more: 10
Number of days with 0.10" or more: 8
Number of days with 0.50" or more: 3
Number of days with 1.00" or more: 0

Snowfall
February total = 8.00"
February maximum = 21.00" in 1989

DAILY EXTREMES: Low temperature = 8 on the 5th
High temperature = 74 on the 28th
Maximum daily precipitation = 0.68" on the 20th
Maximum 24-hour rainfall = 0.78" on the 20th-21st
Maximum wind gust = WNW 37 mph on the 11th
(anemometers inoperative [glazed over] on the 2nd-7th [AM])
Maximum barometric pressure = 30.658" on the 5th
Minimum barometric pressure = 29.425" on the 11th

NUMBER OF:

Days Cloudy: 7
Days Partly Cloudy: 21
Days Clear/Sunny: 1
Days with Fog/Ground fog: 12

Days with thunderstorms: 1
Thunderstorms: 1
Days with some type of snowfall: 4

YEAR-TO-DATE:

Temperatures / Degree Days

Mean maximum: 48.6 (-0.7) Heating: 1495.0
Mean minimum: 31.5 (-0.0) Cooling: 0.0
Mean monthly: 40.1 (-0.3)

Highest: 74, February 28th
Lowest: 8, February 5th
Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 26
Days with minimum temperature <= 32: 14
Days with temperature <= 0: 0

Number of:
Days using Heating: 60
Days using Cooling: 0
Days Cloudy: 17
Days Partly Cloudy: 38
Days Clear/Sunny: 5
Days with fog/ground fog: 27

Precipitation

Aqueous: 8.25" (DEP +0.73")
Maximum monthly: 5.60"/JAN.
Minimum monthly: 2.65"/FEB.

Snowfall: 15.50"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.

Days with some type of snowfall: 13
Days with measurable precipitation: 26 or 43%

Days with thunderstorms: 3
Number of thunderstorms: 3

Greatest 24-hour period rainfall: 1.69"/Jan. 6-7th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.658" on February 5th; Lowest: 29.38" on January 7th

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March, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of March 1996. Time is EST.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	46	-6	30	-3	38.0	-4	27.0		0.18	ESE	19	C	R-
2	46	-9	35	-1	40.5	-5	24.5		0.31	N	22	PC	R-F(AM) GF
3	53	-1	27	-10	40.0	-5	25.0			WNW	40	SU	FROPA WINDY COLDER
4	48	-9	25	-12	36.5	-10	28.5			WSW	20	SU	COLD
5	72	+13	34	-6	53.0	+3	12.0			SSW	42	PC	WINDY WARM
6	**66**	**+10**	**58**	**+19**	**62.0**	**+14**	**3.0**		**0.36**	**S**	**34**	**C**	**F R FROPA(LATE EVE)**
7	66	+9	36	-1	51.0	+4	14.0		0.48	S	30	C	F R RW WARMFROP COLDFROP
8	36	-20	24	-13	30.0	-16	35.0		0.10	S	31	PC	R-IP-S-SW ACCUMULATION: 0.40"
9	31	-24	18	-18	24.5	-21	40.5			W	25	SU	RECORD COLD WINDY (AM)
10	34	-23	23	-13	28.5	-18	36.5			WNW	22	SU	BREEZY COLD
11	40	-18	29	-7	34.5	-13	30.5			NE	28	PC	BREEZY COLD
12	50	-9	32	-7	41.0	-8	24.0			NNE	32	PC	BREEZY
13	59	-3	27	-13	43.0	-8	22.0			NNW	18	SU	FR(AM)
14	73	+13	36	-4	54.5	+5	10.5			W	22	PC	MILD AFT
15	79	+17	52	+12	65.5	+14		0.5	0.35	WSW	32	PC	T RW MILD
16	62	+3	46	+7	54.0	+5	11.0			SE	20	PC	
17	50	-12	41	+2	45.5	-5	19.5		0.58	E	27	C	TRW F
18	49	-10	45	+5	47.0	-3	18.0		T	NE	15	C	F R-(PM)
19	**71**	**+12**	**46**	**+6**	**58.5**	**+9**	**6.5**		**0.19**	**SSW**	**54**	**C**	**R-F FROPA RW WINDY**
20	53	-7	40	+3	46.5	-2	18.5			SSW	37	PC	WINDY
21	56	-5	36	-4	46.0	-4	19.0			WSW	27	PC	BREEZY
22	51	-8	36	-2	43.5	-5	21.5		0.01	SSW NW	27 27	PC	RW-SW-F-
23	55	-5	31	-7	43.0	-6	22.0			NW	33	SU	
24	62	0	29	-13	45.5	-6	19.5			SSE	27	SU	
25	76	+15	41	0	58.5	+8	6.5			SSW	36	PC	MILDER
26	72	+11	49	+8	60.5	+9	4.5			SW	21	PC	FROPA
27	49	-15	40	-2	44.5	-8	20.5			N	29	PC	WINDY COLDER
28	**48**	**-17**	**40**	**-5**	**44.0**	**-11**	**21.0**		**1.19**	**NE**	**25**	**C**	**R F L WINDY RAW**
29	43	-26	38	-7	40.5	-16	24.5		0.03	NNW	24	C	R- L- F
30	56	-12	40	-8	48.0	-10	17.0			N	20	PC	PLEASANT AFTERNOON
31	61	-5	40	-6	50.5	-5	14.5		0.12	SE	15	PC	R-F-

SUMMARY OF MARCH 1996:

TEMPERATURE:

Monthly mean: High = 55.3 Low = 36.3 Mean = 45.8
Departure < Normal: High = -4.5 Low = -3.2 Mean = -3.8

Degree Days: Heating = 597.0 Cooling = 0.5
Number of Days Using: Heating = 30 Cooling = 1

Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 1
Days with minimum temperature <= 32: 11
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 3.90" Departure < Normal = -0.53" or 88%
Normal month = 4.43"
Average daily = 0.13" Normal daily = 0.14"
Number of days with measurable precipitation = 12

Year-to-date = 12.15" Departure = +0.20" 102% of normal

Maximum for March = 10.96" in 1994 --> (Since
Minimum for March = 0.89" in 1986 --> 1977)

Number of days with 0.01" or more: 12
Number of days with 0.10" or more: 10
Number of days with 0.50" or more: 2
Number of days with 1.00" or more: 1

Snowfall
March total = 0.40"
March maximum = 14.00" in 1980

DAILY EXTREMES: Low temperature = 18 on the 9th
High temperature = 79 on the 15th
Maximum daily precipitation = 1.19" on the 28th
Maximum 24-hour rainfall = 1.19" on the 28th
Maximum wind gust = SSW 54 mph on the 19th
Maximum barometric pressure = 30.937" on the 10th
Minimum barometric pressure = 29.196" on the 19th

NUMBER OF:

Days Cloudy: 8
Days Partly Cloudy: 17
Days Clear/Sunny: 6
Days with Fog/Ground fog: 11

Days with thunderstorms: 2
# of Thunderstorms: 2
Days with some type of snowfall: 2

YEAR-TO-DATE: (through March 31st, 1996)

Temperatures

Mean maximum: 50.9 (-2.0)
Mean minimum: 33.1 (-1.1)
Mean monthly: 42.0 (-1.6)

Degree Days

Heating: 2094.0
Cooling: 0.5

Precipitation

Aqueous: 12.15" (DEP +0.20")
Maximum monthly: 5.60"/JAN.
Minimum monthly: 2.65"/FEB.

Highest: 79, March 15th
Lowest: 8, February 5th
Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 27
Days with minimum temperature <= 32: 48
Days with temperature <= 0: 0

Number of:
Days using Heating: 90
Days using Cooling: 1
Days Cloudy: 25
Days Partly Cloudy: 55
Days Clear/Sunny: 11
Days with fog/ground fog: 38

Snowfall: 15.90"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.

Days with some type of snowfall: 15
Days with measurable precipitation: 38 or 42%

Days with thunderstorms: 5
Number of thunderstorms: 5

Greatest 24-hour period rainfall: 1.69"/Jan. 6-7th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.937" on March 10th; Lowest: 29.196" on March 19th

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April, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of April 1996. Time is EST/EDT.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	72	+5	50	+6	61.0	+5	4.0		0.61	NNW	23	PC	R F RW FROPA
2	56	-12	40	-4	48.0	-8	17.0		0.02	NNW	32	PC	RW (AM) WINDY
3	73	+6	37	-9	55.0	-1	10.0			WSW	26	SU	
4	83	+14	56	+8	69.5	+11		4.5		SW	27	SU	
5	67	0	45	-2	56.0	-1	9.0			N	28	PC	FROPA (AM)
6	48	-16	38	-7	43.0	-11	22.0		0.89	ENE	21	C	R F FROPA COLD
7	52	-12	39	-4	45.5	-8	19.5			N	22	PC	
8	59	-7	35	-10	47.0	-9	18.0		0.03	SSW	22	PC	K-(AM) R-(EVENING)
9	46	-19	39	-7	42.5	-13	22.5		0.76	NNW	35	C	R F FROPA BREEZY COLD
10	53	-14	35	-10	44.0	-12	21.0			NNW	29	PC	VIRGA (AFT)
11	70	+1	38	-7	54.0	-3	11.0			WNW	25	SU	
12	85	+13	53	+7	69.0	+10		4.0		W	28	PC	MILD
13	86	+18	58	+9	72.0	+13		7.0		WSW	25	PC	MILD
14	69	+1	53	+4	61.0	+3	4.0			SSW	24	PC	FROPA
15	71	+2	49	+0	60.0	+1	5.0		T	SSE	40	PC	WINDY PM RW
16	69	0	48	-1	58.5	0	6.5		1.52	WNW	49	PC	FROPA TRW(2) RW
17	63	-7	44	-4	53.5	-6	11.5			NW	28	PC	BREEZY
18	77	+7	40	-7	58.5	0	6.5			SE	21	SU	
19	79	+8	54	+5	66.5	+6		1.5	.06	SW	28	PC	RW
20	81	+10	60	+10	70.5	+10		5.5	.05	SSW	31	PC	RW(EVE) DST LTG (EVE)
21	83	+11	61	+10	72.0	+10		7.0		W	24	PC	
22	88	+17	62	+13	75.0	+15		10.0		SW	29	PC	BREEZY WARM
23	**86**	**+15**	**64**	**+14**	**75.0**	**+14**		**10.0**	**.20**	**SW**	**36**	**PC**	**BREEZY TRW(PM)**
24	65	-9	47	-3	56.0	-6	9.0		.04	NNW	33	PC	RW(AM) FROPA COOLER
25	77	+3	48	-3	62.5	0	2.5			S	38	PC	BREEZY
26	81	+9	55	+4	68.0	+6		3.0	.09	SW	46	PC	RW FROPA
27	64	-11	51	-1	57.5	-6	7.5			WSW	20	PC	PLEASANT
28	76	+3	45	-8	60.5	-2	4.5			SSE	25	PC	H-
29	84	+10	58	+7	71.0	+9		6.0	.04	SSW	32	PC	RW(AM) TRW(AFT) H-
30	77	+3	54	+2	65.5	+2		0.5	.89	SSW	49	PC	RW TRW WINDY F- FROPA

