

1984

## Highway Detention Basins: A Means of Controlling Highway Runoff Pollution

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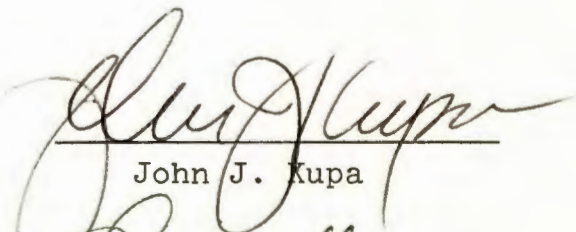
HIGHWAY DETENTION BASINS:  
A MEANS OF CONTROLLING HIGHWAY RUNOFF POLLUTION

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Graduate Curriculum in  
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December, 1984

MASTER OF COMMUNITY PLANNING  
RESEARCH PROJECT  
OF  
JANE WEIDMAN

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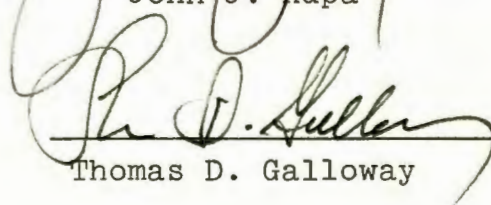
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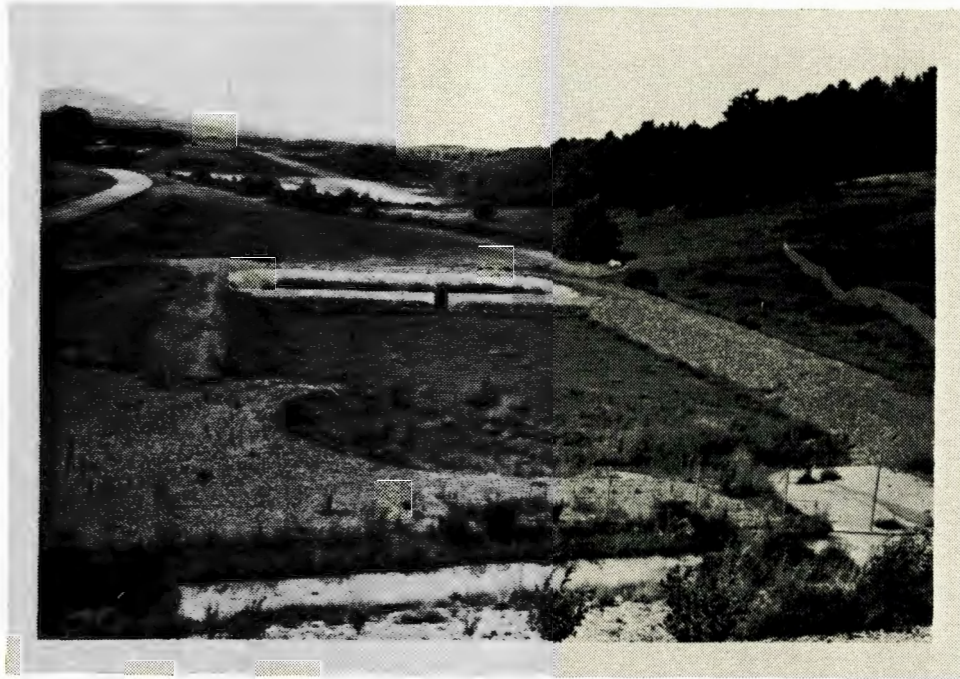
Director



Thomas D. Galloway

## ACKNOWLEDGEMENTS

The undertaking of this project required research of both a general nature on highway runoff and methods of control, and on specific studies and projects which have been put into place to control highway runoff. I would like to acknowledge those persons in various positions throughout Rhode Island who assisted me in my information gathering. These persons include Eva Hoffman, Graduate School of Oceanography, URI; Robert Dyer of the Providence office, and Robert Milligan of the Boston office of the Federal Highway Administration; Tony Winiarski, formerly of the Planning Division of the RI Department of Transportation; James Capaldi of the Public Works Division of the Department of Transportation; Phil Albert of the Division of Water Resources of the RI Department of Environmental Management; William Falcone and Peter Calise of the RI Water Resources Board; John Feinstein of Wilber Smith and Associates; and Joe Giordano of Gordon Archibald, Inc. I would especially like to acknowledge Professor John Kupa for providing me with much background material, guidance and review, and Kenneth DeCosta for technical review.



CONTAINMENT BASIN  
INTERSTATE 190, MASSACHUSETTS

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## CHAPTER I. HIGHWAY RUNOFF CONTAMINANTS AND IMPACTS

### Introduction

In recent years, much attention has been focused on non-point source pollution as a significant contributor to the degradation of water quality in this country. Non-point source pollution is simply stormwater runoff from urban or developed land which carries surface contaminants into a receiving water body - a stream, river, reservoir, lake, bay or ocean. Under federal water pollution control legislation, point sources such as industrial and municipal wastewater discharges have been regulated (i.e. limited) through a permit system and requirements for certain levels of treatment and treatment technology. With this system of regulation established, concern has shifted to control of non-point pollution, which is at least equally important, but considerably more difficult to achieve.

Aside from the amount of precipitation and the size of its drainage area, the quality and quantity of runoff entering a water body is a function of land use. More developed land, which has a higher percentage of impervious surface, will generate a greater volume of runoff per area for a given storm event. The more populated or densely developed land will show higher concentrations of contaminants. In general, pollution loadings (mass of pollutant per unit of land area) in an urban area will be highest for industrial and lowest for residential land.



This report focuses on runoff emanating from a particular land use that is often not studied as a separate category - roadways. More specifically, the report will address the problems and solutions in terms of our major thoroughfares, highways.

Roadways constitute a significant percentage of the land in urban areas, and their surface is generally impervious pavement. In quantity alone, roadways would seem to be major sources of urban runoff. However, highway runoff is also a special concern because it contains a variety of pollutants associated with the automobile and road maintenance. Among others these include solids, oil and grease, heavy metals, salts, and sometimes pesticides. During storm conditions these pollutants, and others collected on the roadway from atmospheric fallout, are generally transported directly into the nearest water via conventional methods of highway drainage. While the extent of the impact of highway runoff on natural water bodies is not well defined, it can cause loss in biological productivity and a general lowering of the quality of potable water supplies.

#### Highway Drainage Systems

The design goal of roadway drainage systems is to provide travel safety and rideability under conditions of rainfall and snowmelt by preventing the pooling of water on the pavement. Drainage structures and channels are designed to accommodate the volume of runoff from a certain area of pavement under hydrologic conditions resulting from a particular storm intensity.

The typical drainage design for an at-grade (ground level) roadway is a system of drainage inlets connected to storm sewers. An above-grade roadway is typically drained by means of channels or overland flow to side ditches which then drain either into natural channels or inlets connected to storm sewers. On elevated roadways, storm-water inlets are connected to downspouts in the structure itself, which then drain into storm sewers. Below grade roadways are drained by means of side ditches or gutters with inlets connected to storm sewers or natural drainage channels. In all cases, water is drained from the pavement by crowning along the centerline or sloping the pavement in one direction.

A storm sewer or natural drainage channel must eventually discharge to a water body. It is not uncommon for a storm sewer to be tied with a sanitary line, but it is not an accepted practice in new construction and is not often the case with major highway drainage. Roadway runoff, as with urban runoff in general, is typically directed towards the nearest water body with a sufficient capacity to receive it. However, the constituents of highway runoff are such that harm can be done to the receiving lake or stream, and to the area groundwater as well.

#### Contaminants in Highway Runoff

The following is a description of pollutants commonly found in roadway runoff.

## Heavy Metals:

Metals which collect on the pavement surface include lead, zinc, iron, copper, nickel, chromium and mercury. Except for mercury, these toxic metals originate from various aspects of motor vehicle operations.

Lead, the metal found in the highest concentrations in highway runoff is primarily deposited through the emissions of motor vehicles using leaded fuels. It is also deposited through the wear of tires with lead oxide used as a filler. Most of the lead emitted from gasoline combustion is released into the atmosphere, although some is deposited in the engine, manifold and exhaust system. Lead in the exhaust system can be released under conditions of rapid acceleration. Based upon relatively high emission percentages and assumed average driving conditions and car maintenance, it was calculated that an automobile may release up to 130 mg. of lead per mile<sup>(1)</sup>.

Lead deposited on the roadway is in particulate form, between 5 and 50  $\mu\text{m}$  in diameter, and is relatively insoluble (undissolvable). While smaller lead particulates,  $<1\ \mu\text{m}$ , become airborne, these larger particles remain within 30 to 50 meters from the paved surface<sup>(2)</sup>. Lead deposited near the roadway remains within the top few centimeters of soil, and while the lead content here can be several times normal concentrations, it does not contribute significantly to water pollution. However, the runoff from the highway surface can contain lead concentrations 1,000 to 10,000 times higher than background concentrations in receiving surface water<sup>(3)</sup>.

Zinc, is also used as filler material in tires, and as a stabilizing additive in motor oil. While zinc is typically deposited at levels several times lower than lead, the levels of soluble zinc are higher than soluble lead in runoff<sup>(4)</sup>. Because the zinc deposited on roadways is much more soluble than lead, the smaller levels of zinc have a greater polluting effect.

Iron, is deposited on roadways as a result of corrosion of motor vehicle bodies, engines and exhaust systems, and the rusting of guard rails.

Copper, nickel and chromium are present in much smaller quantities in highway runoff. They are deposited through the wear of metal platings, bearings, bushings, and other moving parts in the engine. These metals are also present in highway de-icing salts applied to the road surface<sup>(5)</sup>. Copper is also deposited as a result of the wear of copper impregnated brake linings.

Mercury, present on the road surface originates from atmospheric fallout.