SUMMARY OF APRIL 1996:

TEMPERATURE:

Monthly mean:	High = 71.3	Low = 48.5	Mean = 59.9
Departure < Normal:	High = +1.6	Low = +0.3	Mean = +1.0

Degree Days:	Heating = 211.0	Cooling = 59.0
Number of Days Using:	Heating = 19	Cooling = 11

Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 0
Days with minimum temperature <= 32: 0
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 5.20" Departure < Normal = + 1.60" or 145%
Normal month (to date) 3.60"
Average daily = 0.17"
Normal daily = 0.12"
Number of days with measurable precipitation = 13

Year-to-date = 17.35" Departure = +1.80" 112% of normal

Maximum for April = 7.08" in 1991 --> (Since
Minimum for April = 1.21" in 1985 --> 1977)

Number of days with 0.01" or more: 13
Number of days with 0.10" or more: 6
Number of days with 0.50" or more: 5
Number of days with 1.00" or more: 1

Snowfall
April total = 0.00"
April maximum = 1.1" in 1983

DAILY EXTREMES: Low temperature = 35 on the 8th and 10th
High temperature = 88 on the 22nd
Maximum daily precipitation = 1.52" on the 16th
Maximum 24-hour rainfall = 1.52" on the 16th
Maximum wind gust = WNW 49 mph/SSW 49 mph on the 16th/30th
Maximum barometric pressure = 30.341" on the 28th
Minimum barometric pressure = 29.649" on the 16th

NUMBER OF:

Days Cloudy: 2
Days Partly Cloudy: 24
Days Clear/Sunny: 4
Days with Fog/Ground fog: 4

Days with thunderstorms: 4
# of Thunderstorms: 5
Days with some type of snowfall: 0

YEAR-TO-DATE: (through April 30th, 1996)

Temperatures

Mean maximum: 56.0 (-1.1)
Mean minimum: 36.9 (-0.8)
Mean monthly: 46.4 (-1.0)

Degree Days

Heating: 2305.0
Cooling: 59.5

Precipitation

Aqueous: 17.35" (DEP +1.80")
Maximum monthly: 5.60"/JAN.
Minimum monthly: 2.65"/FEB.

Highest: 88, April 22nd
Lowest: 8, February 5th
Days with maximum temperature >= 90: 0
Days with maximum temperature <= 32: 27
Days with minimum temperature <= 32: 48
Days with temperature <= 0: 0

Snowfall: 15.90"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.
Seasonal total: 16.20"
Days with some type of snowfall: 15
Days with measurable precipitation: 51 or 42%

Number of:
Days using Heating: 109
Days using Cooling: 13
Days Cloudy: 27
Days Partly Cloudy: 79
Days Clear/Sunny: 15
Days with fog/ground fog: 42

Days with thunderstorms: 9
Number of thunderstorms: 10

Greatest 24-hour period rainfall: 1.69"/Jan. 6-7th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.937" on March 10th; Lowest: 29.196" on March 19th

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May, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of May 1996. Time is EST/EDT.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	70	-5	47	-6	58.5	-6	6.5			E	25	SU	COOLER
2	77	+3	52	0	64.5	+1	0.5			NE	21	PC	H-K
3	83	+8	56	+3	69.5	+6		4.5		SSE	25	SU	K H-
4	87	+14	62	+8	74.5	+11		9.5		W	31	SU	HUMID BREEZY
5	76	+4	58	+4	67.0	+4		2.0		ESE	22	PC	FROPA BREEZY
6	70	-5	57	+3	63.0	-1	2.0		.83	S	29	PC	TRW+(AM) FROPA
7	57	-17	51	-3	54.0	-10	11.0		.84	E	24	C	R L F COOLER
8	67	-7	53	-1	60.0	-4	5.0		.02	SSE	19	PC	RW- F
9	79	+5	57	+4	68.0	+5		3.0	T	NNE	21	PC	F RW H
10	88	+11	56	+2	72.0	+7		7.0		WSW	25	PC	F(AM) H-
11	88	+10	68	+12	78.0	+11		13.0	.09	WSW	55	PC	HOT HUMID SQUALL LINE/ TRW (EVE)
12	68	-10	54	-3	61.0	-7	4.0		.03	NNW	27	PC	RW-(AM) FROPA COOLER
13	64	-14	49	-8	56.5	-11	8.5			E	19	PC	BREEZY COOLER
14	63	-13	47	-11	55.0	-12	10.0		.04	N/SE	18	PC	RW-(AM)
15	70	-7	44	-13	57.0	-10	8.0		.21	SSE	21	PC	R-(PM)
16	**69**	**-8**	**56**	**0**	**62.5**	**-4**	**2.5**		**.61**	**SW**	**19**	**C**	**R-F RW**
17	80	+2	62	+4	71.0	+3		6.0	T	ESE	16	PC	F RW- H HUMID
18	90	+10	64	+5	77.0	+8		12.0		WSW	14	PC	FH HOT HUMID
19	97	+18	67	+8	82.0	+13		17.0		WSW	14	SU	FH(EARLY AM) HOT HUMID
20	98	+22	70	+11	84.0	+16		19.0		WSW	20	SU	HOT
21	93	+14	71	+11	82.0	+12		17.0		WSW	23	PC	H HOT BREEZY
22	79	+1	63	+5	71.0	+3		6.0		NNE	35	PC	DST LTG FROPA COOLER
23	85	+3	58	-2	71.5	0		6.5		SSE	21	SU	
24	86	+5	65	+3	75.5	+4		10.5		SSE	25	PC	H DST LTG
25	71	-9	61	0	66.0	-4		1.0	.10	NE	19	C	FROPA TRW F
26	72	-6	60	-1	66.0	-4		1.0	.02	SE	19	C	RW F
27	67	-10	58	-1	62.5	-5	2.5		.86	SE	30	C	F RW TRW(2) L
28	63	-15	58	-1	60.5	-8	4.5		.16	ESE	16	C	F RW(AM) COOL FROP
29	65	-17	57	-5	61.0	-11	4.0		T	ENE	19	C	F L-
30	67	-14	53	-9	60.0	-12	5.0		.09	NNE	26	PC	RW-(AM) F FROPA
31	71	-13	47	-16	59.0	-15	6.0		.00	SE	20	SU	RECORD LOW TEMP

SUMMARY OF MAY 1996:

TEMPERATURE:

Monthly mean: High = 76.1 Low = 57.5 Mean = 66.8
Departure < Normal: High = -1.4 Low = +0.2 Mean = -0.6

Degree Days: Heating = 79.5 Cooling = 135.0
Number of Days Using: Heating = 15 Cooling = 16

Days with maximum temperature >= 90: 4
Days with maximum temperature <= 32: 0
Days with minimum temperature <= 32: 0
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 3.90"
Normal month (to date) 4.10"
Average daily = 0.13"
Normal daily = 0.13"
Number of days with measurable precipitation = 13

Departure < Normal = - 0.20"
or 95%

Year-to-date = 21.25" Departure = +1.60" 108% of normal

Maximum for May = 8.06" in 1988 --> (Since
Minimum for May = 1.02" in 1986 --> 1977)

Number of days with 0.01" or more: 13
Number of days with 0.10" or more: 7
Number of days with 0.50" or more: 4
Number of days with 1.00" or more: 0

Snowfall
May total = 0.00"
May maximum = 0.00"

DAILY EXTREMES: Low temperature = 44 on the 25th
High temperature = 98 on the 20th
Maximum daily precipitation = 0.86" on the 27th
Maximum 24-hour rainfall = 1.67" on the 6-7th
Maximum wind gust = WSW 55 mph on the 11th
Maximum barometric pressure = 30.417" on the 7th
Minimum barometric pressure = 29.636" on the 21st

NUMBER OF:

Days Cloudy: 8
Days Partly Cloudy: 16
Days Clear/Sunny: 7
Days with Fog/Ground fog: 13

Days with thunderstorms: 4
# of Thunderstorms: 5
Days with some type of snowfall: 0

YEAR-TO-DATE: (through May 31st, 1996)

Temperatures

Mean maximum: 60.1 (-1.1)
Mean minimum: 41.1 (-0.6)
Mean monthly: 50.6 (-0.9)

Highest: 98, May 20th
Lowest: 8, February 5th
Days with maximum temperature >= 90: 4
Days with maximum temperature <= 32: 27
Days with minimum temperature <= 32: 48
Days with temperature <= 0: 0

Number of:
Days using Heating: 124
Days using Cooling: 28
Days Cloudy: 35
Days Partly Cloudy: 95
Days Clear/Sunny: 22
Days with fog/ground fog: 55

Degree Days

Heating: 2384.5
Cooling: 194.5

Precipitation

Aqueous: 21.25" (DEP +1.61")
Maximum monthly: 5.60"/JAN.
Minimum monthly: 2.65"/FEB.

Snowfall: 15.90"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.
Seasonal total: 16.20"
Days with some type of snowfall: 15
Days with measurable precipitation: 64 or 42%

Days with thunderstorms: 9
Number of thunderstorms: 10

Greatest 24-hour period rainfall: 1.69"/Jan. 6-7th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.937" on March 10th; Lowest: 29.196" on March 19th

June, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia 23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of June 1996. Time is EDT.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	78	-6	47	-17	62.5	-12	2.5			SSE	21	SU	RECORD AM LOW TEMP
2	80	-3	51	-12	65.5	-8		0.5		SE	21	SU	
3	68	-14	57	-6	62.5	-10	2.5		0.25	NNE	23	PC	RW F
4	81	0	57	-7	69.0	-3		4.0		S	27	PC	DST LTG F
5	81	-1	66	+3	73.5	+1		8.5	T	WSW	21	PC	TRW- F FROPA H-
6	84	+1	65	+1	74.5	+1		9.5		ESE	21	PC	F+(AM)
7	90	+6	67	+1	78.5	+3		13.5	T	S	24	PC	F+L-(AM) H-
8	90	+3	70	+4	80.0	+3		15.0		S	28	SU	BREEZY (AFT) HOT
9	86	+2	70	+4	78.0	+3		13.0	0.22	S	30	PC	RW DST LTG BREEZY(AM)
10	82	-2	72	+6	77.0	+2		12.0	0.04	S	26	PC	F- RW HUMID
11	82	-1	67	+4	74.5	+1		9.5	0.51	W	23	PC	F- RW+ TRW DST LTG HUMID
12	89	+4	67	+3	78.0	+4		13.0	0.38	S	27	PC	TRW(2) F- H RW
13	87	+4	66	+2	76.5	+3		11.5	T	W	25	PC	RW-(AM) F- H-
14	90	+5	68	+4	79.0	+4		14.0		W	16	SU	F-(AM) H
15	90	+3	69	+3	79.5	+3		14.5	T	SE	25	PC	F-(AM) H TRW- DST LTG
16	93	+7	70	+2	81.5	+5		16.5		S	22	PC	F-(AM) H DST LTG
17	90	+5	69	+2	79.5	+4		14.5		SSW	24	PC	
18	94	+8	71	+4	82.5	+6		17.5		S/E	19	PC	HOT HUMID H
19	91	+5	71	+3	81.0	+4		16.0		S	23	PC	HOT HUMID
20	92	+5	71	+2	81.5	+4		16.5	0.14	ESE	21	PC	H DST LTG TRW
21	88	+2	70	+4	79.0	+3		14.0	T	N	21	SU	RW-(AM) H DST LTG
22	94	+8	69	+2	81.5	+5		16.5		SW	20	SU	H
23	87	+1	75	+8	81.0	+4		16.0		21NNE		PC	H
24	**94**	**+9**	**69**	**+3**	**81.5**	**+6**		**16.5**	**1.80**	**28**	**N**	**PC**	**H HOT TRW(3)**
25	88	+4	69	+3	78.5	+3		13.5	0.15	18	SW	PC	H F- TRW- FROPA
26	79	-6	65	-2	72.0	-4		7.0		29NNE		SU	PLEASANT
27	82	-5	60	-8	71.0	-6		6.0		16NNE		SU	
28	86	-2	63	-4	74.5	-3		9.5		17NNW		SU	H- WEAK FROPA
29	81	-7	67	-1	74.0	-4		9.0		20ENE		C	FROPA (AM)
30	77	-10	59	-9	68.0	-10		3.0	0.36				RW (AM)

SUMMARY OF JUNE 1996:

TEMPERATURE:

Monthly mean: High = 85.8 Low = 65.9 Mean = 75.9
Departure < Normal: High = + 0.8 Low = 0.0 Mean = + 0.5

Degree Days: Heating = 5.0 Cooling = 330.5
Number of Days Using: Heating = 2 Cooling = 28

Days with maximum temperature >= 90: 11
Days with maximum temperature <= 32: 0
Days with minimum temperature <= 32: 0
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 3.85"
Normal month (to date) 3.65"
Average daily = 0.13"
Normal daily = 0.12"
Number of days with measurable precipitation = 9

Departure < Normal = + 0.20"
or 105%

Year-to-date = 25.10" Departure = +1.80" 108% of normal

Maximum for June = 7.56" in 1978 --> (Since
Minimum for June = 0.94" in 1980 --> 1977)

Number of days with 0.01" or more: 9
Number of days with 0.10" or more: 8
Number of days with 0.50" or more: 2
Number of days with 1.00" or more: 1

Snowfall
June total = 0.00"
June maximum = 0.00"

DAILY EXTREMES: Low temperature = 47 on the 1st
High temperature = 94 on the 18th, 22nd, 24th
Maximum daily precipitation = 1.80" on the 24th
Maximum 24-hour rainfall = 1.95" on the 24th-25th
Maximum wind gust = S 30 mph on the 9th
Maximum barometric pressure = 30.344" on the 1st
Minimum barometric pressure = 29.690" on the 23rd

NUMBER OF:

Days Cloudy: 2
Days Partly Cloudy: 19
Days Clear/Sunny: 9
Days with Fog/Ground Fog: 13
Days with Dense Fog: 2

Days with thunderstorms: 7
# of Thunderstorms: 10
Days with some type of snowfall: 0

YEAR-TO-DATE:

Temperatures

Mean maximum: 64.3 (-0.8)
Mean minimum: 45.2 (-0.5)
Mean monthly: 54.8 (-0.6)

Highest: 98, May 20th
Lowest: 8, February 5th
Days with maximum temperature >= 90: 15
Days with maximum temperature <= 32: 9
Days with minimum temperature <= 32: 45
Days with temperature <= 0: 0

Number of:
Days using Heating: 126
Days using Cooling: 56
Days Cloudy: 37
Days Partly Cloudy: 114
Days Clear/Sunny: 31
Days with fog/ground fog: 55

Degree Days

Heating: 2389.5
Cooling: 525.0

Precipitation

Aqueous: 25.10" (DEP +1.80")
Maximum monthly: 5.60"/JAN.
Minimum monthly: 2.65"/FEB.

Snowfall: 15.90"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.
Seasonal total: 16.20"
Days with some type of snowfall: 15
Days with measurable precipitation: 73 or 40%

Days with thunderstorms: 16
Number of thunderstorms: 20

Greatest 24-hour period rainfall: 1.95"/June 24-25th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.937" on March 10th; Lowest: 29.196" on March 19th

July, 1996

MONTHLY SUMMARY OF CLIMATOLOGICAL DATA - PORTSMOUTH, VIRGINIA
Portsmouth Weather Records Service
Portsmouth, Virginia   23702-2017 (3 miles south / West Cradock Section)

Monthly summary of Local Climatological Data for Portsmouth, Virginia, West Cradock Section, during the month of July 1996. Time is EDT.

D	HT	DN	LT	DN	MT	DN	HDD	CDD	PREC	WD	WS	SC	WXR TYPE/REMARKS
1	81	-5	70	+1	75.5	-2		10.5		NNE	19	PC	F H
2	92	+5	70	+1	81.0	+3		16.0	T	ESE W	16 16	PC	F-H- DST LTG RW-
3	**87**	**-1**	**64**	**-5**	**75.5**	**-3**		**10.5**	**0.76**	**N**	**36**	**PC**	**F-H-RW- TRW+ FROPA**
4	78	-9	61	-9	69.5	-9		4.5		NW	27	PC	COOLER
5	85	-3	58	-12	71.5	-7		6.5		WSW	18	PC	TIED RECORD LOW
6	89	0	69	-2	79.0	-1		14.0		S	18	PC	H-
7	93	+3	68	-3	80.5	0		15.5		SSW	18	PC	H-
8	94	+4	73	+4	83.5	+4		18.5	0.53	NW	28	PC	H- HOT HUMID TRW
9	92	+1	71	0	81.5	0		16.5	0.17	WSW	18	PC	F TRW-(AM) RW H
10	82	-8	67	-5	74.5	-6		9.5		N	21	PC	FROPA
11	80	-9	65	-6	72.5	-8		7.5	T	SE	19	PC	RW- (LATE EVE)
12	79	-11	70	-2	74.5	-7		9.5	2.78	ESE	46	C	**RW+TRW+F WINDY EVE**
13	88	-3	70	-4	79.0	-3		14.0	0.61	E	54	C	**RW+TRW F HURRICANE BERTHA** PASSES 25 MILES WEST OF STATION; MINIMUM BAROMETR PRESSURE 29.373"
14	93	-2	74	0	83.5	+1		18.5	0.19	S	28	PC	H TRW MUGGY
15	**88**	**-1**	**74**	**+1**	**81.0**	**0**		**16.0**	**0.69**	**SSW**	**26**	**PC**	**F-H MUGGY TRW (2)**
16	89	0	71	-1	80.0	-1		15.0		SSW	19	PC	F-H MUGGY
17	93	+4	73	+1	83.0	+2		18.0		W	20	SU	F-H HOT MUGGY
18	**93**	**+4**	**71**	**-1**	**82.0**	**+1**		**17.0**	**2.53**	**WSW**	**32**	**PC**	**F-H TRW+(3)**
19	88	-2	70	-1	79.0	-2		14.0	0.90	SW	24	PC	F TRW+(AM) H-
20	82	-9	67	-4	74.5	-6		9.5		N	22	SU	FROPA DRIER
21	85	-6	62	-11	73.5	-8		8.5		WNW	16	SU	PLEASANT
22	90	+1	67	-6	78.5	-2		13.5	T	S	20	PC	GF-(AM) H RW-DST LTG
23	84	-3	73	+1	78.5	-1		13.5		NNW	18	PC	F- H HUMID
24	86	-3	72	+1	79.0	-1		14.0	T	ESE	15	PC	F H RW-
25	**93**	**+4**	**69**	**-3**	**81.0**	**+1**		**16.0**	**0.61**	**SE**	**28**	**PC**	**F H HUMID HOT TRW**
26	86	-3	71	0	78.5	-1		13.5	0.01	WNW	18	PC	FROPA RW-(AM)
27	88	-1	65	-7	76.5	-4		11.5		ESE	16	PC	
28	88	0	68	-3	78.5	-2		13.0		ESE	21	PC	H WARM HUMID
29	81	-7	71	+1	76.0	-3		11.0	1.00	ESE	16	PC	F TRW+ RW
30	88	+1	70	0	79.0	0		14.0	T	SSW	21	C	F RW-
31	92	+3	68	-3	80.0	0		15.0	1.02	WSW	47	PC	H HUMID TRW(1)TRW+(2)