#### Inorganic Salts:

The common use of de-icing chemicals along our roadways for snow and ice control has led to high seasonal concentrations of sodium and calcium chlorides in highway runoff. Frequent and liberal applications of sodium chloride (NaCl) and calcium chloride ( $\text{CaCl}_2$ ) is the primary means of keeping ice off the road surface. While the quantity of salt used by a roadway maintenance official is dependent upon a number of factors including temperature,

storm conditions, amount of ice and traffic volumes, the rate for one application usually ranges from 400 to 1200 lbs. of salt per two-lane mile<sup>(6)</sup>. Over a winter season, a typical roadway may receive more than 20 tons of salt per lane mile. Salt usage in the United States ranges between 9 and 10 million tons per winter season<sup>(7)</sup>.

It is not surprising that chloride concentrations in winter highway runoff can be in the thousands and tens of thousands milligrams per liter. This runoff enters a receiving water course or percolates into the groundwater. While there has been some experimentation with substitute materials, use of road salts remains the most practical method of preventing hazardous winter driving conditions.

#### Oil and Grease:

Oil and grease is deposited on the roadway surface from spills or leaks of motor vehicle lubricants, antifreeze and hydraulic fluids. It can also leach from roads with asphalt paved surfaces. Oil and grease are the major organic constituents of roadway particulates.

#### Particulates:

Tiny particles that break down from larger solids are also carried in highway runoff. The sources, typical of runoff in general, include dirt, sand, stones, glass and plastics. This material is deposited from dirt accumulated on vehicle bodies, sanding and salting, pavement wear, erosion adjoining the road surface and litter.

#### PCB's, Pesticides:

The PCB's (polychlorinated biphenyls) originate primarily from the use of weed killers along the highway. Specific pesticides may also be present. The presence of these chemicals vary from roadway to roadway, depending upon particular maintenance practices.

#### Nutrients:

Nitrogen and phosphorus are nutrients that collect on the roadway primarily from the use of fertilizers. However, nutrient levels in highway runoff are usually lower than those in urban runoff in general due to the decomposition of biological wastes.

Other contaminants found along highways result from automobile usage:

Asbestos is deposited on the roadway through the wear of brake linings, clutch facings and disc pads. Results of a study done in 1973 showed that average levels of asbestos emitted from passenger cars was 28.5  $\mu\text{g}$  per vehicle mile, while the average levels from heavy trucks ranged upward to 951  $\mu\text{g}$  per mile<sup>(8)</sup>.

Rubber particles are deposited on the road surface through tire wear. The average rubber loss for one tire throughout the period of its use is calculated at 144 mg per mile, although the rate of accumulation of tire dust is a function of such factors as vehicle speed and road surface<sup>(9)</sup>. The yearly loading from tire rubber loss in the United States is approximately 800,000 tons<sup>(10)</sup>.



## Impacts of Highway Runoff

The impact of highway runoff on receiving waters is site specific, depending upon both the characteristics of the runoff and the water body. In general, highway runoff can negatively effect water quality in terms of aquatic life, water supply and recreational use in a number of ways, including aesthetic loss, toxicity, sedimentation and eutrophication. These long-term impacts result from the accumulation of contaminants in the water column and sediments which exert a continuing damaging effect. Highway runoff can also have short-term impacts in the form of shock or acute loadings during single storm events when high concentrations of pollutants are suddenly introduced. This is usually associated with the first flush phenomenon, when the initial period of rapidly increasing rate of stormwater runoff carries the highest pollutant concentrations. A series of shock loadings can result in permanent alterations, such as changes in biological species composition<sup>(11)</sup>.

Heavy metals and pesticides which have run off into a water body may exert a continuing toxic effect by leaching from the sediments into the water column. This is difficult to assess because of possible synergistic effects of the interactions of various metals. In addition, the actual concentrations of the metals may not be as important as the physical or chemical state. Studies have shown that soluble heavy metals, particularly lead and zinc, inhibit algae growth by interfering with photosynthetic process, and increase fish mortality by damaging gills<sup>(12)</sup>. When

associated with particles in suspension in the water column, heavy metals also bio-accumulate, i.e., persist in the food chain with greater concentrations in higher consumers.

Some of the metals including lead, mercury and chromium, are objectional contaminants in public drinking water supplies due to suspected carcinogenic effects. Lead, in particular, is a serious poison that accumulates in the body, and may result in brain damage, convulsions and death. Lead should not exceed 50 µg/l in drinking water. Zinc, copper and iron, on the other hand, are present in natural waters and are essential for human metabolism and growth. However, these metals also have limits for suitable drinking water. Most notable is iron, whose concentration above 0.3 mg/l gives water a bitter taste and causes staining. Concentrations above 1 mg/l are toxic to fish.

The presence of highway salts can seriously disturb salt balances in roadside soils and vegetation, and receiving waters. Salt affects the physiological processes of plants, causing damage to plant parts and reducing water uptake. It lessens soil fertility and alters soil structure. In freshwater bodies, high salt concentrations can significantly affect physical characteristics; in small lakes it can prevent or delay fall and spring mixing which provides the necessary circulation of nutrients and oxygen. Salt concentration in water greater than 1% (1g/100g of water) endangers the health and reproduction of all freshwater species, including man<sup>(13)</sup>.

In general, organic contaminants, including oil and grease, and rubber particles can cause deterioration of the receiving waters'



ecological system. Like metals, organic contaminants are toxic in high concentrations. Oil and grease also cause aesthetic deterioration by the formation of slicks on the water surface.

Highway runoff carries the majority of pollutants in the form of very fine silt or particulates. Aside from its pollution potential, suspended solids have a damaging effect on the biota. Silt inhibits organism growth by particle entrapment in the gut which restricts the passage of water and allows the adsorption of toxic materials.<sup>(14)</sup> Suspended solids increases turbidity which reduces the infiltration of light necessary for productive waters. On the other hand, solids which settle can smother bottom-dwelling organisms and impair fish spawning.

Nutrients carried by stormwater runoff can contribute to excessive unnatural aquatic growth (eutrophication). This results in aesthetic and odor problems, and when the weeds and algae decay, results in oxygen depletion.

Studies have shown that the levels of biological oxygen demand required by bacteria in a five-day period to decompose organic matter ( $BOD_5$ ), and the concentrations of both solids and metals in runoff from streets in urban areas can be many times the levels in raw sewage.<sup>(15, 16)</sup> A study of hydrocarbon input into Rhode Island coastal waters via urban runoff, which analyzed hydrocarbon loading as a function of land use, showed the highest loadings from an industrial site (Allens Avenue, Providence) and a high volume highway site (Route 95 and Route 10) followed by commercial and residential sites.<sup>(17)</sup> An analysis of trace metals

in the runoff from each site showed the highest levels from the highway site. These facts serve to point out the significance of highway runoff as a pollution source.

To compare the pollution potential of a number of highways with different characteristics, the Federal Highway Administration sponsored a sampling program of 159 storm events monitored at six different highway sites in various states between 1970 and 1977<sup>(18)</sup>. The sites included one rural and five urban roadways, with average daily traffic (ADT) ranging from 24,000 to 149,000 vehicles. There were variations in the drainage area, from 100% paved to predominantly grassy, and variations in design, surface type, length and number of lanes. The results of the study are summarized below.

Solids concentrations were highest for the highway with the largest drainage area but the average solids loading, which ranged from 19.6 lbs./acre/storm event to 60 lbs./acre/storm event, was lowest for the rural highway and highest for the highway with a 100% impervious drainage area. In general, concentrations were much higher in the winter because of salting and sanding practices.

Average lead concentrations among the sites, which ranged from 0.10 mg/l to 2.9 mg/l, was lowest for the rural highway, which also had the lowest traffic volumes, and highest for the highway with the 100% impervious drainage area. Iron, which ranged from 2 mg/l to 16.5 mg/l, and zinc, which ranged from 0.08 mg/l to 0.72 mg/l, were lowest for the rural highway and highest for the highway with the greatest traffic volumes.

Chloride levels were related to highway salting practices. However, discrepancies between the volumes of applied salt and the monitored levels in the runoff revealed that much of it is reaching the groundwater, or is removed, even after allowing for unmeasured melts.

Concentrations of nutrients were lowest for the rural highway and both concentrations and loadings of nutrients were highest for the highway with the greatest traffic volumes. In general, the concentrations of nutrients were lower than those levels normally present in secondary treatment effluent.

Little or no measurable quantities of asbestos were found, and PCB's were found in very low concentrations. Average oil and grease concentrations were 1 mg/l for the highway with the grassy drainage area, and 14 mg/l for the highway with the greatest traffic volumes.

While multiple correlations were also made between pollutant loadings and various highway characteristics, two significant factors affecting pollutant loading emerged from this study - traffic volumes and the degree of imperviousness of the drainage area. This serves to point out that concern should be focused on major roadways with heavy volumes and/or large impervious drainage areas.

## CHAPTER II. METHODS OF MITIGATING IMPACTS OF HIGHWAY RUNOFF

### Introduction

Reducing the polluting impacts of highway runoff on receiving water bodies is most efficiently done at the roadway or at some point between the roadway and the water body. At the roadway, it would involve changing pavement characteristics, or regulating traffic or motor vehicle characteristics in order to reduce the amount of pollutants deposited on the road surface. Between the roadway and point of discharge, it would involve a system of controlling runoff by detaining it until its level of contamination is reduced. Treating the water, whether by dredging accumulated sediments, aeration, or filtration and chemical treatment for recreational, ecological, or water supply purposes, is the most costly and least efficient means of countering highway runoff pollution.

In addition to the frequency and type of storms, there are a number of highway characteristics which determine the level of pollutants in the runoff. These features, except those based upon travel demand, can all be modified to some degree to reduce pollutant loading. They are described as follows:

### Roadway Characteristics

#### Area and Type of Pavement:

The larger the paved area, the greater the volume of runoff. Although any roadway will have a minimum of two travel lanes, the

pavement area, as described by the width and number of lanes, is generally a function of traffic volumes. Therefore, not only is pavement area a design factor which cannot be modified, it can also be related to the quantities of those pollutants which are discharged directly by the motor vehicle - heavy metals, oil and grease and asbestos. One means of reducing unnecessary pavement area, however, is through establishment of grassed rather than paved medians.