SUMMARY OF JULY 1996:

TEMPERATURE:

Monthly mean:	High = 87.3	Low = 68.8	Mean = 78.0
Departure < Normal:	High = -1.7	Low = -2.5	Mean = -2.2

Degree Days:	Heating = 0.0	Cooling = 404.5
Number of Days Using:	Heating = 0	Cooling = 31

Days with maximum temperature >= 90: 10
Days with maximum temperature <= 32: 0
Days with minimum temperature <= 32: 0
Days with minimum temperature <= 0: 0

PRECIPITATION:

Total month = 11.80"
Normal month (to date) 5.06"
Average daily = 0.38"
Normal daily = 0.16"
Number of days with measurable precipitation = 13

Departure < Normal = + 6.74"
or 233%

Year-to-date = 36.90" Departure = +8.54" or 130% of normal

Maximum for July = 11.80" in 1996 --> (Since
Minimum for July = 1.32" in 1978 --> 1976)

Number of days with 0.01" or more: 13
Number of days with 0.10" or more: 12
Number of days with 0.50" or more: 10
Number of days with 1.00" or more: 4

Snowfall
July total = 0.00"
July maximum = 0.00"

DAILY EXTREMES: Low temperature = 58 on the 5th
High temperature = 94 on the 8th
Maximum daily precipitation = 2.78" on the 12th
Maximum 24-hour rainfall = 3.43" on the 18th-19th
Maximum wind gust = E 54 mph on the 13th
Maximum barometric pressure = 30.295" on the 11th
Minimum barometric pressure = 29.373" on the 13th

NUMBER OF:

Days Cloudy: 2
Days Partly Cloudy: 27
Days Clear/Sunny: 2
Days with Fog/Ground Fog: 17
Days with Dense Fog: 0

Days with thunderstorms: 12
# of Thunderstorms: 18
Days with some type of snowfall: 0

YEAR-TO-DATE:

Temperatures

Mean maximum: 67.7 (-0.9)
Mean minimum: 48.6 (-0.8)
Mean monthly: 58.1 (-0.9)

Degree Days

Heating: 2389.5
Cooling: 929.5

Highest: 98, May 20th
Lowest: 8, February 5th
Days with maximum temperature >= 90: 25
Days with maximum temperature <= 32: 9
Days with minimum temperature <= 32: 45
Days with temperature <= 0: 0

Number of:
Days using Heating: 126
Days using Cooling: 87
Days Cloudy: 40
Days Partly Cloudy: 139
Days Clear/Sunny: 34
Days with fog/ground fog: 72

Precipitation

Aqueous: 36.90" (DEP +8.54")
Maximum monthly: 11.80"/JUL.
Minimum monthly: 2.65"/FEB.

Snowfall: 15.90"
Maximum daily: 4.50"/JAN. 6
Maximum monthly: 8.00"/FEB.
Seasonal total: 16.20"
Days with some type of snowfall: 15
Days with measurable precipitation: 86 or 40%

Days with thunderstorms: 28
Number of thunderstorms: 38

Greatest 24-hour period rainfall: 3.43"/July 18-19th

Wind (Highest Recorded Wind Gust): SSW 64 miles per hour, JAN. 19
Barometer: Highest 30.937" on March 10th; Lowest: 29.196" on March 19th

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Appendix A-5

Statistical Analysis of Monitoring Data

TOTAL SUSPENDED SOLIDS (TSS), (mg/L)						Storms Removed =	none		
					Square		Square		Square
Date	**Influent**	**Sand**	**CSF**	**Influent-Sand**	**Influent-Sand**	**Influent-CFS**	**Influent-CFS**	**Sand-CSF**	**Sand-CSF**
Dec 9, '95	10	93	64	-83	6889	-54	2916	29	841
Feb 21, '96	37	6	12	31	961	25	625	-6	36
Mar 6, '96	15	28	61	-13	169	-46	2116	-33	1089
Mar 19, '96	138	100	20	38	1444	118	13924	80	6400
Mar 28, '96	14	4	3	10	100	11	121	1	1
Apr 24, '96	8	6	6	2	4	2	4	0	0
May 16, '96	7	4	5	3	9	2	4	-1	1
Jun 24, '96	7	42	36	-35	1225	-29	841	6	36
Jul 3, '96	19	7	8	12	144	11	121	-1	1
Jul 15, '96	13	4	5	9	81	8	64	-1	1
Jul 18, '96	9	3	4	6	36	5	25	-1	1
Jul 25, '96	8	2	3	6	36	5	25	-1	1
MEANS	**23.8**	**24.9**	**18.9**						
% Decrease in Concentration (neg. value = increase in conc)				**-4.9%**		**20.4%**		**24.1%**	
Sum of differences				-14		58		72	
Mean Difference				6.3		10.2		3.9	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					11098		20786		8408
Square of sum of differences				196		3364		5184	
n =	12								
Standard Deviation				**31.74**		**43.18**		**26.93**	
t(paired), test statistic				**0.685**		**0.817**		**0.503**	
t(0.10,11), tabular value				**1.363**		**1.363**		**1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				16026		5413		11406	
Sum of (Xi) or (Yi)'s	285	299	227						
Sum of (Xi)^2	21771	21379	9841						
Correlation between groups, r				**0.62**		**0.00**		**0.65**	

TOTAL SUSPENDED SOLIDS (TSS), (mg/L)						Storms Removed =	Dec9, Mar19		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	37	6	12	31	961	25	625	-6	36
Mar 6, '96	15	28	61	-13	169	-46	2116	-33	1089
Mar 28, '96	14	4	3	10	100	11	121	1	1
Apr 24, '96	8	6	6	2	4	2	4	0	0
May 16, '96	7	4	5	3	9	2	4	-1	1
Jun 24, '96	7	42	36	-35	1225	-29	841	6	36
Jul 3, '96	19	7	8	12	144	11	121	-1	1
Jul 15, '96	13	4	5	9	81	8	64	-1	1
Jul 18, '96	9	3	4	6	36	5	25	-1	1
Jul 25, '96	8	2	3	6	36	5	25	-1	1
MEANS	**13.7**	**10.6**	**14.3**						
% Decrease in Concentration (neg. value = increase in conc)				**22.6%**		**-4.4%**		**-34.9%**	
Sum of differences				31		-6		-37	
Mean Difference				**3.1**		**-0.6**		**-3.7**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					2765		3946		1167
Square of sum of differences				961		36		1369	
n =	10								
Standard Deviation				**17.22**		**20.93**		**10.70**	
t(paired), test statistic				**0.569**		**-0.091**		**-1.094**	
t(0.10,9), tabular value				**1.383**		**-1.383**		**-1.383**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				1296		2013		3454	
Sum of (Xi) or (Yi)'s	137	106	143						
Sum of (Xi)^2	2627	2730	5345						
Correlation between groups, r				**-0.14**		**0.03**		**0.84**	

TOTAL SUSPENDED SOLIDS (TSS), (mg/L)						Storms Removed =	Dec9, Mar19, Mar6, Jun24		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	37	6	12	31	961	25	625	-6	36
Mar 28, '96	14	4	3	10	100	11	121	1	1
Apr 24, '96	8	6	6	2	4	2	4	0	0
May 16, '96	7	4	5	3	9	2	4	-1	1
Jul 3, '96	19	7	8	12	144	11	121	-1	1
Jul 15, '96	13	4	5	9	81	8	64	-1	1
Jul 18, '96	9	3	4	6	36	5	25	-1	1
Jul 25, '96	8	2	3	6	36	5	25	-1	1
MEANS	**14.4**	**4.5**	**5.8**						
% Decrease in Concentration (neg. value = increase in conc)				**68.7%**		**60.0%**		**-27.8%**	
Sum of differences				79		69		-10	
Mean Difference				9.9		8.6		-1.3	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					1371		989		42
Square of sum of differences				6241		4761		100	
n =	8								
Standard Deviation				**9.19**		**7.50**		**2.05**	
t(paired), test statistic				**3.040**		**3.252**		**-1.722**	
t(0.10,7), tabular value				**1.415**		**1.415**		**-1.415**	
Conclusion				**Reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				582		846		234	
Sum of (Xi) or (Yi)'s	115	36	46						
Sum of (Xi)^2	2353	182	328						
Correlation between groups, r				**0.55**		**0.88**		**0.76**	

TOTAL PHOSPHORUS (TP), (mg/L)						Storms Removed =	none		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Dec 9, '95	0.11	0.13	0.19	-0.02	0.0004	-0.08	0.0064	-0.06	0.0036
Feb 21, '96	0.08	0.04	0.04	0.04	0.0016	0.04	0.0016	0.00	0.0000
Mar 6, '96	0.11	0.09	0.09	0.02	0.0004	0.02	0.0004	0.00	0.0000
Mar 19, '96	0.19	0.11	0.05	0.08	0.0064	0.14	0.0196	0.06	0.0036
Mar 28, '96	0.06	0.11	0.04	-0.05	0.0025	0.02	0.0004	0.07	0.0049
Apr 24, '96	0.26	0.18	0.17	0.08	0.0064	0.09	0.0081	0.01	0.0001
May 16, '96	0.06	0.13	0.09	-0.07	0.0049	-0.03	0.0009	0.04	0.0016
Jun 24, '96	0.11	0.24	0.22	-0.13	0.0169	-0.11	0.0121	0.02	0.0004
Jul 3, '96	0.13	0.07	0.08	0.06	0.0036	0.05	0.0025	-0.01	0.0001
Jul 15, '96	0.10	0.07	0.04	0.03	0.0009	0.06	0.0036	0.03	0.0009
Jul 18, '96	0.09	0.06	0.04	0.03	0.0009	0.05	0.0025	0.02	0.0004
Jul 25, '96	0.09	0.06	0.05	0.03	0.0009	0.04	0.0016	0.01	0.0001
MEANS	**0.1158**	**0.1075**	**0.0917**						
% Decrease in Concentration (neg. value = increase in conc)				**7.2%**		**20.9%**		**14.7%**	
Sum of differences				0.10		0.29		0.19	
Mean Difference				**0.0083**		**0.0242**		**0.0158**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.0458		0.0597		0.0157
Square of sum of differences				0.0100		0.0841		0.0361	
n =	12								
Standard Deviation				**0.0639**		**0.0692**		**0.0340**	
t(paired), test statistic				**0.452**		**1.210**		**1.615**	
t(0.10,11), tabular value				**1.363**		**1.363**		**1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				0.1628		0.1422		0.1532	
Sum of (Xi) or (Yi)'s	1.39	1.29	1.10						
Sum of (Xi)^2	0.1967	0.1747	0.1474						
Correlation between groups, r				**0.37**		**0.36**		**0.85**	

TOTAL PHOSPHORUS (TP), (mg/L)						Storms Removed =	Dec9		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Feb 21, '96	0.08	0.04	0.04	0.04	0.0016	0.04	0.0016	0.00	0.0000
Mar 6, '96	0.11	0.09	0.09	0.02	0.0004	0.02	0.0004	0.00	0.0000
Mar 19, '96	0.19	0.11	0.05	0.08	0.0064	0.14	0.0196	0.06	0.0036
Mar 28, '96	0.06	0.11	0.04	-0.05	0.0025	0.02	0.0004	0.07	0.0049
Apr 24, '96	0.26	0.18	0.17	0.08	0.0064	0.09	0.0081	0.01	0.0001
May 16, '96	0.06	0.13	0.09	-0.07	0.0049	-0.03	0.0009	0.04	0.0016
Jun 24, '96	0.11	0.24	0.22	-0.13	0.0169	-0.11	0.0121	0.02	0.0004
Jul 3, '96	0.13	0.07	0.08	0.06	0.0036	0.05	0.0025	-0.01	0.0001
Jul 15, '96	0.10	0.07	0.04	0.03	0.0009	0.06	0.0036	0.03	0.0009
Jul 18, '96	0.09	0.06	0.04	0.03	0.0009	0.05	0.0025	0.02	0.0004
Jul 25, '96	0.09	0.06	0.05	0.03	0.0009	0.04	0.0016	0.01	0.0001
MEANS	**0.1164**	**0.1055**	**0.0827**						
% Decrease in Concentration (neg. value = increase in conc)				**9.4%**		**28.9%**		**21.6%**	
Sum of differences				0.12		0.37		0.25	
Mean Difference				**0.0109**		**0.0336**		**0.0227**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.0454		0.0533		0.0121
Square of sum of differences				0.0144		0.1369		0.0625	
n =	11								
Standard Deviation				**0.0664**		**0.0639**		**0.0253**	
t(paired), test statistic				**0.545**		**1.745**		**2.975**	
t(0.10,10), tabular value				**1.372**		**1.372**		**1.372**	
Conclusion				**Do not reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**Difference could be variation in data**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				0.1485		0.1213		0.1285	
Sum of (Xi) or (Yi)'s	1.28	1.16	0.91						
Sum of (Xi)^2	0.1846	0.1578	0.1113						
Correlation between groups, r				**0.38**		**0.43**		**0.91**	

TOTAL PHOSPHORUS (TP), (mg/L)						Storms Removed =	Dec9, Jun24		
					Square		Square		Square
Date	*Influent*	*Sand*	CSF	*Influent-Sand*	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	0.08	0.04	0.04	0.04	0.0016	0.04	0.0016	0.00	0.0000
Mar 6, '96	0.11	0.09	0.09	0.02	0.0004	0.02	0.0004	0.00	0.0000
Mar 19, '96	0.19	0.11	0.05	0.08	0.0064	0.14	0.0196	0.06	0.0036
Mar 28, '96	0.06	0.11	0.04	-0.05	0.0025	0.02	0.0004	0.07	0.0049
Apr 24, '96	0.26	0.18	0.17	0.08	0.0064	0.09	0.0081	0.01	0.0001
May 16, '96	0.06	0.13	0.09	-0.07	0.0049	-0.03	0.0009	0.04	0.0016
Jul 3, '96	0.13	0.07	0.08	0.06	0.0036	0.05	0.0025	-0.01	0.0001
Jul 15, '96	0.10	0.07	0.04	0.03	0.0009	0.06	0.0036	0.03	0.0009
Jul 18, '96	0.09	0.06	0.04	0.03	0.0009	0.05	0.0025	0.02	0.0004
Jul 25, '96	0.09	0.06	0.05	0.03	0.0009	0.04	0.0016	0.01	0.0001
MEANS	**0.1170**	**0.0920**	**0.0690**						
% Decrease in Concentration (neg. value = increase in conc)				**21.4%**		**41.0%**		**25.0%**	
Sum of differences				0.25		0.48		0.23	
Mean Difference				**0.0250**		**0.0480**		**0.0230**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.0285		0.0412		0.0117
Square of sum of differences				0.0625		0.2304		0.0529	
n =	10								
Standard Deviation				**0.0497**		**0.0449**		**0.0267**	
t(paired), test statistic				**1.590**		**3.379**		**2.725**	
t(0.10,9), tabular value				**1.383**		**1.383**		**1.383**	
Conclusion				**Reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				0.1221		0.0971		0.0757	
Sum of (Xi) or (Yi)'s	1.17	0.92	0.69						
Sum of (Xi)^2	0.1725	0.1002	0.0629						
Correlation between groups, r				**0.61**		**0.70**		**0.79**	

TOTAL KJELDAHL NITROGEN (TKN), (mg/L)						Storms Removed =	none		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Dec 9, '95	0.12	1.13	2.34	-1.01	1.0201	-2.22	4.9284	-1.21	1.4641
Feb 21, '96	0.40	0.27	0.30	0.13	0.0169	0.10	0.0100	-0.03	0.0009
Mar 6, '96	0.75	0.45	0.48	0.30	0.0900	0.27	0.0729	-0.03	0.0009
Mar 19, '96	1.04	0.54	0.39	0.50	0.2500	0.65	0.4225	0.15	0.0225
Mar 28, '96	0.37	0.64	0.41	-0.27	0.0729	-0.04	0.0016	0.23	0.0529
Apr 24, '96	0.90	0.80	0.85	0.10	0.0100	0.05	0.0025	-0.05	0.0025
May 16, '96	0.26	0.56	0.25	-0.30	0.0900	0.01	0.0001	0.31	0.0961
Jun 24, '96	1.00	1.96	1.85	-0.96	0.9216	-0.85	0.7225	0.11	0.0121
Jul 3, '96	0.76	0.63	0.67	0.13	0.0169	0.09	0.0081	-0.04	0.0016
Jul 15, '96	0.39	0.12	0.13	0.27	0.0729	0.26	0.0676	-0.01	0.0001
Jul 18, '96	0.52	0.36	0.27	0.16	0.0256	0.25	0.0625	0.09	0.0081
Jul 25, '96	0.60	0.61	0.45	-0.01	0.0001	0.15	0.0225	0.16	0.0256
MEANS	**0.5925**	**0.6725**	**0.6992**						
% Decrease in Concentration (neg. value = increase in conc)				**-13.5%**		**-18.0%**		**-4.0%**	
Sum of differences				-0.96		-1.28		-0.32	
Mean Difference				**-0.0800**		**-0.1067**		**-0.0267**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					2.5870		6.3212		1.6874
Square of sum of differences				0.9216		1.6384		0.1024	
n =	12								
Standard Deviation				**0.4777**		**0.7498**		**0.3907**	
t(paired), test statistic				**-0.580**		**-0.493**		**-0.236**	
t(0.10,11), tabular value				**1.363**		**1.363**		**1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				5.2839		4.9684		8.6696	
Sum of (Xi) or (Yi)'s	7.11	8.07	8.39						
Sum of (Xi)^2	5.1931	7.9617	11.0649						
Correlation between groups, r				**0.32**		**0.00**		**0.83**	