Pavement condition is also a factor in pollutant loading; in general, poor to fair pavement which collects particulate debris in uneven surfaces and reduces motor vehicle efficiency, will have a higher pollutant loading than good to excellent pavement.

Another roadway characteristic impacting runoff quality is pavement type. Unlike concrete pavement, an asphalt surface can leach oil and grease because of its petroleum base. The extent of this leachate is not well documented, however.

A significant reduction in runoff volume is achieved by altering pavement design to give it a surface porous enough to retain the storm water. Porous pavement, which allows the water to infiltrate, reduces both runoff volumes and water quality damage. Porous pavement consists of a relatively thin course of open-graded asphalt mix with a coarse surface texture and high void ratio, over a deep base of large-sized crushed stones rolled into an open interlocking structure.<sup>(19)</sup> Porous pavement can also consist of blocks of concrete lattice. The base serves as a storage area for runoff water until it percolates into the soil. Porous asphalt



has the additional advantage of reducing the need for storm drainage systems and reducing hydroplaning between the tire and pavement. However, at the present use of porous pavement is limited primarily to parking lots and low volume roads. Given the existing level of information, the benefits versus costs of its use would have to be determined on a site-by-site basis.

#### Vegetation:

In addition to the pavement area and surface condition and type, contamination in roadway runoff is also a function of the characteristics of the surrounding land, specifically, the amount of vegetation present. Vegetated areas absorb a greater volume of surface water, resulting in less runoff. Adequate vegetation also prevents soil loss. Most important in terms of pollution reduction, however, is the fact that vegetation serves to capture and retain metals in runoff. A study done in the State of Washington in 1982 compared the metals concentrations discharged from drainage channels of three distinct types - paved, mud-bottom and grassed<sup>(20)</sup>. While a small decrease in lead concentration occurred along the mud channel, rapid declines of lead, zinc and copper occurred along the grassed channel. Based upon the study data, a grassed channel length of 60 meters was given a statistical average of 90% metals removal efficiency within the 95 percent confidence interval. Lead, which has the lowest solubility among the metals, had the highest degree of removal. Along the paved channel, the metals concentrations did not exhibit a steady decline, presumably

because the particles in the runoff remained in suspension due to the high flow velocity.

Removal of metals similar to that occurring through grassed channels occurs when runoff flows directly over grassy shoulders. Therefore, roadway vegetation serves not only as an aesthetic buffer and means of erosion control, but as an important factor in reducing roadway contaminants before the runoff reaches receiving waters.

#### Roadway Maintenance:

A final roadway characteristic affecting the quality of its runoff is the level of maintenance a road receives. These maintenance activities include those of a positive impact - sweeping and litter patrol, and those of a negative impact - mowing and clearing. A regular schedule of sweeping and litter pick-up keeps down the accumulation of solids and organics, and allows less of the roadway contaminants to run off. Another positive maintenance activity is pavement repair, which is necessary for good pavement condition over the long term. However, other maintenance activities considered positive from a safety or aesthetic point of view can have negative impacts in terms of water quality. Deicing results in accumulation of high levels of salt and sand, and mowing reduces buffering vegetation. Therefore, the degree of maintenance along a roadway can significantly impact the levels of pollutants in the runoff.

## Traffic Characteristics

### Traffic Volumes and Patterns:

Daily volumes of traffic, as previously discussed, is a factor in the size of the highway and consequently, the area of pavement. More importantly, the number of motor vehicles traveling along the roadway will be the primary factor in determining the levels of oil and grease and heavy metals which collect on the road, as these pollutants are discharged directly from the vehicle. In general, heavily traveled roads will also have greater amounts of litter and solids collected along the shoulders.

Travel patterns are also a factor since the greater the degree of slowing and accelerating, the higher rates at which metals and asbestos are released. In addition, speeds above 55 mph result in the consumption of more gasoline per mile, leading to higher levels of emitted metals. Higher speeds also cause greater tire wear, resulting in greater amounts of deposited rubber particles.

The generalized relationships described above, however, are difficult to quantify and are difficult or near impossible to control in order to achieve a specified reduction of roadway pollutants. Instead, they serve to point out the general need to establish mitigating measures for runoff from heavily travelled roadways.

### Cumulative Motor Vehicle Characteristics:

The combined characteristics of motor vehicles that have traveled along a given section of roadway is also a major factor



related to levels of roadway contaminants. Although impossible to calculate, the age and efficiency of every motor vehicle, the type of gasoline it utilizes and its body condition affect the levels of lead and other heavy metals that are emitted from exhaust pipes, and the amounts of iron and particles deposited from automobile bodies. The mechanisms for controlling these factors have already been instituted into law: anti-pollution devices for exhaust systems, unleaded fuel and annual motor vehicle inspections. Making the automobile less polluting, which is most important in terms of air quality, is a national policy with long-term results. As such, it is not an effective means of controlling water pollution on a site-specific basis.

#### Highway Runoff Containment

An alternative method for lessening the damaging impact of highway runoff on water quality involves the interception and containment of the runoff before it reaches a water body. Given the difficulty of controlling the pollutant levels deposited on the roadway, containment of the runoff after it leaves the roadway is a much more effective means of preventing water quality degradation. It is also more cost-effective than the conventional treatment techniques mentioned in the introduction to this chapter.

Preventing the direct discharge of contaminated runoff into a water body is accomplished by means of basins or pools which intercept and contain the water. Like conventional drainage facilities, such as channels, catch basins and storm sewers, containment areas

are designed to accommodate flows from a given size drainage area after a given storm intensity. Among containment areas, however, a distinction is made between retention basins, which provide total containment, and detention basins, which provide storage with controlled outflow.

Total containment eliminates surface water pollution since the retained stormwater is disposed of by infiltration through the soil. However, it is necessary to consider the percolation rate and filtering capacity of the soil before constructing a retention basin; soil which drains too quickly can result in groundwater pollution. Retention basins are best suited for runoff volumes from drainage areas of less than five acres (21).

The primary purpose of detention basins, on the other hand, has been to store runoff and release it slowly to avoid flooding conditions when drainage channels or manmade drainage facilities are inadequate. The use of small detention basins for flood-peak reduction is not uncommon in this country. In most cases they are constructed by developers as required by ordinances specifying detention as a permanent means of compensating for increased runoff from large developments such as shopping centers, and residential and industrial complexes.

Although designed as a means of flood and erosion control, a detention basin can also have positive water quality impacts. In one regard, controlling the release of stormwater extends the delivery of pollutants to the receiving water, thereby aiding

assimilation. In another regard, reducing the flow velocity at the detention basin site allows some suspended solids and other pollutants to settle out. Detention basins in the form of sedimentation pools are often built during the construction phase of highways and other large scale land developments to prevent severe erosion, and siltation of streams. Usually left in place as part of the drainage system, these sedimentation pools, like flood retarding detention basins, can serve a dual purpose: pollution control and stormwater control.

Runoff containment is considered a low structural means of providing protection from flooding and erosion, erosion damage, and water quality damage at the source of the stormwater runoff. Based upon 325 public agency responses to a survey done by the American Public Works Association in 1980, the most common detention facility is a dry basin which stores excess runoff only during and after storms<sup>(22)</sup>. It often doubles as a recreational site, such as an athletic field. The second most common type of detention facility is parking lot storage, followed by ponds or wet basins. Other less common forms of detention include rooftop storage, underground tanks and oversized storm sewers. In all cases the primary purpose of the facility was to reduce flooding. However, secondary objectives included capturing silt and reducing pollution.

Wet basins, which are recommended for more effective pollution control and also for aesthetic reasons, retain a certain water elevation which is controlled by its outflow design. Part

of the retained volume is consumed by plants, evaporation or infiltration to the ground, but the basin maintains a permanent water pool between storms. This design allows for the retention of pollutants, which in a dry basin could be resuspended and washed out by a following storm. The construction of detention ponds normally involves the modification of natural drainage channels or land features, such as depressions or swales. Vegetation in the basin not only provides nutrient and metals removal, but keeps the soil layer on the basin floor loose and permeable, thereby aiding infiltration.

#### Detention Basin Design Concepts:

The effectiveness of a detention basin in reducing the levels of runoff pollution entering downstream waters is dependent upon a number of factors, involving both the characteristics of the basin and the specific pollutants. For flood control, the purpose of a detention facility is to redistribute the rate of runoff by providing temporary storage, thereby reducing downstream flooding. The key design factor is the discharge rate from the basin. For pollution control, the purpose of detention is to allow the settlement of suspended particles of sediment, heavy metals, petroleum hydrocarbons and other pollutants. The key design factor is the storage time in the basin - the time between when water enters the basin and when it leaves. Storage time is a function of three factors: the rate of flow entering the basin



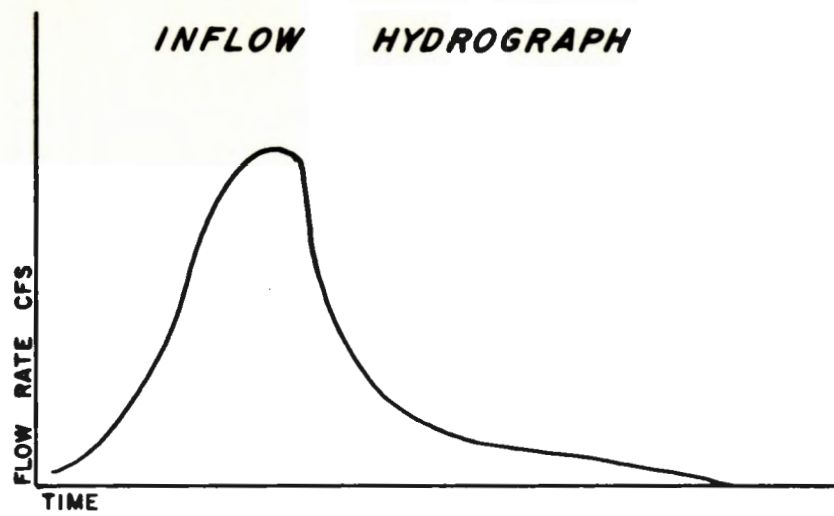
over the storm's duration, the rate of discharge from the basin during and for some period after the storm, and the storage volume and configuration of the basin.