TOTAL KJELDAHL NITROGEN (TKN), (mg/L)						Storms Removed =	Dec9		
					Square		Square		Square
Date	**Influent**	**Sand**	**CSF**	**Influent-Sand**	**Influent-Sand**	**Influent-CFS**	**Influent-CFS**	**Sand-CSF**	**Sand-CSF**
Feb 21, '96	0.40	0.27	0.30	0.13	0.0169	0.10	0.0100	-0.03	0.0009
Mar 6, '96	0.75	0.45	0.48	0.30	0.0900	0.27	0.0729	-0.03	0.0009
Mar 19, '96	1.04	0.54	0.39	0.50	0.2500	0.65	0.4225	0.15	0.0225
Mar 28, '96	0.37	0.64	0.41	-0.27	0.0729	-0.04	0.0016	0.23	0.0529
Apr 24, '96	0.90	0.80	0.85	0.10	0.0100	0.05	0.0025	-0.05	0.0025
May 16, '96	0.26	0.56	0.25	-0.30	0.0900	0.01	0.0001	0.31	0.0961
Jun 24, '96	1.00	1.96	1.85	-0.96	0.9216	-0.85	0.7225	0.11	0.0121
Jul 3, '96	0.76	0.63	0.67	0.13	0.0169	0.09	0.0081	-0.04	0.0016
Jul 15, '96	0.39	0.12	0.13	0.27	0.0729	0.26	0.0676	-0.01	0.0001
Jul 18, '96	0.52	0.36	0.27	0.16	0.0256	0.25	0.0625	0.09	0.0081
Jul 25, '96	0.60	0.61	0.45	-0.01	0.0001	0.15	0.0225	0.16	0.0256
MEANS	**0.6355**	**0.6309**	**0.5500**						
% Decrease in Concentration (neg. value = increase in conc)				**0.7%**		**13.4%**		**12.8%**	
Sum of differences				0.05		0.94		0.89	
Mean Difference				**0.0045**		**0.0855**		**0.0809**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					1.5669		1.3928		0.2233
Square of sum of differences				0.0025		0.8836		0.7921	
n =	11								
Standard Deviation				**0.3958**		**0.3623**		**0.1230**	
t(paired), test statistic				**0.038**		**0.782**		**2.182**	
t(0.10,10), tabular value				**1.372**		**1.372**		**1.372**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				5.1483		4.6876		6.0254	
Sum of (Xi) or (Yi)'s	6.99	6.94	6.05						
Sum of (Xi)^2	5.1787	6.6848	5.5893						
Correlation between groups, r				**0.57**		**0.65**		**0.97**	

TOTAL KJELDAHL NITROGEN (TKN), (mg/L)						Storms Removed =	Dec9, Jun24		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Feb 21, '96	0.40	0.27	0.30	0.13	0.0169	0.10	0.0100	-0.03	0.0009
Mar 6, '96	0.75	0.45	0.48	0.30	0.0900	0.27	0.0729	-0.03	0.0009
Mar 19, '96	1.04	0.54	0.39	0.50	0.2500	0.65	0.4225	0.15	0.0225
Mar 28, '96	0.37	0.64	0.41	-0.27	0.0729	-0.04	0.0016	0.23	0.0529
Apr 24, '96	0.90	0.80	0.85	0.10	0.0100	0.05	0.0025	-0.05	0.0025
May 16, '96	0.26	0.56	0.25	-0.30	0.0900	0.01	0.0001	0.31	0.0961
Jul 3, '96	0.76	0.63	0.67	0.13	0.0169	0.09	0.0081	-0.04	0.0016
Jul 15, '96	0.39	0.12	0.13	0.27	0.0729	0.26	0.0676	-0.01	0.0001
Jul 18, '96	0.52	0.36	0.27	0.16	0.0256	0.25	0.0625	0.09	0.0081
Jul 25, '96	0.60	0.61	0.45	-0.01	0.0001	0.15	0.0225	0.16	0.0256
MEANS	**0.5990**	**0.4980**	**0.4200**						
% Decrease in Concentration (neg. value = increase in conc)				**16.9%**		**29.9%**		**15.7%**	
Sum of differences				1.01		1.79		0.78	
Mean Difference				**0.1010**		**0.1790**		**0.0780**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.6453		0.6703		0.2112
Square of sum of differences				1.0201		3.2041		0.6084	
n =	10								
Standard Deviation				**0.2457**		**0.1972**		**0.1293**	
t(paired), test statistic				**1.300**		**2.871**		**1.908**	
t(0.10,9), tabular value				**1.383**		**1.383**		**1.383**	
Conclusion				**Do not reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**Difference could be variation in data**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				3.1883		2.8376		2.3994	
Sum of (Xi) or (Yi)'s	5.99	4.98	4.20						
Sum of (Xi)^2	4.1787	2.8432	2.1668						
Correlation between groups, r				**0.44**		**0.66**		**0.80**	

AMMONIA (NH3), (mg/L)						Storms Removed =	none		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Dec 9, '95	0.04	0.04	1.56	0.00	0.0000	-1.52	2.3104	-1.52	2.3104
Feb 21, '96	0.05	0.13	0.14	-0.08	0.0064	-0.09	0.0081	-0.01	0.0001
Mar 6, '96	0.36	0.11	0.29	0.25	0.0625	0.07	0.0049	-0.18	0.0324
Mar 19, '96	0.11	0.10	0.04	0.01	0.0001	0.07	0.0049	0.06	0.0036
Mar 28, '96	0.12	0.19	0.09	-0.07	0.0049	0.03	0.0009	0.10	0.0100
Apr 24, '96	0.13	0.08	0.11	0.05	0.0025	0.02	0.0004	-0.03	0.0009
May 16, '96	0.04	0.05	0.04	-0.01	0.0001	0.00	0.0000	0.01	0.0001
Jun 24, '96	0.44	0.44	0.31	0.00	0.0000	0.13	0.0169	0.13	0.0169
Jul 3, '96	0.17	0.15	0.14	0.02	0.0004	0.03	0.0009	0.01	0.0001
Jul 15, '96	0.04	0.04	0.04	0.00	0.0000	0.00	0.0000	0.00	0.0000
Jul 18, '96	0.12	0.04	0.04	0.08	0.0064	0.08	0.0064	0.00	0.0000
Jul 25, '96	0.04	0.06	0.05	-0.02	0.0004	-0.01	0.0001	0.01	0.0001
MEANS	**0.1383**	**0.1192**	**0.2375**						
% Decrease in Concentration (neg. value = increase in conc)				**13.9%**		**-71.7%**		**-99.3%**	
Sum of differences				0.23		-1.19		-1.42	
Mean Difference				**0.0192**		**-0.0992**		**-0.1183**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.0837		2.3539		2.3746
Square of sum of differences				0.0529		1.4161		2.0164	
n =	12								
Standard Deviation				**0.0849**		**0.4508**		**0.4479**	
t(paired), test statistic				**0.782**		**-0.762**		**-0.915**	
t(0.10,11), tabular value				**1.363**		**-1.363**		**-1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				0.3218		0.3735		0.3080	
Sum of (Xi) or (Yi)'s	1.66	1.43	2.85						
Sum of (Xi)^2	0.4188	0.3085	2.6821						
Correlation between groups, r				0.77		-0.03		-0.06	

AMMONIA (NH3), (mg/L)						Storms Removed =	Dec9		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	0.05	0.13	0.14	-0.08	0.0064	-0.09	0.0081	-0.01	0.0001
Mar 6, '96	0.36	0.11	0.29	0.25	0.0625	0.07	0.0049	-0.18	0.0324
Mar 19, '96	0.11	0.10	0.04	0.01	0.0001	0.07	0.0049	0.06	0.0036
Mar 28, '96	0.12	0.19	0.09	-0.07	0.0049	0.03	0.0009	0.10	0.0100
Apr 24, '96	0.13	0.08	0.11	0.05	0.0025	0.02	0.0004	-0.03	0.0009
May 16, '96	0.04	0.05	0.04	-0.01	0.0001	0.00	0.0000	0.01	0.0001
Jun 24, '96	0.44	0.44	0.31	0.00	0.0000	0.13	0.0169	0.13	0.0169
Jul 3, '96	0.17	0.15	0.14	0.02	0.0004	0.03	0.0009	0.01	0.0001
Jul 15, '96	0.04	0.04	0.04	0.00	0.0000	0.00	0.0000	0.00	0.0000
Jul 18, '96	0.12	0.04	0.04	0.08	0.0064	0.08	0.0064	0.00	0.0000
Jul 25, '96	0.04	0.06	0.05	-0.02	0.0004	-0.01	0.0001	0.01	0.0001
MEANS	**0.1473**	**0.1264**	**0.1173**						
% Decrease in Concentration (neg. value = increase in conc)				**14.2%**		**20.4%**		**7.2%**	
Sum of differences				0.23		0.33		0.10	
Mean Difference				**0.0209**		**0.0300**		**0.0091**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					0.0837		0.0435		0.0642
Square of sum of differences				0.0529		0.1089		0.0100	
n =	11								
Standard Deviation				**0.0888**		**0.0580**		**0.0796**	
t(paired), test statistic				**0.781**		**1.717**		**0.379**	
t(0.10,10), tabular value				**1.372**		**1.372**		**1.372**	
Conclusion				**Do not reject Ho**		**Reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**True concentration difference**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				0.3202		0.3111		0.2456	
Sum of (Xi) or (Yi)'s	1.62	1.39	1.29						
Sum of (Xi)^2	0.4172	0.3069	0.2485						
Correlation between groups, r				0.75		0.92		0.73	

BIOCHEMICAL OXYGEN DEMAND (BOD5), (mg/L)						Storms Removed =	none		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Dec 9, '95	0.5	0.5	4	0	0	-3.5	12.25	-3.5	12.25
Feb 21, '96	3	3	2	0	0	1	1	1	1
Mar 6, '96	5	2	2	3	9	3	9	0	0
Mar 19, '96	5	2	2	3	9	3	9	0	0
Mar 28, '96	3	7	3	-4	16	0	0	4	16
Apr 24, '96	7	4	6	3	9	1	1	-2	4
May 16, '96	3	4	3	-1	1	0	0	1	1
Jun 24, '96	4	34	29	-30	900	-25	625	5	25
Jul 3, '96	11	7	6	4	16	5	25	1	1
Jul 15, '96	4	2	0.5	2	4	3.5	12.25	1.5	2.25
Jul 18, '96	5	3	2	2	4	3	9	1	1
Jul 25, '96	6	3	3	3	9	3	9	0	0
MEANS	**4.7083**	**5.9583**	**5.2083**						
% Decrease in Concentration (neg. value = increase in conc)				**-26.5%**		**-10.6%**		**12.6%**	
Sum of differences				-15		-6		9	
Mean Difference				**-1.25**		**-0.50**		**0.75**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					977		712.5		63.5
Square of sum of differences				225		36		81	
n =	12								
Standard Deviation				**9.3335**		**8.0312**		**2.2714**	
t(paired), test statistic				**-0.464**		**-0.216**		**1.144**	
t(0.10,11), tabular value				**-1.363**		**-1.363**		**1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				344.25		300		1117	
Sum of (Xi) or (Yi)'s	56.50	71.50	62.50						
Sum of (Xi)^2	340.25	1325.25	972.25						
Correlation between groups, r				**0.03**		**0.03**		**0.98**	