The storage time necessary for a given removal efficiency depends upon the settleability, or settling time, of pollutants in a basin water column of given depth. Therefore, for effective water quality control, the inflow-outflow relationship and the volume characteristics of the basin must be such that there is sufficient detention time to allow pollutants to settle out.

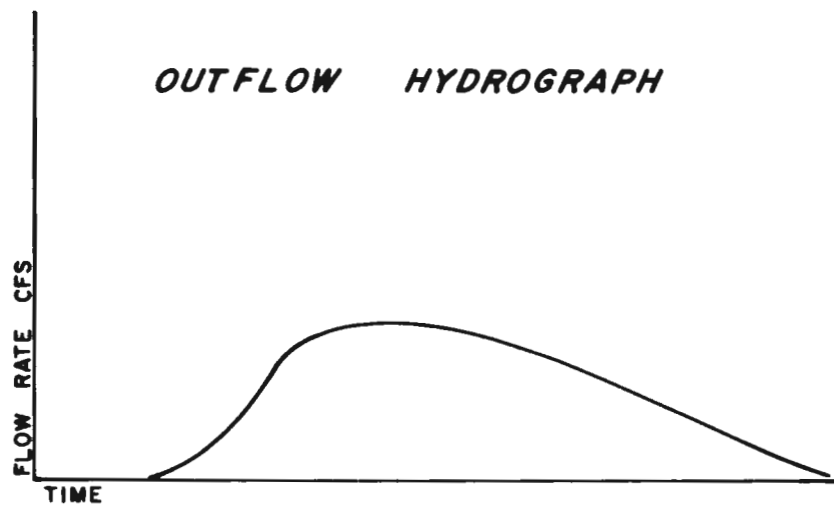
The rate of flow entering the detention basin, or in general, the rate of stormwater runoff measured at a specific point in any watershed is given; it is a function of the particular storm intensity and the size and characteristics of the drainage area. Appendix A contains a discussion of the methods commonly used to calculate runoff rates and volumes. Of course, the intensity of the stormwater flow varies over time; it reaches a peak after a steady increase, then steadily declines at about the same rate until near zero where the level of decline drops slowly until the flow stops. For each drainage area and each storm, the hydrograph described above will vary. The peak flow rate is higher and is reached sooner for a drainage area which is more impervious than for another drainage area of the same size and drainage pattern. The total runoff volume is also greater because there is less infiltration through the ground. For a given drainage area, a storm of greater intensity will have a higher peak flow rate and a greater runoff volume than another storm of the same duration, and similar antecedent conditions.

A typical hydrograph is shown in Figure 1. The flow rate, represented by the Y-axis, is typically given in cubic feet per seconds (cfs). It is a function of time, represented by the X-axis. Time is given in minutes or hours. The area under the curve represents the total volume of runoff. A retention basin would involve the design of a storage volume equal to this amount. In a detention basin, which is the type of containment recommended in this paper for highway runoff, an outlet is provided to allow release of the stored water after the basin reaches a given level. The effect of detention on runoff flow rates is shown in Figure 2, in the form of a typical outflow hydrograph. The total volume of runoff is not reduced, but peak flow rate is significantly lower. The storage provided by the basin allows the stormwater to be discharged into downstream drainage facilities or receiving waters at a lesser flow over a longer period of time than the original runoff hydrograph. The storage volume required for the detention basin can be seen by superimposing the inflow and outflow hydrographs. As shown in Figure 3, the storage volume is represented by the shaded area between the two curves, bounded by the point in time where the outflow rate equals the inflow rate.

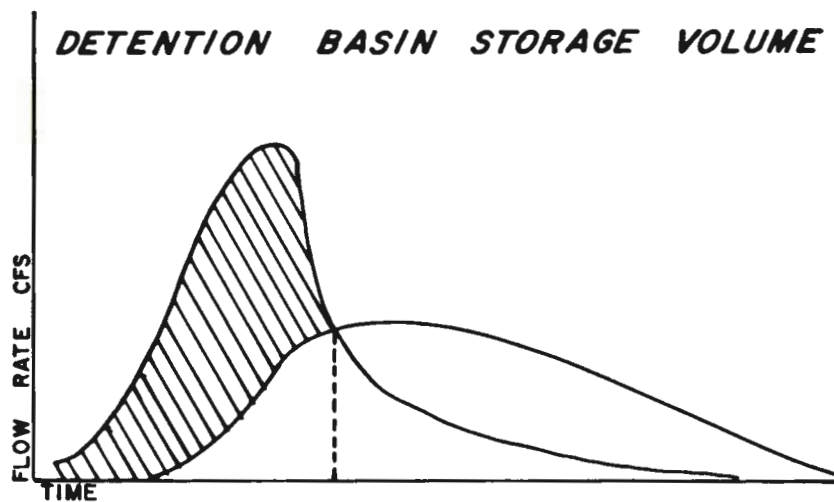
Unlike inflow rate, the outflow rate is a factor which can be adjusted to meet the capacity of the drainage system it discharges to, and the basin volume and detention time requirements. The discharge rate is controlled by the sizing of the outlet structure, whether it is a weir design or a pipe. If the outlet



**FIGURE 1**



**FIGURE 2**



**FIGURE 3**

is a submerged pipe, the rate is also controlled by the basin water elevation; a higher water depth has greater water pressure, and consequently, a faster outflow rate. However, the relationships between the inflow rate, the basin elevation, the basin volume, and the outflow rate are very complex and a detailed technical discussion with mathematical formulas is omitted in favor of a description of a typical detention basin.

A typical detention basin whose purpose includes water quality control by pollutant entrapment is one designed to handle a range of storm frequencies by means of staged outlets. A small sized outlet is placed at the lowest elevation to provide prolonged retention for the "settlability design storm," or the first flush producing storm event which contributes the most polluted runoff. The next highest outlet structure is set at an elevation to provide the maximum storage volume required by the settlability design storm. If the basin is designed only for settlability, this outlet structure would be sized to let flow discharge at the same rate at which it enters. If the basin also provides flood control, this outlet must restrict the discharge rate to prevent downstream flooding. In either case, an additional outlet structure in the form of an emergency spillway is placed at the highest elevation. This outlet provides for flood storage and/or containment of runoff resulting from a storm more severe than the design storm. Figure 4 shows a cross section of the staged outlet just described as well as a compound weir outlet which functions in the



same manner. In either case, the lowest outlet structure can be set at an elevation to allow a maximum depth of standing water.

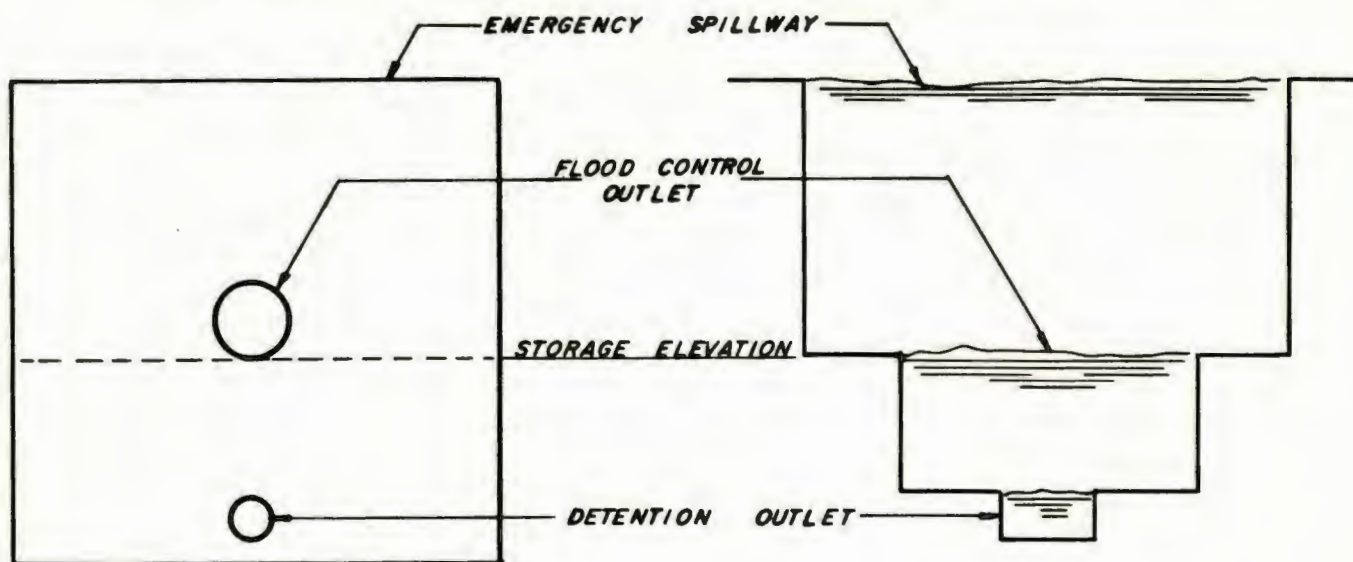
A staged outlet is necessary because of the detention time requirement for pollution settlability. Appendix B contains a more complete discussion on research regarding the settling rates of suspended pollutants, but in general it will take several hours (one to two days) to achieve a significant percentage reduction in the levels of various pollutants in the runoff. Because the required detention time is so long, it would extend beyond the duration of the storm in the case of normal rainfall events. This means that the inflow and outflow hydrographs would not overlap, as they do in Figure 3; storage for the entire volume of the storm's runoff would be required. The resulting basin would not only be large, but would require a mechanism to allow release of the water only after a specified time period. A staged outlet, however, would provide storage for only the most polluted first-flush, or that flow equal to a small storm event, referred to previously as the settlability design storm. The remainder of the stormwater would pass through the detention basin much faster, contained only long enough to prevent an outflow rate having downstream flooding potential.

Further limitation on basin size can be accomplished by the placement of baffles, which retard the flow. Baffles, a series of dividers or weirs, prolong residency time by increasing the length of channel flow, or by creating a number of smaller basins which

must be successively filled (see Figure 5). Typical detention basins also have a long narrow configuration with the inlet and outlet structures at opposite ends. This serves to maximize residency time for a basin of given volume.

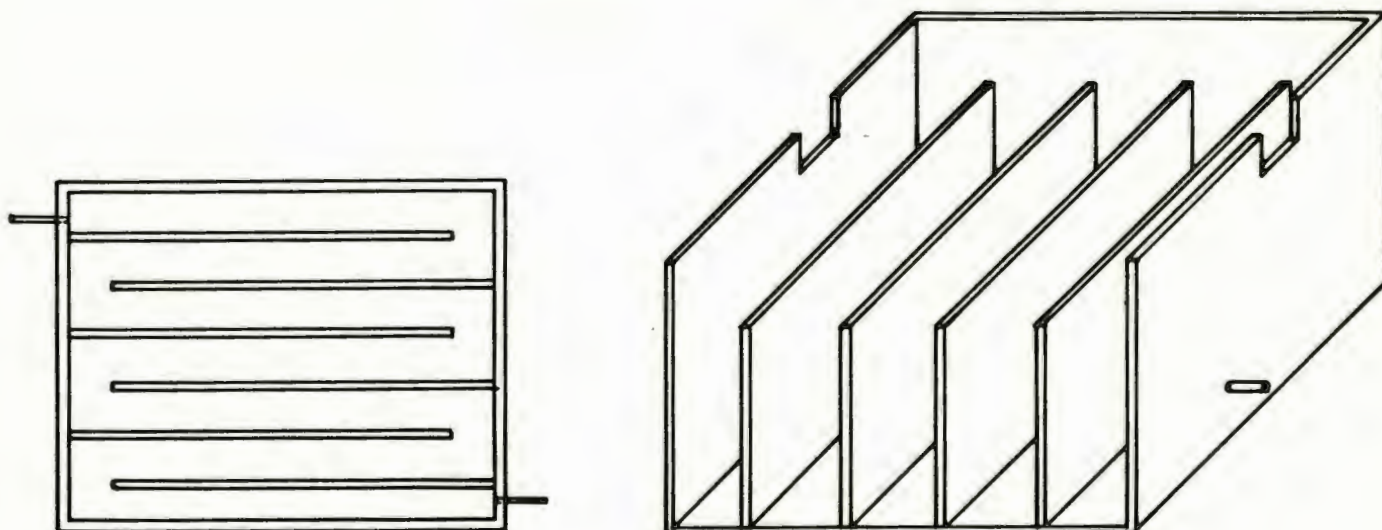
**DETENTION BASIN OUTLET STRUCTURES**

**PIPE DESIGN** **WEIR DESIGN**



**FIGURE 4**

**BAFFLE DESIGNS**



**FIGURE 5**

## CHAPTER III. CONTAINMENT STRUCTURES FOR HIGHWAY RUNOFF

### Parking Lot Runoff Detention

Detention of runoff from highways is less common than that from large land developments or parking lots. In Rhode Island, an example of parking lot runoff detention is at the site of the recently constructed Showcase Cinemas at the intersection of Route 2 and Route 401 (Division Street) in Warwick.

Approval from the State Department of Environmental Management for construction of the theater complex was required because of the presence of a nearby stream, a tributary of the Maskerchugg River, and its adjoining wetlands. Aside from concerns over noise, traffic, litter and loss of quality of life (factors which the DEM was not authorized to consider), nearby residents opposed the project primarily on the grounds that it would greatly aggravate the flooding problem associated with the Maskerchugg River. They were also concerned with protection of the groundwater and water quality in general.

Consultants for the cinema company responded with a proposal to excavate a 750 foot long detention pond from the stream bed for the purpose of mitigating flow during storm conditions. Designed to detain flow from a 100-year storm, the 400,000 cubic feet of storage receives runoff from the parking lot while reducing flooding from pre-existing conditions<sup>(23)</sup>. Drainage from the 28 acre parking lot travels by three culverts to the roughly graded earthen basin which has a rounded concrete weir outlet

(see Figure 6). Flow travels under the weir through a one-foot diameter pipe to a small pool with a riprap wall at the opposite end; it discharges into the stream from the pool through a two-foot diameter outlet pipe under the riprap. The pipes carry normal stream flow through the detention pond. The volume of water contained at the elevation of the top of the weir is the storage volume. The larger diameter outlet pipe allows water to be discharged faster if the weir is crested, an event which occurs after normal heavy rainfall. The riprap wall, which is flattened on top to create a weir, serves as an emergency spillway.

Although its original purpose was flood control, the detention pond is constructed as a dual purpose basin with staged outlets. Because it was designed to provide an average interior flow velocity of only 0.05 feet per second, the basin also serves to reduce sediment loading downstream by facilitating settling of suspended particles. The pond and the sides of the basin were seeded with reed canary grass. The pond also supports a healthy stand of cattails and other wetland vegetation which enhances pollutant removal. However, no testing has yet been done to determine the effectiveness of the detention pond in removing pollution in the parking lot runoff.

#### Highway Runoff Detention for Protection of Reservoir Water Quality

Not surprisingly, major examples of existing or proposed highway runoff detention structures are those whose purpose is



SHOWCASE CINEMAS DETENTION POND

FIGURE 6



to protect public drinking water. When highways cross the watershed of a reservoir, they exist as a major source of pollution, particularly road salts, and as a potential source of hazardous wastes from accidental truck spills. An obvious public health need exists to prevent the degradation of reservoir water quality from highway drainage. The following examples of existing and proposed highway runoff detention structures involve the Wachusett Reservoir in Massachusetts, and the Scituate Reservoir and proposed Big River Reservoir in Rhode Island.

#### Interstate Route 190:

The most significant local example of a structural response to potential reservoir water quality damage is along a ten mile segment of Route 190, a recently constructed major highway in central Massachusetts. The highway runs from Worcester north to Route 2, a major east-west route in the northern portion of the state. The area of concern was the central segment of Route 190 which crosses the watershed of the Wachusett Reservoir, a major drinking water supply for the metropolitan Boston area. Before construction of this final segment of highway, a series of large sedimentation basins were built as the major means of erosion control. The primary purpose of the basins was to remove suspended sediment in stormwater runoff from areas under construction by intercepting and detaining the water prior to its discharge to tributaries entering the reservoir.

The thirty-five basins are divided into two sections, a retaining area and a filtration area separated by a concrete barrier (see Figure 7). The larger retention area is lined with an impervious material. It contained the runoff to allow settling of suspended sediment before being discharged into the filtration area through a weir manually controlled by flashboards. The filtration area of the basin passed the water through a filter of two feet of specially graded sand to meet a given turbidity level (5 NTU). The sedimentation basins were designed to drain six inches of runoff from the given construction area over 120 hours<sup>(24)</sup>.

During the construction phase, turbidity readings in the reservoir did not change from pre-construction levels; this was attributed to the presence of the sedimentation basins. Construction of the highway was completed in 1982. The basins have remained as permanent drainage structures whose purpose is also to protect the reservoir by trapping hazardous material spills. In addition, they have served as models for the design of basins proposed for the protection of the two reservoirs in Rhode Island.

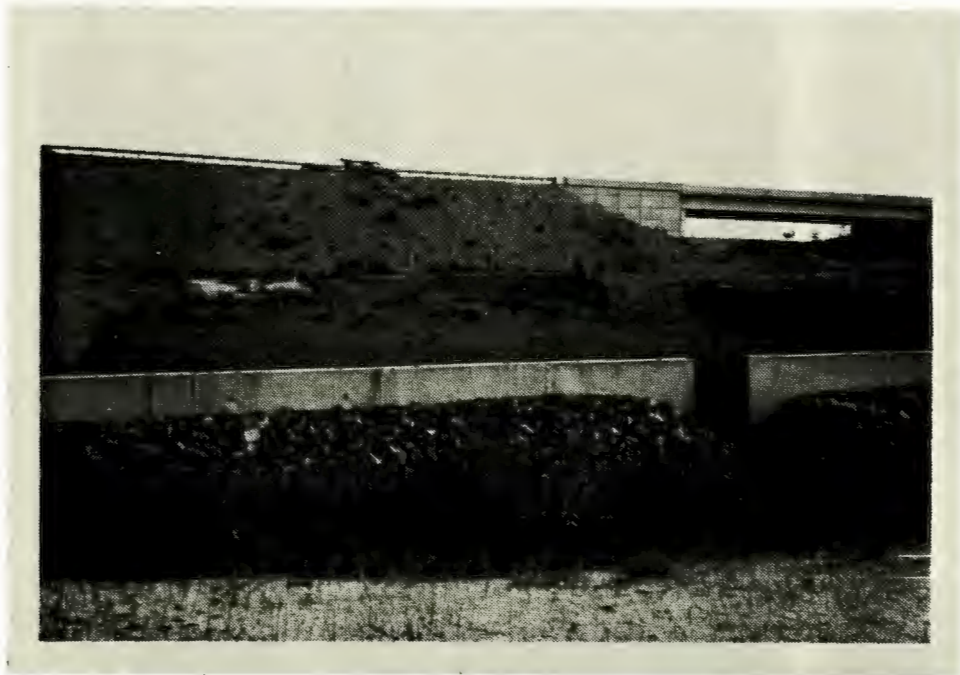
#### Roadways in the Scituate Reservoir Watershed:

An important precedence in controlling highway runoff was recently made in Rhode Island as a result of an evaluation of highway drainage in the Scituate Reservoir watershed. The study, whose focus was the preservation of the water quality in the reservoir, was completed in 1982 for the RI Department of Environmental Management<sup>(25)</sup>. Highways in the watershed with drainage





LARGE SEDIMENTATION BASIN BUILT ALONGSIDE ROUTE 190



BASIN WEIR SEPARATING RETENTION AND FILTRATION AREAS

FIGURE 7

structures discharging into the reservoir, or streams feeding the reservoir, were classified according to proximity to the reservoir, and volume and type of traffic. At the eight most critical drainage locations, where roadways cross or border directly on the reservoir, the construction of diversion ditches leading to sedimentation basins with emergency spillways was recommended. At the six next most critical locations, where roadways run close to the reservoir, planting of vegetation and construction of sediment traps at all culverts was recommended. Finally, at seven of the twenty-three roadway crossings of major streams, planting of vegetation, riprap installation on steep slopes and construction of sediment traps where possible, was recommended. The purpose of all recommendations is to reduce the introduction of sediment and highway contaminants into the Scituate Reservoir. The study is significant in that it focused on the impacts of the operation of existing highways rather than the impacts of highway construction, and for its recommendation to establish basins to contain the runoff. No design details were specified. The report was sent as a policy statement to the State Department of Transportation.