BIOCHEMICAL OXYGEN DEMAND (BOD5), (mg/L)						Storms Removed =	Dec9, Jun24		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	3	3	2	0	0	1	1	1	1
Mar 6, '96	5	2	2	3	9	3	9	0	0
Mar 19, '96	5	2	2	3	9	3	9	0	0
Mar 28, '96	3	7	3	-4	16	0	0	4	16
Apr 24, '96	7	4	6	3	9	1	1	-2	4
May 16, '96	3	4	3	-1	1	0	0	1	1
Jul 3, '96	11	7	6	4	16	5	25	1	1
Jul 15, '96	4	2	0.5	2	4	3.5	12.25	1.5	2.25
Jul 18, '96	5	3	2	2	4	3	9	1	1
Jul 25, '96	6	3	3	3	9	3	9	0	0
MEANS	**5.2000**	**3.7000**	**2.9500**						
% Decrease in Concentration (neg. value = increase in conc)				**28.8%**		**43.3%**		**20.3%**	
Sum of differences				15.0		22.5		7.5	
Mean Difference				**1.50**		**2.25**		**0.75**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					77		75.25		26.25
Square of sum of differences				225		506.25		56.25	
n =	10								
Standard Deviation				**2.4608**		**1.6541**		**1.5138**	
t(paired), test statistic				**1.928**		**4.301**		**1.567**	
t(0.10,9), tabular value				**1.383**		**1.383**		**1.383**	
Conclusion				**Reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				208		182		129.0000	
Sum of (Xi) or (Yi)'s	52.00	37.00	29.50						
Sum of (Xi)^2	324	169.0000	115.25						
Correlation between groups, r				**0.38**		**0.74**		**0.66**	

TOTAL ORGANIC CARBON (TOC), (mg/L)						Storms Removed =	none		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Dec 9, '95	1.98	1.26	2.74	0.72	0.5184	-0.76	0.5776	-1.48	2.1904
Feb 21, '96	1.64	2.72	1.90	-1.08	1.1664	-0.26	0.0676	0.82	0.6724
Mar 6, '96	7.80	4.70	4.50	3.10	9.6100	3.30	10.8900	0.20	0.0400
Mar 19, '96	5.09	3.26	1.60	1.83	3.3489	3.49	12.1801	1.66	2.7556
Mar 28, '96	7.09	5.36	2.95	1.73	2.9929	4.14	17.1396	2.41	5.8081
Apr 24, '96	5.06	7.89	2.38	-2.83	8.0089	2.68	7.1824	5.51	30.3601
May 16, '96	4.05	5.99	6.11	-1.94	3.7636	-2.06	4.2436	-0.12	0.0144
Jun 24, '96	30.08	40.98	41.71	-10.90	118.8100	-11.63	135.2569	-0.73	0.5329
Jul 3, '96	10.26	16.08	7.18	-5.82	33.8724	3.08	9.4864	8.90	79.2100
Jul 15, '96	6.58	3.20	7.05	3.38	11.4244	-0.47	0.2209	-3.85	14.8225
Jul 18, '96	6.91	4.21	10.07	2.70	7.2900	-3.16	9.9856	-5.86	34.3396
Jul 25, '96	10.22	6.68	8.48	3.54	12.5316	1.74	3.0276	-1.80	3.2400
MEANS	**8.0633**	**8.5275**	**8.0558**						
% Decrease in Concentration (neg. value = increase in conc)				**-5.8%**		**0.1%**		**5.5%**	
Sum of differences				-5.57		0.09		5.66	
Mean Difference				**-0.4642**		**0.0075**		**0.4717**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					213.3375		210.2583		173.9860
Square of sum of differences				31.0249		0.0081		32.0356	
n =	12								
Standard Deviation				**4.3771**		**4.3720**		**3.9464**	
t(paired), test statistic				**-0.367**		**0.006**		**0.414**	
t(0.10,11), tabular value				**-1.363**		**1.363**		**1.363**	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could *be variation in* data**		**Difference could *be variation in* data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				1678.4702		1640.4309		2052.5068	
Sum of (Xi) or (Yi)'s	96.76	102.33	96.67						
Sum of (Xi)^2	1391.1992	2179.0787	2099.9209						
Correlation between groups, r				**0.96**		**0.96**		**0.93**	

TOTAL ORGANIC CARBON (TOC), (mg/L)						Storms Removed =	Dec9, Jun24		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Feb 21, '96	1.64	2.72	1.90	-1.08	1.1664	-0.26	0.0676	0.82	0.6724
Mar 6, '96	7.80	4.70	4.50	3.10	9.6100	3.30	10.8900	0.20	0.0400
Mar 19, '96	5.09	3.26	1.60	1.83	3.3489	3.49	12.1801	1.66	2.7556
Mar 28, '96	7.09	5.36	2.95	1.73	2.9929	4.14	17.1396	2.41	5.8081
Apr 24, '96	5.06	7.89	2.38	-2.83	8.0089	2.68	7.1824	5.51	30.3601
May 16, '96	4.05	5.99	6.11	-1.94	3.7636	-2.06	4.2436	-0.12	0.0144
Jul 3, '96	10.26	16.08	7.18	-5.82	33.8724	3.08	9.4864	8.90	79.2100
Jul 15, '96	6.58	3.20	7.05	3.38	11.4244	-0.47	0.2209	-3.85	14.8225
Jul 18, '96	6.91	4.21	10.07	2.70	7.2900	-3.16	9.9856	-5.86	34.3396
Jul 25, '96	10.22	6.68	8.48	3.54	12.5316	1.74	3.0276	-1.80	3.2400
MEANS	**6.4700**	**6.0090**	**5.2220**						
% Decrease in Concentration (neg. value = increase in conc)				**7.1%**		**19.3%**		**13.1%**	
Sum of differences				4.61		12.48		7.87	
Mean Difference				**0.4610**		**1.2480**		**0.7870**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					94.0091		74.4238		171.2627
Square of sum of differences				21.2521		155.7504		61.9369	
n =	10								
Standard Deviation				**3.1952**		**2.5571**		**4.2826**	
t(paired), test statistic				**0.456**		**1.543**		**0.581**	
t(0.10,9), tabular value				**1.383**		**1.383**		**1.383**	
Conclusion				**Do not reject Ho**		**Reject Ho**		**Do not reject Ho**	
Interpretation				**Difference could be variation in data**		**True concentration difference**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				443.297		380.3689		339.7786	
Sum of (Xi) or (Yi)'s	64.70	60.09	52.22						
Sum of (Xi)^2	482.4724	498.1307	352.6892						
Correlation between groups, r				**0.58**		**0.59**		**0.25**	

TOTAL RECOVERABLE COPPER (T.R. Cu), (ug/L)						Storms Removed =	none		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Dec 9, '95	13	29	13	-16	256	0	0	16	256
Feb 21, '96	20	21	21	-1	1	-1	1	0	0
Mar 6, '96	25	22	25	3	9	0	0	-3	9
Mar 19, '96	68	21	16	47	2209	52	2704	5	25
Mar 28, '96	18	30	11	-12	144	7	49	19	361
Apr 24, '96	39	36	46	3	9	-7	49	-10	100
May 16, '96	8	15	11	-7	49	-3	9	4	16
Jun 24, '96	36	37	30	-1	1	6	36	7	49
Jul 3, '96	32	58	54	-26	676	-22	484	4	16
Jul 15, '96	23	7	5	16	256	18	324	2	4
Jul 18, '96	18	13	11	5	25	7	49	2	4
Jul 25, '96	28	16	9	12	144	19	361	7	49
MEANS	**27.3**	**25.4**	**21.0**						
% Decrease in Concentration (neg. value = increase in conc)				**7.0%**		**23.2%**		**17.4%**	
Sum of differences				23		76		53	
Mean Difference				**3.5**		**6.9**		**3.4**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					3779		4066		889
Square of sum of differences				529		5776		2809	
n =	12								
Standard Deviation				**18.43**		**18.05**		7.72	
t(paired), test statistic				0.667		1.326		1.510	
t(0.10,11), tabular value				1.363		1.363		1.363	
Conclusion				**Do not reject Ho**		**Do not reject Ho**		**Reject Ho**	
Interpretation				**Difference could *be variation in* data**		**Difference could *be variation in* data**		**True *concentration* difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				8870		7755		8419	
Sum of (Xi) or (Yi)'s	328	305	252						
Sum of (Xi)^2	11684	9835	7892						
Correlation between groups, r				**0.22**		**0.33**		**0.87**	

TOTAL RECOVERABLE COPPER (T.R. Cu), (ug/L)						Storms Removed =	Dec9		
Date	Influent	Sand	CSF	Influent-Sand	Square Influent-Sand	Influent-CFS	Square Influent-CFS	Sand-CSF	Square Sand-CSF
Feb 21, '96	20	21	21	-1	1	-1	1	0	0
Mar 6, '96	25	22	25	3	9	0	0	-3	9
Mar 19, '96	68	21	16	47	2209	52	2704	5	25
Mar 28, '96	18	30	11	-12	144	7	49	19	361
Apr 24, '96	39	36	46	3	9	-7	49	-10	100
May 16, '96	8	15	11	-7	49	-3	9	4	16
Jun 24, '96	36	37	30	-1	1	6	36	7	49
Jul 3, '96	32	58	54	-26	676	-22	484	4	16
Jul 15, '96	23	7	5	16	256	18	324	2	4
Jul 18, '96	18	13	11	5	25	7	49	2	4
Jul 25, '96	28	16	9	12	144	19	361	7	49
MEANS	**28.6**	**25.1**	**21.7**						
% Decrease in Concentration (neg. value = increase in conc)				**12.4%**		**24.1%**		**13.4%**	
Sum of differences				39		76		37	
Mean Difference				3.5		6.9		3.4	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					3523		4066		633
Square of sum of differences				1521		5776		1369	
n =	11								
Standard Deviation				**18.40**		**18.82**		7.13	
t(paired), test statistic				0.639		1.218		1.564	
t(0.10,10), tabular value				1.372		1.372		1.372	
Conclusion				***Do not reject Ho***		***Do not reject Ho***		**Reject Ho**	
Interpretation				**Difference could be variation in data**		**Difference could be variation in data**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				8493		7586		8042	
Sum of (Xi) or (Yi)'s	315	276	239						
Sum of (Xi)^2	11515	8994	7723						
Correlation between groups, r				0.26		0.30		0.89	