#### Route 6:

An additional study regarding protection of the Scituate Reservoir focused on the upgrading of Route 6, the largest volume road in the watershed<sup>(26)</sup>. Completed in late 1983 for the Department of Transportation, the study evaluated various drainage

alternatives to protect the reservoir from accident-related hazardous spills. Present drainage conditions along Route 6 do not provide any safety measures. Among the alternatives, both partial and full containment were evaluated. Both containment alternatives would provide full interception of roadway runoff by means of ditches leading to storage ponds or tanks designed to handle a spill occurring during the peak of a 100-year storm.

The partial containment option would require construction of eleven permeable settlement ponds and four settlement tanks along the roadway. The outlets would be located to allow overland flow for a considerable distance before reaching a stream in the reservoir watershed. This system would allow maximum absorption into the ground, providing natural filtration of the runoff. As such, it is ideally suited as a containment and treatment system for normal highway runoff rather than hazardous spills.

The size of the ponds and the general degree of protection provided would depend upon the classified zone of pollutant risk, areas measured in terms of susceptibility to direct contamination of the open water. This risk zone categorization is very similar to the critical drainage location system of the previously discussed study. Zone I areas, those immediately adjacent to the reservoir, would require a closed drainage system leading to one of the four settlement tanks. Each tank would be equipped with a pump connected to a force main to relocate the outlet flow to a point where overland flow can take place. Zone II areas, those

in proximity to major stream systems, would require a primarily closed drainage system leading to the larger settlement ponds. Zone III, areas with defined channels of overland flow, and minor streams leading to major streams or the reservoir, and Zone IV, areas least susceptible to direct contamination, would be given the same treatment. This would consist of double ditches alongside the roadway leading to smaller settlement ponds. The inner ditch would contain a series of small dams to create several linear storage ponds, thereby slowing the flow rate, permitting absorption and controlling the contamination from a hazardous spill. Outlets from the inner ditches would discharge to a settlement pond. The outer ditches would carry non-roadway storm-water flow.

The settlement ponds would be constructed to permit slow drainage through the berms which make up the sides of the basin, as well as absorption to the groundwater. Each outlet pipe would have a valve for manual closure to retain hazardous spills, thereby preventing a concentrated release and allowing some degree of removal by clean-up. The settlement tanks in Zone I would provide a greater degree of security since the pumps could be shut off after a spill occurred.

By contrast, the full containment option would considerably reduce the chances of contamination from a hazardous spill because of the presence of large retention ponds with impermeable bottoms, based upon the design of the retention basins constructed



along I-190. Each pond would have two chambers separated by a barrier with a sluice gate. The first chamber would hold the runoff from a 100-year storm while the second chamber would hold half of that volume. The outlet would consist of a crushed stone and sand channel in the wall of the second chamber. Flow would enter the second chamber from the first chamber only by manually releasing it at the sluice gate.

The drainage system would either be closed or consist of impervious ditches. All roadway runoff would enter a retention pond, and if uncontaminated, be released directly into the reservoir. Because of the provision for complete containment and the lack of ditch storage, seventeen ponds having a total storage capacity of over six times the total capacity of the partial containment system would be required. In addition, while the full containment system would provide total confinement of spill materials, it would not allow percolation of the runoff through the ground. It would directly discharge into the reservoir any pollutants that did not settle out.

The partial containment system, utilizing permeable ditches, ditch dams, permeable settlement ponds and overland flow would be much more effective in reducing the levels of highway pollutants entering the reservoir on a daily basis. Protecting the reservoir from contamination due to hazardous spills might be accomplished as a matter of policy; trucks carrying potentially spillable hazardous material could be prohibited from traveling along the highway.

## Roadways in the Big River Reservoir:

Similar efforts to protect a public drinking water supply from highway runoff and hazardous materials are being undertaken by the Rhode Island Water Resources Board for the proposed Big River Reservoir, a massive capital project to provide metropolitan Providence and the East Bay area with their projected water supply needs. Similar to the analysis done on roadways in the Scituate Reservoir watershed, the roadway network in the study area of the Big River Reservoir watershed was classified according to risk zones. The option of both total and partial containment was also evaluated<sup>(27)</sup>.

The analysis of drainage and spill protection was limited to the (soon to be) relocated portions of the four secondary roads within the property limits of the Water Resources Board (45% of the 29 square mile watershed), and all of Routes 95 and 3 within the watershed. Evaluation of Route 95 was most important since under present conditions a large portion of the stormwater runoff from the highway would discharge directly into the planned reservoir. The designated risk zones were based upon proximity to the reservoir and major tributaries. Zone 1 consists of roadways that will directly abut or cross the reservoir; Zone 2 consists of road sections that cross a major tributary; Zone 3 consists of roadways that will be within 500 feet of the reservoir or water course; and Zone 4 consists of all other roadways (beyond 500 feet) in the study area of the watershed.

The selective containment alternative would involve construction of eight impermeable holding basins for runoff from Zones 1 and 2, along Route 95 and Route 3, and seventeen permeable basins for runoff from Zones 3 and 4 along the two highways and the highest volume secondary roads. Runoff would enter the permeable basins through grass-lined open channels. The lower volume secondary roads would have no special drainage structures.

The design of the holding basins would also be based upon the design of the basins located along I-190. They would consist of two compartments separated by an embankment section with removable stop blocks. The large impervious holding compartment would have a maximum volume of 150% of the runoff from a 100-year storm, allowing the containment of a hazardous spill under those conditions. The permeable second compartment would have an outlet channel consisting of graded sand and small stone to gradually filter out insoluble materials. Water would pass into the second compartment only by manually removing stop blocks after allowing for settling. By contrast, the seventeen permeable basins would consist of one compartment designed to contain the volume of runoff from a 100-year storm.

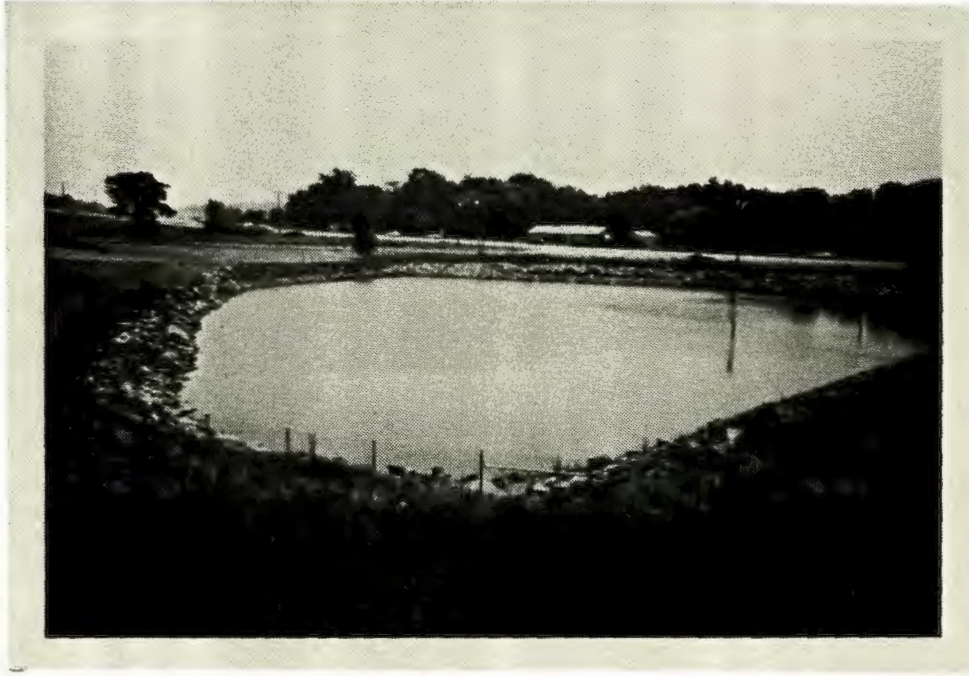
Because of the concern over a hazardous waste spill, a total containment alternative was also evaluated. This would involve construction of thirty-seven holding basins to contain runoff from all the roads in the study area. However, this alternative would have an estimated construction cost of 7.4 million dollars,



over twice the cost of the selective containment alternative. The interim report on control of roadway runoff in the watershed recommended selective containment.