TOTAL RECOVERABLE ZINC (T.R. Zn), (ug/L)						Storms Removed =	none		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Dec 9, '95	41	78	112	-37	1369	-71	5041	-34	1156
Feb 21, '96	32	59	64	-27	729	-32	1024	-5	25
Mar 6, '96	35	79	63	-44	1936	-28	784	16	256
Mar 19, '96	96	158	116	-62	3844	-20	400	42	1764
Mar 28, '96	41	193	132	-152	23104	-91	8281	61	3721
Apr 24, '96	69	32	45	37	1369	24	576	-13	169
May 16, '96	59	84	86	-25	625	-27	729	-2	4
Jun 24, '96	90	272	220	-182	33124	-130	16900	52	2704
Jul 3, '96	65	366	362	-301	90601	-297	88209	4	16
Jul 15, '96	77	110	112	-33	1089	-35	1225	-2	4
Jul 18, '96	73	128	122	-55	3025	-49	2401	6	36
Jul 25, '96	115	179	147	-64	4096	-32	1024	32	1024
MEANS	**66.1**	**144.8**	**131.8**						
% Decrease in Concentration (neg. value = increase in conc)				**-119.2%**		**-99.4%**		**9.0%**	
Sum of differences				-945		-788		157	
Mean Difference				**-82.5**		**-65.2**		**17.4**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					164911		126594		10879
Square of sum of differences				893025		620944		24649	
n =	12								
Standard Deviation				90.70		**82.49**		**28.32**	
t(paired), test statistic				**-3.153**		**-2.737**		**2.124**	
t(0.10,11), tabular value				**-1.363**		**-1.363**		**1.363**	
Conclusion				**Reject Ho**		**Reject Ho**		**Reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				124765		111337		316538	
Sum of (Xi) or (Yi)'s	793	1738	1581						
Sum of (Xi)^2	59877	354564	289391						
Correlation between groups, r				**0.36**		**0.28**		**0.96**	

TOTAL RECOVERABLE ZINC (T.R. Zn), (ug/L)						Storms Removed =	Dec9		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	32	59	64	-27	729	-32	1024	-5	25
Mar 6, '96	35	79	63	-44	1936	-28	784	16	256
Mar 19, '96	96	158	116	-62	3844	-20	400	42	1764
Mar 28, '96	41	193	132	-152	23104	-91	8281	61	3721
Apr 24, '96	69	32	45	37	1369	24	576	-13	169
May 16, '96	59	84	86	-25	625	-27	729	-2	4
Jun 24, '96	90	272	220	-182	33124	-130	16900	52	2704
Jul 3, '96	65	366	362	-301	90601	-297	88209	4	16
Jul 15, '96	77	110	112	-33	1089	-35	1225	-2	4
Jul 18, '96	73	128	122	-55	3025	-49	2401	6	36
Jul 25, '96	115	179	147	-64	4096	-32	1024	32	1024
MEANS	**68.4**	**150.9**	**133.5**						
% Decrease in Concentration (neg. value = increase in conc)				**-120.7%**		**-95.3%**		**11.5%**	
Sum of differences				-908		-717		191	
Mean Difference				**-82.5**		**-65.2**		**17.4**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					163542		121553		9723
Square of sum of differences				824464		514089		36481	
n =	11								
Standard Deviation				**94.12**		**86.50**		**25.31**	
t(paired), test statistic				**-2.909**		**-2.499**		**2.275**	
t(0.10,10), tabular value **Conclusion**				**-1.372** **Reject Ho**		**-1.372** **Reject Ho**		**1.372** **Reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**True concentration difference**	
CORRELATION									
Sum of (Xi)*(Yi)'s				121567		106745		307802	
Sum of (Xi) or (Yi)'s	752	1660	1469						
Sum of (Xi)^2	58196	348480	276847						
Correlation between groups, r				**0.31**		**0.27**		**0.97**	

HARDNESS, (mg/L)						Storms Removed =	none		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Dec 9, '95	2.00	29.00	14.00	-27.00	729.0000	-12.00	144.0000	15.00	225.0000
Feb 21, '96	1.49	1.87	6.01	-0.38	0.1444	-4.52	20.4304	-4.14	17.1396
Mar 6, '96	2.25	14.50	8.59	-12.25	150.0625	-6.34	40.1956	5.91	34.9281
Mar 19, '96	6.89	11.30	17.80	-4.41	19.4481	-10.91	119.0281	-6.50	42.2500
Mar 28, '96	2.11	11.50	19.20	-9.39	88.1721	-17.09	292.0681	-7.70	59.2900
Apr 24, '96	2.70	32.80	26.50	-30.10	906.0100	-23.80	566.4400	6.30	39.6900
May 16, '96	1.71	34.80	35.90	-33.09	1094.9481	-34.19	1168.9561	-1.10	1.2100
Jun 24, '96	4.62	17.40	21.30	-12.78	163.3284	-16.68	278.2224	-3.90	15.2100
Jul 3, '96	7.36	22.40	20.50	-15.04	226.2016	-13.14	172.6596	1.90	3.6100
Jul 15, '96	4.58	9.14	10.00	-4.56	20.7936	-5.42	29.3764	-0.86	0.7396
Jul 18, '96	5.68	11.10	14.40	-5.42	29.3764	-8.72	76.0384	-3.30	10.8900
Jul 25, '96	4.14	17.60	23.70	-13.46	181.1716	-19.56	382.5936	-6.10	37.2100
MEANS	**3.7942**	**17.7842**	**18.1583**						
% Decrease in Concentration (neg. value = increase in conc)				**-368.7%**		**-378.6%**		**-2.1%**	
Sum of differences				-167.88		-172.37		-4.49	
Mean Difference				-13.9900		**-14.3642**		**-0.3742**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					3608.6568		3290.0087		487.1673
Square of sum of differences				28183.6944		29711.4169		20.1601	
n =	12								
Standard Deviation				**10.7027**		**8.6026**		**6.6434**	
t(paired), test statistic				**-4.528**		**-5.784**		**-0.195**	
t(0.10,11), tabular value				**-1.363**		**1.363**		**1.363**	
Conclusion				**Reject Ho**		**Reject Ho**		**Do not reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				766.6265		827.3714		4580.4337	
Sum of (Xi) or (Yi)'s	45.53	213.41	217.90						
Sum of (Xi)^2	219.3133	4922.5965	4725.4382						
Correlation between groups, r				-0.19		0.00		0.76	

HARDNESS, (mg/L)						Storms Removed =	Dec9		
					Square		Square		Square
Date	Influent	Sand	CSF	Influent-Sand	Influent-Sand	Influent-CFS	Influent-CFS	Sand-CSF	Sand-CSF
Feb 21, '96	1.49	1.87	6.01	-0.38	0.1444	-4.52	20.4304	-4.14	17.1396
Mar 6, '96	2.25	14.50	8.59	-12.25	150.0625	-6.34	40.1956	5.91	34.9281
Mar 19, '96	6.89	11.30	17.80	-4.41	19.4481	-10.91	119.0281	-6.50	42.2500
Mar 28, '96	2.11	11.50	19.20	-9.39	88.1721	-17.09	292.0681	-7.70	59.2900
Apr 24, '96	2.70	32.80	26.50	-30.10	906.0100	-23.80	566.4400	6.30	39.6900
May 16, '96	1.71	34.80	35.90	-33.09	1094.9481	-34.19	1168.9561	-1.10	1.2100
Jun 24, '96	4.62	17.40	21.30	-12.78	163.3284	-16.68	278.2224	-3.90	15.2100
Jul 3, '96	7.36	22.40	20.50	-15.04	226.2016	-13.14	172.6596	1.90	3.6100
Jul 15, '96	4.58	9.14	10.00	-4.56	20.7936	-5.42	29.3764	-0.86	0.7396
Jul 18, '96	5.68	11.10	14.40	-5.42	29.3764	-8.72	76.0384	-3.30	10.8900
Jul 25, '96	4.14	17.60	23.70	-13.46	181.1716	-19.56	382.5936	-6.10	37.2100
MEANS	**3.9573**	**16.7645**	**18.5364**						
% Decrease in Concentration (neg. value = increase in conc)				**-323.6%**		**-368.4%**		**-10.6%**	
Sum of differences				-140.88		-160.37		-19.49	
Mean Difference				**-12.8073**		**-14.5791**		**-1.7718**	
TEST FOR SIGNIFICANCE IN DIFFERENCES									
Sum of squared differences					2879.6568		3146.0087		262.1673
Square of sum of differences				19847.1744		25718.5369		379.8601	
n =	11								
Standard Deviation				**10.3700**		**8.9887**		**4.7711**	
t(paired), test statistic				**-4.096**		**-5.379**		**-1.232**	
t(0.10,10), tabular value				**-1.372**		**-1.372**		**-1.372**	
Conclusion				**Reject Ho**		**Reject Ho**		**Do not reject Ho**	
Interpretation				**True concentration difference**		**True concentration difference**		**Difference could be variation in data**	
CORRELATION									
Sum of (Xi)*(Yi)'s				708.6265		799.3714		4174.4337	
Sum of (Xi) or (Yi)'s	43.53	184.41	203.90						
Sum of (Xi)^2	215.3133	4081.5965	4529.4382						
Correlation between groups, r				**-0.10**		**-0.04**		**0.88**	