#### Highway Runoff Detention for Flood Control

Aside from the protection of drinking water supplies from sediment and hazardous spills, containment basins for highway drainage are also used for flood control (like those associated with large land developments). An example of this is the large detention pond at the site of the Route 4 extension in North Kingstown, RI, built to negate the highway's impact on the Hunts River flood plain (see Figure 8). Similar to the Showcase Cinema parking lot detention pond, the basin will serve as a permanent means of flood control by providing storage for runoff from a 165 acre drainage area which includes the new roadway and adjoining overland areas to the west<sup>(28)</sup>. The pond is designed to contain runoff resulting from a 100-year storm and discharge it through a culvert under the nearby Route 2 into the Hunts River. The outlet structure will consist of an 18 inch concrete pipe installed 3 feet above the bottom of the basin. The bottom of the basin is also permeable. This design will provide water quality benefits, as well as flood protection, in that it will allow some settling of sediment and other runoff pollution.



ROUTE 4 DETENTION POND

FIGURE 8

## CHAPTER IV. PLANNING CONSIDERATIONS OF HIGHWAY RUNOFF DETENTION PONDING

### Introduction

The increased use of detention ponding as a means of storm-water management, and the availability of evidence regarding its pollution control potential, gives credibility to the concept of using detention ponds as part of the drainage systems of major roadways. They are already both being used and being planned for the protection of the water of greatest concern -- public drinking supplies. Although the emphasis in these cases is on protection from hazardous waste spills, it is evident that specially designed basins can serve to reduce the amount of normal highway runoff pollution that enters a reservoir. The broader policy recommended in this paper is the establishment of basins for the protection of water that is crucial for other purposes as well, such as recreation and shellfishing.

As an issue and as a policy effort, there is no better time than now to focus on controlling pollution from highway runoff. In late 1982, Congress passed the Surface Transportation Act which levied a nickel per gallon tax on gasoline for the purpose of financing road repair and construction across the nation. Existing roadways are being widened and otherwise repaired, and many new roads of major proportions, long planned, are now being built. Although this highway program will not match the scope of that occurring in the 1960's, this "rebuilding" of

America's road system presents an opportunity to address the secondary impacts of this major form of infrastructure.

In Rhode Island, the Department of Transportation has proposed to spend about \$700 million on a six-year highway improvement program from 1984 through 1989, with only approximately \$120 million in state bond money required<sup>(29)</sup>. Nearly 300 projects, ranked according to priority for completion, are scheduled for some phase of implementation over the six year period. Among the prioritized projects are 105 included in the "RRR" program (the restoration, rehabilitation, resurfacing of existing roadways), for which \$12 million annually is budgeted. In addition to roadway and bridge repair and construction, the Rhode Island transportation improvement program is to include refurbishing of drainage systems. Recommendations regarding coordination of a policy of providing detention basins at crucial highway drainage locations with the ongoing program of transportation improvements are made following a discussion of issues regarding the planning for and management of detention basins.

#### Stormwater Management

Achievement of the reduction in highway runoff pollution can find a parallel in efforts to control urban runoff in general; highway runoff is one part of a problem which requires total urban water resource management. Comprehensive management in this area

may include the development of master plans for watersheds, storm-water control ordinances and other environmental protection legislation.

Problems of environmental degradation more often than not transcend political boundaries. Establishing regional planning approaches for the protection and management of a geographical feature, such as a river basin or for solutions to area-wide problems, such as solid waste disposal, is not a new concept. Establishing specially designed drainage features such as detention basins for pollution control also should be evaluated, proposed and constructed on an area-wide, specifically watershed, basis. This is apparent in terms of protection of reservoir water quality since contamination in any part of its drainage area will eventually impact the reservoir water. However, planning for water quality control on a watershed basis also allows for more cost-effective decision making. Evaluation of other water pollution sources, prioritizing water bodies in terms of degree of importance and need for improvement or protection, and greater accuracy in terms of predicting water quality improvements can all result from an approach on a watershed basis.

Successful implementation of a comprehensive approach to water quality management requires legislative support. This approach is found at the federal level through Section 208 of the Federal Water Pollution Act (Pub. L. 92-500, 86 Stat. 816), which required the submission of areawide waste treatment management



plans. While Section 208 required states to inventory industrial and municipal sources of water pollution by designated regions and develop a plan for regulation of these sources, it also required identification of non-point sources. Specifically, this involved an assessment of stormwater systems and identification of measures to control runoff. Control of runoff was to occur through "best management practices" which must include regulatory programs as well as structural controls.

At the local level, one method of comprehensive water quality control has been passage of stormwater runoff control ordinances which regulate the location, design, construction and maintenance of new urban development and associated drainage systems. A typical such ordinance would require a water management plan for a specific site to be approved at some point in the review process before development occurs. Similar to an environmental impact assessment, the plan would include a description of the existing environment and the proposed project; the predicted impacts of the development, specifically in terms of water quality and flooding; and proposed methods of mitigating the impacts. The ordinance would establish performance and design standards to be followed. Performance standards usually include restoring runoff volume and flow rates to predevelopment levels, maintaining water quality and otherwise minimizing environmental harm. Design standards include prohibiting direct discharge of collected runoff into waterbodies, prohibiting alteration of natural water courses, placement

of erosion and sedimentation control devices, preservation of vegetated buffer strips, and use of retention and detention ponds. Containment of stormwater runoff, particularly the most polluted first flush, is often a major feature of a stormwater runoff control ordinance.

To date, such ordinances have dealt with developments and not highway systems. However, they are characteristic of the trend of legislating land-use controls to allow man-made systems to harmonize with the natural environment. The scope of land-use legislation can be expanded to control sources of highway runoff pollution as well. It is most important, however, that runoff controls be integrated into a comprehensive planning, management and regulatory process. The most common problem of use of detention ponding for runoff management has been a piecemeal approach involving construction at various sites within a watershed without regard for cumulative impacts. With highway runoff detention ponding, this problem would be circumvented by establishing responsibility at the state level. Coordination would have to occur between the Department of Environmental Management, the agency responsible for the protection of the components of the natural drainage system -- wetlands, recharge areas and flood plains -- and the Department of Transportation, the agency responsible for the construction and maintenance of roadways and associated drainage systems.

## Maintenance Procedures for Detention Basins

While detention basins may serve as a low-cost structural means of controlling water pollution, they also require monitoring and maintenance. In addition to preserving the integrity of the basin and the operation of the outlet structure, transportation department personnel must see to the periodic removal of sediment and debris, and if necessary, the harvesting of vegetation. Over time, of course, the basin will silt-up, decreasing its volume and subsequently its detention time, thereby decreasing its ability to allow pollutant settling. Maintaining the available volume by removing accumulated sediment is the most important maintenance activity. Since plants contribute to the effectiveness of the basin by providing nutrient and metals uptake, their removal should only be done when excessive growth occurs or in conjunction with sediment removal.

Removal of the sediment also presents an issue in terms of its disposal. Depending upon its metals and petroleum content, sediment from a detention basin receiving highway runoff could be classified as hazardous waste. As such, its handling and disposal would be subject to federal and state regulations. Although the magnitude of the problem would be considerably smaller, disposal of detention basin silt could be similar to that of disposal of dredge spoils. This issue of disposal simply represents the trade-off involved in protecting downstream water bodies.

There are also issues related exclusively to the use of wet ponds. One is the potential safety hazard; depending upon its accessibility to the public, the basin may require placement of warning signs or fencing. However, fencing would be more costly and less aesthetically attractive than proper grading and landscaping. Flat slopes, secure shorelines, shallow water depths close to the basin's edge and/or planting of dense thorny shrubs could all serve to limit access. In general, however, significant problems of public safety would not be expected for detention ponds within highway right-of-ways.

Other potential problems associated with detention ponds are algae growth and mosquito breeding. Control of aesthetic problems are especially important from a public perception point of view; while the benefits of improved water quality are not highly visible, basins containing stagnant water or debris are.

#### Research Needs for Application of Detention Ponding

Use of detention ponding for stormwater management in terms of pollution control is a relatively new practice, and its specific use as part of highway drainage systems is not at all widespread. The more common use of detention ponds to mitigate impacts of new developments have focused on flood control rather than pollution control. Therefore, it is evident that more research needs to be done on both the design and effectiveness of detention ponds for trapping suspended pollutants. Specifically,

relationships need to be established between basin geometry and design features, and the degree of pollution removal efficiency. Another area requiring research is increased knowledge of the settlability of specific pollutants. Finally, of crucial importance is more information on the fate of pollutants in detention basins -- whether they accumulate, transform or degrade.

While these are questions requiring the input of research scientists and engineers, one means of gathering more information on the effectiveness of detention ponding is evaluation of the performance of existing facilities. The State of Rhode Island has an excellent opportunity to undertake this at the Showcase Cinemas detention pond in Warwick, and in the future, at the Route 4 detention basin in North Kingstown. During storm events samples could be taken from the inflow to the basins, and at various intervals from the basins's outflow. This would allow comparison of the pollutant levels of the inflow with those of the outflow. Variables such as amount of rainfall and estimated detention time could also be evaluated as factors impacting these pollutant levels. In addition, settlability tests could be performed on various pollutants from runoff at these sites and at other highway sites in the State.



## Recommendations for Establishing Highway Detention Ponding in Rhode Island

An outline of several steps necessary to initiate possible use of detention ponds along roadways in Rhode Island has been developed as the conclusion to this paper. These recommendations for implementation are directed to the State Department of Transportation and the Department of Environmental Management. Legislative action may also be required to establish policy.

### Establish Planning Areas:

Planning regions for water quality management have been developed by the Statewide Planning Program for the purpose of basin planning under Section 303 of the Water Pollution Control Act. These regions include the Blackstone, Pawtuxet, Pawcatuck and Narragansett. Although they are divided along town boundaries, these regions include the State's major river basins and the Bay. The Blackstone region includes the Blackstone River basin and most of the Mohassuck and Woonasquatucket drainage areas; the Pawtuxet region includes the Pawtuxet River basin and most of the Moosup River basin; the Pawcatuck region coincides approximately with the Rhode Island portion of the Pawcatuck River basin; and the Narragansett region consists of the Bay and adjacent lands draining into it<sup>(30)</sup>. These basins could serve as planning regions for the implementation of highway detention ponding as well as other means of water quality management. Division of these areas into smaller watersheds would be done as necessary.

#### Identify Major Roadways within each Watershed:

After establishment of each planning area or sub-area along watershed boundaries, every major roadway should be assigned to each watershed which it intersects. A list of the State's major road systems is given in Appendix C. This would represent the minimum number of roads which should be evaluated.

#### Evaluate Drainage Systems of Major Roadways:

Identification of existing potential water quality problems caused by roadway drainage in Rhode Island would require an evaluation of the drainage systems of major roadways to determine where and what volumes they discharge. This has already been done for Route 6 and other roadways in the Scituate Reservoir watershed, and for roadways in the proposed Big River Reservoir watershed.

#### Sample and Analyze Highway Runoff:

The first concrete step in addressing the problem of polluted highway runoff in Rhode Island would be the actual sampling and testing of runoff from highway drainage at about five given locations for a number of storm events. Roadways of various widths, pavement type and condition and most importantly, traffic volumes and characteristics, could be selected for comparison of results. This work should build upon the results of the U.R.I. Graduate School of Oceanography study of pollution of the Bay from stormwater runoff, which included sampling of drainage from Route 95 (Hoffman, Quinn). The results of the sampling

program could be extrapolated to estimate runoff pollution levels from the remainder of roadways in the State.

#### Identify and Prioritize Critical Drainage:

Based upon the study of roadway drainage systems and the results of the sampling program, critical drainage locations -- those with a high probability of negatively impacting the downstream water body -- could be identified. It is recommended that the selection and prioritization of these sites follow the "risk zone" example provided by the three Rhode Island reservoir drainage area studies, which designate degree of pollution risk by proximity to a water course. The critical drainage locations could also be ranked on a statewide basis according to the water's public value. Public water supplies and other Class A waters should have the greatest priority, followed by waters, both coastal and fresh, important for fishing and recreation.

#### Select Sites for Roadway Detention Basins:

The critical drainage locations of the highest priority will be those containing the runoff having the greatest potential to cause damage to the State's most important waters. Beyond the general guidelines stated above, no attempt is made here to define these variables in terms of degree. As a result, even if all the necessary data was available, the actual number of critical drainage locations could vary according to individual interpretation. Guidelines to limit such discretion must be

established. Equally important, the definition of critical roadway drainage locations in terms of establishing detention basins will also be influenced by the cost of these facilities and their perceived benefits. Ideally, the cost of protecting water quality and subsequently, public health, should not be a deciding factor because of the difficulty of assessing the external costs of water pollution, and the value of improvement or protection of water quality. However, the cost of mitigating measures will often determine the degree to which they can be pursued. This will occur regarding the establishment of highway detention ponds. Initially, the State should select a few sites where prototype detention basins can be constructed as part of a major roadway's drainage system. If possible, these roadways should also be those scheduled to undergo widening or repaving to allow coordination of construction activities.

#### Establish Policy for Use of Detention Basins:

Assuming the overall effectiveness and positive benefit to cost ratio of highway detention ponding, a policy must be established to insure its use as a form of runoff and pollution control on a systematic basis. Following the construction of detention basins at the most critical drainage locations, this policy could insure that basins be provided at less critical drainage locations if new road construction should take place, or if traffic conditions or water quality needs should change.

A policy for the protection of Rhode Island waters from highway runoff by detention already has legislative support. Water bodies used for drinking water are protected under Chapter 46-14 of the General Laws of Rhode Island, which prohibits the discharge of any polluting drainage into these waters. The Rhode Island Fresh Water Wetlands Act prohibits the placement of highway runoff into any wetlands without approval from the Department of Environmental Management. Detention basins for highway runoff could become, under a state policy by the Departments of Transportation and Environmental Management, a required mitigating measure for the water quality damages caused by operating roadways.



## APPENDIX A

### METHODS FOR DETERMINING RATE AND VOLUME OF RUNOFF

There are numerous approaches for determining the rate of storm-water runoff. One method is the rational formula which takes into account the watershed drainage characteristics. The following formula is used:

$$Q = CiA, \text{ where:}$$

$Q$  = peak runoff rate, cfs

$C$  = runoff coefficient,  $<1$

$i$  = average rainfall intensity, in./hr.

$A$  = drainage area, acres

The coefficient,  $C$ , is a factor which represents several variables, including infiltration rate, ground cover and surface storage. Average coefficients for various types of land use range from a low of 0.10 for undeveloped land to a high of 0.95 for the most intensely developed type of land (a downtown commercial district). Given that a typical drainage area will have a variety of land uses, the area of each type should be measured in order to develop a composite runoff coefficient.

Coefficients have also been developed for various surface types for calculating runoff from small land areas. These range from a low of 0.05 for lawns with sandy soil and flat slopes, to a high of 0.95 for roofs and pavement. Pavement, asphaltic and concrete, has a coefficient range of 0.70 to 0.95. These coefficients are applicable for storms of 5 to 10 year frequencies, and assume that the ground is not frozen.

Rainfall intensity is a function of the storm frequency (5 year, 10 year, etc.), intensity-duration characteristics of the particular storm frequency, and time of concentration (the time it takes rainwater falling on the most distant part of the watershed to reach the location of the drainage facility). This information is obtained from local drainage manuals; rainfall-intensity relationship is often shown in a series of curves for rainfall intensities of given storm frequencies. Boundaries of the drainage area are a function of topography. They are determined by field surveys or topographic mapping.

The rational formula is limited in use to drainage areas of less than five square miles because it does not account for storage and subsurface drainage flows which are characteristic of larger drainage areas. It also cannot be directly used for determining volume of runoff because it does not provide runoff rate (inflow) with respect to time.

The hydrograph method, another common approach to the determination of runoff, allows for computation of volume. Runoff hydrographs, the graphic representation of runoff rate over time, is calculated from rainfall hyetographs (time-intensity patterns of rainfall) and drainage basin data. Often involving the use of computer models, hydrographs are developed by the input of data such as infiltration, land-use, antecedent rainfall and depression storage. The resulting hydrographs represent runoff rates at specific drainage inlet points.

The unit hydrograph method involves the correlation of characteristics of measured outflow hydrographs to develop a unit graph. One of the most commonly used unit hydrograph methods is that developed by the US Soils Conservation Service, which has produced 58 unit hydrographs for use in various watersheds in the nation. Use of the SCS method requires identification of hydrologic soil groups, watershed area, percent impervious and overall slope. Rainfall volumes for particular storm frequencies are selected from given rainfall hyetographs, and runoff volume is selected from a table with runoff curve numbers and rainfall volume. Runoff volume can be converted to peak discharge by use of a multiplier.

This method can be used for watersheds of 1 to 2,000 acres. Although it has little application for pavement inlet design, it does have application where design for storage is necessary. It also can be used for drainage areas which include areas outside of highway pavement.

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## APPENDIX B

### SETTLABILITY OF SUSPENDED POLLUTANTS

The process of pollutant settling is the slowing of the movement of particulates in suspension, and their adsorption and flocculation to form larger particles which then fall out of the water column to form a bottom sludge. Some work has been done regarding the settlability rates of various pollutants in runoff. One study was completed in 1981 in New Jersey which involved a composite of samples taken over one storm duration at each of five sites with densely developed watersheds. The degrees of settling of various pollutants were measured over time in a column depth of six feet, representative of a typical detention basin. The results, summarized below, show the percent of settling after 32 hours:

<u>Pollutant</u>	<u>% Settling</u>
Total Suspended Solids	70%, mean
Hydrocarbons	65%, mean
BOD <sub>5</sub>	50%, two samples, 20%, one sample
Phosphates	60%, two samples, 30-40%, two samples
Lead	85%, one sample, 60%, three samples
Copper, Nickel	30-50%, four samples
Zinc	17-36%, four samples

The study showed the variation in settlability rates among pollutants, and from runoff of different sites. However, on the average, one can see significant levels of settling over the period of a day and a half.



Another study of settling rates was done in 1982 using runoff from three different shopping mall parking lots in Virginia. A total of seven runoff events were sampled, and each sample from each site was analyzed separately rather than composited. Settling tubes of four foot water column depths were used in calculating the removal rates of several pollutants over a 48-hour period. The results are summarized below:

<u>Pollutant</u>	<u>% Settling</u>	
	<u>Range</u>	<u>Mean</u>
Total Suspended Solids	87-98%	90%, seven samples
COD	18-67%	45.5%, six samples
TOC	11-49%	34%, five samples
BOD <sub>5</sub>	60-68%	64%, three samples
Phosphorus	47-85%	56%, seven samples
Nitrogen	9-77%	33%, seven samples
Zinc	12-73%	44%, six samples
Lead	78-94%	86%, four samples.

Substantial reductions were obtained for suspended solids, lead and BOD. To prevent high concentrations of other pollutant particles from remaining in suspension, the authors recommended the use of coagulating chemicals.

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## APPENDIX C

### MINIMUM LIST OF ROADWAYS IN RHODE ISLAND FOR EVALUATION OF DRAINAGE SYSTEMS

Route 100; Burrillville, Glocester  
Route 102; North Smithfield to North Kingstown  
Route 7; Burrillville to Providence  
Route 146; North Smithfield to Providence  
Route 122 - Route 146A; Woonsocket, North Smithfield  
Route 121 - Route 114; Cumberland to Middletown  
Route 44; Glocester to Providence  
Route 295; Cumberland to Warwick  
Route 6; Foster to Johnston  
Route 195; Johnston to East Providence  
Route 95; Pawtucket to Hopkinton  
Route 10; Providence, Cranston  
Route 1; Providence to Westerly  
Route 136; Warren, Bristol  
Route 4; Warwick to North Kingstown  
Route 2; North Kingstown to Charlestown  
Route 138; North Kingstown to Tiverton  
Route 24; Tiverton, Portsmouth  
Route 81; Tiverton, Little Compton  
Route 77; Tiverton, Little Compton  
Route 138; South Kingstown to Exeter

## FOOTNOTES

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